NON-ROCKET
NEAR SPACE INDUSTRIALIZATION:
PROBLEMS, IDEAS, PROJECTS

2022

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uSpace

Astroengineering Technologies
LLC Unitsky String Technologies Inc.

NON-ROCKET NEAR SPACE INDUSTRIALIZATION: PROBLEMS, IDEAS, PROJECTS

Collection of Articles
of the V International Scientific and Technical Conference
(September 23–24, 2022, Maryina Gorka)

Minsk
StroyMediaProject
2023

Anatoli Unitsky,

**an author of a global EcoSpace program and its major investor for 50 years.
A chairman of the Organizing Committee of the International Scientific
and Technical Conference “Non-Rocket Near Space Industrialization:
Problems, Ideas, Projects” (since 1988)**

A scientist, engineer and visionary who devoted his entire conscious life to preventing global ecological disaster and preserving the biosphere environment for future generations by developing unique ground (Unitsky String Transport) and geocosmic (General Planetary Vehicle) transportation, as well as biosphere-friendly engineering technologies and biotechnologies.

A businessman who has built a powerful engineering corporation with offices in Belarus, Russia and the United Arab Emirates. Anatoli Unitsky’s team includes skilled designers, technologists, scientists and engineers – more than 1,000 specialists who have achieved significant results and succeeded in the creation and practical implementation of transport and infrastructure technologies, energy solutions, urbanism and agriculture.

The author of more than 300 scientific papers and 20 scientific monographs, the owner of more than 200 patents and certificates for inventions, prototypes and trademarks in the construction, transport, engineering, electronic and chemical industries, which are patented in several dozens of countries. Over 50 of Anatoli Unitsky’s inventions are applied in production in many countries.

**The anthropogenic oppression of the biosphere and the depletion of natural resources have now reached a disastrous level.
If the current rate of growth and development of the technosphere persists, we risk leaving a lifeless desert unfit for existence as a legacy to our grandchildren.
My program “EcoSpace” is justified and conceptualized in the research centers of Belarus and the UAE. By joining our efforts, we are able to refocus the Earth’s technosphere on the space vector of civilization development.
Thus, we will eliminate the anthropogenic factor of biosphere oppression.**

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Opening Speech by Anatoli Unitsky,

Chairman of the Organizing Committee of the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects"

Dear friends, colleagues and partners!

I have a great honor to welcome the participants of the anniversary V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects".

Following a good tradition, we have gathered here, on the territory of the former tank range, which is currently the natural oasis – the Aquarelle EcoPark, to discuss the development of the Earth's technogenic human civilization, i.e., our future. The conference is a unique platform where in the form of an open live dialogue we have the opportunity to discuss and work out ways to solve problems caused by tectonic changes taking place in the world.

The so-called "global elites", although no one has elected or appointed them, are lobbying for the deindustrialization and decarbonization of the world economy, which will inevitably lead to a reduction in the Earth's population. Thus, protecting their interests, these quasi-elites cause enormous damage to developing economies and humanity as a whole, up to the programming of self-destruction of our technocratic civilization in the foreseeable future.

However, I see another way – the path of creation, i.e., the biospheric technological one, the basis of which will be the ecological and social sustainability of the development of all countries and nations, not only the so-called "golden billion". And here Russia and Belarus, which have enormous resource and intellectual potential, will play a key role having united into a Union State.

The need for in-depth industrial and social cooperation between our states has been debated for more than one year. The topic is constantly discussed at the meetings of the Presidents; the governments have created specialized working groups that determine specific points of contact. Due to the current special geopolitical situation in the world, the integration of fraternal countries has reached a fundamentally new level.

Just by truly uniting, Russia and Belarus will be able to successfully resist external pressure and thereby neutralize all its negative consequences. A positive result in this case is possible only if there is a significant revision of government approaches in the field of monetary policy, as well as a change of priorities in infrastructure and technological development. The system-forming infrastructure industries should be brought to the fore. They will be able to contribute to the economic recovery of the Union State to the maximum extent and will allow it to take a leading position in the world within one generation.

I am convinced that the following biospheric industry-forming solutions created and developed by the international Unitsky Group of Companies can become their basis:

1) uEnergy, i.e., waste-free relict solar bioenergy on brown coal and shale;

2) uTerra, i.e., biospheric agriculture that is completely organic and based on living humus;

3) uCity, i.e., construction technology of pedestrian linear cities consisting of self-sufficient residential, industrial and multifunctional clusters;

4) uST transport and infrastructure complexes based on Unitsky String Technologies, that will create a highly efficient and environmentally friendly transport industry of a new generation.

The time has come to implement a rebooting towards the biospheric path of civilizational development. Its launch site will be the construction of the first targeted projects within the framework of the formation of a fundamentally new planetary eco-infrastructure that is string-rail "second level" transport above ground, linear ecocities, as well as relict solar ecobiopower plants, producing highly fertile biohumus as their industrial waste.

Just by truly uniting, Russia and Belarus will be able to successfully resist external pressure and thereby neutralize all its negative consequences.

Each of the proposed solutions is scientifically substantiated and conceptually implemented by the international Unitsky Group of Companies, primarily by the parent engineering and scientific organization Unitsky String Technologies Inc., located in Belarus. Today, during the conference and the debates, we will introduce them to you thoroughly. We will also discuss issues of technological progress in various fields of science, technology and society – from natural science and calculations of technically complex equipment to philosophical and social problems that will inevitably arise in connection with the removal of the technosphere

Welcome Speech by Hussain Al Mahmoudi,

CEO of the Sharjah Research Technology and Innovation Park and American University of Sharjah

created by mankind beyond the limits of the biosphere that nurtured it.

An intelligent civilization is capable of intelligently disposing of limited Earth resources. It will be able to find solutions to relocate the harmful part of the industry from the living biosphere to outer space. It must have time to fulfill this important mission before the point of civilizational no return, when it will be too late to change anything.

We need to start thinking and acting on a global scale. By the middle of the 21st century, the industrialization of near space should be carried out. The resources of the Solar System are sufficient to satisfy all the technological needs of mankind for millions of years to come. Before it is too late, it is necessary to choose the biospheric path of sustainable development of our technogenic civilization in the logic of "Earth is for life. Space is for industry".

I would like to thank all the participants and guests of the conference, among whom there are scientists, public figures, leading design engineers, opinion leaders, cosmonauts and test pilots who came to us from the states of the Eurasian region, European Union, as well as United Arab Emirates, Great Britain and other countries of the world. I am convinced that such a representative composition of experts will make it possible to conduct a detailed analysis of existing and future problems and to outline ways to solve them, including enhanced integration interaction. I wish you all fruitful work!

The V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" is declared open.

Before it is too late, it is necessary to choose the biospheric path of sustainable development of our technogenic civilization in the logic of "Earth is for life. Space is for industry".

I, Hussain Al Mahmoudi, am grateful to Dr. Anatoli Unitsky for the invitation to make a welcome speech.

Space exploration is a key factor in the industrial and economic growth. In this regard, the UAE government has recently launched a space program, the main task of which is to work out new approaches to solving the problem of climate change. Using the economic potential of the UAE's Mars and space programs, we, together with academia, the private sector and the government, strive to create an ecosystem that will contribute to the formation of human activity in near-Earth space.

In addition, one of the goals of the Sharjah Research Technology and Innovation Park is the development of human potential. The implementation of the space program will allow to raise talents – future leaders and scientists capable of overcoming the problems associated with environmental impact. We also hope to offer inventions and technologies within the framework of this project that will help not only to save our planet, but also to make it more self-sufficient and sustainable.

I am sure, through a conference held in Belarus, many companies together with innovators, scientists and students will be developing, promoting and implementing solutions intended to preserve Earth from ecological problems, including the consequences of human activities that harm the whole world. Today's event is a great chance to share best practices with each other in order to understand how it would be best to approach such an important issue as environmental protection.

I would like to thank Dr. Anatoli Unitsky again for his global work and creating this kind of scientific platforms that allow scientists and everyone concerned to engage, debate, solve problems together and find ideas that will make us better and more successful. Thank you for this opportunity!

The implementation of the space program will allow to raise talents – future leaders and scientists capable of overcoming the problems associated with environmental impact.

Welcome Speech by Lembit Opik,

Chairman of the Parliament of the Space Kingdom of Asgardia

I am Lembit Opik, Chairman of the Parliament for Asgardia, the world's first space nation and fully functioning digital democracy.

By the end of this year, NASA is planning to launch their Artemis 1 mission to the Moon. It is truly impressive to see the work, which the aerospace agency has done to bring the very advanced of today's technology to a project, which has been 50 years in the making. Nevertheless, we are still talking about traditional methods of the near-Earth space exploration, whereas Dr. Anatoli Unitsky's plan regarding the General Planetary Vehicle (GPV) represents a qualitatively new approach to the development of something important and sustainable for everyone, not just for individuals. I would say that the GPV is as big a jump from standard rocket technology as a difference between Vickers Vimy bomber, which made the first historic crossing of the Atlantic Ocean, and Concorde, created half a century later.

To many people, there's also technical and ecological concern about what we are doing to the Earth. Whether you believe or not that humans are causing climate damage, it is clear to everyone that if we want to exist as a species and thrive for centuries or millennia, we must go into space. Its exploration will help us to sustain the precious resources of our home planet and to reduce the global pressure that industrial society inevitably exerts on the ecology, because with its development, we always seem to have a bigger demand for energy.

Now those kinds of problems can be fixed by the GPV. However, this is a very complicated task, since the spacecraft proposed by Anatoli Unitsky not based on traditional rocket technologies, but on a much more inspiring qualitative change in our approaches to the use of space.

I believe that the GPV is a vital invention, if you look at the future history of the human race across many thousands of years. Nevertheless, we will not need so much time to carry out the industrialization of space without the use of rockets. And this is the meaning of the conference.

The people gathered here are able to significantly speed up this process together and, in fact, reinvent the ways of entering near-Earth space, inhabiting it and arranging life in it. Non-rocket near space industrialization is a necessary and essential component of our movement forward as a species and indeed as lifeforms on this planet.

It's been said many times: if we do not change our attitude to what is happening on Earth, then humanity will cease to exist. Therefore, each of us is morally obliged to contribute to the cause that Dr. Anatoli Unitsky has been promoting for a long time and that together we are able to bring to life.

Asgardia has an unshakable belief that we can have babies born in space and that we have to do that, otherwise, we never escape from the Earth environment. We also believe that the community that Asgardia is trying to create fits in perfectly with the vision that Dr. Anatoli Unitsky and the conference participants regarding the further development of civilization. As we move into that new environment, we want to create a peaceful new society in space, doing the very best we can to reduce the burden we put on Earth.

On behalf of Asgardia, I express gratitude for creating the technology we need to build the advanced society. I am sure that collectively we can create a non-rocket near space industrialization environment which will benefit not only the people involved in this task, but also the whole of humanity.

Thank you for giving me the opportunity to share these thoughts with you.

I look forward to working with you from now into the future. I would like to attend the conference in person next year. I hope that I will be able to contribute to the promotion of an idea of creating the GPV.

Please accept my congratulations on the occasion of the next meeting!

Non-rocket near space industrialization is a necessary and essential component of our movement forward as a species and indeed as lifeforms on this planet.

Welcome Speech by Sergey Korotkov,

Director of the UNIDO Center for International Industrial Cooperation in the Russian Federation

Dear colleagues, dear friends!

On behalf of the United Nations Industrial Development Organization (UNIDO), I am glad to greet you at the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects".

Today, the world faces many challenges, on the solution of which our future depends. Among them are the problems of global warming, saving forests and the World Ocean from the consequences of human activity, as well as issues of transition to alternative energy sources, development of industry using environmentally friendly and resource-saving technologies.

The UNIDO actively supports projects and programs aimed at implementing the Sustainable Development Goals proclaimed in 2015 by the UN General Assembly, in particular, Goal 9 "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation".

Industrialization is the most significant driving factor in the achievement of human prosperity and general well-being. There is no country in the world that has achieved a high degree of economic and social development without the improvement of the industrial sector. Nevertheless, these transformative structural changes are often accompanied by environmental degradation and increased social inequality.

The UN Goals are designed to become the basis for the integration of economic, social and environmental aspects necessary for the full realization of sustainable development for the benefit of succeeding generations. However, this process is impossible without the designing and implementation of innovative engineering and technical solutions and the participation of people who see the world through the eyes of dreamers thinking about a better future for posterity.

Glad to be here among the dreamers and entrepreneurs who make these changes possible. I believe that the industrial exploration of space and purposeful activities within the framework of the international EcoSpace platform can become an important part of the sustainable development concept, and the results achieved in the course of exploring outer space will be applicable at the world level.

I wish the participants of the anniversary conference an interesting and fruitful work, useful meetings and successful implementation of the planned projects!

Welcome Speech by Igor Babichev,

Academician of the Russian Academy of Natural Sciences, Doctor of Law, Head of Staff of the State Duma Committee on Regional Policy and Local Self-Government, Chairman of the Department of the Russian Academy of Natural Sciences for Federal Structure, Local Self-Government and Local Communities

Dear colleagues, friends!

I greet you at the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" not only on my own behalf, but also on behalf of our delegation. We represent the Russian Academy of Natural Sciences, which is engaged in regional and local self-development, as well as the Federal People's Council, which is responsible specifically for designing a public, social and economic future. Our activities are in tune with the tasks that Anatoli Unitsky and his team are solving, therefore we wish all the participants of the scientific forum, as well as our countries, the Union State of Russia and Belarus a broad technological movement and a social breakthrough.

We live in a critical time, it is today that we must think about the fate of our planet – to outline a path that succeeding generations will follow. In doing so, we will save the Earth, turn it into a blossoming garden and provide our children with a kinder, more comfortable and brighter future.

All the best to everybody in achieving this goal!

We live in a critical time, it is today that we must think about the fate of our planet – to outline a path that succeeding generations will follow.

Welcome Speech by Gennady Cherepov,

Member of the Board of the Association "Power Industry and Civil Society", Co-Chairman of the Arctic Council of the Eurasian Peoples' Assembly, Director of the International Arctic Summit and Representative of the Saint Petersburg Arctic Public Academy of Sciences in Moscow

Dear participants and guests of the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects"!

On behalf of the Association "Power Industry and Civil Society", the Arctic Council of the Eurasian Peoples' Assembly and the Directorate of the International Arctic Summit, I sincerely greet you at this unique platform for discussing technologies for the development of near-Earth space without the use of rockets.

Today, the focus is on the search for ideas and the solution of relevant problems of a social, biological and engineering nature for the implementation of an industrial exit into space of the Earth's civilization, and therefore, for the sake of saving our Blue Planet.

I wish you fruitful work and success in achieving your goals!

Today, the focus is on the search for ideas and the solution of relevant problems of a social, biological and engineering nature for the implementation of an industrial exit into space of the Earth's civilization, and therefore, for the sake of saving our Blue Planet.

The Union State of Russia and Belarus as the Hub for Rebooting the New World to the Biospheric Path of the Civilizational Development

A. Unitsky,
Dr. of Transport Philosophy

UDC 339+629

The main prerequisite for the development of the Program for Rebooting the Economy of the Union State of Russia and Belarus to the Biospheric Path of Civilizational Development (hereinafter referred to as the Program) is the existence of fundamental problems in the current models of civilizational structure and the disruptive nature of their technological and social development.

The ruling "global elites" (it would be more correct to call them pseudo- or quasi-elites as they are impostors and self-appointed mandarins – no one has elected, appointed or accepted them into the global elite) lobby for increased control over people and reduction of the human population, including that through deindustrialization and decarbonization of the world economy.

Thus, protecting the interests of their clan, these "elites" do damage to developing economies and humanity as a whole, up to the programming of the self-liquidation of our industrial civilization in the foreseeable future.

In contrast to these scenarios of civilizational development, a biospheric technological path is proposed with the center of forces not in the West and East, but in the Union State of Russia and Belarus, relying on their own elites.

To strengthen and develop the Union State, the following global problems of our time were systematically analyzed:

- **pollution of the environment and the Earth's biosphere in general;**
- **local and global climate changes;**
- **national and civilizational security – resource, technological, infrastructural, transport, energy, food, medical, cultural, social, educational, informational, psychological, etc.**

Consideration of problems and ways to tackle them from the perspective of Russia – the backbone of the Union State – is caused not only by its influence on all the ongoing civilizational processes as a Eurasian state with a huge territory, but also as a state with enormous resource and intellectual potential.

The proposed Program is not limited to the Union State and consists of the following biospheric engineering technologies:

- **relict solar bioenergy (RSBE);**
- **biospheric agriculture;**
- **construction of cluster-type pedestrian linear cities;**
- **"second level" transport and infrastructure complexes – Unitsky String Transport (uST);**
- **non-rocket near space industrialization.**

Each of the proposed solutions is scientifically justified and conceptually materialized in the research centers (located in the Republic of Belarus and the United Arab Emirates), which are part of the international group of companies called Unitsky Group of Companies (UGC) and established by engineer A. Unitsky.

The introduction of the Program – even in the context of the Union State, without the participation of other countries in the first stages of implementation – will allow to overcome the social, economic, ecological and resource crises in which mankind finds itself today.

A thorough description of the steps in the implementation of the Program makes it possible to see that the transformation of the existing capitalist system without evolutionary upheavals is real, with the Union State as a new world center of power.
The considered effect for Russia and Belarus from rebooting to the biospheric path of civilizational development assures us of the rightness to choose this direction, capable of saving the Earth's technocratic civilization from degradation, extinction and death in the existing reality.
The estimated budget of the Program clearly illustrates its comparability with the state programs for the development of individual sectors that have been adopted but are less effective: the Program embraces all essential aspects of life for both individual citizens and regional societies or the state as a whole.
The conclusions deal in detail with the creation of uNet – an international transport and infrastructure network, combined with power industry, IT sector and agricultural production – as a fundamental instrument of implementation of the Program for Rebooting the World Economy to the Biospheric Path of Civilizational Development, which will give Russia and Belarus a real opportunity to become world leaders and great nations within a generation.
Economic rebooting of the Union State assumes the implementation of the uSpace program as an element to ensure the transition of the Earth's technogenic civilization to the space vector of technological development and large-scale space industrialization relying on non-rocket geocosmic transport technology – the General Planetary Vehicle (GPV) situated in the equatorial plane.
In this context, political and social institutions of the Union State can act as consolidators not only for the states of the equatorial belt, but also for member states with high economic, scientific and engineering potential. This will ensure the completion of a global project to improve the quality of life of both individuals and humanity as a whole, without population restrictions or harm to the planetary environment – the Earth's biosphere.
Russia and Belarus, together with the multi-ethnic people of the Union State, will once again prove their greatness and special civilizational role in the world, confirming the prophetic words about Moscow as the "Third Rome that stands" and the "Fourth Rome that will never be".

Keywords: *biospheric path of civilizational development, climate change, General Planetary Vehicle (GPV), "horizontal skyscraper", linear city (uCity), pollution of the environment, relict solar bioenergy (RSBE), transport and infrastructure complexes, uSpace geocosmic program, vertical greenhouse.*

Introduction

The main purpose of this paper is to continue research on the development and detailed elaboration of a socio-technological way out of the critical situation that has unfolded on the planet.

All present-day humanity is actually declared a hybrid war by neurolinguistic reprogramming from the current civilizational vector of "Technological and intellectual progress" to the destructive vector of "Personal, social and civilizational suicide". This war is being waged through digital information tools and media that have replaced the "Truth matters most" principle with the more monetizable "Serving the master" concept.

The state as a political institution is meant to protect its citizens from internal and external threats. For this purpose, it has everything it might need at its disposal. Below you will find a rather detailed description of the innovations which will enable to:

- intensify the development of our Earth's technocratic civilization in a creative aspect;
- solve all the environmental and social problems of mankind without detriment to the planet and its biosphere;
- raise the living standards of any country and of humanity as a whole;
- give us all a chance for a better future – safer, more comfortable and more humane.

However, primarily it is necessary to say a few words about the anti-human plans that are voiced by the quasi-elites mentioned above.

Wars, economic and social crises, accelerated growth of consumption jeopardize the basic values of our civilization and our very future. It is becoming increasingly obvious that humanity has once again reached a dead end.

As a solution to all the problems on Earth, some suggest developing Mars, others – reducing the world population to the "golden billion". Furthermore, today we are not just recommended, but rather brutally forced to adopt these programs. Think of the infamous coronavirus, for example. No matter how hard they try to present it as some kind of mega-disaster, it is obvious to everyone: it is not.

First, it is clear that the pandemic is the result of man's detrimental impact on nature, immense and thoughtless consumption. It is easy to give an example: the virus is believed to have been passed on to humans from animals. One version suggests that pangolins are the main culprits. Chinese gourmands – well-fed and even jaded people – traditionally have a rush for these animals, which has brought pangolins to the brink of extinction. As we all understand, it is not about hunger: pangolin meat is a spoil of affluence, an element of up-market consumption [1].

Some estimates suggest that there are about a trillion species of living organisms on Earth today, with only 1.75 mln (0.000002 %) described [2, 3]. Because of human actions, more than 70 species die every day; about 26,000 per year. The scale of the negative impact on the environment is only increasing every year, thus forcing the planet to simply defend itself against the aggressive actions of humans.

Second, the lifestyle we follow today makes humans the main cause of pandemics.

Massive overcrowding in cities, with huge numbers of people in close contact with each other; the use of outdated transportation systems, with large accumulations of passengers – all this only exacerbates the spread of viruses.

Junk food, new ingredients (sweeteners, anti-caking agents, leavening agents, GMOs, etc.) and a less active lifestyle weaken the immune system and, as a result, cause various diseases [4, 5]. Clever marketing and associated advertising are trying to sell us as many trendy food additives as possible, talking about their curative properties and benefits for the body. But our immune system cannot replace any of the drugs developed by man, including those taken as vaccines and inoculations. Without trying to deal with the cause, and just fighting the consequences of disease, we once again become a convenient target for advertisers and an inexhaustible source of their profit.

If you look back in history, you will realize that all the wars and economic problems of the 20th century stemmed from the overcrowding of people and their irresistible desire to consume as much as they could. As a result, the struggle for resources and spheres of influence intensifies. And this struggle is one of the basic elements of the capitalist system, which is built entirely on and around profit.

In general, the capitalist system assumes the necessity and inevitability of crises, which each time bring increasingly catastrophic consequences [6]. Most economic experts share this view. Accordingly, there is a demand for reform of capitalism, since alternative models (e.g., socialism) are not accepted by global quasi-elites. After all, these are capitalist elites. They cannot give up on themselves.

Historically, experts associate crises with overproduction [6]. Based on this logic, they can be avoided by changing the way we produce and consume. Before exploring how exactly the quasi-elites intend to arrange the new world, let us take a moment to look briefly at how this is happening now.

The worker produces the goods and gets paid for his labor. The surplus value is left to the enterprise to spend on the development of production, its own needs and the needs of the state through taxes. However, the goal of any production is to increase profits. Accordingly, on the one hand, it is necessary to optimize technological processes and reduce the cost of labor, and, on the other hand, to increase the number of products.

It turns out that the output must increase all the time, and the relative wages for labor should decrease. Who are the most popular customers for products? Wage earners. If they get less, they will buy less. But more and more goods and services are being offered every day. As a result, there is a surplus of products that no one wants. And then the manufacturer is forced to downsize, stop the production and minimize production costs.

The economy is slipping into crisis. Some manufacturers go bankrupt, others optimize production, prices for accumulated surpluses go down, and overstuffed warehouses are gradually emptied. Once again, the demand exceeds supply. Everything repeats with a new round of development. War or pandemic, by the way, can significantly smooth out the situation, since new sales markets and jobs are createdin a short time, there appears a demand for certain product categories, orders, etc. This is why wars start when the economy is at its peak. This is not a consequence of excess power, but a way to avoid the forthcoming sharp and painful fall from the top. Is it possible to avoid crises in any other way? It seems so.

Problems and Prerequisites for the Transition to a New Post-Capitalist Economy

Currently, the problems associated with the crisis of the Western European model of capitalism [7], as well as liberal and neoliberal doctrines as a socio-political extension of the dominant economic and technological model of civilizational structure, have become more pressing in the world.

As a reaction to the emerging crisis, Western European and North American power institutions and quasi-elites are actively promoting programs aimed at artificially restraining the industrial development of the world economy, while it is industry that is the basic civilizational technological platform of all modern humanity. This industrial technology platform has been created by engineers and scientists around the world over the past hundreds of years. However, if the starting point of industrial age is set from the invention of the wheel (which marked the beginning of transport), it took about 10,000 years to build the industry on Earth, and if it starts from the invention of the fire (which pioneered all thermochemical technologies, and not only cooking with fire, but later metallurgy, engine building, power engineering, etc.), it took even hundreds of thousands, if not millions, of years.

The so-called "global elites" not only propose, but fiercely impose on our entire Earth's technocratic civilization, which they are an integral part of, projects to deindustrialize the economy (through its decarbonization) and to desocialize and depopulate humanity (through deindustrialization and digitalization) in order to strengthen control over people and systematically speed up the reduction of the world population.

First and foremost, these programs affect the so-called "developing economies", while at the same time serving the interests of "developed countries" and the global transnational corporations based there.

In this context, geopolitical confrontation on a global scale is intensifying. On the one hand, the USA and its partners are trying to impose their model of the world order to all other countries, which implies the domination of corporations, the obliteration of territorial boundaries and the gradual loss of the role of national states in all aspects of public life and economic activity, all the way to the abolition of states and transfer of their functions to global corporations. On the other hand, alternative centers of power are emerging, defending their interests and sovereignty [8]. Among them, the Union State of Russia and Belarus plays a key role in the geopolitical context.

At the end of May 2022, after a long break caused by the COVID-19 pandemic, the World Economic Forum was held in Davos in full-time format. For the first time in 35 years, the Russian Federation did not participate in it. Belarus also did not attend the event.

The exclusion of representatives of the Union State from the number of delegates of one of the largest and leading forums in the world is due to Russia's special operation in Ukraine. At the same time, military actions, their causes and consequences had been declared as the main topic of the event. During the discussion of the situation, Western experts stated that they would continue to support Ukraine and assist in its reconstruction. Ukrainian leader Vladimir Zelensky called for "the toughest possible" sanctions to stop Russia's "aggression". Suggestions included an oil embargo, blocking all banks, a complete withdrawal of European companies from the Russian market and a halt to trade. For Ukraine, he asked for financial and military aid of 5 bln USD per month.

David Beasley, Executive Director of the United Nations World Food Programme, drew attention to the blockage of grain supplies and expressed the opinion that "failure to open the ports in Ukraine will be a declaration of war on global food security" [9]. He said that if food supplies remain off the market, the world could face grain shortages in the next 10–12 months, and that "would be hell on Earth".

Jens Stoltenberg, NATO Secretary General, called the special military operation a "turning point" not just for European security, but for the "broader international order". In addition, he added, "peace in our continent has been shattered" in recent months. The politician argued that "freedom is more important than free trade" and called on business leaders to defend common values. Stoltenberg warned that ignoring the threat from authoritarian regimes "undermines security" [9].

Speaking at the forum, Ursula von der Leyen, President of the European Commission, said that the special military operation in Ukraine has put into question "our whole international order". Instead of addressing climate change and shaping the global economy, "we must address the costs and consequences" of the conflict.

According to Olaf Scholz, Chancellor of Germany, the Russian government "wants a return to a world order in which strength dictates what is right; in which freedom, sovereignty and self-determination are simply not for everyone. This is imperialism. That is an attempt to blast us back to a time when war was a common instrument of politics, when our continent and the world were without a stable peaceful order... Putin underestimated the unity and vigour with which the G7, NATO and the EU would respond to his aggression. Working together, we have imposed sanctions that are tougher and further-reaching than any previously imposed on a country of Russia's size" [9].

The so-called "European community" has demonstrated exceptional, hitherto uncharacteristic cohesion in its perception of the "common foe" and the fight against it. It is unlikely that this attitude towards Russia and the Union State as a whole can change much in the near future. This means we need to look for new ways of development. The key problems here are import substitution, i.e., technological independence, decreasing the significance of energy exports for the economy, and building up political, social, technological and economic sovereignty as vigorously as possible. In addition, there is a growing need to find new partners, to reorient exports and imports to new markets, and to deepen integration with allied countries. First and foremost, we should talk about deepening of integration of the closest neighbors – Russia and Belarus, which in deed confirmed their readiness and ability to interact even under strong external pressure.

The need for in-depth industrial cooperation between Russia and Belarus has been discussed for many years. The matter has been constantly reviewed at the meetings of the two presidents. The governments have set up special working groups that develop specific common grounds [10]. It is not easy for Russia and Belarus to solve problems on their own, therefore, joint organizational and technical solutions are being promptly considered now.

Among the wide list of sanctions, technological ones are among the most painful. To compensate for the lack of sophisticated modern equipment and industrial technologies, as well as the knowledge and skills to create them in Russia, it will take a long time, since it cannot be fast – it takes years and sometimes even decades to master these technologies and production methods. Such a high commercial credit for the state economy in the very near future can destroy any production and, as a consequence, leave millions of citizens jobless, and the budget – without income.

Belarus, although it managed to preserve and in a number of industries even multiply the industrial heritage of the USSR, also cannot manage on its own. A small country lacking natural riches, such as oil and natural gas, does not have enough resources to compete in the market. It is just by joining forces that Russia and Belarus will be able to successfully resist external pressure and thereby offset all of its negative consequences [11]. However, a positive outcome in this case will be possible only with a fundamental revision of approaches in the monetary system. It will also require a change of priorities in infrastructure and technological development, including the main role of those scientific and industrial sectors, which can contribute most to the economic growth of the Union State and which have the appropriate prerequisites for occupying leading positions in the world.

The sanctions imposed on the Union State countries open a window of opportunity to rebuild and increase production capacity. Until now, Russian enterprises have essentially acted as assembly plants for foreign companies. This happened because the existing monetary system in the country did not permit to maintain and develop deep technological redistribution of industries with high added value, although the size of the market and access to cheap energy could contribute to the creation of a different model. For Belarus, the determinant of its lagging behind was its inability to withstand the financial and technological power of transnational corporations. The forces too incomparable in their scale and capabilities clashed on the market battlefield.

By changing and uniting, redirecting export and import flows to the shared domestic market, Russia and Belarus will be able to significantly compensate for vulnerabilities in each other's economies, and further ensure their rapid economic growth. This requires conscious and consistent actions from the governments of the two countries and all business entities, as well as financial institutions. Unfortunately,many steps in this direction do not seem right at present.

The wave raised by Russia's liberal financial and economic wing could "wash away" the remnants of technology and production in the country. Before the "inclusion" of sanctions, a considerable part of state revenues, including funds of the National Welfare Fund, were accumulated abroad, in the USA [12]. Almost 700 bln USD had been accrued in such funds. This Russian money was controlled by foreign institutions.

Huge funds, trillions of dollars over the past 30 years, which were withdrawn from the country, could have been invested in the development of national industry, and lowering the lending rate would have opened up tremendous opportunities for domestic investment and would have created a real reserve for rapid development. But this money was withdrawn from the Russian economy. They essentially became an investment in the USA economy and industry. Russia counted on foreign investment, the arrival of foreign technology and energy exports. As a result, this system led to a dependent semi-colonial status.

As soon as the situation in relations with the West worsened, technology and investment left Russia, gas and oil sales declined. Approximately 60 % of the funds accumulated in foreign financial institutions were frozen and made inaccessible after the start of the special operation in Ukraine [13]. The amount lost is equal to two annual budgets of Russia. However, the Central Bank, even in the current crisis, does not lower its lending rate to stimulate business growth and import substitution, but, on the contrary, raises it to keep the Russian ruble to US dollar exchange rate. *(For comparison: in the USA this rate is only 1.7 %.)*

Obviously, the monetary system that led to this situation must be reviewed in the first place. It is necessary to create conditions for intensive domestic investments within the Union State. Alongside traditionally prioritized economic sectors, it is imperative to support knowledge intensive industries, as well as fundamentally new technologies, and especially in backbone sectors such as transport, energy, agriculture, industrial and civil infrastructure, which determine the level of development of national sovereignty and security. This is what the Western ideologists are afraid of, insisting on sanctions and governing the activities of the Central Bank of the Russian Federation through the International Monetary Fund (IMF). They do not want to al-low the industrial development of countries that in their eyes act as rivals in the struggle for "living space" or even "enemies", as they are now trying to portray Russia.

The second most important topic of the previously mentioned World Economic Forum in Davos was traditionally the ecology and global warming. Despite the attractive and outwardly humane wrapping, the ideas voiced during the discussions on environmental protection are intended to achieve the same goals as the sanctions imposed on Russia – the elimination of rivals. For example, Ronald Busch, Execu-tive Director of Siemens AG, proposed to take radical measures at the level of international legislation – to set prices for carbon, which, according to him, would create an incentive for businesses to decarbonize their operations [9]. In fact, it is easy to understand that such a decision would not be an incentive at all, but a lethal technological sanction against those countries and businesses that, for financial reasons, cannot afford to pay for carbon, and especially to decarbonize production with complex, expensive and inefficient equipment.

All Western actions and rhetoric since the outbreak of the COVID-19 pandemic show that Europe and the USA are not willing to cooperate with countries that, in their view, are not sufficiently developed. There are a majority of such countries on the planet, including the countries of the Union State. The behavior of the European powers demonstrates that they only pursue the interests of a narrow "inner circle". For example, it does not matter to them that sanctions against Russia threaten them with a fuel and food crisis of their own. Although they are aware of this.

Also at Davos in May 2022, IMF Managing Director Kristalina Georgieva said that developing countries faced food shortages due to sanctions against Russia, which is the main supplier [14]. Despite this acknowledgement, sanctions pressure has not waned; it is likely that this situation pleases the IMF and the EU. In their view, developing countries should not develop too much, otherwise they may threaten the leadership and hegemony of the IMF and the EU, which these organizations will try to counter with all their might, as we have seen in the case of Russia and Belarus.

Therefore, in the current situation, Russia and Belarus have to rely only on each other. At the same time, strengthening integration in the Union State opens up new opportunities and horizons for the countries, allowing them to refocus

on the domestic agenda, building a course for increasing autonomy, sovereignty (including technological) and economic growth. The Union State can create, from scratch, new financial institutions, form a new government and a better monetary system, unaffected by unfriendly countries, as well as implement various programs involving a full rebooting of the Union economy onto new technological rails.

Obviously, in order to achieve these plans, it is necessary to gain independence from the supranational liberal global systems (WTO, WHO, Kyoto Protocol, IMF, etc.) created by the "deep power" and quasi-elites with a single and deeply concealed goal – to rule the world through their agenda and in their interests. The sovereignty of the Union State – political, social, technological and economic – is in no way a part of these interests.

In order to achieve sustainable development goals in the Union State, we need to make considerable efforts to radically change the nature-intensive raw materials trends in the Russian Federation, which have gained enormous inertia. It is becoming more apparent (and the recent crisis has confirmed this) that the export-raw materials model of the Russian economy has exhausted itself. And environmental sustainability must become an important aspect of the new model [15].

Problems that need urgent solution by the leaders of the Union State are: depletion of natural capital as a factor of economic growth; grave impact of the polluted environment on human health; structural shifts in the economy, which increase the share of nature-intensive and polluting industries; greater environmental risks due to considerable physical deterioration of equipment; high environmental intensity levels; natural resource orientation of exports; ecologically unbalanced investment policy, leading to an imbalance between nature-intensive and processing, manufacturing and infrastructure sectors of the economy; other.

The above problems arise largely from the underestimation of the ecological factor in macroeconomic policy, which leads to further degradation of the environment and the depletion of non-renewable natural resources. In Russia, the negative ecological structural shifts were exacerbated by the crisis, during which the most survivable sectors were raw materials exports, largely due to government support. The crisis has clearly shown the enormous dependence of the Russian economy on the exploitation of the Earth's interior and the sale of natural raw materials [16].

Despite the efforts made by the Russian leaders in the field of innovation, modernization, diversification and import substitution, there is still a risk that the country's economy will become solely export-raw material one, and there is a growing share of industries with a strong adverse ecological impact. In addition, we can observe further pollution and degradation of the natural environment and disruption of the fragile balance of biosphere ecosystems, which leads to the aggravation of human health and limits the possibilities of civilizational development. Rough estimates of risks from water and air pollution allow us to say that the economic costs to maintain the health of the Russian population are on average not less than 4–6 % of GDP. In the regions, particularly in the Ural, the health detriment for environmental reasons can be as much as 10 % of the GRP [17].

Environmental Pollution Problems

In 2022, Victoria Abramchenko, Deputy Prime Minister of the Russian Federation, named the most environmentally unfavorable cities in Russia, where the degree of air pollution should be reduced by 20 % after implementation of the federal project "Clean Air". These are Chelyabinsk, Nizhny Tagil, Magnitogorsk (where large metallurgical plants are located), Norilsk, Novokuznetsk, Omsk, Krasnoyarsk, Cherepovets, Lipetsk, Bratsk (which has large aluminum smelters), Chita and Mednogorsk [18].

Of course, in many settlements, industrial enterprises and power plants create a critical environmental situation, but they still have a local character, although they pose quite high risks to the health of people in the regions of allocation.

The most unfavorable factor of environmental impact on the health of the population is air pollution from motor vehicles.

The second place in this dubious rating is urban noise. As a result of rapid development of transport load over the past 20–25 years, its level has increased by 5–10 dB, i.e., 2.5 times in terms of subjective perception of loudness [19]. Accordingly, we can assume that the effects of noise on the health of urban residents are quite significant.

Although we are now witnessing a decrease in hazardous emissions into the atmosphere and, albeit slowly, improving pollution indicators, the rate of soil deterioration is not decreasing; on the contrary, there is an accelerated degradation of their quality and fertility. This indicates that the existing government interventions do not fully ensure the preservation of soil fertility as a resource that guarantees the food security of the country and as the most essential natural component that contributes to the sustainable functioning of biosphere ecosystems – not only local and regional, but also global, planetary.

Soil is the bedrock of agriculture and the natural environment in which almost all food crops grow. It is estimated that 95 % of food is produced directly or indirectly on natural soils [20]. Today, about 30 % of land is moderately to severely degraded due to erosion, salinization, compaction, acidification and chemical contamination [21].

Soil impoverishment and degradation are now such that the ability of future generations to meet their most urgent needs is threatened. Based on available estimates of current demographic trends and the predicted growth of the world population by 2050 (10 bln people), we can assume that agricultural production in the world would have to grow by 60 % on average and by almost 100 % in developing countries in order to just meet the demand for food [22].

According to data from the Federal Service for State Registration, Cadastre and Cartography, as of January 1, 2021 the acreage of the land fund of the Russian Federation accounted for 1,712 mln ha, including 1,126 mln ha of forest land (65.8 %) and 381.7 mln ha (22.3 %) of agricultural land [23]. Statistics from recent years show that agricultural land is declining, as it has lost its original quality, overgrown with forests and became unsuitable for further use for its intended purpose. Thus, in the period from 2011 to 2021 the total area of agricultural land in the Russian Federation decreased by 12.6 mln ha, or over 3 %. In this regard, priority objectives for the development of the country's agro-industrial complex are aimed at gradually involving previously unused lands with improved properties in agricultural turnover.

The total area of land resources in the Republic of Belarus is 20.76 mln ha; forests and agricultural land prevail, with an area of 9.6 mln ha and 8.3 mln ha, respectively. *(For comparison: the Tyumen Region of the Russian Federation alone with its autonomous districts occupies 146.4 mln ha, which is seven times the area of Belarus.)*

The influence of Russia as a Eurasian state and its giant territory on global climatic, environmental, geopolitical, economic, social, demographic, resource, infrastructure, energy, investment, innovation, intellectual and other problems of our time exceeds the influence of Belarus by one or two orders of magnitude, therefore, in this analysis, the problems of the Union State are considered primarily from the perspective of the geopolitical interests of Russia, which occupies 1/9 of the land surface (for Belarus, this indicator is 1/722).

Analysis of the results of soil monitoring for organic matter (humus) as the main determinant of soil fertility revealed that slightly humus soils prevail in the Russian Federation. It is 37 mln ha, or 37.1 % of the surveyed area. Soils containing less than a minimum of humus make up a significant part – 25 mln ha (25.1 %); medium humus soils account

for 26.2 mln ha (26.3 %), while the proportion of highly humus soils does not exceed 11.4 mln ha (11.4 %) [24]. The biggest part of arable lands with humus content below the minimal level is in Samara region (2.8 mln ha, or 99.2 %), Orenburg region (2.5 mln ha, or 41.2 %), Kurgan region (2.1 mln ha, or 86.2 %), Rostov region (2 mln ha, or 51.1 %), Saratov region (1.7 mln ha, or 29.9 %), Stavropol Krai (1.3 mln ha, or 32.1 %), Volgograd region (1.3 mln ha, or 23.1 %), Chelyabinsk region(1.1 mln ha, or 44.1 %), Altai Krai (1.1 mln ha, or 18.8 %).

Climate Change Problems

According to the data provided in the relevant evaluation reports by the Russian Federal Service for Hydrometeorology and Environmental Monitoring, the average annual temperature in the territory of the Russian Federation is growing more than 2.5 times faster than the global rate of 0.45 °C per 10 years, and it is particularly rapid in the Arctic zone, where the growth rate reaches 0.8 °C per 10 years. In the Arctic in recent decades there has been a sharp decrease in sea ice area with significant inter-annual variability. Based on calculations in Russia during the 21st century, average surface air temperature is expected to grow. The greatest warming is likely in Siberia and northern regions of the country, as well as in the Arctic. Further degradation of permafrost is expected, which is accompanied by an increase in the thickness of the seasonally thawed layer and a northward shift of the border separating the areas of seasonal thawing and seasonal freezing of soils. Reduction of the ice cover of the Arctic Ocean will continue throughout the 21st century, mostly due to a reduction in the area of perennial ice.

World statistics confirm the validity of model calculations and forecasts by scientists and experts on the acceleration and growth of the socio-economic consequences of both global and regional warming and other climate changes, including those in Russia. Experts of the World Economic Forum have been publishing annual reports with ratings of global risks for more than 10 years, among which the highest positions are occupied by threats to the population and economy associated with climate change.

Extreme weather topped the list of global risks in the 2021 ranking, taking first place in terms of probability and second in terms of the scale of impact and severity of consequences. Natural disasters and failures in the efforts to reduce the man-made impact on the climate and adapt to climate change are also among the leaders in both criteria. In addition, large-scale forced migration, a type of which is referred to as "climate refugees", is a priority in terms of probability. In recent times, general concerns about environmental threats have been growing. For the first time in the decade-long history of global risk analysis, the World Economic Forum determined that environmental hazards ranked all of the top five risks by probability and three of the top five risks by impact [25].

There is also an alternative perspective put forward by independent researchers and experts, including those from Russia and Belarus. It is as follows: global warming is not caused by man-made factors, but by natural cycles caused by processes in the bowels of the Sun and the Earth, as well as by their movement along planetary and galactic orbits. In particular, we know that there is a constant acceleration of thermonuclear combustion of hydrogen in our luminary and an increase in its brightness, which in time (about 5 bln years) will even turn the Sun into a red giant, which will expand and consume the Earth. This position is also supported by such a fact that in a historical retrospective the temperature on the planet was not strictly related to the content of greenhouse gases in the Earth's atmosphere, including carbon dioxide.

The entire multimillion-year history of life on our planet demonstrates that CO_2 is not the main climatic factor (from the perspective of the greenhouse effect, the content of water vapor in the Earth's atmosphere and ozone in the ozone layer are much more relevant). For example, 250–320 mln years ago, in the Carboniferous period, the concentration of carbon dioxide was half as high as today, and the average temperature was 10 °C higher. Whereas 150–200 mln years ago, its content was almost an order of magnitude higher than today – 0.3 %, and 400–600 mln years ago – even 0.6 %, and there was no global warming then. On the contrary, virtually the entire planet was covered in ice.

It is obvious to the author of this study that the "5D" program (digitalization, deindustrialization, decarbonization, desocialization, depopulation), which is being imposed on humanity with manic persistence by the global quasi-elites through their spokesmen (the Club of Rome, the World Economic Forum and the UN and World Health Organization bodies under their control) and is currently underway throughout the world, pursues completely different strategic goals than those that the Western mass media are talking about.

In fact, the consequences of global warming do not really matter for Russia and Belarus. For example, Russia will only benefit from it, as the climate of its northern territories will become more favorable. The rising ocean level will flood only the coastal area, primarily the shoreline of the Arctic Ocean, which is practically uninhabited by people. But it will improve Russian and international logistics, because the Northern Sea Route will be free of multiyear ice. It will also make it easier and cheaper to extract natural resources – apart from hydrocarbons, the Russian Arctic has unique deposits of phosphorus, mercury, titanium, tantalum, tin, diamonds, gold, nickel, copper, silver, tungsten, uranium, platinum, palladium, molybdenum, as well as precious, rare, rare-earth and non-ferrous metals.

Furthermore, the rising level of the slightly warmer Arctic Ocean will increase Russia's marine biological resources, increase opportunities for northern aquaculture and expand the area of agriculture and its productivity, as winter in the north will not be as severe and summer will be warmer. Multiple reasonable forecasts indicate that the ocean level in the next thousand years will not rise higher than 10 m, which threatens not Moscow and Minsk, but such megacities as London and New York. That is why it is the British and Americans who are so anxious about global warming and climate risks. But why must the Union State, to the detriment of its own interests, help its explicit geopolitical adversaries in solving their problems? After all, they are not enthusiastic about supporting Russia and Belarus, and on the contrary, over the centuries they have brought us a lot of irresolvable problems and horrific troubles.

Transport Complex Problems

The Russian economy is marked by a high degree of spatial heterogeneity. The key objectives of the Transport Strategy of Russia until 2030 are to create a common transportation space, to make transport safer and to improve accessibility for passengers [26].

Russian regions differ significantly in the level of socio-economic development, natural resource and production specificity. The main reason for the critical shortage of permanent population is not as much the harsh natural and climatic conditions as the transport isolation, which automatically deprives citizens of basic mobility and access to the basic benefits of civilization such as a diverse range of products and consumer goods.

The strategic problems of transport complex development in Russia are:

- low mobility of the population;
- limited accessibility of transport and logistics services;
- low efficiency and cost-effectiveness of the transport complex;
- unsatisfactory technical level and orientation to outdated century-old transport technologies;
- insufficient use of transit potential, lack of connection with the elements of global logistics;
- overall instability of regional and national economic development.

Solving the problems of sustainable development and finding a balance between economic growth and quality of life are especially relevant for cities, which are home to the majority of the world's population. The United Nations Population Fund predicts that by 2030 the number of urban dwellers in the world will reach 5 bln, with the urban population

Problems of urban mobility

Economic	Social	Environmental
Traffic congestion	Impediments to mobility of disadvantaged groups of the population	Air pollution
Increased costs for the maintenance and development of transport and related infrastructure	Negative impact on public health	Degradation of urban ecosystems
Increase in user costs	Negative impact on social relations and active use of public spaces	Negative impact on water bodies and urban soil
Limited mobility of urban population	Low livability of urban areas	Excessive use of non-renewable natural resources
Losses in traffic accidents (deaths and injuries to citizens)	Negative impact on visual appearance of urban environment	Noise pollution
Loss of urban land for agricultural production	Isolation of some urban areas	Urban sprawl and emergence of environmental problems in surrounding areas
Loss of urban land due to development of the street and road network and parking space	Negative impact on the level of urban security	Burial of urban waste (including household waste) in adjacent areas; resulting degradation of soils and regional ecosystems
Loss of time and deterioration of logistics due to spatial urban sprawl		

growing mostly in medium and large cities rather than in megacities. In addition to the increase in the number of city dwellers, urban settlements are also expanding. According to the United Nations, by 2030 the area of cities will increase three times in developing countries and 2.5 times in industrialized regions [27]. For example, the world's largest industrial city of Chongqing (China) has already caught up with Austria in terms of its area – it has taken over 82,000 km^2 of land from nature.

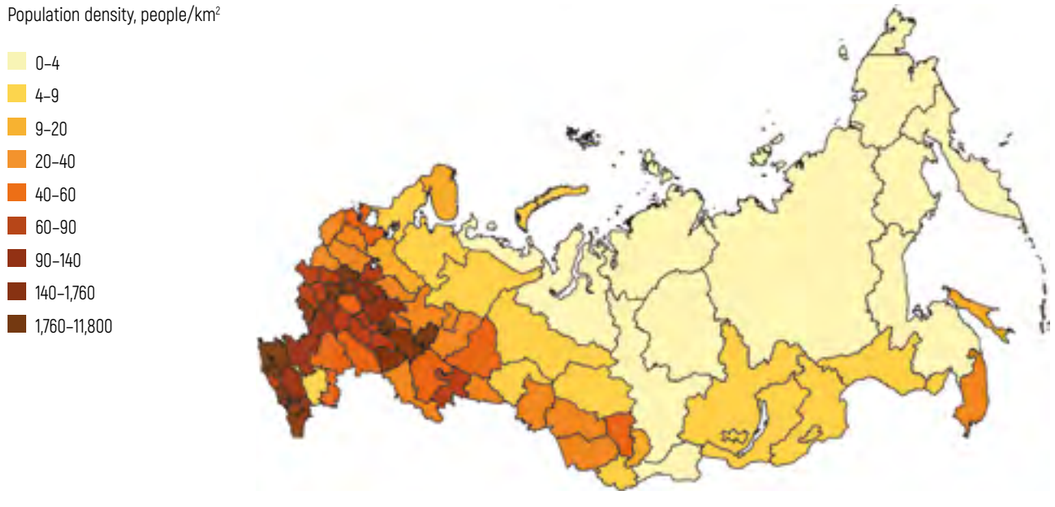
As reported by the Federal State Statistics Service, the total population of Russia as of January 1, 2022 was 145.4 mln people, with a population density of 8.5 people/km^2. By the first indicator the Russian Federation ranks ninth among all states of the world, and 180th by the second (179th – Bolivia, 181st – Chad). Statistically, there are 29 people per 1 km^2 in the European part of Russia; the population density in its Asian part is only 2.5 people/km^2. The population density of the north is generally low – 1.03 people/km^2.

This imbalance is primarily due to geographic and historical factors. The European part of Russia was populated earlier, so there are more inhabitants today. The Asian region is the least inhabited for climatic reasons. For example, Siberia is characterized by a harsh climate (average air temperature from –15 °C to –30 °C). Furthermore, the population is affected by the infrastructure, which is not very well developed in many areas of the Asian part of the Russian Federation. In this regard, most of Russia's population is concentrated in its European territory, which, as people say, is more suitable for habitation.

Conclusions

With the current approaches in the economy and modern anti-sustainable trends, the Russian economy may finally turn into a raw-material nature-exploiting economy with dwindling natural resources, which is on the periphery of global development and suffers from any (even a slight) decline in raw materials prices. Such unfavorable prospects are the most compelling reason for the necessity of a speediest and large-scale modernization of the national economy. However, it should be remembered that the Russian man, according to the world quasi-elites, is needed merely as a servant of the territory, which is a raw materials appendage and a resource pantry for the industrially developed Western countries. This means that the population of Russia and Belarus must be "optimized" – reduced at times, to 50 mln and even 30 mln people. All methods will be good for such a goal – pandemic, war, replacement of the economy of real values with the economy of imaginary entities, social and moral degradation.

Thus, the problem of balancing socio-economic development and the improvement of the natural, social and economic environment is an urgent task not only for Russian cities, but also for the whole country. This requires the use of a distinctive macroapproach to the territory spread over 1/9 of the Earth's land surface as a social, ecological and economic system with equal attention to all the most important aspects of human life and the functions of the surrounding Live Nature.



Russia's Potential for a Possible Technology Breakthrough

As the largest country in the world, with its enormous resource and intellectual potential, Russia seeks to pursue an independent policy focused on protecting the interests of its people, maintaining its territorial integrity and sovereignty in all its manifestations – from socio-economic to moral and spiritual. However, for a number of reasons, its position in the global geopolitical and civilizational confrontation has been weakened.

Russia's economic and technological lagging behind its geopolitical rivals is due to the historical events associated with the collapse of the Soviet Union and the long period of recovery that followed. At a time when the country was forced to solve the basic tasks of state and economic construction, other countries were able to allocate resources to stimulate the growth of scientific and technological potential. As a result, they were far ahead in many technical aspects.

In the current situation, attempts to catch up with European states and the USA in technological development within the conventional spheres and industries occupied by transnational corporations representing these countries are hardly feasible. In view of this, it is more appropriate to focus on innovative development in those breakthrough areas in which Russia is able to be the first and where it will be able to establish itself as a world leader forever.

For such steps to be effective, the innovative projects must be largely scaled, embrace the entire range of advantages of the Union State and allow the full development of the territorial and resource potential of Russia and Belarus, and then ensure rapid growth of export opportunities through the supply of implemented breakthrough technologies to all countries of the world.

Russia also understands the need for fundamental changes in the existing development model in the world, as well as within the country. At the Rio+20 UN Conference on Sustainable Development in June 2012, Chairman of the Government of the Russian Federation Dmitriy Medvedev underlined: "Society, the economy and nature are inseparable. This is exactly why we need a new paradigm of development that can ensure society's prosperity without excessive burdens on nature. We must balance the interests of the economy with conservation in the long term. That said, we must achieve innovative, energy efficient and green economic growth that will benefit all countries" [28]. Perhaps the main task of the Russian economy at the moment, which is reflected in the key documents of the country's development in the medium and long term, is to abandon the raw materials model of the economy. This direction is also the centerpiece of the concept of green economy, with most of its goals included in the fundamental documents.

The future economy of the Union State must have the following important attributes:

- the crucial value of environmental and economic living conditions of citizens and their guaranteed and stable supply of basic products and services;
- priority in the development of science-intensive, high-tech, manufacturing and infrastructure industries with minimal impact on the environment;
- a significant reduction in the share of the raw materials sector in the economy;
- a drastic increase in the efficiency of the use of natural resources and their saving, which is reflected in a steep decline in the cost of natural resources and the amount of pollution per unit of the end result (reduction of the nature intensity and pollution intensity indicators);
- a substantial reduction in environmental pollution in industry and transport.

The state can facilitate and accelerate the transition to the new economy through environmentally balanced economic reforms and the creation of an appropriate macroeconomic environment [29].

In general, it is possible to identify the main problems faced primarily by the Russian regions in the sustainability of socio-economic development:

- division of power in the economic sphere between the federal center and the regions, especially in the public sphere;
- non-diversified structure of the region's economy;
- disproportions in the financial sphere (deficit of finances in the real sector);
- growing social tensions (social stratification, an increasing proportion of the population living below the poverty line);
- insufficient development of intraregional and interregional ties, including foreign economic relations;
- unresolved issues of ensuring environmental safety;
- lack of a clearly developed system of quantitative target indicators of regional development sustainability;
- lack of an effective system of state regulation of sustainable socio-economic development;
- insufficient competitiveness of regional products, displacement of domestic manufacturers from the national market as a result of imports of foreign products.

For the development of regions with a certain degree of inertia, the timing is important. If we assume the thesis that the territory is a social, ecological and economic system, the question of time will be crucial. The economic decisions made today in such an interconnected system have long-term consequences both in terms of the impact on society, i.e., the social component, and in terms of the environmental impact, i.e., the environmental component [27]. Moreover, solutions designed for immediate economic effect without focusing on environmental and social aspects may turn out to be less profitable in the future, when society will have to bear additional significant costs due to environmental degradation or the creation of an adverse social situation.

The innovative option assumes, on the one hand, narrowing of differences in the level of socio-economic development of the Union State subjects; reduction of interregional differences in the level and quality of life of the population; creation of equal opportunities for all citizens, regardless of their place of residence, to exercise their social and economic rights. On the other hand, there should be a balance between building the economic potential of each subject of the state and/or municipal entity and the comfort of the living environment for the residents of the respective territories – the natural environment must not be degraded. In this regard, the key direction is the balanced development of the transport and infrastructure complex, which will provide logistics and infrastructure conditions for the growth of the innovative component of the economy, improve the quality of life and ensure the transition to a polycentric model of spatial progress of the Union State.

Activities for the development of the new transport and infrastructure complex of the Union State are:

- creation of a network of territorial and production clusters – residential, industrial, energy, IT-hubs, scientific, educational, tourist, recreational, shopping and entertainment and others, which focus on high-tech, knowledge-intensive and industry-forming technology and production;
- arrangement of territorial and production clusters focused on deep processing of raw materials and energy production, which ensure the development of new territories (mountains, sea shelf, taiga, tundra, etc.);
- establishment and development of tourist and recreational areas in the Crimea, on the Black Sea coast, Altai, Baikal, Kamchatka, the Russian North and other regions;
- development of major transport, logistics and industrial and energy hubs in the West and Northwest of the Union State, the Urals, Siberia, the Arctic, the Far East, Southern Russia and other regions, including four southwestern regions annexed to the Russian Federation in 2022.

When exercising this scenario, the modernization of the transport and infrastructure complex of the state must progress at an advanced rate compared to other sectors of the economy and the social sphere in order to lift infrastructure constraints of prospective socio-economic development, which depends on communications – transport, energy and information.

Therefore, new requirements to the transport and infrastructure complex arise: on the basis of breakthrough transport and infrastructure technology there should be a transition from the current extensive development model to the intensive one. That is why transport and infrastructure innovations are to become the starting point of sustainable growth in the economy of the Union State.

Suggestions of the Unitsky Group of Companies on the Program for Rebooting the Economy of the Union State of Russia and Belarus to the Biospheric Path of Civilizational Development

Currently, the EcoSpace program [30] developed by the international Unitsky Group of Companies (UGC) proposes technologies that completely satisfy the above-mentioned requirements:

- relict solar bioenergy (RSBE), which relies on the energy of the ancient Sun (which illuminated the Earth hundreds of millions of years ago);
- biospheric agriculture based on the mass production and use of living humus derived from brown coal and shale (instead of chemical fertilizers, toxic chemicals, pesticides and genetic modification of crops);
- construction of linear cities (uCities), made up of cluster-type pedestrian settlements;
- "second level" transport and infrastructure complexes – Unitsky String Transport (uST);
- creation of a geocosmic spacecraft – the General Planetary Vehicle (GPV), designed to provide large-scale passenger and cargo traffic required for the industrialization of near space, which is millions of passengers and millions of tons of cargo per year.

An international group of companies, created by engineer A. Unitsky, initiates rebooting of the productional and economic system of the world economy through a return to Live Nature, of which the Earth's industrial civilization is a biological part, and a very insignificant one at that. It is proposed to accomplish this transition through natural (biospheric) technologies, but by no means through nature-like technologies. Such rebooting can be implemented in two directions, which can develop in parallel.

First direction. Using innovative biospheric technologies in residential, industrial and transport infrastructure, in energy and agriculture – based on the forms of economic management established in the world. This will ensure significant economic growth and large-scale implementation of these biospheric technologies on a planetary level.

Second direction. Gradual transition (within a generation, as it was carried out, for example, in the era of Stalin's industrialization in the USSR) to a new post-capitalist system, where the economic entities and cultural life will become small communities of a few thousand people, united by place of residence (in pedestrian cluster villages) within a single global transport and infrastructure system of pedestrian clusters of uCities.

Any economic system is built on agriculture and energy. What do today's experts suggest for these industries? Genetically modified products and artificial meat, which are dangerous to human health, as well as the transition to renewable energy sources, which is possible only if the world energy consumption will be considerably, by an order of magnitude, reduced. However, this can happen only as a result of large-scale space development and removal of environmentally hazardous and energy-consuming part of the Earth's industry off-planet, provided that universal human values are observed in the future and the global population is kept at 10 bln people, without its reduction and without digitally modifying people into convergent cyborgs [31].

An alternative to conventional anti-biospheric agriculture and power industry will be biospheric agriculture and environmentally friendly relict solar bioenergy. This is conditioned by the following reasons.

First, agriculture must be localized in places where people live, within a walking distance, making it highly productive and based on the use of living, all-natural and organic fertile humus – without using chemical fertilizers, pesticides and genetic modifications. Wherever food will be produced, all its waste, including sewage and household waste, will be turned into humus. New food will grow on this humus here in the residential cluster, which corresponds to the natural cycle of living matter in the biosphere, as it has always been in the previous hundreds of millions of years of the evolution of life on our planet.

Currently, food for humans grows in one place, while food waste, including sewage, is generated completely elsewhere, even thousands of kilometers away. At the same time, the outflow of nutrients from the living fertile soil of agricultural lands on the planet (billions of tons annually) is not compensated, because only three chemical elements – nitrogen, potassium and phosphorus – are brought back into the soil. Moreover, plants in their growth retrieve from the soil almost the entire periodic table – more than 80 chemical elements [31]. In addition, simple and soluble chemical fertilizers produced by industry, but not complex organic insoluble humates created by nature, are brought into the soil of agricultural lands today, as it happened earlier and is happening now in the natural component of the Earth's biosphere, i.e., in the part where human intervention is avoided or minimal.

Second, the energy stored in brown coal and oil shale is the relict solar energy received from our sun by living organisms that inhabited the planet more than 100 mln years ago. Therefore, oil shale and brown coal, which have the same sets of macro-, micro- and ultramicroelements as the ancient organisms did when the environment was not polluted by industrial waste, can be used not only to generate electric and thermal energy but also to produce relict biohumus – the foundation of any soil fertility.

It has long been known that food chains for animals, including humans, begin in the fertile part of soils consisting of humus and thousands of species of soil microorganisms (their number is up to a trillion living organisms in each kilogram of chernozem). Their symbiosis allows healthy, even healing, food to grow. It is the natural living soil, not the soil that is today killed by mineral fertilizers, arable farming and pesticides all over the world, that is the key link in the biosphere of our planet, which we can call a global immune system. The health of all living organisms on Earth, including humans, depends on the condition of this system. In particular, the biospheric and evolutionarily related human immune systems, weakened by modern industry, are the root causes of epidemics and pandemics.

It is suggested to mix combustion waste (ash, slag, sludge, dust, flue gases) and unburnt shale or brown coal in the ratio of about 1:5, with the addition of any organic raw material – grass, peat, sawdust, manure, household garbage, etc. This multicomponent mixture, which contains both organic and mineral raw materials, is finally processed into living fertile humus in bioreactors with specially selected communities of aerobic and anaerobic microorganisms [32].

The obtained living relict humus can be added to the top soil layer (30–40 cm thick) in an amount of 2 % by mass – with such a small content, even desert sand will become fertile.

That is, a living and highly fertile soil will be created around power plants, where gardens, for example, can be planted. Consequently, grapes, apples and other agricultural products will become a peculiar "waste" of the operation of such relict solar biopower plants.

This is an easy thing to accomplish, since more than 80 chemical elements that make up all of the Earth's living organisms, including ancient plants, have turned into coal and shale in prehistoric times, and they will all (through the restored relict soil in hundreds of millions of years) give a new life to new organisms.

Biopower plants can be combined into complexes with agricultural facilities. Then the excess carbon dioxide from the operation of relict solar biopower plants will not only be chemically bound in humus, but also fed into greenhouses (in cold regions of the world) or orangeries (in tropical regions), from which their productivity will increase many times more. In greenhouses and orangeries carbon will be utilized by plants and processed into dietary carbohydrates, proteins, vegetable fats, enzymes, vitamins and other diverse living matter – as thousands of various organic compounds, including practically the entire periodic table, with carbon accounting for about 60 % of their mass.

The heat (which is about 55 % of the combustion energy) will be used for heating greenhouses in cold climates or for air conditioning of orangeries in hot countries (in special thermal convertors). At the same time, the overnight surplus electricity will be used for additional lighting of greenhouses and orangeries, which will also increase their productivity.

World reserves of brown coal and shale (about 600 tln tons) will be enough for about 15,000 years to provide the future population of the planet of 10 bln people with green energy at the rate of 2 kW per each human, which will amount to a total power capacity of about 20 bln kW. *(For comparison: the capacity of all existing power plants in the world today is an order of magnitude lower – 2.1 bln kW.)*

Third, residential, industrial and transport infrastructure must be deployed in uCities, and within a walking distance, making it possible to effectively fit out not only already developed land, but also remote and inaccessible regions, thereby solving local and global problems, including environmental ones caused by widespread urbanization. This will allow the development, with no negative impact on nature, of currently unpopulated areas, such as the sea shelf or mountains, taiga or jungle, desert or tundra.

Gradually, more and more people will be willing to settle in such places, preferring them for a happy and dignified life instead of wasting it in the pursuit of wages and profits in the concrete and asphalt jungles of the megacities. In fact, the same thing will happen as before, when people moved massively from the countryside to the cities, except that the new migration will be in the reverse direction.

Fourth, the attractiveness of uCities for investors and consumers will be ensured by more comfortable living conditions in them, as well as transport accessibility with significant savings on the construction and operation of all residential, industrial and transport infrastructure. Should, for example, a need arises to visit a certain megacity, it will be possible to do it for an acceptable time and money, even if the residential cluster is hundreds of kilometers away from it.

Communication between the existing cities and clusters of uCities will be arranged through rapid transportation systems in elevated version, known as Unitsky String Transport and currently promoted under uST brand, in which passengers and cargo will travel at speeds of up to 150 km/h in the city and up to 500 km/h in intercity communication. In the future, with the creation of transport systems with tunnels, where the atmosphere will be rarefied to eliminate air resistance, steel-wheeled rail electric cars will accelerate up to 1,500 km/h. Then it will be possible to travel from one edge to another of the world's largest territory – the Union State – in less than 8 h, with maximum comfort, without long waits at airports and train stations.

The arrangement of everyday life in a linear city. A residential cluster with an area of about 100 ha (the size planned is about 1 km) is a pedestrian urban settlement. It will comfortably accommodate from 2,000 (at the rate of 500 m^2/person, or 25 ha per average family of five) to 5,000 residents (200 m^2/person, or 10 ha per family). The cluster is designed for construction on land, but with minor modifications it can also be built on the sea shelf or, if the buildings and structures are floating, in the open sea.

The clusters are sized so that their centers can be connected with each other by uST sagging type transport – in one span, without supporting towers. It is well known that in urban transport, stops at intervals of less than 1 km significantly reduce the average speed of the rolling stock, which in this case would lead to an increase in travel time along a uCity. And if the spans are longer than 1.5 km, the string-rail track structure will sag excessively on them (under its own weight and the weight of the rolling stock), which would require the arrangement of passenger stations at a height of 50 m or more. Therefore, the planned size of the cluster and the span lengths within 1.5 km are optimal both in terms of pedestrian and transport urban logistics, and in terms of technical and economic performance.

The residential area of the cluster of the uCity will be divided into quarters, separated by a forest strip, where there will be places of common use for cluster residents and guests: recreation and sports areas, various public buildings and facilities, sports fields, stadium, health center, medical center, stores, cafes, workshops, kindergarten, school, etc.

In the center of the residential area, within a 10-minute walking distance from any point in the cluster, there will be a dominant building with a uST station on one of the floors (or on the roof). The center of the forest strip at a height of over 10 m will include a string-rail track structure – visually light and delicate, which does not cast even a shadow – which will be at least 10 times cheaper than the traditional subway and provide the same performance. The rolling stock of the low-noise transport complex – a kind of "air metro" – will be steel-wheeled rail electric cars called uPods.

The uPod moving high above the ground, which eliminates the adverse effect on the aerodynamics of the shielding solid roadbed, is considerably more energy efficient than any conventional rolling stock: car, bus, tram, subway train. For example, the uPod is "greener" than a conventional pneumatic-tired electric car by at least three times, as it uses three times less energy for the same amount of transportation.

Residential buildings in the cluster will be combined into an architectural and functional system – a multi-apartment extended house, a kind of "horizontal skyscraper", i.e., a high-rise building "lying on its side". The size of a linear house, including its length, can vary quite widely – from 100 m to 1 km. Each house (with a living area of at least 100 m^2, and a total area of at least 300 m^2) will be designed to accommodate an average family of five. The houses will have two floors – living area and attic.

The buildings can be framed with vacuum glass panels (the know-how of engineer Unitsky) – the thermal insulation properties of such panels, which are up to 20 mm thick, are equivalent to, for example, a brick wall 1.5 m thick. Here the load will be received by the frame of the building (steel, reinforced concrete or other), and the vacuum glass should provide comfortable conditions inside the house for people to live in – optimal temperature, illumination, humidity, air purity, etc. If necessary, such panels can be easily transformed into screens which can display any images. The main material for construction – sand – is sufficient on the planet for trillions of "glass" skyscrapers. It is also important that the glass wall does not need to plaster, paint, protect against external factors – extreme heat and cold, high humidity, high airborne dust, sand, sea salts, etc. With appropriate robustness (glass can be made armored), such a highly-efficient building panel and, accordingly, the building itself can last for hundreds of years without losing its consumer appeal.

In terms of energy efficiency, each "horizontal skyscraper" of the cluster will be made as a "house plus energy" (according to the European classification), when the house with the help of engineering equipment – solar panels, collectors, heat pumps and recuperators – generates more energy than it consumes itself.

Each cluster will be made as an autonomous urban-type settlement, although by the structural arrangement of residence, it is more likely related to rural settlements. The cluster will be provided with all the necessary things from its own production – organic food, clean water, green energy, safe transportation, as well as other products and services. This will ensure food, energy and infrastructure security of the uCity even in the face of pandemics and lockdowns or other natural and man-made disasters.

It is impossible to imagine an actual ecohouse without the production of a variety of organic food for the needs of each household such as vegetables, fruits, meat, milk, eggs, mushrooms, fish, etc.

The roofs (mansards) of each "horizontal skyscraper" in the cluster of the uCity will be made as glass greenhouses (orangeries in hot countries), which are connected to each other and have a road in the center for the entire length of the house in order to transport maintenance equipment [33].

This will allow for centralized and most mechanized and automated growth of not only organic vegetables and fruits in greenhouses (or orangeries) on the roof, but also seafood and fish, both marine and freshwater, as well as mushrooms, poultry and other organic products for food. At the same time, the enclosed agricultural area, completely independent of external natural and climatic conditions, can be maintained commonly for each "skyscraper" by the gardener and agronomist hired by households.

Microgreens and green food for the residents of the cluster of the uCity (for people and animals) will also be produced in greenhouses and orangeries, including those made as vertical farms. This technology feeds the root system of plants with a solution of liquid humus with a natural selection of nutrients. Within 5–7 days the planted seeds will give green shoots – microgreens, which contain a storehouse of vitamins and thousands of biologically active and mineral substances. Since evolutionarily all plants

on the planet are genetically formed to be fed with organic humus, such technology, unlike the conventional nature-like hydroponics on chemical minerals, can be considered as truly natural.

Humus consists of insoluble salts of humic acids stored in the soil [34] and is converted into soluble form by a community of thousands of species of aerobic and anaerobic soil microorganisms immediately in the root system of plants. Therefore, the agricultural farms of the uCity will practice humusoponics – this technology is about feeding plants with liquid humus, in which insoluble salts of humic acids have already been converted to the soluble form. Such experiments have been successfully carried out in the Republic of Belarus by Unitsky's Farm Enterprise [32].

Microgreens grown with humusoponics are natural organic food originally rich in easily digestible nutrients and vitamins; the technology of its cultivation is free of chemical fertilizers, chemical protection (pesticides, herbicides and other toxic chemicals) and GMOs. For example, compared with dry animal feed (mixed fodder, meadow hay), humus-derived wheat sprout feed is better assimilated, more energy-intensive, contains three times more proteins and fats, and exceeds dry feed in terms of carbohydrates, sugar and vitamins by about 10 times. It is also much healthier and more effective than fresh grass and silage. Unlike any feed eaten off-pasture, this feed comes in live form at its peak, preserving all the vitamins and digestive enzymes that animals need so much, particularly in winter.

Another fundamental difference is that the animal eats not only the aboveground part, but also the root part rich in sugars and proteins, as well as the starch-containing seed residues. Various organic wastes from the cluster can be used as a substrate for germination of seeds: straw, oilcake and even specially prepared wood chips, which microorganisms and plant roots convert (ferment) into easily digestible food. As a result, we get a balanced, complete and stable in its composition and quality feed, which provides a variety of necessary nutrients to herbivorous animals.

Regardless of the time of year and climatic conditions (droughts, heavy rains, heat, frost) the humusoponic units can supply fresh green food not only to animals, but also to people in any region all year round, which is especially crucial when vitamin deficiency occurs in winter.

To grow a ton of green fodder you need about 2 tons of water, while the traditional field method requires 400 tons, i.e., 200 times more. For the traditional cattle fodder it is necessary to have about a hectare of land per head, and in the proposed technology on the year-round operating vertical humusoponic farms you need about 1 m^2 of floor, i.e., 10,000 times less. Such technology will exclude (moreover, on natural territories 10,000 times larger) mechanical soil treatment and fertilizers application, as well as such labor-intensive operations as sowing, reaping, harvesting, transportation, drying, etc.

Growin of agricultural products in greenhouses in a protected environment, for instance presently in the Netherlands, yields an average of at least 50 kg/m^2 per year. Accordingly, it is enough to have about 100 m^2 of year-round greenhouses to provide a family of five people with organic fruits, vegetables, berries and herbs.

If you place greenhouses on the roofs of "horizontal skyscrapers", i.e., replace traditional roofs with year-round greenhouses (orangeries in hot regions), each house will be able to feed the family living in it with plant food. The total area of natural soil in such urban development will not diminish as the soil from under the house, even if it is a desert sand, will be enriched with live highly fertile humus and transferred to the roof. So, the construction of such uCities will not decrease, but rather increase the amount of fertile soil on the planet. At the same time, such soil will become "greener" – it will be more productive even compared to chernozem.

The greenhouse of the "horizontal skyscraper" or its common basement floor, made as a common agricultural farm, will also be used for growing mushrooms, fish, seafood, small animals (like rabbits) and poultry (like quails) – for the requirements of the cluster's residents and for sale.

Thus, the residents of the cluster of the linear city will be fully supplied with everything necessary for living – organic food, fresh water, clean air, energy and housing. Neither the state nor corporations will have to take care of them. At the same time, the residents of uCities, who have everything to meet their primary needs, will continue to do some kind of work as part of the existing socio-economic system in general. Their labor will be paid. And their income will be spent on the purchase of goods and services.

With a consistent supply of basic goods, products and services, the volume of demand for everything else will become much more predictable. The risks of overproduction, and thus of economic crises, will be minimized. The social system will be as stable as possible, since even a person who has lost his job will not be without means of livelihood. Consequently, the probability that he or she will go to the "revolutionary barricades" will be drastically reduced. The state will feel much calmer and more stable. Like all citizens of the country and the world.

The above-described technologies have already been created and are being tested and certified in two research centers based in the Republic of Belarus (Maryina Gorka) and the United Arab Emirates (Sharjah). Six types of innovative buildings have been built and successfully operated, the ones that can be erected in the clusters of uCities, including those with greenhouses on the roofs, a subtropical orangery and a garden inside the house.

This garden is arranged according to the principle of a natural ecosystem – all the sewage in the house, including the kitchen and toilet, go to the root system of plants. There, under the ground, all organic waste is processed into fertile humus and technical water enriched with liquid humus with the help of specially selected natural communities of microflora and microfauna (several thousand species taken from the world Bank of fertile soils and soil microorganisms, created on the territory of Unitsky's Farm Enterprise). This experiment confirms that the waste of the person's vital activity is able to feed not only himself, but also one more person, not only without poisoning the Live Nature, but also enriching it with live, fertile humus.

We should note that the uST research centers were built on abandoned lands. In Belarus – on the site of a military training ground, pitted with tank tracks and shells, soaked with gunpowder and diesel fuel; in the UAE – in a lifeless desert. In a few years, these territories have been transformed into oases, where gardens and vineyards grow, including those under uST tracks [35, 36]. For example, more than 20,000 fruit trees and shrubs were planted in Maryina Gorka, about 20 ponds and lakes were dug, where more than 20 species of fish live, comprising five species of sturgeon alone. And this land, which has been killed for decades by the military and industrial machine, has not only been reanimated, but, moreover, in the territory of the Belarusian swamps, one of the best places for recreation and fishing in our republic has been created within just a few years.

"Second level" transport systems – Unitsky String Transport – have been equally successful. uST has been implemented in the EcoTechnoPark (Maryina Gorka) and the uSky Test & Certification Centre (Sharjah): six test tracks with a total length of over 4 km have already been built and put into operation there since 2016. Another five tracks with a total length of more than 7 km are currently under construction.

The developer of uST – the engineering company Unitsky String Technologies Inc. (Minsk, Belarus) – has designed and manufactured at their own production facilities 12 fundamentally different models of unmanned uPods. These models include urban, cargo and high-speed intercity, hinged and suspended vehicles in northern and tropical versions, with a capacity of two to 48 passengers [37]. Five uPod models have already been certified, including those in the tropical design. All necessary components of transport infrastructure – passenger stations, cargo terminals, turnouts, control rooms, automated control systems, power and communication systems – have been tested and certified.

These biospheric technologies have been improved for about 50 years. Over the past period, the range of technologies implemented as part of the project has been continuously expanded. First, we developed the string-rail overpass, with the first test section built in 2001 in the Moscow region (Ozery). In parallel, the possibility of applying the technology for the development of settlements were studied. This activity took place in Russia, including that under the auspices of the United Nations under two grants led by engineer A. Unitsky (in 1998 and 2002).

The first sample of the fourth generation uPod (uBike) ran on the string-rail overpass in Maryina Gorka in 2016. At the same time, projects in agro- and biotechnology began to be actively developed. Meanwhile, the Bank of fertile soils and soil microorganisms from over 100 regions of the world was created, which is constantly replenished by investors in string technology (there are over 500,000 of them), living in 220 states and territories. Aresently, all the mentioned design and technological achievements are patented in the leading countries of the globe.

Today everyone has a chance to see the viability of the proposed biosphere-friendly infrastructure technologies: you can come to our research centers and see everything with your own eyes. Unitsky String Technologies Inc., the parent engineering company of the Unitsky Group of Companies, is ready to offer our solutions to anyone who will develop technologies that will enable the economy to rebooting to rapid industrialization with biosphere engineering technologies in a short period of time. This step will raise gigantic investments, create tens of millions of jobs and stimulate the growth of domestic demand and supply. All the necessary technologies for this purpose are available.

A number of experts, including the author of this study, have a full understanding that the Earth now lacks a spatial niche for the technosphere. Or rather, it exists, and may even expand, but only at the expense of replacement and destruction of the biosphere, which historically, billions of years ago, already occupied the same spatial niche. Meanwhile, humanity cannot give up any of its basic existence platforms – neither the biosphere, which would mean the extinction from the planet of humans as a species of biological beings, nor the technosphere, which would mean the extinction from the planet of human civilization, which exists and develops based on engineering (industrial) technologies.

Thus, we conclude that it is necessary and even inevitable to relocate the Earth's industry beyond the biosphere in the foreseeable future – into near space. Not into deep space (neither on the Moon, nor on Mars), closer to the industrial civilization that created the technosphere, to simplify, facilitate and make cheaper large-scale geocosmic logistics along the Biosphere – Technosphere route.

Many scientists have long been proposing the relocation of industrial facilities from Earth to space as one of the lines of development of the Earth's technogenic civilization to preserve both the biosphere and humanity. The principal arguments in this matter are: exhaustion of limited raw and other natural resources, negative environmental and climatic impact, overpopulation of the planet, where ecosystems are already on the verge of destruction due to overexploitation by man.

Practical implementation of the uSpace program is based on non-rocket development of near space and includes the creation and launching of the GPV [38]. The program also includes the construction of a takeoff and landing overpass and the entire geocosmic infrastructure: on Earth in the equatorial strip and in near space (near-Earth orbits in the equatorial plane at altitudes of about 400 km).

We should note that such geocosmic transportation of the future will be advantageously different from modern rocket-based geocosmic solutions: its efficiency (guaranteed annual cargo and passenger flow of tens of millions of tons and tens of millions of passengers); high comfort and environmental friendliness of geocosmic transportation (owing to the operation using only internal forces of the system, without any mechanical and energy interaction with the Earth's atmosphere); low cost of transportation (about a thousand times cheaper than with carrier rockets), using only electric traction (in its engineering nature, the GPV is a kind of electric car, but a geocosmic one).

Thus, the GPV is meant to take all hazardous industrial production beyond the Earth, opening up the prospects of using the conditions of weightlessness, vacuum, ultra-low and ultra-high temperatures, spatial, energy and raw materials resources of the near space and the infinite Universe [39].

The above biospheric technologies are complementary. Their comprehensive implementation will allow for a large-scale rebooting of the economy of any country, first and foremost of the Union State.

Global Effect of Rapid Industrialization by Biospheric Engineering Technologies

Global processes marked by fast pace (increase in population, development of industry, scientific and technological revolution, emergence and rapid spread of new types of industries and services, involvement in industrial production and expansion of extraction of natural resources in an increasing number of countries, growth of consumption and, as a consequence, speedy degradation of the natural environment), are the most important distinctive features of the second half of the 20th – the beginning of the 21st century. Under these conditions, it is necessary to work out a stable, safe and balanced way of civilizational development in the "Man – Nature – Economy" system, as it becomes obvious that our technogenic civilization has once again reached a dead end. Since experts associate world economic crises mainly with overproduction, it is possible to avoid them only by changing the very nature of production and consumption of goods, products and services.

The solution to these problems needs new approaches to the definition of global and regional economic policy, the development of effective forms and methods to manage the progressive advancement of any territory.

The various recent crises reveal the instability of the world's current model of civilizational development. An important and widely recognized flaw of this model is the absolutization of economic growth at the expense of solving social and environmental problems.

The reports and documents of the UN bodies note that the basis of the transition to sustainable development is the creation of green economy [40]. In all countries the transition to this economic model will be different, because it depends on the specificity of natural, human, physical (artificial) and institutional capital of each state, the level of its development and socio-economic priorities, as well as the social culture, including that in the environmental sphere.

The concept of green economy is no substitute for the concept of sustainable development. But there is a growing recognition that achieving sustainability depends almost entirely on getting the economy right. Over the past decades, humanity has created new wealth predominantly on the basis of an anti-environmental model of "dirty" economy.

Any production, any human activity cannot exist in isolation from nature and society – they are in synergy with the surrounding natural (primarily living) and social environment, where the determinant is the society of a particular country,

which has a centuries-long and even millennia-long unique history. The very possibility of human activity is created by natural conditions and natural resources, and the natural resource potential of the territory affects the level and quality of life for the people.

At the same time, the "quality of life" of the population in any territory is a rather multifaceted concept, which includes economic, social, cultural, environmental and other aspects. Furthermore, the "quality of life" is an evolving category, reflecting the comfort of the physical and spiritual life of a person at a given historical stage of development of the territory. In the process of interaction between the natural and social environment, the natural and social environment surrounding a person is formed. It not only affects people's health, but also determines the specifics of life and economic structure of each region.

The high rate of urbanization, acceleration and complication of urban life, which is the habitat of most of the world's population, determine the increasing need for recreation of a significant number of people [27]. However, the achievement of this need automatically leads to an increase in the load on the natural environment and its subsequent degradation not only in suburban, but also in remote coastal areas, which are most responsive to the conditions of recreation of urban residents.

Rebooting the world economy based on the introduction of biospheric technologies in production, housing and transport infrastructure, power industry and agriculture is the way out of the social, ecological and resource crises in which mankind has found itself today. The development of a network of uCities in the future will create an alternative to modern megacities. The whole world will look different.

Linear cities will fit harmoniously into the environment of any natural and climatic zone on the planet. The urban development will not only prevent the loss of fertile land, but on the contrary, it will expand it. The uCities will be provided with everything they need for their sustainable functioning: relict green energy, organic food, artesian (spring) drinking water and clean air saturated with healing natural phytoncides (biologically active substances released by plants that kill and suppress the growth and development of pathogenic bacteria, including coronavirus). Thanks to uCity, deserts will disappear from the planet, and in the 21st century the Earth will be transformed into a blooming garden, where all future humanity – about 10 bln people – will live and work safely and comfortably [31].

Linear cities should be located 10 m above the current ocean level. If in the distant future its level rises (it does not matter whether it happens due to natural cyclical global warming or man-made warming), the ocean will not flood such settlements.

Each uCity will be designed as pedestrian clusters connected to each other by a "second level" urban electric communicator with a travel speed of up to 150 km/h – Unitsky String Transport as the safest, most energy efficient and environmentally friendly mode of passenger and cargo transportation.

The uNet air transport and communication corridor about 100 m wide will run along the uCity. It will include high-speed cargo and passenger intercity, interregional and intercontinental uST tracks (speed up to 500 km/h) and hypervelocity routes (speed up to 1,500 km/h), placed in forevacuum tunnels, as well as cargo systems.

In order to ensure comfortable traffic with centrifugal accelerations below 1 m/s^2, the curve radii (both vertical and horizontal) on the track structure should have the following values: at least 20 km for 500 km/h speed; at least 200 km for 1,500 km/h. Accordingly, the uCity itself may be convoluted in plan, while the high-speed routes along it must be as straight as possible.

With an average density of settlement in a linear city (for example, 2,000 people/km) for a population of 10 bln people the total length of all cities on the planet (built along the uNet communication network, combined with power plants, transmission lines and communications) will be 5 mln km. Then the worldwide network of uCities will occupy an area of about 5 mln km^2, or 1/27 of land (excluding the coldest continent – Antarctica), and 26/27 of land will be given to national parks, reserves, sanctuaries and reservations with sparing regimes of land use [33].

By the way, deserts on the planet (excluding the polar deserts of Antarctica and the Arctic) are four times larger. That is, if we green deserts and build uCities there, then 40 bln people will be able to live in them, provided with everything required – housing, food, drinking water, energy, transport, work and recreation. And there is no need to plan, even in the most distant future, the development of a remote, cold and totally alien to us Mars, which is hostile to any earthling. All mankind has enough space on its native planet, it is only necessary to learn to be friends with the Earth's nature, not enemies with it.

Such uCities will occupy land conventionally, as gardens will grow on the roofs of all buildings and structures (in greenhouses and orangeries). We will create biogeocenoses and biospheric ecosystems there – even in place of today's deserts and permafrost. All the houses (that is about 2 bln buildings) in such cities will occupy an area of about 200,000 km^2, or 1/750 of the Earth's land. The global length of the uNet network, taking into account cross-lines and "second level" roads entering protected areas and natural resource deposits, will in this case total about 10 mln km.

(For comparison. Currently, the total length of the world network of all types of roads is 68 mln km. These roads have already ripped away from the Earth's biosphere the best land, the size of, for example, five areas of Great Britain – exactly the kind of territory that is now "rolled up" in asphalt and "buried" under sleepers. This land is ruined – there is no life on it and no green plants to produce oxygen, which is necessary not only for our breathing, but also for the operation of industry created on the planet. Besides, cars alone kill more than 1.2 mln people on the roads every year and cripple more than 10 mln [41]. What is really happening on the planet today, and with each of us, does not worry the world's quasi-elites, these "protectors" of the "bright future" for all mankind. They are maniacally concerned only about a virtual (distant and unobvious) future: in particular, about "global warming" and "the level of the World Ocean", which, if it rises a few meters in 100 years, will flood territories much smaller than five areas of Great Britain (in addition, this land will not be destroyed and, moreover, will not be separated from the natural biospheric homeostasis, both ecological and biological). At the same time, the rising level of the ocean will not kill anyone in the literal or figurative sense. Although for the same period of time – 100 years – the existing roads alone will kill more than 120 mln people on the planet and cripple more than 1 bln. And no green electric cars, other green and carbon-free technologies, except uST and pedestrian linear cities, can really save these people.)

Next to the residential clusters along or across the uCity, we will locate infrastructure clusters with different functionality: scientific, educational, manufacturing, sports, shopping and entertainment, tourist, recreational, etc. To improve logistics and service industries, including relict solar biopower plants with a large volume of cargo transportation of raw materials and humus, infrastructure clusters will be located outside the residential area – in the area of the uNet transport and communication corridor. At the same time, the required annual volume of cargo traffic on the world string-rail road network will be about 10 bln tons of brown coal and shale and about the same amount of fertile humus.

Each cluster will have one or more relict solar biopower plants with a total capacity of up to 10,000 kW, located outside the residential area. They will be capable of producing up to 50,000 tons of live fertile humus per year. This will make it possible, for example, to turn about 1 km^2 of desert (which corresponds to the area of an average residential cluster) per year into fertile land, which will be of the same quality as chernozem. Thus, in 25–30 years of operation a planet-wide linear city can increase soil fertility throughout the Earth's land to the level of rich chernozem.

In addition, the relict solar biopower plants can carry out deep processing of some coals and shales in order to obtain from them not only fertile humus (including liquid humus), but also synthetic fuel and the widest range of chemical products – aromatic hydrocarbons, oxygen and nitrogen compounds, alicyclic alcohols, which have hydrogen-donor properties, etc. These power plants will also produce chemical elements of practically the entire periodic table, including gold (up to 40 g/t in shale), elements of the platinum group, tungsten, molybdenum, rare, rare-earth and other metals [33].

For example, some Russian coals contain (in grams per ton of coal): yttrium – 254, scandium – 96, dysprosium – 384, gadolinium – 335, samarium – 211, lanthanum – 46, cerium – 89, neodymium – 806, which amounts in total to over 2 kg of rare earths per ton of fossil fuels. Therefore, the whole demand of Russia in rare-earth metals (about 10,000 tons per year) can be satisfied by processing only 5 mln tons of such coal, and the entire world demand (about 200,000 tons per year) – 100 mln tons, which is less than 1 % of coal and shale to be used in such power plants.

Not only coal (shale), but also derivatives of their combustion – flue gases, dust, ash, sludge, slag – will be used as raw materials to obtain chemical products at biopower plants located in the industrial clusters of uCities. Such technologies have long been available in Russia and Belarus. The lower the energy value of the used coal and shale (i.e., the higher their ash content), the more effective and efficient they will be in terms of output of fertile humus and a variety of chemical elements, products and substances at biopower plants. Thus, the relict solar biopower plants operating on brown coal and oil shale will meet the future needs of mankind in these products for thousands of years to come.

It is clear that such global changes in the economy of any state should happen gradually. One can start with a small fragment of a uCity near a modern megacity or with a string road connecting a new settlement with an old one or an airport with a neighboring megacity. Fragments of a uCity can then be extended, linking pedestrian clusters with each other, until the length of the city reaches hundreds of kilometers. Then other such cities will emerge.

Life in them will be safe and attractive. The air will be clean. Children will be able to spend more time in nature without being afraid of getting hit by a car. The apartment building will produce everything needed for a full family meal. A small community of several thousand people, most of whom can work within walking distance of their homes, will be able to successfully implement different models of self-government.

Closeness to the earth in a uCity will allow man to return to his origins – to Live Nature, of which he is a part and from which he has been taken away, believing in the idol of scientific and technological progress.

Linear city clusters will be the basic platform for community self-organization to survive in the face of fierce global competition while diminishing the role and importance of state borders as socio-economic regulators.

World imperialism, focused on competition and profit, has been imposing for centuries a pseudo-democracy on all mankind, based on lies and a blind fear of the future and hatred for each other and for everything around us. We are afraid of losing our jobs and our ability to pay interest-bearing loans; we are afraid of catching a "fashionable disease" and dying, although we understand the causes and origins of it and the associated lockdowns, masks, tests and other restrictions on our freedoms; we are forced to hate other nationalities, societies and countries with alien cultures and religions; we fear global warming, carbon footprints, horrific natural and man-made disasters, terrorism and wars, which are occurring with increasing frequency and magnitude and accompanied by terrifying messages in all media, from which we cannot hide anywhere, as they are on everybody's digital lips – device and gadget; we are afraid of vaccination, chipping and "electronic concentration camps", but we are herded there, like a herd of sheep, by an even greater fear – the stigma of a negative social rating, the restriction of constitutional and other freedoms, the denial of rights.

Psychologically a person always strives to seek support and mutual understanding among people who are close to him in spirit and way of life: it is not enough for him to feel just a member of society and a citizen of his country. For modern man, tired of constant pressure from the authorities, politicians, businesses and advertising, it is vital to have a kind of outlet: understanding and solidarity, participation without benefit and profit, self-realization, common spiritual and moral guidelines, culture and language.

Such social needs as social and cultural ties, shared values, religion, traditions, art, ethnic and interethnic contacts, etc., are satisfied precisely by small groups with similar interests. Such self-governing communities of different types, manifesting themselves in different ways – spiritual, religious, socio-economic, ethnic, organizational and managerial, communicative, political, educational, historical and environmental – can be created in clusters of uCities.

In this case, the main work for many residents of uCities will be the development of science, culture and education, small and medium-sized businesses, tourism and services, intellectual and spiritual perfection, raising children, communicating with nature, growing organic food for themselves and their families and other areas of intellectual, spiritual and physical activities of man.

This work will be more exciting and more meaningful to any society, including humanity as a whole, than, for example, today's work as a miner, turner, welder, metallurgist, cab driver or truck driver, and it will be paid much better. So, unemployment and poverty will become a thing of the past when the bulk of humanity moves from the concrete and asphalt jungles of megacities, cut off from nature and life, to pedestrian linear cities in harmony with Live Nature.

Here will prevail the innovative strategy of transition of local (cluster) societies of techno-consumers to a new qualitative state – to a socio-technogenic society. Such readjustment of the vector of long-term development of the Earth's industrial civilization involves the conversion of military and industrial complexes, the creation of planetary biospheric infrastructure (transport, industrial, residential, energy, information, other), the use of social resources of territories, spiritual and intellectual potential of each person, as well as energy- and resource-saving technologies. This transformation will be achieved through the transition from the global export of resources and raw materials to the eco-production of goods and services in clusters of uCities from the same raw materials, relying on their own capabilities, inter-regional cooperation and the human dimension in ecology [33].

According to the Program for Rebooting the World Economy to the Biospheric Path of Civilizational Development, the capacity of the world market will be more than 10,000 tln USD in the 21st century. We can identify seven main sectors.

The first one is to build ecohousing in uCities, including infrastructure, for 10 bln people.

The second one is the annual production of billions of tons of organic agricultural products in all clusters of uCities without exception.

The third one is the creation of a network of RSBE operating on brown coal and shale at a rate of up to 5 kW of installed energy capacity per inhabitant of the planet.

The fourth one is the construction of about 10 mln km of the uNet transport and infrastructure network, including safe, rapid, accessible, efficient and environmentally friendly "second level" uST tracks, combined with electric and information networks.

The fifth one is the annual production of billions of tons of living highly fertile humus from RSBE waste and organic waste from uCities.

The sixth one is to increase the natural fertility of soils and improve their biogeocenoses over tens of millions of square kilometers of land.

The seventh one is the elimination of deserts on all continents and the transformation of our planet, which gave birth to and raised our human civilization, into a blooming garden planted on rich chernozem.

It is possible to transform the current economic system (the capitalist system) without disturbing the existing disposition of power and without upheaval. In this case, as with the liberal programs promoted by the globalists, the capitalists will also benefit.

Implementation of this program will allow the world economy to develop steadily with an annual GDP growth of 10 % and a population of 10 bln people within the next 100 years. By that time all environmentally dangerous part of the Earth's industry will be reformed and relocated into near space where it will be capable of sustainable development for the benefit of our Earth's Civilization in our material Universe – infinitely in Time in infinite Space with infinite Resources.

Effect for the Union State of Rebooting the Economy to the Biospheric Path of Civilizational Development

The implementation of comprehensive biospheric-friendly solutions will boost the entire economy of the Union State, both in Russia and Belarus.

The living and highly fertile humus produced by relict solar biopower plants is one of the most sought-after products in today's world, because the planet's fertile soil is being degraded by improper use. Setting up mass production of biohumus from brown coal and shale (peat can also be used for this purpose, the explored reserves of which in the Union State are estimated at 200 bln tons) will enable to export this highly profitable product around the world, getting a profit even higher than that of the current oil suppliers. And the demand for biospheric humus will be much higher than the current demand for anti-biospheric oil.

The conversion of farming towards the use of living humus enriched with associations of favorable soil microorganisms (instead of dead chemical fertilizers) will increase the yield and quality of agricultural products – they will all become organic [33]. In turn, this will be an investment in the health of the population of the Union State and in human potential. It is very important that such products are obtained within walking distance in each cluster of the uCity and by the same producers (cluster inhabitants), who will then consume these food – it is hard to imagine a better-quality control of agricultural products, which are the very basis of our health. Thus, it guarantees the food security of all inhabitants in each uCity and, in the future, of all humanity on Earth for thousands of years to come.

The creation of a new transport and infrastructure industry based on uST technologies will secure orders for companies engaged in construction, mechanical engineering, metallurgy, chemical industry, building materials, software development, electronics, power industry, agriculture, etc.

The construction of uCities will stimulate the real estate market and allow the development of remote and hard-to-reach areas. At the same time, a large part of the costs for all of the above (power industry, agriculture, transportation, housing, etc.) will be borne by the end users – the future residents of uCities, since all of these elements are part of the urban infrastructure. Just as, for example, an elevator in a conventional high-rise building, a playground in the yard or a parking lot are parts of a residential complex, and their cost is included in the price of the apartment one buys.

The state will be able to stimulate demand by starting various programs, comprising mortgages. Then, as uCities are built and people settle in them, the entire socio-economic system of the area will change [33]. To understand what will happen, one should look at the way of life in the new linear settlements.

Besides, with the today's level of psychological stress and the rapid changes of the modern world, which also require rapid adaptation, nature remains the crucial tool of human struggle against stress, overwork and other realities of urban life. The creation and preservation of "green oases" in the urban environment is not only the most important part of the environmental components, such as clean air and noise protection, but can also be used as a tool for the prevention of stress and emotional tension of urban residents.

The predicted reserves of brown coal, shale and peat in the Union State (more than 1 tln tons) are enough to satisfy the energy needs of the future population of the state (200 mln people) for a thousand years at the rate of 5 kW of installed capacity per capita. With a population of, for example, 400 mln people these energy resources will be sufficient for 500 years, and with a power 2.5 kWh/person and a population of 500 mln people – for 800 years. Besides, more than 500 bln tons of biohumus will be produced in total, which will make it possible to cultivate more than 500 bln tons of organic food, while providing food security for the state for at least a thousand years. This will also enable to turn poorly fertile soils into rich chernozem on the area of more than 10 mln km^2, which, in particular, is 43 times more than the area of Great Britain. At the same time, properly organized biospheric agriculture, which is involved in the cycle of living matter on the planet by historically established natural mechanisms, will be eternal, just like the biosphere, which appeared billions of years ago, will exist until its energy source – the star named the Sun – is extinguished.

Together with string transport and uCities, such infrastructural technologies will become the kind of socially oriented biospheric technologies that can save our industrial civilization from the recently intensifying socio-technogenic degradation, which could lead the entire world, including the Union State, to extinction and death. Neither artificial intelligence and digitalization, nor conventional electric cars and deindustrialization, nor wind and solar power plants, nor other so-called "green" and "carbon-free" technologies, which not only fail to solve the urgent problems of humanity, but also cause significant environmental damage to Live Nature, will be able to save our civilization.

The availability of decent housing, desirable jobs, confidence in the future, basic consumer products and services will allow to solve the demographic problem in a short time. Most families will have many children, and by 2050 the population of the Union State will grow to 200 mln people or more. A special demographic mortgage system can be introduced for this purpose. For example, the state allocates funds for mortgages for the construction of a uCity under the Five Children program. At the birth (or presence) of the first child mortgage payments are reduced by 20 %, at the birth (or presence) of the second child – by 40 %, etc. At the birth (or presence) of the fifth child, the mortgage is fully repaid.

There are currently about 1 mln multi-child families in Russia, which is very small for such a huge country.

They should be the first to be provided with 20 % of housing in uCities; and childless families and families with few children should be granted 80 % of housing. There must be at least 10 mln multi-child families in the Union State for sustainable demographic growth, i.e., 10 times more than today. It is for them that homes should be built in uCities during the first 10 years of implementation of the program – 1 mln homes a year, or 2,000 residential pedestrian clusters, given that each cluster would contain on average 500 homes for 2,000–3,000 dwellers.

At this pace, by 2050 there are plans to build 25 mln houses, 50,000 clusters, which will house a significant part of the state's population – 125 mln people. A network of uCities with a total length of about 50,000 km will be erected with two infrastructure backbones of the largest state in the world:

- meridian: Murmansk – Petrozavodsk – Saint Petersburg – Veliky Novgorod – Tver – Moscow – Tula – Voronezh – Volgograd – Rostov-on-Don – Krasnodar – Sochi – Republics of Transcaucasia with branch lines to the Crimea and newly annexed territories;
- latitudinal: Brest – Minsk – Smolensk – Moscow – Vladimir – Nizhny Novgorod – Cheboksary – Kazan – Izhevsk – Perm – Yekaterinburg – Tyumen – Omsk – Novosibirsk – Kemerovo – Krasnoyarsk – Irkutsk – Ulan-Ude – Chita – Birobidjan – Khabarovsk – Ussuriisk – Vladivostok with meridian branch lines in the Urals, Siberia, Yakutia, Khabarovsk Krai and Sakhalin Island.

There will be built about 50,000 km of rapid (up to 150 km/h) "second level" urban roads for a total cost of about 150 bln USD (3 mln USD/km), which will be included in the cost of housing in uCities and make it slightly more expensive (only 3 %).

The transport component of the Russian and Belarusian part of the uNet global transport and infrastructure network, created along linear cities of the Union State, which will be integrated with power lines and communications, including mobile ones, will also comprise the following uST track, built above ground on the second level in the North – South and East – West directions:

- about 50,000 km of high-speed (up to 500 km/h) intercity cargo and passenger routes at a total cost of 350 bln USD (7 mln USD/km). This cost will also be included in the cost of housing in the uCity, which will make it only 7 % more expensive;
- about 50,000 km of cargo routes (up to 150 km/h) at a total cost of 250 bln USD (5 mln USD/km);
- about 20,000 km of hypervelocity (up to 1,500 km/h) intercity cargo and passenger routes at a total cost of 800 bln USD (40 mln USD/km).

In addition, a contour line of transport and defense clusters will be created along all national borders, including those in the Arctic, which will fulfill (along with basic socio-economic functions) additional functions, in particular autonomous military-defense outposts equipped with the most advanced military-defense complexes. The problem of the second line of continuous border control can be effectively solved here by connecting the outposts with the high-speed (up to 500 km/h) cargo and passenger transport and communication network. Having modern checkpoints and observation complexes, such a "second level" transport and communications network, if necessary, can provide ultra-fast redistribution of personnel and equipment across outposts and redeployment of military forces to any part of the state border.

On string-rail routes, launchers camouflaged as a cargo uPod, for example, with cruise missiles, which can be launched without stopping the transport, i.e., on the move, can run at a constant speed of up to 500 km/h. It would be very difficult for a potential enemy to detect and disarm such launchers, as they are capable of changing their location on the uNet road network over a distance of up to 10,000 km in a single day.

The Russian and Belarusian parts of the uNet road network built will serve tens of thousands of passenger stations, cargo terminals and service shops with a single automated control system created by secure digital blockchain technology. Millions of uPods (urban, intercity and cargo) with on-board control systems will travel along the airways. Thus, millions of computers combined into a common distributed system – a supercomputer spread over millions of square kilometers and connected by millions of kilometers of neural and power networks integrated into the string-rail track structure – will operate in the uNet infrastructure and rolling stock. Its computational capabilities are colossal, and the network communication structure (transport, energy and information) is invulnerable to any threats: climatic, man-made, military or terrorist.

The Union State's highest degree of security will stem not only from the network nature of transport and infrastructure functions of uCities and the uNet network, but also from their provision with all the basic types of state security: infrastructure, transport, energy, production, raw materials, housing, social, information, demographic, labor, food, water, etc.

In addition, the entire future Internet and mobile communications of the Union State can be built under the Union's independent standards and also be integrated into the track structure of the uNet network. These communication lines do not require cellular towers and space communication satellites: their functions will be taken over by elements of the transport and energy-information infrastructure – anchoring structures and supporting towers, stations, terminals, relict solar biopower plants, as well as rolling stock and the string-rail track structure which integrates the protected power and information networks.

At the same time, automated control systems of the uNet transport and information network and uCities, created based on blockchain technology, can be easily combined with the production of an electronic unit of account – our own cryptocurrency. It will be mined automatically, without consuming additional resources and power, in the process of, for example, useful transport work, i.e., during cargo and passenger transportation. Consequently, the more passenger-kilometers and ton-kilometers of uNet transportation will be produced, the more kilowatt-hours of electricity, tons of biohumus and agricultural products will be obtained in uCities, the higher the real (and not virtual) value of such a unit of account will be.

The uNet cryptocurrency will be effectively enabled and bound to the transport, energy, residential, industrial and other infrastructure, as well as to its effective functioning on the entire planet, i.e., to true civilizational values. Therefore, over time it will be transformed into the world's main digital currency, controlled by the Union State (in this way the Union State can create a digital equivalent of the US Federal Reserve System).

Project Budget

With an average house cost of 200,000–250,000 USD (considering the cost of urban infrastructure in a uCity) the annual project budget would be about 200 bln USD. Then within 25 years (roughly by 2050) 5 tln USD should be invested in linear urban development. This cost includes not only building 25 mln two- and three-storied residential buildings with a total area of 7.5 bln m^2 and creating a network of urban and intercity high-speed routes with a total length of about 100,000 km; it also includes the cost of all the relevant urban infrastructure of pedestrian linear cities, 250,000 ha of greenhouses and orangeries, 25 mln ha of highly fertile homesteads on which gardens will be planted – more than 1 bln fruit and berry plants.

The plans are to build 50,000 residential clusters (in essence, urban-type villages) with 250,000 km of landscaped streets with everything necessary for a decent, comfortable and safe living for most of the population of the Union State. In addition, this cost includes the creation of a fundamentally new network energy system of the state – RSBE with a total installed capacity of about 600 mln kW to generate 270 mln kW of electricity and 330 mln kW of thermal energy. These figures exceed all the modern anti-biospheric energy in Russia and Belarus, which has a total capacity of about 260 mln kW.

The entire above-mentioned housing stock of the state with the corresponding infrastructure (including transport, energy and farming with a total cost of about 5 tln USD) will be paid for by the population. Citizens of the Union State will buy houses in clusters of uCities, in which, after becoming residents of the largest territory in the world (by then the safest, most comfortable and equipped, with one of the highest living standards in the world), they will live and work decently.

It only needs to pay 1,050 bln USD from the budget (the construction of 70,000 km of cargo and hypervelocity elevated uST tracks), or 42 bln USD each year. The routes being built need to be made transit ones as well (i.e., with a higher capacity), as the Union's transport-infrastructure and communication-logistics network uNet can be extended in the following directions:

- East: through Mongolia and Kazakhstan to Southeast Asia, primarily China and India; to Japan;
- North: across the Bering Strait to Canada and the USA;
- West: to Kaliningrad; to London (and Paris).

In addition, hypervelocity tracks of the uNet network with vacuum tunnels, deployed with zero floatability at a depth of about 50 m, will be able to pass through the oceans (through the Atlantic in the West and the Pacific in the East) and connect not only Asia and Europe, but also Eurasia with America through Russia and Belarus. Then, for example, it would take 2.5 h to get from Moscow to London and 4.5 h from London to New York, which is faster and safer than taking a plane (such a project was first proposed by engineer A. Unitsky over 30 years ago) [42].

The construction of the Union's part of the world transport, energy, information and infrastructure uNet network can raise foreign capital, as well as funds withdrawn by Russian business abroad in previous years, since investments in this case will provide a stable income not only in the 21st century, but also in the centuries to come.

The network of Union's linear cities will produce annually about 500 mln tons of living humus which is more fertile and productive than chernozem (humus makes up 5 % and more in the content of natural chernozem), with a total market value of about 500 bln USD. It is possible to get up to 20 tons of chernozem from a ton of crumbly biohumus, if we add it to non-fertile soil (including desert sand). Accordingly, 500 mln tons of living humus in agricultural production is equivalent to 10 bln tons of chernozem. Half of the produced biohumus as a by-product of the RSBE operation (in terms of its economic essence, it will reach the producer actually for free) can be spent for the needs of the Union State, and the other half can be exported. Given the biohumus costs 1,000 USD/t, this will provide about 250 bln USD of export revenue annually, which is currently almost twice the revenue from the sale of Russian crude oil abroad.

It is planned to create more than 25 mln new high-paying jobs in the Union State – not only in residential areas, but also in nearby infrastructure clusters (manufacturing, scientific, educational, sports, tourist, trade and entertainment, recreational, etc.) situated within walking distance. The required number of such clusters is about 10 times less than that of the residential ones – about 5,000. Consequently, both residential and industrial areas in Russia and Belarus will have a network (cluster, or cellular) structure, which is very resilient to external and internal challenges, self-sufficient and independent, distributed over the whole territory of the state, from North to South and from West to East, and oriented mainly on domestic demand and resources. This principle of organization will provide infrastructural security – such a state cannot be defeated.

By that time the population of the state may expand to 200 mln people and even more; today's Russia and Belarus, which are under sanctions and are demonized by their geopolitical competitors in this deranged modern world, will turn into a highly developed, self-sufficient and prosperous single state, a worthy example for all other countries (no matter developed or developing), which have chosen the regressive path of their civilizational development at the urging of global quasi-elites. This liberal vector leading to a civilizational dead end, which the Union State can avoid thanks to the proposed alternative Program, is based not only on the above mentioned "5D" program (digitalization, decarbonization, deindustrialization, desocialization, depopulation), but also on many less meaningful, but similarly regressive "Ds": demotivation, destabilization, decapitalization, denationalization, degradation, dumbing-down and debiologization of people, societies and humanity in general [33].

The Union State of Russia and Belarus has an abundant heritage and production base from the time of the Soviet Union represented by engineering and scientific schools with a deep immersion in the problems of space development, as well as the technology that allowed the first man, of Russian nationality, to fly into space in 1961.

Currently, one such industrial site with a high level of engineering and intellectual potential is UGC, the international Unitsky Group of Companies. To achieve a common global goal – the transition to the biospheric path of civilizational development of mankind – UGC has united both engineers who create uST transport and infrastructure complexes and the General Planetary Vehicle, biotechnologists who organize comfortable life in enclosed ecosystems, and lawyers, financial experts and sociologists who offer scenarios of centuries-long, sustainable development of the Earth's industrial (i.e., engineering) civilization. All these works are presented annually at the International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" [43] held in Maryina Gorka and are aimed at improving the quality of life of people in our common home – on planet Earth.

Article 2 of the Vienna Convention allows Russia and Belarus, as fully legitimate subjects of international law, to initiate international cooperation agreements for implementation of the large-scale EcoSpace program and its space vector – the uSpace program.

The governments of the Union State, Russia and Belarus and their Presidents can choose their unique biospheric path of progressive civilizational development: protection of independence, self-identity and sovereignty (including technology), preservation of people, rapid industrialization, socialization and demographicization, creation of infrastructure backbones – not only territorial, but also resource (where, in particular, resources are also territory, fertile soil, clean air, natural drinking water), as well as national, social and cultural resources.

The Program for Rebooting the Economy of the Union State of Russia and Belarus to the Biospheric Path of Civilizational Development will relieve all of the present-day pains of the Union State and solve all its major problems in the long term. Particularly, the Program will ensure infrastructure, resource, food, transport and energy security; reshape the export-raw materials orientation of the economy towards domestic demand and the transport and infrastructure development of its largest territory in the world; resolve import substitution issues; create conditions for rapid growth in the indigenous population; solve problems associated with excessive urbanization, degradation of fertile soils and desertification.

We should also point out that the costs required to reboot the economy of the Union State to the biospheric and socially oriented path of developing the economy and society are not that huge – they are nearly the same as of other Russian programs, which are much less important. For example, such programs as the Transport Strategy of the Russian Federation until 2030, which was approved in 2008 to solve only transport problems; its implementation costs were estimated at almost the same 5 tln USD at the time of its adoption [44].

The EcoSpace Program, or the Role of the Union State in the Survival of All Mankind

The economic resources of the Union State, as well as its social and political institutions, can form the basis for the implementation of the large-scale EcoSpace program, including its space vector – uSpace program, which aims to industrialize near space.

As mentioned earlier, the uSpace program involves the creation of a global transport and infrastructure system, where the key elements are the Equatorial Linear City (ELC) with a takeoff and landing overpass, the GPV and the Industrial Space Necklace "Orbit" (ISN "Orbit") in low equatorial orbits.

The Equatorial Linear City is a system of residential, industrial, energy, logistics and other infrastructure facilities stretched along the equator. The main elements of the ELC are distributed along the GPV overpass and, in addition to performing the usual functions for any city, are designated to serve and organize the GPV takeoffs and landings, as well as to distribute passengers and cargo moving along the Earth – Orbit – Earth route.

The General Planetary Vehicle is a self-carrying spacecraft that encircles the planet in the equatorial plane. It is a torus with a cross section of about 1.5 m with a linear electric motor in the core. Centrifugal force, sufficient for lifting into orbit, is ensured by rotation around the planet of belt flywheels placed in longitudinal vacuum channels. Entering into space is achieved by spinning the GPV body around the planet (after ascent beyond the atmosphere) up to the first space velocity of 7.91 km/s. Such transport can make up to 100 trips a year and deliver up to 10 mln tons of cargo and up to 10 mln passengers per each trip to space and back [39]. This will make it possible to industrialize near space in a short period of time.

The Industrial Space Necklace "Orbit" is a system of industrial, residential and energy facilities located in near-Earth orbit. The complex is designed to serve the needs of the Earth's population in space industrial products and energy. It allows access to unlimited resources in space – spatial, energy, raw materials and technological (weightlessness, deep vacuum, technological purity).

The Union State, where we propose to work out a number of fundamental technologies for the uSpace program (uCities and string transport to connect them, etc.), can be their main supplier in the implementation of the project – the most ambitious in the history of civilization. For this purpose, it is necessary to set up a block around the institutions of the Union State, which will include the states located on the equator and other members.

The block's objectives will be entirely peaceful and creative in nature. Their achievement will provide the necessary prerequisites for the gradual relocation of the hazardous part of the technosphere outside the planet and the long-term sustainable development of our civilization on a global scale without limitations on the number of available resources and the size of the population. Thus, the proposed program of rebooting can be developed globally and contribute to solving the environmental, demographic and political problems that jeopardize the survival of all humanity on Earth, possibly the only Intelligent Civilization in our vast Universe.

Conclusions

The uNet transport and infrastructure network should initially be built in the territory of the Union State, taking into account future transit cargo and passenger transportation in both East – West and North – South directions. Therefore, the latitudinal line of uNet can be extended in the future:

- in the West: along the route Brest – Warsaw – Berlin – Brussels – London – Paris – Madrid – Lisbon;
- in the East: along the routes Khabarovsk – Komsomolsk-on-Amur – Sakhalin Island – Tokyo; Ulan-Ude – UlanBator – Beijing – Shanghai; Khabarovsk – Magadan – Anadyr – Bering Strait – Alaska – Canada – Los Angeles – Washington – New York;
- in the South: along the route Omsk – Astana – Tashkent – Dushanbe – Kabul – Islamabad – New Delhi – Hanoi – Shanghai.

All Asian, European and North American countries will be interested in the construction of a worldwide network of uCities and the uNet transport and infrastructure network, so a unified global transport and infrastructure space of the new generation can be created at their expense.

With the right strategy and through foreign investment the Union's component of the uNet global network can be fully funded. However, the unified Union State will become the trendsetter in science and technology and the world leader in the rebooting of the world economy on the above-described biospheric path of technological, social and civilizational development.

The Russian Federation and the Republic of Belarus will transform from sanctioned rogue countries demonized by the globalist oligarchy into a prosperous unified state – an example to follow as a winning country in the planet's undeclared war of ideologies and vectors of civilizational development, which will be won not by lethal weapons, but by intelligence, and not artificial or digital (i.e., nature-like), but natural, human (i.e., existing in nature).

The important thing is to consolidate domestic resources (that already exist) and to build up our own intellectual competencies, which other countries lack, both in the East and in the West, including through the training of the necessary specialists. We need to move as rapidly as possible from consumer capitalism (which sooner or later will bring our entire civilization to suicide) to a fundamentally new creative and socially-oriented model of the world economy.

At the same time, the main weapon of the Union State will no longer be supersonic missiles and nuclear warheads, but mineral and territorial resources – about 20 % of the world's deposits. These resources should belong not to the West and Western-oriented professional liberal globalists, not to officials and oligarchs close to the government, but to the state and the people, and then the Union State will win any war, even a century-long one.

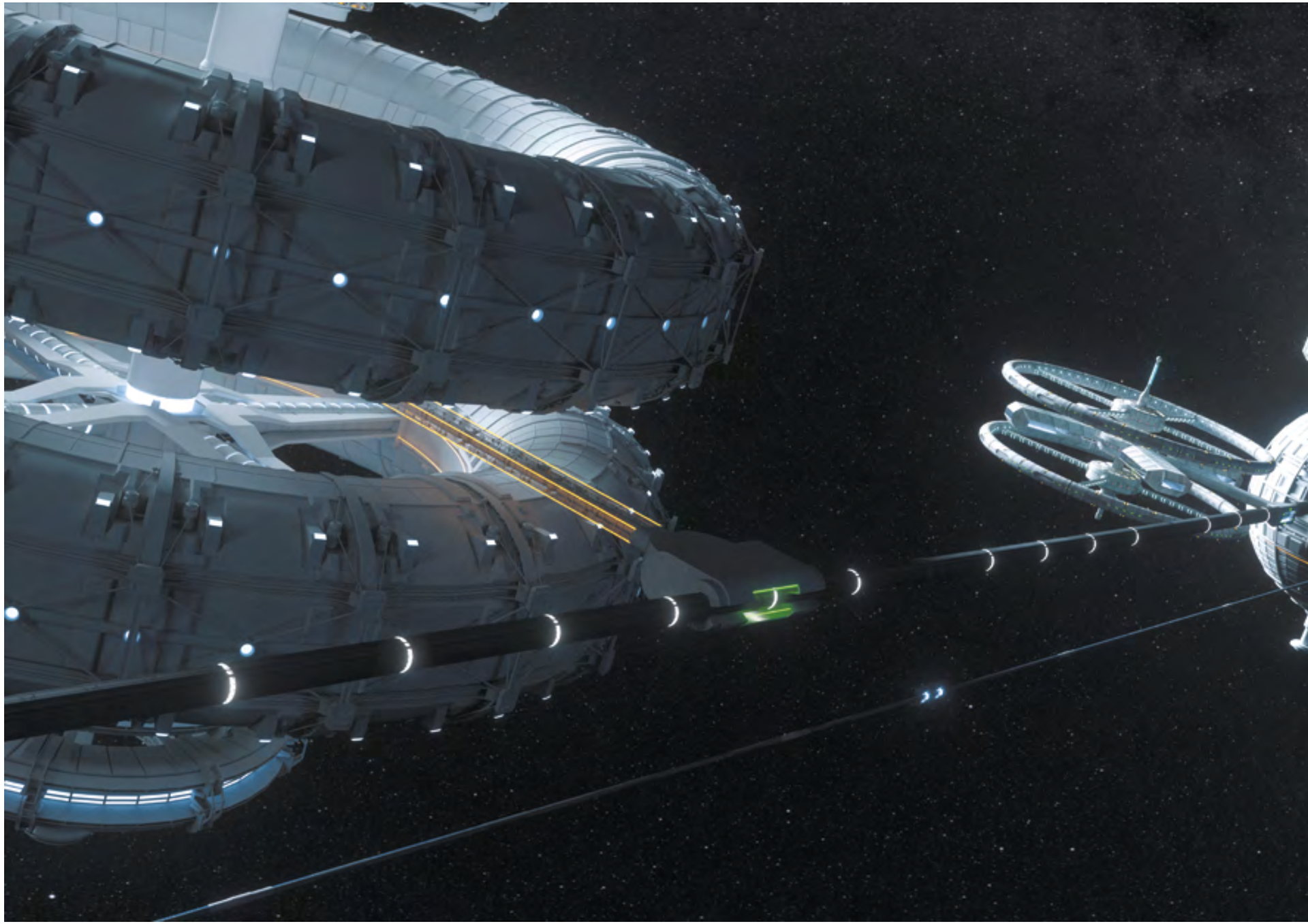
Russia and Belarus, together with the multi-ethnic people of the Union State, will once again prove their greatness and special civilizational role in the world, confirming the prophetic words about Moscow as the "Third Rome that stands" and the "Fourth Rome that will never be".

References

1. *Chem interesny pangoliny i pochemu im ugrozhayet opasnost' [What is Interesting About Pangolins and Why They Are in Danger] [Electronic resource]. – Mode of access: https://animaljaws.com/chem-interesny-pangoliny-i-pochemu-im-ugrozhaet-opasnost.html. – Date of access: 14.09.2022.*
2. *Uchonyye: na Zemle sushchestvuyet trillion vidov zhivykh sushchestv [Scientists: A Trillion Species of Living Beings Exist on Earth] [Electronic resource]. – 2016. – Mode of access: https://ria.ru/20160504/1426121658.html. – Date of access: 11.09.2022.*

3. *Gorkin, A.P. Entsiklopediya "Biologiya" [Encyclopedia "Biology"] [Electronic resource]: in 2 pt. / A.P. Gorkin. – Pt. 1: A – L (il.). – Mode of access: https://fictionbook.ru/static/trials/00/16/05/00160515.a6.pdf. – Date of access: 14.09.2022.*
4. *Immunitet zvereyet ot fastfuda [Immunity Goes Berserk from Junk Food] [Electronic resource]. – 2018. – Mode of access: https://www.nkj.ru/news/33044/l. – Date of access: 11.09.2022.*
5. *Rusakova, Ye. Pishchevaya dobavka-antioksidant oslabila immunitet bol'nykh grippom myshey [Antioxidant Food Additive Weakened the Immunity of Influenza Mice] [Electronic resource] / Ye. Rusakova. – 2019. – Mode of access: https://nplus1.ru/news/2019/04/08/butylhydroquinone. – Date of access: 10.09.2022.*
6. *Pezenti, A. Zakon Seya. Zakon sbyta. Neizbezhnost' krizisov v protsesse kapitalisticheskogo razvitiya [Say's Law. The Law of Sales. Inevitability of Crises in the Process of Capitalist Development] [Electronic resource] / A. Pezenti // Ocherki politicheskoy ekonomii kapitalizma: in 2 vol. / A. Pezenti. – 1976. – Vol. 1. – Mode of access: http://www.bibliotekar.ru/2-8-75-politicheskaya-ekonomiya/102.htm. – Date of access: 07.09.2022.*
7. *Stiglitz, D.Ye. Ideologicheskiy krizis zapadnogo kapitalizma [Ideological Crisis of Western Capitalism] [Electronic resource] / D.Ye. Stiglitz. – 2011. – Mode of access: http://www.trinitas.ru/rus/doc/0012/001c/00122252.htm. – Date of access: 01.09.2022.*
8. *Sumaneyev, Yu. Global'nyye izmeneniya politicheskogo klimata [Global Changes in the Political Climate] [Electronic resource] / Yu. Sumaneyev. – 2018. – Mode of access: https://interaffairs.ru/news/show/21054. – Date of access: 05.09.2022.*
9. *Davos 2022 [Davos 2022] [Electronic resource]. – 2022. – Mode of access: https://katehon.com/ru/article/davos-2022. – Date of access: 09.09.2022.*
10. *Belarus' – ta strana i tot ostrovok mashinostroitel'noy industrii, kotoryye sokhranilis' i ochen' nuzhny Rossii [Belarus Is the Country and the Island of Engineering Industry That Has Been Preserved and Is Very Necessary for Russia] [Electronic resource]. – 2022. – Mode of access: https://www.sb.by/articles/retsept-boglaeva.html. – Date of access: 09.09.2022.*
11. *Golovchenko: Belarus' i Rossiya vmeste mogut protivostoyat' lyubomu vneshnemu davleniyu [Golovchenko: Belarus and Russia Together Can Resist Any External Pressure] [Electronic resource]. – 2021. – Mode of access: https://www.belta.by/politics/view/golovchenko-belarus-i-rossija-vmeste-mogut-protivostojat-ljubomu-vneshnemu-davleniju-473538-2021/. – Date of access: 08.09.2022.*
12. *Kuznetsov, Ye. Zapechatano v kubyshke: ob"yom zamorozhennykh sredstv FNB otsenili v tret' [Sealed in a Thrift-box: the Volume of Frozen Assets of the NWF Was Estimated at a Third] [Electronic resource] / Ye. Kuznetsov. – Mode of access: https://iz.ru/1319618/evgenii-kuznetcov/zapechatano-v-kubyshke-obem-zamorozhennykh-sredstv-fnb-otcenili-v-tret. – Date of access: 08.09.2022.*
13. *West Must Hit Russian Economy Even Harder, Says Liz Truss [Electronic resource]. – 2022. – Mode of access: https://www.theguardian.com/world/2022/apr/05/liz-truss-russian-economy-foreign-currency-reserves-ukraine-war-putin. – Date of access: 07.09.2022.*
14. *Glava MVF Georgiyeva predupredila, chto 41 mln chelovek v arabskom mire podverzheny risku nekhvatki prodovol'stviya [IMF Chief Georgieva Warned That 41 mln People in the Arab World Are at Risk of Food Shortages] [Electronic resource]. – 2022. – Mode of access: https://live24.ru/v-mire/glava-mvf-georgieva-predupredila-chto-41-mln-chelovek-v-arabskom-mire-podverzhen-risku-nehvatki-prodovolstviya.html. – Date of access: 07.09.2022.*
15. *Ustoychivoye razvitiye i "zelonaya" ekonomika v Rossii: aktual'naya situatsiya, problemy i perspektivy [Sustainable Development and Green Economy in Russia: Current Situation, Problems and Prospects] [Electronic resource]. – 2014. – Mode of access: https://ecodelo.org/rossiyskaya_federaciya/27342-ustoychivoe_razvitie_i_zelenaya_ekonomika_v_rossii_aktualnaya_situaciya. – Date of access: 06.09.2022.*
16. *Bobylev, S.N. Krizis: ekonomika i ekologiya [Crisis: Economy and Ecology] / S.N. Bobylev, V.M. Zakharov; Institute for Sustainable Development, Center for Environmental Policy of Russia, Civic Chamber of the Russian Federation. – Moscow: Tipografiya LEVKO, 2009. – 84 p.*
17. *Ustoychivoye razvitiye: vyzovy Rio [Sustainable Development: Rio Challenges]: Report on Human Development in the Russian Federation for 2013 / ed. S.N. Bobylev. – Moscow: RA IL'F, 2013. – 202 p.*
18. *Duel', A. Abramchenko nazvala goroda Rossii s samym zagryaznonnym vozdukhom [Abramchenko Named Russian Cities with the Most Polluted Air] [Electronic resource] / A. Duel'. – 2021. – Mode of access: https://rg.ru/2021/01/29/reg-urfo/abramchenko-nazvala-goroda-rossii-s-samym-zagriaznennym-vozduhom.html. – Date of access: 03.09.2022.*
19. *Ivanov, N.I. Problema shuma v Rossiyskoy Federatsii: "kto vinovat?" i "chto delat'?" [Noise Problem in the Russian Federation: "Who is to Blame?" and "What to Do?"] / N.I. Ivanov // Zashchita ot povyshennogo shuma i vibratsii: Proceedings of the IV All-Russian Scientific and Practical Conference with International Participation, Saint Petersburg, Mar. 26–28, 2013 / ed. N.I. Ivanov. – Saint Petersburg: Aysint, 2013. – P. 14–35.*
20. *Ponyatiye i prichiny degradatsii pochv [Concept and Causes of Soil Degradation] [Electronic resource]. – 2021. –Mode of access: https://agroportal-ziz.ru/articles/ponyatie-i-prichiny-degradacii-pochv. – Date of access: 02.09.2022.*
21. *Degradatsiya zemel' [Land Degradation] [Electronic resource]. – Mode of access: https://dev.abcdef.wiki/wiki/Land_degradation. – Date of access: 02.09.2022.*
22. *FAO: k 2050 godu proizvodstvo produktov pitaniya nuzhno uvelichit' na 60 % [FAO: Food Production Needs to Be Increased by 60 % by 2050] [Electronic resource]. – 2016. – Mode of access: https://produkt.by/news/fao-k-2050-godu-proizvodstvo-produktov-pitaniya-nuzhno-uvelichit-na-60. – Date of access: 01.09.2022.*
23. *Gosudarstvennyy (natsional'nyy) doklad o sostoyanii i ispol'zovanii zemel' v Rossiyskoy Federatsii v 2020 godu [State (National) Report on the Condition and Use of Land in the Russian Federation in 2020] [Electronic resource]. – 2021. – Mode of access: https://rosreestr.gov.ru/upload/Doc/16-upr/Государственный%20(национальный)%20доклад_2020.pdf. – Date of access: 02.09.2022.*
24. *Tsifrovyye tekhnologii dlya obsledovaniya sostoyaniya zemel' sel'skokhozyaystvennogo naznacheniya bespilotnymi letatel'nymi apparatami [Digital Technology for Agricultural Land Surveying by Unmanned Aerial Vehicles] / V.Ya. Gol'tyapin [et al.]. – Moscow: FGBNU "Rosinformagrotekh", 2020. – 88 p.*
25. *The Global Risks Report 2020. – 15th ed. – Geneva: World Economic Forum, 2020. – 96 p.*
26. *Transportnaya strategiya Rossiyskoy Federatsii do 2030 goda s prognozom na period do 2035 goda [Transport Strategy of the Russian Federation Until 2030 with a Forecast Until 2035] [Electronic resource]: Decree of the Government of the Russian Federation, Nov. 27, 2021, No. 3363-r // Government of the Russian Federation. – Mode of access: http://static.government.ru/media/files/7enYF2uL5kFZIOOpQhLI0nUT91RjCbeR.pdf. – Date of access: 06.09.2022.*
27. *Khusnutdinova, S.R. Ustoychivoye razvitiye sovremennykh gorodov [Sustainable Development of Modern Cities] / S.R. Khusnutdinova // Vestnik Kazanskogo tekhnologicheskogo universiteta. – 2010. – No. 2. – P. 421–429.*
28. *Speech at the Third Session of the Plenary Meeting of the UN Conference on Sustainable Development – Rio+20: Dmitry Medvedev's Speech [Electronic resource]. – 2012. – Mode of access: http://archive.government.ru/eng/stens/20349/. – Date of access: 02.09.2022.*
29. *Yegorova, M.S. Ekonomicheskiye mekhanizmy i usloviya perekhoda k "zelonoy" ekonomike [Economic Mechanisms and Conditions of Transition to a Green Economy] / M.S. Yegorova // Fundamental'nyye issledovaniya. – 2014. – No. 6 (pt. 6). – P. 1262–1266.*
30. *Programma "EkoMir": bezraketnaya industrializatsiya blizhnego kosmosa [EcoSpace Program: Non-Rocket Near Space Industrialization] [Electronic resource]. – 2020. – Mode of access: https://unitsky.engineer/assets/files/shares/2022/uSpace_program_2022.pdf. – Date of access: 25.08.2022.*
31. *Unitsky, A.E. Tsivilizatsionnaya yomkost' kosmicheskogo doma po imeni Planeta Zemlya [Civilization Capacity of the Space Home Named Planet Earth] [Electronic resource] / A.E. Unitsky. – Moscow: Mir nauki, 2022. – 136 p. – Mode of access: https://izd-mn.com/PDF/08MNNPM22.pdf?ysclid=la98apfobr284127861. – Date of access: 10.09.2022.*
32. *Unitsky, A.E. Tekhnosfera 2.1 – perezagruzka zemnoy industrii na kosmicheskiy vektor razvitiya [Technosphere 2.1 – Rebooting the Earth Industry to the Space Vector of Development] / A.E. Unitsky // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 36–73.*
33. *Unitsky, A. Civilization Capacity of the Space Home Named Planet Earth / A. Unitsky // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 23–73.*
34. *Unitsky, A. Historical Background of the SpaceWay Program as the Only Way to Sustainable Development of the Technocratic Civilization / A. Unitsky // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 23–29.*

35. *EcoTechnoPark in Belarus [Electronic resource]. – Mode of access: https://unitsky.engineer/projects/ecopark-?lang=en. – Date of access: 19.09.2022.*
36. *uSky Test and Certification Center [Electronic resource]. – Mode of access: https://unitsky.engineer/projects/usky-?lang=en. – Date of access: 21.09.2022.*
37. *Transport Solutions [Electronic resource]. – Mode of access: https://ust.inc/transport-solutions?lang=en. – Date of access: 17.09.2022.*
38. *uSpace – Geospace Program on Non-Rocket Near Space Exploration Technology to Save the Earth's Life [Electronic resource]. – Mode of access: https://aet.space/?lang=en. – Date of access: 21.09.2022.*
39. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
40. *Navstrechu "zelonoy" ekonomike: puti k ustoychivomu razvitiyu i iskoreneniyu bednosti [Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication]: A Summary Report for Authorities [Electronic resource] // UNEP. – 2011. – Mode of access: http://old.ecocongress.info/5_congr/docs/doklad.pdf. – Date of access: 17.09.2022.*
41. *V avtokatastrofakh yezhegodno gibnut 1.2 mln chelovek [1.2 mln People Die Every Year in Car Accidents] [Electronic resource]. – 2004. – Mode of access: https://www.rbc.ru/society/07/04/2004/5703bcdf9a7947afa08caee5?ysclid=la9fb4gr87100112824. – Date of access: 13.09.2022.*
42. *Unitsky, A. The Engineer: Autobiography / A. Unitsky. – Minsk, 2020. – 400 p.*
43. *Annual International Scientific and Technical Conference: Non-Rocket Near Space Industrialization: Problems, Ideas, Projects (NRNSI) [Electronic resource]. – Mode of access: https://aet.space/conference?lang=en. – Date of access: 11.09.2022.*
44. *Transportnaya strategiya Rossiyskoy Federatsii na period do 2030 goda [Transport Strategy of the Russian Federation for the Period up to 2030] [Electronic resource]: Decree of the Government of the Russian Federation, Nov. 22, 2008, No. 1734-r // Government of the Russian Federation. – Mode of access: http://static.government.ru/media/files/Z31ADuvq0eoXIknPdhwWRYI22ISdhpaS.pdf. – Date of access: 05.09.2022.*



Magnetic System of Power Stabilizing Unit of the General Planetary Vehicle

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UDC 53.098

The purpose of this research is to develop the design of a magnetic system of the power stabilizing unit that provides a restriction of five degrees of freedom of the rotor, as well as a theoretical study of its behavior during operation. The solution of the problem of stabilizing the central position of the rotor in the stator channel of the General Planetary Vehicle (GPV) using magnetic field forces of permanent magnets is proposed. The designed system compensates for external forces acting both on the rotor during takeoff preparation and on the stator during ascent. There was modeled a variant when a linear combined motor as part of the GPV performs several tasks: transfer of lifting force from the flywheel to the GPV body; holding the flywheels in vacuum channels for movement, preventing contact with the walls in static and dynamic modes; acceleration of the flywheel, providing it with the required speed; conversion of the kinetic energy of the flywheel into electrical one in the mode of power take-off.

Keywords: *General Planetary Vehicle (GPV), high-speed linear motor, magnetic levitation, magnetic suspension.*

Introduction

One of the fundamental components of the program for the non-rocket exploration of near-Earth space is a geocosmic transport system that allows passengers and cargo to be transported to the Industrial Space Necklace "Orbit" (ISN "Orbit"), as well as to descend them to our planet's surface.

Over 40 years ago, engineer A. Unitsky proposed the design of a geocosmic vehicle capable of delivering millions of tons of payload and millions of people to near space in one flight without the use of conventional jet rocket engines [1, 2]. The operation of the General Planetary Vehicle (GPV) designed by the inventor – a self-supporting aircraft encircling the Earth in the equatorial plane, weighing several tens of millions of tons – involves solving a number of complex engineering problems. One of them is the development and creation of a linear combined electric motor with a length of 40,000 km that will be able to lift such a grandiose structure into space. No other mechanism is acceptable due to the high relative speeds of its moving and stationary parts.

The force that draws the GPV into near space is centrifugal. It acts on any body moving along the segment of a circle, and becomes greater with the increase of the mass and velocity of the object and reduction in the radius of the circle along the arc of which the movement takes place [3–5].

The design of the GPV engine contains a rotor – a belt flywheel, which is located inside the body in a vacuum channel. After receiving the command to prepare for takeoff, the linear motor begins to accelerate the rotor. Under the action of linear electric motor, the rotor starts to move around the Earth along a circle coinciding with the plane of the equator, or parallel to it. A centrifugal force directed away from the center of the Earth begins to act on the rotor, lifting the flywheel vertically upwards. Thus, the question arises about the interaction of the flywheel rushing at great speed and the stationary GPV body with passengers and cargo.

In this paper, the use of magnetic fields is proposed to solve this problem. It describes the design of the magnetic system of the power stabilizing unit, which provides both the retention of the rotor in the vacuum channel of the stator and the transfer of centrifugal force from the rotor to the GPV body. The system automatically stabilizes the position of the GPV body relatively to the longitudinal axis of the rotor when forces of any nature arise that tend to deflect the GPV body in different directions other than this axis.

Analysis of the Forces Acting in the System of Permanent Magnets of Power Stabilizing Unit

Any system that provides levitation must compensate for the effect of gravity. In world practice, there are two types of such systems: electrodynamic and electromagnetic.

To implement levitation in the magnetic fields of electromagnets, a well-known solution is used. A pair of "ferromagnet – electromagnet" [6, 7] or "conductor – electromagnet" [8–10] with feedback on the position of the moving part is used as interacting components. In these systems, in one form or another, there is the same set of composite functional blocks: an electromagnet, its power supply device, a levitating body position control device and an electromagnet control device based on information received from the sensors of the control device. The principle of operation of the composite blocks of such a levitation system may be different, but the algorithm of operation is always the same. The position sensor tracks the distance to the levitating body. The device for monitoring the current flowing through the electromagnet, based on the signal from the sensor, changes the current of the electromagnet so that the magnetic field of the electromagnet, acting on the levitating body, returns it to a predetermined distance from the sensor. Such a system is called electromagnetic.

Figure 1 shows the forces acting on a levitating body: F_1 – the force with which the electromagnet acts on the body; F_2 – the force of universal gravity from the planet, directed to its center, lying in the plane of the equator. When the body is at a given distance from the sensor, the force F_1 is equal to zero. Under the action of force F_2, the body will start to move. The distance to the sensor will decrease. The force F_1 will automatically begin to increase, striving to return the distance to the predetermined value (Figure 1). The equilibrium position in this case is unstable, so the body will make microoscillations, creating the effect of stationary levitation.

Electrodynamic levitation is based on the emergence of eddy currents in conductive materials induced by an alternating electromagnetic field or the field of a moving permanent magnet (Figure 2).

The numbers 1 and 2 (Figure 2) indicate two ring coils nested in each other. A disk of conductive material is placed on top of them. The disk is affected by the force of universal gravity F_2. When an alternating voltage is applied to the coils, an alternating current will flow into them, which will create an alternating electromagnetic field around them, inducing eddy currents in the conductive disk lying on the coils.

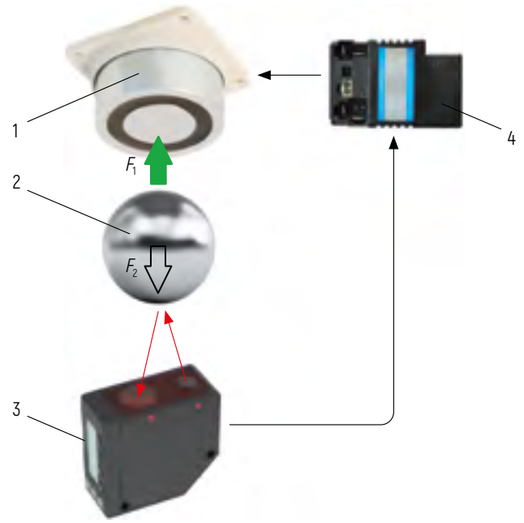

Figure 1 – Electromagnetic levitation:
1 – electromagnet; 2 – levitating body; 3 – distance sensor;
4 – control unit

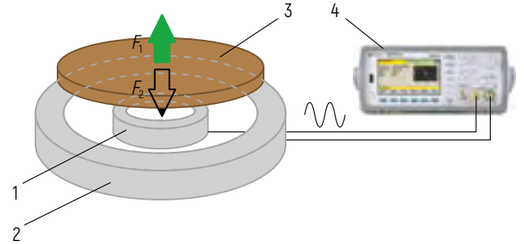

Figure 2 – Electromagnetic levitation:
1 – inner coil; 2 – outer coil; 3 – disk made of conductive material;
4 – alternating voltage generator

The currents will create an alternating electromagnetic field around the disk, which will interact with the field of the coils. The coils and the disc will push off from each other. There will appear the force F_1 (the mass of the disk and the parameters of the coils are chosen so that the force F_1 is greater than the force F_2). The disk will start moving upwards. As the disc moves away from the coils, the force F_1 will decrease. At a certain distance of the disk from the coils, the forces F_1 and F_2 will get equal, the disk will take its equilibrium position in space and begin to levitate.

Both systems considered require constant power supply and uninterruptible power supply of control devices, as well as feedback sensors. In addition, duplication of units is required for security reasons.

The third system used is a "magnet – superconductor" [11, 12]. The method is based on the repulsion of a diamagnet (superconductor) and a ferromagnet (permanent magnet) (Figure 3).

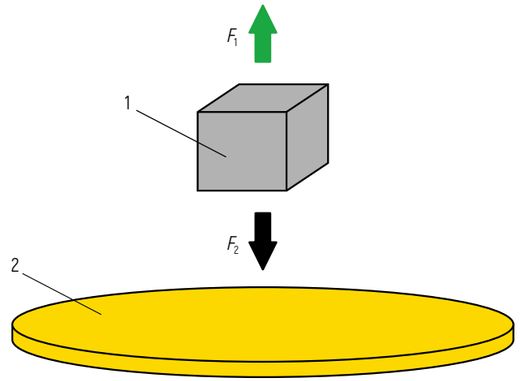

Figure 3 – Levitation over a superconductor:
1 – permanent magnet $Nd_2Fe_{14}B$; 2 – ceramic disc $YBa_2Cu_3O_7$

If a magnet is placed on a ceramic disc at room temperature, an electric current will arise in the disc material, which will excite a magnetic field. This field, interacting with the field of the magnet, will repel it. Since the resistance of the disk material is very high, the current will be negligible, as well as the magnetic field of the disk. If the disk material starts cooling, its specific resistance will decrease, and the current will begin to grow according to Ohm's law. Upon reaching the critical temperature (for $YBa_2Cu_3O_7$ – 90 K) the material of the disk will pass into a state of superconductivity. Now the induced eddy current will be undamped and the excited field will displace the magnetic field of the permanent magnet from the volume of the disk material. There will appear a lifting force F_1. When the force F_1 compensates for the force of gravity F_2, the magnet will begin to levitate, which will continue until the temperature of the disk is below critical. This system, in addition to power supply and control devices, requires a dual-circuit helium-hydrogen cryostat that provides the operating temperature of superconductors and needs electricity to function.

For non-rocket near space exploration, it is necessary to create a magnetic suspension system that does not need a huge amount of electricity to operate. The system should have an exceptionally high efficiency and be relatively economical.

The proposed design has only permanent magnets in its composition and does not require continuous power supply, control mechanisms and adjustment of the rotor position. Let us consider the operation of such a system.

If the direction of the destabilizing force does not coincide with the longitudinal axis of motion of the rotor and the plane perpendicular to it, this force is decomposed into a force acting along the axis of motion of the rotor (for example, the thrust (braking) force of a linear electric motor accelerating (or slowing down) the rotor), and a force perpendicular to the axis of motion of the rotor, which is balanced by the forces of a system of permanent magnets (Figure 4).

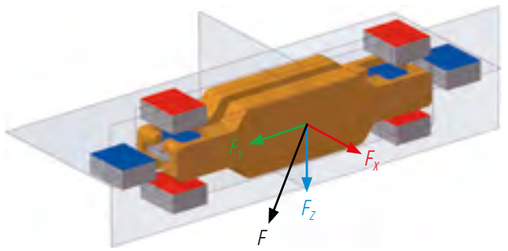

Figure 4 – Decomposition of the destabilizing force

At the stages of the rotor acceleration, the separation of the GPV from the takeoff and landing overpass and the climb to 100 km, destabilizing forces oriented in any direction may occur. Figure 4 shows in black the destabilizing force F (chosen randomly) directed into the volume of the first octant. Let us consider its decomposition into three components. The forces F_Y and F_Z will be compensated by the magnetic field of the stator's magnetic system, and F_X will tend to move the rotor in a useful direction.

The main advantage of this solution is a complete autonomy, no need for power, control systems in static and dynamic modes of operation. The disadvantage is the need to cool the magnetic system in a dynamic mode [4].

The study of literary sources shows that many researchers of magnetic levitation say that it is impossible to create a system of permanent magnets that provide levitation of a solid body without the impact of forces other than magnetic ones on it, since the Earnshaw's theorem [13] (formulated by an English physicist in 1842) is violated. In technology, certain limitations on solving engineering problems are associated with this theorem, in particular, the tasks of developing a stable suspension of a body with the help of permanent magnet fields, i.e., without a direct contact with solid retaining structures. However, the proposed system does not violate the Earnshaw's theorem. The rotor segments, both adjacent and remote, rigidly interconnected, exert the same external influence on each other, making levitation possible.

Magnetic System of Power Stabilizing Unit

Figure 5 schematically shows the design of a magnetic system consisting of identical clusters.

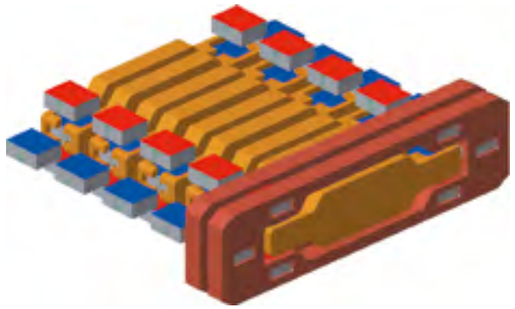

Figure 5 – Magnetic system structure

Clusters are assembled separately and mounted together, creating a magnetic system. Each cluster (Figure 6) consists of two blocks (stator and rotor) holding permanent magnets in a certain position. The stator is rigidly connected to the GPV body, and the rotor levitates in the magnetic field.

The forces of magnetic interaction block the degrees of freedom of linear movement of the rotor along the X and Z axes, as well as the degree of freedom of rotation around the Y axis. The mechanical interaction of magnetic clusters together with the interaction of magnetic fields limit the degree of freedom of rotation around the X and Z axes. The degree of freedom of linear movement along the Y axis remains unblocked (Figure 7).

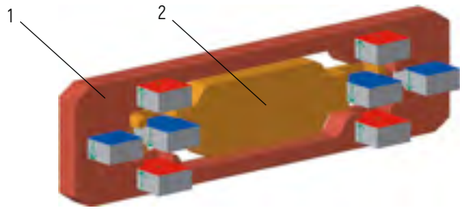

Figure 6 – Magnetic cluster: 1 – stator; 2 – rotor

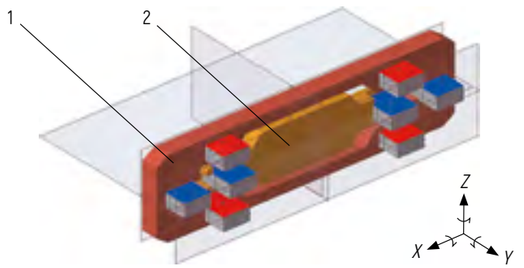

Figure 7 – Rotor freedom degrees: 1 – stator; 2 – rotor

Simulation

In order to obtain information about the stability of the system under development, let us carry out mathematical modeling of the force interaction of groups of stator and rotor magnets on the principle of superposition. The system is placed under gravity conditions at sea level in a static position.

The force acting in the direction of the rotor movement (along the Y axis), shown in Figures 7 and 8, is equal to zero, since this is the resultant force acting on the rotor magnets (green in Figure 8) from the side of the stator magnets. The power lines of the rotor magnets are locked onto the stator magnets (Figure 9).

The force acting in the direction perpendicular to the movement of the rotor and the force of gravity is the course stabilizing force, and it also equals to zero, since according to the simulation conditions there are no forces tending to shift the rotor in the X axis direction (Figures 7, 10).

Magnets A_1, A_2, A_3 (Figure 11) push out magnet B in the direction of magnet C_2 with force F_1. In their turn, magnets C_1, C_2, C_3 push out magnet D in the direction of magnet A_2 with force F_2. If the rotor is at equal distances from magnets A_2 and C_2, forces F_1 and F_2 are equal in modulus and opposite in direction, and their sum is equal to zero.

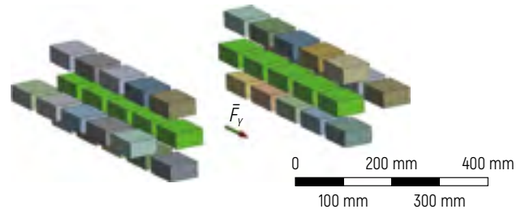

Figure 8 – Force acting in the Y axis direction

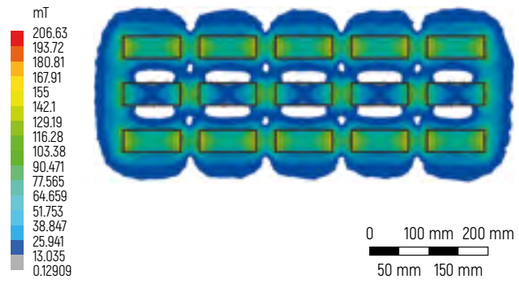

Figure 9 – Magnetic induction lines of the system (view in the X axis direction based on Figure 7)

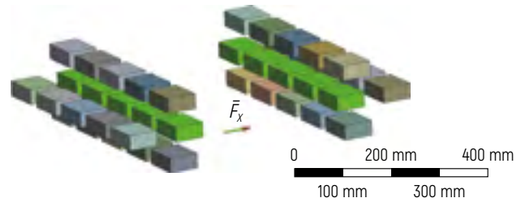

Figure 10 – Force acting in the X axis direction

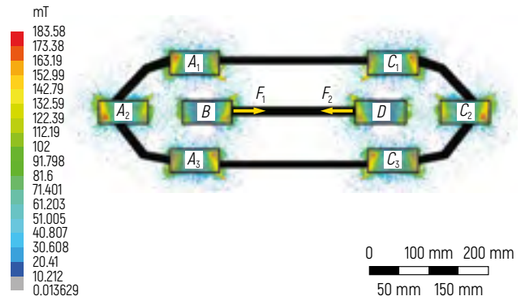

Figure 11 – Forces acting in the X axis direction from the stator side

The force acting in the *Z* axis direction (Figure 7) is a lifting force equal to 2,475 N/m, since, according to the simulation conditions, the gravity force acts on the rotor, tending to shift the rotor in the *Z* axis direction, i.e., to the center of the Earth (Figures 7, 12).

The force of universal gravity acting on the rotor tends to reduce the distance between rows of magnets 2 and 3 (Figure 13), as well as increase the distance between rows 1 and 2.

If the equality of distances from row 2 (rotor row) to rows 1 and 3 (stator rows) is violated, there appears a difference in the interaction forces between the rows, which tends to reduce the difference in distances to zero.

Analyzing Figures 14 and 15, one can notice the reaction of the magnetic field to the destabilizing force applied to the rotor. The magnetic field density was redistributed in such a way that the resulting strength of all the fields of individual magnets would compensate the external disturbance.

The specific load capacity of the magnetic unit is 18,825 N/m, or 1,920 kgf/m. Minus the weight of the hull and equipment, and also taking into account the curvilinearity of the takeoff and landing overpass, the actual load capacity of the GPV will be 350 kg/m.

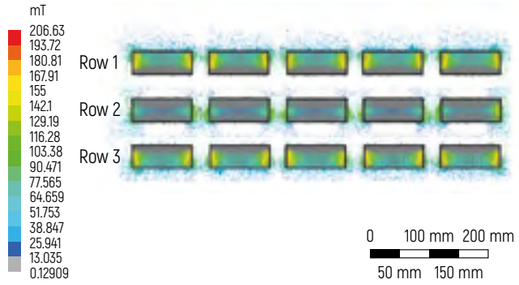

Figure 14 – Distribution of the magnetic field density of the system under microgravity conditions (view in the *X* axis direction based on Figure 7)

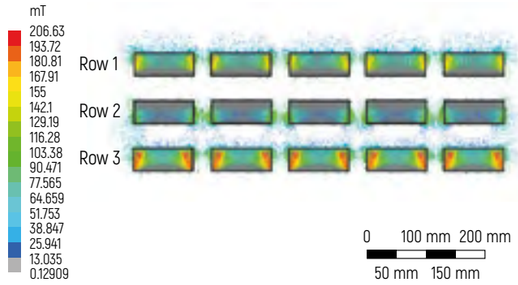

Figure 15 – Change in the distribution of the magnetic field density of the system when the gravity force of the Earth at its surface acts on the rotor (view in the *X* axis direction based on Figure 7)

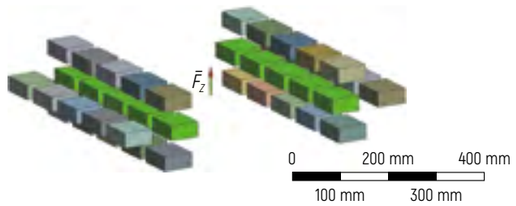

Figure 12 – Force acting in the *Z* axis direction from the stator side

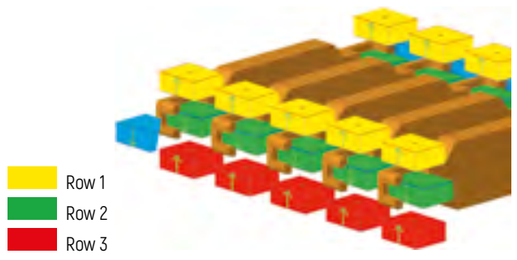

Figure 13 – Rows of rotor magnets (row 2) and stator magnets (rows 1 and 3)

Conclusions and Future Work

As a result of the conducted research and calculations, the configuration of the magnetic system was determined. It provides stabilization of the rotor relatively to the GPV body at the stage of preparation for takeoff, as well as stabilization in the horizon plane of the GPV body relatively to the rotor at the takeoff and landing stages.

The shape of the takeoff and landing overpass in the plane of the equator will differ from the ideal circle due to the terrain of the Earth's surface (Figure 16). The magnetic system stabilizes the position of the rotor relatively to the GPV body in the vertical plane during the preparation for takeoff.

At the takeoff and landing stages of the GPV, the magnetic system stabilizes the position of the GPV body in the vertical plane relatively to the rotor, and also removes the rotation of the rotor inside the channel and excludes the possibility

Figure 16 – Layout of the GPV overpass in the equator plane

of a contact of the rotor with the walls of the vacuum channels at all phases of the operational cycle. In addition, the described system does not interfere with the movement of rotor along the channels.

The next stage of research and simulation is the creation of a rotor and stator construct based on the concept of interaction of magnets proposed in this paper. In addition, an urgent task should be considered to solve the problem of the efficiency of shielding the fields of permanent magnets that affect the redistribution of the power lines of the GPV magnets.

References

1. *Unitsky, A. Peresadochnaya, kosmicheskaya, kol'tsevaya [Interchange, Cosmic, Circular] / A. Unitsky // Izobretatel' i ratsionalizator. – 1982. – No. 4. – P. 28–29.*
2. *Unitsky, A. V kosmos... na kolese [Into Space... by Wheel] / A. Unitsky // Tekhnika – molodozhi. – 1982. – No. 6. – P. 34–36.*
3. *Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – 240 p.*
4. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
5. *Unitsky, A.E. Strunnyye transportnyye sistemy: na Zemle i v Kosmose [String Transport Systems: On Earth and in Space] / A.E. Unitsky. – Gomel: Infotribo, 1995. – 337 p.: il.*
6. *Lineynyy dvigatel' [Linear Motor]: Patent RU 2,370,874 C1 / G.V. Nikitenko, V.A. Grinchenko. – Published 20.10.2009.*
7. *Sarapulov, F.N. Issledovaniye tyagovogo lineynogo asinkhronnogo dvigatelya konveyyernogo poyezda [Research on a Traction Linear Asynchronous Motor in a Conveyor Train] / F.N. Sarapulov, I.A. Smol'yanov, I.Ye. Rodionov // Elektrotekhnika. – 2018. – Vol. 5, No. 1. – P. 34–37.*
8. *Abdullayev, M. Primeneniye lineynykh dvigateley v elektroprivodakh [Application of Linear Motors in Electric Drives] / M. Abdullayev, M. Matkasimov, D. Karimzhonov // Universum: tekhnicheskiye nauki. – 2020. – No. 11 (80). – P. 12–14.*
9. *Sinyuk, K.V. Primeneniye nechotkoy logiki dlya sistem upravleniya lineynym sinkhronnym dvigatelem s postoyannymi magnitami [Application of Indistinct Logic for Control Systems of a Linear Synchronous Motor with Permanent Magnets] / K.V. Sinyuk, V.A. Anchutin // Simvol nauki. – 2018. – No. 3. – P. 21–24.*
10. *Akhatov, S.T. Issledovaniye sistemy sinkhronnoy tyagi s lineynymi dvigatelyami [Research of Synchronous Traction System with Linear Motors] / S.T. Akhatov, V.G. Solonenko, N.M. Makhmetova // Vestnik KazATK. – 2021. – Vol. 116, No. 1. – P. 89–95.*
11. *Kim, K.K. Sistemy elektrodvizheniya s ispol'zovaniyem magnitnogo podvesa i sverkhprovodimosti [Electric Propulsion Systems Using Magnetic Suspension and Superconductivity]: Monograph / K.K. Kim. – Saratov: IPR Media, 2019. – 351 p.*
12. *Penkin, V.T. Sinkhronnyye elektricheskiye mashiny s kompozitnymi i ob"yomnymi sverkhprovodnikami v rotore dlya transportnykh sistem [Synchronous Electric Machines with Composite and Bulk Superconductors in the Rotor for Transport Systems] / V.T. Penkin, K.L. Kovalov. – Moscow: MAI, 2018. – 216 p.*
13. *Martynenko, Yu.G. O problemakh levitatsii tel v silovykh polyakh [On the Problems of Bodies Levitation in Force Fields] / Yu.G. Martynenko // Sorosovskiy obrazovatel'nyy zhurnal. – 1996. – No. 3. – P. 82–86.*

Justification for the Possibility of Hydrogen Use as a Refrigerant in Hypervelocity Vehicles

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UDC 62-6

The study considers the method of heat accumulation during the operation of hypervelocity vehicles (HV) in a rarefied medium and vacuum. We present the justification for creating an active thermal protection unit (heat regenerator) and the choice of a refrigerant in terms of its weight and specific cost. The paper suggests a methodology on how to calculate the cost of different types of refrigerants depending on the modes of the HV operation. We analyze the use of hydrogen as a refrigerant and also outline the way to improve the design of the hydrogen heat regenerator and the possibilities of its application with the HV.

Keywords: *evaluation measure, heat regenerator, hydrogen, hypervelocity vehicle (HV), refrigerant, transport, vacuum, weight.*

Introduction

With the technological advancement, all processes in today's world are becoming more rapid. The speed of movement of people and goods is no exception. Global transport companies regularly offer innovations with improved performance, which solve the problem of speed and profitability of transportation [1, 2], and therefore, improve the level and quality of life, contribute to economic development. Currently, the increase in the speed of vehicles is considered both in the context of urban transportation systems [3] and in intercity and interregional rail and motor traffic [1, 4, 5].

One of the solutions to increase the speed of ground transport is the creation of hypervelocity transport complexes that provide for the movement of vehicles in a rarefied medium in airtight tunnels. This approach enables to reduce the resistance of the environment to motion and to minimize the power used by engines, as well as the overall energy consumption.

Traditional vehicle cooling systems rely on the transfer of thermal energy from a heat source (engine, electrical equipment, human, etc.) to the radiator to dissipate it through blowing by the ram air flow. If there is no sufficient amount of ram air (for example, when the vehicle moves in highly rarefied gaseous medium) the process of heat transfer by convective method to the external environment gets complicated. When the vehicle moves in a complete vacuum (particularly in space), this process becomes impossible. The complex dependence of the amount of dissipated energy on the environmental parameters and the vehicle's speed does not allow a high degree of accuracy to assess the performance of the convective cooling system of vehicles running at different speeds on Earth and in space. The hypervelocity vehicle (HV) also operates in such difficult conditions at speeds above 1,000 km/h. Consequently, it is inefficient to use convective cooling systems; here we should consider other ways of heat abstraction (for example, by its radiation or autonomous conversion into another type of energy). As an option to cool the vehicle in a rarefied medium, we propose a device of on-board heat converters and the possibility to recharge them at the terminal stations.

Justification for the Use of Hydrogen as a Refrigerant

Any moving vehicle generates heat; its amount depends on the efficiency of the systems engaged, as well as on the drag forces that need to be overcome. Increasing the efficiency and reducing the resistance to motion is one of the ways to solve the problem of heat while the vehicle is running.

During the operation of a ground vehicle, a considerable share of the engine power is spent on overcoming the aerodynamic resistance of the air environment and the wheel rolling resistance. It is possible to improve the movement profitability of a vehicle by reducing these parameters. In some cases, resistance to movement is reduced by magnetic levitation [6, 7]. This method allows to elevate the vehicle above the roadway through the electromagnetic field. Another positive effect of this technology is a low noise level in motion. The downside is high capital and operating costs [8, 9], as well as insufficient efficiency of electromagnetic levitation systems (lower than that of a steel wheel).

Another way to cut the energy and cost of travel is to reduce the drag by depressurizing the medium. The essence of this concept is that the vehicle is placed in a pipe, from which air is pumped out to the desired value of rarefaction. The described approach is often combined with magnetic levitation [10]. In addition, there are other theories about the transport drive method in a rarefied medium: the air collected in front of the frontal part of the vehicle after being compressed in the compressor is fed under the lower part of the vehicle body to center it and avoid touching the tunnel walls [11].

Studying this aspect, we should pay attention to the experience of the HV development, see the invention in [12], where the above-mentioned problems are solved. The HV is meant to be a passenger or cargo wheeled vehicle moving on a track structure, which is located in the tunnel, made as a sealed pipe and filled with hydrogen under reduced pressure.

When designing the HV, there are a great number of issues that have not previously appeared in the context of transport complexes. In particular, when a vehicle moves in a rarefied medium, it is inevitable that there are difficulties with the abstraction of heat from the engine, power source, ventilation and air conditioning system of the cabin (heat emissions from passengers and on-board systems).

The simplest and most popular method of cooling technical devices is self-ventilation. This means that cooling occurs due to the ram air flow and its intensity is practically unregulated. It is possible to increase the intensity through forced air cooling – by installing another fan [13]. In rarefied medium conditions, such method is ineffective, because the density of the medium decreases in proportion to the pressure, and, accordingly, the amount of absorbed heat with the same parameters goes down. Although the tunnel is filled with hydrogen [12], which has a value of thermal conductivity coefficient much higher than air, it is necessary to cool the tunnel itself to prevent the medium from overheating.

To reduce the size of the cooling system for the same thermal capacity, it is possible to use liquid cooling, which is a conventional radiator system, the heat from which should also be abstracted to the environment [14], which is not applicable in these conditions. There are additional requirements for the heat abstraction system for a vehicle moving in a vacuum: the minimum possible weight and volume of the system, which affect the weight and volume of the vehicle itself.

Since in a rarefied medium there is no possibility to abstract the heat to the environment, we propose to arrange on board a cold accumulator with a capacity sufficient to absorb the heat, which is released during a trip between the terminal stations. The laws of thermodynamics say that a substance is able to absorb the maximum amount of heat during phase transition (evaporation and melting). It is worth considering this statement when developing evaporative or fusion cooling systems, which exhibit the highest effectiveness with the maximum compactness of the system [15].

Note also that in some systems the pre-treatment of the fuel mixture (to improve the efficiency of the engines) is associated with the accumulation of excess energy, i.e., useful energy is taken from the heat to be abstracted. Thus, there are trucks that use liquefied nitrogen or liquefied air as their source of energy. These substances pre-vaporize, absorb a certain amount of heat, and then are sent to the piston engine and drive the vehicle with better efficiency. This means that the same substance is used not only to drive the vehicle, but also to cool the engine, on-board systems and refrigerated compartment (for special-purpose vehicles) [16, 17].

Besides, this approach is described in the concept of cooling a capsule moving in a magnetic levitation tunnel (Hyperloop Alpha project [18–20]), where helium cooled to –269 °C is used (it is transported on board in a liquid state). Based on the Hyperloop concept, the air fed under the capsule after being compressed in the compressor is cooled with water during a phase transition. The resulting water vapor is stored on board the vehicle until the end of the trip, after which the vehicle is refueled. Solid phase transition batteries, namely ice batteries, which are widely used in the food industry, and most often in the dairy industry, are popular for solving certain problems [21]. In such batteries it is possible to use not only ice, but also other refrigerants: freons, water solutions of glycols and of salts.

Attention should be paid to the creation of the cooling system in aircrafts [22]. In particular, forced cooling is proposed, the so-called active thermal protection systems. In [22], hydrogen is firstly used as a refrigerant (it is directly heated in a cooling jacket or cools a liquid-metal coolant individually), and then sent in heated form to do useful work to an electric turbo-generator and rocket engine. However, the above study does not focus on the pre-heating state of hydrogen. From the viewpoint of the effectiveness of the refrigerant application by weight, it is more reasonable to use hydrogen for heating in the liquid state. Solution of safety problems is the second phase in the development of this direction, which can be the topic of the next study.

Based on the above, it is important to consider the cooling system of a vehicle not as a simple means to accumulate cold, but as a more complex process of heat exchange, involving not only the accumulation of heat, but also combining its conversion and further use for the HV.

The energy source of the HV movement through a tunnel can be an electrical energy storage (power batteries), a contact network or a hydrogen fuel cell (FC) that generates the energy to be consumed immediately on board the vehicle [12] (Figure 1).

When moving in a vacuum, it is not possible to abstract heat to the external medium; therefore, the vehicle must have

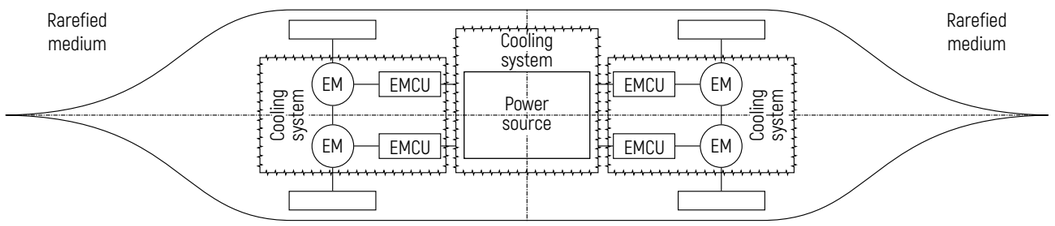

Figure 1 – Diagram of the HV power plant:
EM – electric motor; EMCU – electric motor control unit

an energy storage device capable of absorbing all the heat released during the trip. This paper considers the following substances as refrigerants: ice, liquefied hydrogen and liquefied oxygen. We also describe the "liquefied hydrogen – liquefied oxygen" system in the ratio of consumption, which ensures continuous operation of the hydrogen FC that produces water as the by-product. Ice is chosen as a refrigerant that has been widely and long used for similar applications. Once evaporated and heated to the operating temperature, the hydrogen can be discharged into the tunnel, which assumes a hydrogen environment with lowered pressure; the excess hydrogen will be continuously pumped out by pumps designed to maintain the desired pressure. In the "hydrogen – oxygen" system, two refrigerants after evaporation and heating to the operating temperature are used in the hydrogen FC, which utilizes water as the additional substance during its operation.

The amount of heat absorbed by hydrogen and oxygen was considered when they are heated to the resultant temperature of 37 °C, which allows engaging them further to power the FC. The resultant temperature of molten ice heating is 55 °C, because water is used only for heat absorption and there are thermal energy sources with a temperature of about 77 °C on board the vehicle. Initial values of parameters for each substance differ, which also determines the complexity and energy consumption in obtaining the required indicators of the refrigerant before loading that battery into the vehicle. For hydrogen the reference point is the state of saturated liquid with a temperature of about –253 °C; for oxygen – the state of saturated liquid at –183 °C; for ice two variants are possible: non-melting ice at 0 °C (0 °C ice) and supercooled ice at –100 °C (–100 °C ice).

The heat absorbed by the cold accumulator is taken up by the refrigerants in many processes, which should also be separated physically by installing several heat regenerators. Thus, the temperature of the working body of the cooling system in them will be different, which will allow obtaining cold of different temperature levels for any system.

When the 0 °C ice is involved, the heat is first consumed to convert the entire weight to a liquid state, and then to heat it up. An accumulator with supercooled ice will additionally include a heating stage of ice from –100 °C to the melting temperature. If liquefied hydrogen is used, the heat will be absorbed during its evaporation, and then during heating of gaseous hydrogen to the operating temperature. The case is similar with liquefied oxygen, which will require two heat regenerators. The most complicated and massive system is the "liquefied hydrogen – liquefied oxygen" system, which requires two separate sets of equipment for parallel operation of hydrogen and oxygen, since their further use in the FC is assumed (Figure 2).

This paper compares refrigerants through the theoretical analysis of the effectiveness of particular refrigerants by calculating the amount of heat absorbed and processing of the data obtained. The calculations were made taking into account the temperature dependence of the thermophysical properties of substances based on [23].

Figure 3 shows the dependence of the heat absorbed by each refrigerant on temperature. The amount of absorbed heat is given per 1 kg of substance; in case of the "liquefied hydrogen – liquefied oxygen" system – per 1 kg of water obtained from a reaction in the FC.

For the given resultant temperatures, 1 kg of hydrogen can absorb the greatest amount of heat – 4,150 kJ; pure oxygen (for comparison) – 415 kJ; the "hydrogen – oxygen" system – 830 kJ; the –100 °C ice and the 0 °C ice will absorb 709 kJ and 570 kJ, respectively (the difference in the amount of energy is due to heating ice from –100 °C to 0 °C) (Figure 3).

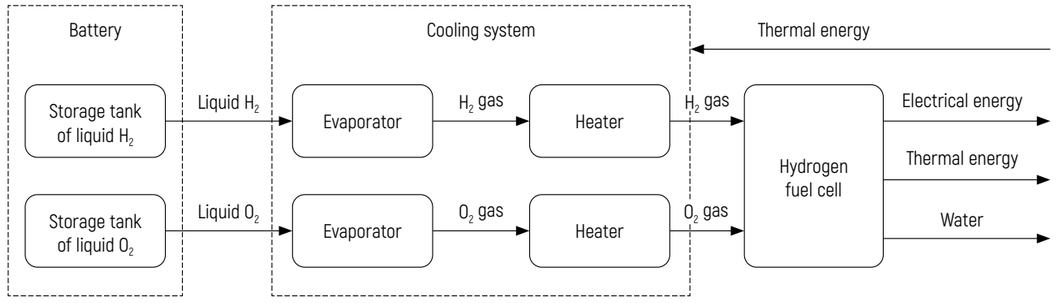

Figure 2 – Diagram of the use of hydrogen and oxygen as a refrigerant and energy sources on board the HV

That is, one of the most efficient refrigerants (with their equal weight) is liquefied hydrogen, which absorbs five times more heat than the second most efficient system based on hydrogen and oxygen. The least amount of heat among the proposed options is absorbed by oxygen upon its evaporation and heating up to 36.85 °C.

Heat emission generators in the HV are a power plant consisting of an energy source and an electric motor, as well as an air conditioning system, the capacity of which is determined by the heat emissions from passengers and on-board electronics. Both an electric battery and hydrogen FC can be used as the energy source (as per the patent [12]).

Consider, for example, the HV with travel time between the endpoints of 30 min. The vehicle is designed for six passengers, the mechanical power of the engine is 100 kW, and the mechanical efficiency of the engine is 90 %. Electrical energy is supplied to the engine from the FC, which has an electrical efficiency of 40 %. The power of heat emission by one passenger at rest is 0.1 kW. The heat emission capacity of the on-board electronics is 1 % of the FC electrical energy. The diagram of the HV heat flows and their estimated capacity are shown in Figure 4.

For the case in question, the heat flow capacity is 179.5 kW; the amount of energy to be accumulated during

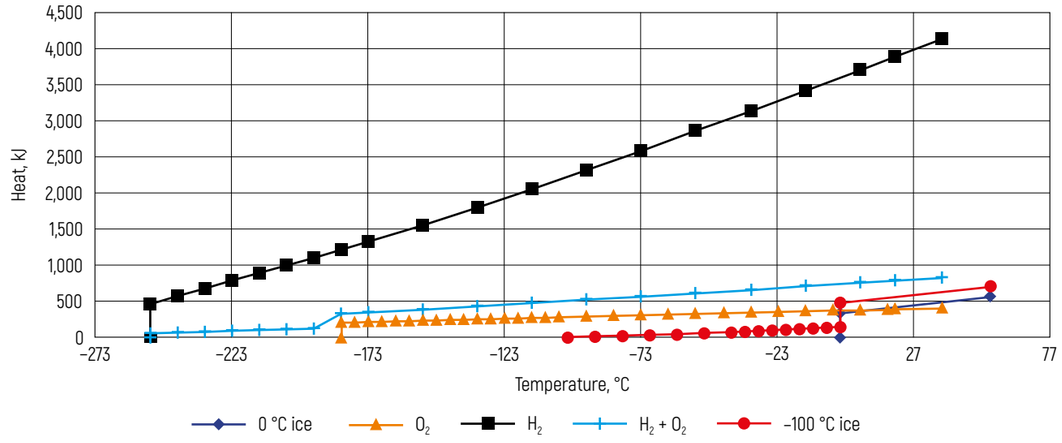

Figure 3 – Dependence of heat absorbed by the refrigerant on temperature

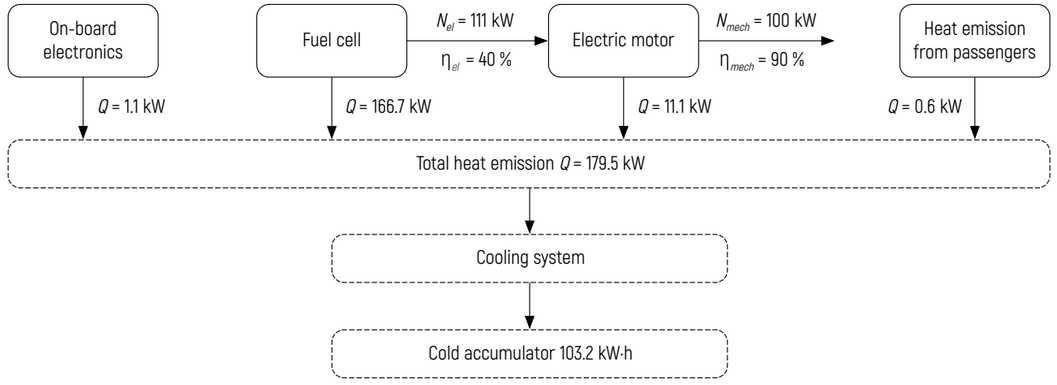

Figure 4 – Flows of excess thermal energy of the HV and their estimated capacity

the vehicle's movement: 179.5 × 1.15 × 0.5 = 103.2 kW·h, or 371.52 MJ (1.15 is a factor to account for capacity reserve).

Next, we will compare the given refrigerants by the weight of the substance, as well as by the cost of refueling per trip. The weight of the system is an important factor, since with a significant increase in the vehicle weight, the engine power rises, and, accordingly, heat emission does too.

The heat recovery system must provide complete absorption of the heat released by other systems. The heat balance equation can be represented as follows:

$$1{,}15Q_{abstr} = Q_{ref}, \quad (1)$$

where Q_{abstr} – heat to be abstracted from the power plant and the air conditioning system, kJ;

Q_{ref} – design heat for recovery by refrigerant, kJ.

The amount of refrigerant is calculated depending on the process in which the latter absorbs heat: heating or phase transition.

When heating, the refrigerant flow rate G (kg/s) depends on the temperature difference at the beginning and the end of the process Δt and on the heat capacity of the substance at the given temperatures c_p:

$$G = \frac{Q_{ref}}{c_p \Delta t}. \quad (2)$$

When a substance in the heat absorption process changes from one physical state to another, its amount will depend on the heat of phase transition r, which is an individual property of the substance and is determined by pressure:

$$G = \frac{Q_{ref}}{r}. \quad (3)$$

For the case with supercooled ice, when it is first heated with a temperature change to Δt^i, then the resulting water melts and is heated with a temperature difference Δt^w, the formula will look as follows:

$$G = \frac{Q_{ref}}{c_p^i \Delta t^i + r + c_p^w \Delta t^w}, \quad (4)$$

where c_p^i – weight isobaric heat capacity of ice, kJ/(kg·°C);

c_p^w – weight isobaric heat capacity of water, kJ/(kg·°C).

The above formulas show that in order to increase the effectiveness of the cooling system the refrigerant with the highest heat capacity must be selected.

Table outlines the specific production cost of 1 kg of refrigerant [23–25] in an evaluation measure (em), which at the first stage can be equated to one euro.

Table – Specific production cost of refrigerants

Refrigerant	Specific cost C, em/kg	Note
0 °C ice, C_1	0.13	
Liquefied oxygen, C_2	0.5	
Liquefied hydrogen, C_3	5.4	
Hydrogen + oxygen, C_4	1	$C_4 = 0.11C_3 + 0.89C_2$
–100 °C ice, C_5	0.19	

Refrigerant cost per trip $C_{p.t.}$ (em) to accumulate the released energy will be determined by the following dependence:

$$C_{p.t.} = GTC, \quad (5)$$

where T – trip time, s;

C – specific cost of the refrigerant with the required parameters, em/kg.

Figure 5 illustrates the results of calculations based on the dependence (5) of the amount of refrigerant to fill the battery for one 30-minute trip and the cost of this amount of the refrigerant with the parameters considered.

The smallest weight of refrigerant is required in the case of liquefied hydrogen, which is 90 kg for the given conditions (Figure 5). In the case of liquefied oxygen, the maximum required weight of refrigerant is 10 times more. In terms of the cost, the most favorable variant is the 0 °C ice: 87 em per trip. It is followed by the –100 °C ice with 99 em. The highest cost is in the case of liquefied hydrogen, which is 483 em.

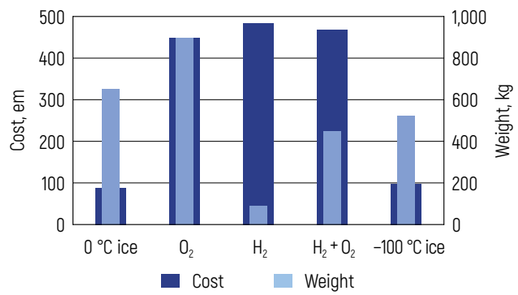

Figure 5 – Cost and weight of the refrigerants in the battery per one HV trip

For the parameters of the vehicle described above, the amount of electrical energy consumption per trip will be 55.6 kW·h, and the amount of heat to be accumulated (taking into account the capacity reserve factor) – 103.2 kW·h. Figure 6 shows the specific cost of refrigerants per 1 kW·h of electrical energy consumption per trip, when using the hydrogen FC as a power source.

Figure 6 demonstrates that the 0 °C ice is the most cost-effective refrigerant, while liquefied hydrogen is the least cost-effective option (with corresponding specific costs of 1.6 and 8.7 em/kW·h). However, if we consider the systems where the refrigerant weight is an important parameter (space rockets, HV, etc.), the use of hydrogen is already considered to be the most effective way of cooling. Furthermore, the cost of refrigerant depends on many factors and can change with time, what can not be said about its weight.

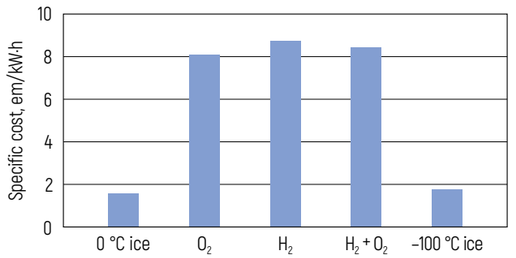

Figure 6 – Specific cost of the refrigerants per 1 kW·h of electrical energy consumption per one HV trip

To implement the model for the use of liquid hydrogen for heat recovery, we propose to choose the diagram shown in Figure 7. The hydrogen boiling process happens directly in the Dewar vessels, which are essential for the transportation of liquid hydrogen. This solution will allow to increase safety and optimize labor intensity of handling liquid hydrogen. An enclosed circuit with the refrigerant with a transition temperature to the solid phase below the temperature of liquid hydrogen (helium can be used as a refrigerant) ensures flow circulation and heat input for boiling exactly into the Dewar vessel. The level of liquid hydrogen declines as it boils and the working part of the liquid immersion circuit decreases. To maintain the required volume of recovered heat, we suggest changing the capacity of the pump that circulates the refrigerant through the enclosed circuit.

It is possible to connect to this heat exchange circuit secondary circuits with heated air streams or circuits of other

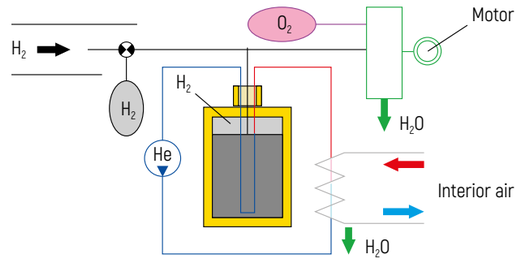

Figure 7 – Working diagram of the hydrogen heat converter

refrigerants from the vehicle interior, engines or other elements that require cooling. The use of secondary circuits will allow the effective treatment of the refrigerants circulating in them (for example, to separate the water contained in the cooled air, which could clog the secondary circuit if it freezes).

The gaseous hydrogen obtained by boiling in the Dewar vessel flows into the hydrogen FC power system, which can be fed with gaseous hydrogen from a separate tank or trunk designed for the vehicle. This solution contributes to power generation regardless of the presence of hydrogen gas in the medium where the HV is moving or the amount of emitted gas in the Dewar vessel.

Conclusions and Future Work

This paper is the first part of an extensive study of heat recovery effectiveness based on the thermophysical properties of substances used as refrigerants. In terms of the minimum refrigerant weight, the optimal substance is liquefied hydrogen.

To make a complete assessment of the use of liquid hydrogen as a refrigerant you should apply a comprehensive approach and consider other aspects: the volume occupied by the heat regenerator; the complexity of the equipment; the cost of the system when working with a particular coolant to ensure reliability and safety; the labor intensity of equipment replacement; requirements for safe operation and qualification of the service personnel. Besides, there is another important point – it is possible to implement the considered method of cold recovery with the existing vehicles. The method proposed in this study allows to do so.

When using liquefied hydrogen, the specific volume of waste (gaseous) and loaded (liquid) hydrogen also changes considerably. A distinctive positive effect when using

hydrogen is a reduction in the weight of not only the refrigerant, but also the entire vehicle. When hydrogen gas is discharged into the tunnel, it is unavoidable that negative consequences arise – an increase in the power of the pumps that maintain the vacuum in the tunnel. For this reason, the discharge of excess hydrogen is undesirable.

This study focuses on the analysis of steady rectilinear movement, i.e., the movement of the vehicle with unchanged power. During acceleration and deceleration, the ratio of electrical energy consumed and thermal energy released will change as compared to a steady movement. Therefore, in the future, it is also necessary to calculate the thermal balance when the vehicle moves in the acceleration and braking sections, which can be another objective for the next research in this direction.

References

1. *Shchitov, S.V. Optimizatsiya energeticheskikh zatrat transportnogo sredstva po skorosti dvizheniya / S.V. Shchitov, Z.F. Krivutsa, Ye.Ye. Kuznetsov // Aktual'nyye voprosy energetiki v APK: Proceedings of the All-Russian International Scientific and Practical Conference, Blagoveshchensk, Feb. 19, 2020 / Far Eastern State Agrarian University. – Blagoveshchensk: Dal'nevostochnyy GAU, 2020. – P. 97–102.*
2. *Yegorov, R.N. Optimizatsiya skorosti v transportnykh protsessakh [Optimization of Speed in Transport Processes] / R.N. Yegorov // Mezhdunarodnyy tekhniko-ekonomicheskiy zhurnal. – 2009. – No. 4. – P. 65–67.*
3. *Basharkin, M.V. Skorostnoy tramvay kak element modernizatsii transportnoy sistemy Samary [Rapid Streetcar as an Element of the Modernization of Samara Transport System] / M.V. Basharkin, A.A. Ionov, S.A. Okladov // Nauka i obrazovaniye transportu. – 2016. – No. 1. – P. 237–240.*
4. *Chechenova, L.M. Perspektivy razvitiya skorostnogo zheleznodorozhnogo transporta [Prospects for the Development of Rapid Rail Transport] / L.M. Chechenova, Yu.V. Yegorov, N.V. Volykhina // Transportnyye sistemy i tekhnologii. – 2019. – Vol. 5, No. 3. – P. 26–35.*
5. *Podverbnyy, V.A. Proyektirovaniye skorostnogo passazhirskogo rel'sovogo transporta Irkutskoy aglomeratsii [Design of Rapid Passenger Rail Transport in the Irkutsk Agglomeration] / V.A. Podverbnyy, V.V. Kazarina, O.V. Podverbnaya // Proyektirovaniye razvitiya regional'noy seti zheleznykh dorog. – 2016. – No. 4. – P. 308–326.*
6. *Mussakayev, O.P. Primeneniye tekhnologii magnitnoy levitatsii na transporte [Application of Magnetic Levitation Technology in Transport] / O.P. Mussakayev, V.K. Chikalina // Sovremennyye tekhnologii i nauchno-tekhnicheskiy progress. – 2020. – Vol. 1, No. 7. – P. 173–174.*
7. *Sivko, Yu.D. Magnitnyye materialy. Levitatsiya. Maglev [Magnetic Materials. Levitation. Maglev] / Yu.D. Sivko, A.P. Ivanova // Molodozhnaya nauka v XXI veke: traditsii, innovatsii, vektory razvitiya: Proceedings of the All-Russian Scientific and Research Conference, Orenburg, Apr. 25, 2019 / Orenburg Institute of Railway Communications – Branch of Samara State University of Railway Communications. – Rostov-on-Don: Yuzhnyy Universitet (IUBiP), 2019. – P. 41–43.*
8. *Tekhnologii [Technologies] [Electronic resource] // Unitsky String Technologies Inc. – Mode of access: https://unitsky.com/technologies?lang=ru. – Date of access: 15.12.2021.*
9. *Dmitriyev, A.I. Transportnyye sistemy na osnove magnitnoy levitatsii: tekhnologiya, ekonomika, bezopasnost' [Magnetic Levitation Transport Systems: Technology, Economics, Safety] / A.I. Dmitriyev // Transportnoye pravo i bezopasnost'. – 2016. – No. 8 (8). – P. 24.*
10. *Lapidus, B.M. Magnitnaya levitatsiya – fundamental'naya osnova dlya sverkhskorostnykh vakuumno-levitatsionnykh transportnykh tekhnologiy [Magnetic Levitation as the Fundamental Basis for Super High-Speed Vacuum-Levitation Transport Technologies] / B.M. Lapidus // Transportnyye sistemy i tekhnologii. – 2018. – Vol. 4, No. 3. – P. 26–35.*
11. *Dudnikov, E.E. Advantages of a New Hyperloop Transport Technology / E.E. Dudnikov // Management of Large-Scale System Development (MLSD): Proceedings of the 10th International Conference, Moscow, Oct. 2–4, 2017 / V.A. Trapeznikov Institute of Control Sciences of Russian Academy of Sciences. – IEEE, 2017. – P. 1–4.*
12. *Giperskorostnoy transportnyy kompleks [Hypervelocity Transport Complex]: Patent BY 037,983 / A.E. Unitsky. – Published 18.06.2021.*
13. *Skvortsov, D.V. Klassifikatsiya vidov okhlazhdeniya elektricheskikh mashin [Classification of Types of Cooling in Electrical Machine] / D.V. Skvortsov, A.G. Mikhaylov, S.S. Plotnikov // Vestnik sovremennykh issledovaniy. – 2016. – No. 2–1 (2). – P. 144–148.*
14. *K voprosu o sistemakh okhlazhdeniya blokov energeticheskikh silovykh ustanovok transportnykh sredstv [On Cooling Systems of Power Units of Vehicles] / V.D. Chervenchuk [et al.] // Innovatsionnyye tekhnologii v APK kak faktor razvitiya nauki v sovremennykh usloviyakh: Collection of All-Russian (National) Scientific and Practical Conference, Omsk, Nov. 29, 2019 / Omsk State Agrarian University named after P.A. Stolypin. – Omsk: Omskiy GAU, 2019. – P. 452–456.*
15. *Garyayev, A.B. Povysheniye nadozhnosti raboty sistem okhlazhdeniya energeticheskogo oborudovaniya putom ustanovki oroshayushchikh ustroystv [Improvement of Reliability of Power Equipment Cooling Systems by Installing Irrigation Devices] / A.B. Garyayev, A.M. Televnyy, O.Ye. Prun // Nadozhnost' i bezopasnost' energetiki. – 2017. – No. 2 (13). – P. 60–62.*
16. *Dearman: Technology Firm Drives a Cold and Power Revolution [Electronic resource]. – Mode of access: https://gov.uk/government/case-studies/dearman-technology-firm-drives-a-cold-and-power-revolution. – Date of access: 02.08.2022.*
17. *Tafonea, A. Integrating an Oxygen Enriched Waste to Energy Plant with Cryogenic Engines and Air Separation Unit: Technical, Economic and Environmental Analysis / A. Tafonea, F.D. Magroa, A. Romagnoli // Applied Energy. – 2018. – No. 231. – P. 423–432.*
18. *Prodan, G. How to Make Quick Changeovers and Storage Optimization / G. Prodan // Science and Society: Collection of Scientific Articles / ed. S.I. Drobyazko. – Namur: Fadette Editions, 2020. – P. 53–58.*
19. *Motwani, S. Experiencing Hyperloops: The Transit of the Future / S. Motwani, A. Gupta // Computer. – 2021. – Vol. 54, No. 7. – P. 37–45.*
20. *Hyperloop Alpha [Electronic resource]. – Mode of access: https://www.tesla.com/sites/default/files/blog_images/hyperloop-alpha.pdf. – Date of access: 02.08.2022.*
21. *Glukhov, Ye.I. Primeneniye l'doakkumulyatora na primere okhlazhdeniya moloka [Application of Ice Accumulator on the Example of Milk Cooling] / Ye.I. Glukhov // Pishchevyye innovatsii i biotekhnologii: Collection of Theses of the IX International Scientific Conference of Students, Graduate Students and Young Scientists as Part of the III International Symposium "Innovations in Food Biotechnology", Kemerovo, May 17–19, 2021 / Kemerovo State University; ed. A.Yu. Prosekov. – Kemerovo: KemGU, 2021 – P. 92–93.*
22. *Moisheyev, I.M. Konturnost' sistemy prinuditel'nogo okhlazhdeniya vodorodom [Circuitry of Hydrogen Forced Cooling System] / I.M. Moisheyev // Teplofizika vysokikh temperatur. – 1974. – Vol. 12, No. 6. – P. 1257–1266.*
23. *Vargaftik, N.B. Spravochnik po teplofizicheskim svojstvam gazov i zhidkostey [Handbook of Thermophysical Properties of Gases and Liquids] / N.B. Vargaftik. – 2nd ed. – Moscow: Nauka, 1972. – 721 p.*
24. *Large-Scale Production and Transport of Hydrogen from Norway to Europe and Japan: Value Chain Analysis and Comparison of Liquid Hydrogen and Ammonia as Energy Carriers / Y. Ishimoto [et al.] // International Journal of Hydrogen Energy. – 2020. – Vol. 45, iss. 58. – P. 32865–32883.*
25. *Price of Breathing. Medical Oxygen Procurement for Hospitals [Electronic resource]. – Mode of access: https://ti-ukraine.org/en/blogs/price-of-breathing-medical-oxygen-procurement-for-hospitals. – Date of access: 02.03.2022.*

Development of the Concept on an Intelligent System of Continuous Remote Diagnostics of the Technical Condition of the Track Structures at the Equatorial Overpass of the General Planetary Vehicle

UDC 624.21.037:620.179.1

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The launching overpass of the General Planetary Vehicle (GPV), located along the equator, is a take-off and landing, energy, infrastructure and communication structure of the overpass type, which is intended for geospace transportation. The GPV overpass is a complex engineering structure that is difficult to access by inspections using traditional technology. In this regard, the use of a system for continuous monitoring of the technical condition of the main elements at the heavy-duty engineering facility in question seems relevant. This paper proposes the concept of an intelligent system for continuous remote diagnostics of the technical condition of the track structures of the equatorial overpass, based on the use of acoustic emission methods and distributed acoustic sounding, which allow to quickly and accurately diagnose defects in linear objects of great length.

Keywords: *acoustic emission, diagnostics, distributed acoustic sounding, General Planetary Vehicle (GPV), non-destructive testing, track structure.*

Introduction

One of the most important tasks in the operation of complex loaded critical technical heavy-duty facilities, which include the overpass of the General Planetary Vehicle (GPV) [1], is to ensure safety. In general, the strength of the elements of such structures and their service life are specified at the development and design stages. However, the impact of alternating loads, highly corrosive environment, temperature fluctuations and other operational factors, as well as the presence of technological or operational defects in the material significantly reduce the service life.

To prevent the transition of the structure to the limit state, which has arisen for the above reasons, it is necessary to carry out non-destructive testing (NDT), and preferably in real time.

Traditional methods and means of flaw detection are aimed at identifying existing defects. At the same time, the most important characteristic of the technical capabilities of NDT methods is sensitivity, which is determined by the smallest sizes of detectable defects:

- for surface defects – the width of the opening at the exit to the surface, the extension into the depth of the material and along the surface of the part;
- for volumetric defects – the size of the defect with an indication of the depth of occurrence.

Comparative data on the sensitivity of some NDT methods are given in Table 1 [2–4].

Acoustic NDT methods are divided into two groups – active and passive. Active methods are based on radiation, reception and analysis of elastic vibrations (acoustic waves), passive methods are based only on the reception and analysis of waves that arise during the formation of a defect, the source of which is the controlled object itself.

According to GOST 18353-79 [5] passive acoustic methods include:

- acoustic emission (AE) method, which makes it possible to detect incipient defects and predict the residual life of parts that have reached their standard service life;
- vibration method, which analyzes the vibration parameters of any individual part or assembly (rotor, bearings, etc.) using contact-type receivers;
- noise diagnostic method that studies the noise spectrum of a working mechanism using microphone receivers.

A typical example of an active method is ultrasonic testing. As a type of NDT, it combines a number of directions, the main of which use the echo method, shadow, mirror, time of flight diffraction (TOFD), phased array method, ultrasonic thickness measurement, etc. These control methods are aimed at searching for localized formed defects, however, they are not capable of detecting defects less than a quarter of the ultrasonic wave length in the controlled material, i.e., less than 2–5 mm [6]. At the same time, information about the defect obtained by active methods does not contain information about the dynamics of its development. In addition, using these methods, it is difficult to carry out continuous monitoring of the technical condition of the object simultaneously throughout its entire length, which is especially important for extended linear objects, that the track structures of the GPV overpass are.

Table 1 – Sensitivity of some NDT methods

Method	Minimum sizes of detected discontinuities, μm		
	Opening width	Depth	Length
Visual-optical	5–100	10–30	100
Capillary:			
• color	1–2	10–30	100–300
• luminescent	1–2	10–50	100–300
Magnetic particle	1	150–200	30
Eddy current	0.5–1	–	600–2,000
Ultrasonic	1–30	2–3 % of product thickness	–
Radiographic	100	1.5–3 % of product thickness	–

During the operation of the object, fatigue damage accumulates in the material, which at the initial stage of development cannot be promptly detected by the technical means of the main NDT methods given in Table 1. The issue of the safe operation of such elements can only be solved using NDT tools that are sensitive to developing defects. Therefore, the task of identifying growing cracks, including those at the initial stage of development, seems to be especially relevant.

In solving this problem, an integral inspection method based on the phenomenon of acoustic emission has proven itself well; it detects and registers cracks that are in the initial stage of occurrence or are capable of developing under the action of a mechanical load, and is highly sensitive to the growth of defects (troubleshoots an increase in a crack by 1–10 μm).

Another alternative direction used to monitor the technical condition of the rails of the GPV overpass track structures is the method of distributed acoustic sounding (DAS). This method is implemented using optical fiber laid along each track. The movement of vehicles causes acoustic vibration of the cable, while surface and deep defects of the interacting "wheel – rail" system lead to a change in the reflection of the signal, which is recorded by a photodetector. Thus, it is possible to record the magnitude of the acoustic impact constantly and continuously, and therefore to monitor the technical condition of the rails throughout the line.

The place of impact on the fiber is determined by the reflectometer by the difference of reflectograms. The location of moving objects is monitored with an accuracy of 1–2 m at a distance of up to 40 km from the reflectometer and the central processor. In addition, their speed, acceleration and location are recorded for the interval control system.

Continuous analysis of diagnostic information generated on the basis of acoustic signals perceived by sensitive elements (sensors) throughout the GPV equatorial overpass, makes it possible for the technical condition monitoring system to objectively assess the danger of processes occurring in a deformable material and predict the destructive load and residual life of individual structural elements and of the entire structure, as well as to quickly manage traffic. This makes it possible to consider the track structure of the GPV overpass as an intelligent device that collects information about its condition through the control system and evaluates it in real time, thus ensuring the necessary and sufficient level of safe operation. Modern computer equipment, software, network and wireless communication technologies make continuous remote access to diagnostic information real, which contributes to the analysis and generalization of the data obtained both within the local areas situated in the most unfavorable conditions, and on the scale of the entire equatorial GPV overpass.

Using the Acoustic Emission Method

The physical essence of the AE method consists in the registration by piezoelectric transducers (sensors) installed on the surface of the structure of discrete unloading waves caused by the structural rearrangement of the material during its deformation and local destruction (plastic deformation, spasmodic crack development, etc.). The AE source changes the dynamic field of forces (or stresses). The propagation of an acoustic wave in a structure is affected by the interaction of the wave with the microstructure of the material, inhomogeneities, and the loading condition of the monitored object (MO). Such structural changes occur as a result of internally generated or externally applied mechanical/thermal stresses. Non-developing defects do not emit AE signals, therefore, the structural material must be loaded to stresses sufficient to propagate a crack [7].

The electrical signals received from the sensor that have passed through amplification, enter the measuring channel of the diagnostic intelligent AE system, where they are filtered, their power is increased and the signal is converted from analog to digital form for subsequent input into the computer of the intelligent monitoring and control system (IMCS) (Figure 1).

The advantages of the AE method are that, on the one hand, it does not require an external excitation source to obtain data on the state of the MO, on the other hand, it allows obtaining information about defects at a considerable distance from them. The development of defects serves as a source of acoustic waves that propagate in the material over considerable distances, and their detection by several sensors makes it possible to accurately determine the location of the hazardous area [8]. In addition, the AE method provides for:

- integrity, i.e., the possibility of monitoring the object as a whole by installing the required number of transducers on its surface;
- high sensitivity. According to the calculated estimates, the ultimate sensitivity of the AE equipment is $\approx 10^{-6}$ mm^2, making it possible to detect cracks with a length of ≥1 μm.

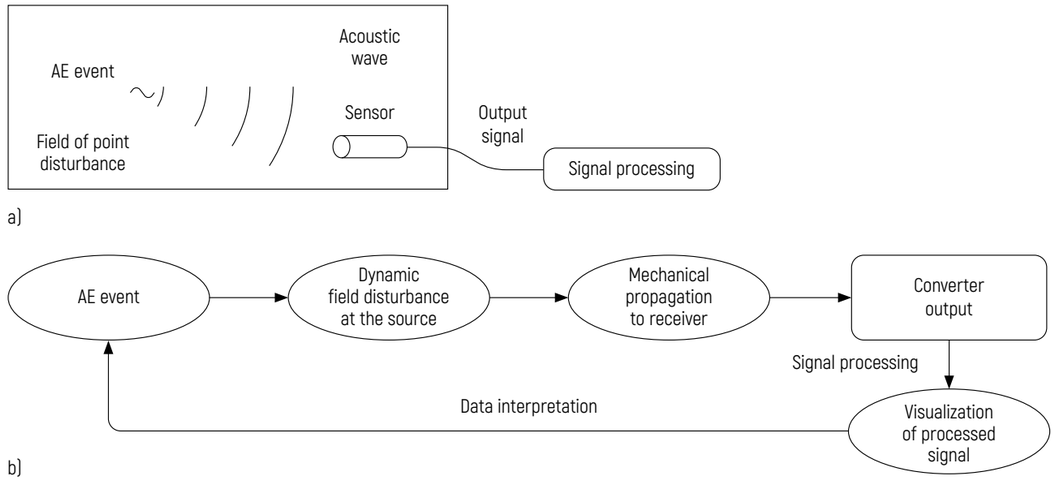


Figure 1 – AE signal analysis circuit: a – schematic diagram; b – general algorithm of functioning

In real conditions, the noise level is higher than in the laboratory, which leads to a decrease in sensitivity. At the same time, in practice, the AE method makes it possible to detect a crack increment of the order of tenths of a millimeter – such a result cannot be achieved by any of the traditional NDT methods;

- possibility of conducting real-time control, which prevents the destruction of technical devices during operation.

The main disadvantages of the AE method:

- need to load the MO, since only under this condition is it possible to initiate the process of damage development and the occurrence of acoustic signals;
- high sensitivity to electromagnetic, climatic, acoustic, vibrational and other noises, which requires the use of special signal filtering techniques.

At the same time, the diagnostic system can work not only with AE sensors, but also with other types of sensors, providing parallel input of acoustic, operational and technological parameters into the IMCS for a long time, as well as automated assessment of the state of the material, including determination of the hazard level, forecast of destructive load and residual service life. This is how an integrated approach to the assessment of the material and structure under loading is implemented, i.e., the "state vector", which considers not individual measurable quantities, but their complex [8].

The mechanical tests carried out by the researchers [8–16] under conditions of static, dynamic, cyclic and impact loading showed that by means of AE it is possible to track the development of damage and destruction of structural materials at virtually all stages, including the actual development of cracks, down to destruction [17]. Approbation of AE methods in the process of diagnosing gas pipelines helped to assess the effect of damage accumulation on the acoustic characteristics of materials of various classes [18]. This allowed, in combination with a large amount of testing of various critical technical objects (pressure vessels, rocket fuel tanks, high-pressure pipelines, etc.), to develop software methods for filtering AE signals in noisy conditions [8, 14], which makes it possible to install sensors at a considerable distance from each other. The value of these distances is determined by the absorption of the signal at the boundaries of the media and its extinction. The specific value of the distances between the sensors requires an experimental determination, taking into account the influence of the characteristics of the materials directly used in the design of the GPV elements.

As a result of analyzing the state of materials of products that have undergone destruction, as well as on a comprehensive study of the kinetics of damage accumulation during fracture of samples from the original material and material that has been in operation for a long time, methods for predicting the residual service life based on the assessment of the gradual accumulation of damage during operation under load are proposed in [8–19].

As examples of the AE process, Figure 2 shows the frequency characteristics of waves propagating in thin plates with velocities lower than the Rayleigh wave velocity C_2, which is equal to 0.31 cm/μs. Figure 2a shows that the thicker the plate δ, the greater the low-velocity wave component in its spectrum. In thicker plates, the spectrum of propagating waves narrows; in a plate 10 cm thick, actually one wave propagates with a velocity of $0.927C_2$, which is close to the Rayleigh one in terms of properties. As follows from the obtained dependence of the wave amplitude on the thickness of the plate and the distance from the place of radiation (Figures 2b, 2c), a source of the same power generates more significant wave amplitudes in a thin plate than in a thick one. This is how it can be explained that the radiation energy is absorbed faster in a larger volume of metal.

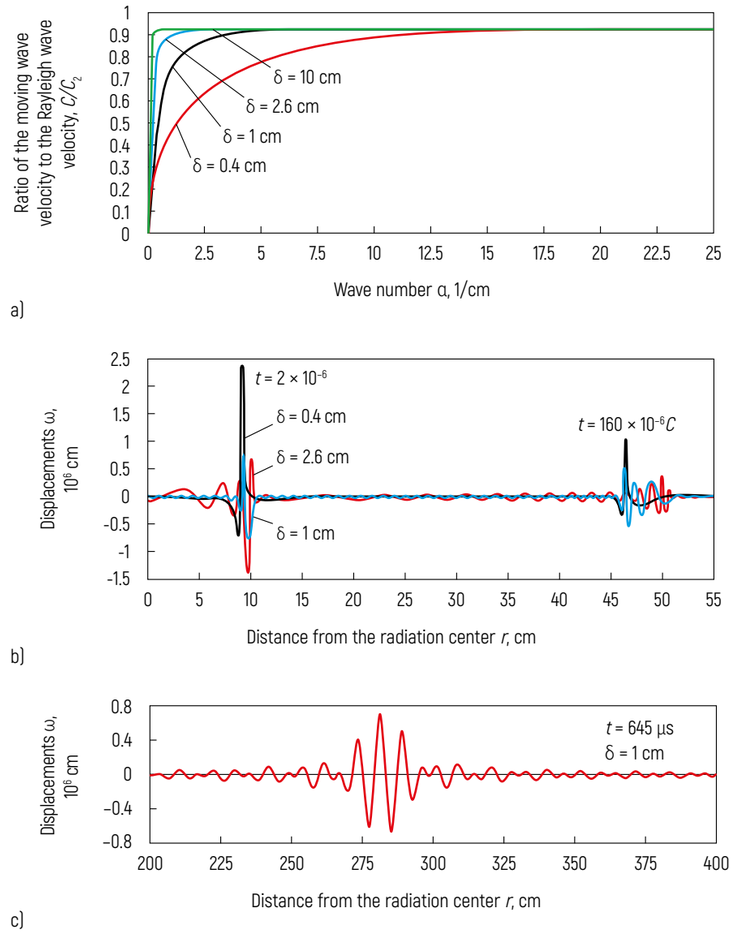


Figure 2 – Spectra of waves and AE signals for plates of different thicknesses [3]:
a – dependence of the wave propagation velocity on the plate thickness;
b – amplitude and spectrum of waves propagating with velocities $<C_2 = 0.31$ cm/μs;
c – amplitude of a wave propagating at a velocity $C = 0.4375$ cm/μs

The obtained results can be used in diagnosing the technical condition of the rails of the track structures of the GPV overpass, the running track of which is made up of vertical steel plates mounted in parallel on an edge (Figure 3), having a thickness in the range corresponding to that shown in Figure 2a (basic characteristics are given in Table 2).

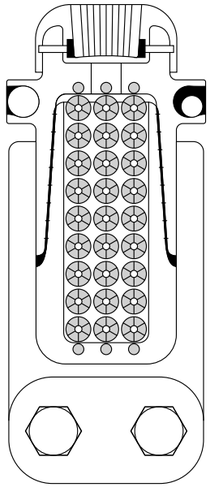


Figure 3 – Rail of the track structure, the running track of which is made up of vertical steel plates mounted in parallel on an edge

Table 2 – Basic characteristics of the material of the running track in rails of the GPV overpass track structures

Parameter	Meaning
Minimum tensile strength, MPa	1,100
Minimum yield strength, MPa	780
Hardness HRC	40–48
Modulus of elasticity, MPa	200,000 ± 2 %
Relative elongation, %, not less	20
Thermal expansion coefficient from –40 °C to +60 °C, μm/(m · °C)	13.8 ± 2 %
Impact toughness at –20 °C, J/cm^2	60
Impact toughness at –40 °C, J/cm^2	40
Maximum torsion at a length of 1,000 mm, °, not less	1

These plates have a prestress of ≈10^6 N and are enclosed in a rail body made of aluminum alloy, which basic characteristics are given in Table 3. The elements of the running track are connected by equal-strength welding, which makes it possible to create plates of infinite length, and the body elements can be either of a dimensional length or infinite if manufactured by extrusion.

Table 3 – Basic characteristics of the material of the body of rails in the GPV overpass track structures

Parameter	Meaning
Minimum tensile strength, MPa	310
Minimum yield strength, MPa	260
Hardness HB, not less	95
Modulus of elasticity, MPa	70,000 ± 2 %
Relative elongation, %, not less	10
Thermal expansion coefficient from –40 °C to +60 °C, μm/(m · °C)	24 ± 2 %
Thermal conductivity, W/(m · K)	180
Electrical resistance at 20 °C, Ω · mm^2/m	0.037

Using the Distributed Acoustic Sounding Method

Fiber-optic sensor systems based on the effects of elastic or inelastic light scattering in standard telecommunication-class optical fibers can be effectively used as tools to perceive and analyze acoustic signals caused by operational loads, vehicle traffic and environmental impacts in the object under study or transport facility. Advantages of these systems: the ability to perform remote continuous monitoring of long-distance objects using a single fiber-optic cable; no need for electricity and irresponsiveness to electromagnetic interference.

The technologies using specially prepared fiber segments (for example, systems based on the fiber Bragg grating (FBG) for monitoring at one or more points) have recently become widespread in the field of acoustic diagnostics using fiber-optic systems. However, truly distributed technologies that allow diagnosing long linear objects and using standard optical fibers are implemented in the DAS systems.

Three scattering processes occur in optical fibers (Brillouin, Raman and Rayleigh (Table 4)), which can be used to measure physical quantities that characterize the deformation or vibration of the monitored object with high spatial resolution.

Brillouin and Raman scattering are inelastic scattering processes that involve the transfer of energy to or from thermal vibrations. Rayleigh scattering is elastic scattering caused by static inhomogeneities in the refractive index. Each scattering process has a certain spectrum, characterized by specific dependencies on physical quantities that can be analyzed (Figure 4).

DAS is based on coherent Rayleigh scattering. The interference of Rayleigh scattering light from many scattering centers in the fiber leads to the formation of a speckle structure, i.e., a random interference pattern, which is formed during mutual interference of coherent waves having random phase shifts or random intensity set. This structure is sensitive to changes in wavelength in the fiber, since a difference of several tens of nanometers causes a significant phase change for light with a typical wavelength of ≈1.5 μm.

Measuring the amplitude of the Rayleigh signal is sufficient for sensitive detection of events that have a wide acoustic spectrum (for example, vibration caused by rolling of the wheel on the rail). Complementing the obtained data with phase information allows accurate quantitative analysis of signals due to the non-linear behavior of the amplitude signal. In this case, the magnitude of the measured amplitude and information about the phase can serve as an information signal indicating the appearance of defects on the running track (tread surface) of the rail or the wheel interacting with it, which makes it possible to carry out continuous remote diagnostics of the track structure and vehicles.

Table 4 – Measured optical quantities and physical parameters of scattering processes in optical fibers

Scattering process	Measured optical quantities	Physical parameters
Raman	Amplitude *T*	Temperature
Brillouin	Frequency ν, amplitude *T*	Temperature, deformation
Rayleigh	Amplitude *T*, phase *s*	Temperature, dynamic deformation

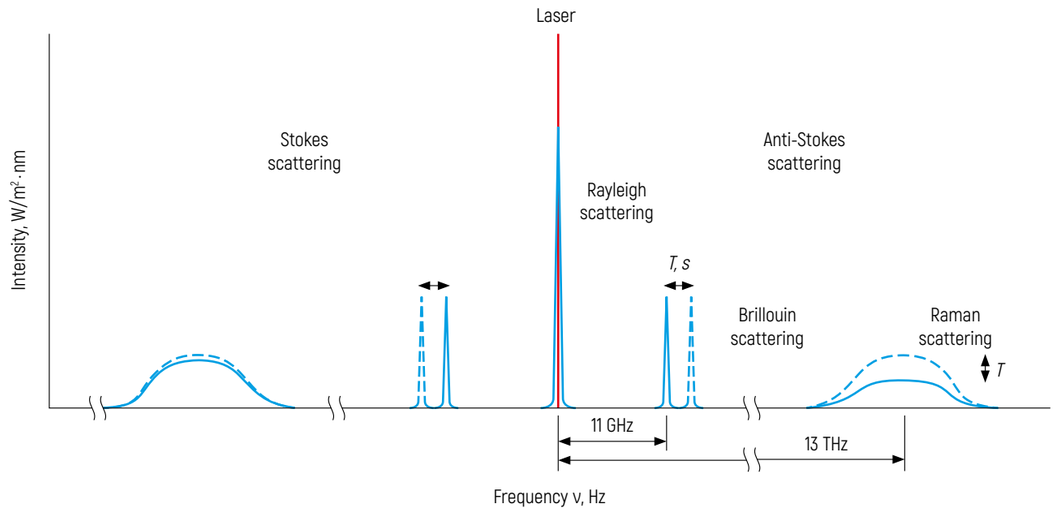


Figure 4 – Schematic representation of the spectral components of light scattering in an optical fiber

A periodic relative elongation of 150 nm of a fiber-optic segment having a length of 15 m leads to the appearance of a signal that is spotted at a distance of 70 km (Figure 5). The observed spatial resolution for this very faint and distant event is ≈15 m; at shorter distances, it is possible to register elongations in the range of 1–10 nm, which indicates a high sensitivity of DAS diagnostics.

Improvement of DAS diagnostic algorithms based on the analysis of the spectral, temporal or spatial characteristics of an event, as well as the use of machine learning technologies will contribute to even more reliable identification of defects, which leads not only to continuity and remote diagnostics, but also to high accuracy in detecting damage and deviations from required operating parameters. At the same time, the design of the rails of the GPV track structures (Figure 3) makes it possible to lay fiber-optic cables directly inside the body elements in which the plates of the assembled running track are installed, which ensures high sensitivity and rational layout of the system

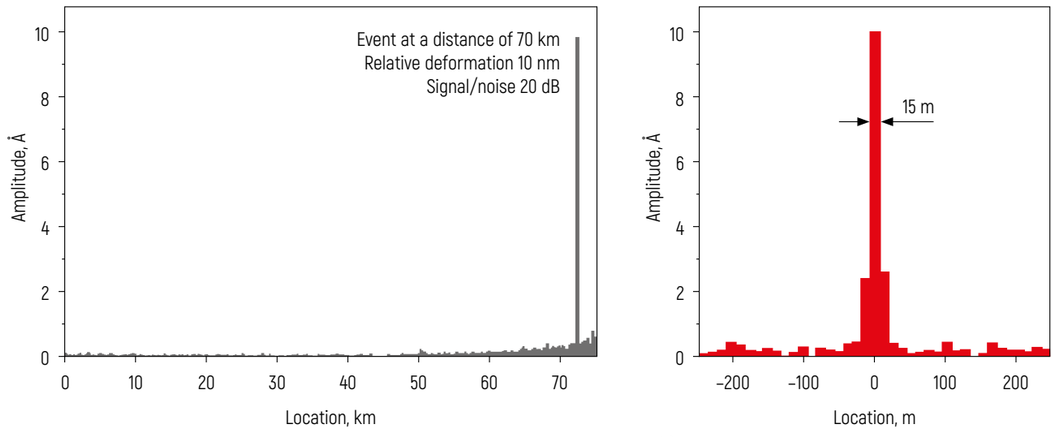
Using the Fiber-Optic Sensor System for Diagnosing Prestressed Elements of the GPV Overpass

The tension of the structural elements of a prestressed structure, to which the GPV overpass belongs, as well as the technical condition of their anchor assemblies (the amount of possible slippage) directly affect the safety, reliability and durability of the entire structure. An approximate determination of the tension value of the considered elements is possible by analyzing the deflections of the interspan sections. At the same time, this method does not provide the required accuracy. The use of strain gauges, which are effectively used to determine stresses, displacements and deformations, cannot be implemented in this case due to the high probability of their damage during the tension of structural elements, steel ropes in particular. Methods for calculating the tension value of prestressed structural elements under the action of operational loads are also probabilistic in nature due to the large number of assumptions.

One of the possible solutions to this problem can be the use of steel ropes, which core is integrated with a fiber-optic cable reinforced with carbon fiber, which is a FBG that was successfully implemented in [20] and is shown in Figure 6.

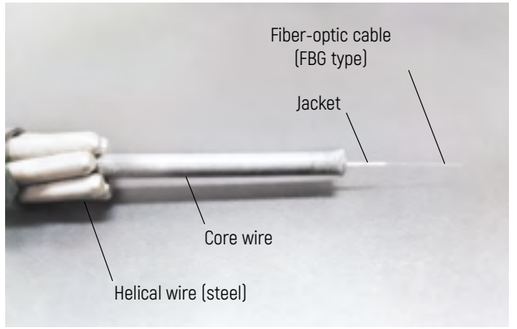
The characteristics of this steel rope are similar to standard ones having the same diameter, in particular, for a steel rope with a diameter of 15.2 mm, the tensile strength is 1,860 MPa. Thus, this steel rope can be considered both as a structural element of the structure and as a measuring sensor of the diagnostic system.

The studies described in [20] showed a high accuracy in determining the tension value of prestressed steel ropes of reinforced concrete structures with an integrated fiber-optic cable, as well as the possibility of accurately determining the amount of slippage of steel ropes in the anchor fastening.

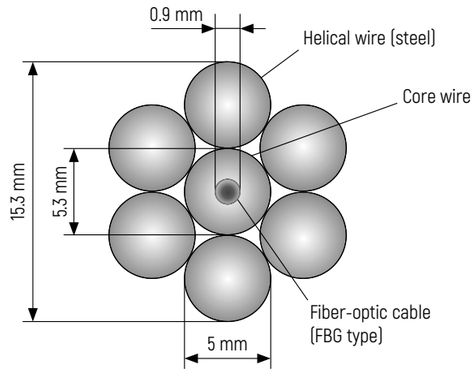


a) b)

Figure 5 – Sensitivity of the DAS method in relation to an event located at a considerable distance: a – registration; b – spatial resolution



a)



b)

Figure 6 – Steel rope with an integrated fiber-optic cable:
a – general view; b – cross section

Determination of the Reliability and Durability of Fiber-Optic Cables of the Intelligent Diagnostics System

The definitions of the service life, reliability and durability of fiber-optic cables are considered in a number of works [21, 22]. The strength of optical fibers depends on many factors, the main of which is the presence of surface and volumetric defects and cracks that occur due to flaws in the workpieces or the abrasive action of solids in contact with the quartz glass surface. When the fiber is loaded, defects act as stress concentrators. The destruction process is determined by the following factors: the nature of the loaded state, the loading rate, the environment and the fiber structure. These parameters must be taken into account in calculations that reflect the specific operating conditions (especially in the case of prestressing) of a real structure or edifice.

In addition, an important control indicator when testing fiber-optic cables is the attenuation coefficient of the optical signal. The procedure for its determination is regulated in [23]. However, cases are known when the attenuation coefficient practically does not change until the optical fiber breaks; sometimes fibers with normal attenuation fail after an insignificant operating time [24]. The reason for this phenomenon may be the unacceptable stretching of the cable during installation or residual deformation that occurred during manufacture. The conducted studies have shown a significant relationship between the relative elongation of the fiber in the cable and its service life [25]. In accordance with the data obtained, the permissible value of the relative elongation of the optical fiber in an optical cable to ensure a service life of 30–40 years should not exceed 0.25–0.3 % [24]. Therefore, when testing optical cables for resistance to mechanical stress, it is proposed to measure the relative elongation of the optical fiber, rather than the attenuation coefficient [24]. Measurements can be carried out by registering the phase change of an amplitude-modulated signal passing through the fiber, or using a Brillouin reflectometer. For example, if it is necessary to ensure the service life of an optical cable for more than 30 years, the relative elongation should not exceed 0.25 % [24].

Based on the foregoing, this parameter should be taken into account when developing design and engineering documentation for the GPV overpass and controlled during the operation of its intelligent diagnostic system.

Automation of the GPV Overpass Elements Technical Condition Monitoring Process

The above methods of acoustic diagnostics for non-destructive testing of the GPV overpass rails under operating conditions can be implemented in the form of continuous monitoring, during which acoustic activity is monitored constantly, and equipping the monitoring system with automation tools allows to receive information about the state of the MO quickly in real time and prevent dangerous situations timely. As a result, the concept of "intelligent design" is applicable to the MO, which itself determines what state it is in and whether it is possible to continue

its further operation. To meet the set requirements, a diagnostic system of this design should provide the following main functions:

- measurement, processing and presentation of the initial data with a preset degree of probability necessary for assessing the technical condition (bearing capacity);
- extrapolation of the received initial data towards the accepted predictive coordinate;
- calculation of the bearing capacity and residual service life according to the received predictive information, as well as additional information characterizing the conditions of production and current maintenance;
- assessment of the condition of the structure and possible scenarios for the development of a defect with the elaboration of options for consequences according to the degree of danger;
- choosing the appropriate option and making the optimal decision;
- in accordance with the decision made, a change in the operating mode (limitation of the mass of vehicles, their speed, axial load on the rails) in order to get out of the emergency state, messaging about the need to perform repair and renewal work, the need for partial or complete termination of the functional activity of sections of track structures or the object as a whole;
- transfer of information about the technical condition of the rails of track structures to the central intelligent control system for making a decision on further operation or changing its parameters.

Thus, the basis of an intelligent diagnostic system is a signal processing unit (SPU), in which acoustic signals are amplified, filtered, digitized using an analog-to-digital converter (ADC), digital processing and registration of signal parameters, their shapes and transmission of these parameters over a radio channel to the workstation. The SPU, which has an ADC of AE, is a fully-featured digital channel that calculates all parameters of acoustic signals and records their shape.

The system can operate in two modes: in the mode of direct transmission of signals from the SPUs to the central transceiver module (CTM) and in the network mode, when the SPUs transmit signals to the CTM along the chain through neighboring SPUs (Figure 7). This mode is most suitable for monitoring extended objects (GPV overpass track structures rails).

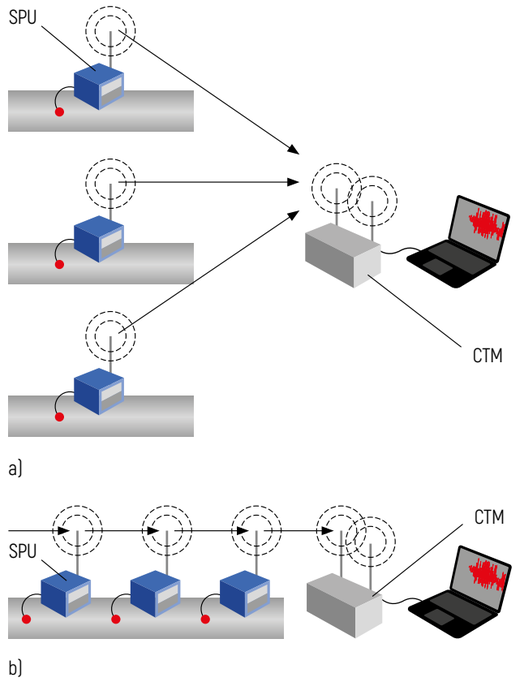


Figure 7 – Intelligent diagnostic system:
a – direct signal transmission mode; b – network mode

Conclusions and Future Work

An analysis of NDT technologies, the use of which is possible for continuous remote diagnostics of the GPV structural elements (in particular, track structures), shows the greatest efficiency of AE and DAS methods.

The first of them is based on the fact that fairly fast physical processes of structure change in a limited volume of material (plastic deformation, destruction, formation and growth of cracks, movement of dislocations, phase transformations, friction, etc.) are accompanied by the emission of acoustic waves. The described phenomenon is called material AE and is used in NDT to detect defects actively developing under load. An important advantage of the presented method is the direct relationship between the informative parameters of AE signals and destruction processes, which is not characteristic of traditional methods. This allows to constantly and remotely receive information about the stage of development and the growth rate of the defect.

DAS technology uses a fiber-optic cable as a sounding element (sensor) to measure the acoustic impact with high spatial resolution along the entire length of the receiving system, which is optimally suited for long objects, and also allows to control the tension of the prestressed structural elements of the GPV overpass.

The development and approbation of the diagnostic and monitoring technologies discussed above based on the AE and DAS methods also require the development of appropriate methods and technical regulatory legal acts that reflect the features associated with the design of rails, track structures and other structural elements of the GPV overpass. In addition, it is necessary to improve the methods and diagnostic tools used. Thus, conditions will be created for an integrated systemic approach to diagnosing, evaluating and predicting the technical condition of such a complex and heavy-duty structure as the GPV overpass, which means that its reliability and safety will be ensured throughout its entire service life.

References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Kholodilov, O.V. Defekty materialov i izdeliy [Defects in Materials and Products]: Study Guide / O.V. Kholodilov. – Gomel: BelGUT, 2022. – 242 p.*
3. *Nerazrushayushchiy kontrol' [Non-Destructive Testing]: Practical Guide: in 5 books / ed. V.V. Sukhorukov. – Moscow: Vysshaya shkola, 1992. – Book 3: Gerasimov, V.G. Elektromagnitnyy kontrol [Electromagnetic Control] / V.G. Gerasimov, A.D. Pokrovskiy, V.V. Sukhorukov. – 312 p.*
4. *Nerazrushayushchiy kontrol' [Non-Destructive Testing]: Reference Book: in 7 vol. / ed. V.V. Klyuyev. – Moscow: Mashinostroyeniye, 2004. – Vol. 3: Yermolov, I.N. Ul'trazvukovoy kontrol' [Ultrasonic Control] / I.N. Yermolov, Yu.V. Lange. – 864 p.*
5. *Kontrol' nerazrushayushchiy. Klassifikatsiya vidov i metodov [Non-Destructive Testing. Classification of Types and Methods]: GOST 18353-79. – Replaces GOST 18353-73; introduced 01.07.80. – Moscow: Izdatel'stvo standartov, 1979. – 12 p.*
6. *Buylo, S.I. Fiziko-mekhanicheskiye, statisticheskiye i khimicheskiye aspekty akustiko-emissionnoy diagnostiki [Physico-Mechanical, Statistical and Chemical Aspects of Acoustic Emission Diagnostics] / S.I. Buylo. – Rostov-on-Don; Taganrog: Izdatel'stvo Yuzhnogo federal'nogo universiteta, 2017. – 183 p.*
7. *Kholodilov, O.V. Akusticheskaya diagnostika [Acoustic Diagnostics] / O.V. Kholodilov // Tribologiya. Sostoyaniye i perspektivy [Tribology. Status and Prospects]: Collection of Scientific Papers: in 4 vol. / eds I.G. Goryacheva, M.A. Bronovets. – Ufa: RIK UGATU, 2016. – Vol. 1. – P. 212–234.*
8. *Opyt IES im. Ye.O. Patona NAN Ukrainy v oblasti akustiko-emissionnogo kontrolya [Experience of E.O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine in the Field of Acoustic Emission Control] / B.E. Paton [et al.] // Tekhnicheskaya diagnostika i nerazrushayushchiy kontrol'. – 2012. – No. 1. – P. 7–22.*
9. *Chernov, D.V. Razrabotka metodov diagnostiki ustalostnykh treshchin s pomoshch'yu akusticheskoy emissii [Development of Methods for Diagnosing Fatigue Cracks Using Acoustic Emission]: Ph.D. Tech. Sc. Diss.: 05.11.13 / D.V. Chernov. – Moscow, 2018. – 148 p.: il.*
10. *Kareyev, A.Ye. Razrabotka metodov obrabotki signalov akusticheskoy emissii na osnove klasternogo analiza dlya povysheniya nadyozhnosti kontrolya mashinostroitel'nykh konstruktsiy [Development of Methods for Processing Acoustic Emission Signals Based on Cluster Analysis to Improve the Reliability of Machine-Building Structures Control]: Ph.D. Tech. Sc. Diss.: 05.02.11 / A.Ye. Kareyev. – Novosibirsk, 2006. – 160 p.: il.*
11. *Stadnichenko, V.N. Metodika issledovaniya perekhodnykh protsessov v uzlakh treniya gidromashin s ispol'zovaniyem metoda akusticheskoy emissii [Technique for the Study of Transient Processes in Friction Units of Hydraulic Machines Using the Acoustic Emission Method]: Ph.D. Tech. Sc. Diss.: 05.04.13 / V.N. Stadnichenko. – Kharkov, 1997. – 186 p.*
12. *Rudakova, A.V. Identifikatsiya opasnykh sostoyaniy mekhanicheskikh konstruktsiy metodom akusticheskoy emissii [Identification of Dangerous States of Mechanical Structures by the Method of Acoustic Emission]: Ph.D. Tech. Sc. Diss.: 05.13.03 / A.V. Rudakova. – Kherson, 1997. – 162 p.*
13. *Kovtun, I.I. Diagnostika prochnosti nerazyomnykh elementov konstruktsiy metodom akusticheskoy emissii [Diagnostics of the Strength of Non-Detachable Structural Elements by the Method of Acoustic Emission]: Ph.D. Tech. Sc. Diss.: 05.02.02 / I.I. Kovtun. – Khmelnitsky, 1998. – 175 p.*
14. *Murav'yov, M.V. Razrabotka metodiki nerazrushayushchego kontrolya rel'sov v usloviyakh ekspluatatsii na osnove analiza formy i energeticheskikh kharakteristik signalov akusticheskoy emissii [Development of a Technique for Non-Destructive Testing of Rails Under Operating*

Conditions Based on the Analysis of the Form and Energy Characteristics of Acoustic Emission Signals]: Ph.D. Tech. Sc. Diss.: 05.11.13 / M.V. Murav'yov. – Novosibirsk, 2003. – 167 p.

15. *Bekher, S.A. Analiz parametrov signalov akusticheskoy emissii i yeyo potokovykh kharakteristik pri diagnostirovanii metalla osey kolosnykh par [Analysis of the Parameters of Acoustic Emission Signals and Its Flow Characteristics in Diagnosing the Metal of the Wheelset Axles]: Ph.D. Tech. Sc. Diss.: 05.02.11 / S.A. Bekher. – Novosibirsk, 2004. – 145 p.*
16. *Goroshko, A.V. Komp'yuterna akustiko-emisiyna diagnostyka tekhnichnogo stanu detaley i konstruktsiy [Computer Acoustically-Emissive Diagnostics of the Technical State of Parts and Structures]: Ph.D. Tech. Sc. Diss. Abstr.: 05.11.13 / A.V. Goroshko; Ivano-Frankivsk National Technical University of Oil and Gas. – Ivano-Frankivsk, 2003. – 20 p.*
17. *Chausov, N.G. Vliyaniye vida napryazhonnogo sostoyaniya na parametry akusticheskoy emissii na zaklyuchitel'nykh stadiyakh deformirovaniya metallov [Influence of the Type of Stress State on the Parameters of Acoustic Emission at the Final Stages of Metal Deformation] / N.G. Chausov, S.A. Nedoseka, A.A. Lebedev // Tekhnicheskaya diagnostika i nerazrushayushchiy kontrol'. – 1993. – No. 3. – P. 18–23.*
18. *Otsenka povrezhdonnosti metalla deystvuyushchikh gazoprovodov metodom AE-skanirovaniya [Assessment of Damage to the Metal of Existing Gas Pipelines by AE Scanning] / A.A. Lebedev [et al.] // Tekhnicheskaya diagnostika i nerazrushayushchiy kontrol'. – 2001. – No. 1. – P. 8–12.*
19. *Nedoseka, S.A. Kompleksnaya otsenka povrezhdonnosti i ostatochnogo resursa metallov s ekspluatatsionnoy narabotkoy [Comprehensive Assessment of Damage and Residual Service Life of Metals with Operating Time] / S.A. Nedoseka, A.Ya. Nedoseka // Tekhnicheskaya diagnostika i nerazrushayushchiy kontrol'. – 2010. – No. 1. – P. 9–16.*
20. *Analysis of Short-Term Prestress Losses in Post-Tensioned Structures Using Smart Strands / K. Sang-Hyun [et al.] // International Journal of Concrete Structures and Materials. – 2022. – Vol. 16, No. 1. – P. 1–15.*
21. *Semenyuta, N.F. Volokonno-opticheskiye linii svyazi i telekommunikatsionnyye sistemy peredachi na zheleznodorozhnom transporte [Fiber-Optic Communication Lines and Telecommunication Transmission Systems on Railway Transport] / N.F. Semenyuta, P.M. Buy. – Gomel: BelGUT, 2012. – 205 p.*
22. *Zubilevich, A.L. K opredeleniyu parametrov nadozhnosti opticheskikh volokon [On the Determination of the Reliability Parameters of Optical Fibers] / A.L. Zubilevich, V.A. Kolesnikov // T-Comm: Telekommunikatsii i transport. – 2015. – Vol. 9, No. 4. – P. 23–26.*
23. *Volokna opticheskiye. Chast' 1–40. Metody izmereniy i provedeniye ispytaniy. Zatukhaniye [Optical Fibers. Part 1–40. Measurement Methods and Testing. Attenuation]: GOST R IEC 60793-1-40-2012. – Introduced 01.07.13. – Moscow: Standartinform, 2012. – 19 p.*
24. *Ovchinnikova, I.A. Opredeleniye nadozhnosti opticheskikh kabeley [Determination of Reliability of Optical Cables] / I.A. Ovchinnikova // Tekhnologii i sredstva svyazi. – 2009. – No. 3. – P. 39–41.*
25. *Ovchinnikova, I.A. Issledovaniya i razrabotka opticheskikh kabeley spetsial'nogo naznacheniya [Research and Development of Special Purpose Optical Cables]: Dr. Tech. Sc. Diss. Abstr.: 05.09.02 / I.A. Ovchinnikova; VNIIKP. – Moscow, 2021. – 41 p.*

Prospects for the Use of Auxetic Materials in the EcoCosmoHouse Structures

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UDC 539.3

The research deals with innovative auxetic materials (auxetics) with high volume compressibility and shear rigidity, capable of expanding/contracting in a direction perpendicular to the direction of stretching/compression, respectively. These features of deformation behavior are expressed in a negative Poisson's ratio. The analysis of the applicability of auxetics in the EcoCosmoHouse (ECH) structures for the manufacture of friction joints of load-bearing elements, sealing and damping devices in order to protect against meteorite fragments and acoustic impacts, as well as to reduce thermal stresses is provided.

Keywords: *auxetics, dynamic loads, EcoCosmoHouse (ECH), negative Poisson's ratio, vibrations, zero thermal expansion.*

Introduction

To ensure the effective functioning of the EcoCosmoHouse (ECH) [1], structural elements made of innovative materials with special deformation properties and having appropriate adaptive reactions to operational impacts (force, temperature, acoustic, etc.) will be in demand [2]. Such innovations can be based on the use of inverted, in particular, auxetic materials (auxetics) having a negative Poisson's ratio ν, i.e., capable of expanding/contracting in a direction perpendicular to the direction of stretching/compression, respectively (Figure 1).

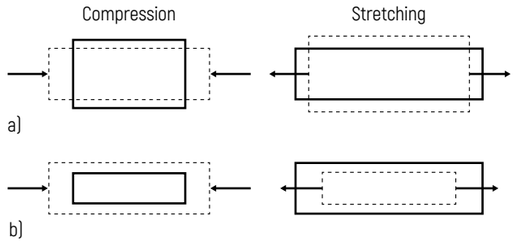

Figure 1 – Deformation modes:
a – conventional material; b – auxetic material

At first glance, the nonpositivity of ν contradicts to common sense, however, the possibility of the existence of such materials is confirmed by the well-known correlation of the theory of elasticity of isotropic bodies [3]:

$$\nu = (3K - 2\mu)/(6K + 2\mu), \qquad (1)$$

where K, μ – modules of volumetric deformation and shear having positive values.

It follows from the correlation (1) that negative values of ν are possible under the condition $\mu > 3/2K$, when the shear modulus exceeds the volume deformation modulus by more than 50 %. This means that the Poisson's ratio of an isotropic body can be in the range –1... 0.5. The upper limit corresponds to incompressible materials (for example, rubber) that retains its volume during deformation with a significant change in shape. The lower limit corresponds to materials with relatively high shear rigidity, the sample of which retains geometric proportions during deformation, but changes its volume. Such materials having ν < 0, are called auxetic, or auxetics (from Greek αὐξητικός – swelling).

Auxetics have been actively researched for several decades. They are found in nature (soils, porous sandstones, zeolites, wood, blood vessels, tubular bones) and can be obtained by various technological methods [4–6]. Examples of such natural and artificial materials and structures, structural levels and common mechanisms for the implementation of this effect are described in sufficient detail in [4, 6–8]. The practical interest in auxetics is due to the possibility of creating products with special characteristics.

The purpose of this work is to analyze the advantages of auxetic materials when used in the ECH structures located in outer space in an equatorial Earth's orbit [1].

Deformation of Auxetics During Indentation

The first artificial auxetics are foam materials. They demonstrate elasticity and at the same time high shear resistance, high fracture toughness and vibration absorption, as well as relatively low cost and ease of formation. Thermoplastic open-porous auxetic polyurethane foams (PUFs) are obtained as a result of a thermomechanical process. With triaxial compression of such materials, a structure with concave cells is formed [9–12]; thermal treatment (heating and cooling) allows to fix it.

The indentation of auxetic PUF [13, 14], ultrahigh molecular polyethylene (UHMPE) [15] and spongy copper [16, 17] showed an increase in yield strength compared to non-auxetic analogues at the same porosity and apparent density (Figure 2). For UHMPE with ν = –0.8 at a load of up to 100 N, the indentation resistance energy is up to eight times higher than that of a conventional porous UHMPE with ν ≈ 0 [15], which contributes to the use of auxetics as a filler for sandwich panels experiencing static [13] and dynamic [18, 19] loads.

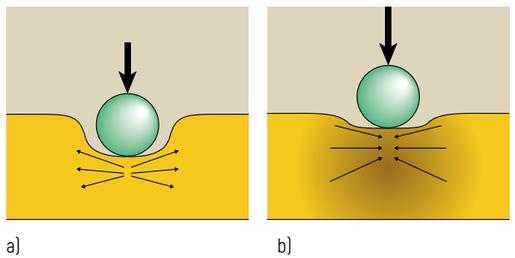

Figure 2 – Behavior during indentation material [14]:
a – conventional material; b – auxetic

Increased resistance to indentation allows to raise the efficiency of protective gear, limiting the traumatic effect of concentrated loads. A lower volume modulus causes an increase in volume deformation [20] and energy absorption during uniaxial compression [21].

Self-Hardening Effect

It was shown in [22–24] that during constrained deformation with friction, self-locking of an elastic element made of auxetic is occurring, which, under the action of the pulling load T, fits more tightly to another part, increasing the bearing capacity (Figure 3). This makes auxetic materials preferable for use in fasteners and friction joints as "adaptive" retainers.

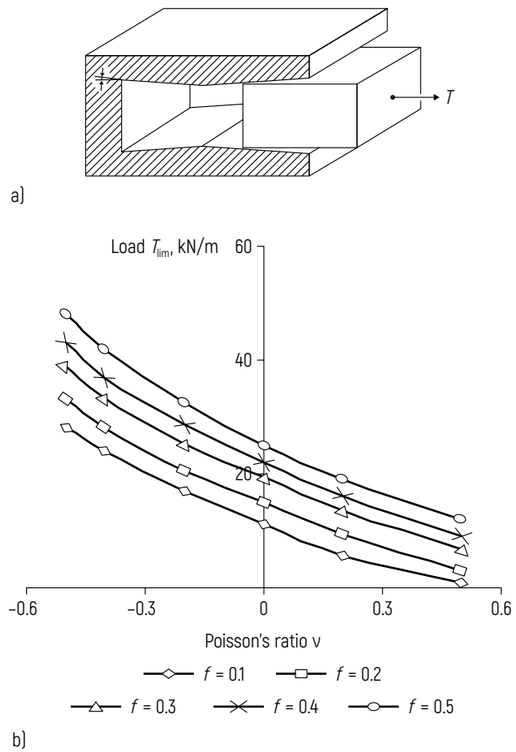

Figure 3 – Frictional behavior of auxetics:
a – structure of the friction joint;
b – dependence of the limiting shear load on the Poisson's ratio ν
at different coefficients of friction

Behavior of Auxetics During Vibration

Studies of the dynamic behavior of a PUF-based auxetic have shown an increase in the loss coefficient and, therefore, the advantage of the material in energy absorption. In Figure 4, the vibration transmission coefficients of K_{vibr} (amplitude 1.5×10^{-4} m) of plates with a size of 10 × 380 × 120 mm made of auxetic and conventional PUF are compared. At the same time, it is necessary to take into account two important points.

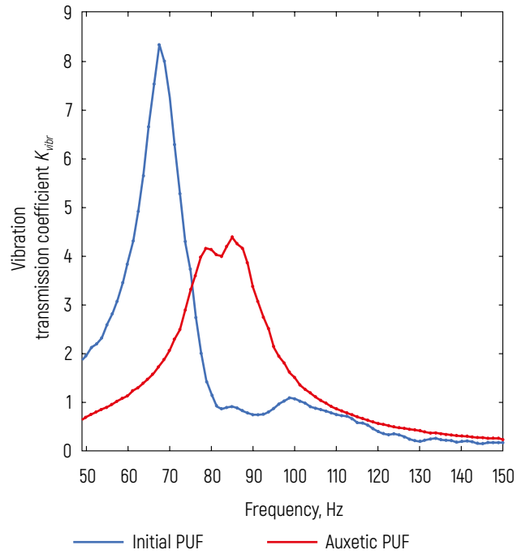

Figure 4 – Vibration transmission coefficients K_{vibr}
of initial and auxetic PUF at small excitation amplitudes [20]

The first is associated with a higher resonant frequency of the plate made of auxetic PUF (83 Hz), compared with the initial PUF (69 Hz). The second, more important, is associated with a strong decrease in peak vibration transmission. At frequencies below 10 Hz, both materials had a predominance of the rigidity factor and the vibration transmittance factor was equal to 1. In the frequency range of 49–150 Hz, the K_{vibr} value for a conventional PUF, due to the large deformation caused by resonance, begins with a value of 2. On the contrary, auxetic PUF still demonstrates a behavior with a predominance of rigidity, even relatively close to resonance [20]. With an increase in the vibration frequency to 110–150 Hz, the values of K_{vibr} in conventional and auxetic PUF are practically the same.

Wave Propagation

As it is known, the acoustic properties of a material are determined by the correlation of the propagation velocities of longitudinal v_l and transverse v_t waves, depending on the Poisson's ratio [25]:

$$v_l/v_t = \sqrt{(1 - 2\nu)/2(1 - \nu)}. \quad (2)$$

If for conventional isotropic materials the correlation v_l/v_t does not exceed $1/\sqrt{2}$, according to equation (2) for auxetics it reaches $\sqrt{3}/2$ [26, 27]. This explains the fact that in auxetic porous materials, the sound absorption coefficient and loss modulus are significantly higher compared to conventional foam plastics with the same porosity and density values [26–29]. Thus, for auxetic UHMPE, the ultrasound absorption coefficient reached 47 dB/cm, which is 1.5 times higher than for conventional foamed polyethylene [27].

Figure 5 shows the results of modeling for sound absorption of auxetic (solid line) and initial (dotted line) samples of PUF with a thickness of 26 mm. The grey area represents the dispersion between the measurement results for the two sides of the samples.

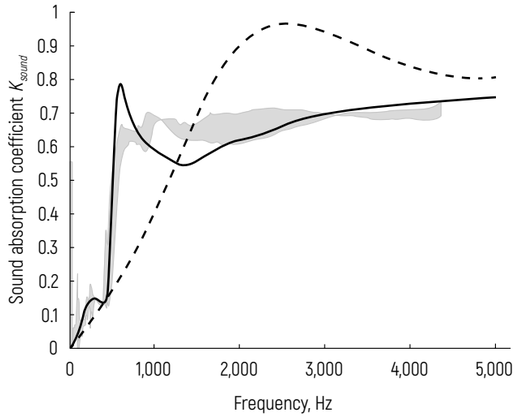

Figure 5 – Sound absorption coefficients K_{sound} of samples with a thickness of 26 mm [31]

The low level of dispersion indicates the homogeneity of the auxetic poromaterial in volume. From a comparison of the absorption rates of conventional and auxetic PUF, it can be seen that during the formation of a porous structure with a concave cell shape, the acoustic properties of the material change significantly. Auxetic poromaterial has higher absorbing properties in the low-frequency range up to 1,500 Hz. Its sound absorption coefficient K_{sound} reaches 0.6 at 500 Hz [30]. At higher frequencies K_{sound} of auxetic reaches a plateau, not exceeding 0.7, compared with the maximum (almost 100 %) absorption of conventional PUF at a frequency of about 2,500 Hz, and the absorption level of auxetic PUF in samples with a thickness of 26, 35 and 39 mm remains almost constant in the frequency range of 1,000–4,500 Hz. According to [31], the resistance to the air flow by auxetics increases in comparison with the samples of the initial PUF from which they were produced (194,300 N·s/m^4 and 12,500 N·s/m^4, respectively).

Behavior of Auxetics Under High-Speed Pulse Effect

To evaluate the efficiency of using auxetics under high-speed loads, experiments were conducted [32–34] to study the pulsed effect of a steel ball with a diameter of 5 mm on a curved sandwich panel made of carbon fiber with a size of 150 × 150 mm, a thickness of 1.05 mm, a radius of curvature of 200 mm and an intermediate layer thickness of 30 mm (Figure 6). Using 3D printing, a honeycomb-like filler with concave-shaped cells (Figure 7) with dimensions h = 6 mm, t = 0.7 mm, l = 3.9 mm and θ = 30° is made of PLA-plastic.

The results of the experiment show that when using auxetics, the penetration depth of the indenter decreases from 1.5 to 1.7 times (Table) compared to PUF having ordinary (convex) cells [32, 33].

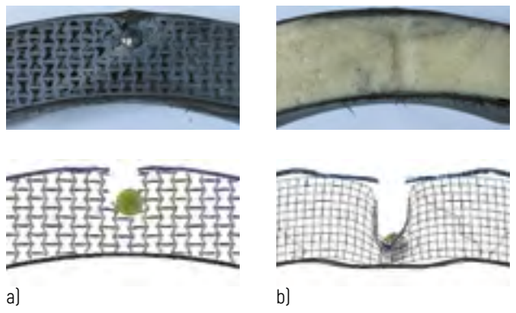

Figure 6 – Experiment and finite element modeling. Pulse effect on a sandwich panel with filler: a – auxetic honeycomb-like material made of PLA-plastic; b – conventional PUF [32]

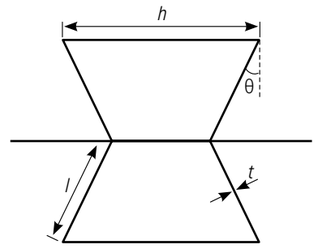

Figure 7 – Elementary cell of a honeycomb-like structure with a negative Poisson's ratio

Table – Parameters of sandwich panel indentation with conventional and auxetic fillers at various impact velocities [32]

Filler	Impact velocity, m/s	Penetration depth, mm
Auxetic honeycomb-like PLA-plastic	101.2	16.06
	100.8	16.12
	99.3	15.90
Conventional PUF	100.9	23.15
	102.5	27.93
	101.9	36.35

Possibility of Reducing Thermal Stresses

Of considerable practical interest is the reduction of thermal stresses resulting from the heating of composite systems, the components of which are made of materials with different coefficient of thermal expansion (CTE). For the ECH, this is relevant due to significant daily temperature changes (thermal cycling). In [2, 35], the possibility of obtaining materials with negative and zero CTE by introducing an auxetic phase into known materials, i.e., a hypothesis is put forward about the possibility of compensating thermal displacements by using the Poisson's effect in the field of negative values of ν.

Finite element modeling of thermal deformations is applied to search for the structure of such a material. The constructed models covered several basic types of structure: layered, porous, composite with inclusions (Figure 8). In the tests performed, the CTE $\alpha = 10^{-5}$ was set. The calculation of thermal deformations was carried out under the assumption of a flat-deformed state. The X and Y axis movements were used as output parameters; a fragment of 5 × 5 cells was used as a representative volume.

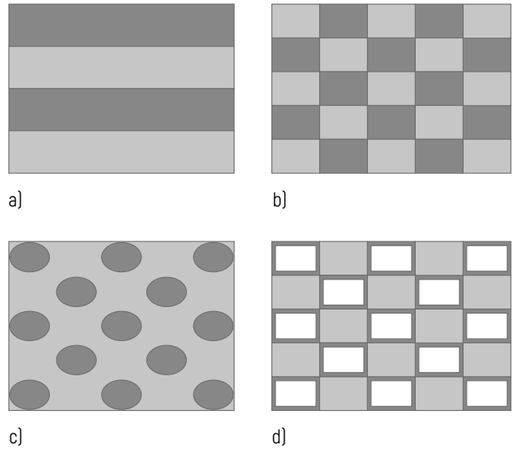

Figure 8 – Structures with auxetic components having zero CTE: a – layered system; b – chess-type system; c – matrix system with disk filler; d – porous system

The analysis of the thermal linear expansion for the layered system showed that the auxetic phase with ν = –0.5 makes it possible to weaken the displacements u_x by 1.22 times, u_y – by 1.44 times compared with the phase having ν = 0.48 (practically incompressible rubber-type material). A more noticeable effect is the alternation of layers (a decrease in u_x and u_y by 1.9 and 1.36 times, respectively). The most significant effect of minimizing CTE was achieved in the case of an auxetic phase with a theoretically permissible minimum value of ν = –1 (3.62 and 5.6). These calculations are carried out for a homogeneous (as per Young's modulus) material consisting of square-shaped cells with alternating auxetic and non-auxetic components. In particular, for ν = –0.5, the decrease in CTE was 1.22 and 1.28, respectively. When varying the Poisson's ratio in the range of acceptable values of 0.5... –1, it was found that thermal displacements close to zero are achieved at ν = –1.

Composite materials with an auxetic phase in the form of disks demonstrate a decrease in CTE by 1.34 and 1.41 times; matrices – by 1.81 and 2.45 times, respectively. A comparison of the thermal expansion characteristics of various materials (layered, homogeneous, with filler) showed that the most noticeable minimization of CTE is observed when using a homogeneous auxetic structure, especially with a minimum value of the Poisson's ratio ν = –1. The effect of the structure is smoothed out with increasing ν and becomes irrelevant when ν > 0,3.

Conclusions and Future Work

Based on the analysis of published experimental studies of auxetics, it can be concluded that combinations of some of their properties indicate a significant potential for using these materials in the aerospace industry as a filler for sandwich panels and a shock-absorbing material with improved features [36, 37].

Auxetics can be used in the ECH:

- as a sound-absorbing component of the inner shell in the range of 150–2,000 Hz (the sound absorption coefficient of the auxetic PUF in this frequency range is 2–3 times higher compared to conventional PUF), which is already practiced by the Rolls-Royce corporation [38];
- as a damper to protect against vibrations at frequencies of 60–100 Hz;
- in the manufacture of friction joints of bearing elements;
- to protect the ECH from meteorite impact.

Earlier, engineer A. Unitsky [36] developed a structure of five compartments, where plastic dampers were located immediately behind the outer casing (Figure 9), being a honeycomb-like structure that filled the entire compartment. The use of auxetic material as a damper will reduce the damage caused by meteorites and space debris.

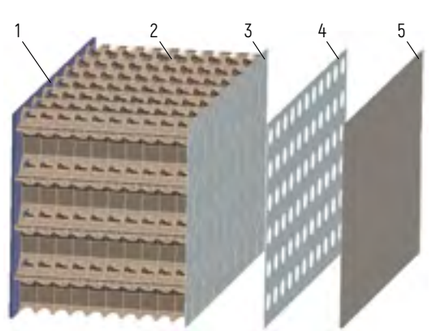

Figure 9 – Perspective view of the structure design of the ECH shell:
1 – outer shell plating;
2 – plastic dampers in the form of interference tunnels;
3 – vacuum insulator; 4 – interference grating; 5 – soil surface [36]

In addition, to prevent damage to the General Planetary Vehicle (GPV) and ECH from space debris of 10 mm or more in size, it was proposed to use sandwich panels with layers of aluminum foam and woven materials in protective screens [37]. Auxetic woven materials and composites based on them are known [39], it is also possible to obtain auxetic perforated aluminum and aluminum foam [40]. The combined use of auxetic aluminum and woven composites will enhance protection and reduce material consumption compared to conventional ones.

The properties of auxetics may in the near future open up prospects for their use in the manufacture of bandages that proportionally distribute medications with an increase in the size of wounds [41], which can also be used in the ECH in case of injury to people for medical care.

References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Shil'ko, S.V. Anomal'no uprugiye materialy kak komponenty adaptivnykh sistem [Abnormally Elastic Materials as Components of Adaptive Systems] / S.V. Shil'ko // Perspektivnyye materialy. – Vitebsk: VGTU, 2009. – Chap. 15. – P. 419–448.*
3. *Landau, L.D. Teoreticheskaya fizika [Theoretical Physics]: in 10 vol. / L.D. Landau, Ye.M. Livshits. – Moscow: Nauka, 1965. – Vol. 7: Teoriya uprugosti [Theory of Elasticity]. – 204 p.*
4. *Materialy s otritsatel'nym koeffitsiyentom Puassona [obzor] [Materials with Negative Poisson's Ratio (Review)] / D.A. Konok [et al.] // Mekhanika kompozitsionnykh materialov i konstruktsiy. – 2004. – Vol. 10, No. 1. – P. 35–69.*
5. *Ji, S. Seismic Velocities, Poisson's Ratios and Potential Auxetic Behavior of Volcanic Rocks / S. Ji, Q. Wang, L. Li // Tectonophysics. – 2019. – Vol. 766, No. 4. – P. 270–282.*
6. *Manufacturing, Characteristics and Applications of Auxetic Foams: A State-of-the-Art Review / W. Jiang [et al.] // Composites: Part B: Engineering. – 2022. – Vol. 235. – 109733.*
7. *Auxetic Metamaterials and Structures: A Review / X. Ren [et al.] // Smart Materials and Structures. – 2018. – Vol. 27, No. 2. – 023001.*
8. *A Review of the Manufacture, Mechanical Properties and Potential Applications of Auxetic Foams / R. Critchley [et al.] // Physica Status Solidi (B). – 2013. – Vol. 250, No. 10. – P. 1963–1982.*
9. *Polyhedron Cell Structure and Method of Making Same: Patent US 4,668,557 A / R.S. Lakes. – Published 26.05.1987.*
10. *Sposob polucheniya poristogo materiala s otritsatel'nym koeffitsiyentom Puassona i ustroystvo dlya yego osushchestvleniya [Method for Obtaining Porous Material with a Negative Poisson's Ratio and a Device for Its Implementation]: Patent BY 6,242 C1 / S.V. Shil'ko, N.N. Bodrunov, D.A. Konok. – Published 30.06.2004.*
11. *Effects of Geometrical and Processing Parameters on Mechanical Properties of Auxetic Polyurethane Foams / N.H.Z. Abedini [et al.] // SN Applied Sciences. – 2022. – Vol. 4, No. 6. – P. 162.*
12. *Effects of Heat Exposure and Volumetric Compression on Poisson's Ratios, Young's Moduli, and Polymeric Composition During Thermo-Mechanical Conversion of Auxetic Open Cell Polyurethane Foam / O. Duncan [et al.] // Physica Status Solidi (B). – 2019. – Vol. 256, No. 1. – 1800393.*
13. *Chan, N. Indentation Resilience of Conventional and Auxetic Foams / N. Chan, K.E. Evans // Journal of Cellular Plastics. – 1998.– Vol. 34. – P. 231–260.*
14. *Strain Densification During Indentation in Auxetic Foams / C.W. Smith [et al.] // Cellular Polymers. – 1999. – Vol. 18, No. 2. – P. 79–101.*
15. *Alderson, K.L. The Strain Dependent Indentation Resilience of Auxetic Microporous Polyethylene / K.L. Alderson, A.F. Fitzgerald, K.E. Evans // Journal of Material Science. – 2000. – Vol. 35, No. 16. – P. 4039–4047.*
16. *Lakes, R.S. Indentability of Conventional and Negative Poisson's Ratio Foams / R.S. Lakes, K.J. Elms // Journal of Composite Materials. – 1993. – Vol. 27, iss. 12. – P. 1193–1202.*
17. *Argatov, I.I. On Local Indentation and Impact Compliance of Isotropic Auxetic Materials from the Continuum Mechanics Viewpoint / I.I. Argatov, R. Guinovart-Díazb, F.J. Sabina // International Journal of Engineering Science. – 2012. – Vol. 54. – P. 42–57.*
18. *Roach, A.M. The Penetration Energy of Sandwich Panel Elements Under Static and Dynamic Loading. Part 1 / A.M. Roach, K.E. Evans, N. Jones // Composite Structures. – 1998. – Vol. 42, iss. 2. – P. 119–134.*
19. *Wave Propagation in Sandwich Plates with Periodic Auxetic Core / M. Ruzzene [et al.] // Journal of Intelligent Material Systems and Structures. – 2002. – Vol. 13, No. 9. – P. 587–597.*
20. *Bianchi, M. Vibration Transmissibility and Damping Behaviour for Auxetic and Conventional Foams Under Linear and Nonlinear Regimes / M. Bianchi, F. Scarpa // Smart Materials and Structures. – 2013. – Vol. 22, No. 8. – 084010.*
21. *The Dynamic Response of Shallow Sandwich Arch with Auxetic Metallic Honeycomb Core Under Localized Impulsive Loading / Y. Li [et al.] // International Journal of Impact Engineering. – 2020. – Vol. 137, No. 5. – 103442.*
22. *Shil'ko, S.V. Treniye anomal'no uprugikh tel. Otritsatel'nyy koeffitsiyent Puassona. Ch. 1: Realizatsiya effekta samostoporeniya [Friction of Abnormally Elastic Bodies. Negative Poisson's Ratio. Pt. 1: Implementation of the Self-Stoppage Effect] / S.V. Shil'ko // Treniye i iznos. – 1995. – Vol. 16, No. 3. – P. 429–437.*
23. *Shil'ko, S.V. Treniye anomal'no uprugikh tel. Otritsatel'nyy koeffitsiyent Puassona. Ch. 2: Raschot parametrov samostoporeniya [Friction of Abnormally Elastic Bodies. Negative Poisson's Ratio. Pt 2: Calculation of Self-Locking Parameters] / S.V. Shil'ko, A.I. Stolyarov // Treniye i iznos. – 1996. – Vol. 17, No. 4. – P. 448–455.*
24. *Shil'ko, S.V. Analiz kontaktnogo deformirovaniya auksetichnykh kompozitnykh materialov [Analysis of Contact Deformation of Auxetic Composite Materials] / S.V. Shil'ko, Ye.M. Petrokovets, Yu.M. Pleskachevskiy // Mekhanika kompozitnykh materialov. – 2006. – Vol. 42, No. 5. – P. 681–692.*
25. *Lippset, A.W. Reexamination of Dynamic Problems of Elasticity for Negative Poisson's Ratio / A.W. Lippset, A.I. Beltzer // Journal of the Acoustical Society of America. – 1988. – Vol. 84, No. 6. – P. 2179–2186.*
26. *Howell, B. Examination of Acoustic Behavior of Negative Poisson's Ratio Materials / B. Howell, P. Prendergast, L. Hansen // Applied Acoustics. – 1994. – Vol. 43, No. 2. – P. 141–148.*
27. *An Experimental Study of Ultrasonic Attenuation in Microporous Polyethylene / K.L. Alderson [et al.] // Applied Acoustics. – 1997. – Vol. 50, No. 1. – P. 23–33.*
28. *Chen, C.P. Dynamic Wave Dispersion and Loss Properties of Conventional and Negative Poisson's Ratio Polymeric Cellular Materials / C.P. Chen, R.S. Lakes // Cellular Polymers. – 1989. – Vol. 8, No. 5. – P. 343–359.*
29. *Chen, C.P. Micromechanical Analysis of Dynamic Behavior of Conventional and Negative Poisson's Ratio Foams / C.P. Chen, R.S. Lakes // Journal of Engineering Materials and Technology. – 1996. – Vol. 118, No. 3. – P. 285–288.*
30. *Shear Stiffness and Energy Absorption of Auxetic Open Cell Foams as Sandwich Cores / H.C. Cheng [et al.] // Physica Status Solidi (B). – 2019. – Vol. 256, No. 1. – 1800411.*
31. *Vibro-Acoustic Properties of Auxetic Open Cell Foam: Model and Experimental Results / I. Chekkal [et al.] // Acta Acustica United with Acustica. – 2010. – Vol. 96. – P. 266–274.*
32. *Usta, F. High-Velocity Impact Resistance of Doubly Curved Sandwich Panels with Re-Entrant Honeycomb and Foam Core / F. Usta, H.S. Turkmen, F. Scarpa // International Journal of Impact Engineering. – 2022. – Vol. 165. – 104230.*

33. *Impact Properties of Uniaxially Thermoformed Auxetic Foams / Q. Zhang [et al.] // International Journal of Impact Engineering. – 2022. – Vol. 163. – 104176.*

34. *A Review on the Energy Absorption Response and Structural Applications of Auxetic Structures [Electronic resource] / M.B. Francisco [et al.] // Mechanics of Advanced Materials and Structures. – 2021. – Mode of access: https://www.researchgate.net/publication/355206997_A_review_on_the_energy_absorption_response_and_structural_applications_of_auxetic_structures. – Date of access: 12.10.2021.*

35. *Shil'ko, S.V. Structural Design and Tailoring of Composites to Obtain Near Zero Coefficient of Linear Thermal Expansion / S.V. Shil'ko, E.M. Petrokovets, Q. Zhang // Mekhanika mashin, mekhanizmov i materialov. – 2019. – No. 4 (49). – P. 55–60.*

36. *Unitsky, A. Meteorite Protection of Near Space Infrastructure on the Example of EcoCosmoHouse / A. Unitsky, R. Sharshov, S. Zharyi // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 211–222.*

37. *Unitsky, A. Protection of the General Planetary Vehicle from Meteoroids and Space Garbage / A. Unitsky, S. Pronkevich, V. Ausianka // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 203–209.*

38. *Nizkoporistyy auksetícheskiy listovoy material [Low-Porous Acoustic Sheet Material]: Patent RU 2,664,895 C2 / K. Berthol'di, M. Teylor, A. Shanian, M. Gerendas, K. Karson. – Published 23.08.2018.*

39. *Rant, D. Auxetic Textiles / D. Rant, T. Rijavec, A. Pavko-Čuden // Acta Chimica Slovenica. – 2013. – Vol. 60, No. 4. – P. 715–723.*

40. *Auxetic Aluminum Sheets in Lightweight Structures / W. Ripplinger [et al.] // Materials Testing. – 2018. – Vol. 60, No. 11. – P. 1071–1076.*

41. *Bulanov, A.V. Ispol'zovaniye auksetikov dlya proyektirovaniya stentov koronarnykh sosudov [The Use of Auxetics for the Designing Coronary Stents] / A.V. Bulanov, O.A. Bludova // Politekhnicheskiy molodozhnyy zhurnal. – 2017. – No. 10 (15). – P. 1–11.*

Simulation of Levitation in an Electromagnetic Field

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An analysis was carried out of the methods of mathematical modeling of electromagnetic levitation, which can be used to predict the movement of vehicles on an electromagnetic suspension, as well as to suspend and center the linear rotor of the General Planetary Vehicle (GPV) [1]. The main advantage of the reviewed method of lifting objects is the absence of friction and wear between the fixed and moving surfaces.
The author models the dynamics of electromagnetic levitation, the obtained results are compared with a full-scale experiment, earlier carried out by the researchers.

Keywords: *boundary element method (BEM), finite element method (FEM), finite element modeling, LS-DYNA, magnetic levitation.*

Introduction

Research in the field of magnetic interaction opens up a wide range of opportunities for the successful application of magnetic levitation methods in industry: in the manufacture of high-speed bearings designed to reduce noise and eliminate friction; in the creation of high-speed ground transport, etc. In addition, electrodynamic magnetic levitation can be used in a space transport system, in particular in the General Planetary Vehicle (GPV), where suspension and stabilization of the rotor in a vacuum tube with a length of about 40,000 km is required to exclude any contact with it [1].

The GPV is a reusable geocosmic transport developed by the engineer A. Unitsky, that allows exploration of near space without the use of rockets. It is a stabilized aerial device of a self-supporting structure, having the shape of a torus, along which the payload is distributed – passengers and cargo placed in special modules.

The functioning of the GPV is founded on principles based on the laws of physics: the flywheels inside the body accelerate to a speed higher than the orbital speed above sea level, and the device, due to the internal centrifugal force, increases in diameter (stretches) and takes off with the load [2].

Thus, the purpose of this study is to develop a technique for modeling levitation in an electromagnetic field.

Analysis of Electromagnetic Levitation Conditions

Currently, the following electromagnetic methods of supporting moving or rotating masses are used [3]:

- repulsion between fixed force magnets and ferromagnetic materials;
- levitation using repulsive forces and diamagnets;
- levitation with the use of superconducting magnets;
- levitation due to repulsive forces generated by eddy currents induced in the conducting surface;
- levitation using the force acting on a linear conductor with current;
- suspension using a tuned RLC circuit and an electrostatic attractive force;
- suspension using a tuned RLC circuit and a magnetic attractive force;
- suspension by means of controlled electromagnets of direct current and an attractive force of the magnetic field;
- mixed levitation system.

Of the above methods, some use repulsive forces, others use attractive forces. The former can be called levitation, the latter – the suspension technique [3]. Modern methods of modeling the interaction of bodies in a magnetic field can significantly reduce the time for evaluating such processes, which makes the use of computers relevant in the conditions under examination.

The phenomenon of electrodynamic magnetic levitation occurs when a rotating and/or moving permanent magnet or current coil creates an alternating magnetic field near a conductor. According to Ampère's law of induction, an electric field is induced in a moving metal surface, which causes the flow of eddy currents in an enclosed circuit near the surface of the conductor. Eddy currents, in turn, form their own magnetic field; its polarity, as per Lenz's law, is opposite to that of the magnet's field. Therefore, it repels itself from the moving metal surface, counteracting the force of gravity. If a magnet is pushed against a moving metal surface, the induced currents and the resulting repulsive force increase, automatically restoring the equilibrium position. Conversely, if the magnet moves upward, the levitating force decreases. This means that the system is internally stable.

It should be taken into account that the magnet must be held in place, since the induced eddy currents also cause an electromagnetic resistance force that tends to pull the magnet in the longitudinal direction along with the moving metal sheet. In practice, the stability of a suspended object is complicated by the fact that any deviation from the equilibrium position under the influence of a repulsive force leads to oscillation around this position. The oscillation may decrease or increase with time depending on whether the net damping force is positive or negative, respectively.

Both active and passive mechanisms can be used to provide pure positive damping and stable suspension. In the case of an attractive force, the feedback system mentioned above creates an effective positive damping force that weakens the harmonic oscillations. In the preferred configuration for most electrodynamic suspension systems, the magnets are placed on board and the electrical conductors – on the guide (Figure 1) [4].

In line with [3], stable equilibrium requires conditions in which all forces are compensated. However, according to the Earnshaw's theorem [5] and Lagrange – Dirichlet theorem [6], this is unrealistic to achieve. For a stable position of the body in the magnetic system, it is necessary to create a magnetic well, where the potential energy has a local minimum. The required condition for levitation in this sense is the presence of a force that compensates for the force of gravity, and a restoring force that ensures the stability of the object.

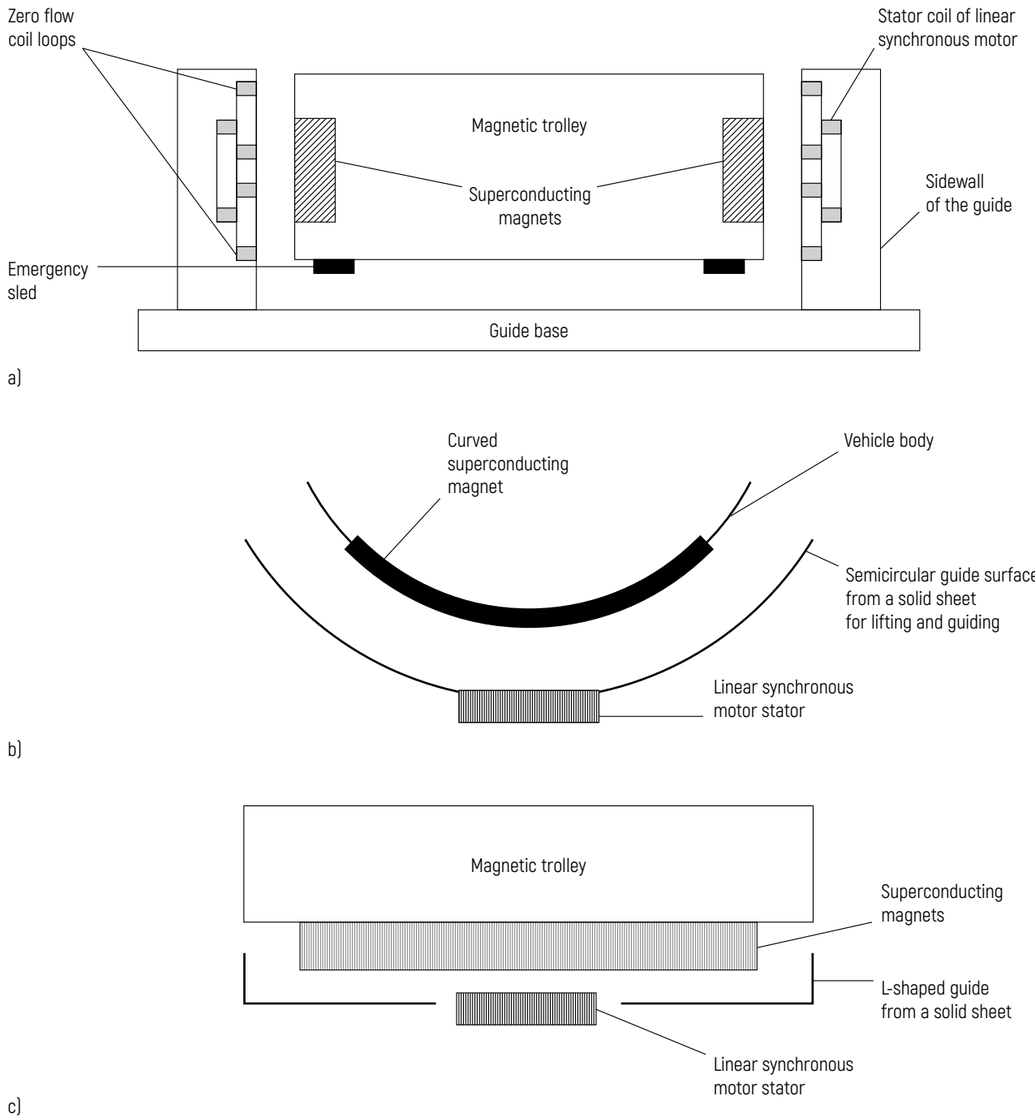


Figure 1 – Electrodynamic suspension systems using superconducting magnets:
a – with an air core in a U-shaped guide; b – with a semicircular guide from a solid sheet;
c – with L-shaped guide from a solid sheet

Under to Earnshaw's theorem, which is a direct consequence of Gauss's law, levitation of static objects in a static electromagnetic field is impossible. This theorem is applicable not only to point charges, but also to extended elastic bodies, from which it follows that their free suspension in an electrostatic, magnetostatic and gravitational field will always be unstable.

In practice, the indicated problem is solved by stabilizing not only in the vertical, but also in the horizontal planes, usually by organizing feedback in the electromagnetic system [3]. An example of a feedback system diagram is shown in Figure 2.

Sensors track the position of the body in space, and when it deviates from the desired equilibrium point, the parameters of the electromagnetic component of the system automatically change, returning the body to a given point. This approach does not contradict Earnshaw's theorem, since in this case the system is not static.

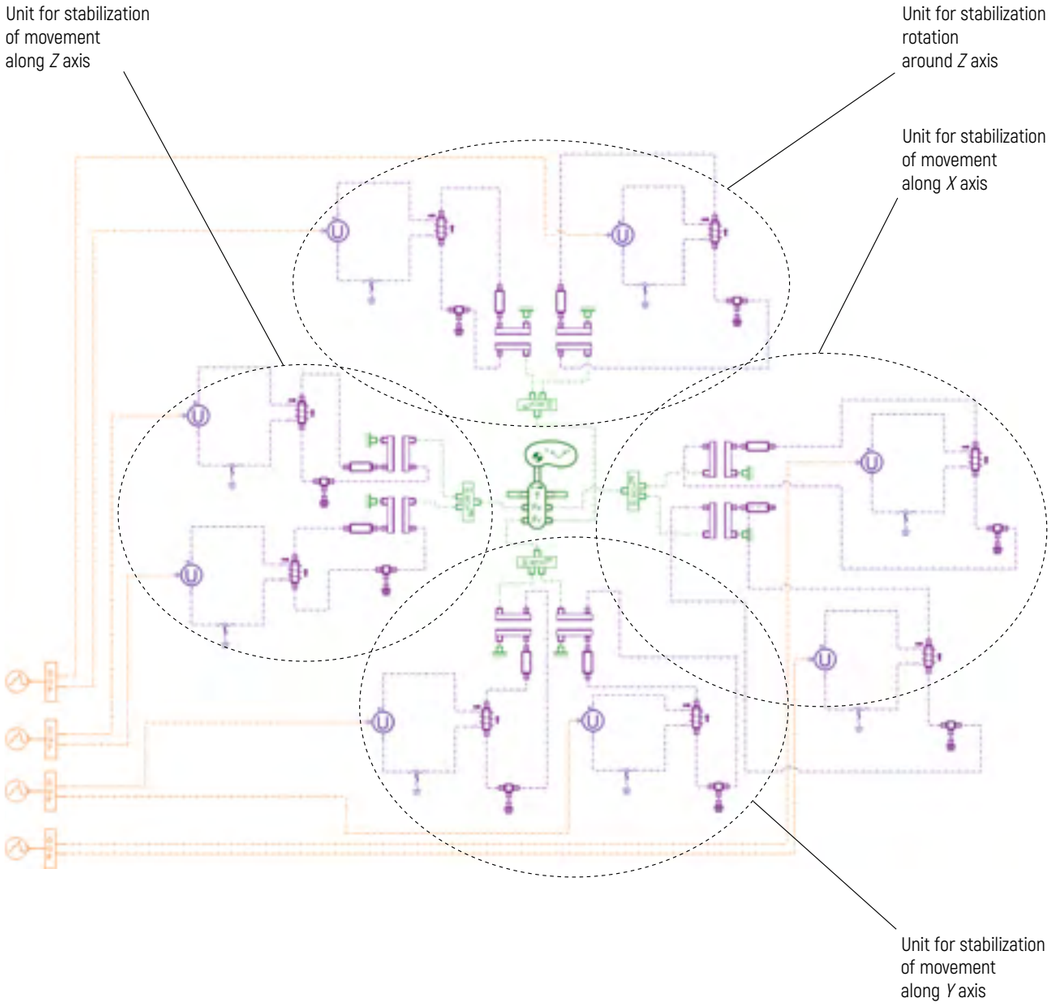


Figure 2 – Diagram of the feedback electromagnetic system

Overview of Electromagnetic Levitation Simulation

Magnetic levitation is one of the types of systems characterized by a variety of applications [7–10]. Its modeling is a complex problem, since, in addition to nonlinearities, one has to deal with an open-loop unstable system with fast dynamics and a very low degree of natural damping. The primary goal of control is the precise positioning of the levitating object, which requires a fairly accurate model.

The modeling of electromagnetic interaction is based on Maxwell's equations [11]. They are partial differential equations, so their solution is largely determined by the initial and boundary conditions. For processes that are harmonic in time, the uniqueness of the solution of the problem without initial conditions is ensured by an arbitrarily small absorption of energy inside the volume V or its leakage through the surface S, which excludes natural oscillations at real resonant frequencies.

The use of numerical methods expands the possibilities for solving Maxwell's equations and, in general, makes it possible to model the behavior of a system with electromagnetic interaction. The main methods are projection ones, in which the solution is projected onto some convenient functional basis, and discretization methods, where a region of space is divided into many small finite regions.

In the Bubnov – Galerkin projection method [12], the solution of the boundary value problem is considered in the form of an approximate finite decomposition in terms of basis functions. Substituting the decomposition into the original equations, with account of the requirement that constraints be orthogonal to the chosen basis functions, results in a system of linear equations for the expansion coefficients.

The finite difference method in the time domain for finding time and spectral dependences [13] was developed specifically for solving the Maxwell's equations, in which the change in the electric and magnetic fields in time depends on the change in the magnetic and electric fields in space, respectively. Within the framework of this method, a region of space and a time interval are subjected to uniform discretization with the assignment of initial conditions. The finite difference equations obtained from Maxwell's equations are solved at each subsequent moment of the time grid until a solution to the problem is found on the entire required time interval.

For computer calculations, more universal discretization methods are more often used. One of them is the finite element method (FEM), which is used for a wide class of problems that come down to partial differential equations. In the theory of electromagnetism, it is more often needed to calculate problems of electrostatics, magnetostatics, wave propagation and nonstationary modeling [14, 15]. In the FEM, the region of space in which a solution is sought is divided into a large number of simple discrete elements, usually triangular (in the two-dimensional case) or tetrahedral (in the three-dimensional case). The shape and density of the elements are adapted to the requirements of the task. The behavior of individual elements is considered as a result of the linear interaction of neighboring nodes of the partition lattice under the action of external forces and is described by matrix equations. Thus, the calculation comes down to solving sparse systems of a large number of linear matrix equations. The method is implemented in many commercial and free software packages.

In addition, some commercial software uses a combination of the FEM and the boundary element method (BEM). In this case, the BEM is practiced to simulate the air space between interacting bodies. The combination of two methods makes it possible not only to calculate the electromagnetic interaction, but also to take into account the mechanical movement of bodies, as well as temperature changes (Figure 3).

The mathematical model can be obtained from the main physical laws or with the help of identification methods based on the measurement of input and output data for an adequately excited system. Often these approaches are combined, the structure is determined according to a theoretical model, and the parameter values are estimated by the measured indicators using identification methods.

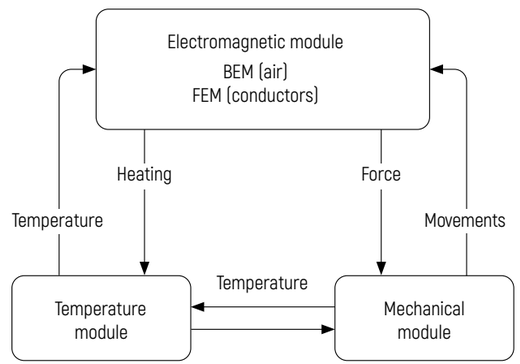


Figure 3 – Diagram for modeling a connected problem: electromagnetic – mechanical – thermal interaction

Description of the Calculation Module

The calculation model of levitation is an electrodynamic levitating device, which consists of two excitation coils and a conductive plate located above them (Figure 4).

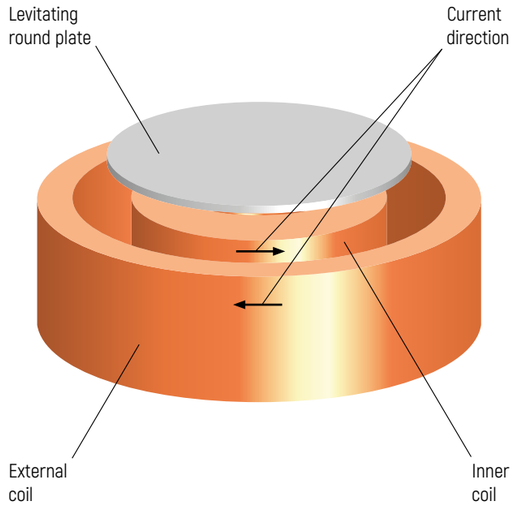


Figure 4 – Calculation model of electromagnetic levitation of the round plate

For the mathematical estimation of the model, Figure 5 shows the design diagram with the given geometric parameters of the levitation bodies.

The simulation was carried out in the LS-DYNA program using an electromagnetic module that allows solving Maxwell's equations in the eddy current (induction-diffusion) approximation, when the propagation of electromagnetic waves in air (or in vacuum) can be considered as an instantaneous phenomenon, as in the case of an electromagnetic field. The electromagnetic fields in the conductors are determined by the FEM, and the modeling of the ambient air/insulators is done by the BEM. Thus, there is no need to create a finite element mesh for air simulation and the movement of conductors can be easily controlled. The electromagnetic module allows introducing an electric current source into solid conductors and calculate the coupled magnetic and electric fields, as well as induced currents. This module is combined with mechanical and thermal solvers. Moreover, the Lorentz forces are added to the equations

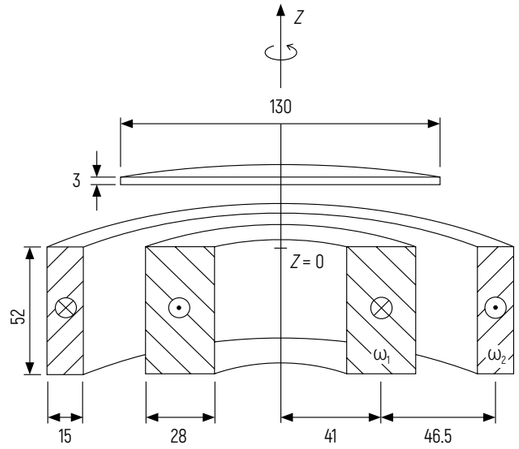


Figure 5 – Dimensions of the electromagnetic levitation device of the round plate, mm

of motion mechanics, and the heating of the conductors is added to the thermal solver in the form of an additional heat source.

The electromagnetic solver can be connected to various current or voltage sources, and in particular to an external circuit (RLC), where the user specifies the resistance (R), inductance (L) and capacitance (C) of the capacitor bank. The electrical parameters (resistance, inductance, mutual inductance) for the coil and workpiece are calculated simultaneously when modeling, taking into account the electrical properties and geometry of the coil and the deformable workpiece. Due to the presence of complete electromagnetic solver systems in the BEM, the cost of modeling an electromagnetic field is much higher compared to the conventional process in the LS-DYNA based only on the FEM.

Finite Element Modeling

As mentioned earlier, the electromagnetic calculation module is computationally demanding, therefore, to optimize the time required to solve the problem, an axisymmetric model was built. In order to reproduce the test case described in [16, 17], a uniform current was applied to the coils (the eddy current and, therefore, the BEM mesh were not calculated). Figure 6 shows an axisymmetric finite element model. Sinusoidal currents $i(t)$ flow through the coils in opposite directions.

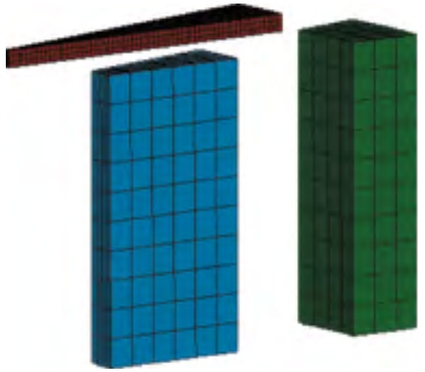


Figure 6 – Finite element model of electromagnetic levitation

To perform calculations, a software model was used with the parameters given in the Table below.

Table – Parameters of the model of electromagnetic levitation

Indicator	Value
Superimposed value of current amplitude, A (coil ω_1)	1.92×10^7
Superimposed value of current amplitude, A (coil ω_2)	1.15×10^5
Oscillation frequency, Hz (coils ω_1, ω_2)	50
Electrical conductivity of the plate, S/m	34
Plate density, kg/m^3	2.687×10^{-3}

Calculation Results

The simulation results show the concentration of the Lorentz force in the center of the plate (Figure 7). The dynamic characteristics are comparable with those obtained in [16, 17] and are in good agreement with experimental data at an oscillation frequency of 3.27 Hz.

Figure 8 shows a graph of vertical oscillations of the plate, demonstrating that after stabilization of the levitation process (time about 8 s), the height of interaction between the bodies is 38 mm.

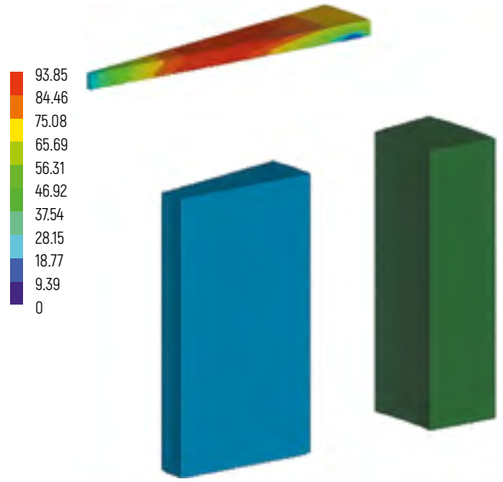


Figure 7 – Distribution of the Lorentz force in the model of electromagnetic levitation, N

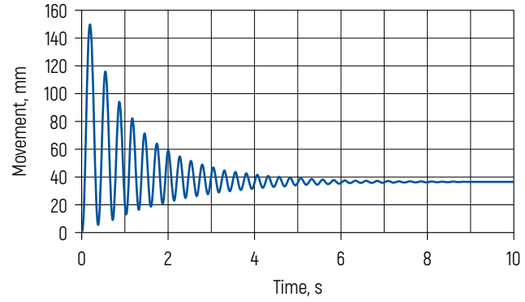


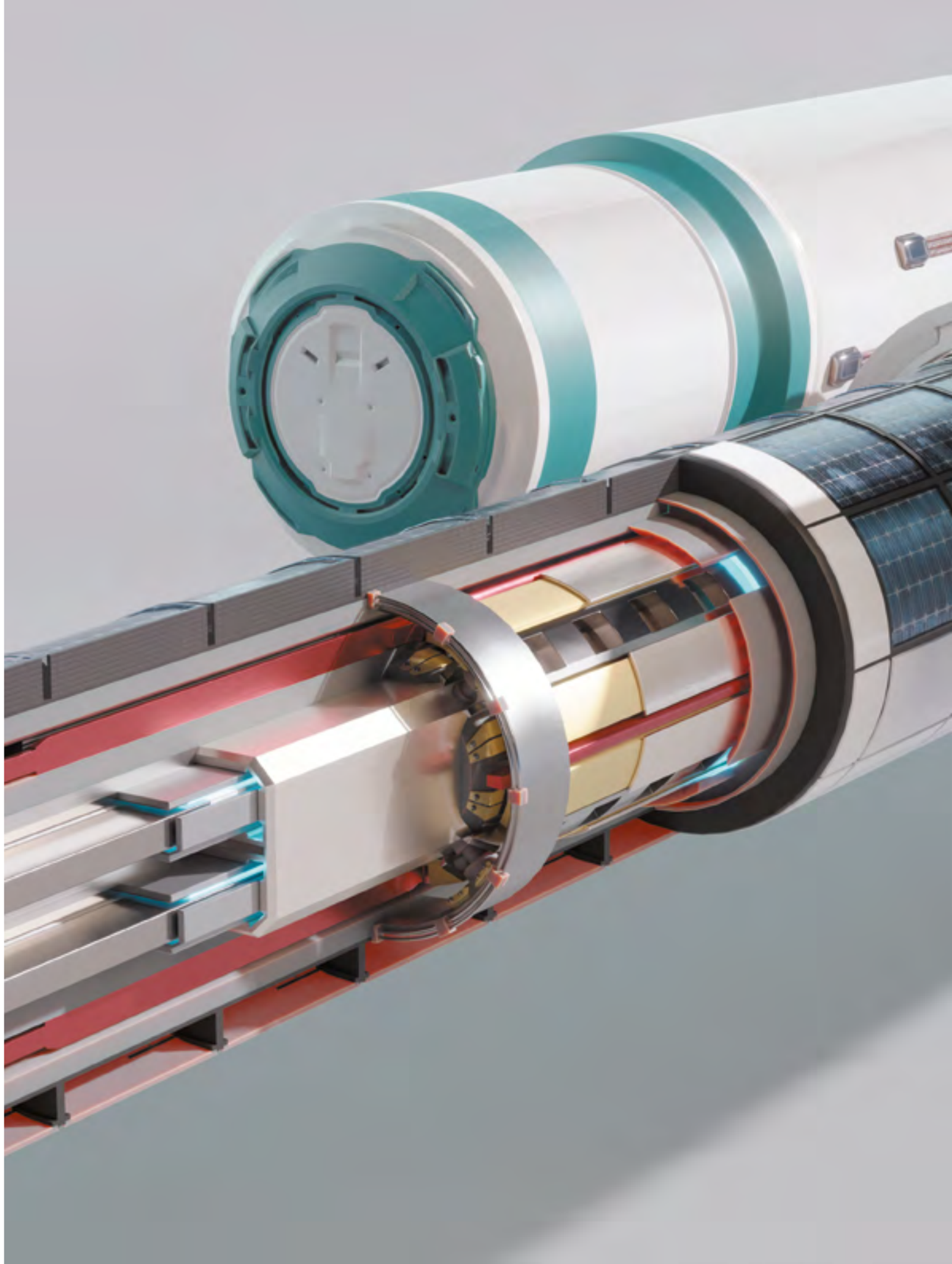
Figure 8 – Graph of vertical oscillations of the plate in an electromagnetic field

Conclusions and Future Work

Based on the proposed model of the interaction of magnetic bodies, a technique for modeling the levitation of a round plate in an electromagnetic field has been developed. The results of theoretical calculations showed that the main problem of the addressed phenomenon is the transverse resistance of the plate. Its destabilization leads to a failure in the system. In this regard, it is proposed to supplement the electromagnetic levitation system with a control and a feedback system. This solution will require additional calculations, which will be the goal of further research.

References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Obshcheplanetarnoye transportnoye sredstvo i kosmicheskoye ozherel'ye "Orbita" kak al'ternativa raketnomu osvoyeniyu okolozemnogo prostranstva [General Planetary Vehicle and the Space Necklace "Orbit" as an Alternative to Rocket Exploration of Near-Earth Space] / A.E. Unitsky [et al.] // Vestnik RUDN. Seriya: Inzhenernyye issledovaniya. – 2021. – Vol. 22, No. 4. – P. 364–372.*
3. *Jayawant, B.V. Electromagnetic Suspension and Levitation / B.V. Jayawant // Reports on Progress in Physics. – 1981. – Vol. 44, No. 4. – P. 412–477.*
4. *Rote, D.M. Magnetic Levitation / D.M. Rote // Encyclopedia of Energy. – Elsevier Science, 2004. – Vol. 3. – P. 691–703.*
5. *Earnshaw, S. On the Nature of the Molecular Forces Which Regulate the Constitution of the Luminiferous Ether / S. Earnshaw // Transactions of the Cambridge Philosophical Society. – 1842. – Vol. 7. – P. 97–112.*
6. *Ajzerman, M.A. Klassicheskaya mekhanika [Classical Mechanics] / M.A. Ajzerman. – Moscow: Nauka, 1980. – 368 p.*
7. *Holmer, P. Faster Than a Speeding Bullet Train / P. Holmer // IEEE Spectrum. – 2003. – Vol. 40, iss. 8. – P. 30–34.*
8. *Feasibility of Magnetic Suspension for Second Generation Gravitational Wave Interferometers / M.E. Varvella [et al.] // Astroparticle Physics. – 2004. – Vol. 21, No. 3. – P. 325–335.*
9. *Berkelman, P.J. Lorentz Magnetic Levitation for Haptic Interaction: Device Design, Performance, and Integration with Physical Simulations / P.J. Berkelman, R.L. Hollis // International Journal of Robotics Research. – 2000. – Vol. 19, No. 7. – P. 644–667.*
10. *Design and Control of a Microrobotic System Using Magnetic Levitation / M.B. Khamesee [et al.] // EEE/ASME Transactions on Mechatronics. – 2002. – Vol. 7, iss. 1. – P. 1–14.*
11. *Maxwell, J.C. A Treatise on Electricity and Magnetism / J.C. Maxwell. – London: Macmillan and Co., 1873. – 500 p.*
12. *Galorkin, B.G. Sterzhni i plastinki. Ryady v nekotorykh voprosakh uprugogo ravnovesiya sterzhney i plastinok [Rods and Plates. Rows in Some Questions of Elastic Equilibrium of Rods and Plates] / B.G. Galorkin // Vestnik inzhenerov. – 1915. – Vol. 1, No. 19. – P. 897–908.*
13. *Yee, K.S. Numerical Solution of Initial Boundary Value Problems Involving Maxwell's Equations in Isotropic Media / K.S. Yee // IEEE Transactions on Antennas and Propagation. – 1966. – Vol. 14, No. 3. – P. 302–307.*
14. *Hrennikoff, A. Solution of Problems of Elasticity by the Framework Method / A. Hrennikoff // Journal of Applied Mechanics. – Vol. 8, No. 4. – P. 169–175.*
15. *Courant, R. Variational Methods for the Solution of Problems of Equilibrium and Vibrations / R. Courant // Bulletin of the American Mathematical Society. – 1943. – Vol. 49, No. 1. – P. 1–23.*
16. *Description of TEAM Workshop Problem 28: An Electrodynamic Levitation Device / H. Karl [et al.] // Proceedings of the TEAM Workshop. – Graz, 1997. – P. 48–51.*
17. *Rapetti, F. An Overlapping Mortar Element Approach to Coupled Magneto-Mechanical Problems / F. Rapetti // Mathematics and Computers in Simulation. – 2010. – Vol. 80, iss. 8. – P. 1647–1656.*



Creation of Production Facilities in Near Space (On the Example of Extractive and Manufacturing Industries)

UDC 65.011.8:629.7

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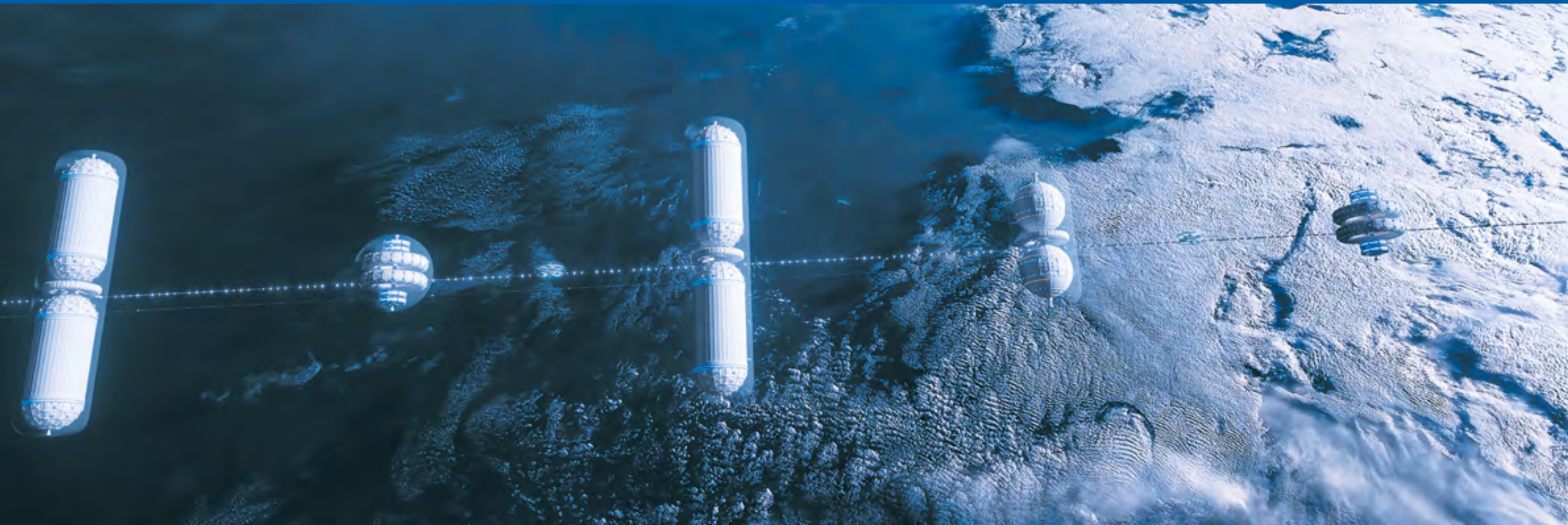
Based on a review of scientific literature, we confirmed the urgent need for space industrialization, creation of full-fledged industries in near-Earth space. In accordance with the methodology developed by the authors, including the use of statistical data and the method of expert evaluation, terrestrial industries (both extractive and manufacturing) were ranked to identify the feasibility of creating the corresponding production facilities in near space. Based on the results obtained in the course of the study, we made conclusions, as well as gave recommendations for their practical use.

Keywords: *criterion, evaluation methodology, expert evaluation, extractive industry, manufacturing industry, near space, practicability index, ranking, space industrialization, statistical data.*



Introduction

You all know that a favorable natural environment is a prerequisite and basis for economic prosperity and the health of humanity. At the same time, unsustainable patterns and global trends of manufacture and consumption, increasing the scale of use of natural resources, driven by population growth, technocratic and consumptive nature of human development, expose it more and more at risk, not coming closer to achieving the goals of sustainable development. Such changes are rapidly worsening the environmental, demographic and several other components of life on Earth, threatening to reduce to zero the progress in all spheres of life that has been made over the past 50 years. In order to eliminate the negative consequences and restore a healthy existence of all mankind, it is crucial to implement effective measures and strengthen international cooperation [1] to reduce greenhouse gas emissions, to switch to green transport and to create industries in outer space. One of the most global and obvious actions is the industrial development of space, the rationale for which is given in numerous writings of scientists, starting with K. Tsiolkovsky [2, 3].

It was back in 1911–1912 when K. Tsiolkovsky emphasized the high cost and low productivity of rocket technology [3], requiring significant fuel costs to carry cargo from Earth to orbit with the extremely grave ecological hazard of such geocosmic transportations.

The concept of non-rocket complex solution of space industrialization and scientific and engineering substantiation of such a project was proposed by engineer A. Unitsky [4, 5] through the General Planetary Vehicle (GPV) and Unitsky String Technologies (uST).

Despite the relevance and inevitability of near space industrialization, numerous scientific papers have so far revealed virtually no studies addressed to one important problem: how exactly (including with respect to the methodological approach) to select sectors of industry for their future functioning in near space.

In [6], the relevance of the creation of production facilities (using the example of specific sectors and enterprises) in Earth orbit is researched, taking into account a number of criteria, and a methodological approach to assessing the practicability of moving production facilities to near space is developed (the theoretical part is presented, without practical evaluation).

At the same time, it is of undoubted scientific interest to revise these approaches, improve the previously developed methodology and adapt it to sectors of industry (both extractive and manufacturing), as well as conduct an actual evaluation and rank industries recommended for creation (including relocation) in near space. This study is addressed to solving these problems.

Literature Review

In [6], based on the statistical data [7], they analyzed individual indicators of human development related to natural, environmental and industrial components on a global scale since 1990. This is the general situation and trends that have been developed to date: "The number of people living on Earth has increased by almost 1.5 times over the past 30 years, while the increase of the share in total energy consumption and carbon dioxide emissions (per capita) has become still greater; the added value in industry has almost doubled (together with the ever-increasing volumes of industrial production). This has resulted in a significant reduction in the area of arable land and forests. In spite of numerous remedial (recreational) activities undertaken by governments and international organizations, it is impossible to stop this trend" [6].

Thus, the only possible reasonable and feasible scenario for saving mankind from imminent catastrophic environmental consequences is the industrial development of space.

Back in 1982 a Belarusian engineer A. Unitsky conducted a system analysis in [4] of the inevitability of near space industrialization by the Earth's civilization: "Our industry is adapted to the conditions on Earth, since there was no choice. Space provides it to us. Incredible opportunities are opening up to locate plants and factories in weightlessness, deep vacuum, ultra-low and ultra-high temperatures, enhanced radiation... And these conditions are just around the corner – a few hundred kilometers away. Most of manufacturing processes will be much more effective and efficient in outer space and mass production will rise to a new qualitative level. Just as now the factory shops are relocated outside the residential area, in the future the main component of production will be moved outside our common home – the Earth, which will be transformed into an evergreen place for life, education and recreation of earthlings. To accomplish all this, geocosmic transport must not only have an annual capacity of billions of tons, but also a low cost of transportation."

In 1983, an American fiction writer and scientist I. Asimov made a prediction for The Stare about the need to develop space based on its advantages: "In fact, projects might even be on the planning boards in 2019 to shift industries into orbit in a wholesale manner. Space... is far more voluminous than Earth's surface is and it is therefore a far more useful repository for the waste that is inseparable from industry. Nor are there living things in space to suffer from the influx of waste. And the waste would not even remain in Earth's vicinity, but would be swept outward far beyond the asteroid belt by the solar wind. Earth will then be in a position to rid itself of the side-effects of industrialization, and yet without actually getting rid of its needed advantages. The factories will be gone, but not far, only a few thousand miles straight up" [8].

In [9] the feasibility of space industrialization and relocation of heavy industries into orbit is also substantiated. At the same time, a Canadian engineer E. Kulu, who focuses a considerable part of his scientific research to the study of space and is the owner of a dedicated website, predicts: although no factories have been built and operated in space so far, they will become commonplace by the end of the 2030s [8].

Numerous literary sources and previously presented materials [6] suggest that industry is one of the main polluters of the environment, as it spans all stages of the resource cycle: extraction of natural raw materials (extractive industry), their processing (manufacturing industry), obtaining the finished product and return of industrial waste to the environment.

In addition, various sectors and directions of industry differ significantly from each other in the extent and nature of the environmental impact (atmosphere, hydrosphere, lithosphere). The most negative impact on the living shell of the planet and its natural system – the biosphere – is caused by such sectors as energy, metallurgy, transport and chemical ones [10].

At the same time, the research results of only a few experts (both Belarusian and foreign) trace ideas and individual concepts regarding the scientific and practical problem of selecting sectors of industry for their deployment off-planet. Among such authors, whose writings are publicly available, are A. Unitsky, V. Klyushnikov, N. Sinyuk, A. Babayan, E. Kulu, E. Rush, etc.

However, scientific papers, except for [6], lack methodological approaches to the selection of industries or individual production facilities for creation of the corresponding industries in space.

Furthermore, we should point out that it is the manufacturing industry, associated with the processing of extracted raw materials and energy (and thus with waste products and considerable hazardous emissions), that poses the biggest danger to the biosphere and to all mankind. However, to consider the impact of industry on the biosphere in terms of its manufacturing component alone, does not seem correct and relevant enough. That is why this study gives a complex approach by considering the processes of creation (including those on the basis of relocation) of sectors of industry in near space on the example of extractive and manufacturing industries. This approach is assumed to enable in the future to achieve the maximum effect (from economic, logistical, engineering and other points of view) from the creation of production facilities and entire industries in near space.

This methodology is adapted to sectors of industry (both extractive and manufacturing) and is based on an appropriate assessment, which includes a symbiosis of reliable statistical data for 2017–2020 of the largest country on the planet – the Russian Federation – and information obtained by expert evaluation.

Method Description

The developed methodology for assessing the practicability of creating production facilities in near space is based on a criterial approach relying on the use of eight criteria with a similar number of corresponding indicators (one indicator per criterion) and the unequal influence of their weight coefficients (specific weights) determined by expert method (Table 1).

In general, the values of the specific weights of the criteria under study slightly differ from similar values given and substantiated earlier in [6].

At the same time, taking into account the revision of individual approaches focused on the objectivity of calculations and the scale of data coverage (macro- and meso-levels), as well as the elimination of some redundancies and shortcomings compared to [6], we proposed to introduce three new criteria, with the values of indicators determined through statistical data:

- "Consumption of energy and fuel";
- "Number of organizations in each sector";
- "Involvement of manpower".

Hovewer, the criteria "Place of location", "Energy capacity" and "Manufacturing area" used in [6] are excluded for the above reasons.

The extractive and manufacturing industries cited in this article correlate perfectly with the International Standard Industrial Classification of All Economic Activities [11].

Although certain sectors of industry (e.g., production of crude oil and natural gas) are not currently represented by the availability of appropriate raw material in space, this study examined each sector [11], which is aimed at conducting a comprehensive analysis and evaluation, as well as the adequacy (relevance) of the developed methodology.

The calculations carried out through the specified methodology produce an integral value of the practicability index in terms of the deployment of production facilities in near space (hereinafter referred to as practicability index *I*) and allow a corresponding ranking of industries.

The values of the indicators for four of the eight criteria (1–4) are identified based on reliable general statistical data on the example of the Russian Federation, and for other four (5–8) – by expert analysis, including the analysis of various dedicated references [12–15], the expert position of individual domestic scientists with assigning a value of adjustment factor δ from 0 to 1 (0; 0.5; 1), depending on the relation of the values of sector indicators for criteria 5–8 of to the scale as per Table 1.

It is quite impossible to search for analytical (statistical) world data on the indicators for criteria 1–4 specified in Table 1 in dedicated scientific literature. This fact is confirmed by the absence of such information in response to inquiries (December 2021) to 12 competent international organizations. That is why reliable actual statistical data of the Federal State Statistics Service of the Russian Federation for 2017–2020 were used for the research and evaluation relying on the developed methodology (in terms of criteria 1–4 and their corresponding indicators) [16, 17].

The largest country in the world – the Russian Federation – occupies 11.4 % of the total land area of the planet (including Antarctica). At the same time, the length of the territory from west to east is about 10,000 km, which is comparable to the diameter of the planet (12,700 km). The country is distinguished by a variety of minerals, fuel and energy resources, climatic belts, relief and other natural assets, which creates both suitable conditions for the development of numerous extractive and manufacturing industries, and objective opportunities for analysis by the indicators of criteria 1–4 from Table 1 and the subsequent assessment. In addition, open sources owned by the competent Russian authorities, unlike analytical materials of other major countries of the world, contain a sufficient amount of reliable statistical information in the field of industry after 2016 [18].

Table 1 – Matrix for assessing the practicability of creating production facilities in near space (on the example of extractive and manufacturing industries)

Criterion	Indicator of corresponding criterion, unit of measure		Criterion weight factor *K* (from 0 to 1)	Adjustment factor δ / the values of indicators (0; 0.5; 1)		
				1	0.5	0
1. Consumption of energy and fuel	Total consumption of energy and fuel in the sector, mln tons of fuel equivalent	The values are determined through statistical data	0.15	See the calculation in Table 2		
2. Hazardous substances emissions	Total hazardous emissions into the atmosphere from stationary emitters in the sector, thous. tons		0.2	See the calculation in Table 2		
3. Number of organizations in each sector	Number of organizations, which are engaged mainly in this sector, thous. units		0.1	See the calculation in Table 2		
4. Involvement of manpower	Average number of employees in the sector, thous. people		0.05	See the calculation in Table 2		
5. Duration of manufacturing process	Average duration of transformation of raw materials (materials and supplies, semi-finished products) into finished products on the Earth in the sector, days	The values are determined through expert analysis	0.1	More than 30	5–30	Less than 5
6. Availability of resources in near space	Assumed availability of resources and raw materials (minerals, solar energy, materials, etc.) in near space necessary for proper production activities in the sector		0.15	In ample supply	Infrequent occurrence (sporadically)	Total absence
7. Quality (competitiveness) of products	Assumed improvement of performance, including service life, of products manufactured (extracted) in space due to natural properties of the environment (weightlessness, deep vacuum, technological purity, etc.)		0.15	Considerable (multiple times / tens of times)	Minor (without significant changes)	Degradation
8. Need for labor force	Rough share of employees, which is reasonable to relocate into near space together with the production facilities to ensure operations (assuming maximum robotization of manufacturing processes), % of the total number of employees		0.1	Less than 20	20–50	More than 50

Based on the developed methodology, practicability index *I* is calculated through the following original formula:

$$I = [(\sum_{n=1}^{2} K_n \times X_n) + (\sum_{n=3}^{4} K_n \times (1 - X_n)) + (\sum_{n=5}^{8} K_n \times \delta_n)] \times 100\ \%, \quad (1)$$

where *I* – practicability index (ranging from 0 to 100 %);

n – ordinal number of a criterion (1–8);

K – weight factor of each criterion which reflects its priority in the creation of production facilities in space;

X – normalized values of criteria 1–4 based on the actual values of the corresponding indicators;

δ – adjustment (estimated) factor for criteria 5–8, depending on the expert assignment of values for the sector to a certain category by the scale.

Calculation of the values of practicability index *I* in terms of adjustment factors for criteria 1–4, with the actual values of the indicators taken from the statistical data of the Russian Federation, was carried out on the basis of one of the most widely used statistical methods for such cases – minimax data normalization method [19].

The normalized value of X for criteria 1–4 and their corresponding indicators is obtained by formula:

$$X_i = \frac{X_{i\,actual} - X_{i\,\min}}{X_{i\,\max} - X_{i\,\min}}, \quad (2)$$

where X_i – actual normalized value of the i^{th} indicator (from 0 to 1);

$X_{i\,actual}$ – actual value of the i^{th} indicator for the sector under consideration during the study period (from 2017 to 2020);

$X_{i\,\min}$, $X_{i\,\max}$ – minimum and maximum values of the i^{th} indicator for the criterion during the same period among all industries.

For indicators calculated by criteria 1 "Consumption of energy and fuel" and 2 "Hazardous substances emissions" we use a direct proportional dependence: the maximum normalized value for each of them (as applied to industries) means the highest degree of feasibility of creating production facilities in space. For criteria 3 "Number of organizations in each sector" and 4 "Involvement of manpower", based on economic and logical considerations, we apply an inverse proportional dependence (the industries which are currently represented on the planet by the minimum number of organizations and employees are mainly recommended for creation in near space).

Outcomes and Analysis

Based on the developed methodology for determining industry-specific practicability index I, we made the appropriate calculations. In this case, we used the summary data from Tables 2 (for criteria 1–4 and their corresponding indicators) and 3 (criteria 5–8 and their corresponding indicators).

Table 2 – Summary of statistical data for 2017–2020 for the Russian Federation and their normalized values for individual indicators (criteria 1–4 in Table 1) by sectors of industry

Subsection* and type (sector) of industry	Value of an indicator by criteria							
	Criterion 1		Criterion 2		Criterion 3		Criterion 4	
	Total consumption of energy and fuel in the sector, mln tons of fuel equivalent**	Normalized value of X_1	Total hazardous emissions into the atmosphere from stationary emitters in the sector, thous. tons	Normalized value of X_2	Number of organizations, which are engaged mainly in this sector, thous. units	Normalized value of X_3	Average number of employees in the sector, thous. people	Normalized value of X_4
1	2	3	4	5	6	7	8	9
Extractive industry								
05. Mining of coal and lignite	20.4	0.076	4,713.5	0.439	0.8	0.014	141.2	0.184
06. Extraction of crude petroleum and natural gas	163.6	0.617	9,631.3	0.896	1.4	0.031	223.3	0.296
07. Mining of metal ores	39.1	0.146	3,773	0.351	3.4	0.082	183.5	0.242
08. Other mining and quarrying	15.6	0.057	498.2	0.046	8.2	0.207	90.2	0.114

End of Table 2

1	2	3	4	5	6	7	8	9
Manufacturing industry								
10. Manufacture of food products	37.8	0.141	752.4	0.07	36.1	0.932	740.3	1
11. Manufacture of beverages	6.4	0.023	146.9	0.013	6.4	0.159	92.9	0.118
12. Manufacture of tobacco products	1.4	0.004	2.2	0	0.3	0	6.2	0
13. Manufacture of textiles	1.6	0.004	17.9	0.001	6.5	0.161	50.3	0.06
14. Manufacture of wearing apparel	1.2	0.003	7	0	13	0.33	73.5	0.092
15. Manufacture of leather and related products	0.4	0	16.9	0.001	1.9	0.044	26.8	0.028
16. Manufacture of wood and of products of wood and cork, except furniture	13.7	0.05	444.9	0.041	22.5	0.577	114.3	0.147
17. Manufacture of paper and paper products	28.2	0.105	369.7	0.034	3.9	0.094	87.5	0.111
18. Printing and reproduction of recorded media	12.5	0.046	12.2	0.001	13.9	0.355	33.7	0.037
19. Manufacture of coke and refined petroleum products	146.9	0.554	2,686.2	0.25	1.3	0.027	128.5	0.167
20. Manufacture of chemicals and chemical products	107.2	0.404	1,552.9	0.144	10.6	0.269	310.2	0.414
21. Manufacture of pharmaceuticals, medicinal chemical and botanical products	11.1	0.04	9.9	0.001	2.1	0.047	71.5	0.089
22. Manufacture of rubber and plastics products	8.4	0.03	81.2	0.007	17.4	0.444	136.4	0.177
23. Manufacture of other non-metallic mineral products	66.8	0.251	1,521.3	0.141	24.1	0.621	298.4	0.398
24. Manufacture of basic metals	264.9	1	10,745.6	1	3.9	0.094	456.7	0.614
25. Manufacture of fabricated metal products, except machinery and equipment	93	0.35	142.3	0.013	38.7	1	456.9	0.614
26. Manufacture of computer, electronic and optical products	7.4	0.027	131.6	0.012	8.9	0.224	357.3	0.478
27. Manufacture of electrical equipment	4.8	0.017	62.2	0.006	8.1	0.204	187.1	0.246
28. Manufacture of machinery and equipment n.e.c.	12.1	0.044	162.6	0.015	16	0.408	303.5	0.405
29. Manufacture of motor vehicles, trailers and semi-trailers	10.2	0.037	107.1	0.01	3.1	0.073	259.4	0.345
30. Manufacture of other transport equipment	16.6	0.061	168	0.015	3.7	0.09	598.7	0.807
31. Manufacture of furniture	5	0.017	28.6	0.002	16.6	0.424	51.7	0.062
32. Other manufacturing	2.4	0.007	9.3	0.001	7.8	0.196	39.5	0.045

* According to [11].

** A ton of fuel equivalent is the energy unit of measure adopted in the Russian Federation, which is equal to 2.93×10^{10} J; it is defined as the amount of energy released during the combustion of a ton of fuel with a calorific capacity of 7,000 kcal/kg (which corresponds to the typical calorific capacity of bituminous coal) [16, 17].

Table 3 – Values of adjustment (estimated) factor δ (0; 0.5; 1) for criteria 5–8 of Table 1, taking into account the expert assignment of values by each sector to a particular category

Subsection* and type (sector) of industry	Values of adjustment factor δ			
	Criterion 5	Criterion 6	Criterion 7	Criterion 8
Extractive industry				
05. Mining of coal and lignite	0	0	0	0
06. Extraction of crude petroleum and natural gas	0.5	0	0	0
07. Mining of metal ores	0.5	1	1	0
08. Other mining and quarrying	0.5	1	1	0
Manufacturing industry				
10. Manufacture of food products	0	0	0.5	1
11. Manufacture of beverages	0	0	0.5	1
12. Manufacture of tobacco products	0	0	0.5	1
13. Manufacture of textiles	0.5	0	0.5	1
14. Manufacture of wearing apparel	0.5	0	0.5	1
15. Manufacture of leather and related products	0.5	0	0.5	1
16. Manufacture of wood and of products of wood and cork, except furniture	0.5	0	0	1
17. Manufacture of paper and paper products	0.5	0	0.5	1
18. Printing and reproduction of recorded media	0	0	0	1
19. Manufacture of coke and refined petroleum products	0	0	0.5	1
20. Manufacture of chemicals and chemical products	0.5	0.5	1	1
21. Manufacture of pharmaceuticals, medicinal chemical and botanical products	0.5	0	1	1
22. Manufacture of rubber and plastics products	0.5	0	1	1
23. Manufacture of other non-metallic mineral products	0.5	0	1	1
24. Manufacture of basic metals	0.5	1	1	0.5
25. Manufacture of fabricated metal products, except machinery and equipment	0.5	1	1	0.5
26. Manufacture of computer, electronic and optical products	0.5	0.5	1	1
27. Manufacture of electrical equipment	0.5	0.5	1	1
28. Manufacture of machinery and equipment n.e.c.	0.5	0.5	1	0.5
29. Manufacture of motor vehicles, trailers and semi-trailers	0.5	0.5	1	0.5
30. Manufacture of other transport equipment	0.5	0.5	1	0.5
31. Manufacture of furniture	0.5	0	0.5	1
32. Other manufacturing	0.5	0.5	0.5	1

* According to [11].

Based on the above formulas (1), (2) and the data of Tables 1–3, we calculated the integral values of practicability index *I* by industries. The corresponding ranking of manufacturing and extractive industries is shown in Figures 1 and 2, respectively.

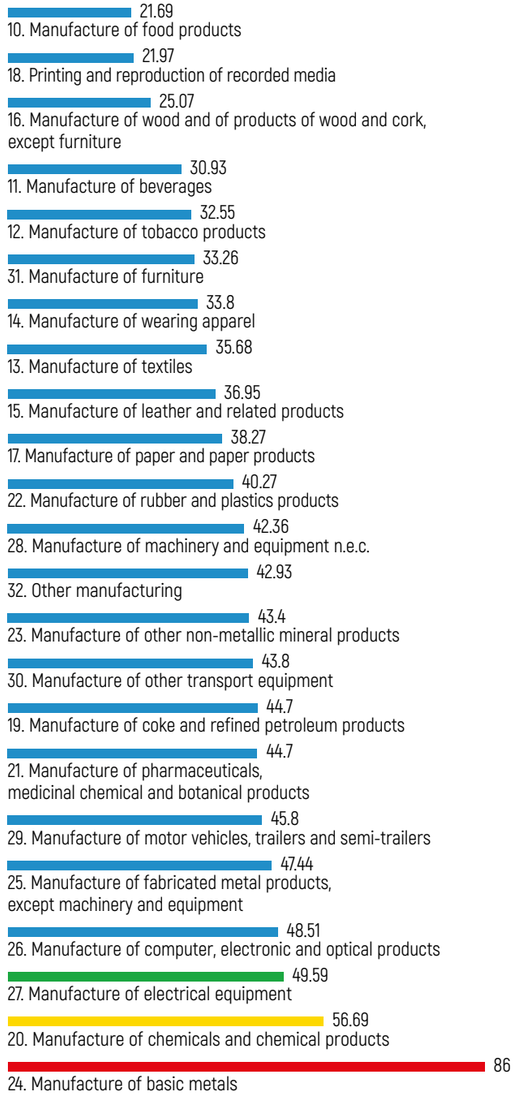


Figure 1 – Ranking of manufacturing industries recommended for creation in near space, depending on practicability index *I*, %

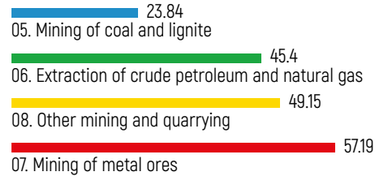


Figure 2 – Ranking of extractive industries recommended for creation in near space, depending on practicability index *I*, %

Conclusions and Future Work

World trends of manufacture and consumption, population growth, hazardous emissions into the environment, and also technocratic and consumptive nature of human development confirm the necessity of the urgent space exploration (and in a non-rocket manner). On this basis we improved the methodology developed earlier in [6] and adapted it to manufacturing and extractive industries: it is supposed to carry out the actual evaluation and ranking of sectors recommended for creation (including relocation) in near space.

As a result, the following manufacturing industries seem the most feasible for creation in near-Earth space:

- manufacture of basic metals (practicability index *I* is 86 %);
- manufacture of chemicals and chemical products (56.69 %);
- manufacture of electrical equipment (49.59 %);
- manufacture of computer, electronic and optical products (48.51 %);
- manufacture of fabricated metal products, except machinery and equipment (47.44 %).

At the same time, manufacture of food products, as well as printing, were identified as those industries that seem premature and not feasible at present in terms of their creation and relocation off-planet.

Based on the results of the evaluation through the above methodology, the following extractive industries seem to be the most feasible in terms of their creation off-planet:

- mining of metal ores (practicability index *I* is 57.19 %);
- other mining and quarrying (49.15 %).

Thus, as part of the forthcoming creation of a new space economy with its unlimited capacities and resources, the results of this study are relevant and can be used by the competent public administration and organizations, including international ones (engaged primarily in the study of space and related problems), as well as by the industrial enterprises

to assess their own capabilities and feasibility of creating production facilities (sectors) off-planet in the near future.

The range of environmental problems and related climate change is a severe crisis, and its consequences are becoming more and more pronounced. The application of the proposed methodological approach may soon make it possible to assist in the implementation of a technological breakthrough and the relocation of the most harmful industrial productions into space, thus ensuring a safe environment on Earth. At the same time, thanks to the agreed work of society, humanity will make a leap and create a really green planet, on which the harmony between people and the environment will be restored.

References

1. *Global Environment Outlook 6 [Electronic resource] // UN Environment Programme. – Mode of access: https://www.unep.org/resources/global-environment-outlook-6?_ga=2.156459387.1569948175.1636633375-320521572.1636633375. – Date of access: 15.03.2022.*
2. *Tsiolkovskiy, K.E. Promyshlennoye osvoyeniye kosmosa [Industrial Space Exploration]: Collection of Works / K.E. Tsiolkovskiy. – Moscow: Mashinostroyeniye, 1989. – 280 p.*
3. *Tsiolkovskiy, K.E. Issledovaniye mirovykh prostranstv reaktivnymi priborami [Exploration of World Spaces with Jet Devices] / K.E. Tsiolkovskiy. – Kaluga: 1-ya Gostipografiya GSNKH, 1926. – 128 p.*
4. *Unitsky, A. Peresadochnaya, kosmicheskaya, kol'tsevaya [Interchange, Cosmic, Circular] / A. Unitsky // Izobretatel' i ratsionalizator. – 1982. – No. 4. – P. 28–29.*
5. *Unitsky, A.E. Strunnyye transportnyye sistemy: na Zemle i v Kosmose [String Transport Systems: On Earth and in Space] / A.E. Unitsky. – Gomel: Infotribo, 1995. – 337 p.: il.*
6. *Unitsky, A. Selection of Industries for Their Transfer to Near Space / A. Unitsky, A. Klimkov // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 137–145.*
7. *Indicators [Electronic resource] // The World Bank. – Mode of access: https://data.worldbank.org/indicator?tab=all. – Date of access: 15.03.2022.*
8. *In-Space Manufacturing & Space Economy [Electronic resource] // Factories in Space. – Mode of access: https://www.factoriesinspace.com/. – Date of access: 20.03.2022.*
9. *What Excites You About In-Space Manufacturing? [Electronic resource] // Filling Space. – Mode of access: https://filling-space.com/2021/02/26/what-excites-you-about-in-space-manufacturing/. – Date of access: 20.03.2022.*
10. *Promyshlennost' i okruzhayushchaya sreda – geografiya otrasley mirovogo khozyaystva [Industry and the Environment – Geography of World Economy Sectors] [Electronic resource] // Compendium.school. – Mode of access: https://compendium.su/geographic/world/109.html. – Date of access: 04.03.2022.*
11. *International Standard Industrial Classification of All Economic Activities (ISIC): Rev. 4 [Electronic resource] / United Nations Organization. – Mode of access: https://unstats.un.org/unsd/classifications/Econ/Download/In%20Text/ISIC_Rev_4_publication_English.pdf. – Date of access: 19.03.2022.*
12. *Production [Electronic resource] // Astroengineering Technologies. – Mode of access: https://aet.space/production. – Date of access: 10.03.2022.*
13. *In-Space Manufacturing: One Giant Leap for Robotkind [Electronic resource] // Aerospace Manufacturing. – Mode of access: https://www.aero-mag.com/in-space-manufacturing-one-giant-leap-for-robotkind. – Date of access: 10.03.2022.*
14. *In-Space Manufacturing [Electronic resource] // NASA. – Mode of access: https://www.nasa.gov/oem/inspace-manufacturing. – Date of access: 11.03.2022.*
15. *In-Space Production Applications: Advanced Manufacturing and Materials [Electronic resource] // ISS National Laboratory. – Mode of access: https://www.issnationallab.org/ispa-materials-manufacturing/. – Date of access: 11.03.2022.*
16. *Promyshlennoye proizvodstvo v Rossii. 2019 [Industrial Production in Russia. 2019]: Statistical Compendium. – Moscow: Rosstat, 2019. – 286 p.*
17. *Promyshlennoye proizvodstvo v Rossii. 2021 [Industrial Production in Russia. 2021]: Statistical Compendium. – Moscow: Rosstat, 2021. – 305 p.*
18. *Geografiya Rossii [Geography of Russia] [Electronic resource] // Wikipedia. – Mode of access: https://ru.wikipedia.org/wiki/География_России#:~:text=Россия%2 –%20трансконтинентальное%20государство%2C%20расположенное%20на,в%20мире%20государством%20по%20территории.&text=Крайние%20северная%20и%20восточная%20материковые,ш. – Date of access: 11.03.2022.*
19. *Normalizatsiya dannykh [Data Normalization] [Electronic resource] // Loginom. – Mode of access: https://wiki.loginom.ru/articles/data-normalization.html. – Date of access: 14.03.2022.*

Integrated Use of Brown Coal in Relict Solar Bioenergy

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UDC 552.576.1:547.992.2:662.757

An overview on the integrated use of brown coal in the creation of relict solar bioenergy (RSBE) is presented. Developments in this area are an important component of the eco-oriented technological platform uEnergy, necessary for the implementation of the EcoSpace program [1]. There are identified the key points of the integrated use of brown coal, which contributes to the introduction of environmentally friendly RSBE, minimally affecting the nature and providing thermal power plants with fuel, and plants – with organic fertilizers. The effectiveness of the method of brown coal wet breakage within the range of 0–100 μm has been experimentally confirmed, which allows to extract humic substances for plant nutrition and to obtain coal-water fuel (CWF).

Keywords: *brown coal, coal grinding, coal-water fuel (CWF), fraction size, humic substances, organic fertilizers.*

Introduction

Relict solar bioenergy (RSBE) is a power industry based on the use of fossil shale and brown coal in order to obtain clean energy and the associated production of living humus intended to restore the fertility of poor and desert lands. RSBE will activate the mineral wealth of ancient soils and the energy of the ancient Sun accumulated by living organisms, primarily plants, during the Mesozoic and Cenozoic periods and then stored in fossil fuels [2].

Brown coal is a rock of plant origin, having a complex multicomponent structure. The composition and properties of microcomponents determine the variety of coal, as well as the choice of the direction of its processing. Unlike other natural combustible minerals (natural gas, oil), coal is characterized by a rich mineral composition (includes more than 80 chemical elements) and has a wider range of physical and technological properties.

In addition, brown coal was the main fuel during the Industrial Revolution. Now it continues to play an important role in the electric power industry, despite the fact that it has been replaced by other resources in many sectors.

The world's coal reserves are more than four times higher than the total reserves of other combustible minerals (oil, gas, peat, shale): the share of coal in terms of geological reserves is 89.53 %, in terms of conditionally mined – 82.66 % [3].

For comparative analysis, the following relevant statistical information is provided: the volume of global coal consumption in 1990–2021 (Figure 1); the volume of coal consumption by countries in 2021 (Figure 2); the share of coal in total energy consumption in 2021 (Figure 3) [4].

Coals are distinguished by a wide variety of composition and properties, which is due to geological and genetic factors that determine the process of coal formation in various conditions and structural zones of the Earth's crust (source material, conditions of accumulation and transformation of matter, exposure to different temperatures and pressures).

According to the composition of the parent substance, coals are divided into humus, sapropel and humus-sapropel. Humus coals were formed from the residues and decomposition products of terrestrial plants; sapropel coals – from algae and their decomposition products. Humus coals are the most widespread and are widely used as fuel and technological raw material [5].

Almost all elements of the periodic table are present in the coals, the concentrations of which vary widely. It is advisable to divide these elements into several groups:

1) main components (the content exceeds 0.1 %, or 1,000 g/t) – carbon, hydrogen, oxygen, nitrogen, sulfur, silicon, aluminum, iron, magnesium, sodium, potassium, titanium, calcium. The listed elements are called macrocomponents of the mineral part or (with the exception of sulfur) ash-forming elements, since they form the bulk of the ash;

2) small components (the content less than 1,000 g/t). This group is usually divided into three subgroups:

- excessively small elements (the content ranges from 10 to 1,000 g/t) – boron, fluorine, phosphorus, chlorine, sometimes titanium, vanadium, chromium, manganese, nickel, copper, zinc, arsenic, lead, barium, zirconium;
- rare elements (the content usually ranges from 0.1 to 10 g/t) – lithium, beryllium, scandium, cobalt, germanium, gallium, selenium, strontium, bromine, rubidium, yttrium, niobium, molybdenum, cadmium, tin, antimony, iodine, cesium, lanthanum, tungsten, bismuth, uranium, ytterbium;
- ultra-rare elements (the content does not exceed 0.1 g/t) – gold, silver, indium, rhenium, mercury, iridium, platinum [6].

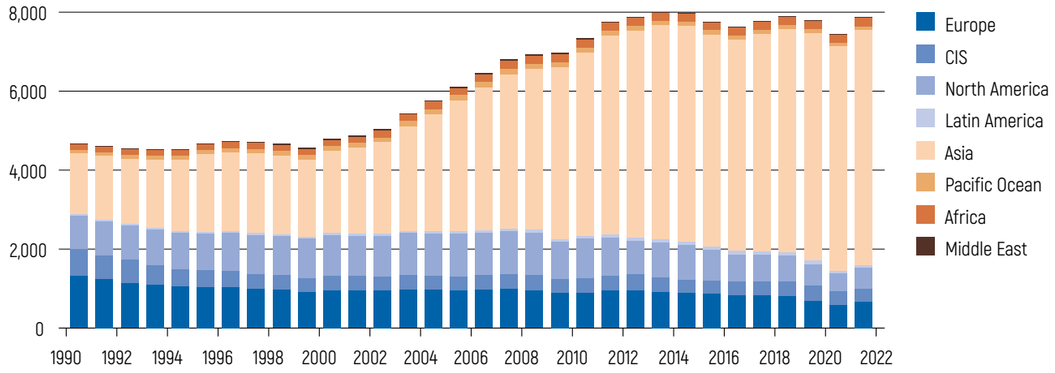

Figure 1 – Global coal consumption in 1990–2021, mln tons

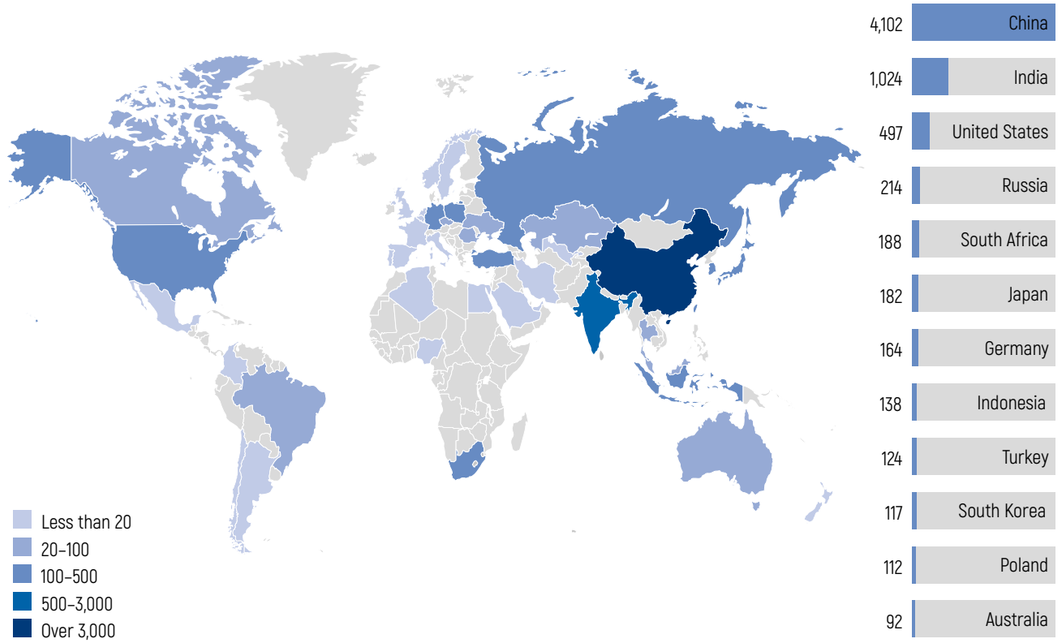

Figure 2 – Coal consumption by countries in 2021, mln tons

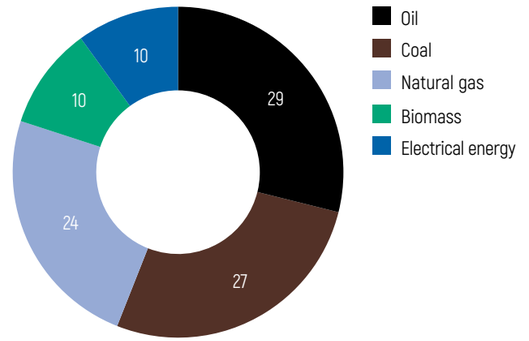

Figure 3 – Share of coal
in total energy consumption in 2021, %

According to GOST 25543-2013 [7], brown coal is represented by one brand (B) having three technological groups: the first brown (1B), the second brown (2B) and the third brown (3B). These groups differ significantly both in appearance and in composition, as well as in quality and directions of use. By outward signs, the following groups are distinguished in petrology: brown earthy, brown dense matte and brown dense shiny coals, which approximately corresponds to three technological groups – 1B, 2B, 3B [6].

Integrated Use of Brown Coal

Currently, coal is used mainly as fuel; as a result of burning of this rock, the useful substances in it are emitted along with combustion products or ash. The development of a technology that makes it possible to isolate useful substances from coal before burning for further application (for example, in crop production) is a promising area of research. This approach is complex in nature, including the preliminary preparation of mineral resource before burning, first of all, the grinding operation.

The diagram for the integrated use of brown coal (Figure 4) comprises the stage of extracting humic substances that are important for normal plant development. The application of these substances as organic fertilizers significantly increases soil fertility and thereby expands the agricultural resource base of fertile lands.

The integrated use of brown coal in RSBE has a number of significant advantages. Extraction of humic substances and parts of macro- and microelements contained in coal and further enriched with associations of agronomically valuable soil microorganisms will ensure the production of organic fertilizers that increase soil fertility. The addition of an optimal proportion of ash to organic fertilizers after burning coal-water fuel (CWF) and active substances after flue gas purification helps regulate the amount of necessary macro- and microelements taken by ancient plants and returned to the soil today. The solid fine fraction of coal after the extraction of humic substances and part of macro- and microelements become the raw material for the CWF production. Reducing the content of impurities in coal leads to an increase in fuel quality and flue gas purity. The ash formed during the burning of CWF and the active substance used in the purification of flue gases are sources of macro- and microelements important for organic fertilizers. The carbon dioxide generated by the burning of CWF increases the yield of greenhouses.

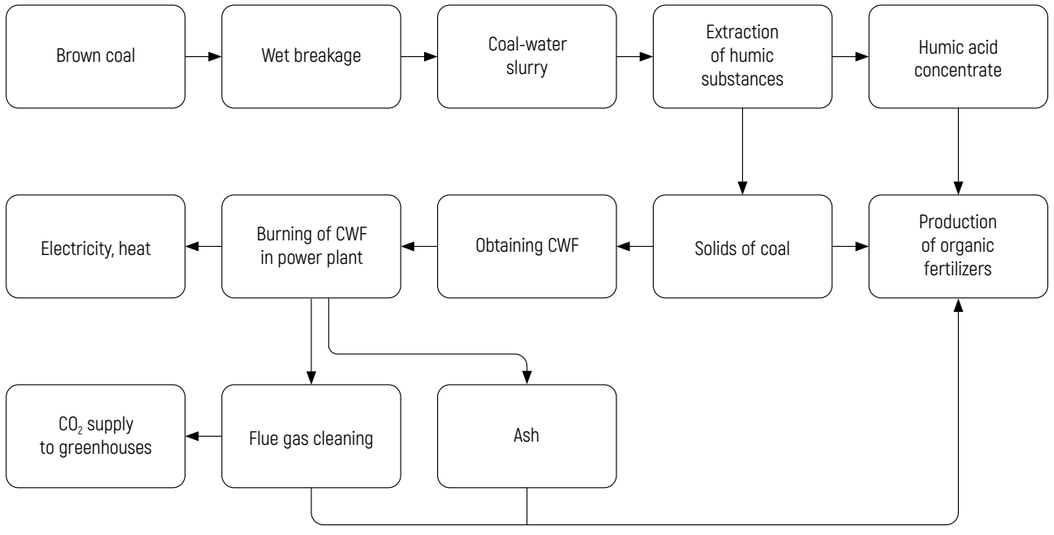

Figure 4 – Integrated (waste-free) use of brown coal

Humic Substances in Brown Coal

Humic substances are the component of the soil organic part and are responsible for its fertility. Currently, liquid organic fertilizers based on humic substances are widely used to increase yields [8]. In the soluble state, these compounds are more quickly included in the process of plant nutrition due to their absorption by the root system from the soil. The composition of humic substances comprises macro- and microelements, nitrogen and phosphorus in an easily digestible form, which are valuable nutrients and are necessary for the growth and yield of agricultural crops. Humic substances increase the resistance of plants to diseases and negative environmental conditions, favorably affect seeds, raising the percentage and reducing the duration of germination. In addition to accelerating plant cell division, soluble humic substances have a positive effect on the plant root system by increasing the permeability of cell membranes. The use of these compounds to improve soil fertility consists in adjusting the hydrogen value of the soil, which is particularly relevant in acidic lands.

Humic substances are a complex multicomponent system containing humus acids, humin and pro-humic substances [9]. In turn, humus acids are a complex of organic compounds isolated from caustic biolites and soils by solutions of alkalis, salts or organic solvents [10]: humic acids, fulvic acids and himatomelanic acids. Humic acids are formed as a result of acidification of an alkaline solution of humus acids; fulvic acids remain in the filler fluid after separation of humic acids; himatomelanic acids are obtained during the treatment of humic acids with a solvent (ethanol, acetone). Humic acids are high-molecular nitrogen-containing organic compounds. Their organic part includes a set of aliphatic and aromatic rings, side hydrocarbon chains with varying degrees of branching, as well as hydrophilic functional groups.

The general formula of coal humic acids has the structure shown in Figure 5 [11]. The bituminous component, humic substances and residual coal are isolated in the organic part of coal. The content of humic acids depends on the type of coal (lignite – 17–70 %, brown coals – 35–70 %).

Humic substances from caustobiolites and soils are extracted with various aqueous solutions: NaOH, KOH, NH_4OH, $NaHCO_3$, $Na_4P_2O_7$, NaF, $Na_2C_2O_4$, $(NH_2)_2CO$, etc.

The results of the humic substances separation depend on the raw material characteristics and process conditions. In addition, the rate and degree of humic acids extraction determined by the concentration of alkali, the degree of dispersion of the raw material and technological modes (temperature, etc.). Taking these factors into account, a standard methodology was developed to determine the yield of humic acids from peat, brown and hard coal [12].

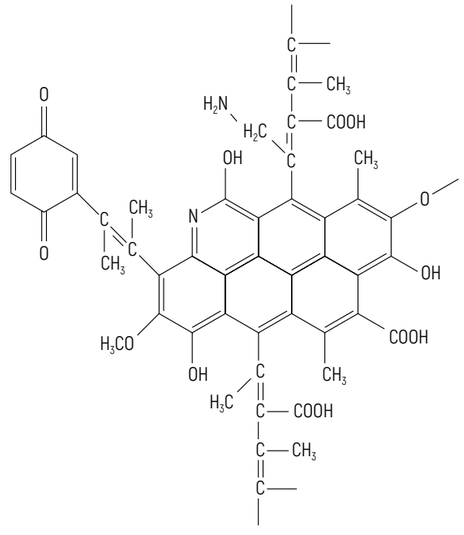

Figure 5 – Fragment of a molecule of coal humic acids

However, the previously proposed method for creating CWF has disadvantages, primarily associated with the production of a fine fraction of coal, from which humic substances can subsequently be extracted and then the CWF required for thermal energy generation can be produced.

Thus, grinding is necessary, first of all, to increase the effectiveness of extraction of humic substances from coal, as well as for further use of the fine coal hard fraction during the preparation of CWF.

Obtaining Coal-Water Fuel

The creation of CWF is the formation of technology for obtaining coal-water slurry (CWS), which was developed in Russia in the 1950s–1960s for burning watered fine coal. CWF is a dispersed system consisting of water, fine coal and chemical additives, in which energy and non-energy coals act as a combustible base.

The idea of using CWF instead of petroleum products was widespread in the early 1970s in China, Japan, Sweden, the USA and other countries during the global oil crisis. Currently, the application of CWF is most widely noted in China and Japan. China's megacities already prohibited the construction and operation of solid coal boilers, and the State Program of the Chinese government provides for the gradual transfer of enterprises from oil and gas fuel to CWF.

Today, three research centers are working on CWF in China, and the State Center for Coal-Water Suspensions has been established. If in 2001 more than 2 mln tons of CWF were produced and consumed annually in this country, then in 2006 the amount was already about 15 mln tons, which is equivalent to the production of 10–12 GW of electric energy; by 2020 the production of fuel was brought to a record figure of 100 mln tons per year [13].

One of the important features of the CWF technology is the preparation of a suitable slurry having a high concentration of coal, low viscosity and good resistance to precipitation. CWF should have excellent fluidity and stability when handling it in the processes of preparation, transportation, storage, spraying and burning. Since CWS is a solid and liquid mixture, many factors (density of a solid, particle shape, volume fraction of a solid, etc.) and characteristics of the solid/liquid interface (interfacial potential, interfacial tension, surface adsorption properties of additives, etc.) significantly affect the properties of CWF [14].

CWF is a homogeneous viscous slurry during storage, transportation and burning. It must be in a homogeneous state to obtain a material in the form of a slurry that can be

distributed through pipes to solve transportation problems. One of the advantages of CWF is the physical properties similar to fuel oil. Due to the fluidity of CWF, for its burning you can use a fuel oil burner, slightly changing it.

The technology of CWF production provides higher safety compared to other methods of coal processing. The slurry of a mixture of water and coal is free from some of the main problems associated with the use of solid coal – the formation of powder dust and the potential for spontaneous combustion during storage and transportation. CWF can be made of low-grade coals [15].

Figure 6 shows a general view of the installation providing wet breakage of brown coal to particle sizes less than 50 μm. Wet grinding significantly reduces dust formation, explosion and fire hazard.

In order to determine the optimal processing time of brown coal in a wet breakage unit to obtain a solid fraction of 0–100 μm, as well as for further analysis of the formed slurry, raw material was crushed. The installation was loaded with 80 kg of brown coal of 0–12 mm fraction, and 200 l of tap water were added. The ratio of mineral resource to water by weight was 40 %. Sampling was carried out after 5, 10 and 15 min.

Figure 6 – Installation of wet breakage of brown coal

Information on the fine solid fraction of the coal contained in the slurry at the unit's output after 15 min of processing is shown in Figure 7. The data are determined using the Analysette 22 NeXT laser device, designed to measure the particles size.

The diagram shows that when brown coal is processed for 15 min, the particle size is mainly in the range of 10–30 μm. It should be assumed that a change in the processing time will also entail a change in the fractional composition of brown coal in the resulting slurry.

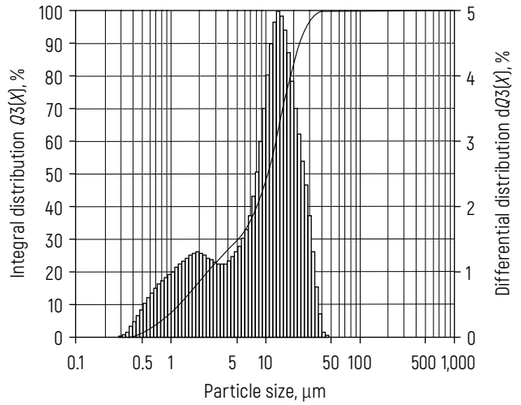

Figure 7 – Fractional composition of crushed brown coal

Conclusions and Future Work

The results of the work show the possibility of using a wet breakage installation to grind brown coal to the specific size and obtain a CWS with the required characteristics. The size of the solid fraction of brown coal is in the range of 0–100 μm. Humic substances and part of macro- and microelements are extracted from the CWS and are later used in the creation of liquid organic fertilizers. The solid fine fraction of coal remaining after extraction is the basis for the production of high-quality and environmentally cleaner CWF.

It should be assumed that changing the parameters of the unit operation (processing time, the ratio of the amount of brown coal and water, the addition of additives) will allow varying the fractional composition of solid particles of brown coal, thus affecting the effectiveness of releasing humic substances from it, as well as the properties of the resulting CWF. The establishment of these dependencies can serve as the purpose of further research.

References

1. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
2. *Unitsky, A. Food Solar Bioenergy / A. Unitsky, V. Vasilevich // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 355–366.*
3. *Alekhnovich, A.N. Energeticheskiye ugli [Energy Coals]: Study Guide / A.N. Alekhnovich. – Chelyabinsk: Tsitsero, 2016. – 164 p.*
4. *Coal and Lignite Domestic Consumption [Electronic resource]. – Mode of access: https://yearbook.enerdata.net/coal-lignite/coal-world-consumption-data.html. – Date of access: 12.06.2022.*
5. *Yeromin, I.V. Petrografiya i fizicheskiye svoystva ugley [Petrography and Physical Properties of Coals] / I.V. Yeromin, V.V. Lebedev, D.A. Tsikarov. – Moscow: Nedra, 1980. – 236 p.*
6. *Kurmazova, N.A. Kompleksnoye ispol'zovaniye mineral'nogo syr'ya (na primere Tataurovskogo mestorozhdeniya burykh ugley) [Integrated Use of Mineral Raw Materials (On the Example of the Tataurovsky Brown Coal Deposit)] / N.A. Kurmazova // Gornyy informatsionno-analiticheskiy byulleten'. – 2018. – No. 12. – P. 121–126.*
7. *Ugli buryye, kamennyye i antratsity. Klassifikatsiya po geneticheskim i tekhnologicheskim parametram [Brown, Stone and Anthracite Coals. Classification by Genetic and Technological Parameters]: GOST 25543-2013. – Replaces GOST 25543-88; Introduced 01.01.2015. – Moscow: Standartinform, 2019. – 16 p.*
8. *Guminovyye veshchestva v biosfere [Humic Substances in the Biosphere] / ed. D.S. Orlov. – Moscow: Nauka, 1993. – 237 p.*
9. *Popov, A.I. Guminovyye veshchestva: svoystva, stroyeniye, obrazovaniye [Humic Substances: Properties, Structure, Formation] / A.I. Popov; ed. Ye.I. Yermakov. – Saint Petersburg: Izdatel'stvo Sankt-Peterburgskogo universiteta, 2004. – 248 p.*
10. *Kononova, M.M. Organicheskoye veshchestvo pochvy, yego priroda, svoystva i metody izucheniya [Soil Organic Matter, Its Nature, Properties and Methods of Study] / M.M. Kononova. – Moscow: Izdatel'stvo Akademii nauk SSSR, 1963. – 314 p.*
11. *Golubkov, V.A. Ispol'zovaniye kamennogo uglya v kachestve istochnika guminovykh kislot [The Use of Coal as a Source of Humic Acids] / V.A. Golubkov, Ye.P. Vorozhtsov, S.V. Bortnikov // Mezhdunarodnyy zhurnal gumanitarnykh i yestestvennykh nauk. – 2020. – No. 1-1 (40). – P. 196–200.*
12. *Toplivo tvordoye. Metody opredeleniya vykhoda guminovykh kislot [Solid Fuel. Methods for Determining the Yield of Humic Acids]: GOST 9517-94. – Replaces GOST 9517-76; Introduced 01.01.97. – Minsk: Mezhgosudarstvennyy sovet po standartizatsii, metrologii i sertifikatsii, 1996. – 9 p.*
13. *Dolinskiy, A.A. Vodougol'noye toplivo: perspektivy ispol'zovaniya v teploenergetike i zhilishchno-kommunal'nom sektore [Coal-Water Fuel: Prospects of Using in Heat Power Engineering and Housing and Communal Sector] / A.A. Dolinskiy, A.A. Khalatov // Promyshlennaya teplotekhnika. – 2007. – Vol. 29, No. 5. – P. 70–79.*
14. *Effect of Compound Inorganic Nano-Stabilizer on the Stability of High Concentration Coal Water Mixtures / Renfu Xu [et al.] // Fuel. – 2006. – Vol. 85, iss. 17–18. – P. 2524–2529.*
15. *Putra, R. An Overview of Coal Water Mixture (CWM) as New Unconventional Energy Potency, and Indonesia Coal Fields for Case Studies [Electronic resource] / R. Putra, J. Alibazah, D. Umar. – 2013. – Mode of access: https://www.searchanddiscovery.com/documents/2013/80333putra/ndx_putra.pdf. – Date of access: 18.07.2022.*

Methodology for Monitoring the Quality and Fertility of Soils of Grape Agrocenoses Based on Multispectral Cosmic Data

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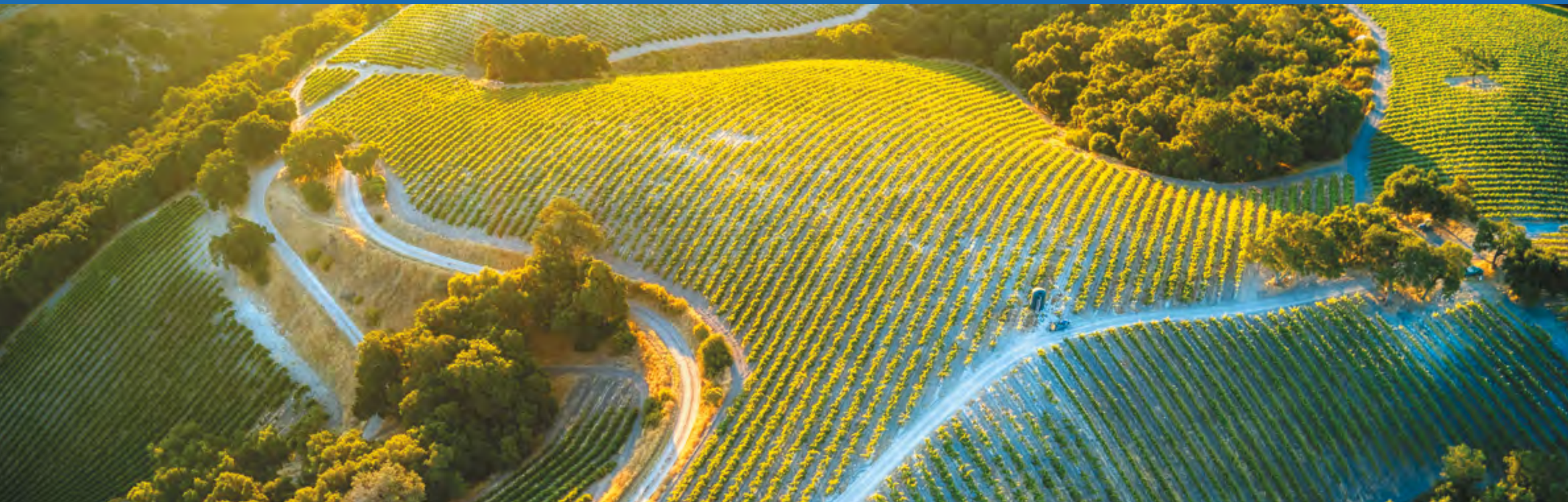
UDC 629.785:528.8.04

The ways of creation and implementation of technologies of complex information support and monitoring of major agricultural territories are considered. These innovations are necessary to obtain basic thematically oriented tools for solving problems of managing sustainable development of territories. Such a process involves the use of the results of cosmic activities not only on Earth, but also under the conditions of the EcoCosmoHouse (ECH). The use of these technologies will allow, when creating a set of monitoring tasks, to use the results of cosmic activities, called "basic elements", to regulate the working out of methods for monitoring the humus content in the soil. Such an approach will foster the reduction of time required to develop basic elements, as well as to create a space monitoring system based on them to solve problems in various sectors of the economy. The method of soil fertility analysis on the example of grape agrocenoses is presented, which assumes the determination of the humus content remotely, based on the assessment of the spectral features of soils. The study was carried out using photography with a digital camera, as well as satellite multispectral equipment. It is shown that the proposed procedures for determining the humus content in the soil have high accuracy and can be used to create an automated system for monitoring the state of soils, including that for precision farming in enclosed ecosystems.

Keywords: *EcoCosmoHouse (ECH), geoinformation platform, humus, intelligent system, multispectral survey, remote probing of the Earth.*



Introduction

In the conditions of the EcoCosmoHouse (ECH), there is a need for the obtaining of plant products, when light potting soils are planned to be used as the main substrate for growing plants [1]. These substrates contain about 10 % of humus by volume; this characteristic is one of the most important, and it needs to be constantly monitored to maintain the biocenosis in balance. At the moment, chemical methods are used to analyze the humus content in the soil, which means its fertility. They are accurate, but require physical sampling from the site, as well as special equipment and additional personnel. In this article, in order to optimize the processes of biotechnological obtaining of plant products, it is proposed to monitor the humus content based on multispectral data. This technology (when having pictures from space) can be successfully used, including for monitoring the state of soils on the Earth's surface.

Today, satellite observation technologies allow getting objective quantitative information about various objects and phenomena. This, in particular, leads to the creation of new information technologies and systems for studying various processes occurring in biogeocenoses and agrocenoses. At the same time, it should be noted that the observation of various types of agrocenoses has its own specifics, which requires the development of specialized information systems providing for the collection and analysis of information homogeneous in time and space. This is especially important when it comes to the study of grape agrocenoses, since their main elements are perennial plants, as well as soils that contribute to obtaining a high-quality harvest. In this case, it is necessary to create special information technologies for monitoring such objects, which will allow in the future to form observations that are homogeneous in time and space, and provide the possibility of conducting an analysis with a high degree of reliability [2]. At the same time, various characteristics of the objects under study should be determined, the parameters of which can be restored on the basis of remote observation data and used to assess their condition and development forecasts. After the Industrial Space Necklace "Orbit" (ISN "Orbit") begins to function, it is also possible to conduct continuous monitoring of the state of soils on our planet on the basis of multispectral space data.

A significant number of articles of domestic [3–7] and foreign [8–12] scientists and researchers are focused on the issues of preserving and restoring the fertility of agrocenoses. There are works considering remote assessment of soil conditions; some experts have used the results of remote probing of the Earth from space to monitor soil fertility, soil mapping, as well as the condition of vineyards.

In the last decade, the institutes of the Russian Academy of Sciences and Lomonosov Moscow State University have developed unique methods, algorithms and technologies for working with satellite data, which made it possible to solve a significant number of scientific problems and create applied systems for remote monitoring [13].

In reference [14], the use of remote probing for terroir analysis in viticulture is considered and methods of object image analysis, spatio-temporal and hyperspectral analyzes and topoclimatology are described.

It should be noted that there are no comprehensive studies in the available publications aimed both at identifying and substantiating significant factors (indicators) that determine the fertility of grape agrocenoses, and at developing methods for their assessment based on Earth remote probing data from space, as well as at building complex models for the development of such agrocenoses and arranging measures to improve or preserve soils under the conditions of the south of Russia.

Materials and Methods

The intensive land use often leads to the development of adverse processes (water and wind erosion, secondary salinization and waterlogging, soil pollution by industrial emissions and pesticides), which significantly degrades the properties of the soil cover. In this regard, there is a need to monitor the indicators of soil condition in order to assess, predict and map it, as well as substantiate measures to increase fertility. Monitoring of the soil cover includes systematic observations of the level of its pollution, the processes of migration of chemicals, the dynamics of soil fertility indicators in space and time. However, this process cannot be limited only to the study of soil samples, since it is inseparable from the study of other components of the landscape, all ways of accumulation of pollutants in both natural and anthropogenic complexes.

In the vast majority of cases, the most important complex characteristic of soil fertility is the content of organic matter in it and its qualitative state. At the same time, it is known that the properties, composition and amount of organic matter determine the biological indicators of soil fertility, the presence of agronomically valuable soil microorganisms. Humus makes up 85–90 % of the organic matter of the soil. Humus substances are dark-colored high-molecular compounds with a complex chemical structure. The types of soils differ in humus content, the amount and ratio of humic acids and fulvic acids, which significantly affects their reflectivity in different ranges of electromagnetic waves.

The main morphological feature of the soil is its color, which depends on the chemical composition, and above all on the content of humus. There is a sufficient number of publications focused on the development and study of ways for assessing the state of vegetation cover by remote probing methods available. However, these approaches are oriented on application in laboratory conditions and have a high computational complexity for use in real information systems for soil quality monitoring.

That is why in this paper an attempt is made to develop the basics of the methodology for assessing humus on the example of grape agrocenoses. At the same time, the assessment of humus was carried out both in laboratory conditions and by means of space spectrosonal imaging.

The objects of research at the first stage were the soils of grape agrocenoses of the southern regions of Russia. The features of the soil cover and geographical data are given in Table 1.

In each case, sampling was carried out from the upper layer (5–15 cm depth). The humus content was determined by the method of I. Tyurin in accordance with GOST 26213-91 "Soils. Methods for determination of organic matter".

The spectral characteristics of the studied soils were determined using the equipment of the multispectral survey system (460–860 nm spectral range) of the Canopus-V satellite (the survey was synchronized with the time of soil sampling; archival data was used), as well as under laboratory conditions using a Canon DS126181 digital camera. The focal length of the camera lens is 55 mm, the resolution is 4,272 × 2,848 pixels, the spectral range of the matrix is 400–780 nm.

Four of the 22 test sites were selected for decryption. They were not occupied by vegetation. In addition, at the time of sampling and satellite imaging, there was no atmospheric interference.

Analysis of the data from the archives of weather stations showed that the surface layers of the soil of all four studied sites were in an air-dry state. This circumstance made it possible not to take into account the influence of soil moisture on its color during decryption and subsequent analysis.

Table 1 – Characteristics of sites and soil

Sample number	Farm, site	Description of soil	Soil type
1	Enterprise "Zolotaya Balka", Blagodatnoye village, Balaklava district of Sevastopol, Crimea. Grape variety – Chardonnay	Relief – undulating plain; humus (0–20 cm layer) – 1.2 %; parent rock – deluvium; HCl boiling – from the surface; salinization – none; pH – 6.9; P_2O_5 – 1.4 mg/100 g of soil; K_2O – 17.5 mg/100 g of soil; Ca – 19.4 mg/100 g of soil	Southern low-humus high-carbonate chernozem
2	Enterprise "Zolotaya Balka", Vilino village, Bakhchisarai district, Crimea. Mother plantation of grape variety Kober	Relief – lowering; humus (65 cm layer) – 1.55 %; parent rock – deluvium; HCl boiling – from the surface; salinization – none; pH – 8; P_2O_5 – 0.9 mg/100 g of soil; K_2O – 20.1 mg/100 g of soil; Ca – 14.5 mg/100 g of soil	Southern low-humus chernozem
3	Enterprise "Magarach", Vilino village, Bakhchisarai district, Crimea	Carbonates (0–60 cm layer) – about 7 %, (1.5 m layer) – 17–19 %; humus content in the soil profile – 2.5 %; pH – 8.1; volume weight of the soil (upper horizon) – 1.29–1.33 g/cm^3; total nitrogen (at the depth of the plantage) – 0.12–0.13 %	Southern low-humus chernozem
4	Enterprise "Chernomorets", Uglovoe village, Bakhchisarai district, Crimea. Grape variety – Pinot Noir and Cabernet Sauvignon	Humus horizon – 80–90 cm; humus (0–20 cm layer) – 3.5 %; gross nitrogen – 0.21–0.3 %; hydrolyzable nitrogen – 5–11 mg/100 g of soil, which indicates a high availability of mobile nitrogen	Ordinary micellar-carbonate foothill chernozem

Soil samples intended for photographing in laboratory conditions were pre-dried to an air-dry state, and also crushed to a size of 0.2–0.25 mm.

During the shooting, artificial lighting with a stabilized voltage source was used, ensuring the accuracy of the supply voltage ±1 %. The soil sample was poured into a glass cuvette, compacted and leveled. The reference white sample was placed nearby and later used to correct the white balance in preparation for shooting and image processing.

The images obtained during the shooting in RAW (digital camera) and GeoTIFF (satellite images) formats were processed for subsequent analysis using the SIPS software package and the Photoshop CS6 graphic editor, which allow determining the average brightness value in spectral channels (R, G, B). To increase the reliability of the images, they were issued in an automatic series of five images, and then averaged. Spectral coefficients were calculated relatively to the brightness of the reference, their averaged values are shown in Table 2.

Table 2 – Spectral characteristics of soils

Sample number	R	G	B	Humus content, %
1	75.6	65.1	51.2	1.2
2	76.1	67.3	53.6	1.55
3	64.3	52.9	42.1	2.5
4	62.9	56.8	45.7	3.5

Results and Discussion

It is advisable to analyze the data obtained during the experiment both based on the results of laboratory shooting with a digital camera and remote probing from a satellite.

From Table 2, it can be concluded that according to the results of laboratory studies, the highest brightness value is observed in the red range (R), the lowest is in the blue range (B).

Comparative characteristics are shown in Figure 1.

Analysis of the results of statistical processing of laboratory survey data suggests that the greatest correlation is observed between the content of humus (H) and the brightness of the red channel of the digital image, the value of the correlation coefficient is $r = -0.93$. Thus, the R channel is the most informative for monitoring the level of humus in the soil.

For optimal assessment of the humus content of the soil, an analytical formula (regression equation) of the dependence of the humus content in the soil on the brightness level of the R channel is obtained:

$$H = -0.136R + 11.651. \quad (1)$$

At the same time, $r^2 = 0.87$, which indicates a high level of correlation; the standard error $m = 2.6$. The values of H calculated by the R level in accordance with (1) are shown in Figure 2.

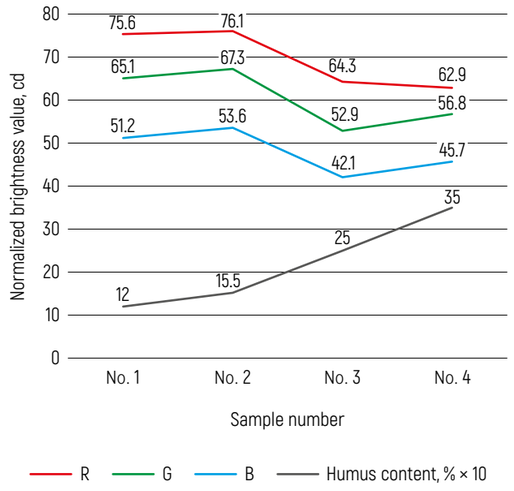


Figure 1 – Channel brightness values and humus content

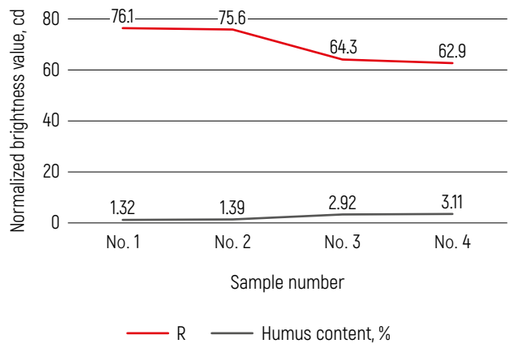


Figure 2 – Brightness of the R channel and calculated values of humus content

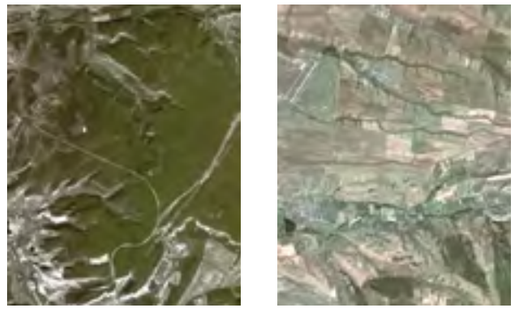
In addition, images of the analyzed sites were obtained from the Canopus-V satellite using multispectral equipment (Figure 3).

A similar list of actions related to the above-mentioned processing of photographic images and statistical analysis of the results was carried out with satellite images.

The following regression dependence is obtained:

$$H = -0.011R + 9.21. \quad (2)$$

Statistical indicators of the obtained regression dependence $r^2 = 0.79$, which indicates a high level of correlation; standard error $m = 4.7$, which suggests a fairly good approximation of the actual results to the obtained regression (Figure 4).



a) b)

Figure 3 – Satellite images of the analyzed sites:
a – Sample No. 1; b – Samples No. 2–4

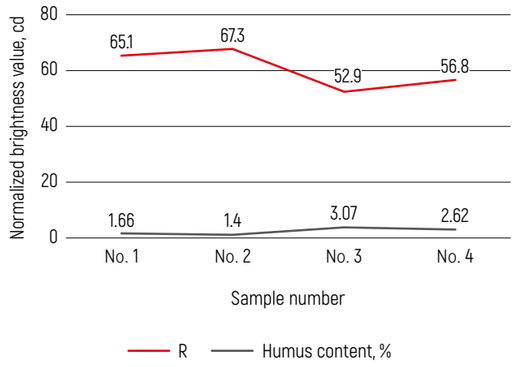


Figure 4 – Brightness of the R channel and calculated values of humus content (based on satellite images)

From the analysis of the data obtained, it follows that the error in the humus content does not exceed 20 % (for laboratory images – 8.5 %). These values indicate the possibility of remote monitoring under consideration.

It should be noted that the research shows only the first results of remote monitoring of the fertility of grape agrocenoses. In the future, it is planned to deploy more test sites for sampling and remote diagnostics. To determine the spectral properties of soils, it is proposed to use a mobile spectrometer that allows measurements to be made directly in the field, based on preliminary forecasts of monitoring specified territories by required satellites, as well as weather forecasts. More reliable results can be achieved by using images obtained with the help of hyperspectral satellite equipment, which makes it possible to identify narrower, particularly informative sections of the spectrum.

Conclusions and Future Work

As a result of the conducted research, a conclusion can be made about the sufficiently high efficiency of cosmic and laboratory methods of measuring the spectral reflectivity of soils for analyzing their fertility by remotely determining the humus content in them.

A method of using a modern digital camera to determine the humus content in the soil has been developed. It is revealed that the accuracy of determining this value practically corresponds to analytical methods. However, particularly important is carrying out these measurements directly in the field, which is possible when using mobile spectrometers. It is shown that it is reasonable to use the spectrum of the red channel of a digital camera photograph to calculate the amount of humus rate in the soils in the southern regions of Russia.

The introduction of a similar methodology for processing and interpreting satellite images also makes it possible to detect the percentage of humus in the soil with sufficient accuracy. This monitoring method should be considered the most optimal, since it requires less labor effort to carry out continuous monitoring of the grape agrocenoses soil cover state and can be used as the basis for automatic analysis of soil quality.

Given the relatively small amount of equipment that is involved in this monitoring of soil condition, the proposed methodology can be successfully applied under the ECH conditions. The analysis of multispectral indicators will allow carrying out the appropriate dosage of humus, liquid humus in various zones of plant cultivation to obtain optimal results.

In the course of further research, it is reasonable to pass from multispectral monitoring methods over to hyperspectral ones, which can improve the accuracy and quality of observations.

Gratitude

The study has been carried out with the support of the Russian Foundation for Basic Research, project No. 20-016-00220.

References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Grishin, I. Remote Sensing: The Method of GIS Application for Monitoring the State of Soils / I. Grishin, R. Timirgaleeva // E3S Web of Conf. – 2020. – Vol. 175, No. 06009. – P. 1–15.*
3. *Blokhina, S.Yu. Primeneniye distantsionnogo zondirovaniya v tochnom zemledelii [Application of Remote Probing in Precision Agriculture] / S.Yu. Blokhina // Vestnik Rossiyskoy sel'skokhozyaystvennoy nauki. – 2018. – No. 5. – P. 10–16.*
4. *Yergina, Ye.I. Dinamika termodinamicheskikh svoystv i zapasov energii v gumuse pochv Krymskogo poluostrova [Dynamics of Thermodynamic Properties and Energy Reserves in the Humus of Soils of the Crimean Peninsula] / Ye.I. Yergina // Geopolitika i ekogeodinamika regionov. – 2012. – No. 8 (1–2). – P. 62–72.*
5. *Kiryushin, V.I. Problema minimizatsii obrabotki pochvy: perspektivy razvitiya i zadachi issledovaniy [The Problem of Minimizing Soil Treatment: Prospects for Development and Research Tasks] / V.I. Kiryushin // Zemledeliye. – 2013. – No. 7. – P. 3–6.*
6. *Kozubenko, I.S. Sputnikovyye dannyye v upravlenii agropromyshlennym kompleksom regiona [Satellite Data in the Management of the Agro-Industrial Complex of the Region] / I.S. Kozubenko, I.Yu. Savin // Vestnik rossiyskoy sel'skokhozyaystvennoy nauki. – 2017. – No. 5. – P. 9–11.*
7. *Kulik, K.N. Metodicheskaya osnova agrolesomeliorativnoy otsenki zashchitnykh lesnykh nasazhdeniy po dannym distantsionnogo monitoringa [Methodological Basis of Agroforestry Assessment of Protective Forest Ranges According to Remote Monitoring Data] / K.N. Kulik, A.V. Koshelev // Lesotekhnicheskiy zhurnal. – 2017. – No. 3. – P. 107–114.*
8. *Elbasiouny, H. Assessment of Environmental Sensitivity to Desertification, Soil Quality and Sustainability in an Area of the North Nile Delta, Egypt / H. Elbasiouny // Egyptian Journal of Soil Science. – 2018. – Vol. 58, No. 4. – P. 399–415.*
9. *Chervan', A. The Assessment of Resource Potential of Agro-Landscapes with Use of Geo-Information Systems on the Basis of Soil Cover Structure / A. Chervan' // The Proceedings of the 10th International Soil Science Congress on "Environment and Soil Resources Conservation", Almaty, 17–19 Oct. 2018 / Soil Science Society of Kazakhstan Cooperation with the Federation of Eurasian Soil Science Societies; eds A. Saparov, R. Kizilkaya, M. Mustafayev. – Almaty: Poligrafservis i K, 2018. – P. 19–20.*
10. *Bonfante, A. Refining Physical Aspects of Soil Quality and Soil Health when Exploring the Effects of Soil Degradation and Climate Change on Biomass Production: An Italian Case Study / A. Bonfante, F. Terribile, J. Bouma // SOIL Discussions. – 2019. – No. 5. – P. 1–14.*
11. *Von Braun, J. Land Use Change and Economics of Land Degradation in the Baltic Region / J. von Braun, A. Mirzabaev // Baltic Region. – 2016. – Vol. 8, No. 3. – P. 33–44.*
12. *Nature-Similar Technologies of the Biogeosystem Techniquein Solvinga Global Social and Environmental Problem / A.P. Glinushkin [et al.] // Biogeosystem Technique. – 2018. – Vol. 5, No. 2. – P. 164–196.*
13. *Sovremennyye podkhody i tekhnologii organizatsii raboty s dannymi distantsionnogo zondirovaniya Zemli dlya resheniya nauchnykh zadach [Modern Approaches and Technologies for Arranging Work with Earth Remote Probing Data for Solving Scientific Problems] / E.A. Lupyan [et al.] // Sovremennyye problemy distantsionnogo zondirovaniya Zemli iz kosmosa. – 2012. – Vol. 9, No. 5. – P. 21–44.*
14. *Hall, A. Remote Sensing Application for Viticultural Terroir Analysis / A. Hall // Elements. – 2018. – Vol. 14, No. 3. – P. 185–190.*

The Use of Roofs of Multi-Purpose Buildings for Allocation of Greenhouses: Specifics and Optimal Solutions

UDC 711.416-122

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The issues of using the roofs of buildings for growing food products are considered. The experience of research and development in the field of creating technologies for the production of plant and animal food in an artificial habitat is summarized. The directions of searching for a new type of residential environment are indicated. Original approaches are proposed in the arrangement of the architectural and planning structure of a group of residential buildings made interlocked in an apartment complex called "horizontal skyscraper" (HS); its structural, engineering, technological and planning features are considered. The conditions affecting the possibility of using the roof when combining residential, industrial and auxiliary functional zones in the HS complex are described. The specifics of functioning and further development of such systems are indicated. The analysis of the possibilities of the HS as an element of a linear type of construction, aggregated with "second level" string-rail transport systems, is presented. The relevance of an integrated approach that can be applied, including the design of cosmic settlements "EcoCosmoHouse" (ECH) and their terrestrial analogues "EcoCosmoHouse on Planet Earth" (ECH-Earth), is noted.

Keywords: *city farming, EcoCosmoHouse (ECH), greenhouses on the roof, "horizontal skyscraper", linear type of accommodation, recycling, residential cluster, uCity, Unitsky String Technologies (uST), vertical greenhouses, waste-free technologies.*

Introduction

According to the Science Daily journal, on May 23, 2007, a demographic revolution took place in the history of the Earth: the urban population of the planet surpassed the rural one. The journal refers to the studies of scientists from the University of North Carolina and the University of Georgia. A study conducted jointly with UN experts showed that it was on the day when the share of urban residents reached 51.3 % of the total Earth's population. Currently, due to the disproportionate distribution of world wealth, rural areas often have a lower standard of living and at the same time receive urban waste – polluted air, water and soil [1]. It should be noted that at the end of 2021 the urban population was 54 % against 46 % of the rural one [2]. The recorded demographic shift indicates a negative trend.

The current situation requires the creation of effective accommodation systems (settlements of a new type) – linear cities (uCities) built on the basis of uST transport and infrastructure solutions (Unitsky String Technologies). The uCities reduce the dependence of households on oversaturated urban life and open up new ways of urban and rural development, which will allow to sustainably distribute the density of people over the entire surface of the planet and ease up the burden of municipal and national governments experiencing serious demographic pressure from overpopulated areas. Such autonomous accommodation systems will become the basis for building residential clusters of the Equatorial Linear City (ELC) as a ground-based structural element of the uSpace non-rocket near space exploration program and transferring the harmful component of the Earth's industry to the equatorial orbit.

The new type of settlements is based on the concept of autonomous existence and provide infrastructural, demographic and food security due to innovative high-tech food production in an urban environment.

Experience in Using Innovative Food Production Technologies

The idea of innovative food production is embodied in the use of potential urban reserves (roofing space of buildings and structures) and the application of a new way of farming (city farming) [3]. To test this idea in the largest megacities of the world, there are peculiar landfills equipped on specially allocated scarce spatial reserves. Greenhouses are located on the roofs of multi-purpose buildings and produce plant food products in a close proximity to the consumer [4].

The 1,900 m^2 greenhouse on the roof of the Brooklyn Whole Foods Market (Figure 1) in New York, USA, arranged by Gotham Greens company, produces annually more than 45 tons of fresh greens, and also protects the roof from overheating in summer and cooling in winter. The green-house operates using Aquaponics technology and produces food products with the use of highly efficient engineering equipment. LED lighting, improved glazing, thermal curtains, passive ventilation, solar panels can significantly save electrical and thermal energy.

The Urbs in Horto city farm (Figure 2) in the Pullman district of Chicago, USA, is located on the roof of the building of the Method company, which produces soap. The greenhouse supplies a large area of the city with products obtained without using any chemicals. The innovative greenhouse is located in the peripheral zone of the megacity and at the same time is a leisure center and a place of employment for the population living within walking distance, which is considered one of the conditions for a comfortable urban environment. Aquaponics technology used in cultivation of green products on this farm is based on the processes of plant growth and development under computer

Figure 1 – Greenhouse on the roof of the Whole Foods Market in Brooklyn, New York, USA [4]

control and demonstrates high quality products, ensuring the absence of herbicides, pesticides and antibiotics. This greenhouse with the area of 16,000 m^2 (1.6 ha) is equivalent in yield to 40.5 ha of land.

The farm project in Colomb, near Paris, France, will contribute to the emergence of a real agricultural city. Hydroponic greenhouses along the A86 motorway outside the French capital, becoming part of the new Magellan residential area, will provide its residents with fresh products all year round. The concept of a vertical greenhouse (Figure 3) was created by the Parisian architectural studio Ilimelgo. The multi-storey greenhouse combines traditional gardening and innovative technologies [5].

Figure 2 – Greenhouse on the roof of the Method company building in Chicago, USA [4]

Figure 3 – Vertical greenhouse concept designed by Ilimelgo studio, France [5]

Specifics of Functioning and Development of Plant Food Production in Vertical Farms and Greenhouses on Roofs

It is customary presumed to call a greenhouse with a multilevel placement a vertical farm. If the requirements for the microclimate are met, it can be located in any premise: in a warehouse, on the territory of an old factory, on the roof of a building, in a basement. It is becoming popular to set up vertical mini-farms in residential premises, as well as to grow microgreens at home. Examples of simple hydroponic systems for home use by the Russian manufacturer "Wealth of Health" are shown in Figures 4, 5.

Figure 4 – Hydroponic installation for home use

Figure 5 – Four-module microgreens germinator for home use

The main differences between vertical agricultural production and traditional greenhouse farms are multi-tiered arrangement and cultivation of green spaces using the controlled-environment agriculture (CEA), which allows harvesting all year round and significantly saving resources: light, water, electricity (Figures 6, 7). The term and idea belong to D. Despommier [6, 7]. He has calculated that 30 % of all the food produced deteriorates during transportation and storage, while farming in vertical farms in cities significantly reduces the logistics component and the time of delivering green products to the consumer's table.

Figure 6 – Application of CEA method in vertical farms [8]

The iFarm company is currently operating in the Russian Federation market. It is not only engaged in the construction of vertical farms, but also produces environmentally friendly products itself [8]: various types of salads, spicy herbs, vegetables, berries (Figure 8). On a vertical farm in Tomsk, the company uses nutritious phyto-solutions, selected methods of biosecurity of salads and vegetables from diseases. It also adjusts watering and the use of phyto-light.

The iFarm company has calculated the parameters of the technology (Table 1), which show the efficiency of building vertical farm modules produced by it in a wide range of premises.

Singapore is home to the world's first commercial vertical farm Sky Greens, where greens and vegetables are grown in 38-tier containers in which plants receive sufficient water, sunlight and air and yield 10 times higher than the results in the open ground.

In the United Arab Emirates, there is a vertical farm Badia Farms. The installation occupies 790 m^2 and produces 18 types of leafy vegetables, including arugula, mustard and mint, without the use of chemicals and pesticides.

The Infarm company owns 50 vertical farms in Berlin, Germany, where it grows 200 varieties of vegetables, fruits, herbs, greens and mushrooms. Cloud technologies and big data analysis are actively used in farm management, helping to adapt the level of illumination, temperature, pH and nutrient composition individually for each plant variety [8].

Figure 7 – Farming with CEA method [8]

Figure 8 – Strawberry cultivation in vertical farms of the iFarm company, Russian Federation [8]

Table 1 – Technological parameters of the iFarm company [8]

Parameter	Value			
Premise area, m^2	20	50	200	500
Growing area, m^2	47	117	478	1,000
Ceilings height, m/quantity of tiers in the module	3/7	4.5/9	4.5/9	5/9
Total number of modules (for seedlings and cultivation), pcs	4	10	41	115
Required power consumption (peak), kW	7	19	77	220
Harvest of greens (average value), kg/month	130	300	1,200	2,500

Development of Eco-Oriented (Biospheric) Technologies on the Roofs of Buildings

The movement of modern civilization towards harmonious relations with the environment and careful attitude to resources is becoming an urgent necessity. Increasingly, the attention of researchers and practitioners is attracted by the ideas of settlements of a new type – linear accommodation along transport corridors [9].

The uST transport and infrastructure complexes, which are being worked on under the supervision of engineer A. Unitsky, according to the EcoSpace program [10], make up a system of transport channels – the uNet communication and infrastructure network. The uCities and ELC, built using eco-oriented (biospheric) technologies, will appear on the basis of uST solutions. The planning unit of the new type of settlements will be a residential cluster consisting of "horizontal skyscrapers" (HSs) – interlocked into single-family low-rise buildings with a set of engineering systems that provide residents with everything necessary for life, including organic food, drinking water from artesian wells, electrical and thermal energy, as well as a full biospheric cycle of household recycling waste.

Urban agriculture, arranged in residential clusters, will improve the economy and ecology of cities, preserve the ecological environment, improve architecture and supply the population with fresh, environmentally friendly food. It is necessary to highlight some specific areas in the development of green technologies on the roofs of buildings:

- combining vertical greenhouses with commercial, office or residential structures, which will allow using heat and carbon dioxide that are present in air flows discharged into the atmosphere through exhaust ventilation, and redirecting them to greenhouses, saving energy resources spent on heating and obtaining carbon dioxide for plant fertilization;
- return of urban waste, including sewage, as secondary resources (recycling) into the chain of production and consumption, i.e., the waste will be processed into products, materials or substances regardless of whether they serve their original or any other purposes. A specific type of recycling is the processing of organic waste for composting [11];
- transition to the concept of modularity and compliance with the zoning requirements of technological premises. At the same time, it is supposed to create relatively isolated spaces (for example, plantlet, seedlings and vegetable sections), which will allow dividing the greenhouse area into automated regulated zones [12];
- formation of an automated control system to ensure the interaction of operational personnel with lower-level systems, implementation of dispatching control of processes and receipt of operational data from sensors in the systems of drip irrigation, microclimate monitoring, window ventilation, shading, carbon dioxide fertilization, additional illumination, as well as heating, air recirculation and automation of microclimate mode [12];
- application of multi-tiered narrow-cell arrangement and humusoponics, which uses liquid biohumus as plant nutrition, rather than chemical mineral substances, and allows for organic plant growing.

Organic products for cluster residents (people and animals) are planned to be grown in greenhouses located on the roofs of HSs in vertical farms. A solution with nutrients contained in soil humus – liquid biohumus – will be supplied to the root system of plants. This technology is natural in contrast to the traditional nature-like hydroponics based on chemical mineral compositions. After all, plants evolutionarily feed on substances that are formed due to the transformation of insoluble organic and mineral compounds into soluble salts of humic acids by a community of aerobic and anaerobic soil microorganisms that initially live in any naturally fertile soil.

Therefore, liquid biohumus should contain not only nutrients, but also communities of thousands of species of agronomically valuable soil microorganisms, and in greater quantities than, for example, they are contained in rich chernozem (about a trillion microorganisms per liter of humus). By analogy with hydroponics, this system is called "humusoponics". In the agricultural farms of uCities, just humusoponics will be used – when plants feed on liquid humus, where insoluble salts of humic acids have already been converted into a dissolved substance. Such experiments are successfully carried out in the Unitsky's Farm Enterprise, Maryina Gorka, Belarus.

In order to test innovative farming technologies in new type settlements, a large-scale project has been conceived on the basis of the Unitsky's Farm Enterprise – construction of a multifunctional building (Figures 9–14), in which various blocks will be combined, including residential, auxiliary, technical, as well as premises for growing and processing green food. The purpose of the experiment is to study and approve the advantages of such a combination.

At this facility, it is planned to install and test innovative technologies for heating, ventilation and air conditioning (HVAC); wastewater treatment and reuse; obtaining and using humus from organic waste and sludge accumulations of wastewater.

At Unitsky String Technologies Inc., Minsk, Belarus, research has been conducted and positive practical results have been achieved in testing certain technologies that are planned to be used in this multifunctional building: growing of tropical plants on lightweight soil [13], production of edible and medicinal mushrooms [14], production of natural phytoncide-containing extracts, liquid soap [15], processing of organic waste using vermicomposting and growing with the use of the resulting substrate of plant products (vegetables, green crops, microgreens) [16]. Using modern technologies, medicinal herbs are cultivated on the territory of the Unitsky's Farm Enterprise on an area of about 1,000 m^2 [17], and they also breed quails.

In the projected greenhouse, various pipeline systems are separated, transporting the following:

1) aqueous solutions of liquid vermicompost (adjustment of concentration of substances is possible);

2) rain water from storage tanks;

3) secondary water from domestic wastewater treatment tanks;

4) drinking water;

5) carbon dioxide gas for plant nutrition extracted from the fume emissions of a heat source.

Systems 1–3 can be combined with each other in a drip irrigation complex. All engineering networks are arranged in special zones that transit through a multifunctional building, executed in the HS ideology.

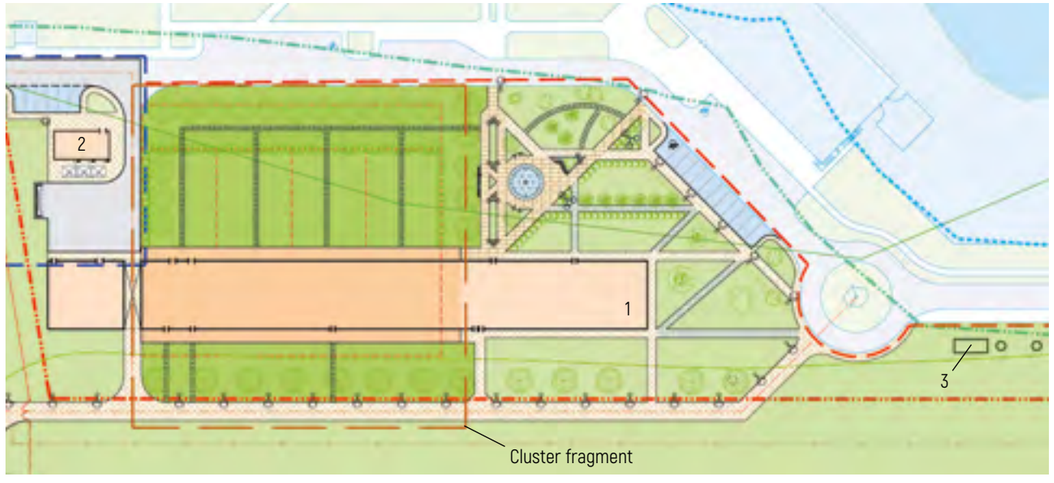

Figure 9 – Layout of a multifunctional building on the territory of the Unitsky's Farm Enterprise (variant):
1 – multifunctional building; 2 – boiler room; 3 – wastewater treatment unit

Figure 10 – General view of a multifunctional building
on the territory of the Unitsky's Farm Enterprise (variant)

Figure 11 – Structural diagram of a multifunctional building
made of prefabricated elements (fragment, variant)

Figure 12 – General view of the second floor
of a multifunctional building (greenhouse, variant)

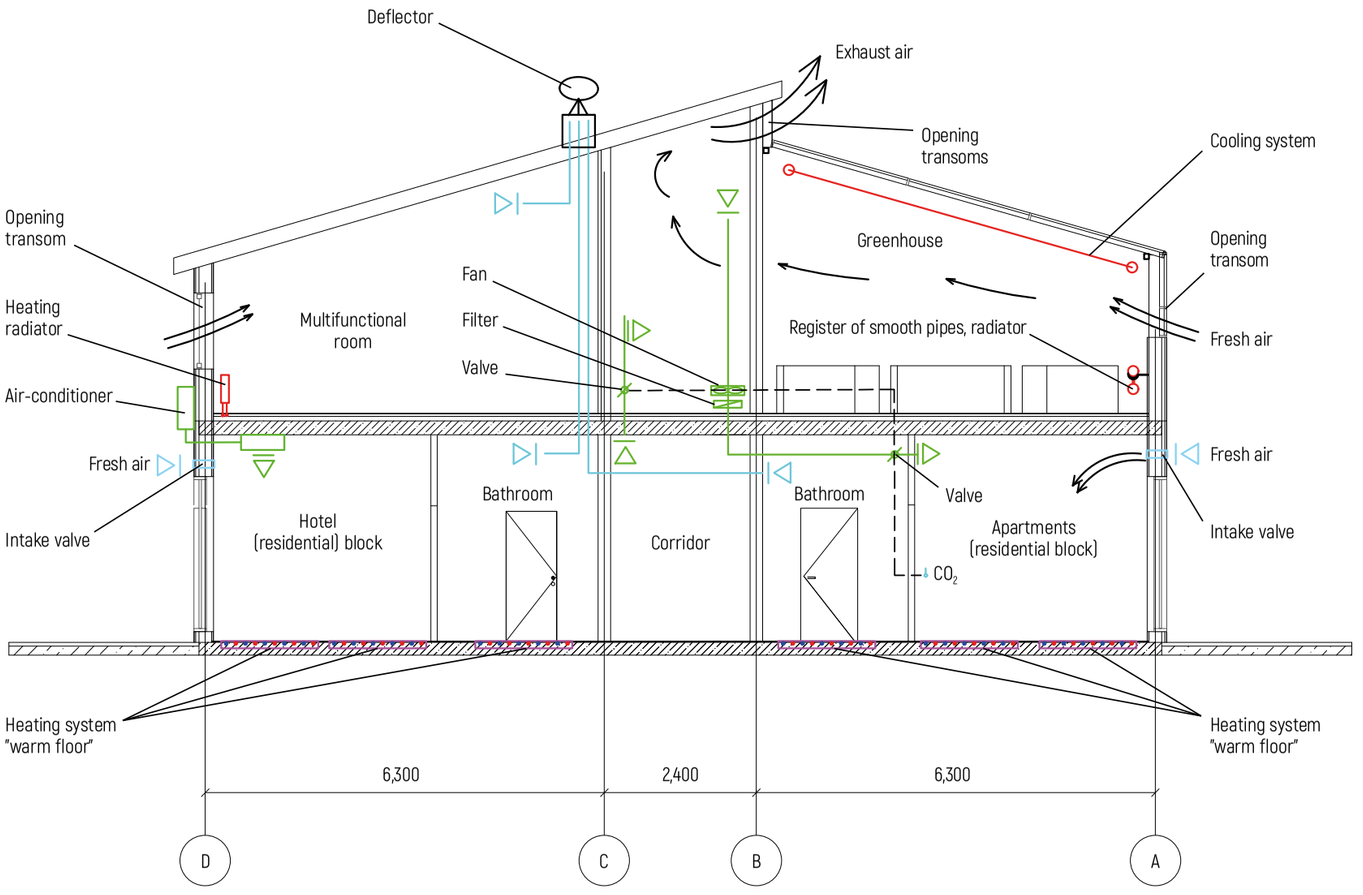

Figure 13 – Diagram of HVAC systems of a multifunctional building (variant)

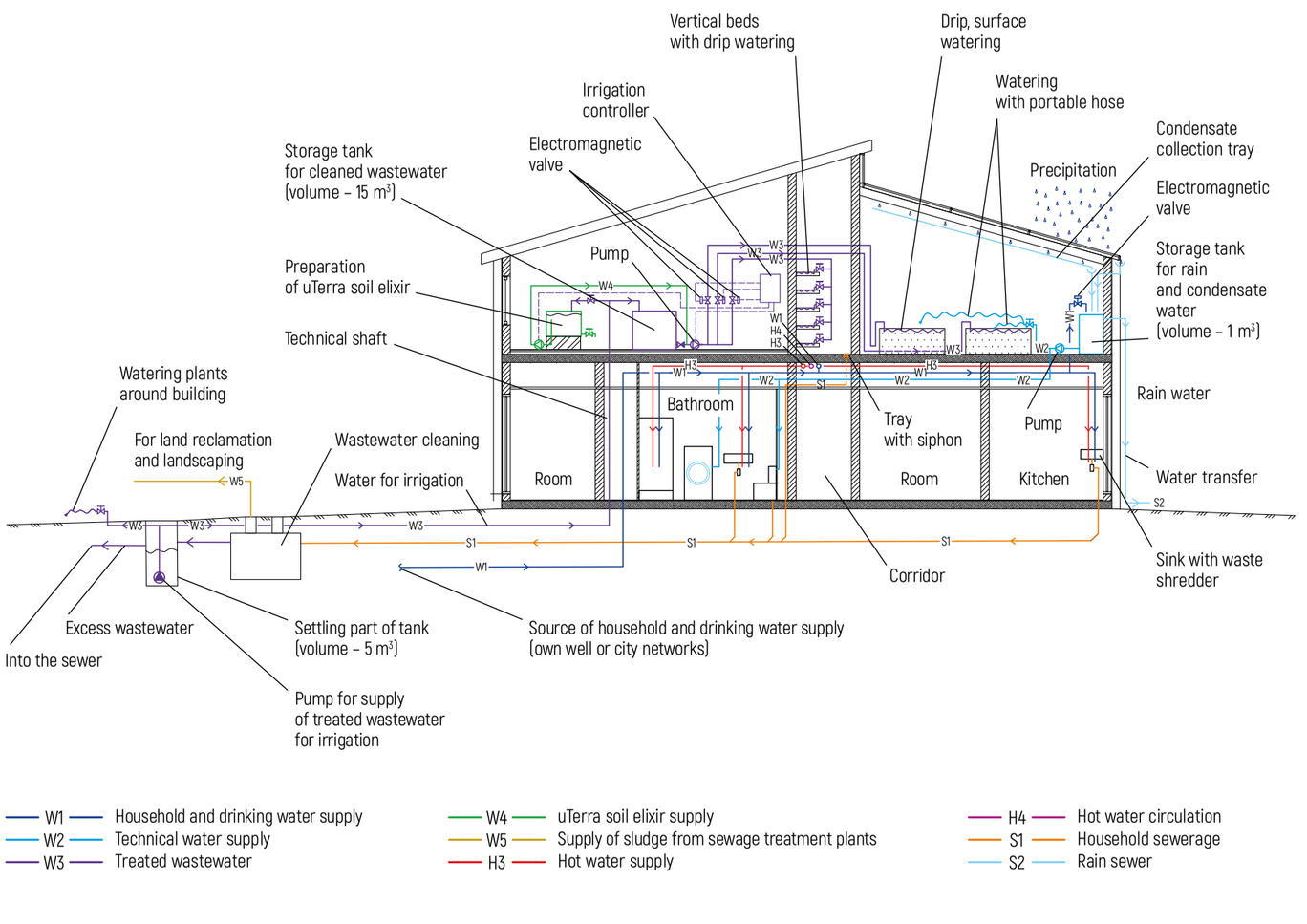

Figure 14 – Diagram of water reuse in a multifunctional building (variant)

Specifics and Conditions for Functioning of the Premises Located on the Second Floor of a "Horizontal Skyscraper"

The second floor of a HS in the residential cluster of the uCity will be rented by a farmer, and the residents of the house, as members of the condominium, will become participants in the process, receiving their part of the income from grown organic products. A year-round working farm will be able to produce enough food products on the roof of the HS to meet the needs of every family living in the house.

The rationally designed layout of the second floor is adapted for the functioning of a greenhouse. The entrance to the roof is arranged from the HS sidewalls. In the center of the building there is a through corridor with a narrow-gauge line for an automated cargo trolley transporting pallets with crops, humus, agricultural waste and auxiliary materials to cargo elevators arranged at the sides of the house.

The space of the second floor of the HS is divided into technological sections and blocks:

- a greenhouse for growing agricultural crops, medicinal herbs, decorative plants, which is a single premise oriented to the south side, covered with a glazed roof to ensure maximum light transmission;
- a room for growing microgreens in vertical farms;
- premises for microclonal propagation of plants (*in vitro*), which is based on the unique property of the plant somatic cell – totipotency, i.e., the ability of cells to implement the potential of the whole plant;
- a site for growing mushrooms (oyster mushrooms, etc.), which are a valuable dietary product that has a low-calorie content (38–41 kcal) and contains many substances necessary for the human body. Oyster mushroom is unpretentious to fluctuations in temperature, humidity and light levels, easy to care for, and is characterized by rapid germination [18];
- an area for breeding quails and other small animals to provide residents with dietary products (eggs, meat);
- a site for the production of biohumus and zoohumus. Biohumus is a biologically active, environmentally friendly and natural organic fertilizer, which is created as a result of processing organic residues in the soil by red California worms. Zoohumus is a product of the vital activity of fly larvae; it is a loose, finely granulated mass from gray to brown in color, having a faint smell of ammonia. Zoohumus is used as an organic fertilizer for all types of crops, in forestry and floriculture, as well as for the restoration of polluted soils. To obtain liquid vermicompost, it is proposed to use bio- and zoohumus together, and, if necessary, mineral components to regulate the content of certain elements. The mixture of biohumus, zoohumus and mineral components is diluted with water in a ratio of 1:10, then it is dispersed in a cavitation unit to a stable emulsion state. This suspension can be filtered and/or centrifuged. Figure 15 shows the general diagram of processing solid food waste to obtain plant products;
- public premises;
- utility area;
- dressing rooms, bathrooms, utility rooms.

In vertical farms, which are a complex of modules, plants are cultivated in conditions of protected soil and controlled environmental parameters. Mainly leaf and salad crops are grown, as well as microgreens, using such technologies.

Various types of microgreens have significant nutritional value not only for humans, but also for animals. Obtained on humusoponics, it is a natural organic food rich in easily digestible nutrients and vitamins. There are no chemical fertilizers and chemical means of protection (pesticides, herbicides, etc.) in this cultivation technology. Humusoponic feed from wheat seedlings (i.e., grown using humusoponics technology) as a green fodder additive or individual feed is energy-intensive and has a high content of proteins and fats, vitamins and other important micronutrients. It is fundamentally different from other ones, since the animal eats not only the aboveground part, but also the remains of seeds with starch, the root part rich in sugars and proteins.

Regardless of the time of year and climatic conditions (drought, heavy rains, heat, frost, etc.), humusoponic installations can provide both animals and people with fresh green food, which is especially important for vitamin deficiency in winter.

In addition to vertical farms, it is planned to arrange high round-shaped beds in the greenhouse on the second floor of the HS – cheap and easy to maintain, with a diameter of 1.91 m (perimeter of 6 m). They are easy to disassemble and relocate, service from all sides; each bed can be planted with its own culture.

The choice of plants for cultivation in the HS takes into account the food preferences of people and the peculiarities of the country's location (regional consumption traditions, seasonality of local production, price fluctuations, maintaining a healthy lifestyle, etc.).

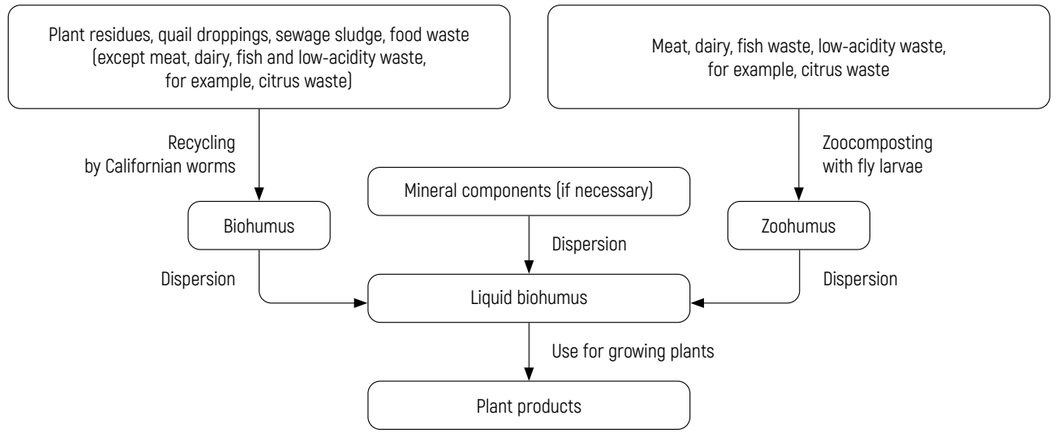

Figure 15 – Diagram of processing solid food waste to obtain plant products

The most optimal for the majority of plants valuable from a nutritional and/or medicinal point of view is a subtropical climate, therefore, the atmospheric conditions of the green-house are close to it. The entire space for growing crops on the roof of the HS is one climatic zone, the features of which are suitable for all plants selected taking into account the established climatic requirements.

To adjust the temperature and humidity in certain areas of the greenhouse, it is proposed to use mechanisms for local control of these parameters: fans, IR heaters, LED lamps, additional irrigation systems.

Climatic and technological conditions for growing crops in the HS are planned to be observed within the following limits:

- air temperature: 20–28 °C during the day, 16–25 °C at night;
- irrigation water temperature: 15–25 °C;
- humidity: 60–80 % (adjustable);
- type of lighting lamps: LED lamps with a spectrum of 380–780 nm;
- natural lighting and additional illumination: 10,000 lux;
- daylight period: 12–16 h;
- air exchange rate: 4–90 m^3/h per 1 m^2 (adjustable);
- CO_2 content in the air: 350–1,000 ppm (0.03–0.1 %) during daylight hours;
- installation in industrial greenhouses of an appropriate number of axial fans with a capacity of 0.25 kW each.

The irrigation system is planned to be automated: the volume and schedule of drip root irrigation of plants with purified wastewater of certain features are programmed (Table 2).

Table 2 – Requirements to wastewater for irrigation of plants

Indicator	Value
1	2
In accordance with the resolution of the Ministry of natural resources and environmental protection of the Republic of Belarus No. 16 dated May 26, 2017 "On some issues on regulation of discharges of chemical and other substances in wastewater"	
Biochemical oxygen consumption, mg/l, max	25
Chemical oxygen consumption, mg/l, max	125
Suspended solids, mg/l	30

End of Table 2

1	2
In accordance with GOST 17.4.3.05-86 "Nature protection. Soil. Requirements to wastewater and its precipitation for irrigation and fertilization" and the applied technology of cultivation of plant products, GOST 33045-2014 "Water. Methods for the determination of nitrogen-containing substances"	
Size of solid particles, μm, max	50
Total nitrogen, mg/l, max	31
Total phosphorus, mg/l, max	30
Total potassium, mg/l, max	58
pH, units	6–8
Microelements, heavy metals, pollutants	Taking into account their concentration in the soil and norms for cultivated crops
Unpleasant odors, on a five-point scale	Max 3
In accordance with Sanitary Regulations and Norms 2.1.7.573-96 "2.1.7. Soil, cleaning of populated areas, household and industrial waste, sanitary protection of soil. Hygienic requirements to the use of wastewater and its sediments for irrigation and fertilization"	
The number of LPC (lactose-positive *E. coli*), the permissible content of CFU per 1 l, max	10^4
Pathogenic microorganisms (according to epidemiological indicators), quantity per 1 l	None
Viable geohelminth eggs (ascarids, whipworms, hookworms), content in 1 l	None
Viable biohelminth eggs (teniid oncospheres, fasciol eggs), content in 1 l	None
Viable intestinal pathogenic protozoan cysts (giardia, balantidium cysts, cryptosporidium oocysts), content in 1 l	None

The amount of carbon dioxide absorbed by plants varies during the day and depends on the intensity of illumination and the quality of light (spectral composition of the luminous flux). The greatest need for CO_2 occurs in the morning and afternoon, when the photosynthesis process reaches peak values. If the needs of plants are not met and the concentration of carbon dioxide is increased at night, the growth and fruit formation processes slow down due to the suppression of plant respiration.

There are several types of carbon dioxide supply to plants: root feeding, at the point of growth, in the assimilating mass of the plant. Since carbon dioxide is twice as heavy as air and tends to accumulate at the bottom of the greenhouse, it is advisable to introduce CO_2 at the highest point – at the point of growth (with closed transoms).

To date, the most efficient and environmentally friendly equipment is considered to be the one that supplies to greenhouses not smoke, but carbon dioxide purified from impurities. This method requires a network of gas pipelines for distributing CO_2 to greenhouses and an automated gas supply control system. In addition, a storage tank for liquid carbon dioxide, a gasifier, a heater and other equipment are needed.

Inside the greenhouse, the gas is distributed by contours, i.e., the concentration of CO_2 in various parts of the structure is maintained at the same level. Independent gas supply to the greenhouse circuits is controlled with sensors, which in turn, on command from the controller, adjust the valve attached to this circuit [19].

Conclusions and Future Work

The use of roofs of buildings for growing food products is of paramount importance for the creation of a new type of residential development. Their principles of construction can be used not only in uCities, ELC, EcoCosmoHouse on Planet Earth (ECH-Earth), but also on space orbits in EcoCosmoHouses (ECHs). Technologies for obtaining plant and animal food in a controlled environment open up a fundamentally different level of production, distribution and consumption of natural goods and ensure the food security for the population of any country.

A new type of residential environment is based on combining many functions into a common architectural and planning structure, where groups of residential buildings interlocked into an apartment complex called a "horizontal skyscraper" make up a single structural, engineering, technological and planning organism. Such ecohouses during construction will not take away the land from the Earth's biosphere – from under the foundation of a building, even if it is desert sand, it will be raised to the roof, enriched to the fertility of rich chernozem with humus made from local organic waste, and will be able to feed a family living in the house with full-fledged organic food practically without involving additional external biospheric resources.

The fulfillment of the conditions described in the presented article makes the use of HSs roofs real and allows to combine residential, industrial and auxiliary functions into one harmonious whole. Being innovative, this way of creating a new type of living environment will become the basis for further developments. These features of the HSs functioning will determine the development of such systems as a key element of residential development of uCities and ELC settlements based on uST transport and infrastructure technologies.

References

1. *Gorodskoye naseleniye Zemli prevysilo sel'skoye [The Urban Population of the Earth Has Exceeded the Rural One] [Electronic resource] // Vokrug sveta. – 2007. – Mode of access: https://www.vokrugsveta.ru/news/1094. – Date of access: 20.05.2022.*
2. *Schotchik naseleniya Zemli [The Counter of the Earth's Population] [Electronic resource] // Naseleniye Zemli. – 2022. – Mode of access: https://countrymeters.info/ru/World. – Date of access: 29.07.2022.*
3. *Koval', N.V. Tendentsii razvitiya siti-fermerstva v sovremennykh gorodakh [Trends in the Development of City Farming in Modern Cities] / N.V. Koval' // Matritsa nauchnogo poznaniya. – 2021. – No. 4-2. – P. 65–79.*
4. *Sembin, M.S. Opyt poiska gradostroitel'nykh rezervov dlya razvitiya gorodskogo sel'skogo khozyaystva v sovremennykh megapolisakh [Experience in Finding Urban Planning Reserves for the Development of Urban Agriculture in Modern Megacities] / M.S. Sembin, Sh.Zh. Surankulov, Ye.A. Akhmedova // Gradostroitel'stvo i arkhitektura. – 2019. – Vol. 9, No. 3. – P. 151–158.*
5. *Magellan's Urban Farm [Electronic resource] // Ilimelgo. – Mode of access: https://ilimelgo.com/fr/projets/cultiver/hautes-serres. – Date of access: 01.07.2022.*
6. *Despommier, D. The Vertical Farm: Feeding the World in the 21st Century. – New York: Thomas Dunne Books, 2010. – 320 p.*
7. *Despommier, D. The Vertical Farm: The Sky-Scraper as Vehicle for a Sustainable Urban Agriculture / D. Despommier, E. Ellingsen // Tall & Green: Typology for a Sustainable Urban Future: CTBUH 8th World Congress, Dubai. – 2008. – P. 311–318.*
8. *Ot Chikago do Dubaya: obzor vertikal'nykh ferm [From Chicago to Dubai: An Overview of Vertical Farms] [Electronic resource]. – 2018. – Mode of access: http://project409440.tilda.ws/verticalfarmingworld. – Date of access: 30.04.2022.*
9. *Ot idey Soria-i-Mata do "Sibstrima" i "Strategii-2030": obzor otechestvennykh i zarubezhnykh proyektov lineynykh gorodov i sistem rasseleniya [From Soria-and-Mat Ideas to Sibstream and Strategy 2030: A Review of Domestic and Foreign Projects of Linear Cities and Accommodation Systems] / I.M. Dolinskaya [et al.] // Universum: tekhnicheskiye nauki. – 2021. – No. 5-2 (86). – P. 63–74.*
10. *Programma "EkoMir" [EcoSpace Program] [Electronic resource]. – 2020. – Mode of access: http://ecospace.org/images/Program_EcoSpace_RU.pdf. – Date of access: 05.06.2022.*
11. *Zadorozhnaya, L.Ye. Mirovaya i otechestvennaya praktika bezotkhodnogo proizvodstva posredstvom perekhoda k tsirkulyarnoy ekonomike [World and Domestic Practice of Waste-Free Production Through the Transition to a Circular Economy] / L.Ye. Zadorozhnaya // Ekonomicheskiy vestnik IPU RAN. – 2020. – Vol. 1, No. 1. – P. 106–124.*
12. *Prudtskikh, N.V. Vertikal'nyye teplitsy: perekhod k kontseptsii modul'nosti [Vertical Greenhouses: Transition to the Concept of Modularity] / N.V. Prudtskikh // Avtomatizatsiya, mekhatronika, informatsionnyye tekhnologii: Materials of the VIII International Scientific and Technical Internet-Conference of Young Scientists, Omsk, May 16, 2018 / International Concern Festo [et al.]. – Omsk: OmGTU, 2018. – P. 32–35.*
13. *Fertility and Physico-Chemical Indicators of Light "Space" Potting Soils for EcoCosmoHouse / A. Unitsky [et al.] // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International*

Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 309–324.

14. *Unitsky, A. Medicinal and Edible Mushrooms in an Enclosed Ecosystem: Cultivation, Properties, Application / A. Unitsky, A. Kostenevich // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 267–278.*
15. *Zyl, N. Plants of Special Purpose and Their Use in EcoCosmoHouse / N. Zyl, N. Batalevich, E. Shakhno // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 191–197.*
16. *Unitsky, A. EcoCosmoHouse as a Space for the Conservation of Species Diversity of Tropical and Subtropical Flora / A. Unitsky, V. Pavlovsky, D. Feofanov // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 153–157.*
17. *Shakhno, E. Medicinal Plants for EcoCosmoHouse: Selection, Growing Conditions, Scope of Application / E. Shakhno, N. Zyl // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 281–289.*
18. *Makhmutov, A.N. Sistema avtomaticheskoy podachi gaza CO_2 v teplichnyye pomeshcheniya [Automatic System of CO_2 Gas Supply to Greenhouses] / A.N. Makhmutov // Ovoshchi Rossii. – 2017. – No. 3 (36). – P. 64–69.*
19. *A Review on Study of Growth and Cultivation of Oyster Mushroom / J. Nongthombam [et al.] // Plant Cell Biotechnology and Molecular Biology. – 2021. – Vol. 22, iss. 5–6. – P. 55–65.*

The Use of the Electrohydraulic Effect for the Disinfection of Wastewater in the Conditions of Human Habitation in Space

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UDC 628.316.6

An analysis of the existing methods of water disinfection was carried out, their advantages and disadvantages were indicated in terms of the possibility of using them in the Industrial Space Necklace "Orbit" (ISN "Orbit"). The results of tests on the disinfection of water contaminated with spore-forming bacteria *Bacillus subtilis* were presented, as well as native lake water at the UniThorr experimental electrohydraulic discharge equipment (EHDE), developed by Unitsky String Technologies Inc. The high efficiency of using the electrohydraulic discharge for disinfection was shown, which will allow switching to a reagentless method and obtaining a closed-loop water consumption cycle in the EcoCosmoHouse (ECH).

Keywords: *EcoCosmoHouse (ECH), electrohydraulic discharge, electrohydraulic discharge equipment (EHDE), electrohydraulic effect, Industrial Space Necklace "Orbit" (ISN "Orbit"), wastewater, water disinfection.*

Introduction

Purification and disinfection of water in the living conditions of people in cosmos have their own specifics, which are explained by the high cost of cargo delivery, lack of room, etc. According to the data [1], transportation of 1 kg of cargo to the International Space Station (ISS) costs 5,000–6,000 USD. In this regard, at such facilities, a mandatory requirement is the presence of a closed-loop water supply system. Thus, water regeneration at the Mir space station made it possible to reduce the cost of its delivery by about 300 mln USD per year. At the same time, despite the circular nature of the water consumption process, irretrievable water losses amounted to 7 % and were replenished only by transporting it from Earth.

To date, astronauts are allowed to consume 2.7 l of water per day to maintain their vital activity. The annual water consumption for all the needs of the space station with a crew of six people is about 9 m^3 [1]. The ISS has an implemented purification system, including distillation and iodization [2], which needs to be improved.

The Industrial Space Necklace "Orbit" (ISN "Orbit") is a multiorbital transport-infrastructural and industrial-residential complex, encompassing the planet in the equatorial plane. Created in space to serve terrestrial humanity, it will become a functional equivalent of an Equatorial Linear City, as well as a base for protection against space threats (including meteoroids) and a technological platform for the expansion of terrestrial civilization into deep space [3–5].

The EcoCosmoHouse (ECH) is an integral part of the residential and industrial infrastructure of the ISN "Orbit". The ECH is an enclosed ecosystem of the biospheric type, in which all inhabitants must not only receive a balanced diet, but also be provided with safe drinking water that meets the most stringent hygienic requirements and standards [5–7]. Under such conditions, there is an acute need to create an effective closed-loop system of water disposal, water purification and then water supply to the inhabitants of the ECH with high-quality drinking water [8, 9].

Currently, chemical (reagent), physical, as well as complex methods of disinfection are used. Note that the location of the ISN "Orbit" makes it difficult to deliver chemicals, antimicrobials, antiseptics, so the most preferred ways to obtain good quality water can be ultraviolet radiation and electrohydraulic discharge.

An effective alternative to traditional methods of disinfection in the process of developing a closed-loop purification system intended for implementation in the ECH and its terrestrial counterpart EcoCosmoHouse on Planet Earth (ECH-Earth) will be the use of an electrohydraulic discharge equipment (EHDE). Its mode of operation is based on the electrohydraulic effect (Yutkin effect) [10], the essence of which is the creation of intentional ultra-high hydraulic pressure, leading to the death even of *Bacillus anthraci* spores, the infectious agents of anthrax [11].

Analysis of Disinfection Methods

The choice of one or another method of disinfection depends on the type of water, its volume, further purpose after purification and the concentration of pollutants. The following methods are most common on Earth:

- chemical (use of various reagents and oxidizers – chlorine, chlorine dioxide, sodium hypochlorite, etc.);
- physical (heat treatment, ultraviolet radiation, exposure to ultrasound, electric discharge, etc.);
- combined (physico-chemical).

The principle of disinfection using strong oxidizers, for example, active ions of halogen derivatives, is based on their introduction into the cell shell of microorganisms, penetration and destruction of its structure. This method is used at stations of centralized water supply of settlements. However, it is ineffective against Giardia cysts. In addition, oxidizers lead to the formation of carcinogens and toxic substances. The main disadvantage of this disinfection technique is the presence of residual chlorine in drinking water, which is dangerous for humans.

Under the conditions of the ISN "Orbit", this method should not be used due to the danger of cylinder leakage, the high volatility of chlorine, as well as the need for regular delivery of reagents and oxidizers into orbit.

In space, the use of hydrogen peroxide is also impractical. The main mechanism of its bactericidal action is the formation of superoxide and hydroxyl radicals, which can have either a direct cytotoxic effect or an indirect one, leading to damage to DNA molecules, and later to the death of the bacterial cell. These radicals have a greater bactericidal effect than the original hydrogen peroxide. The disadvantages of this method include the importance of maintaining a constant temperature. So, its decrease from 18–20 °C down to 1–4 °C negatively affects the activity of hydrogen peroxide, especially in case of massive contamination of water by microorganisms [12].

The use of ultraviolet rays (recommended wavelength range 200–280 nm) for disinfecting water to drinking quality has recently gained popularity due to the fact that this method is effective against most viruses and bacteria, including cholera and typhoid pathogens, hepatitis and influenza viruses, dysentery bacilli, *Escherichia coli*. The UV spectrum coincides with the DNA absorption spectrum (λ_{max} = 260 nm), breaking hydrogen bonds between complementary DNA strands and forming dimers in the DNA molecule, and uracil hydroxylation in RNA. As a result, the process of DNA replication is hindered, which causes cell death. The longer exposure to UV light, the greater the damage. The average dose of such radiation exposure at water disinfection stations being commissioned and planned in the USA, Canada, Great Britain and France is 50–100 mJ/cm^2 [13]. This physical method has a number of advantages: high efficiency, preservation of the taste of water, no need to use reagents. However, there are a number of disadvantages: strict requirements for the degree of transparency of the medium (in terms of turbidity), the complexity of the design when used as industrial disinfection units, the impossibility of long-term storage due to the risk of re-contamination. It is worth noting that when applying UV radiation, a careful selection of the dose is necessary to prevent the appearance of any toxic by-products in the water. This is due to the fact that the disinfection effect is achieved at much lower doses of bactericidal radiation compared to the photochemical transformation of dissolved organic substances. The use of UV radiation in the living conditions of people in Earth orbit is difficult due to the need for regular delivery of lamps for replacement (every 8,000–12,000 h of operation), as well as due to the difficulties associated with the process of their disposal [13].

The methods based on changing the properties of an object due to the impact of high-voltage electric fields on it may include ozonation and the use of the electrohydraulic discharge effect.

Ozone is obtained when a silent electric discharge is applied to oxygen in special ozonator devices. Electrosynthesis of ozone is carried out in a generator, which is an emitter consisting of two electrodes separated by a dielectric. Oxidative ability is based on the destruction of cell membranes and walls, the effect on the redox system of bacteria and their protoplasm. However, when using ozone, technical and environmental problems arise: the need for large production areas, a separate building, powerful ventilation in the room; stiff requirements for the qualification of service personnel; toxicity, explosiveness.

Electric purification methods seem to be the most promising. Their essence lies in the conversion of electrical energy into other types that affect the purification object.

Electrowave methods use electromagnetic energy of various frequencies, such as microwave processing, laser or ultrasonic treatment. Electrostatic methods use the energy of high voltage electrical fields, and in particular electrohydraulic shock, based on the electrohydraulic effect [10]. A number of works have shown the effectiveness of the EHDE for purifying livestock waste from pathogenic microflora [10, 11, 14], ballast wastewater disposed into the marine environment [15, 16].

Electrohydraulic discharge in water caused by electric pulses of short duration (several microseconds) at high instantaneous power (50–1,000 MW), gives rise to active free radicals, atomic oxygen and hydrogen, nitrogen compounds and the simplest amino acids. The process is facilitated by air and other gases dissolved in water. Microbial flora, first of all bacterial, dies heavily, which is associated with ultrasonic, ultraviolet and X-ray radiation of the discharge channel plasma, as well as with a powerful oxidizing effect of atomic oxygen [17].

The authors [10, 18, 19] consider ultraviolet radiation and ultrasound generated by an electrohydraulic discharge to be the dominant disinfecting factors in the EHDE, rather than thermal shock, ultrahigh hydraulic pressure or chemicals. However, it is stated in [20] that it is the shock wave generated during the formation of the plasma channel that is the most important factor responsible for the inactivation of microorganisms, while the effect of UV radiation, chemical oxidizers and pulsed electric fields is insignificant. It was also shown in [21, 22] that the bacterial cell wall is damaged by the shock wave generated by the pulsed discharge plasma.

Obviously, when disinfecting water with an electrohydraulic discharge, a complex of factors leads to the death of microflora, depending on the type/strain of the microorganism. The liquid treated in this way acquires bactericidal properties that do not decrease over time. Disinfection is very intensive, and the speed of the process is proportional to the number and energy of pulses that cause electrohydraulic discharges [23].

One of the main advantages of using electrohydraulic discharge technologies in space life is environmental friendliness, which is dictated by the absence of chemicals and by-products. In addition, the presence of solar energy allows getting cheap electricity in sufficient quantities to power the water purification system.

The safety of drinking water in an epidemic sense is determined by the absence of pathogenic bacteria, viruses and protozoa in it, its compliance with the standards

for microbiological and parasitological indicators [23]. The literature describes studies on the effect of electrohydraulic discharge on various non-spore-forming microorganisms, including the intestinal bacteria group, the main representative of which is *Escherichia coli* [18, 19, 24, 25]. However, bacteria that have the ability to sporulate, upon the onset of unfavorable conditions for life, form a dense shell under the outer membrane.

In this case, spores are not a method of bacteria reproduction; at the same time, the reduced volume due to the partial loss of water allows them to survive and spread more efficiently. Spores can be dormant for a long time and are characterized by a low level of metabolic activity distinguished by an unusually high heat resistance, maintaining their viability when boiled for several hours, as well as increased resistance to ultraviolet radiation and mechanical stress. In view of the foregoing, it can be concluded that the use of electrohydraulic discharge is relevant for the disinfection of water, also if it contains spore-forming microorganisms.

The purpose of this work is to study the effect of electrohydraulic discharge on the death of spore-forming microorganisms using the *Bacillus subtilis* (*B. subtilis*) testing culture as an example.

According to the purpose, the following tasks were solved:

- determination of the effect of electrohydraulic discharge on the death of microorganisms;
- establishing the dependence of the degree of disinfection on the treatment time and the initial concentration of microorganism cells in the solution.

Materials and Methods of Research

Gram-positive spore-forming soil bacterium *B. subtilis* strain G BKM B-911 was chosen as the object of study (Figure 1). It was taken from the own bank of microorganisms of the Biotechnology Department laboratory of Unitsky String Technologies Inc. [5].

B. subtilis, or hay bacterium, a microorganism inhabiting the soil, the intestines of animals and humans, as well as occurring in water and air, is one of the most studied representatives of the genus *Bacillus*, which can form spores or endospores located in the central part of the mother cell and having an oval shape with a multilayer hard-to-penetrate shell.

As a rule, the studied inoculum of microorganisms contains spores, vegetative cells and vegetative cells with

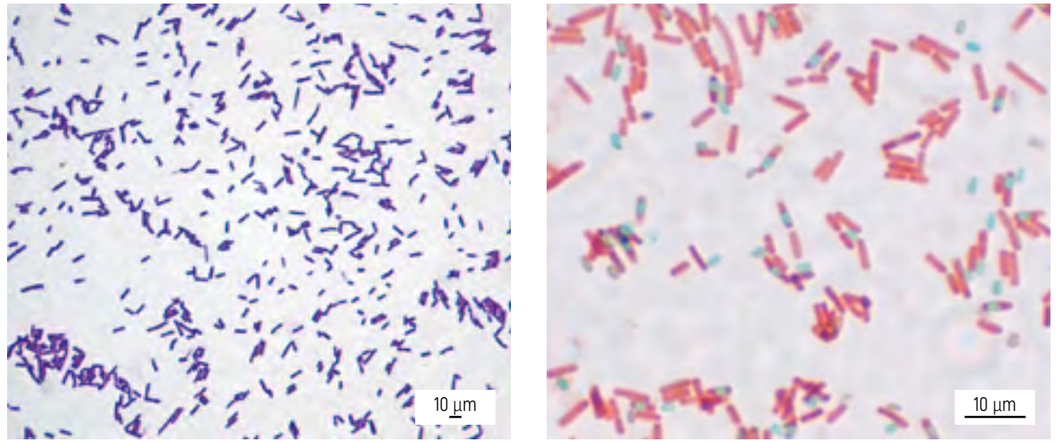
Figure 1 – Growth of *B. subtilis* colonies in a Petri dish

endospores in various proportions (Figure 2). When negatively affected, vegetative cells are the least resistant, and spores are the most viable; therefore, aged 3–4-day cultures were used for the experiment (during such a period, bacteria, presumably, pass through all stages of development).

The effectiveness of the use of electrohydraulic discharge, implemented in the UniThorr EHDE (developed by the Test Equipment design bureau of Unitsky String Technologies Inc.), was studied in water artificially contaminated with spore-forming microorganisms up to a concentration that corresponds to the content of bacteria in wastewater.

The production of the inoculum of the testing culture *B. subtilis* strain G BKM B-911 was carried out in the Biotechnology Department laboratory using the periodic method [26].

The culture fluid with different initial concentrations of microorganisms was subjected to electrohydraulic discharge in the time interval from 6 s to 40 min; pulse energy – 400 kJ. The EHDE operation parameters: voltage – 45 kV, current – 15 kA, charging circuit capacity – 0.4 μF, working chamber volume – 9 l. Water sampling before and after exposure was performed aseptically. The repetition rate of each sample was equal to three. Seeding on the surface of a dense agar medium was carried out by the Koch method, followed by incubation, after which the colonies grown on nutrient agar were counted [26]. The degree of water disinfection was estimated by the change in the number of colony-forming units (CFU) as a result



a) b)

Figure 2 – *B. subtilis* microorganisms stained with methylene blue solution:
a – as per the Loeffler method; b – as per the Peshkov method (vegetative cells are red, spores are green/blue)

of exposure to the EHDE. The total number of microorganisms in the initial samples was in the range of 10^4–10^5 CFU per 1 ml of solution.

Next, we studied lake water sampled in the Aquarelle EcoPark (Maryina Gorka, Belarus). This artificially created water reservoir was chosen as the most likely prototype of a secluded aquatic ecosystem.

Obtained Results

Experiments to determine the effect of electrohydraulic discharge on the death of microorganisms of the selected testing culture with a concentration of 4.5×10^5 CFU/ml, carried out at the UniThorr EHDE, revealed a decrease in total microbial count (TMC) by one order of magnitude after 10 min of exposure. An increase in the operating time of the EHDE to 40 min leads to a decrease in TMC by 99 %, but does not allow to achieve a complete destruction of microorganisms (Figure 3).

At a higher initial concentration of microorganisms in the solution – 4.5×10^5 CFU/ml – an intense disinfecting effect is observed with an exposure time of up to 10 min, then the dependence of TMC on the treatment time is linear (Figure 3). In the interval from the 10th to the 15th min of treatment, the TMC value increases, and then its further decrease is noted. This phenomenon can be explained

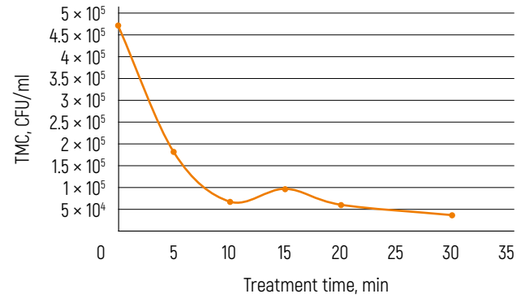


Figure 3 – Influence of treatment time on TMC
at the initial concentration of microorganisms of 4.5×10^5 CFU/ml

by the so-called bacterial explosion effect. The possibility of its occurrence is described in [10]. This phenomenon is due to the fact that the weakest microorganisms are initially destroyed and those most resistant to external factors remain in the solution. In addition, during electrohydraulic discharge, the content of nitrogen compounds and other nutrients in the water medium increases. After the EHDE operation is stopped and in the presence of nutrients (including nitrogen), a rapid growth of the surviving and strongest representatives of the bacterial colony occurs.

The residual value of TMC during electrohydraulic discharge treatment of contaminated water with the initial

concentration of microorganisms of 5.5×10^4 CFU/ml is less than 50 CFU/ml, which meets the requirements of sanitary rules and norms [23] for the quality of drinking water by this indicator. However, a less pronounced effect of the bacterial explosion was noted at the 10^{th} min of treatment (Figure 4).

A decrease in the initial concentration of microorganisms from 5.5×10^4 CFU/ml to 3×10^3 CFU/ml showed that the most intense disinfecting effect is observed already during the first 5 min of treatment (Figure 4).

In further experiments, the repeatability of the results obtained was confirmed, the time range was narrowed, and the influence of the minimum exposure time on the TMC of water was studied. Fixed reference points were determined: 6 s and 10 s. The nature of the dependence of TMC on the treatment time coincided (Figure 5) except the points when the operating time of the EHDE was 6 s and 10 s. It was revealed that it is during the first 6–10 s up to 94 % of microorganisms are destroyed (Figure 5).

Taking into account the data obtained, the dependence of TMC on the treatment time was conditionally divided into three sections (Figure 6).

Section I, lasting up to 10 s, is characterized by a sharp decrease in TMC from 3×10^4 CFU/ml to 2×10^3 CFU/ml, which is up to 93 %. It is assumed that the death of predominantly vegetative cells occurs in this area, as they are the least resistant to the effects of electrohydraulic discharge. In section II, lasting from 10 s to 15 min, there is a decrease in TMC values from 2×10^3 CFU/ml to 1×10^2 CFU/ml, which is probably associated with the death of vegetative cells with endospores. Section III of the dependence of TMC on time, which begins after 15 min, has a linear, almost horizontal shape. A slight decrease in TMC at the last stage is probably caused by the destruction of spores remaining in the water medium, which have a dense shell and tolerate adverse environmental conditions well.

The complex nature of such a disinfection method as electrohydraulic discharge is especially important when purifying waters containing a wide range of microorganisms. In this regard, further research was carried out on the effect of treating native lake water at the UniThorr EHDE. The obtained data (Figure 7) identical to the results of treatment of water contaminated with *B. subtilis* (Figures 3, 4). The efficiency of lake water disinfection was 99 %. The residual value of TMC after treatment at the UniThorr EHDE is 75 CFU/ml. However, despite the high efficiency of treatment, the required indicators of drinking water were not achieved (the standard according to sanitary rules and norms is no more than 50 CFU/ml) [23].

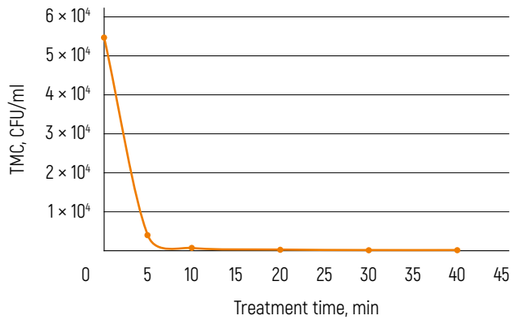


Figure 4 – Influence of treatment time on TMC at the initial concentration of microorganisms of 5.5×10^4 CFU/ml

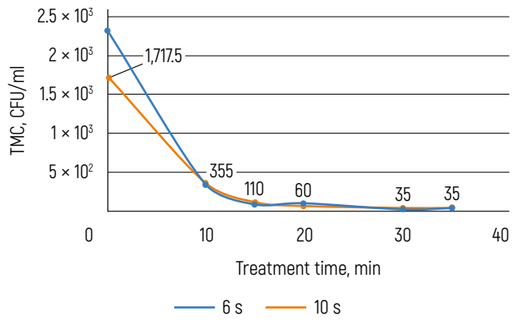


Figure 5 – Influence of treatment time on TMC at the initial concentration of microorganisms of 3×10^4 CFU/ml

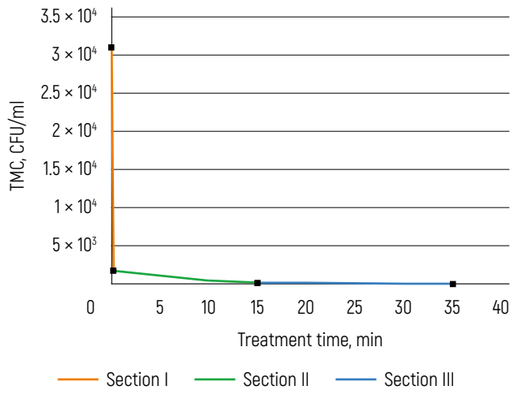


Figure 6 – Influence of treatment time on TMC at the initial concentration of microorganisms of 3×10^4 CFU/ml with the division of the graphic chart into sections (I, II, III)

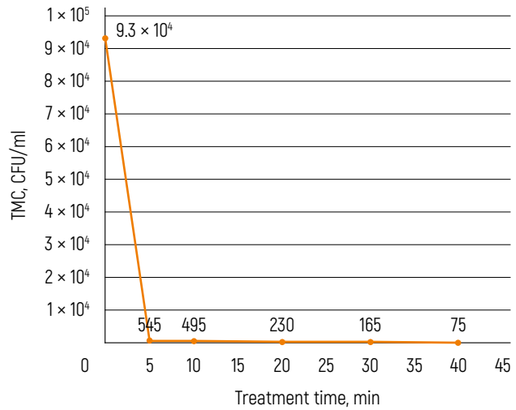


Figure 7 – Influence of treatment time on TMC of lake water

In accordance with [23], which establish the requirements for the quality of water in centralized drinking water supply systems, control is carried out according to the following microbiological indicators: the total microbial count, the content of common thermotolerant and coliform bacteria, spores of sulfite-reducing bacteria, coliphages and Giardia cysts. In addition, drinking water should not contain viruses and protozoa. In this regard, it is advisable to expand studies on the influence of the electrohydraulic discharge on these indicators.

The results of the experiments carried out show that the use of electrohydraulic discharge can reduce biological pollution.

Conclusions and Future Work

This article reflects the problem of limited water resources for people in the conditions of being in space. An assessment is given to the best existing methods of water disinfection, taking into account the possibility of their use in the ISN "Orbit", their advantages and disadvantages are shown.

The possibility of using the UniThorr EHDE for water disinfection was studied (by the examples of native lake water and water artificially contaminated with the *B. subtilis* strain) and the high efficiency of this method was confirmed (the degree of disinfection reached 99 %). Note that disinfection for 40 min of water containing spore-forming bacteria at a concentration of 5.5×10^4 CFU/ml made it possible to achieve the quality of drinking water as per TMC.

The conducted microbiological studies have revealed a significant decrease in the bacterial contamination of wastewater under the influence of electrohydraulic discharge, which indicates a high degree of disinfection. Further work will be aimed at increasing the efficiency of purification using the EHDE, as well as studying changes in the microbiological contamination of waste, river and other water in terms of microbiological and parasitological indicators.

Therefore, it can be concluded that it is expedient to use the UniThorr EHDE in the water purification system at the stage of water disinfection, which will make it possible to switch over to the reagentless method and obtain a closed-loop water consumption cycle in the ECH, which requires water of not only drinking, but also technical quality, as well as for irrigation of cultivated plants. In addition, the ISN "Orbit", where the most harmful industrial production will be removed to from the planet Earth in the future, will need effective water purification systems with subsequent disinfection. In this regard, on the basis of additional experiments, options for a closed-loop water purification system will be proposed, taking into account its purpose of use.

References

1. *Regeneratsiya vody na MKS [Water Regeneration at the ISS] [Electronic resource] // Vodoochistka. – 2019. – No. 1. – Mode of access: https://panor.ru/articles/regeneratsiya-vody-na-mks/5091.html. – Date of access: 06.06.2022.*
2. *Dolina, L.F. Ochistka stochnykh vod v usloviyakh kosmosa [Wastewater Purification in Space] / L.F. Dolina, Yu.A. Zhdan, D.A. Dolina // Nauka ta progres transportu. – 2020. – No. 2 (86). – P. 7–15.*
3. *Unitsky, A.E. Strunnyye transportnyye sistemy: na Zemle i v Kosmose [String Transport Systems: On Earth and in Space] / A.E. Unitsky. – Gomel: Infotribo, 1995. – 337 p.: il.*
4. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
5. *Unitsky, A. Soil and Soil Microorganisms in EcoCosmo-House Biosphere / A. Unitsky, E. Solovyova, N. Zyl // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 179–183.*
6. *Unitsky, A. Creating of a Mathematical Model of the General Planetary Vehicle: Accelerating Flywheels, Passing*

the Atmosphere, Going into Orbit / A. Unitsky, R. Sharshov, A. Abakumov // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 77–83.

7. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
8. *Unitsky, A. The Engineer: Autobiography / A. Unitsky. – Minsk, 2020. – 400 p.*
9. *Unitsky, A. System Foundations of Non-Rocket Near Space Industrialization: Problems, Ideas, Projects / A. Unitsky. – Minsk: Gradient, 2021. – 568 p.*
10. *Yutkin, L.A. Elektrogidravlicheskiy effekt i yego primeneniye v promyshlennosti [Electrohydraulic Effect and Its Application in Industry] / L.A. Yutkin. – Leningrad: Mashinostroyeniye, 1986. – 253 p.*
11. *Golovko, A.N. Perspektivy ispol'zovaniya elektricheskikh metodov dlya ochistki zhidkikh organicheskikh otkhodov zhivotnovodstva [Prospects for the Use of Electrical Methods for Purifying Liquid Organic Waste of Animal Farming] / A.N. Golovko, A.M. Bondarenko // Vestnik agrarnoy nauki Dona. – 2018. – No. 1 (41). – P. 52–57.*
12. *Sokolova, N.F. Sredstva i sposoby obezzarazhivaniya vody (analiticheskiy obzor) [Means and Methods of Water Disinfection (Analytical Review)] / N.F. Sokolova // Meditsinskiy alfavit: Epidemiologiya i gigiyena. – 2013. – No. 1. – P. 43–54.*
13. *Ul'yanov, A.N. Ul'trafioletovoye izlucheniye dlya dezinfektsii pit'yevoy vody [Ultraviolet Radiation for Disinfection of Drinking Water] [Electronic resource] / A.N. Ul'yanov // Santekhnika. – 2003. – No. 4. – Mode of access: https://www.abok.ru/for_spec/articles.php?nid=2173. – Date of access: 03.06.2022.*
14. *Popenko, A.Yu. Primeneniye elektrofizicheskikh metodov dlya ochistki zhidkikh organicheskikh otkhodov zhivotnovodstva [Using Electrophysical Methods for Purifying Liquid Organic Waste of Animal Farming] / A.Yu. Popenko, A.N. Golovko, A.V. Khatsenko // Aktivnaya chestolyubivaya intellektual'naya molodozh' sel'skomu khozyaystvu. – 2021. – No. 2 (11). – P. 90–95.*
15. *Kavitatsionnoye ustroystvo dlya obezzarazhivaniya i ochistki vody [Cavitation Device for Disinfection and Purification of Water]: Patent RU 71,739 U1 / V.D. Dudyshev, U.A. Kamalov. – Published 20.03.2008.*
16. *Sovershenstvovaniye sistemy obezzarazhivaniya i ochistki ballastnykh vod [Improving the System of Disinfection and Purification of Ballast Water] / A.G. Danilyan [et al.] // Vcheni zapysky TNU imeni V.I. Vernads'kogo. Seriya: Tekhnichni nauky. – 2019. – Vol. 30 (69), pt. 2, No. 3. – P. 143–147.*
17. *Dobromirov, V.N. Tekhnologiya obezzarazhivaniya zhidkostey na osnove elektrogidravlicheskogo effekta [Technology of Disinfection of Liquids Based on the Electrohydraulic Effect] / V.N. Dobromirov, D.V. Avramov, N.V. Martynov // Voda i ekologiya: problemy i resheniya. – 2019. – No. 2 (78). – P. 17–23.*
18. *Escherichia coli Disinfection by Electrohydraulic Discharges / W.K. Ching [et al.] // Environmental Science & Technology. – 2021. – Vol. 35 (20). – P. 4139–4144.*
19. *Ching, W.K. Soluble Sunscreens Fully Protect E. coli from Disinfection by Electrohydraulic Discharges / W.K. Ching, A.J. Colussi, M.R. Hoffmann // Environmental Science & Technology. – 2003. – Vol. 37 (21). – P. 4901–4904.*
20. *Lee, C. Inactivation of MS2 Bacteriophage by Streamer Corona Discharge in Water / C. Lee, J. Kim, J. Yoon // Chemosphere. – 2011. – Vol. 82 (8). – P. 1135–1140.*
21. *Effects of Pulsed and Continuous Wave Discharges of Underwater Plasma on Escherichia coli / S.J. Lee [et al.] // Separation and Purification Technology. – 2018. – Vol. 193. – P. 351–357.*
22. *Effects of Electrode Parameters on Sewage Disinfection by Underwater Pulsed Arc Discharge / J. Yang [et al.] // Journal of Electrostatics. – 2019. – Vol. 98. – P. 34–39.*
23. *Pit'yevaya voda. Gigiyenicheskiye trebovaniya k kachestvu vody tsentralizovannykh sistem pit'yevogo vodosnabzheniya. Kontrol' kachestva [Drinking Water. Hygienic Requirements for Water Quality of Centralized Drinking Water Supply Systems. Quality Control]: SanPiN 10-124 RB 99. – Introduced 01.01.2000. – Minsk: Gosstandart: Belorusskiy gosudarstvennyy institut standartizatsii i sertifikatsii, 2000. – 112 p.*
24. *An Electrohydraulic Direct Current Discharge for Inactivation of Escherichia coli in High-Bacterial Density Wastewaters / E. Gwanzur [et al.] // International Journal of Engineering Research in Africa. – 2021. – Vol. 55. – P. 190–206.*
25. *Pulsed Submerged Arc Plasma Disinfection of Water: Bacteriological Results and an Exploration of Possible Mechanisms / R.L. Boxman [et al.] // Plasma Assisted Decontamination of Biological and Chemical Agents: Proceedings of the NATO Advanced Study Institute on Plasma Assisted Decontamination of Biological and Chemical Agents, Cesme-Izmir, Sep. 9–18, 2007. – Springer, 2008. – P. 41–45.*
26. *Kontsevaya, I.I. Mikrobiologiya: fiziologicheskiye gruppy bakteriy [Microbiology: Physiological Groups of Bacteria]: Practical Guide / I.I. Kontsevaya. – Chernigov: Desna Poligraf, 2017. – 40 p.*

Analysis on the Causes of Shrinkage of Noise and Thermal Insulation Nonwoven Fabrics and Drafting of Measures to Prevent It

UDC 677.026.4

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The use of nonwoven materials in the construction of the General Planetary Vehicle (GPV) is substantiated. Studies of two types of fibers have been carried out, technological features of the production of nonwoven fabrics are described. Since a physico-chemical method of forming polymer glues is used to obtain such materials, the optimal drying temperature of the canvases has been experimentally established to prevent their increased shrinkage.

Keywords: *experiment, fiber, nonwoven materials, sample, secondary raw materials, temperature, textile industry.*

Introduction

The construction of the General Planetary Vehicle (GPV) will require a large number of various materials, which will mainly be delivered from Earth. The use of ecomaterials [1], as well as secondary raw materials (waste) in the erection of the GPV is one of the aspects of reducing the environmental burden on the planet. Waste from the textile industry can also be involved in this process (for example, in the arrangement of the EcoCosmoHouses (ECHs) or for the sound and thermal insulation of transport modules in the GPV).

A promising direction of textile waste application as secondary raw materials is the manufacture of nonwoven composite materials by the method of thermal bonding, which has three modifications: hot pressing, welding and autogesion interaction. The canvases obtained in this way can be used:

- in the construction as noise and thermal insulation, substrates for laminate and linoleum;
- in mechanical engineering as a noise insulation for vehicles [1, 2].

The use of nonwoven composites from textile waste can significantly reduce the complexity of manufacturing materials for the construction of transport and residential buildings; in the future, it will have a positive impact on the cost of work on the erection of the GPV.

One of the stages of the technological process in the production of these materials is the drying (stabilization) of the fibrous canvas by exposing it to temperature. Thermal fixation takes place in a furnace due to the melt of evenly distributed binding fibers.

The Vitebsk State Technological University (VSTU) has developed different compositions of fiber mixtures [3], however, all of them contain components that shrink when exposed to temperature, which reduces the size of the finished canvas. For use in mechanical engineering, nonwovens are laminated and shaped according to the size and configuration of the parts for which they are intended. During thermal fixation, the fibrous canvas must be exposed (in order to prevent shrinkage during lamination) to a temperature that will allow the fibers to bond together, i.e., create splices, while performing forced shrinkage in compliance with the required linear dimensions of the canvas width. In this paper, attention is paid to this process.

Research Description

Bicomponent polyester fiber of the 4DE51SIon brand (Figure 1) and polyester fiber of the 6DE64 brand (Figure 2) – a hollow, highly developed, unsiliconized fiber – are used as a heat-binding (bonding) fiber in the splices.

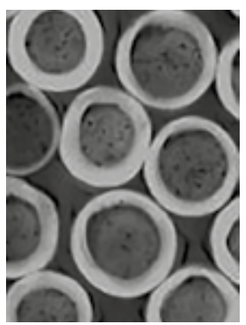
Figure 1 – Fiber of 4DE51SIon brand (manufactured in Korea)

Figure 2 – Fiber of 6DE64 brand (manufactured in Korea)

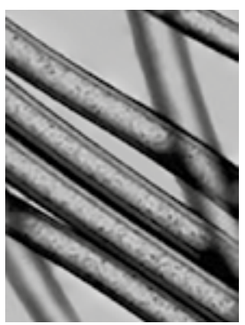
The manufacturers have declared the following melting point of the fibers:

- 4DE51SIon brand – 160–180 °C;
- 6DE64 brand – 140–160 °C.

The fiber of 4DE51SIon brand contains two components in its structure – the core and the shell. Due to the low melting point of the shell, bicomponent polyester fiber (BIC), also referred to as "light melt", is used as a binding element. The appearance of such a fiber under a microscope is shown in Figure 3.



a)



b)

Figure 3 – View of the BIC under a microscope: a – fiber cross section; b – fiber by length

The BIC shell consists of polyethylene, has the property of increased softness, and is also characterized by a low junction temperature; therefore, it can be used as a binding component in a mixture of fibers or with other materials. The core substance (polyester) is necessary to ensure the integrity of the product. The core does not melt during the connection and creates a three-dimensional netting, adding strength to the nonwoven product.

The drying (stabilization) process is carried out as follows: the cloth is automatically placed on the conveyor in front of the furnace and moves along the line between two perforated conveyor belts. The furnace consists of hot chambers and a cooling section. In the hot chamber, the air is forced into the fan through the diffuser. On the burner, the air is heated to the preset fiber processing temperature. In the cooling section, the fan operates in a suction mode, using external air to cool and stabilize the product. Then the air is blown out through the exhaust pipe.

When exposed to temperature, all fibers undergo changes. Let us consider the behavior of a canvas consisting of an experimental mixture (Table 1) in the stabilization process.

The height of the canvas at the exit from the canvas-forming machine was 0.2 m, after passing the furnace under the modes and parameters specified in Table 2 – 0.16 m; the width of the canvas before drying – 1 m, after drying – 0.98 m.

Thus, the shrinkage of the material was 20 % in height and 2 % in width, which indicates its anisotropy. Such indicators are unacceptable, since the maximum possible shrinkage in width, which is subsequently compensated by the pressure shafts in the cooling section, is equal to 1 %.

Let us analyze the percentage of fiber components at the outlet of the furnace for the sample shown in Table 1. The research was carried out at the VSTU Testing and Certification Center.

Table 1 – Fibrous composition of the experimental mixture

Component	Proportion of component specified by recipe in finished mixture, %	Actual proportion of component in the test sample, %	Absolute difference, %	Uneven distribution of component fibers in the mixture, %
Polypropylene	15.6	15	0.6	3.8
Polyester	40	43	3	7.5
Grating mixture	2.8	0	2.8	100
Polyamide	13.6	13	0.6	4.4
Wool	12	13	1	8.3
Viscose	8	8	0	0
Cotton	8	8	0	0

Table 2 – Technical characteristics of the thermal fastening furnace

Indicator	Value
Furnace length, m	9
Exposure temperature, °C	180
Speed of canvas passage, m/min	15

The results according to the test report are given in Table 3: the proportion of components in the test sample of nonwoven material decreased in comparison with the indicators of the sample of the generated canvas. Such changes are associated with the behavior of fibers included in the mixture. Some of their properties are presented in Table 4 [4].

Table 4 shows that polypropylene and polyethylene included in the BIC have melted – they are not identified in the finished material, and wool, viscose and cotton are close to destruction at the temperature of the furnace operation, which explains the decrease in their proportion.

The considered method of obtaining nonwovens is physico-chemical, based on the creation of splices of polymers included in the mixture and being under the impact of temperature. The activation of the adhesive ability of the fibers is carried out when they transition to a viscous-flow state. Polymers (polypropylene, polyester, polyamide) in this form, like liquids, are able to spread over the surface of the fibers and wet it, which is necessary to make up an adhesive contact and obtain a strong adhesive bond.

Splices are created by a layer of a binding component between the fibers at their intersections, and therefore are considered contacting ones. They have minimal dimensions and strength, as well as optimal hinge mobility (Figure 4).

The width of the finished canvas should be at least 1 m. Shrinkage of 1 cm across the width of the nonwoven fabric, as noted earlier, is compensated when passing between the sealing shafts after the cooling system. In this case, the irregularities are cut off with a longitudinal cutter.

Table 3 – Percentage of components in the experimental mixture

Proportion of component in the test sample of the generated canvas		Proportion of component in the test sample of nonwoven material*	
Component	Content, %	Component	Content, %
Polyester	43	Polyester	40
Polypropylene	15	Wool	10
Polyamide	13	Other types of fibers (polyamide, viscose, cotton)	50
Wool	13		
Viscose	8		
Cotton	8		

* The proportion of a component in the nonwoven material sample under study was determined by two types of fibers, since the test protocol did not detect a component content below 10 %.

Table 4 – Properties of components in the experimental mixture

Component	Temperature, °C		Shrinkage at melting point, %
	Melting	Destruction	
Polypropylene	130–170	325	12–15
Polyester	255–260	341	40–50
BIC: • core (polyester) • shell (polyethylene)	 255–260 130–145	 341 349	 40–50 1–2
Polyamide	254–260	355	1–2
Wool	–	170	2–3
Viscose	–	150–160	5–8
Cotton	–	180–220	2–6

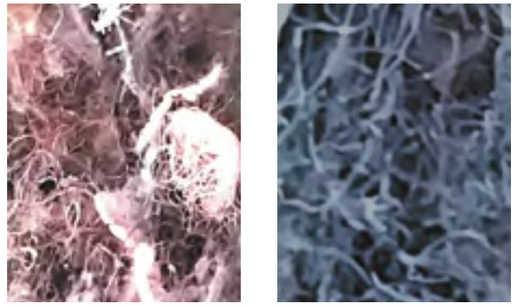


Figure 4 – View of the formed canvas under a microscope

Thus, when creating nonwovens, shrinkage is an essential characteristic (respectively, also the temperature range in which it is detected). However, it is important to know not only the possible change in the size of the canvas as a result of this process, but also the shrinkage rate at different temperatures.

As for any thermally activated relaxation process, the rate and time of shrinkage are determined by the activating energy. Therefore, it is of interest to determine the relaxation parameters of the canvas shrinkage process according to linear dilatometry data in order to establish the mechanism, kinetics of the process and assess the stability of nonwovens with polymer content at different temperatures.

To optimize the technological process of thermal fixation, it is necessary to choose such a temperature of exposure to the material that would allow creating splices sufficient for adhesion, while not changing the width of the canvas in the finished form. To do this, an experiment was conducted in which mixtures with different percentages of binding fiber were used (in some, the binding element was BIC 4DE51SIon, in others – polyester fiber 6DE64) (Table 5).

The work was guided by the following parameters: the planned thickness of the canvas – 27 mm, the speed of the tape – 15 m/min, the duration of temperature exposure to the samples – 36 s. The shrinkage of the canvas with an initial thickness of 0.2 m was neglected, since the material is compacted to a thickness of 27 mm in a follow-up.

The test results are shown in Figure 5.

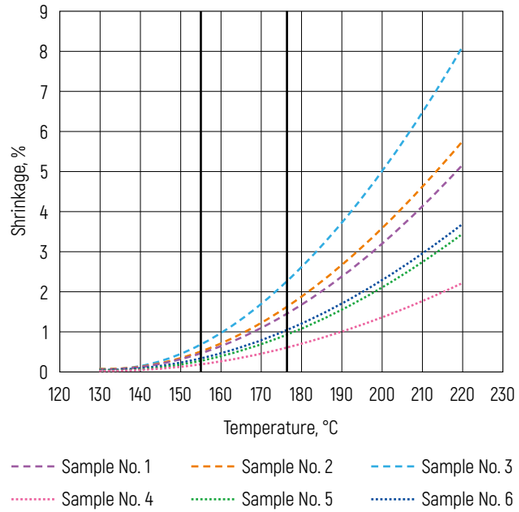


Figure 5 – Graph on the dependence of the shrinkage of samples on the exposure to temperature

The lowest limit of the experiment temperature is selected by the melting point of polyethylene, the upper limit is selected by the maximum possible temperature of the furnace.

Table 5 – Composition of experimental mixtures

Sample	Components	Proportion in the mixture, %	Sample	Components	Proportion in the mixture, %
No. 1	6DE64	15	No. 4	4DE51SIon	15
	Regenerated fiber	85		Regenerated fiber	85
No. 2	6DE64	25	No. 5	4DE51SIon	25
	Regenerated fiber	75		Regenerated fiber	75
No. 3	6DE64	35	No. 6	4DE51SIon	35
	Regenerated fiber	65		Regenerated fiber	65

Conclusions

The graph (Figure 5) shows that mixtures with BIC 4DE51Slon content should be dried at a temperature of 130–178 °C, and with the content of fiber 6DE64 brand – 130–160 °C (with a maximum allowable shrinkage of the material of no more than 1 %). Non-compliance with these temperature conditions contributes to increased shrinkage of canvases in width and, as a result, manufacturing of defective products. In order to prevent defects in finished products, these parameters should be taken into account during the further lamination of a material for its use in the GPV.

References

1. *Garanin, V. Applicability of Wood-Based Eco-Materials in Structural Elements of the General Planetary Vehicle / V. Garanin // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 159–171.*
2. *Zimina, Ye.L. Tekhnologicheskiye i teoreticheskiye osnovy polucheniya materialov s ispol'zovaniyem tekstil'nykh otkhodov [Technological and Theoretical Basics for Obtaining Materials Using Textile Waste]: Monograph / Ye.L. Zimina, A.G. Kogan, V.I. Ol'shanskiy. – Vitebsk: VGTU, 2019. – 230 p.*
3. *Tekhnologii pererabotki otkhodov khimicheskogo volokna kovrovogo proizvodstva [Technologies for Processing Waste of Chemical Fiber of Carpet Production] / Ye.L. Zimina [et al.] // Khimicheskiye volokna. – 2019. – No. 1. – P. 23–25.*
4. *Zimina, Ye.L. Razrabotka tekhnologii proizvodstva shumoizolyatsionnykh materialov s ispol'zovaniyem otkhodov [Development of Technology for the Production of Noise Insulation Materials Using Waste] / Ye.L. Zimina, N.V. Ul'yanova, O.D. Vashchenko // Khimicheskiye volokna. – 2020. – No. 5. – P. 43–45.*

Determination of Key Parameters of Service Lighting for Plants

UDC 581.143:621.3

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An analysis of the currently used lighting units in terms of their effectiveness in the cultivation of plants in closed ground conditions, in particular, in the EcoCosmoHouse (ECH), has been carried out. The main lighting parameters that directly affect the growth and development of crops has been determined.

Keywords: *anthocyanins, carotenoids, chlorophyll, EcoCosmoHouse (ECH), fluorescent lamps, high-pressure sodium arc (HPS) lamps, LED lamps, mercury lamps, metal halide lamps (MHL), photosynthetically active radiation (PAR).*

Introduction

The lighting factor has a significant impact on the vital activity of plants. Light is the main source of energy not only for flora, but also indirectly for all other components of the ecosystem that need producers. Growing crops in closed ground conditions is one of the most relevant areas of scientific and practical activities related to providing the population with food, solving the issue of seasonal availability of fresh vegetables, fruits and berries, as well as eradicating hunger.

For successful cultivation of crops, it is necessary to take into account the characteristics of their main photoreceptors and photopigments, as well as the processes of interaction between light and plants. Each of them is a complex system of photopigments, which, reacting to radiation, determine all numerous photobiological processes, often independently.

Pigments are substances that selectively absorb radiation in the range of the flux of photosynthetically active radiation (PAR). In this case, part of the light waves is reflected, and depending on the spectral composition of the reflected light, the pigments acquire a color: green, yellow, red, etc.

There are three main types of photosynthetic substances: chlorophylls, carotenoids and anthocyanins [1]. In addition to photopigments, plants also have photoreceptors that are activated at very low levels of irradiation and directly affect the development of crops [2].

Almost all phototrophs contain chlorophyll. When a quantum of light (photon) hits it, the electron of the chlorophyll molecule is temporarily knocked out to a higher energy level. Since the place of the transferred electron is not occupied for some time, the entire chlorophyll molecule becomes excited. Over time, the departed electron returns to its level with the release of energy, which is spent on the formation of carbohydrates from CO_2 and water.

Carotenoids are an important part of the mandatory photosynthetic pigments and are divided into carotene (orange), xanthophyll (yellow), lycopene, lutein, etc. They are localized in all colored plastids, participate in photosynthesis as additional antenna complexes and, absorbing light inaccessible to other pigments (most effectively at wavelengths of 425, 445, 450, 475 and 480 nm), transfer its energy to chlorophyll. Additionally, carotenoids inhibit light oxidation of chlorophyll, and it usually masks carotenoids, making them hardly noticeable before the onset of cold weather.

Anthocyanins provide red, violet and blue coloration of fruits and leaves. These pigments capture the optical radiation of the red part of the spectrum, and then convert the received energy into thermal energy, thereby protecting plants in the cold spring and autumn periods. An increase in the amount of anthocyanins occurs not only when temperatures drop, but also when chlorophyll synthesis stops and near ultraviolet is captured.

Accordingly, the main factor for the start of photobiological reactions is the presence in the plant of substances that absorb radiation of a certain wavelength. Activation of photopigments under the action of radiation transfers the substance molecule to an active state, starting a sequence of photochemical reactions, at the end of which the photopigment molecule returns to its original state and can again absorb the radiation quantum. Photosynthetic pigments (chlorophyll *a*, chlorophyll *b*, carotenoids and anthocyanins), which give color to various parts of plants, and photoreceptors (cryptochrome, phototropin, phytochrome) have different absorption maxima of the light spectrum (Figure 1).

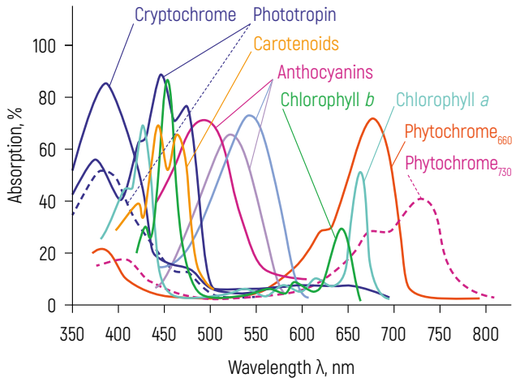

Figure 1 – The range of absorption of optical radiation by photobiologically active substances of plants

Therefore, a plant can be conditionally represented as an adaptive and self-regulating photodetector that selectively absorbs the energy of optical radiation by certain photopigments, thereby triggering multiple processes.

Comparison of Current Lighting Systems

Cultivation of plants is increasingly taking place in greenhouses. Thus, it is possible to obtain more products from a smaller area, minimizing water consumption, making fresh food available even despite the seasonality of growing with traditional methods. In order to create favorable conditions for plant crops, with a lack of natural sunlight, fluorescent, mercury, LED and high-pressure sodium arc (HPS) lamps are most often used.

A prerequisite for the widespread use of luminescent devices for lighting greenhouses was the research of A. Kleshnin (1954) in the field of plant photoproductivity. As a result of experiments with colored (selective) fluorescent lamps, a different nature of the impact of ranges of red, green and blue parts of the spectrum on the productivity of the studied crops was revealed; the priority of red and blue ranges over the green one was determined, and for different plants it differed [3]. In subsequent experiments, a hypothesis was put forward about the maximum effectiveness of optical radiation in the peak range of 450–650 nm for several vegetable crops and a variant of the optimal spectrum with the ratio R : G : B equal to 2.5 : 1 : 1.5 was proposed [4]. Such photobiological studies of the dependence of productivity on illumination for the first time made it possible to obtain experimentally confirmed data on the spectral preferences of plants and the "light curves" of productivity.

Practice has shown significant disadvantages of fluorescent lamps: a decrease in light flux during operation, a short service life, significant energy consumption, difficulties in disposal, noise. In addition, on the basis of modern research, the proposed optimal ratio R : G : B (2.5 : 1 : 1.5) has been refuted, and the range of the spectrum necessary for plant life has been expanded [5]. However, plant cultivation technologies using such lamps are currently widely applied, which is explained by the high cost of re-equipping greenhouses and the mandatory disposal of functioning lighting systems.

Modern greenhouses are equipped with metal halide lamps (MHL), which are high-pressure mercury lamps with the addition of various metal halides to improve selectivity. Due to the high color differentiation, this type of lighting devices was created for photobiological research. The most commonly used lamps covered the blue-violet (DRTI 1000), green (DRTI 1000-2) or red (DRTI 1000-3) parts of the spectrum (Figure 2).

MHLs are characterized by low power consumption, long service life and a sufficiently high luminous flux intensity (by combining several of these lamps, you can get effective illumination in the range of 400–675 nm). Their disadvantages include high heat generation, insufficient reliability during operation and special requirements for disposal.

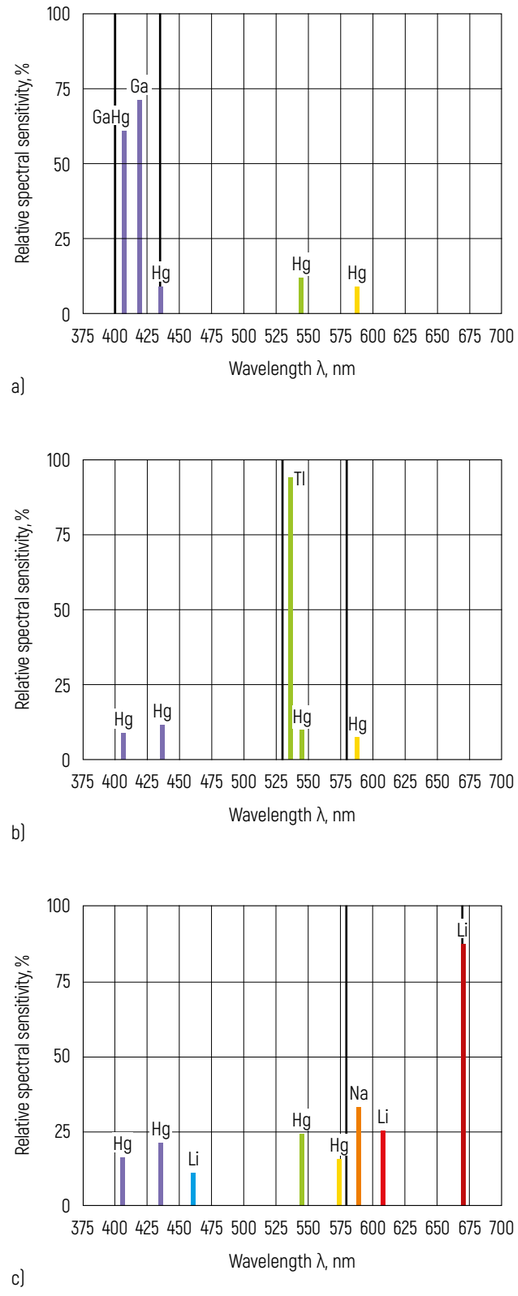

Figure 2 – MHL spectra:
a – DRTI 1000; b – DRTI 1000-2; c – DRTI 1000-3

One of the latest lighting technologies is growing crystals and then coating them with a phosphor, which makes it possible to create a gallium-based LED white light source. This innovation allows the production of LEDs with narrow spectral emission regions for the most accurate photobiological studies, while guaranteeing the exclusion of the influence of other spectral ranges. There are seven main types of colored (selective) LEDs that completely cover the PAR area and have a radiation range Δλ (at a level of 0.5 from the maximum intensity) in the order of 10–20 nm: royal blue, blue, cyan, green, amber, red-orange, red (Figure 3).

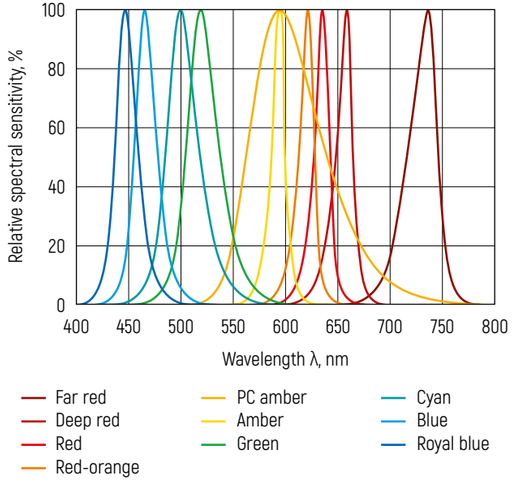

Figure 3 – Typical spectra of colored LED lamps

The use of LEDs in the cultivation of plants in conditions of lack of natural light is due to the high intensity of the light flux at low energy consumption and long service life. Among the disadvantages of such lamps, it should be noted the increased requirements for the stability of the operation of power supply systems.

In modern greenhouses, HPS lamps are widely used. They produce a yellow-orange light, which is considered the most similar to sunlight. The high-power HPS lamps are comparable to LEDs in terms of luminous flux intensity [6], operate in a wide temperature range (–60... +45 °C) and are relatively inexpensive. A significant disadvantage of such devices is the low color rendering index (Figure 4) and its strong dependence on the composition of the outer glass.

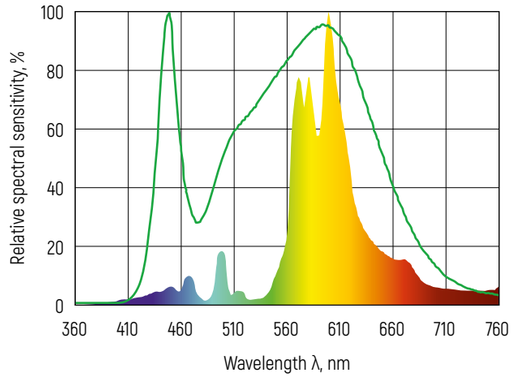

Figure 4 – Comparison of the spectral composition of the radiation of a typical HPS 1000 lamp and a typical LED (green line)

At the same, time the cost of the lamps increases significantly when high-quality glass is used for better color rendering.

Thus, if the key factors of lighting for the cultivation of plants in closed ground conditions are the service life, energy efficiency, saturation of the light flux and ease of disposal of lamps, then LED sources have clear advantages (Table 1).

Optical Emission Analysis for Plant Cultivation

In addition to such important characteristics as the service life and energy efficiency of lamps, when choosing lighting devices, it is necessary to take into account a key factor for plants – the quality of light. Lighting capacity parameters are usually indicated in lux or lumens. However, lux is a unit of measurement for the illumination of a surface of 1 m^2 with a luminous flux of 1 lm [7]. A lumen is equal to a luminous flux with a luminous intensity of 1 cd [7]. Candela, being one of the seven basic SI units, is defined as the luminous intensity in a given direction of a source emitting monochromatic radiation with a frequency of 540 × 10^{12} Hz, the energy intensity of which in this direction is 1/683 W/sr. Monochromatic radiation has a very small frequency range (under ideal conditions – one) and at a frequency of 540 × 10^{12} Hz corresponds to a wavelength of 555.016 nm in air under standard conditions [8], which is almost equal to the maximum sensitivity of the human eye. Thus, the values of lux, lumen and candela quantify the monochromatic radiation most noticeable to our vision and do not take into account the needs of the plant in the blue and red ranges of the spectrum.

Table 1 – Key parameters of different types of lighting devices

Type of lamp	Service life, thous. h	Power, W	Light flux, μmol/s/m^2	Special requirements for disposal
Fluorescent	8–25	6–120	100–330	Yes
MHL	1–20	30–2,000	250–850	Yes
HPS	5–30	20–600	90–2,200 and more	Yes
LED	50 and more	1–15	1,100–2,200 and more	No

Numerous studies confirm the different reaction of cultures to the radiation of individual ranges of the PAR spectrum. The maximum productivity of cabbage and beets was achieved with irradiation in the orange-red range, peas – in violet [9]. In experiments, green-yellow radiation turned out to be minimally effective. However, the importance of this PAR range is due to the fact that green light, reaching the lower shaded leaves, can provide relatively more photosynthesis than blue light, and is approximately equal to red light [10, 11]. In a study of lettuce productivity, the effect of increasing the mass of green leaves was confirmed when adding up to 24 % green radiation to red-blue [12]. Photobiological experiments using selective lamps also demonstrated a method for controlling the concentration of nitrates and reducing it in products with additional irradiation in the red spectral range at the end of the vegetation of green crops (lettuce, marjoram, green onion) [13].

Since plants need light for photosynthesis, the effectiveness of lighting can be determined through the amount of light expended for this process. For the formation of 1 mole of glucose, 8–10 light quanta are consumed [14], for convenience, the flux of quanta is denoted in micromoles per second per square meter (1 μmol is equal to 6.02 × 10^{17} quanta).

During the study, on June 23, 2022 in Minsk, the authors measured the level of natural light (Figure 5) with a quantometer Skye (range 400–700 nm, measurement error maximum 1 %). The place for the experiment was chosen taking into account the fact that from the beginning to the end of the measurements, shading from buildings, structures and trees should be excluded. Clear skies were observed

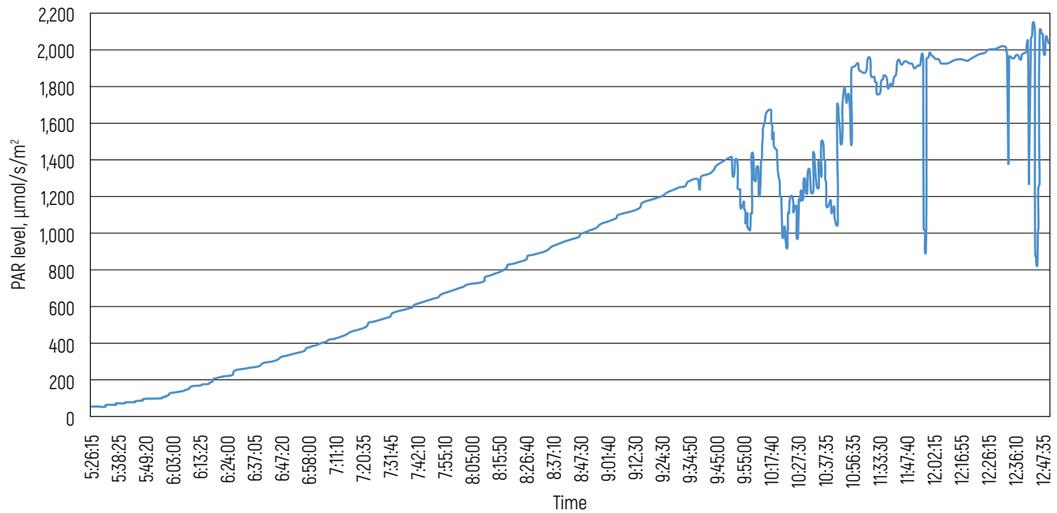

Figure 5 – Level of natural light, Minsk, June 23, 2022

almost from dawn; the level of PAR increased uniformly by 100 μmol/s/m^2 over 30 min. Partly cloudy conditions began at 10:00, which significantly reduced the level of illumination.

It should be noted that most photobiological studies are carried out in the range of 100–200 μmol/s/m^2, and values of 400–700 μmol/s/m^2 are considered abnormally high [15] despite the fact that the natural light level of 700 μmol/s/m^2 is observed as early as at 8:00.

For an approximate comparison of various types of lamps with one another and with natural light (Table 2), installations of the same power (100 W) were used, the PAR flux was measured at a distance of 20 cm from the light source.

Table 2 – Level of the luminous flux
of different types of lighting devices of the same power

Type of lamp	Service life, thous. h	Power, W	Light flux, μmol/s/m^2
Fluorescent	8	100	330
MHL	1.5	100	380
HPS	28	100	400
LED	50 and more	100	900–2,200 and more

Conclusions and Future Work

When cultivating plants in protected ground, it is necessary to justify the choice of light sources. On the one hand, the light flux should have the maximum photosynthetic effect on the cultivated crop, taking into account its characteristics, in the entire range of the photosynthetic spectrum, and also contribute to its accelerated growth, flowering or fruiting. On the other hand, sources of optical radiation should rationally consume electrical energy and not harm people and the environment, which is especially important in the EcoCosmoHouse (ECH) conditions [16]. Therefore, floodlight LED fixtures are preferred for plants. High light output and long working life will significantly reduce the cost of electricity and operating costs for lighting equipment. In addition, LED emitters have inherent advantages such as design flexibility, mechanical strength and ease of disposal.

In space, the spectrum of solar radiation differs significantly from the spectrum on the Earth's surface, so in the future it is planned to conduct research on the use of natural light in space conditions (using certain light filters in the ECH) in combination with lamps.

References

1. *Chub, V.V. Pogloshcheniye sveta rasteniyami i biologicheski aktivnyye molekuly [Light Absorption by Plants and Biologically Active Molecules] / V.V. Chub, O.Yu. Mironova // Svetotekhnika. – 2019. – No. 7. – P. 13–18.*
2. *Zhizn' rasteniy [Plant Life]: in 6 vol. / ed. A.L. Fodorov. – Moscow: Prosveshcheniye, 1974–1982. – Vol. 5, pt. I: Tsvetkovyye rasteniya [Flowering Plants] / ed. A.L. Takhtadzhyan. – 1980. – 430 p.*
3. *Kleshnin, A.F. Rasteniye i svet: Teoriya i praktika svetokul'tury rasteniy [Plant and Light: Theory and Practice of Plant Light Culture] / A.F. Kleshnin. – Moscow: Izdatel'stvo Akademii nauk SSSR, 1954. – 457 p.*
4. *Corth, R. New Fluorescent Lamp for Plant Growth Applications / R. Corth, G.M. Jividen, R.J. Downs // Journal of the Illuminating Engineering Society. – 1973. – Vol. 2, iss. 2. – P. 139–142.*
5. *Meng, Q. Spectral Manipulation Improves Growth and Quality Attributes of Leafy Greens Grown Indoors: A Dissertation / Q. Meng. – Michigan State University, 2018. – 149 p.*
6. *Rokhlin, G.N. Razryadnyye istochniki sveta [Discharge Light Sources] / G.N. Rokhlin. – 2nd ed., revised and supplemented. – Moscow: Energoatomizdat, 1991. – 720 p.*
7. *Den'gub, V.M. Yedinitsy velichin [Units of Quantities]: Dictionary-Reference / V.M. Den'gub, V.G. Smirnov. – Moscow: Izdatel'stvo standartov, 1990. – 240 p.: il.*
8. *Photometry – The CIE System of Physical Photometry: ISO 23539:2005(E)/CIE S 010/E:2004 [Electronic resource]. – Mode of access: https://cdn.standards.iteh.ai/samples/41641/7ff64d9b5e4e4a478dae39965b92a7cd/ISO-23539-2005.pdf. – Date of access: 15.07.2022.*
9. *Prikupets, L.B. Optimizatsiya kharakteristik fitooblucateley na osnove fotobiologicheskikh eksperimentov [Optimization of the Characteristics of Phytoirradiators Based on Photobiological Experiments] / L.B. Prikupets, G.S. Sarychev, D.V. Fedyun'kin // Svetotekhnika. – 1978. – No. 5. – P. 19–21.*
10. *Green-Light Supplementation for Enhanced Lettuce Growth Under Red- and Blue-Light-Emitting Diodes / H.-H. Kim [et al.] // HortScience. – 2004. – Vol. 39, No. 7. – P. 1617–1622.*
11. *Smith, H.L. Don't Ignore the Green Light: Exploring Diverse Roles in Plant Processes / H.L. Smith, L. McAusland, E.H. Murchie // Journal of Experimental Botany. – 2017. – Vol. 68, No. 9. – P. 2099–2110.*
12. *Green Light Drives Leaf Photosynthesis More Efficiently Than Red Light in Strong White Light: Revisiting the Enigmatic Question of Why Leaves Are Green / I. Terashima [et al.] // Plant and Cell Physiology. – 2009. – Vol. 50, No. 4. – P. 684–697.*
13. *Solid-State Lamp for the Improvement of Nutritional Quality of Leafy Vegetables / Z. Bliznikas [et al.] // Elektronika ir Elektrotechnika. – 2009. – Vol. 96, No. 8. – P. 85–88.*
14. *Renewable Biological Systems for Alternative Sustainable Energy Production / ed. K. Miyamoto // FAO Agricultural Services Bulletin. – 1997. – Vol. 128. – 108 p.*
15. *Avercheva, O.V. Fiziologicheskiye effekty uzkopolosnogo krasno-sinego osveshcheniya rasteniy (na primere kitayskoy kapusty Brassica chinensis L.) [Physiological Effects of Narrow-Band Red-Blue Illumination of Plants (As in the Case of Chinese Cabbage Brassica chinensis L.)]: Ph.D. Biol. Sc. Diss. Abstr.: 03.01.05 / O.V. Avercheva; Lomonosov Moscow State University. – Moscow, 2010. – 24 p.*
16. *Unitsky, A. Features of Design of a Residential Space Cluster "EcoCosmoHouse" – Mission, Goals, Purpose / A. Unitsky // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 51–57.*

Application of the Plants Microclonal Propagation in the EcoCosmoHouse Conditions

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There is a description of the possibility to apply microclonal propagation of plants in the conditions of an enclosed ecosystem within the EcoCosmoHouse (ECH). The method of vegetative reproduction of plant cultures *in vitro* is presented, as well as the advantages and disadvantages of this approach regarding continuously active enclosed ecosystems. The necessary components for creating conditions to implement this technology in an enclosed isolated space are indicated.

Keywords: *EcoCosmoHouse (ECH), enclosed ecosystem, in vitro plants, microclonal propagation, phytohormones.*

Introduction

Microclonal propagation of plants is an alternative way to mass-produce seedlings in a relatively short time. This method is more preferable than conventional vegetative reproduction: by cuttings and runners. The main advantage is a large number of healthy (i.e., without pathogenic organisms) uniform plants cultivated in a short time period. The success of microclonal propagation depends on many factors such as composition of the nutrient medium, cultivation conditions and the mother plant's genotype [1]. The development of techniques for rapid *in vitro* reproduction of any kind of plant crops presents a significant commercial potential for the industrial implementation of this technology on an industrial scale.

This method of plant cultivation being used in modern agriculture can be also widely applied in artificial ecosystems intended for the long standing of man. This study is especially relevant regarding the phytocenosis process within enclosed ecosystems such as, for example, the EcoCosmoHouse (ECH) [2, 3], where maintaining a genetically stable population is essential for the balance in a closed medium.

Basic Principles of the Plants Microclonal Propagation

Microclonal propagation of plants can be divided into several stages:

1) selection of donor plants (parent plants) and phytopathological testing of them – selection of the most genetically healthy organisms;

2) sterilization and introduction of explants into the *in vitro* crop – a transfer of the plant into a test tube;

3) micropropagation – getting cuttings with a large number of internodes, without roots;

4) rooting of shoots – transfer of microtransplants to a new nutrient medium to stimulate rhizogenesis;

5) adaptation of the obtained plants to field conditions.

Each variety of plant culture requires a careful selection of nutrient medium, which should contain different amounts of mineral components, sucrose, agar-agar, as well as natural phytohormones [4, 5]. They distinguish five main groups of phytohormones in terms of their function: auxins, cytokinins, gibberellins, abscisins and ethylene. Auxins in tissue culture cause cell growth by stretching, and in high concentrations they cause cell division, in combination with cytokinins – organogenesis. In biotechnology, they use both natural auxins (indolylacetic acid – IAA) and synthetic ones (indolyl-3-butyric acid – IBA; indolyl-3-propionic acid – IPA; 2,4-dichlorophenoxyacetic acid – 2,4-D; naphthylacetic acid – NAA).

Figure 1 illustrates the growth stages of the Marquette grape vine in microclonal propagation. The experiment was carried out in the laboratory of the Biotechnology Department of Unitsky String Technologies Inc.

The economic benefit of *in vitro* plant production is based on several factors:

- minimum planting areas;
- minimum labor input;
- minimum cost of initial materials (one plant is enough);
- maximum yield of planting material from one plant (1,000–10,000 seedlings).

a)

b)

c)

Figure 1 – Growth stages of the Marquette grape vine in microclonal propagation:
a – at the test-tube stage, ready for adaptation (1–1.5 months from the cuttings stage);
b – at the adaptation stage (one week from the moment of planting from the test tube);
c – seedling, ready for planting in the open ground (1–1.5 months from the moment of planting from the test tube)

Significant feature of *in vitro* plants is the preservation of genetic stability and the simplification of genetic information storage.

Peculiarities of Technology Transfer in Enclosed Ecosystem Conditions

For the ECH, *in vitro* plant production can become an integral part of the existence of an enclosed space. The ECH is a system of two capsule cylinders with reciprocal rotation around a common axis [3]. The diameter of the outer cylinder is 500 m, and of the inner one – 300 m with a length of 500 m. The whole structure is 1 km long. The available layouts for the settlement of the residential area of this space provide accommodation for at least 5,000 people, and with high-density housing it is possible to accommodate about 10,000 people. These parameters were taken into account when calculating the needs of the ECH in plant crops of seven groups: fruit trees, vegetable crops, exotic fruit plants, aquatic, food, technical and medicinal plants (Table 1). In addition to providing and maintaining such a number of plant crops in the phytocenosis, *in vitro* technology will allow to preserve their species diversity, genetic stability by species and varietal character, accelerate planting material production techniques.

Besides, the ECH also needs areas for parent plants. The areas of mother plantations for crops propagated naturally and *in vitro* are almost equal, but the survival rate of shoots differs. Losses in reproduction by grafts and cuttings are up to 40–50 %, and 2 % by *in vitro*. Estimated areas necessary for the implementation of the microclonal propagation technology in the ECH are 75 m^2, about 50 m^2 are required for the mother plantations, 25 m^2 – for laboratory (15 m^2 – for washing room with an autoclave and for the preparation of nutrient medium; 10 m^2 – for a small light room for culture rearing, as well as a laminar-flow box).

To set up the technology of microclonal propagation in an enclosed ecosystem, it is important to provide the following laboratory equipment:

- laminar-flow box;
- autoclave to sterilize test tubes and flasks;
- laboratory balance instruments;
- laboratory utensils;
- reagents (salts) for the preparation of nutrient medium;
- light shelving.

As nutrient medium for plant propagation, they mainly use Murashige and Skoog medium, Anderson medium and minor modifications thereof. The basis of all nutrient medium for cultivation of plant explants is a mixture of mineral salts: nitrogen compounds as nitrates, nitrites, ammonium salts; phosphorus as phosphates; sulfur as sulfates; soluble salts of K^+, Na^+, Ca^{2+}, Mg^{2+}. Iron is used in the form of chelates (FeO_4 or Fe_2O_4 + EDTA (ethylenediaminetetraacetic acid) or its disodium salt (trilon B)) which is the most accessible form for assimilation by plant tissues. Biological catalysts – vitamins B (B_1, B_6, B_{12}), C (ascorbic acid), PP (nicotinic acid), mesoinositol – are used to stimulate biochemical reactions in the cell.

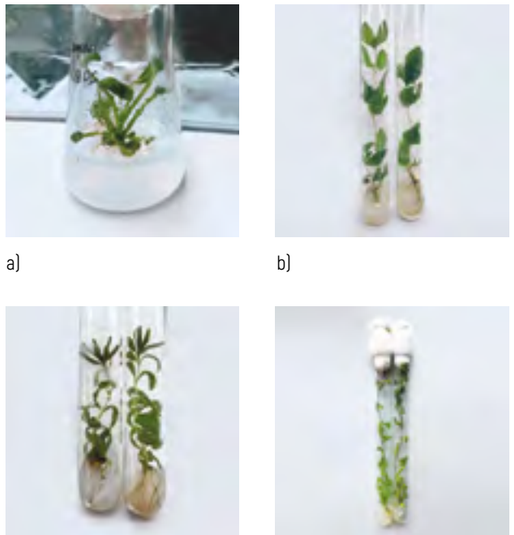
The composition of medium is selected individually for each species of plants, taking into account intervarietal differences.

Table 1 – Minimum need for plants in the ECH

Groups of plants	Estimated need of the ECH, pcs
1. Fruit trees	3,000
2. Vegetable crops	100,000
3. Exotic fruit plants	10,000
4. Aquatic plants	500,000
5. Food plants	200,000
6. Technical plants	200,000
7. Medicinal plants	200,000
In total	1,213,000

The laboratory of the Biotechnology Department of Unitsky String Technologies Inc. develops methods for the production of cultivated, ornamental and medicinal plants (Figure 2). They select sterilization methods and nutrient medium with appropriate content of phytohormones and vitamins for each plant crop.

Necessary personnel for the laboratory: two employees with secondary education (for the production of planting material and plant care); one employee with higher biological education (to control the process, as well as to develop the setup of experiments). Unlike market sales, there is no year-round need for seedlings in the experiment, so the employees can have other employments. The average number of cuttings produced by one employee (including time for preparing nutrient medium, preparing planting material, sterilizing tools and washing utensils) is about 1,500 pieces per month. Cultivation of such cuttings before planting in the ground, including the period of adaptation, is from one month (for herbaceous plants) to one year (for woody crops). Shrub plants need about three months. For example, after planting grape seedlings in a sterile nutrient medium, it takes about a month first, then 1–1.5 months to adapt to the conditions of the soil substrate in light rooms, after which the seedlings are ready for planting in the open ground.



a) b) c) d)

Figure 2 – Plants obtained by microclonal propagation in the laboratory of the Biotechnology Department of Unitsky String Technologies Inc.:
a – medicinal sage (*Salvia officinalis*);
b – edible honeysuckle (*Lonicera edulis*);
c – narrow-leaved lavender (*Lavandula angustifolia*);
d – garden lobelia (*Lobelia erinus*)

Advantages and Disadvantages of the Plants Microclonal Propagation in an Enclosed Ecosystem

Since in an enclosed medium a constant deficit of new plant crops is assumed and there is a need to produce a large number of them within the ecosystem to maintain proper genetic diversity, the use of *in vitro* reproduction technology is the optimal solution [6]. The laboratory of the Biotechnology Department has fully developed the technology of microclonal propagation of grape vine of four varieties (Marquette, Solaris, Briana and Crystal) from cuttings to seedlings, suitable for planting in the open ground. To compare the yield percentage of viable seedlings, we relied on the standard technique of grape cutting – by single-tree cuttings. With this method, the survival rate was 49 % (49 out of 100 cuttings), while *in vitro* planting produced 90 %.

Furthermore, the risk of obtaining genetically unstable plants is reduced due to the homogeneity of the population of a certain species and variety. Even after several years, it will be difficult to maintain the seed stock (especially of ornamental and fruit plants) because of crop degeneration and emergence of numerous genetic aberrations of the plant genome. Table 2 represents the advantages and disadvantages of microclonal propagation in the ECH.

One of the disadvantages of *in vitro* technology is the need for constant application of phytohormones [7]. Under laboratory conditions, chemically pure compounds that are purchased from suppliers are used, which is cheaper and easier. However, in an enclosed ecosystem, difficulties may arise with the replenishment of the necessary components, so one should provide alternative ways to obtain them.

Thus, the use of *Rhizobium leguminosarum* rhizosphere bacteria strains as producers of IAA is an option [8]. In addition to the involvement of these bacteria in microclonal propagation, they can be used as a biological soil fertilizer [9]. To obtain gibberellins, it is possible to use a strain of the micromycete *Fusarium moniliforme* [10]. During 8–10 days of deep cultivation, the maximum production of gibberellin is 400–700 mg in 1 l of culture broth [11]. To implement this technology, the selected strains are added to the microorganism stock and stored in the ECH laboratory.

Table 2 – Advantages and disadvantages of microclonal propagation of plants

Advantages	Disadvantages
Maintaining genetic diversity	Application of nutrient medium that need constant replenishment; associated creation of new technologies for the production of nutrient medium in the ECH conditions
Producing the necessary number of seedlings	
No need for seed stock	
High rooting rate	Labor intensity to obtain woody plant clones, especially in the first 10–15 years
Faster transition of plants from the juvenile to the reproductive stage	
Ability to breed plants that are difficult to propagate by conventional methods	

Conclusions and Future Work

An enclosed ecosystem requires the development of multiple mechanisms and systems to maintain self-sustenance. In the ECH, it is planned to create laboratories that are capable of controlling all the biological processes essential to the existence of the ecosystem. Unconventional propagation methods are needed to conserve plant populations and minimize losses when they degenerate. Setting up microclonal propagation in an enclosed ecosystem will provide the ECH with all the plant species in the right quantities and give the opportunity to replenish them. However, for this purpose, the production of phytohormones for the preparation of various nutrient medium should be organized using the proposed methods (through micromycetes and rhizobacteria).

Moreover, microclonal propagation will be adopted to obtain callus cultures and biologically active compounds from them, which will also be widely used in an enclosed ecosystem.

References

1. *Kumar, N. In vitro Plant Propagation: A Review / N. Kumar, M.P. Reddy // Journal of Forest and Environmental Science. – 2011. – Vol. 27, No. 2. – P. 61–72.*
2. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
3. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
4. *Microclonal Propagation of Plant Process Modeling and Optimization of Its Parameters Based on Neural Network / O.A. Ivashchuk [et al.] // Drug Invention Today. – 2018. – Vol. 10, No. 3. – P. 3170–3175.*
5. *Suleymanova, S.D. Mikroklonal'noye razmnozheniye plodovykh kul'tur (obzor) [Microclonal Propagation of Fruit Crops (Review)] / S.D. Suleymanova // Vostochno-yevropeyskiy nauchnyy zhurnal. – 2016. – Vol. 11, No. 2. – P. 47–54.*
6. *Rout, G.R. In vitro Manipulation and Propagation of Medicinal Plants / G.R. Rout, S. Samantaray, P. Das // Biotechnology Advances. – 2000. – Vol. 18, No. 2. – P. 91–120.*
7. *George, E.F. Plant Propagation by Tissue Culture / E.F. George, M.A. Hall, G.-J. De Klerk. – 3rd ed. – Springer, 2008. – Vol. 1: The Background. – P. 514.*
8. *Kuznetsova, Ye.A. Primeneniye Rhizobium leguminosarum dlya polucheniya preparata fitogormonov [Application of Rhizobium leguminosarum for Preparation of Phytohormones] / Ye.A. Kuznetsova // Gorizonty biofarmatsevtiki: Collection of Studies on the Proceedings of the VI All-Russian Scientific and Practical Conference, Kursk, Oct. 30, 2020 / Kursk State Medical University; ed. V.P. Gavrilyuk, L.P. Lazurina. – Kursk: KGMU, 2020. – P. 23–24.*
9. *Indole Acetic Acid and ACC Deaminase-Producing Rhizobium leguminosarum bv. trifolii SN10 Promote Rice Growth, and in the Process Undergo Colonization and Chemotaxis / R.B. Bhattacharjee [et al.] // Biology and Fertility of Soils. – 2012. – Vol. 48, No. 2. – P. 173–182.*
10. *Gibberellic Acid Fermented Extract Obtained by Solid-State Fermentation Using Citric Pulp by Fusarium moniliforme: Influence on Lavandula angustifolia Mill. Cultivated in vitro / A.L.L. da Silva [et al.] // Pakistan Journal of Botany. – 2013. – Vol. 45, No. 6. – P. 2057–2064.*
11. *Shtamm mikromitseta Fusarium moniliforme – produtsent fitogormonov gibberellinov A_4, A_7 [Micromycete Strain of Fusarium moniliforme – Producer of Phytohormones Gibberellins A_4, A_7]: Patent RU 2,084,531 C1 / G.S. Muromtsev, L.M. Krasnopol'skaya. – Published: 20.07.1997.*

Callusogenesis as an Alternative Way of Obtaining Biologically Active Substances in an Enclosed Ecosystem

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The possibility of cultivating plant cells for the production of medicinal raw materials in the EcoCosmoHouse (ECH) is considered. Compared with the classical technology, this approach contributes to a more efficient accumulation of active substances (AS). The impact of phytohormones on the growth of passaged cells and quantitative indicators of the accumulation of biologically active substances were evaluated. Callus tissues of purple coneflower (*Echinacea purpurea* L.), common sage (*Salvia officinalis* L.), lemon-scented gum (*Corymbia citriodora* Hook.), St. John's wort (*Hypericum perforatum* L.), wormwood (*Artemisia absinthium* L.) were obtained. The accumulation of the following AS was studied: caftaric acid (echinacea); essential oil (sage, eucalyptus, wormwood); flavonoids (St. John's wort).

Keywords: *biologically active substances, callus tissues, EcoCosmoHouse (ECH), enclosed ecosystem, medicinal plants.*

Introduction

Medicinal plants are the main source of natural biologically active substances for medical purposes. In enclosed ecosystems with limited resources and areas, there is an urgent need to create methods and ways for obtaining medicinal raw materials at the lowest cost.

An example of such an enclosed ecosystem are the EcoCosmoHouse (ECH) and the EcoCosmoHouse on Planet Earth (ECH-Earth) [1], where year-round human habitation is provided. As in any enclosed space, a person may face the development of respiratory and other infectious diseases [2]. Therefore, for a favorable existence in such an environment, it is necessary to have a large database of medicinal compounds, as well as their availability and the possibility of obtaining them.

At the moment, there are over 142 different viruses in urban settlements that cause acute respiratory viral infection (ARVI), which is accompanied by fever and one or more other symptoms, such as chills, headache, general malaise, loss of appetite. In addition, ARVI, affecting the respiratory system, manifests itself in the form of rhinitis, pharyngitis, tonsillitis, laryngotracheitis, bronchitis, and sometimes conjunctivitis [3, 4]. Consequently, it is difficult to overestimate the importance of organizing the production of medicinal compounds from natural sources in the ECH.

In medicine, various drugs are used to fight diseases, including those based on substances isolated from medicinal plants.

The need for medicinal plant raw materials is constantly increasing, which leads to a reduction in the area of growth of medicinal herbs due to their unlimited collection by the population and pharmaceutical companies [5, 6].

The groups of useful substances include many different components obtained as a result of long-term synthesis of metabolites inside the cell [5, 6]. Thus, the World Health Organization identifies more than 14 families in the monographs on medicinal plants: *Papaveraceae, Rosaceae, Apiaceae, Araliaceae, Fabaceae, Asteraceae, Elaeagnaceae, Hypericaceae, Lamiaceae, Peganaceae, Plantaginaceae, Polygonaceae, Tiliaceae, Poaceae,* etc. [3]. The State Pharmacopoeia of the Republic of Belarus (SP RB) includes over 115 different plant species [4] belonging to more than 20 different families.

In the ECH, medicinal herbs need time and usable land for the accumulation of secondary metabolites in organs and tissues. The traditional method of cultivation is replaced by the cultivation of plant tissues and organs in an isolated nutrient medium with the possibility of influencing the accumulation of secondary metabolites in the structure.

Plants under stress are able to trigger regeneration through the formation of undifferentiated tissue – callus. The obtained callus cells *in vitro* allow regulating the accumulation of biologically active substances, optimizing the nutrient medium by changing the mineral complex, correcting the level of phytohormones, elicitors and precursors of synthesis, as well as regulating the temperature and lighting of tissues [5].

Thus, the main purpose of the article is to study the possibility of obtaining and practical application of medicinal substances extracted from plants and their further use in an enclosed ecosystem.

Main Characteristic and Potential Application of Selected Crops

Currently, the Biotechnology Department of Unitsky String Technologies Inc. has obtained callus and suspension cultures of the following medicinal plants: purple coneflower (*Echinacea purpurea* L.), common sage (*Salvia officinalis* L.), lemon-scented gum (*Corymbia citriodora* Hook.), St. John's wort (*Hypericum perforatum* L.), wormwood (*Artemisia absinthium* L.).

One of the most famous producers of immunostimulants is purple coneflower; the main classes of biologically active substances of this plant are water-soluble polysaccharides, hydroxycinnamic acids, flavonoids, etc. [6].

Phenolic carboxylic acids and their derivatives (chlorogenic, rosemary, etc.), characterized by antioxidant, neuroprotective, antiviral, hepatoprotective effects, prevail in the phenolic compounds of common sage [7].

Essential oils of lemon-scented gum have a large number of terpenoids (citronellal, isopulegol, etc.), monocyclic terpenes (1,8-cineole and β-pinene). In medicine, cineole is used as part of antiseptic, expectorant drugs and as a component of toothpastes.

St. John's wort contains several important biologically active compounds: hyperforin and quercetin. The first substance acts as a natural antidepressant, the second is considered a powerful anti-cancer drug and a useful tool for the treatment of Alzheimer's disease [8].

Wormwood contains a significant amount of polyphenols, which make up the largest group of natural antioxidants, flavonoids and terpenoids. They, in turn, differ in biological activity when used separately, as well as synergistically increase the bioavailability of artemisin [9], which is characterized by pronounced antimalarial activity [10].

All the presented plant species have different pharmacological effects and are able to synthesize secondary metabolites that differ in chemical structure and physico-chemical properties.

Breeding these plants in a natural environment can become a factor in inhibiting the accumulation of a secondary metabolite in the right concentrations, which will lead to a noticeable decrease in the medicinal effect. It is much more expedient to cultivate plants in the form of callus tissues under *in vitro* conditions – this technology will increase the release of the required amount of medicinal substance.

Materials and Methods

The object of research is callus cultures obtained from intact plants and regenerating plants of purple coneflower (*Echinacea purpurea* L.), common sage (*Salvia officinalis* L.), lemon-scented gum (*Corymbia citriodora* Hook.), St. John's wort (*Hypericum perforatum* L.), wormwood (*Artemisia absinthium* L.). Callus tissue isolated from various parts of regenerating plants was cultured on Murashige and Skoog nutrient medium. In addition, phytohormones were used during the experiment (according to the application doses given in Table 1): from the auxin group – 2,4-D (2,4-dichlorophenoxyacetic acid) and α-NAA (α-naphthylacetic acid); from the cytokinin group – 6-BAP (6-benzylaminopurine) and kinetin. Their influence on the process of callus formation was studied.

The plant material was cultivated in a light room, where a thermal mode of 25 °C and an 11-hour photoperiod was maintained along with providing illumination with white fluorescent lamps with an intensity of 3,000 lux. The degree of influence of phytohormones on the growth and development of the callus was assessed by its average daily growth, as well as length, width and weight. The callus growth index was calculated as the ratio of the final tissue mass to the initial one.

To extract phenolic compounds, the plant material was crushed and then extracted with hot 96-percent ethanol in Soxhlet apparatus. The total content of soluble phenolic compounds (with Folin – Denis reagent), flavans (with vanillin reagent) and flavonols (with aluminum chloride) was detected in the obtained extracts (substances) by spectrophotometric method. Calibration curves for determining the total content of soluble phenolic compounds and flavans were constructed by epicatechin, for determining flavonols – by rutin.

In order to calculate the essential oil content, 20 g of the test raw material, crushed immediately before the experiment (except eucalyptus), was laid out in a flask with a capacity of 500 ml, then 250 ml of water was added. A graduated tube was filled with 0.5 ml of xylene. Distillation was carried out at a rate of 2–3 ml/min for 2 h (for sage and eucalyptus) and 3 h (for wormwood) [4].

Results and Discussions

Formation of Callus Tissues by Plants under *in Vitro* Conditions

During the experiment, it was noted that two aspects play a key role in callus formation:

- content of phytohormones in the nutrient medium;
- accumulation of active substances (AS) in the callus, which directly depends on the composition of the mineral medium that formed it.

Table 1 – The use of phytohormones for the growth and development of callus tissues

Phytohormone	Dose of phytohormones, mg/l									
	Purple coneflower		Common sage		Lemon-scented gum		St. John's wort		Wormwood	
	Option 1	Option 2	Option 1	Option 2	Option 1	Option 2	Option 1	Option 2	Option 1	Option 2
2,4-D	0.5	–	0.5	0.5	–	1	0.5	–	–	0.5
α-NAA	1	0.5	–	–	1	–	–	0.5	1	–
6-BAP	–	–	1	0.5	–	1	0.5	–	–	0.5
Kinetin	0.1	0.5	–	–	1	–	–	1	0.5	–

In this regard, a two-stage method of cell cultivation was applied in practice: at the first stage, the plants were in a nutrient medium containing a hormone for callus growth; at the second, they moved to a producing nutrient medium where the active synthesis of secondary metabolites in cells began.

According to the data obtained, the maximum growth index was observed in samples with wormwood (α-NAA – 1 mg/l; kinetin – 0.5 mg/l) and common sage (2,4-D – 0,5 mg/l; 6-BAP – 1 mg/l) (Figure 1).

The equal content of phytohormones auxins in relation to cytokines did not lead to an active growth of callus. In the early days of callus passaging, all growth indicators were similar to variants with unequal ratios of phytohormones.

Accumulation of Active Substances in Callus Tissues of Plants

In order to identify the degree of accumulation of AS in the cells of passaged plant callus, a comparative assessment of the AS content in various growing conditions was carried out; the requirements of the SP RB acted as benchmarks for the content of AS. The data obtained are presented in Table 2.

Purple coneflower is an invasive species on the territory of Belarus; the amount of photosynthetically active radiation (PAR) per plant is insufficient, which affects the total accumulation of AS in tissues.

When studying the content of AS (caftaric acid in terms of a kilogram on dry plant mass) in plants grown on the territory

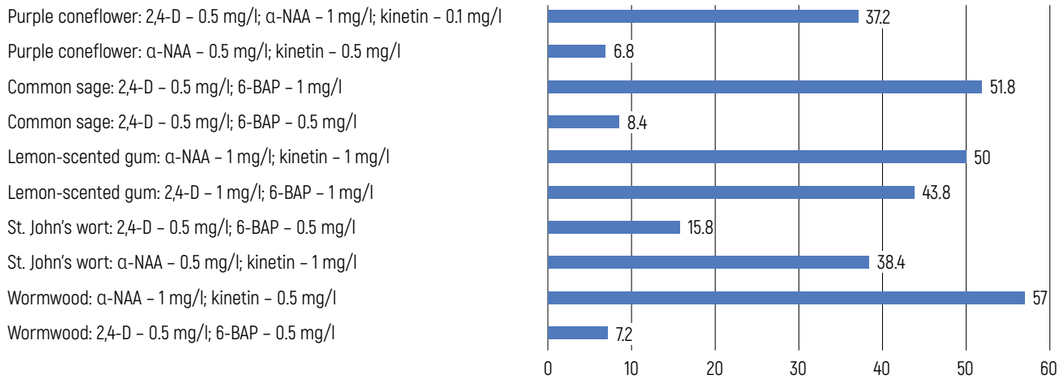

Figure 1 – Callus tissues growth index

Table 2 – Comparative experimental data on the content of AS in plant tissues cultivated under different conditions

Plant	Main medicinal component	Indicator for SP RB	Pharmaceutical raw material	Plants grown in the Unitsky's Farm Enterprise	Wild plants	Callus tissues
Purple coneflower	Caftaric acid, %/kg on dry mass	0.1	0.18	0.1	–	0.22
Common sage	Essential oil, ml/kg on dry mass	8	9.4	8.1	6.1	4.7
Lemon-scented gum	Essential oil, ml/kg on dry mass	10	12.4	–	–	11.7
St. John's wort	Flavonoids, %/ml on rutin	1.5	1.5	2.4	0.4	1.8
Wormwood	Essential oil, ml/kg on dry mass	2	4.8	5.1	2.7	1.8

of the Unitsky's Farm Enterprise in 2021, 0.1 % of caftaric acid on dry mass was found. At the same time, in raw materials produced in Germany (offered in pharmacies in Minsk), the indicator was 0.18 % on dry mass. Such values of active components meet the requirements of the SP RB; therefore, such raw materials can be considered medicinal.

Callus tissues obtained from plants growing on the territory of the Unitsky's Farm Enterprise and passaged on the Murashige and Skoog nutrient medium with the addition of phytohormones 2,4-D (0.5 mg/l), α-NAA (1 mg/l), kinetin (0.1 mg/l) in 30 days accumulated 2.2 times more secondary metabolites than required by the SP RB, and 1.2 times more than is permissible for the sale of medicinal raw materials. Upon further observation, the content of AS in the callus decreased significantly, which may be due to a noticeable slowdown in the rate of development of the plant callus on the 30th and subsequent day.

Common sage is also not typical for the flora of Belarus. The therapeutic effect is due to the essential oil, which is obtained from the flowers and leaves of the plant and which content directly depends on a number of factors, such as temperature, daylight, the amount of minerals received, etc.

Content of essential oil in the tissues of vegetated invasive crops is 1.16 times more than in plants bred on the territory of the Unitsky's Farm Enterprise. The requirements for abiotic factors in sage are very high. Representatives of flora that do not grow in Belarus accumulate more AS than those grown in our republic, however, sage cultivated on the territory of the Unitsky's Farm Enterprise has formed a sufficient amount of essential oil according to the requirements of the SP RB.

The passaged sage callus did not contribute to a significant increase in essential oil in the tissues. Upon detailed study, it was found that the cells of the sage callus were actively dividing. In addition, the callus was quite dense and formed a large amount of collenchyma (mechanical tissues), which led to less accumulation of AS.

Lemon-scented gum accumulates a lot of essential oil, which has a significant amount of terpenoids. The norm of the essential oil content is at least 10 mg/kg on dry matter; in the callus, it was possible to obtain more than 11 mg/kg. The eucalyptus callus had a loose black tissue; the callus formed from the leaf plate contained 4.01 times more AS than the one formed from the stem.

St. John's wort is characterized by various types of secretory structures specializing in the storage of metabolites and common in all reproductive and vegetative tissues of the plant.

Pale glands (Figure 2), containing a large amount of hyperforin are concentrated in the leaf blade; they penetrate the parenchyma and are limited to two layers of epidermal cells.

Dark glands containing hypericin are morphologically evenly distributed throughout the plant and are immersed in the mesophyll with two layers of flattened cells.

During the passaging of St. John's wort callus (Figure 3), it was possible to obtain the synthesis of these glands in the structure of the callus; at the same time, a large amount of AS which is 1.3 times higher than the required rate was accumulated. The callus did not stop growing on the 30th day – it continued to grow, retaining active division.

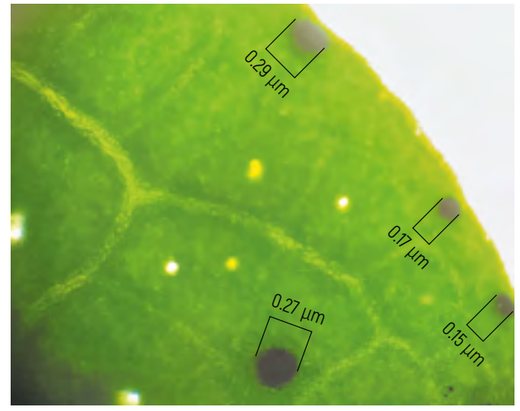

Figure 2 – Morphological location of glands on St. John's wort leaf

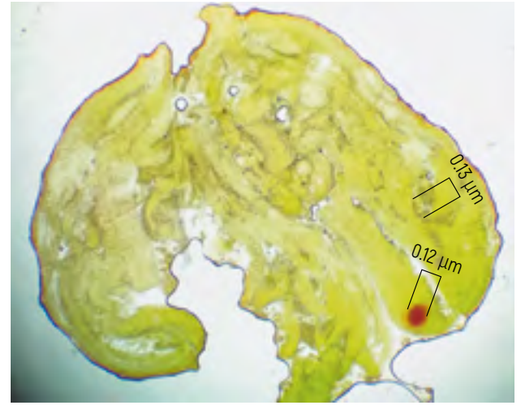

Figure 3 – Location of glands in St. John's wort callus

Wormwood essential oil accumulates in the capsules of the epidermis, as well as in the hairs of the plant itself. During the passaging of wormwood callus, the formation of these capsules is not as significant as during the natural vegetation of plants, which led to a decrease in the oil content in the callus structure. However, when culturing callus in a liquid medium, the content of essential oil increased slightly.

Conclusions and Future Work

It is proved that the accumulation of AS in the callus of plant tissues directly depends on the donor organs from which the callus itself was obtained. Phytohormones often serve as activators of secondary metabolite processes, however, there are protein and elicitor components that promote directed metabolism in cells, which requires further confirmation.

It is noted that the number of secondary metabolites accumulated in callus tissues in most cases exceeds their content in vegetated plants. The conditions of cultivation of such cells, i.e., placement in a sterile environment, contribute to reducing the pathogenic load on the plant organism. In the absence of pathogens, the synthesis of secondary metabolites will be isolated and directed.

Callusogenesis as a method of obtaining biologically active compounds finds its application in the production of certain medicinal substances from plants. Callusogenesis of the studied plants is the most optimal way to isolate many types of medicinal compounds from plant raw materials in the ECH conditions. This technology, involving the use of minimal areas, will allow to establish the production of medicinal components for therapeutic and preventive purposes in an enclosed ecosystem, as well as plant raw materials (in raw or dried form) for the preparation of teas, infusions and natural flavors.

References

1. *Unitsky, A. System Foundations of Non-Rocket Near Space Industrialization: Problems, Ideas, Projects / A. Unitsky. – Minsk: Gradient, 2021. – 568 p.: il.*
2. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
3. *WHO Monographs on Medicinal Plants Commonly Used in the Newly Independent States (NIS). – WHO, 2010. – 448 p.*
4. *Gosudarstvennaya farmakopeya Respubliki Belarus' (GF RB II) [State Pharmacopoeia of the Republic of Belarus (SP RB II)]: in 2 vol. / Ministry of Health of the Republic of Belarus, Center for Examinations and Tests in Health Service RUE; ed. A.A. Sheryakov. – Molodechno: Pobeda, 2012. – Vol. 1: Obshchiye metody kontrolya kachestva lekarstvennykh sredstv [General Methods of Quality Control of Medicines]. – 1220 p.*
5. *Santalova, G.V. Respiratornyye virusnyye infektsii: podkhody k terapii s pozitsii kliniko-patogeneticheskikh aspektov zabolevaniya [Respiratory Viral Infections: Approaches to Therapy from the Perspective of Clinical and Pathogenetic Aspects of the Disease] / G.V. Santalova, S.V. Plakhotnikova // Meditsinskiy sovet. – 2022. – Vol. 16, No. 1. – P. 36–41.*
6. *Fitokhimicheskiy sostav predstaviteley roda Ekhinatseya (Echinacea Moench.) i yego farmakologicheskiye svoystva (obzor) [Phytochemical Composition of Representatives of the Genus Echinacea (Echinacea Moench.) and Its Pharmacological Properties (Review)] / V.N. Samorodov [et al.] // Khimiko-farmatsevticheskiy zhurnal. – 1996. – Vol. 30, No. 4. – P. 32–37.*
7. *Polyphenol-, Mineral Element Content and Total Antioxidant Power of Sage (Salvia officinalis L.) Extracts / M. Then [et al.] // XXVI International Horticultural Congress: The Future for Medicinal and Aromatic Plants, Toronto, Aug. 11–17, 2002 / Acta Horticulturae. – Toronto, 2004. – P. 123–129.*
8. *Goodine, T. Corymbia citriodora: A Valuable Resource from Australian Flora for the Production of Fragrances, Repellents, and Bioactive Compounds / T. Goodine, M. Oelgemöller // ChemBioEng Reviews. – 2020. – Vol. 7, No. 6. – P. 170–192.*
9. *The Biochemical and Genetic Basis for the Biosynthesis of Bioactive Compounds in Hypericum perforatum L., One of the Largest Medicinal Crops in Europe / P. Rizzo [et al.] // Genes. – 2020. – Vol. 11, No. 10. – P. 1–20.*
10. *Kano, S. Artemisinin-Based Combination Therapies and Their Introduction in Japan / S. Kano // Journal of Infection and Chemotherapy. – 2010. – Vol. 16, No. 6. – P. 375–382.*

Principles of Creating a Genetic Bank of Living Organisms for the Long-Term Existence of an Enclosed Ecosystem

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The article deals with the principles of creating a genetic bank of living organisms (microorganisms, plants, animals) and the features of their existence in the enclosed ecosystem of the EcoCosmoHouse (ECH). It considers theoretical aspects and proposes possible solutions for maintaining the life of a population in an isolated space.

Keywords: *cryopreservation, EcoCosmoHouse (ECH), enclosed ecosystem, genetic pool, lyophilization, population.*

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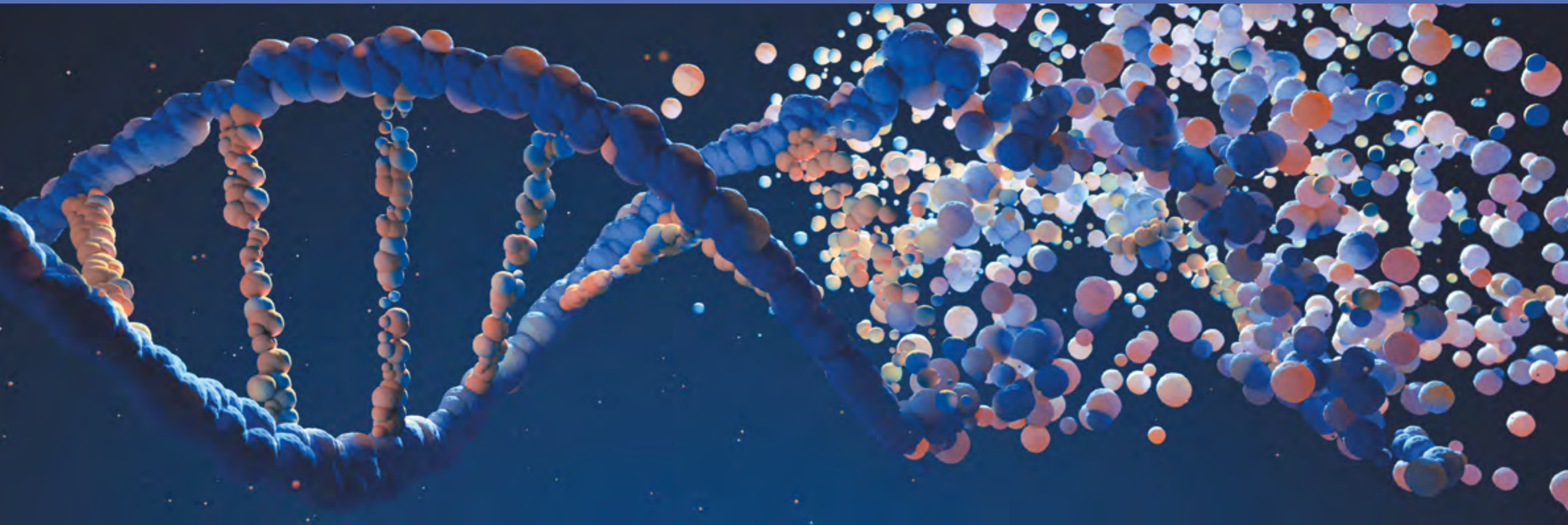

Introduction

In order for enclosed ecosystems (for example, the Eco-CosmoHouse (ECH) [1, 2]) to exist infinitely, it is important to maintain food security, i.e., to provide sufficient food, create waste-free technologies and preserve soil fertility that can be achieved by conducting a breeding farm, seed production and maintaining a bank of strains of microorganisms.

Any population (microorganisms, plants, animals) tends towards the appearance of homozygous lines capable to accumulate recessive alleles that provoke the occurrence of diseases. In addition, populations may experience crossover leading to changes in the genotype of living organisms, as well as to mutations.

The purpose of this study is to examine the problems of the existence of living organisms (microorganisms, plants, animals) at the level of genetic information and to provide solutions for the effective maintenance of healthy populations in an enclosed ecosystem.

Microorganisms

Mineral fertilizers used in modern agriculture have the ability to accumulate in the soil by binding with other components and passing into a form inaccessible to plants. As a result of studying lands in various regions of Belarus, a shortage of organic fertilizers was noted; the humus content in the soil varies from 0.9 to 2 % [3]. At the same time, agricultural enterprises annually apply solid mineral fertilizers before the main processes of plant cultivation (during autumn and spring treatments), causing soil salinization and leaching of individual elements into groundwater under the impact of rain and melt water. Such technologies cannot and should not be implemented in the enclosed ECH ecosystem. The application of an alternative technique that increases the yield of agricultural crops is the key concept of the ECH existence. One of these methods is the use of bacterial preparations.

It is known that these substances favorably affect 60–70 % of agricultural crops. Microorganisms improve the nitrogen and phosphorus nutrition of the plant, contribute to the development of its immune system, and also increase the yield by 20–30 % or more. In addition, they partially compensate for the lack of mineral fertilizers in the soil due to the intake of nitrogen and phosphorus in the cultivated crops. The waste products of microorganisms increase the absorption and synthetic activity of the root system.

However, the activity of introduced microorganisms is associated with their survival in soil layers. The concentration of microorganisms depends on the correct selection of the strain, agronomic mixtures and associations. In order to guarantee the effectiveness of bacterial preparations, it is needed to overcome the causes of the survival rate of microorganisms in the root zone.

Based on the above, it is necessary to create a bank of microorganisms for use in the ECH. To do this, the best way to store them should be found.

The collection of microorganisms is maintained by conservation. The complete preservation of populations and genetic stability is problematic, especially if we consider the diversity of microorganisms and their viability under certain conditions, which is associated with the genus and species of microorganisms.

There are two main approaches in the methods of storing microorganisms:

- short-term storage: periodic replanting on agarized media, storage of crops using mineral oil, in water-salt solutions, etc. These are some of the easiest ways to preserve microorganisms from several weeks to one year, however, they have a number of disadvantages: dissociation of microorganisms, pollution, non-guaranteed viability period, etc. In addition, the wrong choice of nutrient medium can lead to the loss of microorganisms. Most of these methods are not suitable for the preservation of microorganisms;
- long-term storage. This approach is capable to provide inhibition of vital processes occurring in the cell without loss of properties. This result is achieved in two ways: deep freezing of microorganisms, or cryopreservation (from –70 °C to –196 °C); drying from the frozen (lyophilization) or liquid state.

To maintain the collection of microorganisms, it is reasonable to use long-term storage methods: lyophilization and cryopreservation.

Lyophilization of Microorganisms

Lyophilization (freeze-drying) is understood as a drying technology that allows ice to evaporate, bypassing the liquid phase.

The lyophilization procedure takes place in several stages: freezing, primary drying, additional drying (secondary drying) (Figure 1).

The freezing has an impact on the final agent quality. If the process does not take long, less ice crystals are formed in the substance. Consequently, during drying, moisture evaporates much faster (Figure 2).

Freezing is required to preserve all properties, as well as to maintain the viability of microorganisms. Freezing is carried out at temperatures from –40 °C to –60 °C.

It is possible to evaluate the quality of freeze-drying by such parameters as the dissolution rate of the agent (no more than 1–2 min), residual moisture (no more than 1–3 %), the initial viscosity of the agent after its dissolution (depends on the dissolution medium), the pH-medium of the substance (pH 7–7.4) [4].

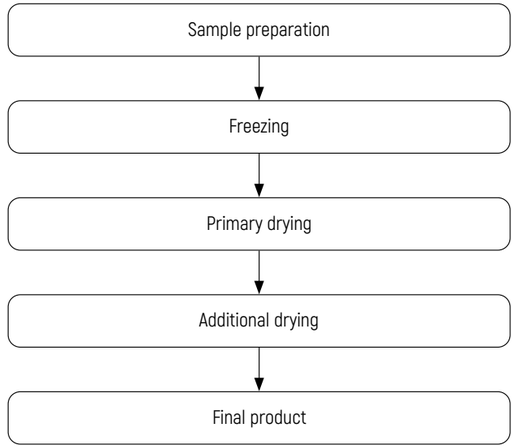

Figure 1 – Stages of lyophilization

Cryopreservation of Microorganisms

Almost all the studied groups of bacteria can be preserved for a long time in a frozen state at low (cryogenic) temperatures (less than –153 °C) [5–8].

In cryopreservation, the use of liquid nitrogen is most common, since it is available, safe and is the optimal refrigerant for most crop collections.

Bacterial cultures in some collections are effectively stored at temperatures provided by modern freezers (Dewar vessels), usually up to –86 °C. Under such conditions, the death rate can be 1,000 times less than at –10 °C [5].

Before cryopreservation, the cells of microorganisms are grown on an appropriate nutrient medium – agarized or liquid.

In the case of slow cell cooling (at a rate of 1 °C/min), it is possible to achieve the best results in the survival and recovery of bacteria [9, 10]. The samples are stored in liquid nitrogen at a temperature of –196 °C or above nitrogen vapor at a temperature of –150 °C. Thawing occurs during rapid heating of frozen microorganisms, which leads to their rapid recovery [11].

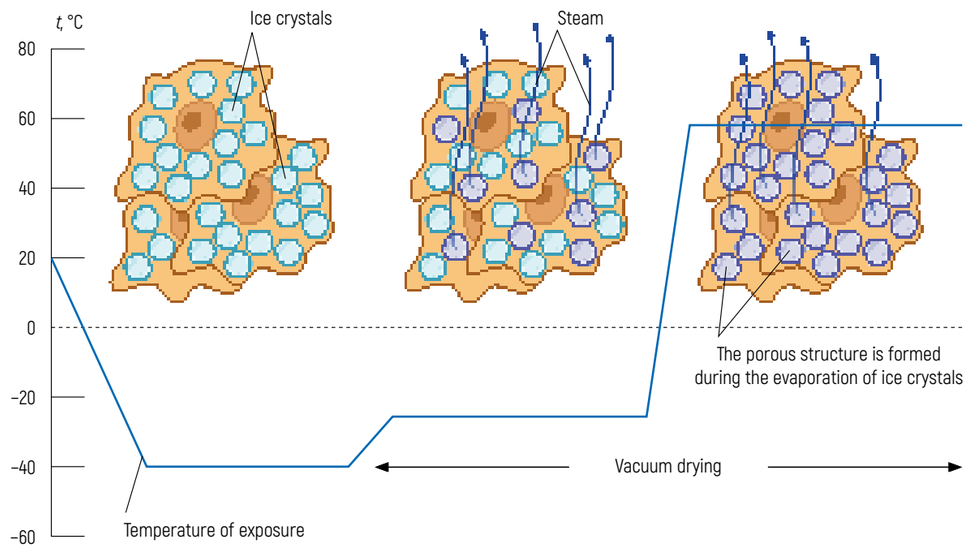

Figure 2 – Process of lyophilization

Animals

Livestock breeding is one of the most important areas of agricultural production. Pedigree stock is considered to be farm animals used for breeding and recorded in the state register.

Farms are interested in raising breeding individuals. There are several options for solving this issue. One of them is the purchase of breeding young animals or the use of embryo transplantation. It will be slower, but more reliable to use the artificial insemination of own livestock and obtain purebred animals through a number of generations.

In order to improve the genetic properties of animals, mechanisms of interrelated and complementary actions are required. The main task is to assess the breeding qualities of animals. Next is the selection of individuals in groups and the compilation of parental pairs for subsequent generations. These measures are necessary to increase the productivity of animal breeds used in agriculture. Another important aspect is the development of resistance to diseases and the adaptability of breeds to the feeds available.

When analyzing adjacent generations, it is possible to note changes in gene frequencies in the number of animals. These changes are the essence of genetic evolution. Natural and artificial selection, migrations, gene drift are the main factors of evolution.

Inversion, translocation, deletion and duplication are considered to be one of the causes of genetic variation in populations. Spontaneous changes in genetic information lead to the accumulation of mutations in the phenotype. Recombination of the gene structure of phenotypic traits in generations causes changes in the reproductive cells of parents.

The current mechanism of natural selection in populations is gene drift, which leads to mutation of the genetic structure of the population, in small populations in particular [12].

In a homozygous or heterozygous state, any animal in the genotype has allelic genes. Recessive alleles are usually located in a heterozygote. When crossing closely related individuals (inbreeding), the risk of merging identical gametes carrying modified genes in a heterozygous state and their transition to a homozygous state increases. This probability corresponds to the degree of kinship of the mated animals [13].

The result of inbreeding is changes in gene frequencies. In addition, recessive homozygotes may be cleaved, which leads to inbred depression, expressing in a decrease in the viability and fertility of animals and the birth of abnormal individuals [14].

The largest number of recessive alleles is rejected by natural selection or excluded in the selection process. First of all, these are dominant signs that manifest phenotypically in a heterozygous state, and numerical changes in sets of chromosomes. Recessive genes in a heterozygous state and in the process of rearranging the structure of chromosomes obviously do not affect the viability of their owners [15].

Genomic variability leads to the formation of polymorphism in populations – a variety of frequencies of alleles, homozygotes in dominant traits, heterozygotes or homozygotes in recessive genes (Figure 3).

English naturalist C. Darwin developed the doctrine of selection and established that the emergence of new forms of living organisms, as well as the modification and improvement of existing ones are due to natural and artificial selection [16].

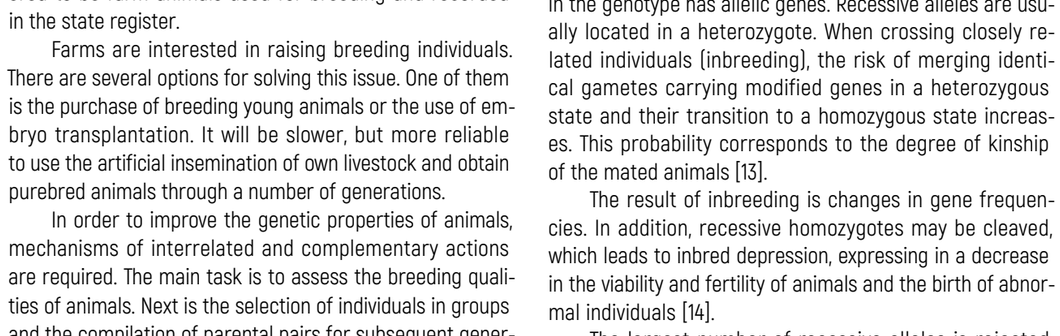

Figure 3 – The trend of populations towards a heterozygous state: *A* – dominant trait; *a* – recessive trait; *P* – parents (P_1, P_n, etc.)

The main point of his theory is that all species are not invariable created forms, but are the result of a long process of the animal struggle for existence. The features of obtaining food, ways of dealing with rivals and enemies are transmitted, strengthened and accumulated by inheritance from parents to offspring. Accordingly, each new generation is more organized, has more chances to outlive the weak and continue the race. This process of improving species is called "natural selection". The evolution of wild animals occurs due to the survival and reproduction of more adapted individuals [16].

Selection of genetic material, i.e., haploid cells (spermatozoa and oocytes), and its cryopreservation will help to avoid closely related crossing in the first and subsequent generations and to maintain desirable qualities.

In the first generation of animals living in the ECH, totipotent stem cells will be immediately taken and transferred to the ECH genetic bank (Figure 4). The genetic bank will start operating from the second generation; its representatives will also be selected for genetic material for cryopreservation and the use of cells in artificial insemination of the hundredth generation of the ECH animals.

To obtain the most diverse genotypes within the ECH animal population, the selected material is planned to be used only after the hundredth generation. Until then, it is planned to use pre-prepared genetic material stored in the ECH genetic bank, taken from various animal populations on the planet Earth.

Each subsequent generation of the ECH, starting from the second, should use the genetic bank as a source of creating healthy and progressive offspring, as well as contribute their own totipotent stem cells to replenish the genetic diversity of the bank.

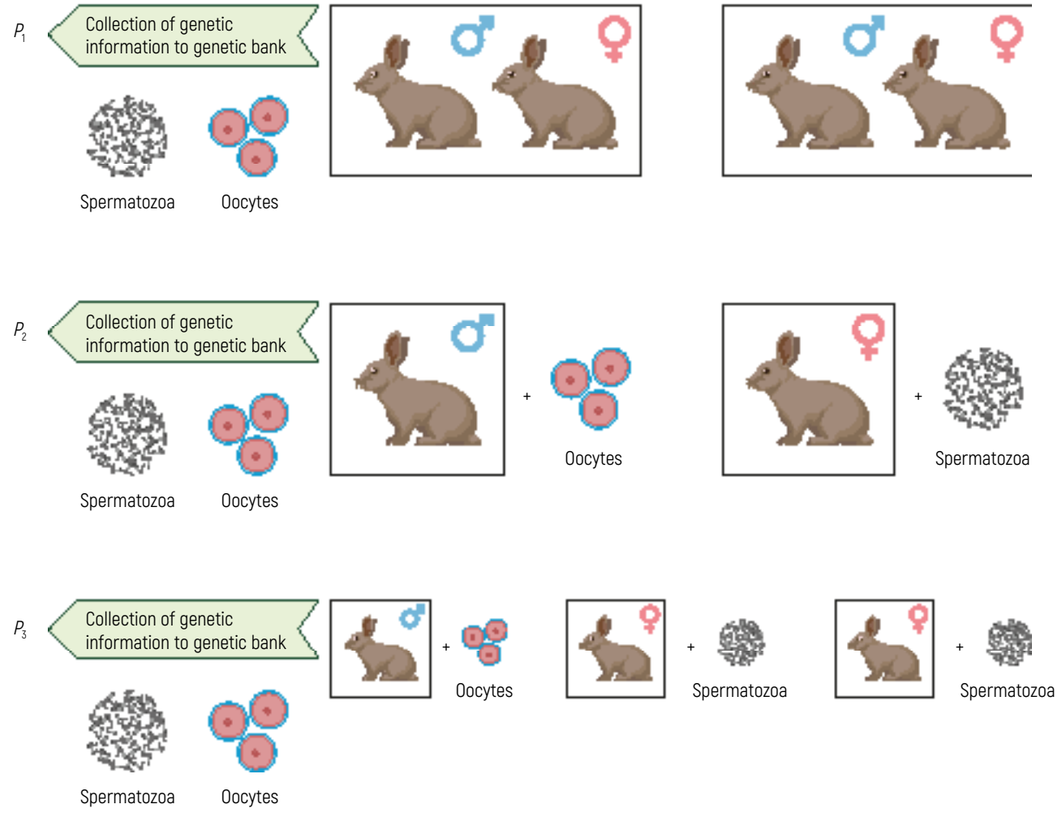

Figure 4 – The role of the genetic bank of hereditary information in an enclosed ecosystem: *P* – parents (P_1, P_2, P_3, etc.)

Plants

Plants in an enclosed ecosystem require the maintenance of constant traits in populations. A significant part of the flora cultivated on Earth is cross-pollinated, which leads to the splitting of descendants according to phenotypic traits (Mendel's second law).

The splitting of traits causes an imbalance of properties beneficial for humans in plants, which ultimately causes degradation of plant domestication. The ECH conditions do not allow taking and replenishing the gene pool of useful plant crops, which results in necessity to maintain their genetic bank.

Plants, unlike bacteria and animals, have callus tissues, which are considered analogous to stem cells. Callus cells have totipotency (storing genetic information about the whole organism in one cell), thanks to which the flora representatives are able to renew the whole organism with all its functions.

Callusogenesis greatly facilitates the process of preserving the plant gene pool and accelerates traditional ways of maintaining phenotypic traits. The technology that will help to obtain callus tissues is tissue and cell culture *in vitro* (microclonal propagation). This method also frees plants from pathogenic organisms (viral, fungal and bacterial) [17].

The cells formed by microclonal propagation are genetically identical to the cell donors (queen cells), which helps to transfer the uniqueness of the original specimen to the cuttings. For the production of callus cultures, it is necessary to use meristem tissues or cambium of plants (Figure 5). At the beginning of the microclonal propagation process, these cells should be selected, and then transferred to a nutrient medium that contains mineral components and phytohormones required for callus growth.

The described mechanism helps not to lose the signs of useful properties in plants, but there is a problem with the long-term preservation of the cells themselves. Similar tasks are solved by their cryopreservation. Being in a deep freeze, plant cells do not lose their uniqueness for a long time.

In addition, various cryoprotectors are used to freeze cells, which help to reduce the traumatic effect of physicochemical factors during cryopreservation.

The authors of this study propose the following cooling technique:

1) reducing temperature from 20 °C to –35 °C at the beginning of the process. At the same time, the speed should be 0.5 °C/min and the cells should stay at this temperature for at least 15 min;

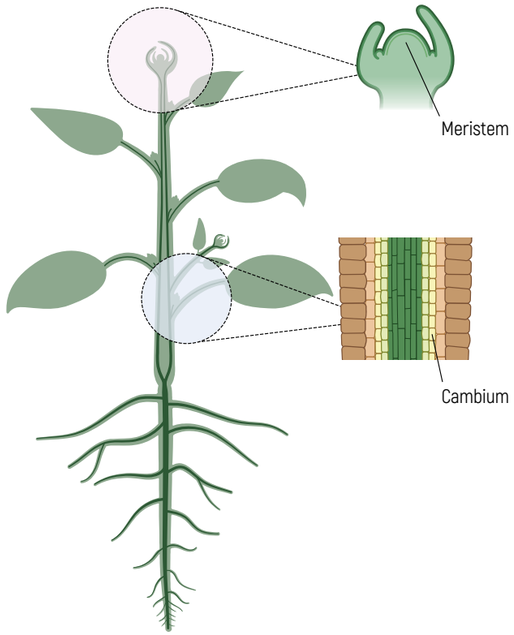

Figure 5 – Formative plant tissues

2) immersion in liquid nitrogen (instant cooling to –196 °C level) [18].

After the defrosting process, the restoration of cellular activity in plants is going much better compared to animals. Callus tissues are capable of dividing after prolonged cryonic storage. The cells are thawed at room temperature. As soon as the cells are released, they are immersed in a solution of 10 % sucrose or 20 % glucose for 15 min to resume cellular activity.

The main methods of cell division leading to the formation of callus are as following:

- the use of phytohormones (through the optimal concentration of auxins and cytokines in the nutrient medium);
- changing the temperature regime (by shock freezing or short-term treatment with high temperature);
- application of agrobacteria (due to plasmid sites responsible for stimulating the production of auxins and cytokines).

The callus can be separated and divided into a large number of parts, while cells separated from the callus are capable of forming a new callus with subsequent new division or passage into the plants explant (Figure 6).

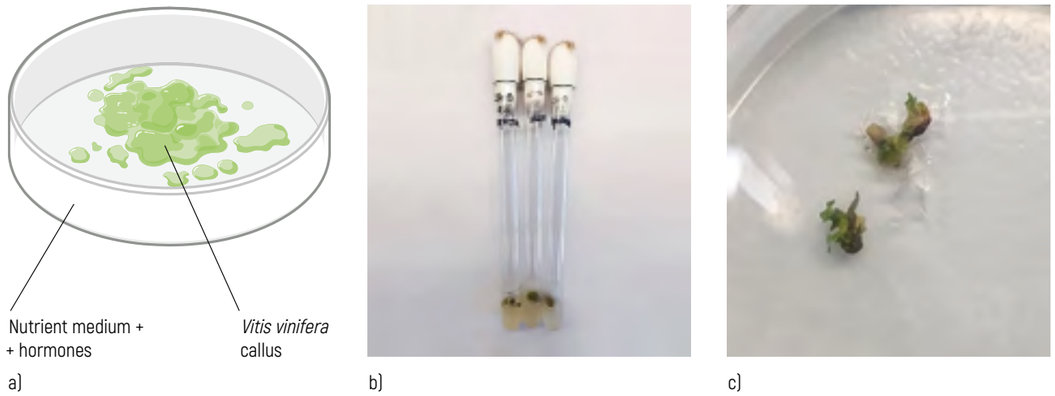

Figure 6 – Grape vine callus (*Vitis vinifera*): a – schematic representation; b, c – obtained in laboratory conditions

Conclusions

The appearance of homozygous lines and the accumulation of recessive alleles leads to various diseases of the offspring. This means that in order to support a stable life in the ECH and ensure food security of people, it is necessary to maintain a breeding farm, which involves the use of a genetic bank and the selection of genetic material for cryopreservation, and seed production according to the proposed method (using microclonal propagation or callusogenesis). In addition, it is important to create a bank of microbial strains that will be formed in the enclosed ECH system using cryopreservation and lyophilization.

References

1. *Unitsky, A. System Foundations of Non-Rocket Near Space Industrialization: Problems, Ideas, Projects / A. Unitsky. – Minsk: Gradient, 2021. – 568 p.: il.*
2. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
3. *Lapa, V.V. Produktivnost' zernotravyanogo sevooborota i izmeneniye agrokhimicheskikh pokazateley dernovo-podzolistoy legkosuglinistoy pochvy [Productivity of Grain-Grass Crop Rotation and Changes in Agrochemical Indicators of Sod-Podzolic Light Loamy Soil] / V.V. Lapa, M.M. Lomonos // Pochvovedeniye i agrokhimiya. – 2010. – No. 1 (44). – P. 73–79.*
4. *Khandagale, P.M. Lyophilization Technique: A Review / P.M. Khandagale, B.A. Bhairav, R.B. Saudagar // Asian Journal of Research in Pharmaceutical Sciences. – 2016. – Vol. 6, No. 4. – P. 269–276.*
5. *Hubalek, Z. Protectants Used in the Cryopreservation of Microorganisms / Z. Hubalek // Cryobiology. – 2003. – Vol. 46, No. 3. – P. 205–229.*
6. *Chervyakova, N.S. Ispol'zovaniye liofil'nykh apparatov kamernogo tipa v kollektsiyakh patogennykh mikroorganizmov [The Use of Chamber-Type Lyophilic Devices in Collections of Pathogenic Microorganisms] / N.S. Chervyakova, T.V. Valova, A.V. Osin // Problemy osobo opasnykh infektsiy. – 2014. – No. 3. – P. 65–68.*
7. *Donev, T. Methods for Conservation of Industrial Microorganisms / T. Donev. – Sofia: NBIMCC, 2001. – 93 p.*
8. *Stepanskyi, D.O. Investigation the Long-Term Storage of Aerococcus / D.O. Stepanskyi, I.P. Koshova, G.M. Kremenchutskyi // Vostochno-yevropeyskiy nauchnyy zhurnal. – 2016. – Vol. 6, No. 1. – P. 70–73.*
9. *Gerna, R. Khraneniye mikroorganizmov [Storage of Microorganisms] / R. Gerna // Metody obshchey bakteriologii: in 3 vol.: transl. from English / eds F. Gerhardt [et al.]. – Moscow: Mir, 1983. – Vol. 1. – P. 512–534.*
10. *Hammes, W.P. The Genera Lactobacillus and Carnobacterium / W.P. Hammes, C. Hertel // Prokaryotes. – 2006. – Vol. 4. – P. 320–403.*

11. *Pokhilenko, V.D. Metody dlitel'nogo khraneniya kollektsionnykh kul'tur mikroorganizmov i tendentsii razvitiya [Methods of Long-Term Storage of Collection Cultures of Microorganisms and Development Trends] / V.D. Pokhilenko, A.M. Baranov, K.V. Detushev // Izvestiya vysshikh uchebnykh zavedeniy. Povolzhskiy region. Meditsinskiye nauki. – 2009. – No. 4 (12). – P. 99–121.*
12. *Inge-Vechtomov, S.G. Genetika s osnovami selektsii [Genetics with the Basics of Breeding] / S.G. Inge-Vechtomov. – Moscow: Vysshaya shkola, 1989. – 592 p.: il.*
13. *Nikolaychuk, V.I. Genetika s osnovami selektsii [Genetics with the Basics of Breeding] / V.I. Nikolaychuk, B.B. Nad'. – Uzhhorod: Medium, 2003. – 196 p.*
14. *Genetics: A Beginner's Guide / B. Gutman [et al.]. – Oxford: Oneworld, 2002. – 308 p.*
15. *Meditsinskaya genetika [Medical Genetics] / N.P. Bochkov [et al.]. – Moscow: Masterstvo, 2001. – 190 p.*
16. *Bochkov, N.P. Klinicheskaya genetika [Clinical Genetics] / N.P. Bochkov. – 3rd ed., corrected and supplemented. – Moscow: GEOTAR-Media, 2004. – 480 p.*
17. *Naletov, I.V. Opredeleniye poroga vredonosnosti gamma-luchey na sukhiye zarodyshi tvordoy pshenitsy (Triticum durum Desf.) [Determination of the Threshold of Harmfulness of Gamma Rays on Dry Germs of Durum Wheat (Triticum durum Desf.)] / I.V. Naletov, D.S. Simonenko // Innovatsii i puti povysheniya effektivnosti rasteniyevodstva: Collection of Articles Based on the Materials of the International Scientific Conference, Dedicated to the 180th Anniversary of the BSAA and 95th Anniversary of the Faculty of Agronomy, Gorki, May 28, 2020 / BSAA; eds N.A. Duktova (editor-in-chief) [et al.]. – Gorki: BGSHA, 2020. – P. 47–50.*
18. *Shirokov, A.I. Osnovy biotekhnologii rasteniy [Fundamentals of Plant Biotechnology] / A.I. Shirokov, L.A. Kryukov. – Nizhny Novgorod: NNGU, 2012. – 49 p.*

Living in the EcoCosmoHouse as a Way to Prevent Premature Aging of the Body

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The aging of the human body is a phenomenon that leads to the incomplete use of a specific biological resource, and therefore belongs to the group of medical and social problems. This article highlights the main issues related to the aging process. Information about the risk factors of premature aging is provided. Modern views on the means of restraining age-related changes are presented; the possible preventive role of the EcoCosmoHouse (ECH) in preventing this phenomenon is shown.

Keywords: *antioxidants, EcoCosmoHouse (ECH), enclosed ecosystem, premature aging, prevention of aging.*

Introduction

Body aging is a spontaneous process that occurs under the influence of factors of the external and internal environment; it can occur in a physiological (natural) and accelerated (premature) type. Natural aging differs from accelerated aging primarily by the fact that it is not burdened with diseases and, accordingly, does not require treatment. Of course, the deterioration of the environmental situation provokes premature aging of people, the emergence of new diseases and, as a result, is the cause of a reduction in life expectancy. Practice shows that in recent years, aging has mainly been accelerated. The study of the factors determining this process and their detection (as far as possible) will allow to work out measures not only to prevent premature aging, but also to maintain active longevity of the population [1].

At all times, there has been a desire to increase the average life expectancy on the planet Earth. In near-Earth settlements, this trend, obviously, should not be interrupted, but develop. The study of factors affecting the aging of people living in the EcoCosmoHouse (ECH) will help to optimize the habitat and continue progress of civilizational development.

The proposed material will serve as the beginning of the process of finding ways to increase the life expectancy of a person through his relocation to near space.

Causes of Premature Aging

Systematic and Network Mechanisms

There are several competing theories of the aging process. To date, it is accepted that many mechanisms violating the functioning of human body cells act simultaneously; cells also need to spend reserves to protect themselves from many processes occurring in parallel. To determine the relationship between the mechanisms of combating functional disorders, a systematic approach to the phenomenon of aging is presented, which takes into account a large number of such processes. In addition, this method helps to clearly separate the factors that affect the body at different stages of life. For example, over time, an increase in the amount of active oxygen forms leads to a decrease in energy production.

Molecular Mechanism

The first studied mechanism of premature aging is molecular. The principle of its negative impact on the human body are internal and external stochastic (spontaneous) factors, which include active oxygen forms (AOF) and active nitrogen forms (ANF), electromagnetic and radioactive irradiation.

The oxygen molecule and the product of its complete restoration by hydrogen – water – are non-toxic. At the same time, the restoration of the oxygen molecule proceeds in such a way that almost at all stages of the reaction products that damage cells are created – free radicals (superoxide anion radical, hydrogen peroxide (H_2O_2) and hydroxyl radical), which can appear in cells under the impact of radiation, chemical reactions and temperature changes. Radicals have a negative effect on the functions of proteins, initiate disorders in RNA and DNA, cause peroxidation of lipids [2].

Simultaneously with AOF, a significant role in the development of pathological processes in the human body is played by ANF. These include nitric oxide (NO), nitrogen dioxide (NO_2), nitroxyl anion (NO^-) and other physiological derivatives of nitric oxide.

Deterioration of Cells and Their Components

The deterioration of cells and intercellular matter is a combination of macro- and micro-damages in cells during their functioning and/or the action of random factors. It is not always possible to separate such factors. During the normal functioning of certain cellular structures of the body, stress and breakdown of a certain number of them occur simultaneously, as well as the formation of AOF, ANF and other endogenous stochastic factors [3].

A circulation of proteins is necessary for the existence of cells. The appearance of affected and excess proteins is critical for this process. Oxidized proteins are a characteristic result of the action of AOF, which are formed during many ongoing processes in the cell and often interfere with the work of protein molecules. As a result of improper functioning of the protein molecules, irregularities occur in its structure. It is believed that the accumulation of affected proteins may be responsible for diseases that manifest with age, such as Alzheimer's disease, Parkinson's disease and cataracts [4].

Risk Factors for Accelerated Aging

Action of Free Radicals

The driving force of pathological processes in the human body that cause accelerated aging and the appearance of many diseases is the excessive accumulation of free radicals of oxygen, nitrogen, as well as damaged proteins.

As a result of the harmful effects of free radicals, the walls of blood vessels and cell membranes are injured, lipids are oxidized. This condition is called oxidative stress. Currently, the participation of radicals and other toxic forms of oxygen in the process of cell damage in coronary heart disease has been proven [3].

Ecology and Transport

Analyzing the data [5], it can be concluded that atmospheric air contamination contributes to an increase in the total mortality of the population from cardiovascular diseases.

The most dangerous for a city dweller is the proximity of industrial enterprises to the city limits. According to [5], which shows the influence of environmental factors on morbidity, the share of emissions from operating enterprises is 75 % of the total number of atmospheric pollutants. The location of industries harmful to human health near the city implies the rapid transfer of pollutants to the residential part of the city.

The inhaled air is characterized to a certain extent by a constant composition; it is a mixture of gases and suspended solids (Table 1) [6]. About 98 % of the mass of the substance polluting the atmosphere of the planet Earth belongs to gases or gaseous substances: carbon monoxide (CO), nonmethane hydrocarbons and volatile organic hydrocarbons, nitrogen oxide (NO_2).

Table 1 – Composition of atmospheric air

Gas	Content in dry air, %
Nitrogen (N_2)	78.08
Oxygen (O_2)	20.95
Argon (Ar)	0.93
Carbon dioxide (CO_2)	0.03

Researches in recent years have confirmed the relationship between the long-term effect of polluted air and the risk of heart diseases: with an increase in the concentrations of solid particles in the air, an increase of 6 % in total mortality and 11 % in mortality from cardiovascular diseases was revealed [7]. Many scientists in their works prove the relationship between environmental pollution by black carbon and other substances associated with transport and increased blood pressure in the population [8].

In addition, excessive noise pressure, which accompanies transport and industrial air pollution with suspended particles, is dangerous. Presently, a significant number of epidemiological researches have been accumulated studying the effect of noise from highways and industrial buildings on the state of the human cardiovascular system. Various experiments have been conducted on the quantitative and qualitative assessment of pollutants, which allows to draw the main conclusion: constant noise coming from automobile, railway and aviation transport or industrial enterprises negatively affects the human body, causing high blood pressure and the development of arterial hypertension [9].

At the same time, one should not forget about the individual factors of environmental potential risk associated, for example, with the habitat of an individual or with his psychoemotional state. Each of the reasons can have a negative impact on the cardiovascular system both independently and in combination with others.

Increasing the literacy of society in the field of adverse effects of noise exposure and air pollution on the human body and recognizing them as standard risk factors will help in developing efficient solutions aimed at reducing noise and air pollution, as well as reducing their negative impact on people's health.

Thus, the task of creating a technology for bringing the Earth's industry out into the near space is currently urgent in order to improve the living conditions of the world's population, most of which live in cities.

Photoaging

Photoaging, or premature aging of the skin, occurs as a result of exposure to the human body with ultraviolet radiation (UV radiation), the main source of which on the planet Earth is sunlight (UV rays). UV rays are electromagnetic radiation invisible to the eye, occupying the spectral region between visible (380–780 nm) and X-ray (10^{-2}–10^2 nm) radiation. The wavelength of UV rays is 100–400 nm; they act on the cells of the human body in any weather and at different times of the day. Depending on the wavelength and effect on human skin, three types of UV radiation are distinguished:

- UV-A (320–400 nm) – rays cause a decrease in the immune potential of human skin cells; pigmentation begins;
- UV-B (290–320 nm) – rays cause a critical decrease in the immune potential of human skin cells, cause a protective reaction of human skin in the form of sunburn, wrinkles, provoke the development of skin diseases (cancer);
- UV-C (200–290 nm) – rays with the strongest potential of action on human tissue; they are absorbed in a significant amount by the ozone layer of the Earth's atmosphere [10].

Photoaging and its consequences can occur at any age, the degree of manifestation correlates with the total dose of UV radiation received over the entire period of life.

From a modern point of view, a person grows old as a result of the accumulation of damage in cells. The rate of accumulation of changes is primarily due to expenses for the restoration and maintenance of cellular structures [11].

Modern Views on the Means of Preventing Accelerated Aging

Preserving youth and prolonging the phase of active longevity is one of the priority tasks in the modern world. However, there is no universal method that can solve it at once. Thus, it is important to find and study the means by which it is possible to protect cells and the human body from the impact of harmful environmental factors and prolong active longevity.

Geroprotectors

Presently, more than 100 types of geroprotectors are known, which may be able to increase life expectancy. These remedies have a stimulating effect on the body and normalize the impaired functions of systems and organs, as well as metabolism. Geroprotectors include pharmacological preparations of various groups, with the help of which it is possible to correct the processes occurring with age-related changes, to strengthen the regulatory mechanisms responsible for the physiological type of aging [12]: unsaturated fatty acids, hormones, vitamins, biostimulants, stem cells. The most efficient, common and affordable geroprotectors are antioxidants.

Antioxidants

Antioxidants are substances that protect cell molecules from damage by free radicals of oxygen and nitrogen. The human body has its own system of antioxidants, which consists of enzymes. In various diseases, as well as due to unfavorable factors of the external and internal environment, the natural antioxidant system weakens, the body becomes more susceptible to oxidative stress [13].

There are two ways an antioxidant can affect human cells. In the first mechanism, the substance interacts with the oxygen (nitrogen) free radical and gives it the missing electron (Figure 1). The result of the reaction is that AOF (ANF) becomes neutral: it does not strive to react with molecules and does not pose a danger to healthy human cells.

The second mechanism is that antioxidants react as biological catalysts (these include antioxidant enzymes produced in the body), accelerate the neutralization reactions of free radicals, turning them into harmless compounds [13].

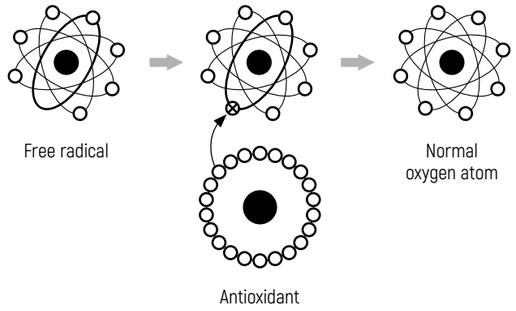

Figure 1 – Mechanism of action of an antioxidant on a free radical

Antioxidant enzymes are substances characterized by high specificity: superoxide dismutase (SOD), catalase, glutathione peroxidase, glutathione S-transferase, peroxiredoxins.

SOD is a metalloenzyme that performs the function of a biological catalyst; it removes the aggressive superoxide anion radical and creates a stable hydrogen peroxide at the same time. The mechanism of action of SOD is as follows:

$$O_2^{\cdot-} + O_2^{\cdot-} + 2H^+ \xrightarrow{\text{SOD}} O_2 + H_2O_2.$$

Catalase is an enzyme present in all cells of the human body and has high activity. In erythrocytes, it is located in the cytosol and protects hemoglobin from oxidation. It is a catalyst for the reaction of decomposition of hydrogen peroxide into water and molecular oxygen. The mechanism of action of this enzyme as follows:

$$2H_2O_2 \xrightarrow{\text{Catalase}} O_2 + 2H_2O.$$

The functions of antioxidants in the human body, with all the diversity and mechanisms of their action, are reduced to blocking oxidation reactions that underlie in the aging process and the development of most diseases.

Tests on model organisms have confirmed that the use of antioxidants promotes health and can increase average life expectancy. Consequently, these substances actually help to maintain active longevity, reduce the risk of developing cancer, heart attack, degenerative processes in the nervous system, diabetes, etc.

Organic Products

Recently, the idea of an ecological lifestyle has become more and more relevant in the world. The proceeding of organic products is a positive factor in the development of agricultural food entities and the improvement of the environmental situation. The main goal of obtaining such products is the ecological safety of all components: agricultural raw materials, technologies, equipment, the environment. Today, natural products are the guarantor of safety and health of the population. In accordance with international requirements, the life cycle of the product from the field to the store counter is fully controlled in the growing of organic agricultural products. It is forbidden to use anything that can harm human health – chemical fertilizers and plant protection means, GMOs, antibiotics, growth hormones, food additives [14]. The most popular directions in obtaining natural products are farm food and organic cosmetics.

Role of the EcoCosmoHouse in Preventing Premature Aging

Modern man has mastered almost all of the Earth's space: from polar ice to hot tropical deserts, from Siberian forests to jungles. By mastering the Earth's expanses, involving natural resources in economic turnover, erecting residential, industrial buildings and road networks, he has changed the natural environment, in many cases gave it properties unfavorable and even hostile to himself.

In order to preserve the natural ecosystem, the species diversity of the planet Earth and the possible extension of active longevity, the technological platform "EcoCosmoHouse" is being developed – a structure in outer space with a habitable area that is isolated from the external aggressive cosmic environment. Inside the ECH, it is planned to create an enclosed terrestrial ecosystem, including artificially obtained gravity, living fertile soil, flora and fauna, as well as an atmosphere with adjustable parameters (temperature, humidity, etc.) for unlimited long-term, autonomous, eco-comfortable living and activities of both individuals and their groups, and thousands of settlements in equatorial orbits of the planet Earth [15].

Creation of Optimal Conditions for Autonomous Living of People

The peculiarity of a person's place of residence consists in a diverse interweaving of social and natural aspects. Getting into unusually new external natural conditions, a person often experiences the influence of little-known, but sometimes harsh environmental factors, to which he is not yet evolutionarily adapted.

One of the most effective methods of preventing premature aging of people on the scale of the ECH is the formation of optimal conditions for an unlimited long-term residence. To solve this problem, an artificial atmosphere will be created in the ECH – a specially selected mixture of gases that ensures normal respiration and gas exchange in living organisms, including humans, staying under the conditions of an enclosed ecosystem [15]. The artificial atmosphere is not inferior to the terrestrial one. The parameters of a person's comfortable living are determined quite accurately and have the values [16] shown in Table 2.

Table 2 – Parameters of conditions comfortable for a person living

Indicator	Optimal values
Air temperature, °C	22–26
Relative air humidity, %	30–60
Gas composition of inhaled air, %:	
• nitrogen (N_2)	78.08–78.12
• oxygen (O_2)	20.95*
• argon (Ar)	0.934–0.935
• carbon dioxide (CO_2)	0.03–0.032
Atmospheric pressure, mm Hg	760
Radiation background, μR/h	Up to 8–12

*There is a possibility of increasing the indicator to 23 in order to prevent respiratory diseases.

The Use of Natural Antioxidants

The harmful effects of free radicals can be significantly reduced by a systematic use of products with high natural antioxidant activity. Let us consider medicinal herbs widely used in traditional and folk medicine as such products.

In accordance with the concept of engineer A. Unitsky [15], the necessary set of tools for plant growth will be selected in the ECH, including a fertile soil layer and associations of agronomically valuable soil microorganisms. Thus, it can be assumed that the natural environment and soil-climatic conditions of an enclosed terrestrial-type ecosystem will be the most favorable for the growth and collection of medicinal raw materials. Separately, it should be noted that the peculiarity of medicinal herbs grown in the ECH will be considered their high quality due to the absence of air pollutants, as well as the introduction of organic fertilizing.

Various drugs are used in medicine to combat diseases that cause early aging, including those produced on the basis of substances extracted from plants. When choosing medicinal

raw materials as an additive to food, it is necessary to be guided by the following principles: high antioxidant effect, pharmacological properties, availability, content of essential oils (this parameter makes it possible to use raw materials in the proceeding of natural cosmetic products).

Peppermint (*Mentha piperita* L.) is a perennial cultivated plant, a valuable raw material (Figure 2). The aboveground parts of mint are rich in essential oil, the concentration of which reaches 6 % in the inflorescences. The main component of the essential oil is menthol, which is part of medicines used for diseases of the upper respiratory tract. In addition, the beneficial properties of mint are due to the flavonoid contained in it – hesperidin, which has P-vitamin activity, as well as macro- and microelements (copper, manganese, potassium, calcium, sodium, magnesium, phosphorus, iron) [17].

Due to their soothing, antiseptic and analgesic properties, mint extracts are widely used in the production of natural medicines. The leaves of the plant contain carotene (up to 40 mg), which protects cells and the human body from viruses and, as a result, prevents the occurrence of inflammations. Peppermint is used as an oil solution in cosmetology (ointment, lotion, cream).

Figure 2 – Peppermint

Common sage (*Salvia officinalis* L.) is a perennial cultivated plant (Figure 3). The chemical composition of the leaves is due to the presence of both organic acids (oleanolic, ursolic, chlorogenic) and vitamins P and PP, of group B, phytoncides, tannins, providing antimicrobial and anti-inflammatory properties. The roots of the plant contain flavonoid – a highly active antioxidant quercetin, which fights free radicals in the human body. Sage belongs to the group of essential oil-bearing plants, in which the amount of essential oil in the aboveground part reaches 2.5 %. In addition, bitter-tasting leaves of the plant increase the secretory activity of the gastrointestinal tract, thereby contributing to the improvement of digestion [18]. Common sage is used in the form of infusions, teas and decoctions.

Figure 3 – Common sage

St. John's wort (*Hypericum perforatum* L.) is a perennial herbaceous plant (Figure 4). The main active compounds are red coloring substances, the amount of which reaches 0.5 %. St. John's wort is a source of vitamins C and PP, carotene (up to 55 mg), phytoncides, macronutrients (potassium, calcium, magnesium, iron), microelements (manganese, copper, zinc, cobalt), ultramicroelements (selenium, germanium). Along with this, the plant contains tannins (up to 10 %), essential oil (up to 0.5 %) and hyperforin that can increase the level of serotonin and dopamine, which are responsible for a person's mood. Preparations based on St. John's wort have hemostatic and anti-inflammatory effect, stimulate the restoration of elements of human cells and tissues, have a positive effect on the state of the central nervous system, increase appetite and working capacity, can be used as natural antidepressants [19]. St. John's wort is also popular as a tea brew.

Figure 4 – St. John's wort

Blessed milk thistle (*Silybum marianum* (L.) Gaertn.) is an annual (in cultivation) or biennial (in nature) plant (Figure 5). Milk thistle fruits contain a unique group of biologically active compounds – flavolignans capable of binding nitrogen and oxygen free radicals. Flavolignans include silybin, dihydrosilybin, silicristine, silidianin and eriodictyol. An important group of biologically active substances is fatty oil, the concentration of which in the fruits of the plant reaches 32 %. In addition, milk thistle is a rich source of essential oil, alkaloids, organic acids, vitamins E, K, D, of group B, macro- and microelements, protein compounds.

Blessed milk thistle, due to its beneficial properties, is used for the treatment of acute and chronic hepatitis, cirrhosis, as well as poisoning with toxic chemicals, chronic diseases of the stomach and intestines. A decoction or infusion of milk thistle roots is used for gastritis and convulsions. The powder obtained from crushed seeds reduces the level of sugar in the blood, helps to cleanse it [20].

Figure 5 – Blessed milk thistle

Proper Nutrition

Food is necessary to maintain vital activity and ensure the normal functioning of the body. The human diet is one of the fundamental factors affecting health, working capacity and the duration of an active life. It is noted that a significant part of diseases is associated with the deterioration of the ecological situation in the habitat and, as a consequence, with the poor-quality food consumed.

Due to the absence of pollution in the atmospheric air and the presence of sufficient oxygen volume and fertile soil populated with agronomically valuable associations of microorganisms, the problem of obtaining plant-derived nutrients will not arise on the ECH technological platform [15]. In order to maintain balance in an artificial ecosystem of the biospherical type, specialists will select trophic chains of animals intended for settlement. Animal feed will consist of exclusively environmentally friendly components. This means that the farm product obtained at the output will be guaranteed to be natural, i.e., it will distinguish by a high amount of useful substances, the absence of preservatives, GMOs.

The main advantage of organic products in comparison with conventional ones is the ability to positively influence on the health of population. First of all, because organic fruits and vegetables have an increased content of natural antioxidants. Meat of animals and birds produced by organic agriculture is less fatty, it contains more unsaturated fatty acids, which reduces the risk of developing cardiovascular and oncological diseases, diabetes and prevents the accumulation of excess body weight [21].

The above factors that favorably affect the human body and contribute to the prevention of premature aging in the ECH are summarized in the form of a flowchart (Figure 6).

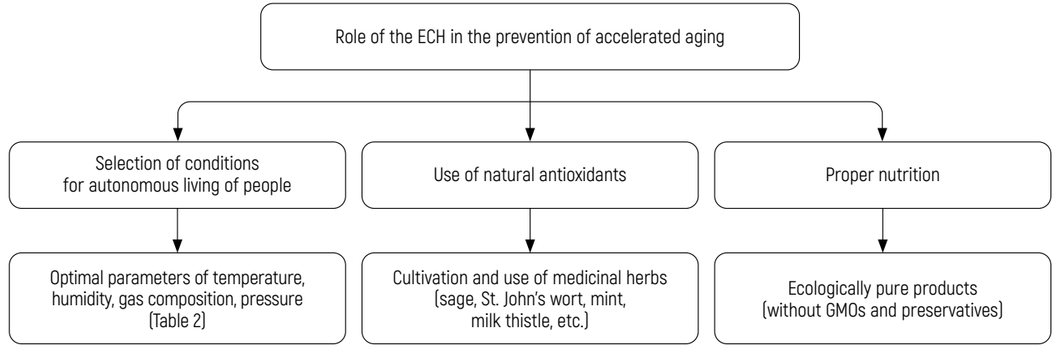

Figure 6 – Flowchart on the role of the ECH in the prevention of premature aging

Conclusion

The most important task of our Earth's technogenic civilization is to preserve the planet's resources and improve the quality of life and health of the world's population. The issue of preventing accelerated aging requires a change in the model of human activity, reorientation of many industries to environmentally friendly production, which implies large-scale work of a wide range of specialists and arrangement of appropriate events.

The theoretical data presented in the article allow to better understand the role of natural antioxidants in the fight against premature aging, transformation of AOF and ANF biomolecules, as well as in the prevention of various pathologies accompanied by oxidative stress.

In addition, in an enclosed ecosystem of the terrestrial type, the use of means to maintain autonomy is required. Medicinal herbs as a source of medical substances are a promising direction in which infusions, flavorings and natural essential oils are obtained helping to prevent age-related changes.

Thus, this article comprehensively substantiates one of the important areas identified in the development of the ECH – improvement of public health by reducing excessively dangerous emissions into the atmosphere and traffic noise, creation of eco-comfortable living conditions for groups of people in the long-term perspective, and hence solving the problem of premature aging of the human body.

References

1. *Kharakteristika fenomena dolgoletiya. Vzglyad na problemu [Characteristics of the Longevity Phenomenon. A Look at the Problem] / M.S. Pristrom [et al.] // Meditsinskiye novosti. – 2016. – No. 1. – P. 48–51.*
2. *Garifzyanov, A.R. Obrazovaniya i fiziologicheskiye reaktsii aktivnykh form kisloroda v kletkakh rasteniy [Formations and Physiological Reactions of Reactive Oxygen Forms in Plant Cells] / A.R. Garifzyanov, N.N. Zhukov, V.V. Ivanishchev // Sovremennyye problemy nauki i obrazovaniya. – 2011. – No. 2. – P. 26–32.*
3. *Mimić-Oka, J. Free Radicals in Cardiovascular Disease / J. Mimić-Oka, D.V. Simić, T.P. Simić // Facta Universitatis. Series: Medicine and Biology. – 1999. – Vol. 6, No. 1. – P. 11–22.*
4. *Vozmozhnaya rol' genov, svyazannykh s lizosomnymi boleznyami nakopleniya, v patogeneze bolezni Parkinsona [Possible Role of Genes Associated with Lysosomal Accumulation Diseases in the Pathogenesis of Parkinson's Disease] / M.M. Rudenok [et al.] // Molekulyarnaya biologiya. – 2019. – Vol. 53, No. 1. – P. 28–36.*
5. *Vliyaniye transportnogo shuma i zagryazneniya vozdukha na metabolicheskuyu i serdechno-sosudistuyu zabolevayemost' i smertnost' [Impact of Traffic Noise and Air Pollution on Metabolic and Cardiovascular Morbidity and Mortality] / A.V. Pyko [et al.] // Neotlozhnaya kardiologiya i kardiovaskulyarnyye riski. – 2018. – Vol. 2, No. 1. – P. 270–279.*
6. *Issledovaniye sostava vozdukha v razlichnykh vozdushnykh massakh [Research of Air Composition in Various Air Masses] / O.Yu. Antokhina [et al.] // Optika atmosfery i okeana. – 2018. – Vol. 31, No. 9. – P. 752–759.*
7. *Long Term Exposure to Ambient Air Pollution and Incidence of Acute Coronary Events: Prospective Cohort Study and Meta-Analysis in 11 European Cohorts from the ESCAPE Project / G. Cesaroni [et al.] // British Medical Journal. – 2014. – No. 348. – P. 1–16.*
8. *Black Carbon Exposure, Oxidative Stress Genes, and Blood Pressure in a Repeated-Measures Study / I. Mordukhovich [et al.] // Environmental Health Perspectives. – 2009. – Vol. 117, No. 11. – P. 1767–1772.*
9. *WHO Environmental Noise Guidelines for the European Region: A Systematic Review on Environmental Noise and Cardiovascular and Metabolic Effects: A Summary / E. van Kempen [et al.] // International Journal of Environmental Research and Public Health. – 2018. – Vol. 15, No. 2. – P. 379.*
10. *Goryachkina, M.V. Kozha i solntse: klinicheskiye proyavleniya i sovremennaya profilaktika fotodermatozov [Skin and Sun: Clinical Manifestations and Modern Prevention of Photodermatoses] / M.V. Goryachkina, T.A. Belousova // Dermatologiya. Prilozheniye k zhurnalu Consilium Medicum. – 2015. – No. 2. – P. 12–17.*
11. *Mushkambarov, N.N. Stareniye: priroda i mekhanizmy [Aging: Nature and Mechanisms] / N.N. Mushkambarov // Prostranstvo i Vremya. – 2012. – No. 1 (7). – P. 182–194.*
12. *Klinicheskaya farmakologiya [Clinical Pharmacology]: Textbook / ed. V.G. Kukes. – 3rd ed., revised and supplemented. – Moscow: GEOTAR-Media, 2006. – 944 p.: il.*
13. *Deystviye antioksidantov na obrazovaniye svobodnykh radikalov – pervichnykh produktov peroksidaznoy reaktsii [The Effect of Antioxidants on the Formation of Free Radicals – the Primary Products of Peroxidase Reaction] / D.Yu. Izmaylov [et al.] // Biofizika. – 2017. – Vol. 62, No. 4. – P. 686–694.*
14. *Nikiforova, T.A. Organicheskaya produktsiya i pishchevyye dobavki dlya yeyo proizvodstva [Organic Products and Food Additives for Its Production] / T.A. Nikiforova, T.N. Gubasova // Pishchevaya promyshlennost'. – 2012, No. 6. – P. 52–54.*
15. *Unitsky, A.E. Lokalizatsiya ob"yektov promyshlennogo naznacheniya na krugovoy ekvatorial'noy okolozemnoy orbite [Localization of Industrial Objects in Circular Equatorial Near-Earth Orbit] / A.E. Unitsky, A.V. Kushnirenko, Ye.N. Kulik // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 230–245.*
16. *Adaptatsiya cheloveka k prirodnym usloviyam i otsenka komfortnosti prozhivaniya naseleniya [Human Adaptation to Natural Conditions and Assessment of the Comfort of Living of the Population] / B.I. Kochurov [et al.] // Problemy regional'noy ekologii. – 2010. – No. 2. – P. 41–48.*
17. *Ushkalova, A.V. Effektivnost' i bezopasnost' antidepressivnykh i sedativnykh sredstv rastitel'nogo proiskhozhdeniya [Efficacy and Safety of Antidepressants and Sedatives of Plant Origin] / A.V. Ushkalova, T.S. Illarionova // Farmateka. – 2007. – No. 20 (154). – P. 10–14.*
18. *Pastushkova, Ye.V. Analiz rastitel'nogo tekhnicheskogo syr'ya s vysokoy antioksidantnoy aktivnost'yu, proizrastayushchego na territorii Sverdlovskoy oblasti [Analysis of Plant Technical Raw Materials with High Antioxidant Activity Growing on the Territory of the Sverdlovsk Region] / Ye.V. Pastushkova // Nauchnoye obozreniye. Tekhnicheskiye nauki. – 2016. – No 3. – P. 78–86.*
19. *Rasteniya dlya nas [Plants for Us]: Reference Edition / K.F. Blinova [et al.]; ed. G.P. Yakovlev, K.F. Blinova. – Saint Petersburg: Uchebnaya kniga, 1996. – 652 p.: il.*
20. *Rastoropsha pyatnistaya [Blessed Milk Thistle] / V.A. Kurkin [et al.]. – Samara: Ofort, 2010. – 118 p.*
21. *K voprosu o tselesoobraznosti proizvodstva pishchevykh organicheskikh produktov [On the Issue of the Expediency of Producing Food Organic Products] / M.A. Prishchepov [et al.] // Agropanorama. – 2014. – No. 6. – P. 31–35.*

Medicinal Cosmetics for the Residents of the EcoCosmoHouse: World Trends, Innovative Ingredients, Production Features

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We studied the feasibility of the production of natural beauty products in the EcoCosmoHouse (ECH). Prevalent hair diseases, as well as the proposed market solutions to this problem are considered. We reviewed innovative cosmetic ingredients and offered specific recipes for the production of natural skincare and the minimum necessary selection of cosmetics for the ECH residents.

Keywords: *beauty products, EcoCosmoHouse (ECH), innovative cosmetic ingredients, manufacture of beauty products, medicinal cosmetics, natural cosmetics.*

Introduction

All over the world, the cosmetics and beauty products industry is one of the sectors that remains immune to the ups and downs of the economy. Overall sales may decline when the economy goes into recession, however, because the products are always in demand not only among women, but also men, the industry has shown steady growth year after year.

According to the report "Cosmetics Market by Category, Gender, and Channel: Global Opportunity Analysis and Industry Forecast, 2021–2027", published by Allied Market Research, the volume of the global market in this segment in 2019 was estimated at 380.2 bln USD. According to the company's forecasts, it will reach 463.5 bln USD by 2027, and the average annual growth rate will be 5.3 % from 2021 to 2027 [1].

There is a trend among various manufacturers to use natural constituents to meet the ever-growing demand for natural and organic beauty products.

Human need for cosmetics grew in parallel with the expansion of knowledge about medicinal plants, the advancement of chemistry, the development of methods of separation and purification of various substances and the emergence of new laboratory equipment. This led to the origin and evolution of cosmetic chemistry – the science about the structure and properties of substances used for cosmetic purposes, the technologies for the manufacture of cosmetics and their effect on human skin, hair, nails. It is based on the achievements in physics, chemistry of natural and synthetic compounds, as well as biology and biochemistry, pharmaceutics, medicine and some other sciences [2].

We should mark the rapid evolution of the cosmetics industry over the last two decades. This is explained by the fact that society has formed the idea that a successful person is not only a person who has achieved high professional results and a high social status, but is also a comprehensively (including appearance) developed and well-groomed person. The popularity of beauty products is in no small part due to the monthly release of new goods that allow the consumer to pick up the product solely for his/her skin and hair type. High efficiency correlates inextricably with considerable industrial emissions and waste. The only possibility to minimize them on our planet is to relocate all production facilities off the Earth, which can be implemented on the basis of the Industrial Space Necklace "Orbit" (ISN "Orbit") that follows the concept of engineer A. Unitsky [3]. Moreover, the relocation of plants will provide the residents of this complex with natural medicinal beauty products.

Thus, it becomes relevant to analyze current trends in the cosmetics industry, the possibilities to obtain natural plant ingredients in enclosed ecosystems and the development of formulations that are most suitable for residents of the EcoCosmoHouse (ECH).

Classification of Cosmetics

A cosmetic product is any substance or formulation meant to be put on various human outer surfaces (skin, hair, nails, etc.) or on the teeth and oral mucous membranes. Beauty products are used to cleanse, give a pleasant odor, improve the natural scent, change the appearance, as well as to protect and keep the human skin in a good condition [4].

Each year the world market produces a large number of diverse beauty products. The entire range is usually divided into two groups:

1) skincare;

2) makeup.

The first group is intended for care, helps to remove various dermatological problems, as well as to preserve youthfulness and beauty. Today such beauty products are produced for the body, face, hair and nails; they are available in lines for women, men and children.

The second group is intended for the correction of appearance and includes foundations, mascara, lipsticks, eye shadows, pencils, blushers, nail polish, etc.

We should note a relatively recent trend – cosmeceuticals (the term appeared as a merger from the words "cosmetics" and "pharmaceuticals") [5]. There is no established definition of cosmeceutical products, but ordinary people understand them as a combination of cosmetics with medicines, i.e., curative cosmetics. In this connection the names "medicinal cosmetics", "curative cosmetics", "cosmeceuticals" are very often used, implying one and the same thing.

Overview of Cosmetics Market Trends

During the analysis of the cosmetics market, it was noted that products with a high content of natural components are in great demand [6]. Among the popular trends in the cosmetics industry we should also highlight the following:

- higher quality standards for formulations due to the growing level of people's awareness of the matter;
- a particular interest in cleansers and moisturizers because of the frequent hand, face and body washing recommended in the COVID-19 pandemic;
- customization and DIY (do-it-yourself) approaches due to the shutdowns of beauty salons after the start of the pandemic and the increasing amount of time spent at home;
- the demand for effective home care, not inferior to professional procedures, in order to save personal time;
- growing awareness among consumers that skin problems can be associated with a disrupted microbiome, which in turn brings about an increase in the supply of beauty products in this category;
- a strong focus on health and sustainability has boosted the demand for Clean Beauty products, which has resulted in a growing emphasis on the tags "natural", "eco" and "cruelty-free";
- the desire of manufacturers to meet the expectations of consumers encourages beauty companies to obtain a variety of quality certificates for their products: Ecocert, ICEA, BDIH, COSMOS, Cosmebio, Vegan.

Pharmaceuticals for Common Hair Diseases

Alopecia

Statistically, the number of people who visit dermatologists with hair loss problems is constantly growing and makes up about 8–10 % of those suffering from skin diseases [7]. Daily hair loss (up to 100 hairs), evenly distributed over the entire scalp, is a normal physiological process. However, under the influence of various external and internal factors, the synchronism of hair cycles is disturbed leading to excessive hair loss (up to 1,000 per day), which causes alopecia [8].

Many factors contribute to the development of this disease: autoimmune, endocrine, acute infections, foci of chronic infections, peripheral vascular and cerebral vascular disorders, functional disorders of the nervous system, imbalance of nutrients and changes in blood rheological properties [9]. Up to 25 % of patients have alopecia in a personal or family history [10].

In this situation, preparations with natural constituents can be one of the most effective treatments. The popular ones are Selencin (Alkoy-Pharm Ltd), Aminexil® and SP94™ (Laboratoires Vichy), etc.

The mode of action of Selencin can be represented as two phases:

1) inhibition of 5α-reductase activity, leading to a decrease in the conversion of testosterone to dehydrotestosterone, which, when exceeded, disrupts the hair follicle;

2) stimulation of hair growth by improving microcirculation in the hair follicle area.

The Selencin cosmetic line includes shampoo, balm and lotion spray (for daily use), hair mask and tablets (for a course of two months).

The mode of action of Aminexil® is that this complex prevents fibrosis (accumulation of excess collagen around the hair follicle), thus making the hair root stronger and the connective tissue spreading. Collagen "squeezes" the capillaries, which stops the growth of hair in the bulb, so that even if it does come out, it will be weakened and will soon fall out.

It is commonly believed that problems with the collagen sheaths of hair follicles are characteristic of men in particular, since excess collagen is often formed under the influence of testosterone. For this reason, anti-alopecia care formulas were originally developed for men. Later it was discovered that in women under the influence of even mild hormonal disorders testosterone can trigger a similar process, thus weakening the hair follicles and thinning the hair shaft.

Apart from strictly genetic factors that induce the risk of alopecia, there are also a number of external factors:

- overuse of hair styling products;
- hot air drying;
- bad habits;
- emotional stress;
- skin diseases;
- malnutrition;
- disturbance of the daily routine;
- iron deficiency in the body.

Hair Graying

In the modern world, the aesthetics of a person's appearance is of great importance, therefore, the study of the mechanism of hair pigmentation is of particular importance. Cosmetic experts are searching for ways to prevent graying or to restore the pigmentation of growing gray hair in the follicles. It is now established that the main melanogenic factor is α-melanocyte-stimulating hormone (α-MSH), which belongs to the melanocortin family. The most exciting finding of the last decades is the discovery of melanocortin biosynthesis and their reception immediately in hair follicles. And the melanocortin 1 receptor (MC1R) is the main melanogenic mediator. It is localized in the melanocytes – specialized skin cells that produce melanin pigment [11].

Melanogenesis (pigment production) is associated with hair growth and remodeling cycles. Given that each of these cycles in humans takes 3.5 years, in the first 35 years of life, there are only 10 cycles with a fairly complete restoration of the pigment complex. Then, melanogenesis gradually decreases, accompanied by both a decline in the number of melanocytes and disruptions in the transfer of melanosomes, i.e., pigment-filled organelles, from melanocytes to keratinocytes of growing hair [12]. These processes are the ones that cause hair graying.

Multiple reports suggest that the proliferative potential of skin stem cells and melanocyte precursor cells is depleted with age [13]. However, some authors argue that there are also abnormalities in hormonal regulation of melanogenesis.

Besides, recent years have seen a remarkable breakthrough in clarifying the essential role of oxidative stress in hair graying. It is assumed that the very process of pigment formation by the conversion of tyrosine to dihydroxyphenylalanine and then to melanin is accompanied by the generation of large amounts of free oxygen radicals. For example, millimolar concentrations of hydrogen peroxide (H_2O_2) were found in the follicles of gray hair, which is enough to damage macromolecules, including catalase and methionine sulfoxide reductase, and thus impair antioxidant protection [14].

However, both hormonal mechanisms and oxidative stress cannot explain the heterogeneity of hair graying in different parts of the human body. In addition, there is still an unresolved question: what is the relationship between hair graying and the aging of the entire body.

One should look for an answer in the possible correlations between structural hair changes and age-dependent diseases. Some studies have demonstrated that premature graying may be correlated with indicators of cardiometabolic disorders, as well as with psycho-emotional stress [15, 16].

Despite considerable progress in the study of local mechanisms of hair graying, the research in this area is still in its infancy, and the systemic mechanisms remain unclear. In our opinion, it is important to focus on the possible suppression of melanogenesis by glucocorticoids when they are used locally or systemically, as well as when their blood levels increase under stress and aging. The mechanism of such suppression is already quite clear – it is a decrease in melanocortin production with melanogenic potential [11].

Suggestions are that hormones with anti-stressor action, especially melatonin [17], may be very useful for local or systemic counteraction to oxidative stress and antiproliferative effect of glucocorticoids.

Overview of Innovative Ingredients in Medicinal Cosmetics

Here is the consideration of the innovative ingredients that have gained a reputation in the cosmetics market.

Procapil™

Procapil™ is a highly effective complex to combat the main triggers of alopecia:

- low blood microcirculation in the scalp. Apigenin, a flavonoid and natural antioxidant in the complex, improves microcirculation;
- follicle atrophy caused by dihydrotestosterone (DHT) and follicle aging. Excess DHT attacks the hair follicle and causes alopecia. DHT, in turn, is formed under the influence of 5α-reductase. Oleanolic acid in the preparation is a powerful inhibitor of 5α-reductase enzyme, and Biotinoyl Tripeptide-1 stimulates cellular metabolism, strongly fixing the hair follicle.

SymReboot™ L19

SymReboot™ L19 is a unique complex of postbiotic (Lactobacillus Ferment) and prebiotic (Maltodextrin). This product contains treated bacteria with intact cell walls that mimic the action of probiotics to restore the skin's instinctive defense mechanisms. The primary functions of SymReboot™ L19:

- increased expression of antimicrobial peptides;
- increased expression of filaggrin to strengthen the skin's protective barrier;
- reduction of redness due to stress factors, including *Staphylococcus aureus*.

Actual and visible skin improvements from SymReboot™ L19:

- less dryness, improved appearance;
- enhanced protection against aggressive external effects, such as air pollution.

The complex is approved by leading European certification companies, including COSMOS and Vegan.

SymVital® MADA

SymVital® MADA is a ginger extract obtained in an environmentally sound area of Madagascar by supercritical CO_2 extraction. The main function of this product is to reduce the negative effects of blue light on human skin.

The development of new photoprotection principles is an urgent task in today's dermatocosmetology. It is believed that the main cause of skin damage and aging is the UV spectrum of the sun. Recently, however, scientists have been focusing more and more on the visible part of the spectrum. Visible light, long considered harmless and even healthy, can cause certain adverse changes in various organs and tissues (retinal cells, skin).

The visible light spectrum consists of seven colors: red, orange, yellow, green, cyan, blue and violet. The most prominent effect on the body comes from blue – high-energy visible light (HEV) with a wavelength of 400–500 nm. It can have both positive and negative effects, so it is the most important synchronizer of the circadian system. The exposure to such light during the day is important to inhibit the secretion of melatonin, which plays a crucial role in circadian rhythms. Besides, experts observe an acceleration of healing of wound surfaces, as well as a reduction of acne and psoriasis symptoms. At the same time, blue light can have adverse effects that are currently being thoroughly studied. So far, it is known to cause oxidative stress, which weakens the barrier functions of the epidermis and alters skin pigmentation related to the effect on opsin 3 receptors.

Recent studies show that HEV rays cause the breakdown of carotenoids, which are considered essential anti-oxidants to protect the skin from free radicals. The barrier function of the epidermis deteriorates and the skin becomes more susceptible to external effects and the first signs of aging.

SymVital® MADA is a strong antioxidant that counters the damaging effects of free radicals, thus protecting against photoaging, evens skin tone, improves its glow and reduces the negative effects of aggressive environmental factors.

We should note that all of the above substances, as well as other innovative ingredients, such as essential oils of medicinal plants, postbiotics and mushroom extracts, can also be obtained in the ECH conditions with a minimum of chemical utensils and equipment. A number of innovative cosmetic ingredients have already been successfully synthesized in the laboratory of the Biotechnology Bureau at Unitsky String Technologies Inc.

The Use of Medicinal Cosmetics in the EcoCosmoHouse

The ECH is a cosmic structure with an internal inhabited environment, isolated from the external aggressive outer space. An enclosed Earth-like ecosystem will be created inside the ECH including artificially derived gravity, living fertile soil, flora and fauna (as well as microflora and microfauna), atmosphere with regulated parameters (temperature, humidity, etc.) for unlimited long-term, autonomous, eco-comfortable living and activity of both individuals and their groups and many thousands of settlements on equatorial planet orbits, as well as in open near and deep space [18].

In the ECH, medicinal cosmetics should not only act as skincare or makeup, but also be a kind of preventive medicine, which averts not only negative changes in human appearance due to natural causes, but diseases of the skin and to some extent other organs due to the complex effect.

It is crucial to understand that when addressing acute skin and hair problems, cosmetics selected by a competent specialist (dermatovenerologist, trichologist) are the most important factors on the way to their solution along with a healthy diet that implies a full range of macro- and micronutrients, achieving energy balance, shifting the balance of fats towards the unsaturated ones, which must be at least 90 % in the human diet [19].

One of the most important constituents for skin hydration is hyaluronic acid. It is produced in optimal quantities up to the age of 25. Then the synthesis of hyaluronic acid slows down, and after 40 years the lack of hyaluronic acid makes it impossible for the body to synthesize collagen in the required amount, and the aging process gets irreversible. Accordingly, if there is not enough hyaluronic acid in the body, the first signs of aging appear: dry skin, wrinkles and dull complexion.

Ultraviolet radiation is one of the negative factors affecting the formation of hyaluronic acid. Under the influence of UV rays its cleavage happens faster, and the synthesis in the skin cells stops, so after a long stay in the sun the skin gets dry and dehydrated, and the aging process is accelerated.

Properly selected cosmetics (hyaluronic serums, day and night creams with UV filters) can offset the negative effects of the above factors.

We should also mention the cleansing process. Choosing the right product is an important matter, which will help maintain healthy skin at any age. All skincare products should be chosen by the consumer according to his/her skin type (normal, dry, oily, combination).

The anionic surfactant Sodium Laureth Sulfate is particularly popular in the cosmetics industry. Its prevalence is due to the low cost, high availability on the market and good foaming ability. However, this substance is suitable for oily skin types. For people with dry or combination skin, a cleanser with the above surfactant would cause a transepidermal dehydration (due to the destruction of the epidermis lipid layer), which would lead to dryness, flabbiness, peeling and fine lines. At the same time, choosing not to use facial cleansers or washing the skin of the face with toilet or laundry soap has no less (and often more) negative consequences.

Obtaining Natural Raw Materials in the EcoCosmoHouse Conditions

The definition of the ECH suggests that the living conditions in it will not be strikingly different from those on Earth, and therefore the rules and conclusions established in cosmetic practice are applicable in the ECH.

We will consider the delivery of cosmetic ingredients in detail.

The ECH assumes cultivation of medicinal herbs, fruit and berry plants, vegetable crops and mushrooms, which can be used to obtain extracts, hydrolates and essential oils. Thus, there is no need to deliver the active constituents from Earth. However, there is a need for transportation of texturing agents (foundations), which are difficult to synthesize at the early functioning stages of the ECH.

In addition, in conditions of enclosed ecosystems, it is possible to achieve high quality parameters of the obtained natural components due to the use of exclusively organic fertilizers.

In view of the above facts, we decided that it is advisable to have a minimum essential range of cosmetic products for the ECH residents (Table 1).

Production of Medicinal Cosmetics in the EcoCosmoHouse

In the ECH, most of the active constituents are supposed to be grown on local agricultural land. At the first stages, the texturing agents need to be delivered externally.

An area of 100–150 m^2 is enough to provide the ECH residents with cosmetics, the active constituents of which will be natural essential oils, extracts of medicinal plants and mushrooms. In this case, for growing certain types of crops (thyme, mint), a multilevel planting system can be used.

The main process equipment for the manufacture of cosmetic products consists of a reactor and scales.

As an example, we provide the formulations for the manufacture of two types of cosmetic products: facial cleansing gel and hand cream.

Facial Cleansing Gel Formulation

See Table 2 for the composition of the facial cleansing gel. Below are the manufacture steps for this cosmetic product:

1) heating phase A to 65 °C while stirring until a homogeneous texture is obtained;

2) alternate insertion of phases B, C into phase A;

3) pH correction (phase D);

4) injection of phase E while stirring;

5) injection of phase F to control viscosity of the product;

6) injection of the preservative (phase G).

Hand Cream Formulation

See Table 3 for the composition of the hand cream. Below are the manufacture steps for this cosmetic product:

1) mixing the components of phase A;

2) injection of phase B into phase A while stirring to a homogeneous texture;

3) heating phase C to 50 °C and injection into phases A + B;

4) injection of the preservative (phase D);

5) injection of the fragrance (phase E).

Table 1 – List of cosmetic products necessary for a resident of the ECH (calculation for the needs of one person per month)

Product	Weight, g	Functional purpose	Active constituents
Facial cleansing gel	50	Skin cleansing	Chamomile essential oil, vitamin B_5, comfrey extract
Face cream with UV filters	20	Skin moisturizing, protection against UV radiation	Postbiotic, probiotic, melissa extract, UV filters
Hand cream	70	Moisturizing, skin nutrition	Water-soluble olive oil, melissa extract, peppermint essential oil, St. John's wort extract
Shampoo	250	Cleansing hair and skin from contaminants and excessive sebum secretion	Water-soluble argan oil, melissa extract, lofanthus extract, panthenol
Shower gel	300	Skin cleansing	Water-soluble olive oil, St. John's wort extract, orange essential oil, postbiotic

Table 2 – Composition of the facial cleansing gel

Phase	Ingredient	Mass fraction, %	Functional purpose
A	Aqua	54.8	Solvent
	Sodium Cocoyl Isethionate	1.5	Surfactant
B	PEG-7 Glyceryl Cocoate	2	Emollient
	Cocamidopropyl Betaine	8	Surfactant
	Sodium Lauryl Glucose Carboxylate (and) Lauryl Glucoside	10	Surfactant
	Coco-Glucoside, Glyceryl Oleate	8	Enhancer
C	Acrylates/Beheneth-25 Methacrylate Copolymer	3	Texturing agent
D	Sodium Hydroxide	0.9	pH control agent
E	Disiloxane	5	Emollient
	Poloxamer 407	5	Surfactant
F	PEG/PPG-120/10 Trimethylolpropane Trioleate, Laureth-2	0.8	Texturing agent
G	Benzyl Alcohol, Ethylhexylglycerin, Tocopherol	1	Preservative

Table 3 – Composition of the hand cream

Phase	Ingredient	Mass fraction, %	Functional purpose
A	Aqua	91.8	Solvent
	Glycerin	3	Humectant
B	Sodium Polyacrylate	1	Stabilizer
C	Coco Caprylate/Caprate	3	Viscosity control agent
D	Benzyl Alcohol, Ethylhexylglycerin, Tocopherol	1	Preservative
E	Parfum	0.2	Fragrance

Conclusions and Future Work

Considering the above, the authors made a conclusion that the production of cosmetic products for the needs of the ECH residents can be deployed on its territory. This solution is feasible, since a large amount of the necessary raw materials will grow within the cosmic settlements, which in turn will cut the costs of their delivery from Earth.

As the main type of cosmetic products for the ECH residents, we have chosen medicinal skincare, which is a kind of preventive remedy, protecting the consumer not only from negative changes in appearance due to natural processes, but also from possible of skin diseases.

A list of cosmetic products, which should be provided to each resident of the ECH, is proposed.

As an example, we present our original formulations for the production of natural cosmetic products, based on the positive effects of individual constituents.

Thus, advanced cosmetics of various purposes can be obtained in the ECH: makeup, skincare and medicinal. Since there is no need for long-term storage before use (up to three days) there is an opportunity to avoid preservatives, which adversely affect the skin and hair. The use of organic raw materials will ensure high quality indicators of the cosmetic products and along with other environmental biotechnological solutions will allow the ECH residents to remain young with healthy skin and hair.

To study the impact of the cosmetic complex on the human body, in the future we plan to conduct experimental studies.

References

1. *Chouhan, N. Cosmetics Market by Category, Gender, and Distribution Channel: Global Opportunity Analysis and Industry Forecast, 2021–2027 [Electronic resource] / N. Chouhan, H. Vig, R. Deshmukh. – Mode of access: https://www.alliedmarketresearch.com/cosmetics-market. – Date of access: 11.07.2022.*
2. *Samuylova, L.V. Kosmeticheskaya khimiya [Cosmetic Chemistry] / L.V. Samuylova, T.V. Puchkova. – Moscow: Shkola kosmeticheskikh khimikov, 2005. – 11 p.*
3. *Unitsky, A.E. Lokalizatsiya ob"yektov promyshlennogo naznacheniya na krugovoy ekvatorial'noy okolozemnoy orbite [Localization of Industrial Facilities in Circular Equatorial Earth Orbit] / A.E. Unitsky, A.V. Kushnirenko, Ye.N. Kulik // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 230–245.*
4. *O bezopasnosti parfyumerno-kosmeticheskoy produktsii [On the Safety of Perfumes and Cosmetics]: TR CU 009/2011: Approved by the Decision of the Customs Union Commission of Sep. 23, 2011, No. 799. – Moscow, 2011.*
5. *O nekotorykh pravovykh aspektakh oborota kosmetiki lechebno-profilakticheskogo deystviya na farmatsevticheskom rynke [On Some Legal Aspects of the Circulation of Therapeutic and Prophylactic Cosmetics on the Pharmaceutical Market] / L.M. Kuzyakova [et al.] // Innovatsii i investitsii. – 2019. – No. 8. – P. 183–189.*
6. *Verner, M.S. Issledovaniye strukturnykh sdvigov potrebitel'skogo sprosa na rynke kosmeticheskikh produktov [Study of Structural Shifts in Consumer Demand on the Cosmetics Market]: Master's Diss.: 38.04.02, 38.04.02.06 / M.S. Verner. – Krasnoyarsk, 2018. – 74 p.*
7. *Color Atlas and Synopsis of Clinical Dermatology / T. Fitzpatrick [et al.]. – 3rd ed. – New York [et al.]: McGraw-Hill Education, 1997. – 885 p.*
8. *Skin Disease: Diagnosis and Treatment / T. Habif [et al.]. – 2nd ed. – Mosby, 2004. – 672 p.*
9. *Ivanov, O.L. Kozhnyye i venericheskiye bolezni [Skin and Sexually Transmitted Diseases] / O.L. Ivanov. – Moscow: Meditsina, 1997.*
10. *Kozhnyye i venericheskiye bolezni [Skin and Sexually Transmitted Diseases]: Guide for Doctors: in 2 vol. – 2nd ed., revised and supplemented. – Vol. 2 / ed. Yu.K. Skripkina, V.N. Mordovtseva. – Moscow: Meditsina, 1999. – 880 p.*
11. *Pigmentation in Mammalian Skin and Its Hormonal Regulation / A. Slominski [et al.] // Physiological Reviews. – 2004. – Vol. 84. – P. 1155–1228.*
12. *Trueb, R.M. Aging of Hair / R.M. Trueb // Journal of Cosmetic Dermatology. – 2005. – Vol. 4. – P. 60–72.*
13. *Sarin, K.Y. Aging, Graying and Loss of Melanocyte Stem Cells / K.Y. Sarin, S.E. Artandi // Stem Cell Reviews and Reports. – 2007. – Vol. 3. – P. 212–217.*
14. *The Redox-Biochemistry of Human Hair Pigmentation / K.U. Schallreuter [et al.] // Pigment Cell & Melanoma Research. – 2011. – Vol. 24. – P. 51–62.*
15. *Premature Hair Whitening Is an Independent Predictor of Carotid Intima-Media Thickness in Young and Middle-Aged Men / T. Endogan [et al.] // Internal Medicine. – 2013. – Vol. 52. – P. 29–36.*
16. *Association of Premature Hair Graying with Family History, Smoking and Obesity: A Cross-Sectional Study / H. Shin [et al.] // Journal of the American Academy of Dermatology. – 2015. – Vol. 72. – P. 321–327.*
17. *Prokhorov, L.Yu. Ontogenetic Role of Melatonin and Neuroactive Steroids as Antistress Hormones / L.Yu. Prokhorov, V.I. Goudochnikov // Gerontology. – 2014. – Vol. 2. – P. 157–170.*
18. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
19. *Zyl, N. Development of All-Inclusive Diet for the EcoCosmo-House Residents / N. Zyl, K. Shakhno // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 257–266.*

Innovative and Traditional Ways of Cooking and Preserving Natural Food in the EcoCosmoHouse

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The researches of recent years have been summarized in the field of modern optimal ways of food storage and cooking, which can be applied in the EcoCosmoHouse (ECH) conditions. An analysis has been made on drying methods that ensure maximum preservation of the nutritional and taste characteristics of products, as well as technologies for creating a gaseous environment for storing fruits in a controlled atmosphere and sous vide vacuum cooking technology.

Keywords: *dehydration, EcoCosmoHouse (ECH), new technologies, shelf life, sous vide cooking method.*

Introduction

According to the conclusion of experts from the World Health Organization, human health is approximately 50 % dependent on proper nutrition, the remaining 50 % is due to social factors, genetics, ecology, etc. In this regard, high quality, naturalness and usefulness of food are the main criteria for choosing products in the EcoCosmoHouse (ECH) [1].

Given the seasonality of fruit ripening and the need to maintain food security around the world, the question of preserving the crop before harvesting a new one is increasingly being raised. However, no matter how hard a person tries, some of the products inevitably deteriorate for various reasons. An essential role in this process belongs to microorganisms: bacteria and mold fungi. In addition, the shelf life of crop products is also affected by place of storage, its microclimate, as well as method of harvesting and delivery. Each of these factors is very important. According to the International Institute of Refrigeration, the total loss of all food products in the world is approximately 25 % of the total produced, including perishables – up to 20 % [2]. So, during mechanical harvesting, picking, digging out, transportation, shipment from bunker to storage and other operations performed by machines severely injure the fruits and compromise their integrity. In damaged vegetables or fruits putrefactive bacteria and other pathogens develop, which significantly reduces the potential shelf life.

In connection with the foregoing, the purpose of this work is to analyze modern methods of storing food products and preparing healthy meals for proper human nutrition in the ECH. Tasks: study of drying technologies, creation of a gaseous environment for storing fruits in a controlled atmosphere; choosing the optimal method for drying fruits, mushrooms and vegetables; analysis of methods of heat treatment of food; practical rationale for the benefits of using the sous vide technology for cooking products in the ECH.

Drying Technologies

As it is known, drying fruits and vegetables allows to eat them for a long time, while the taste of these products change slightly. Dried fruits are delicious, nutritious, lightweight, easy to cook, convenient to store and use. They are high in fiber, carbohydrates and low in fat, making them an important part of a healthy lifestyle [3].

The shelf life of products depends on the activity of water they contain – the higher it is, the faster they deteriorate. The value of this indicator in dried products is one of the lowest. Consequently, when drying fruits and vegetables, the likelihood of developing pathogenic microflora decreases.

Ways to extend shelf life and reduce food spoilage are constantly being improved. The achievements of recent years in the field of dehydration and the development of new drying methods make it possible to prepare a wide range of dehydrated products and semi-finished products from fruits and vegetables that meet the requirements of quality, stability and functionality, combined with cost-cutting [4].

Drying in the Sun

The sugar and acid found in fruits are considered natural preservatives, making the sun-drying process safe [5]. In vegetables, these substances are few, and this increases the risk of spoilage. Protein-rich meat is an ideal environment for microbial growth, especially when it is impossible to control the temperature and humidity of the ambient atmosphere.

Hot (from 30 °C) dry windy days are best suited for drying in the sun in the Earth conditions. The second important requirement for effective dehydration in the sun is air humidity (below 60 %). Such climatic parameters for several days in a row are not possible everywhere. Since the weather is uncontrollable, drying in the sun can be risky. In the southern regions, high humidity is a problem for high-quality dehydration. The complexity of controlling the indicators required for dehydration makes it necessary to look for alternative ways to preserve crop production [6].

In the ECH, it is possible to arrange orbital drying in the sun at certain combinations of temperature and airless parameters (different depths of air rarefaction, up to deep vacuum), but this direction requires separate studies that are beyond the scope of this work.

Drying in a Dehydrator

The dehydrator is a housing with a heating element, a fan and a temperature control sensor installed inside. The intensity of heating is regulated by the control panel. Pre-prepared (sliced) products – vegetables, fruits, mushrooms, herbs – are placed on mesh trays, allowing air to circulate freely between them. Most dehydrators are capable of maintaining temperatures within the range of 35–70 °C, which is quite enough to complete the existing tasks.

It has been experimentally established that drying at high temperatures (65–70 °C) is more efficient than at low ones (35–50 °C). Different products require individual factors for effective dehydration. Temperature of 45 °C is optimal for herbs, 55 °C – for fruits, 50 °C – for mushrooms, 65 °C – for meat. The dehydrator has a temperature control function, which leads to the expansion of the range of its application. The main problem with choosing the wrong temperature is over-dried foods that can only be consumed after soaking or preparing them as part of soups, sauces or stews.

Freeze Drying

Freeze drying is a more advanced and modern way of dehydration. Due to the high cost of the equipment used, it has only recently been widely used. The essence of the method is as follows: at low atmospheric pressure, water exists only in solid and gaseous states of matter (the triple point of water at a temperature of 0.01 °C and a pressure of 611 Pa); with these parameters, ice can be converted into vapor directly without converting it into liquid condition.

With this method of dehydration, the products are frozen and the ambient pressure begins to decrease. Under vacuum conditions, they are heated to 0 °C, which causes ice to evaporate, and all vitamins and other useful substances are preserved.

Freeze drying as a dehydration option is commonly used to extend the shelf life of perishable foods or to make them more convenient to transport; it is most in demand in the manufacture of medicines, starter cultures, extracts of medicinal plants, enzymes and other products, i.e., where it is necessary to save the greatest number of valuable properties for a long time.

Due to the minimum humidity (only up to 5 %), the finished product can be stored for a long time even at room temperature (up to 25 °C), which is extremely important for medicinal components of pharmaceutical drugs [7]. In the food industry, freeze drying not only allows to retain all the useful substances, aroma and taste of products for a long time, but also increases their shelf life up to five years even at varying temperatures within ±50 °C. It is also worthwhile to note the minimum volumetric shrinkage with this method of dehydration. In addition, the product is easily restored to its original structure by adding a small amount of water, as it acquires a porous structure during the sublimation process.

Osmotic Dehydration

The process of osmotic dehydration is the partial removal of water from plant products by immersing them for a certain time and at a certain temperature in concentrated aqueous

solutions containing salts and/or sugars and having high osmotic properties. As a result, water moves from a lower concentration of a dissolved substance to a higher concentration through a semipermeable membrane, leading to an equilibrium state on both sides of it.

Osmotic dehydration is a multicomponent diffusion process that includes three types of mass transfer phenomena:

1) outflow of water from the tissue cells of the product;

2) transfer of the dissolved substance from the osmotic solution to the product;

3) washing out of dissolved substances from the tissue cells of the product (vitamins, minerals, organic acids) into the osmotic solution.

The third process is quantitatively insignificant compared to the first two types of transfer, but it is decisive in relation to the composition of the product. Its driving force is the difference in osmotic pressure of solutions on both sides of semipermeable cell membranes.

Osmotic dehydration makes it possible to obtain a finished food product with high organoleptic properties and optimal energy value due to the partial removal of moisture [8]. Compared to other drying methods, this process is characterized by minimal damage to cell walls, thereby retaining nutrients in greater quantities.

Osmotic dehydration reduces the amount of water in the cells of the product, necessary for participation in chemical and biochemical reactions. Thus, the lower the mass fraction of water in the product, the lower the likelihood of microbiological growth on its surface [9].

Storage Chambers with Controlled Gas Content

Fruits and vegetables continue to breathe after being harvested, i.e., they absorb oxygen (O_2) and release carbon dioxide (CO_2). Over time, this leads to a deterioration in their quality (withering, spots, etc.).

In order to reduce the intensity of respiration, one usually tries to keep the crop in a cold place. However, lowering the ambient temperature is not always enough to keep food fresh and extend its shelf life. The most effective is the combination of methods: controlling the ambient temperature, minimizing the level of O_2 and increasing the content of CO_2 in the chamber.

The process of fruit oxidation slows down with a decrease in the concentration of O_2, but up to a certain limit, below which the anaerobic respiration of microorganisms resumes. Therefore, it is necessary to maintain a low content of O_2, the amount of which is individual for each type of product.

The sucrose found in fruits is gradually converted into fructose. In chambers with a high CO_2 content, this process slows down, which allows the fruits to retain its firmness and attractive appearance for a longer period.

According to studies, storage in a controlled atmosphere leads to a drop in the intensity of metabolic processes by 2–3 times, radically prolonging the shelf life [10]. Another advantage of this technology is the reduction in the development of physiological and fungal diseases (by 20–25 %). The wilting period of apples, for example, increases by 20–30 %. Due to the slowdown of dissimilation processes, the fruits have the original quality of the components (aromatic substances, acid, sugar, etc.). At the end of the shelf life, fruits remain as tasty and fresh as at the beginning.

There are several types of controlled atmosphere in storage chambers:

1) traditional controlled atmosphere (TCA): 3–4 % of O_2, 3–5 % of CO_2. Chambers are loaded over 7–10 days; the required gas concentration should be reached within 2–3 weeks. The recommended temperature ranges within 0–3.5 °C;

2) with low oxygen (LO) content: 2–2.5 % of O_2, 1–3 % of CO_2;

3) with ultra-low oxygen (ULO) content: less than 1–1.5 % of O_2, 0–2 % of CO_2 (sometimes higher). These values depend on the variety of vegetables and fruits, growing area, degree of ripeness and other factors. Chambers should be loaded with products as quickly as possible.

There are the following technologies for creating a gaseous environment and storing fruits in a controlled atmosphere:

- RCA (rapid controlled atmosphere) – fast decrease in oxygen concentration;
- ILOS (initial low oxygen stress) – ultra-fast decrease in the oxygen level in the chamber over a short period of time;
- LECA (low ethylene controlled atmosphere) – decrease in the level of ethylene in the chamber;
- CO_2 shock treatment – exposure to an atmosphere with a high content of CO_2 (up to 30 %);
- DCA (dynamic controlled atmosphere) – maintaining the storage mode depending on the physiological state of the fruit [11].

The choice of technology is determined by the type of product, shelf life and the set technological tasks.

Table 1 compares the technologies for drying and storing horticultural products [12].

Table 1 – Comparative analysis of drying and storage technologies for horticultural products

Method	Advantages	Disadvantages
Drying in the sun (in natural conditions)	Economic efficiency	Uneven drying Low drying speed Dependence on weather conditions
Drying in a dehydrator	Temperature control Air flow uniformity	Limited volume of the dehydrator, which affects the quantitative yield of the product per unit of time
Freeze Drying	Preservation of aromatic substances and taste qualities of the product for up to five years Extending the shelf life of a perishable product Convenient product transportation Minimum product shrinkage Use for preservation of lactobacilli, microorganisms and biologics	Expensive equipment in the Earth conditions
Osmotic dehydration	Slight damage to the cell walls of the food product Preservation of a large number of nutrients	The need to select osmotic agent, its concentration and immersion time for each type of product
Storage chambers with controlled gas content	Reduction of the intensity of metabolic processes by 2–3 times Preservation of firmness and attractive appearance of fruits for a longer period Reducing the development of physiological and fungal diseases	Large and expensive equipment in the Earth conditions, designed for large volumes of processed raw materials

Sous Vide Cooking

In the catering market, the search for solutions to improve the quality and consumer properties of products does not stop. Not only organoleptic, but also physico-chemical and microbiological indicators are compared and studied, likewise the presence of toxic elements in the studied samples. Providing high-quality, healthy and safe products is one of the priority tasks for arranging a healthy diet for the ECH residents.

In conditions of market competition, subject to the pace of living of a modern person, manufacturers constantly have to introduce various innovations and streamline operations, look for ways and methods to reduce costs and at the same time comply with the requirements of international documents for food quality and safety in order to make it possible to reach a new level and increase sales [13].

One of these innovative ways is cooking meat and vegetables in vacuum packaging mainly in a water bath using sous vide technology, which allows preserving useful properties during heat treatment, reduce technological losses and minimize the consumption of energy and labor resources per unit of product. Gentle heat treatment of raw materials ensures uniform heating, preservation of not only the organoleptic characteristics of the product, but also its high biological and nutritional value [14]. The dish is prepared from the raw state in a vacuum bag at relatively low temperatures (50–80 °C). If the temperature inside the product does not exceed 68 °C, its cells retain the ability to keep liquid, which means that it does not lose juiciness.

The process takes longer than with other heat treatment methods, but the cooking temperature is much lower. An additional advantage is that the product cooks evenly in its own juice and does not come into contact with the medium

(water, oil), which contributes to the preservation of a uniform consistency, rich taste and all nutrients.

When preparing various dishes with this method, it is necessary to constantly monitor the temperature with an accuracy of 1 °C. Such strict control should begin at the stage of raw materials selection and continue until the end of the process in order to exclude the growth of pathogenic microflora, which will be destroyed during prolonged heating and temperatures close to the pasteurization temperature (65–80 °C) [15].

Advantages of vacuum packaging [16]:

- allows heat to be efficiently transferred from water (steam) to food;
- prevents aftertastes from oxidation;
- prevents losses due to evaporation of volatile aromatic substances and moisture during cooking;
- reduces the growth of aerobic bacteria;
- makes it possible to easily store prepared food in the refrigerator or freezer for later use – directly in the vacuum bag.

Vacuum packaging helps to extend the shelf life of products, and without the use of additives, which facilitates the work of housewives and is in demand at catering enterprises, for which the shelf life of the goods and, accordingly, the time of its sales play an important role in competitiveness.

To confirm the above, the following experiment was carried out: chicken fillet of the 1st category weighing (200 ± 10) g was subjected to heat treatment in three ways:

1) baking in an oven at a temperature of 200 °C for 25 min in food-grade aluminum foil;

2) cooking in salted water with spices for 40 min;

3) cooking in a vacuum bag in a thermostat at a temperature of 60 °C for 50 min.

During the study, standard physico-chemical and organoleptic methods were used. For all cooking methods, the same set of spices and extra virgin olive oil were used.

The original chicken fillet samples are shown in Figure 1.

Samples of chicken breast after heat treatment are shown in Figure 2.

a) b) c)

Figure 1 – Raw chicken fillet before heat treatment:
a – for baking in food-grade foil; b – for boiling in salted water with spices; c – for cooking in a vacuum bag using sous vide technology

a) b) c)

Figure 2 – Chicken fillet after heat treatment:
a – baked in food-grade foil; b – boiled in salted water with spices; c – cooked in a vacuum bag using sous vide technology

In order to record the difference in taste over time, organoleptic parameters were studied for three days. A taste panel of 10 people evaluated the chicken fillet according to a standard 9-point scale (Table 2).

The "juiciness" indicator was additionally checked using the ML-50 Moisture Analyzer. The results are shown in Table 3.

In a similar way, studies of the heat treatment of vegetables were carried out as in the case of young carrots:

1) baked in food-grade foil for 50 min in an oven at a temperature of 220 °C;

2) boiled for 60 min in salted water at low boiling;

3) cooked for 50 min in a vacuum bag in a thermostat at a temperature of 80 °C.

The results of heat treatment of carrots are shown in Figure 3.

Data on the evaluation of the experiment with carrots are given in Table 4.

The taste panel gave the highest scores for organoleptic indicators to chicken meat and carrots cooked in a vacuum bag using the sous vide method. Three days later,

Table 2 – Evaluation of the organoleptic indicators of the chicken fillet cooked in different ways

Indicator	Average score, points		
	Baking in an oven	Cooking in salted water with spices	Sous vide cooking
Juiciness	7	5	9
Taste, color, smell	8	4	9
Chewy texture (softness)	8	4	9

Table 3 – Moisture of the chicken fillet cooked in different ways

Indicator	Baking in an oven	Cooking in salted water with spices	Sous vide cooking
Moisture, %	65.6	67.4	70

a) b) c)

Figure 3 – Carrots after heat treatment:
a – baked in food-grade foil; b – boiled in salted water; c – cooked in a vacuum bag using the sous vide method

Table 4 – Evaluation of the organoleptic characteristics of carrots cooked in different ways

Indicator	Average score, points		
	Baking in an oven	Cooking in salted water	Sous vide cooking
Taste	7	4	9
Color, smell	8	6	9

he products did not lose their juiciness and other important characteristics.

The sous vide technology is available not only for catering establishments and the food industry, but can also be used in everyday home cooking, including the ECH. The market offers a lot of sous vide units (submersible and stationary) and related products, such as household vacuum sealers [14].

Conclusions

Today, everyone has access to modern technologies for preserving the harvest and extending the shelf life of horticultural products with minimal time spent and with maximum conservation of nutrients.

Given the lack of free time an urbanized person has, scientific developments make the cooking process brief, and dishes varied and healthy, which is very important for the health and vitality of people, including those in the ECH. The household dehydrator is designed for quick drying of various products, such as greenery, berries, fruits, mushrooms, meat, and allows any family to provide themselves with procurements. One of the ways of heat treatment of food products with maximum preservation of organoleptic characteristics is the sous vide technology, which is confirmed by the results of the experiments. To date, household sous vide systems have also been developed, which are small-sized and easy to use, functional and will allow residents of the ECH to cook all kinds of delicious dishes on their own.

References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Genel', L.S. Uvelicheniye sroka khraneniya pishchevoy produktsii [Increasing the Shelf Life of Food Products] / L.S. Genel', M.L. Galkin // Pishchevaya industriya. – 2017. – No. 3 (33). – P. 34–36.*
3. *Zimenkova, F.N. Pitaniye i zdorov'ye [Nutrition and Health]: Study Guide / F.N. Zimenkova. – Moscow: Prometey, 2016. – 168 p.*
4. *Glukhov, Ye.I. K voprosu o sushke produktov [To the Question of Drying Products] / Ye.I. Glukhov // Pishchevyye innovatsii i biotekhnologii: Collection of Abstracts of the IX International Scientific Conference of Students, Graduate Students and Young Scientists Within the Framework of the III International Symposium "Innovations in Food Biotechnology", Kemerovo, May 17–19, 2021: in 2 vol. / Kemerovo State University; ed. A.Yu. Prosekov. – Kemerovo: KemGU, 2021. – Vol. 2. – P. 94–95.*
5. *Effect of Air-Drying Temperature on Physico-Chemical Properties, Antioxidant Capacity, Colour and Total Phenolic Content of Red Pepper (Capsicum annuum, L. var. Hungarian) / A. Vega-Gálvez [et al.] // Food Chemistry. – 2009. – Vol. 117, No. 4. – P. 647–653.*
6. *Ispol'zovaniye kontsentrirovannoy solnechnoy energii dlya sushki plodovo-yagodnogo syr'ya [The Use of Concentrated Solar Energy for Drying Fruit and Berry Raw Materials] / Z.A. Isayev [et al.] // Sovremennyye tekhnologii i dostizheniya nauki v APK: Collection of Scientific Papers of the All-Russia Scientific and Practical Conference, Makhachkala, Nov. 22–23, 2018. – Makhachkala: FGBOU VO Dagestanskiy GAU, 2018. – P. 201–204.*
7. *Wanning, S. Pharmaceutical Spray Freeze Drying / S. Wanning, R. Süverkrüp, A. Lamprecht // International Journal of Pharmaceutics. – 2015. – Vol. 488, No. 1–2. – P. 136–153.*
8. *Different Drying Methods: Their Applications and Recent Advances / N. Ahmed [et al.] // International Journal of Food Nutrition and Safety. – 2013. – Vol. 4, No. 1. – P. 34–42.*
9. *Issledovaniye protsessov sublimatsionnoy sushki yagod [Study of the Processes of Freeze Drying of Berries] / V.A. Yermolayev [et al.] // Tekhnika i tekhnologiya pishchevykh proizvodstv. – 2011. – No. 1 (20). – P. 67–70.*
10. *Semonov, P.N. Khraneniye plodov i ovoshchey v reguliruyemoy gazovoy srede [Storage of Fruits and Vegetables in a Controlled Gas Environment] // Dostizheniya nauki – sel'skomu khozyaystvu: Materials of the All-Russia Scientific and Practical Conference, Vladikavkaz, Oct. 2–3, 2017. – Vladikavkaz: FGBOU VO GGAU, 2017. – Vol. I, pt. I. – P. 235–238.*
11. *Petrov, Ye.T. Osobennosti eksperimental'nogo i predproyektnogo issledovaniya kamer fruktoovoshchekhranilishch s reguliruyemoy gazovoy sredoy [Features of Experimental and Pre-Project Study of Fruit and Vegetable Storage Chambers with Controlled Gas Environment] / Ye.T. Petrov, A.A. Kruglov, A.F. Opalikhin // Vestnik Mezhdunarodnoy akademii kholoda. – 2016. – No. 3. – P. 62–67.*
12. *Shkarupa, I.L. Keramicheskiy vysokotemperaturnyy reaktor na bystrykh neytronakh [Ceramic High-Temperature Fast Neutron Reactor] / I.L. Shkarupa, A.K. Khmel'nitskiy, M.I. Shkarupa // Science and World. – 2022. – Vol. II, No. 4 (104). – P. 50–58.*
13. *Stryapikhin, N. Tekhnologiya su-vid: v chom opasnost' i unikal'nost? [Sous Vide Technology: What Is the Danger and Uniqueness?] // Myasnyye tekhnologii. – 2018. – No. 8 (188). – P. 24–25.*
14. *Meretukova, F.N. Issledovaniye pokazateley kachestva polufabrikatov iz myasa indeyki, prigotovlennykh po tekhnologii su-vid [The Study of Quality Indicators of Semi-Finished Products from Turkey Meat Prepared Using Sous Vide Technology] / F.N. Meretukova, N.V. Abregova // Novyye tekhnologii. – 2021. – Vol. 17, No. 2. – P. 48–55.*
15. *Karpenko, Yu.V. Otsenka pokazateley kachestva i bezopasnosti rybnoy produktsii, poluchennoy po tekhnologii sous vide (su-vid) [Assessment of Quality and Safety Indicators of Fish Products Obtained Using Sous Vide Technology] / Yu.V. Karpenko, Ye.M. Panchishina, V.A. Skal'skaya // Nauchnyye trudy Dal'rybvtuza. – 2019. – No. 2. – P. 52–61.*
16. *Pokrovskiy, G.D. Su-vid – innovatsionnaya tekhnologiya na predpriyatiyakh obshchestvennogo pitaniya [Sous Vide is Innovative Technology at Public Catering Enterprises] / G.D. Pokrovskiy // Konkurentosposobnost' territoriy: Materials of the XXII All-Russia Economic Forum of Young Scientists and Students, Ekaterinburg, Apr. 22–26, 2019: in 5 pt. / resp. for issue Ya.P. Silin, Ye.B. Dvoryadkina. – Ekaterinburg: UrGEU, 2019. – Pt. 1. – P. 215–217.*

Quantitative Assessment of the Carbon Balance of Autotrophic and Heterotrophic Communities in the Enclosed Ecosystem Prototype

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Factors have been analyzed, which influence the existence of autotrophs and heterotrophs, the role of humus in maintaining the stability of the soil ecosystem has been manifested. The carbon balance data obtained during the experiment on the creation of an enclosed ecosystem have been given, similarly an estimate has been provided for the dynamics of concentration of carbon dioxide from the moment of formation of the ecosystem to the steady gas continuity.

Keywords: *carbon balance, circulation of elements, CO_2 emission, EcoCosmoHouse (ECH), ecosystem metabolism, enclosed ecosystem, photosynthetically active radiation (PAR).*

Introduction

Currently, due to the rise in the number of global environmental problems, serious attention has been paid to the issues of the biosphere (the extinction of species, climate change, depletion of natural resources) and its constituent ecosystems. A large amount of data on the structure of ecosystems has been accumulated, however, little is known so far about the processes that conduct and regulate the substances, energy and information exchange in them, as well as about the homeostasis maintaining principles. There is a clear lack of a reliable theoretical base and practical skills for closing natural cycles in ecosystems (for example, the carbon cycle under the EcoCosmo-House (ECH) conditions). To solve this problem, a significant role is given to the study of biospheric processes based on the construction of equivalents of biogeocenoses [1]. In connection with the above, on October 11, 2021, the authors created a small enclosed ecosystem for practical research aimed at meeting the needs of the ECH.

Any ecosystem is maintained in a stable state due to its metabolism – a cyclic functioning mechanism, which consists of two oppositely directed processes: anabolism (synthesis of biomass from mineral elements) and catabolism (destruction of dead organic matter down to mineral elements). The function of anabolism is mainly performed by phytocenosis, while that of catabolism – by pedocenosis. The symbiosis of the components forms a system of mutual life sustenance.

In enclosed ecosystems, the circulation of elements must be arranged in such a way that substances used by some links at a certain rate are regenerated by other links at the same average rate from the end products of their metabolism to the initial state, and then reused. The ECH assumes a directed human impact on biological processes to maintain them in an optimal state.

Such an equilibrium principle is applicable not only to the circulation of biogenic elements (carbon, nitrogen, phosphorus, etc.), but also to the dynamics of populations. The number of individuals in a population, its density, relationships, duration of ontogeny are the most important factors in the existence of ecosystems. It is rather difficult to control and take into account these parameters for all organisms in an enclosed ecosystem, therefore, first of all, one should focus on the dominant species, which carry out the main work on the transformation of substances and energy in the system. These encompass representatives of different trophic groups, which include a larger portion of energy and matter in the turnover cycles of generations. In the process of life, these species perform the most significant transformations of the environment and are characterized by wide ranges of environmental tolerance to many factors.

Influence of Environmental Factors on the Stability of Enclosed Ecosystems

Since there is a need to choose the optimal parameters for an enclosed ecosystem, it is necessary to provide a general concept of the term "stability". In literature, authors interpret it differently [2, 3]. A number of researchers believe that any ecosystems are stable already by virtue of the very fact of their existence, others consider those in which there are no obvious evolutionary changes to be stable. Many ecosystems during their developmental stages are characterized by the absence of a stationary state, and even the final stage of succession (climax) is distinguished by changes [4]. In this context, it seems most correct to consider stability as a characteristic of a long-term dynamic balance of key biogenic elements.

The stability of ecosystems is largely determined by abiotic factors too. The species composition, magnitude and functional relationships of different groups of soil animals may change during the growing season. Depending on the climatic conditions, the key functional parameters of pedocenosis vary, such as the intensity of the input and destruction of organic substances, the composition of the microbial community. It is assumed that these changes also impact the trophic relationships of soil microbiophage animals. In addition, changes in temperature and humidity determine the life cycles of soil animals and their behavior.

Numerous works of domestic and foreign experts prove the important role of humic substances (Figure 1) in supporting the homeostasis of ecosystems [5–7]. The uniqueness of biopolymers of humic origin, peculiarities of structural organization, biological activity and forms of occurrence in nature determine their global role in maintaining the homeostasis of soil communities. The main form of organic matter in humus is soluble compounds that act as a buffer system responsible for the accumulation and bioavailability of organic and inorganic substances for plant and animal organisms.

In addition, humic acids form chelates with macronutrients [8]. The high mobility and reactivity of fulvic acids promote interaction with microelements (mainly with metals

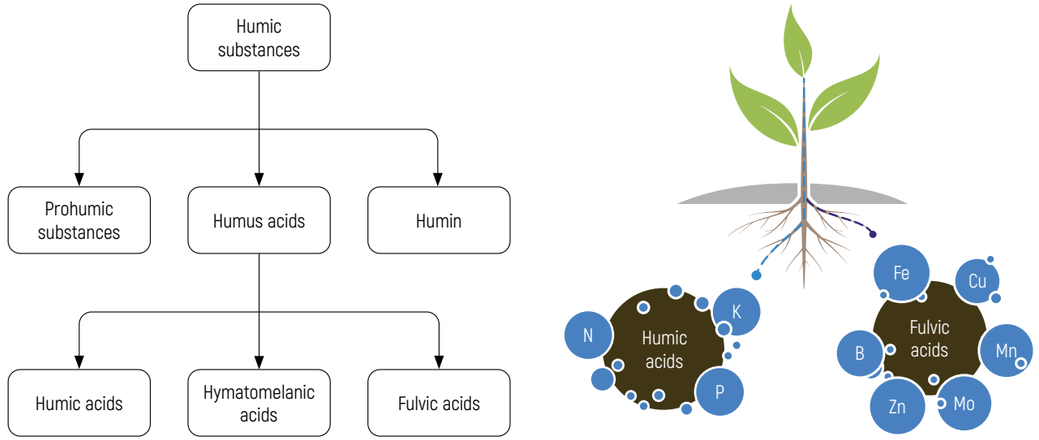

Figure 1 – Classification of humic substances

and their ions), resulting in the formed chelates of these acids delivering essential microelements to plants.

The biogenic circulation of substances and chemical elements between the soil, plants, animals and microorganisms ensures the maintenance of the ecosystem balance and is determined by climate, geography features, type of plant habitat and ontogeny. Conclusions can be drawn about the success of carbon and nitrogen cycles based on the study of the dynamics of the gas composition of the ecosystem and the analysis of soils for microelement composition (CO_2 fluctuations within the range of 350–1,000 ppm; N_2O – 300–400 ppb; CH_4 – 2,000–3,000 ppb). One should also take into account the close connection of the oxygen cycle with the carbon and nitrogen cycles. Oxygen is used by bacteria in the following nitrification reactions [9]:

$$2NH_3 + 3O_2 \rightarrow 2HNO_2 + 2H_2O + E;$$
$$2HNO_2 + O_2 \rightarrow 2HNO_3 + E.$$

Influence of Autotrophs on the Formation of Ecosystems

Autotrophs are the main producer organisms that synthesize organic substances using light energy. Their number and diversity should be as high as possible in the ecosystem. Calculation of the required quantity of autotrophs is carried out depending on the flows of energy consumption in the ecosystem, as well as the volume and intensity of metabolism of consumers.

Plants are the base that determines the selection of the components of the animal community (soil microorganisms and consumer animals). The number of individuals in populations of animals and plants in enclosed ecosystems is in dynamics (these fluctuations will be minimal in a successful ecosystem), and the main task is to control their number within the given allowable limits. The range of fluctuations depends on the birth rate and mortality, population density, structure and dynamics. In addition, to control the population, it is worth considering intraspecific and interspecific interactions of organisms (competition, predation, symbiosis), as well as survival rate, age structure and type of population growth. Graphically they take the form of a uniformly increasing straight line (natural increase in the number of individuals) with sharp declines (high mortality at the time of reaching the age limit) and a subsequent uniform increase. Such a period ends with reaching a stability plateau.

In enclosed ecosystems that have a complex structure and function under stable environmental conditions, population control is carried out mainly by internal mechanisms, i.e., factors that primarily depend on population density.

When choosing a climate, it is worth considering the purpose of an enclosed ecosystem. For a comfortable balanced existence of a large number of species that ensure its stable state, one should consider the subtropical or subequatorial climate, since it is in these areas that the greatest

biodiversity is observed, and they are well suited for humans. Therefore, abiotic factors in an enclosed ecosystem can be regulated by maintaining the temperature in summer at 21–25 °C, in winter – 15–18 °C and humidity in the range of 60–85 %. These parameters, along with illumination, wind strength and hydrological regime, should be controlled and varied depending on the needs of the ecosystem – until a state of stable rest occurs.

The Role of Carbon Balance in Maintaining the Stability of an Enclosed Ecosystem

In natural ecosystems, the carbon balance is closely related to the CO_2 cycle and is concertedly regulated in the process of ecosystem metabolism, when dead biomass (necromass) undergoes mineralization from soil biota. Mineralization products in the form of gases, solutions and colloids are used by phytocenosis in the process of photosynthesis carried out by new biomass. Gases are absorbed by leaves, solutions – by roots, and colloids are deposited in the soil mass. Mineral elements that were not demanded by phytocenosis interact with organic radicals of decaying necromass, forming soil humus under the action of agronomically valuable microorganisms, which is a strategic reserve of mineral nutrition elements. Phytocenosis releases oxygen, which is necessary for pedocenosis to oxidize dead biomass, as a by-product of the respiration process. The exchange of waste products between plants and soil ensures stability of the air composition, partners are relieved from energy expenditure for the search and extraction of nutrient resources. This mutually beneficial cooperation contains the main meaning of combining diverse biota into a single ecosystem, which must be taken into account when creating an equivalent of natural biogeocenosis.

For the practical study of the described processes with the aim of subsequent construction of large-volume enclosed systems (for example, the ECH in the orbit of the planet Earth [10]), in October 2021, the authors created an enclosed ecosystem with auto- and heterotrophic communities (Figure 2).

"Space" potting soil was chosen as a substrate of the enclosed ecosystem, being lightweight fertile soil uTerra, developed by Unitsky String Technologies Inc. in the course of scientific research in 2019–2022. Pre-sterilized stones were added to collect condensed moisture. The substrate also contains soil algae, nitrogen-fixing bacteria and haircap moss. Undersized white clover was chosen as the main producer. This choice is due to the fact that clover is an important commercial leguminous crop, and is also able to self-pollinate due to the special arrangement of stamens relative to the pistil.

The animal component amounted to 10 woodlice (*Porcellio scaber* Latreille) and 10 red Californian worms (*Eisenia fetida*). To increase the bioavailability of inorganic elements, 5 ml of humic substances were added (the content of humic acids – 20 %).

The abiotic parameters for the enclosed ecosystem were selected from the point of view of the comfort of the organisms inhabiting it (similar conditions are planned to be

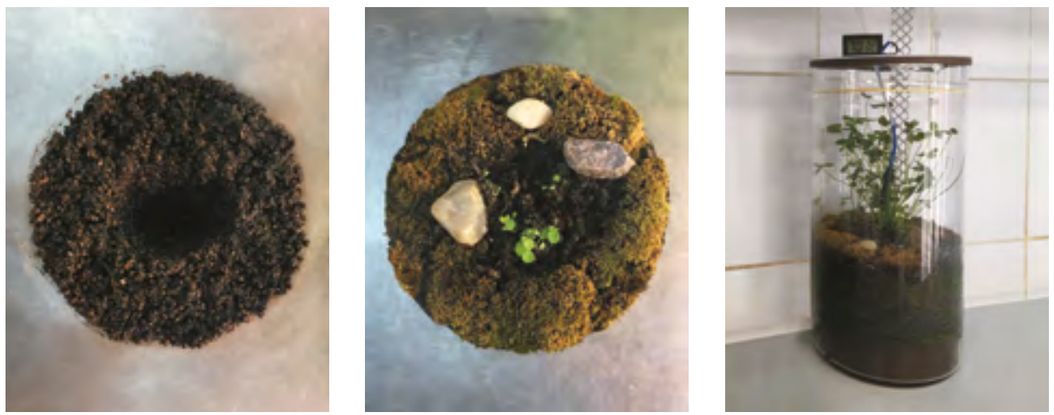

Figure 2 – Creation of an enclosed ecosystem

created in the ECH [11]): air temperature of 21–25 °C, humidity from 60 %, light day of 14 h, illumination level in the range of 200–300 μmol/s/m^2. The control of temperature and humidity inside and outside the ecosystem was carried out by two thermohygrometers. For the possibility of thermoregulation within the ecosystem, a plate of thermally conductive metal (aluminum) was hermetically installed in the lid. Illumination level was controlled by the quantometer Skye (light wave range of 400–700 nm, measurement error of maximum 1 %). The CO_2 concentration was measured through tubes hermetically installed in the lid (Figure 3), to which the gas analyzer was connected.

The air from the enclosed ecosystem was hermetically supplied to a non-dispersive infrared gas analyzer LI-COR LI-820 (measurement range of 0–20,000 ppm, maximum error of 3 %) and was also hermetically returned to the ecosystem. The CO_2 concentration was recorded every 5 s, the measurements were carried out while maintaining the temperature and illumination level in the range determined for the ECH. Since the formation of carbon dioxide at the initial stages of the existence of an ecosystem should be much greater than its consumption, ventilation was provided between measurements of the CO_2 emission rate.

At the very beginning of the study, CO_2 emission (Figure 4) was distinguished by a high rate (7,876 ppm/h), which is explained by the lack of the required number of plants as the main consumer of carbon dioxide.

Figure 3 – Measurement of CO_2 concentration in the enclosed ecosystem

As the crops grew, the flow rate of CO_2 naturally decreased to 6,216 ppm/h in November and 6,339 ppm/h in December 2021. Despite this decrease, it is significant and several times higher than natural indicators. From January 2022 carbon dioxide flow rate stabilized (Figure 5) and made 1,732 ppm/h in January and 1,712 ppm/h in February.

In March, the CO_2 emission rate continued to decrease (to 1,321 ppm/h), however, the concentration of carbon dioxide did not reach an equilibrium plateau until April (Figure 6).

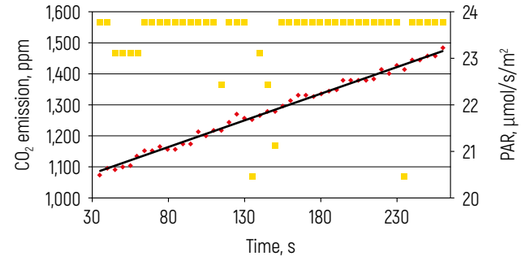

Figure 4 – CO_2 flow rate (shown in red) and photosynthetically active radiation (PAR) (shown in yellow) on October 11, 2021

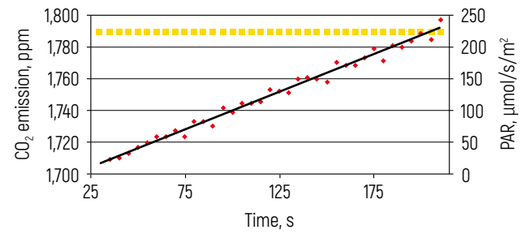

Figure 5 – CO_2 flow rate (shown in red) and PAR (shown in yellow) on February 7, 2022

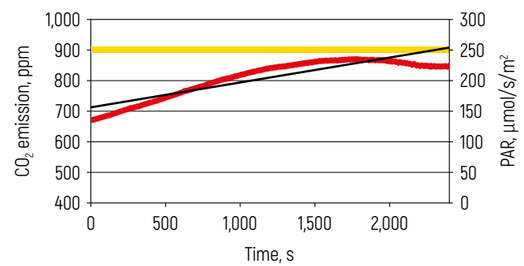

Figure 6 – CO_2 flow rate (shown in red) and PAR (shown in yellow) on April 11, 2022

The relatively low rate of emission in April (289 ppm/h) was for the first time replaced by absorption of CO_2 (Figure 7) in June (–293 ppm/h).

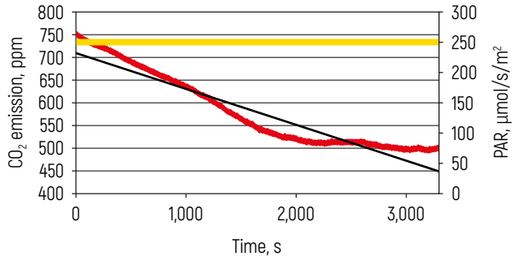

Figure 7 – CO_2 flow rate (shown in red) and PAR (shown in yellow) on June 13, 2022

Conclusions and Future Work

During the existence of the enclosed ecosystem, its gas composition has undergone significant changes and relatively stabilized after six months. At the moment, it is in a stable state in terms of the rate of emission and consumption of CO_2.

Woodlice and worms inhabiting the ecosystem survived, however, because of the small living space, interspecific competition occurred, where woodlice dominate, which is expressed in their constant large number (about 60) and a gradual decrease in the number of worms. Despite the favorable environment for the development of moss, it was noted that an increased number of woodlice inhibits its growth. The selected abiotic conditions are suitable for the study and satisfy all the needs of the biota inhabiting the ecosystem.

In the course of the experiment, the timeframe for achieving the gas balance of CO_2 of a certain volume under controlled conditions (while maintaining the vital activity of all components of the ecosystem) was established, which in a practical manner confirms the correctness of the choice of abiotic parameters and makes it possible to predict the periods of biological filling-up of the ECH.

Woodlice and worms survive at extremely high concentrations of carbon dioxide during the initial stages of the study. The readings of CO_2 dynamics at all stages of the white clover growth makes it possible to record and control this vital indicator at any time without resorting to constant measurements. A vector of interspecies interaction (woodlice and worms) under specific conditions has been identified, which makes it possible to determine the required number of these species, being pivotal for the soil well-being.

The experiment is planned to be continued; in the future, a shift in the established balance is expected during the emergence period of new white clover plants.

References

1. *Degermendzhi, A.G. Sozdaniye iskusstvennykh zamknutykh ekosistem zemnogo i kosmicheskogo naznacheniya [Creation of Artificial Enclosed Ecosystems of the Terrestrial and Space Purpose] / A.G. Degermendzhi, A.A. Tikhomirov // Vestnik Rossiyskoy akademii nauk. – 2014. – Vol. 84, No. 3. – P. 233–240.*
2. *Van Meerbeek, K. Unifying the Concepts of Stability and Resilience in Ecology / K. Van Meerbeek, T. Jucker, J.-C. Svenning // Journal of Ecology. – 2021. – Vol. 109, No. 9. – P. 3114–3132.*
3. *Holling, C.S. Resilience and Stability of Ecological Systems / C.S. Holling // Annual Review of Ecology and Systematics. – 1973. – Vol. 4. – P. 1–23.*
4. *Smirnova, O.V. Suktsessiya i klimaks kak ekosistemnyy protsess [Succession and Climax as an Ecosystem Process] / O.V. Smirnova, N.A. Toropova // Uspekhi sovremennoy biologii. – 2008. – Vol. 128, No. 2. – P. 129–144.*
5. *Guminovyye veshchestva kak regulyatory ekologicheskogo gomeostaza [Humic Substances as Regulators of Ecological Homeostasis] / N.P. Avvakumov [et al.] // Izvestiya Samarskogo nauchnogo tsentra Rossiyskoy akademii nauk. – 2016. – Vol. 18, No. 2 (2). – P. 267–271.*
6. *Popova, N.V. Metody ispol'zovaniya dannykh po skorosti osvobozhdeniya khimicheskikh elementov iz podstilki dlya diagnostiki ustoychivosti ekosistem [Methods of Using Data on the Rate of Release of Chemical Elements from the Substrate for Diagnosing the Stability of Ecosystems] / N.V. Popova // Vestnik RUDN. Seriya: Ekologiya i bezopasnost' zhiznedeyatel'nosti. – 2007. – No. 1. – P. 19–26.*
7. *Humic Substances: Structure, Function and Benefits for Agro-Ecosystem: A Review / J. Tiwari [et al.] // Pedosphere. – 2022.*
8. *Larionov, Yu.S. Rol' ugleroda i krugovoroty na yego osnove kak predposylki sovershenstvovaniya sistemy monitoringa plodorodiya pochv [The Role of Carbon and Cycles Based on It as Prerequisites for Improving the Soil Fertility Monitoring System] / Yu.S. Larionov // Interekspo Geo-Sibir'. – 2019. – Vol. 4, No. 2. – P. 124–134.*
9. *Microbial Ecology of the Closed Artificial Ecosystem MELiSSA (Micro-Ecological Life Support System Alternative): Reinventing and Compartmentalizing the Earth's Food and Oxygen Regeneration System for Long-Haul Space Exploration Missions / L. Hendrickx [et al.] // Research in Microbiology. – 2006. – Vol. 157, No. 1. – P. 77–86.*
10. *Review of Possible Structural Solutions of the EcoCosmoHouse Facility on the Planet Earth / A. Unitsky [et al.] // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 169–177.*
11. *Unitsky, A. EcoCosmoHouse as a Space for the Conservation of Species Diversity of Tropical and Subtropical Flora / A. Unitsky, V. Pavlovsky, D. Feofanov // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 153–157.*

Growing Mycelium of Basidiomycetes on Organic Substrates in an Enclosed Ecosystem

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The technology of growing mushrooms in an enclosed ecosystem has been presented. Variants of application of organic substrates obtained as a result of crop production for the cultivation of edible basidiomycetes are considered: oyster mushrooms (*Pleurotus ostreatus*), reishi (*Ganoderma lucidum*), shiitake (*Lentinus edodes*), lion's mane (*Hericium erinaceus*). The peculiarity of the study is the examination of the formation of primordia on substrates from plant materials. Practical data obtained indicates the potential for growing fungal fruiting bodies on such substrates. It is proposed to use blocks with fungal mycelium after their cultivation for feeding farm animals in the EcoCosmoHouse (ECH).

Keywords: *basidiomycetes, EcoCosmoHouse (ECH), enclosed ecosystem, plant substrates, renewable resources.*

Introduction

The global production of edible mushrooms is about 34 mln tons per year, and over the past 20 years its volume has increased by 13–18 % annually. A well-known specialist in the field of mushroom cultivation, Professor S.T. Cheng believes that in the 21st century, the intensive development of the production of edible mushrooms and products thereof will lead to a "non-green revolution" (more than 70 % of plant residues that are not usually used in other industries can be processed by fungi into medicinal substances and food) [1].

When planning the existence of people in an enclosed environment, it should be considered that food must be available, grown and produced through renewable sources of the ecosystem. Life in the EcoCosmoHouse (ECH) is considered as an example of an infinitely long stay of a person in a closed environment [2, 3]. A natural balanced ecosystem will be created here; it will be characterized by the presence of a subtropical climate, diverse vegetation and wildlife. Accordingly, it becomes relevant to consider growing mushrooms in this environment.

The type of substrate is one of the most important factors in the productive cultivation of basidiomycetes, since soluble inorganic and organic substances included in its composition are absorbed by fungi as nutrition for the development of fruiting bodies [4]. A good substrate should contain sufficient amounts of nitrogen (for example, through the addition of nitrogen supplements) and carbohydrates to support and accelerate growth [1]. Considering that many different types of substrate are suitable for the cultivation of mushrooms, there is a potential opportunity to use the available plant waste in this process.

According to studies [5], the use of sawdust of many tree species as a substrate leads to the formation of heterogeneous low-density mycelium, which slows down the development of fungal fruiting bodies. This may be due to the low protein content, which is not enough to support growth. Therefore, other materials rich in lignocellulose are usually chosen [5]: cotton waste, rice straw, branches of fruit trees, paper waste [6]. Substrates can also be palm cones, corn cobs, sugarcane bagasse [7, 8], sunflower husks, cardboard and vegetable fiber, hazelnut and lime tree leaves, wheat straw. The latter is a lignocellulosic material [9] rich in cellulose, hemicellulose and lignin; it can supply nutrients for the development of mycelium and fruiting of fungi and demonstrates the highest biological efficiency.

When choosing a substrate, several most important parameters should be considered:

- maintaining humidity is necessary for the growth of both mycelium and fruiting bodies. A low amount of moisture does not allow nutrients to be transported into the mycelial cells, while excess moisture will contribute to its blockage, preventing water from evaporating. The average humidity that should be maintained in the substrate is 65–80 % [10];
- selection of the appropriate pH indicator is required for the development of mycelium and fruiting bodies, since both low and high values inhibit growth and development. The optimal pH is 5–6.5 for mycelium and 6.5–7 for the formation of fruiting bodies [1];
- carbon and nitrogen are necessary for the nutrition of mushrooms in a certain concentration. Thus, a suitable C : N ratio for growing oyster mushrooms is within the range (19–22) : 1 [11]. High concentrations of nitrogen cause the destruction of lignin and, as a result, lead to the prevention of mycelial development. In addition, they do not allow the formation of fruiting bodies in most species of basidiomycetes [12].

The purpose of the work is to study various types of plant materials for use as a substrate in the cultivation of various types of basidiomycetes.

Materials and Methods of Experiment

To set up an experiment on growing oyster mushrooms (*Pleurotus ostreatus*), reishi (*Ganoderma lucidum*), shiitake (*Lentinus edodes*) and lion's mane (*Hericium erinaceus*), the following types of plant waste were selected: birch leaf litter, soft wheat straw, sawdust of common alder and English oak.

Substrate preparation technology:

1) substrate was soaked in hot water (92–95 °C) for 20 min for better moistening;

2) substrate was packed in dedicated polypropylene bags with a filter and sterilized at a temperature of 121 °C for 35 min;

3) on the following day, the cooled substrate was inoculated with pure mycelium of the basidiomycete under aseptic conditions;

4) the substrate package was tightly sealed in a sterile box and transferred to a room, in which the required environmental parameters were set.

For the experiment, pure cultures of basidiomycetes were prepared in advance, after being obtained on a grain substrate in separate containers to exclude infection of the finished plant substrate with other types of microorganisms. The grain substrate for mycelium cultivation was rinsed with water to remove dust, then soaked in hot water (92–95 °C) for 15 min to swell and create a favorable environment for microorganisms, allowing bacterial forms with spores to awaken, which increases the importance of autoclaving such substrates. Wet grains were placed in 50 ml containers, tightly closed with lids, and autoclaved under standard conditions (121 °C, 20 min). Grain substrates were inoculated with basidiomycetes in a sterile environment.

Substrate bags were made from autoclavable polypropylene bags using a manual sealer. In the upper part, several holes were made with needles, covered with a filter and soldered. The filter is necessary for gas exchange in the substrate package and maintaining sterility and sufficient humidity at the beginning of the fungus mycelium growing process.

Cultivation was carried out in a separate ventilated room, where relative humidity in the range of 75–85 % and a temperature of 18 °C were maintained.

During the experiment, the rate of infection of the substrate with mycelium, the visible area of infection and the characteristics of the substrate (content of cellulose and lignin) were determined.

Experiment Results

In the course of the experiment, it was noted that such basidiomycetes as oyster mushrooms and lion's mane were best cultivated on a substrate of fallen birch leaves. These species adapted to the new environment more quickly and consumed nutrients for the development of mycelium more actively. Primordia appeared on the substrate of birch leaf litter, infected with lion's mane, and the formation of fruiting bodies began in oyster mushrooms. The wheat straw substrate also showed a good result: primordia of oyster mushrooms were formed.

Figure 1 shows the mycelia of basidiomycetes on a birch leaf litter substrate. It is noticeable that the growth of reishi mycelium (Figure 1c) is 30 % less than that of other species participating in the experiment. Growth was similar on the wheat straw substrate. Such material is widely used in the cultivation of mushrooms due to the rapid development of mycelium on it. The substrate of alder and oak sawdust is less captured by mycelium (by 20–40 % compared to leaf litter). Presumably, the features of this type of substrate are due to the presence of polyphenolic substances – tannins, which inhibit the growth of mycelium. However, due to the low diversity of trees in an enclosed ECH system, all substrates should be considered. It is possible to neglect the growth rate of mycelium and fruiting bodies, if it is necessary to reuse the waste products formed by the components of the ecosystem.

a)

b)

c)

d)

Figure 1 – Cultivation of basidiomycetes
on a birch leaf litter substrate:
a – lion's mane; b – oyster mushroom; c – reishi; d – shiitake

Indicators of mycelium growth rate and substrate coverage are shown in Figure 2.

The highest percentage of coverage and the shortest time of overgrowth with mycelium in all types of fungi were recorded on substrates of leaves and straw, which is associated with the simple composition of the raw material to be decomposed by fungal enzymes.

We have to point out that the formation of primordia occurs only on a substrate of leaves and straw for oyster mushrooms and on leaf litter for lion's mane. Probably, this result is due to the synthesis of lignocellulolytic and hydrolytic enzymes. Manganese-dependent peroxidase, one of the main lignin-degrading enzymes, was found in oyster mushrooms. This contributes to a more rapid overgrowth of the substrate with mycelium, and oyster mushrooms faster than other mushrooms give primordia and subsequently fruiting bodies.

The percentage of cellulose and lignin in the substrates, obtained by the nitrogen-alcohol method [13], is presented in the Table below.

The Table shows that alder and oak sawdust contains the largest amount of cellulose and lignin: 58.77 % and 26.11 % for alder, 60.04 % and 28.87 % for oak, respectively. These substances, as a result of their partial destruction, are components for the nutrition of the fungus as a source of carbon and energy. However, the bioavailability of thesecompounds to cellulolytic and lignolytic enzymes is worse than that of straw and leaf litter, so such substrates are colonized more slowly, but can be used for longer.

Figure 3 features the appearance of oyster mushrooms on a birch leaf litter substrate. The formation of fruiting bodies indicates the presence of all the necessary available components for the growth of mycelium.

A large number of fruit trees will grow within the ECH, so it is possible to use their sawdust. It should be noted that the wood of apple, apricot and pear trees is highly valued due to the high content of hemicellulose and other polysaccharides.

Spent substrate blocks can be used as a feed supplement in the main diet of farm animals grown in the ECH. This approach is justified, since solid substrates infected with the mycelium of basidiomycetes have a rich nutritional value due to the high content of proteins, amino acids, enzymes and vitamins necessary for the proper development of the animal organism. According to scientific sources, the use of spent substrates with oyster mushroom mycelium in fodder production for young cattle improves the digestibility of plant roughage and animal blood parameters (true protein increases by 7.1–11.3 times). The introduction of such an additive will also reduce fodder costs [14].

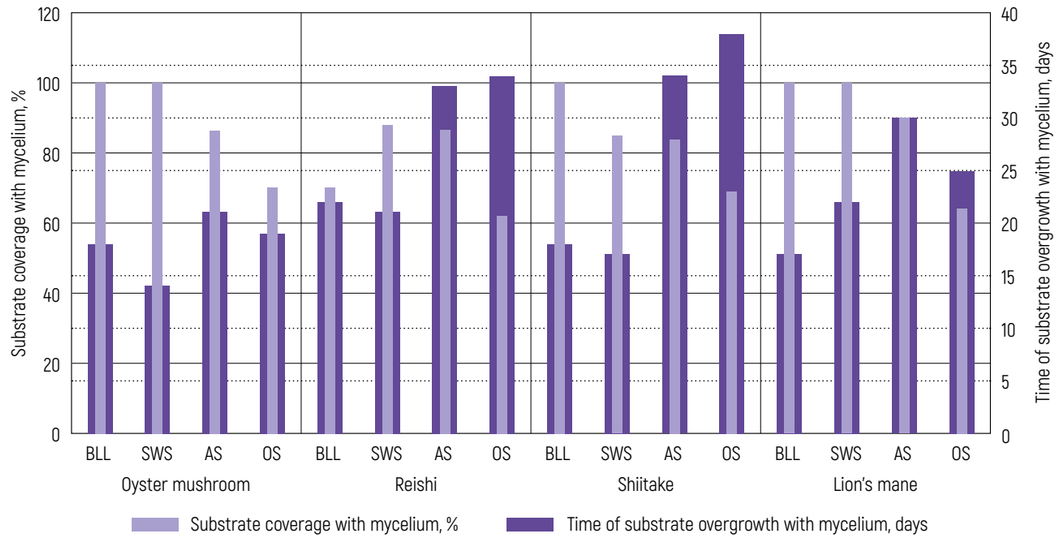

Figure 2 – Growth and development of mycelium on various substrates:
BLL – birch leaf litter; SWS – soft wheat straw; AS – alder sawdust; OS – oak sawdust

Table – Cellulose and lignin content in the substrate before and after mushrooms cultivation

Fungus	Substrate	Cellulose content, %		Lignin content, %	
		before cultivation	after cultivation	before cultivation	after cultivation
Oyster mushroom	BLL	48.87	14.5	21.77	15.61
	SWS	48.02	11.4	21.5	14.22
	AS	58.77	9.1	26.11	19.48
	OS	60.04	20.4	28.87	20.12
Reishi	BLL	48.87	18.66	21.77	17.28
	SWS	48.02	22.81	21.5	17.36
	AS	58.77	27.55	26.11	19.46
	OS	60.04	20.37	28.87	22.81
Shiitake	BLL	48.87	25.78	21.77	18.62
	SWS	48.02	22.55	21.5	17.13
	AS	58.77	49.59	26.11	21.72
	OS	60.04	52.81	28.87	23.65
Lion's mane	BLL	48.87	22.41	21.77	11.79
	SWS	48.02	22.89	21.5	11.64
	AS	58.77	45.73	26.11	22.16
	OS	60.04	52.79	28.87	26.36

Figure 3 – Formation of fruiting bodies of oyster mushrooms on a substrate of birch leaf litter

Conclusions and Future Work

Of all the selected substrates, the best growth of basidiomycetes was observed on birch leaf litter and soft wheat straw. Oak and alder sawdust have insufficient fungicidal properties and moisture and require more thorough processing.

One of the reasons for the low overgrowth rate of sawdust-based substrates can be the high percentage of complex components in the composition of wood (lignin and cellulose). Lignin is not the main source of carbon and energy during the development of the basidiomycete, however, with a lack of carbon, nitrogen or sulfur, it is capable of partial decomposition. An increased content of lignin and cellulose in the substrate imparts a dense structure to the fruiting body of the fungus, but with an excess of lignin, the mycelium of the fungus does not adapt well to the substrate and long-term cultivation is required to degrade high-molecular components.

During the experiment, it was revealed that, in addition to the formation of dense mycelium, the development of fruiting bodies of oyster mushrooms began on the substrate of birch leaf litter. The large number of formed primordia

limited the growth of fruiting bodies, which could be caused by insufficient air flow and an unbalanced composition of the substrate. However, the presence of emerging fruiting bodies indicates the possibility of adjusting the composition for growing mushrooms on such a cheap and accessible substrate. The productivity of fruiting on a birch leaf litter substrate is probably due to the fact that the C : N ratio in the composition of the leaves and the total nitrogen content are optimal.

Based on the data obtained, in the ECH, as in other enclosed ecosystems, it is possible to successfully use secondary plant materials (leaf litter, straw, sawdust) as substrates for growing basidiomycetes.

In the future, it is planned to conduct studies regarding the possibility of obtaining fruiting bodies of basidiomycetes grown on other types of plant materials. In addition, options for improving the methods of preparation of plant substrates, providing comprehensive actions for any organic raw materials, will be considered.

References

1. *Chang, S.T. Mushrooms: Cultivation, Nutritional Value, Medicinal Effect, and Environmental Impact / S.T. Chang, P.G. Miles. – Boca Raton [etc.]: CRC Press, 2004. – 480 p.*
2. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
3. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
4. *A Review on Valorization of Oyster Mushroom and Waste Generated in the Mushroom Cultivation Industry / W.A.W. Mahari [et al.] // Journal of Hazardous Materials. – 2020. – Vol. 400. – 123156.*
5. *Ogundele, G.F. Effect of Pure and Mixed Substrate on Oyster Mushroom (Pleurotus ostreatus) Cultivation / G.F. Ogundele, R.O. Abdulazeez, O.P. Bamidele // Journal of Experimental Biology and Agricultural Sciences. – 2014. – Vol. 2, iss. II (S). – P. 215–219.*
6. *Growth and Yield Performance of Pleurotus ostreatus (Jacq. Fr.) Kumm (Oyster Mushroom) on Different Substrates / Z. Girmay [et al.] // AMB Express. – 2016. – Vol. 6, No. 1. – 87.*
7. *Samuel, A.A. Growth Performance and Yield of Oyster Mushroom (Pleurotus ostreatus) on Different Substrates Composition in Buea South West Cameroon / A.A. Samuel, T.L. Eugene // Science Journal of Biochemistry. – 2012.*
8. *Puchkova, T.A. Vliyaniye razlichnykh substratov na rost mitseliya i biokhimicheskiy sostav plodovykh tel griba Ganoderma lucidum (Curt.: Fr.) P. Karst [Influence of Various Substrates on the Growth of Mycelium and Biochemical Composition of the Fruiting Bodies of the Ganoderma lucidum Fungus (Curt.: Fr.) P. Karst] / T.A. Puchkova, V.V. Trukhonovets // Biotekhnologii mikroorganizmov: Proceedings of the International Research and Practical Conference, Minsk, Nov. 27–29, 2019 / Belarusian State University. – Minsk: Ekoperspektiva, 2019. – P. 150–153.*
9. *Obodai, M. Yield of Seven Strains of Oyster Mushrooms (Pleurotus spp.) Grown on Composted Sawdust of Triplochiton scleroxylon / M. Obodai, L.C.B. Sawyerr, P.-N.T. Johnson // Tropical Science. – 2000. – Vol. 40, No. 2. – P. 95–99.*
10. *Growth and Yield Performance of Oyster Mushroom on Different Substrates / M.S. Naeem [et al.] // Mycopath. – 2014. – Vol. 12, No. 1. – P. 9–15.*
11. *Sözbir, G.D. Lignocellulosic Wastes Used for the Cultivation of Pleurotus ostreatus Mushrooms: Effects on Productivity / G.D. Sözbir, I. Bektas, A. Zulkadir // Bioresources. – 2015. – Vol. 10, No. 3. – P. 4686–4693.*
12. *Yang, W. Yield and Size of Oyster Mushroom Grown on Rice / Wheat Straw Basal Substrate Supplemented with Cotton Seed Hull / W. Yang, F. Guo, Z. Wan // Saudi Journal of Biological Sciences. – 2013. – Vol. 20, No. 4. – P. 333–338.*
13. *Khimiya drevesiny i sinteticheskikh polimerov [Chemistry of Wood and Synthetic Polymers]: Laboratory Practicum / comp. A.I. Lamotkin, Zh.V. Bondarenko. – Minsk: BGTU, 2005. – 82 p.*
14. *Ispol'zovaniye otrabotannogo solomennogo substrata posle kul'tivirovaniya griba veshenka obyknovennaya v kormlenii molodnyaka krupnogo rogatogo skota [The Use of a Spent Straw Substrate After Cultivation of the Oyster Mushroom During the Feeding of Young Cattle] / T.A. Puchkova [et al.] // Vestsi Natsyyanal'nay akademii navuk Belarusi. Seryya biyalagichnykh navuk. – 2016. – No. 4. – P. 42–47.*

Prospective Compositions and Methods for the Production of Light Potting Soils for the EcoCosmoHouse

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UDC 631.427.3

This article is a continuation of a research project on the creation of uTerra light "space" potting soils, developed by Unitsky String Technologies Inc. Rationale has been given for the use of such substrates, the results of experiments have been provided on their production from mineral fillers and the organic part – humus made from brown coal and enriched with humic acids and an association of agronomically valuable microorganisms that ensure fertility. A method for the industrial production of light potting soils has been proposed; new results of earlier experiments on plants grown on the substrates under consideration have been analyzed. Recipes with optimized mineral and organic parts have been presented. The features of the technology of plant cultivation in light potting soils have been described, as well as maintaining the microbiological diversity and stable composition of these substrates in the EcoCosmoHouse (ECH).

Keywords: *crop production, EcoCosmoHouse (ECH), enclosed ecosystem, humus, light potting soil, potting soil, soil elixir, soil microorganisms, universal substrate for plants.*

Introduction

The EcoCosmoHouse (ECH) is an infrastructure solution designed for a long and comfortable stay of man in near-Earth orbit. It is planned to create conditions for long-term residence of people and provide them with everything needed. In addition, a robust existence requires a balanced diet of healthy organic food, clean air, sufficient space for physical activity, a guarantee of safe living, the most pleasant microclimate and other components of a healthy living environment [1].

In order to comply with all these requirements, it is necessary to develop a technology for cultivating plants in enclosed ecosystems in general and the type of soil substrate used in particular. Not only the quality of the plant products obtained in the ECH, but also the stability of the ECH biosystem, as well as the economic indicators of its construction, largely depend on the choice of potting soil and the method of its manufacture.

Description of the Idea of Light Potting Soils

Light potting soils are a class of substrates intended for plant cultivation; they are widely used in modern agriculture due to a number of advantages (low specific weight, high aeration of the root system, significant moisture-retaining capacity, ease of use, relative cheapness [2], a full set of macro-, micro- and ultramicroelements that plants need).

The composition of light soils includes:

- light mineral fillers;
- minerals acting as sources of macro-, micro- and ultramicroelements;
- an organic part, which comprises humic acids and communities of thousands of species of agronomically valuable microorganisms, including psychrophiles (several species of *Pseudomonas*).

The most common method of growing agricultural, ornamental and medicinal plants is cultivation in a solid (friable) substrate. In terms of the number of mobile forms of elements valuable for plant nutrition, the developed light potting soils are not inferior to denser counterparts. At the same time, the disadvantages of new substrates include the need for careful selection of the composition and its control, as well as a slightly higher cost than for potting soils obtained only from natural materials and not undergoing additional processing [3–5].

For the ECH, light potting soils should serve as the basis on which it is planned to grow the entire list of plants, along which people and animals will move, and in which the processing of organic waste by agronomically valuable soil microorganisms will take place [6, 7]. Studies focused on light potting soils solve the issue of the best possible arrangement of the plant products cultivation on the territory of the entire enclosed ecosystem [8].

Table 1 provides comparative characteristics of modern technologies for growing plant products, indicating their strengths and weaknesses.

Based on Table 1 and taking into account the requirements for substrates intended for growing plants in the ECH, the technology that involves the use of light potting soils is the most optimal. It allows getting organic plant products and at the same time is a fairly stable system, which is monitored periodically. Expanded perlite can be applied for 20 plant vegetation cycles, after which 10–20 % of the material should be added. When cultivating plants with a short vegetation period (green crops, radishes), instead of traditional nature-like hydroponics and aeroponics it is proposed to use natural humusoponics based on liquid biohumus developed by Unitsky String Technologies Inc. (Minsk, Belarus) and the Unitsky's Farm Enterprise (Maryina Gorka, Belarus). Therefore, there is no need to frequently change the substrate for plants, which means that a fast and efficient process for the production of plant foods can be established.

Table 1 – Comparative characteristics of plant cultivation technologies

Indicator \ Technology	Growing on soil and standard substrates	Growing on light potting soils	Hydroponics (growing without soil)	Aeroponics (growing without soil)
Possibility of obtaining completely organic plant products	Yes	Yes	Yes (technology in development)	Yes (technology in development)
Substrate or nutrient solution density, t/m^3	1–1.5	0.2–0.5	About 1	About 1
Possibility and feasibility of growing shrubs and tree crops	Yes	Yes	No	No
Need for constant monitoring of the composition	No	No	Yes	Yes
Ease of changing the substrate, the ability to quickly adjust the composition of the nutrient solution	No	No	Yes	Yes

Types of Light Potting Soils Used at the Moment

Light potting soils should be divided according to the composition of the mineral part, which is a filler, has water-retaining and structure-forming properties, and also partially acts as a source of macro- and microelements. There are several main types of mineral fillers used for light potting soils. Based on the literature data and the results of previous studies, comparative characteristics of light substrates were compiled (Table 2).

As can be seen from Table 2, the most promising mineral filler for the preparation of light potting soils intended for use in the ECH is perlite. Several experiments were carried out with it, during which various fractions were used. All the performed experiments showed good results, the vegetation of plants corresponded to the norm.

Other options were considered as possible fillers: vermiculite, lava, pumice, slags used in urban landscaping. However, they have a number of disadvantages: high cost, composition instability, acidification or alkalization of the substrate. Perlite allows achieving the desired water balance, it is also used in arid climate, as it is able to give moisture to plant roots through capillaries, which accumulate it during irrigation. The manufacturing process of expanded perlite [9] includes the stage of expansion that occurs at temperatures of 900–1,100 °C, which leads to the absence of pests and weeds in it [10].

Table 2 – Comparison of light substrates with various mineral fillers

Indicator \ Mineral filler	Perlite	Clay pellets	Mixed kind
Density, t/m^3	0.15–0.4	0.2–0.6	0.3–0.5
pH stability	Yes	No	Yes
Plant growth experiment results	No difference from soil	Vegetation indicators are slightly reduced	No difference from soil
Soil biome development	The growth of earthworms, algae, fungi, as well as the development of soil microorganisms is observed		

Description of Research Results

In the Biotechnology Department of Unitsky String Technologies Inc., studies were carried out on potting soils created on the basis of perlite and containing a different ratio of fractions of this filler. At the same time, the amount of the organic part is up to 10 % by volume.

Figure 1 shows the compositions and the mint plants bedded out in them. The numbers of the jars correspond to the serial numbers of the soil compositions indicated in Table 3.

In this experiment, watering was carried out with water without the addition of nutrients. Despite this, even with a relatively small amount of substrate, mint continued to grow, a medicinal herb weighing 10–20 g was harvested from each variant four times a year. During the experiment, the appearance of the plants practically did not change: the foliage became somewhat brighter, which points to good conditions of maintenance and the presence of a sufficient amount of nutrients in the used potting soils.

It is noted that in all five compositions there is a slight difference in the rate of vegetation of plants and their appearance: less statistical error. This result indicates a greater impact of the organic component of light potting soil on the plants, but not its mineral composition.

a)

b)

Figure 1 – Mint grown using light potting soils: a – July 2021; b – July 2022

Table 3 – Extended compositions of light potting soils

Components and their ratio by volume	Potting soil volume, l	Quantity of organic components	Obtained composition density, t/m³
1. Perlite 0.16–3 mm	1	Biohumus 50 g uTerra humus 50 g [11]	0.142
2. Clay pellets 1–3 mm	1	Biohumus 50 g uTerra humus 50 g	0.505
3. Perlite 0.16–3 mm + clay pellets 1–3 mm (2 : 1)	1	Biohumus 50 g uTerra humus 50 g	0.263
4. Perlite 0.16–5 mm + clay pellets 1–5 mm (2 : 1)	1	Biohumus 50 g uTerra humus 50 g	0.24
5. Layering in the ratio of 4 : 1: • perlite 0.16–5 mm (on the top) • clay pellets 1–5 mm (at the bottom)	1	Biohumus 50 g uTerra humus 50 g	0.198

Figure 2 features experimental beds on which light potting soils have been tested since the beginning of 2021. The following compositions of substrates have been used for this experiment [12] (from left to right):

- Composition No. 1 by volume: 90 % of clay pellets + 5 % of uTerra humus + 5 % of biohumus;
- Composition No. 2 by volume: 45 % of clay pellets + 45 % of perlite + 5 % of uTerra humus + 5 % of biohumus;
- Composition No. 3 by volume: 90 % of perlite + 5 % of uTerra humus + 5 % of biohumus.

a)

b)

Figure 2 – General view of the beds with light potting soils:
a – July 2021; b – July 2022

Gain in growth of citrus plants from July 2021 to July 2022:

- cumquat – from 40 to 60 cm (20 cm);
- lemon – from 45 to 55 cm (10 cm);
- lime – from 35 to 50 cm (15 cm);
- mandarin – from 40 to 60 cm (20 cm).

The average gain in growth of citrus plants per year has been 16 cm.

Banana gain in growth from July 2021 to July 2022: from 40 to 110 cm (70 cm).

Experimental samples, which are grown using light potting soils based on clay pellets, perlite and their mixtures, continue to vegetate. In addition, earthworms live in potting soils during this experiment, a coating of soil algae formed on the surface of the glass, and the cellulose-destroying fungus *Leucocoprinus birnbaumii* began to develop (Figure 3).

Figure 3 – *Leucocoprinus birnbaumii* on a bed with light potting soil

The development of cellulose-destroying fungi indicates the presence in the substrate of a stock of unprocessed plant residues that it uses for nutrition and at the same time decomposes. As a result of this and other similar processes, there occur mineralization of organic residues, additional formation of humus in the soil, maintenance and increase of its fertility.

Based on the indicators of the gain in growth measurements (Figure 2), it can be concluded that the fractional composition in the studied range has an insignificant effect on plants.

Options for Economical Production of Light Potting Soils

Classic potting soils, light and of standard density, are produced according to the technological chain shown in Figure 4.

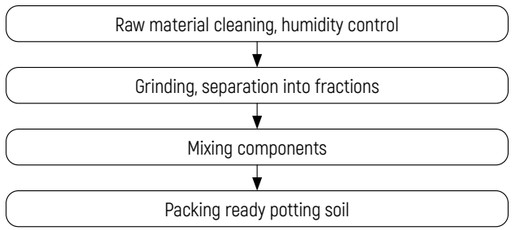

Figure 4 – Technological chain of classic potting soils production

This technological chain can be modified depending on where it will be applied: on Earth or in space. In the case of the construction of an ECH prototype on our planet and the need for relatively small volumes of light potting soils, ready-made solutions for the production of potting soils can be used, providing for the replacement of basic components (peat, sand, compost) with perlite.

To reduce costs when arranging the output of a large volume of light potting soil, it will be necessary to create a production of perlite and a concurrent production of vermicompost (biohumus), as well as a testing laboratory. Let us consider the required area and equipment capacity that are needed to produce 33,600 m^3 of light potting soil per year with a density of 0.3 t/m^3 (working in three shifts). This process (schematically shown in Figure 5) makes it possible, with minimal logistics costs, to get demanded products and process livestock and crop waste.

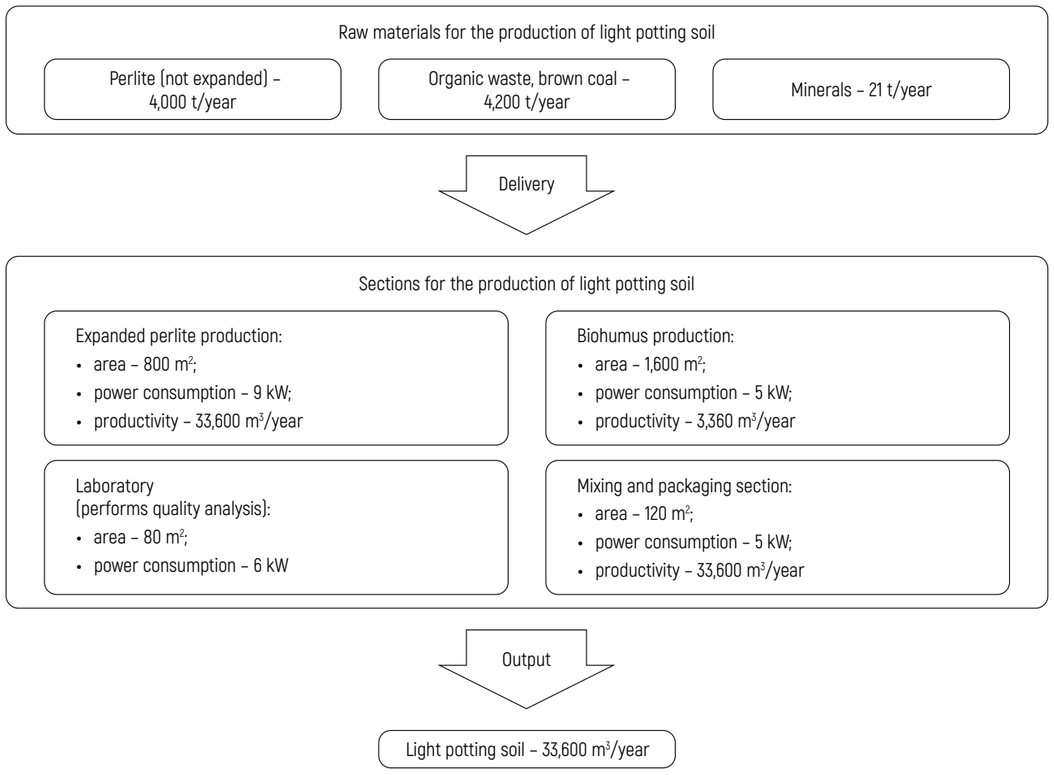

Figure 5 – Diagram of the complex for the production of light potting soil

Figure 6 shows a typical perlite production process flow diagram. The presented technology involves not only the production of expanded perlite, but also the purification of exhaust gases [13, 14].

Figure 7 shows typical equipment that is used for the production of perlite, mixing of components [15] and the production of biohumus [16]. Using this equipment, it is possible to arrange the comprehensive processing of raw materials

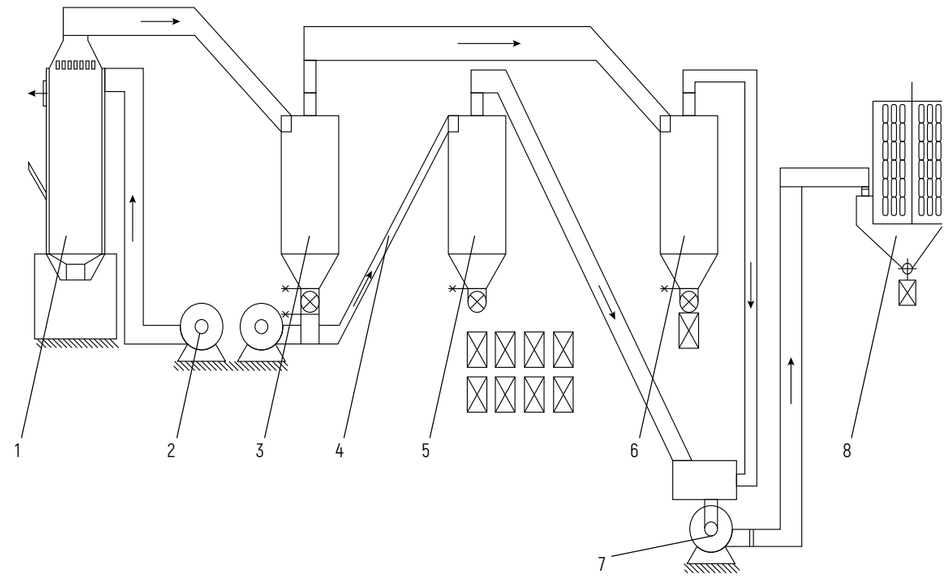

Figure 6 – Perlite production process flow diagram:
1 – shaft expansion furnace; 2 – air supply fan; 3, 5, 6 – cyclones;
4 – additional path of pneumatic transport; 7 – smoke exhauster; 8 – bag filter

a) b) c)

Figure 7 – Equipment for the production of light potting soils:
a – furnace for the production of perlite; b – mixer with a feeding hopper for obtaining light potting soil;
c – complex for the production of biohumus

and the continuous production of light potting soil in one technological chain.

The parameters of the components of the complex are shown in Table 4.

The total area of the complex intended for the production of light potting soil is about 2,600 m^2, the energy consumption for the main production processes is 25 kW.

The consumption of thermal and electrical energy for heating buildings, lighting and other needs in this case was not considered, since this parameter will vary significantly from region to region.

The production of light potting soils will be an effective solution both for the implementation of the ECH project and for obtaining substrates, which will be required for green roofs and growing plants in buildings, where such soils will help reduce the load on floor slabs. Taking into account the planned equipment, production can be reoriented to the manufacture of various types of potting soils, products for agriculture and the construction industry (expanded perlite of various fractions).

Output of Plant Products and Maintaining the Stability of Potting Soils Composition Under the EcoCosmoHouse Conditions

Under the ECH conditions, when growing plants using potting soils [17, 18], it is assumed that the resulting organic wastes are processed with the help of aerobic microorganisms and earthworms, as well as only anaerobic microorganisms. It is planned that the supply of phytogenic and other wastes into the thickness of light potting soil will be carried out after preliminary crushing and settling.

Pre-treatment should be used for wastewater. In this case, sediment, which is activated sludge, a mixture of microorganisms, protozoa, organic substances, a fine fraction of contaminants and mineral components, will be fed into the ECH soil (i.e., into light potting soil) from the treatment plant [19].

When circulating waters (technical, waste, condensate) intended for watering food plants is used in the ECH, it is required that the content of lactose-positive *Escherichia coli* in them be less than 10^4 CFU/cm^3 [20]; the presence of pathogenic microorganisms, viable intestinal protozoan cysts, viable helminth eggs is not allowed. The amount of macroelements necessary for plant nutrition (nitrogen, phosphorus, potassium) should correspond to their consumption by plant organisms for vegetation. Taking into account irrigation and the use of liquid biohumus, it is proposed to adopt the following norm for the content of nutrients in circulating water – 50 % of their removal from the soil by vegetable crops.

Other requirements (the content of microelements, heavy metals, pollutants, as well as acidity, the size of mechanical impurities, unpleasant odors) should be determined based on the applied irrigation technology for agricultural areas. In the ECH, with sequential purification of organic residues, a high degree of purification and maximum neutralization of possible biological contaminants can be achieved.

The ratio of the amount of plant products and light potting soil for its cultivation should provide a balance of macro-, micro- and ultramicroelements introduced into the soil [21]. Since the ECH is an enclosed ecosystem that functions continuously, the amount of waste (by weight) and the nutrients of plant organisms contained in them should be commensurate with the amount of nutrients taken out by plants.

Table 4 – Parameters of the components of the complex for the production of light potting soil

Section	Area, m^2	Power consumption, kW	Productivity, m^3/month
Expanded perlite production	800	9	2,800
Biohumus production	1,600	5	280*
Mixing and packaging section	120	5	2,800
Laboratory	80	6	Quality control
Total	2,600	25	2,800**

* Biohumus occupies the space between the granules of expanded perlite.
** The output of the finished product from the mixing and packaging section.

The mass of humus obtained (during the processing of organic waste by microorganisms and worms in the soil layer) is approximately 2–4 times less [22] than the mass of waste, which should be taken into account when designing technologies for cultivating plants and breeding animals, as well as in the processing of waste and in other processes related to the circulation of the substance in the ECH.

An important factor is the presence of some nutrient buffer, which is available in the natural environment and which is necessary in order to compensate for possible fluctuations in the composition of light potting soil.

Conclusions and Future Work

The implementation of the ECH project will require a significant amount of light potting soil, which will be the main substrate for the manufacture of organic plant products in an enclosed ecosystem. Humusoponics (the use of liquid organic plant foods) will pose as an additional method for obtaining bioproducts with a short vegetation period. Among the mineral materials used to create light potting soils, perlite with a fraction of 2–5 mm is ideal in terms of the sum of its characteristics (versatility, density, availability of material, stability of properties). This size of the fraction provides a low density of the substrate, as well as its high moisture capacity and air permeability. Expanded perlite can be partially replaced by clay pellets (up to 1/3 of the total volume).

Organizing the production of light potting soil in the ECH (full cycle) and obtaining 33,600 m^3 per year of finished products requires an area of about 2,600 m^2, as well as 25 kW of electric power for the main equipment (with a continuous three-shift operation).

This solution is able to provide high-tech potting soils not only for the ECH, but also for buildings in which it is necessary to carry out landscaping on roofs and indoors. In addition, it is planned to release required products for agriculture and construction. In the course of production processes, animal farming and crop waste will be processed, which will serve as a guarantee of the positive impact of the entire complex of light potting soil production on the environment.

The use of light potting soils in the ECH and traditional types of farming will make it possible to constantly, and at the same time with minimal material and labor costs, obtain high-quality organic plant products directly in the place where people live.

In the future, it is planned to study light potting soils in the open field, determine changes in their density and mechanical properties during several cycles of plant cultivation, clarify production characteristics and the rate of decomposition of organic residues in the thickness of the substrate.

References

1. *Kornekova, S.Yu. Rol' prodovol'stvennogo potrebleniya v udovletvorenii potrebnostey cheloveka: evolyutsiya predstavleniy [The Role of Food Consumption in Meeting Human Needs: Evolution of Ideas] / S.Yu. Kornekova // Peterburgskiy ekonomicheskiy zhurnal. – 2017. – No. 3. – P. 7–14.*
2. *Ivanov, D.I. Izucheniye sostava substrata dlya vyrashchivaniya rassady ovoshchnykh kul'tur [Study of the Composition of the Substrate for Growing Seedlings of Vegetable Crops] / D.I. Ivanov, N.N. Ivanova, A.S. Rodionova // Tendentsii razvitiya nauki i obrazovaniya. – 2021. – No. 73-2. – P. 138–141.*
3. *Perspektivy ispol'zovaniya perlita v sel'skom khozyaystve [Prospects for the Use of Perlite in Agriculture] / M.S. Salakhov [et al.] // Sovremennyye tendentsii razvitiya nauki i tekhnologiy: Collection of Scientific Papers Based on the Materials of the III International Research and Practice Conference, Belgorod, Jun. 30, 2015: in 6 pt. / APNI; ed. Ye.P. Tkachova. – Belgorod: IP Tkachova Ye.P., 2015. – Pt. II. – P. 60–63.*
4. *Volokhova, O.A. Primeneniye perlita v sel'skom khozyaystve [The Use of Perlite in Agriculture] / O.A. Volokhova, N.A. Maydannikov // Nauka i molodozh': Collection of Scientific Papers. – Novocherkassk: NIMI DGAU, 2016. – Iss. 3: Innovatsii v sovremennom agropromyshlennom komplekse [Innovations in Modern Agroindustrial Complex]. – P. 9–11.*
5. *Veremeychik, L.A. Ispol'zovaniye promyshlennogo keramzita dlya proizvodstva tomatov v usloviyakh zashchishchonnogo grunta [The Use of Industrial Clay Pellets for the Production of Tomatoes Under the Protected Ground Conditions] / L.A. Veremeychik, L.S. Gerasimovich // Ekologicheskiye problemy razvitiya agrolandshaftov i sposoby povysheniya ikh produktivnosti: Materials of the International Scientific and Ecological Conference, Krasnodar, Mar. 27–29, 2018 / Kuban State Agrarian University; eds A.I. Trubilin, I.S. Belyuchenko; comp. L.S. Novopol'tseva. – Krasnodar: Kubanskiy GAU, 2018. – P. 84–86.*
6. *Unitsky, A. EcoCosmoHouse as a Space for the Conservation of Species Diversity of Tropical and Subtropical Flora / A. Unitsky, V. Pavlovsky, D. Feofanov // Non-Rocket*

Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 153–157.

7. *Nebylov, A. Stability of Closed Space Biosystems for Algea Ecology / A. Nebylov, V. Perliouk, A. Knyazhsky // 9th International Conference on Recent Advances in Space Technologies (RAST), Istanbul, Jun. 11–14, 2019. – IEEE, 2019. – P. 941–947.*
8. *Unitsky, A. Features of Design of a Residential Space Cluster "EcoCosmoHouse" – Mission, Goals, Purpose / A. Unitsky // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 51–57.*
9. *Hydroponics as an Advanced Technique for Vegetable Production: An Overview / N. Sharma [et al.] // Journal of Soil and Water Conservation. – 2018. – Vol. 17, No. 4. – P. 364–371.*
10. *Automatic Monitoring and Control System in Aeroponic Plant Agriculture / I.F. Rahmad [et al.] // 8th International Conference on Cyber and IT Service Management (CITSM), Pangkal, Oct. 23–24, 2020. – IEEE, 2020. – P. 1–5.*
11. *Meliorant-pochvouluchshitel' "Gumus UniTerra". Tekhnicheskiye usloviya [Ameliorant-Soil Improver "UniTerra Humus". Technical Specifications]: TU BY 691935133.002-2019. – Introduced 19.03.2019. – Minsk: Gosstandart: Belorusskiy gosudarstvennyy institut standartizatsii i sertifikatsii, 2019. – 12 p.*
12. *Razrabotka sostava pochvogrunta dlya zamknutoy ekosistemy v kosmicheskom prostranstve [Development of Soil Composition for an Enclosed Ecosystem in Outer Space] / A.E. Unitsky [et al.] // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 412–423.*
13. *Khisamiyeva, M.M. Razrabotka predlozheniy po sovershenstvovaniyu kompleksa po proizvodstvu vspuchennogo perlita [Development of Proposals for Improving the Complex for the Production of Expanded Perlite] / M.M. Khisamiyeva, V.L. Sovetkin // Teplotekhnika i informatika v obrazovanii, nauke i proizvodstve: Collection of Reports of the I All-Russia Research and Practice Conference of Students, Graduate Students and Young Scientists with the International Participation, Ekaterinburg, Mar. 29–30, 2012 / UrFU; ed. N.A. Spirin. – Ekaterinburg: UrFU, 2012. – P. 147–149.*
14. *Konoplich, A.N. Teplotekhnologicheskoye oborudovaniye i energosnabzheniye zavoda po proizvodstvu stroitel'nykh materialov [Heat Technology Equipment and Power Supply of a Plant for the Production of Construction Materials] / A.N. Konoplich // Aktual'nyye problemy energetiki: Materials of the 72nd Scientific and Technical Conference of Students and Graduate Students, Minsk, Apr. 26, 2016 / Belarusian National Technical University. – Minsk: BNTU, 2016. – P. 463–465.*
15. *Yakubov, R.M. K voprosu snizheniya energoyomkosti protsessa smeshivaniya v lopastnom smesitele nepreryvnogo deystviya [On the Question of Reducing the Energy Intensity of the Mixing Process in a Continuous-Action Paddle Mixer] / R.M. Yakubov, A.T. Lebedev, V.V. Ochinskiy // Vestnik APK Stavropolya. – 2014. – No. 4. – P. 92–95.*
16. *Vermikompostirovaniye kak resheniye ekologicheskoy problemy utilizatsii otkhodov zhivotnovodstva [Vermicomposting as a Solution to the Environmental Problem of Animal Waste Disposal] / I.M. Sukhanova [et al.] // Uchonyye zapiski Kazanskoy gosudarstvennoy akademii veterinarnoy meditsiny im. N.E. Baumana. – 2015. – Vol. 223, No. 3. – P. 194–198.*
17. *Winter Strawberry Production in Greenhouses Using Soilless Substrates: An Alternative to Methyl Bromide Soil Fumigation / A. Paranjpe [et al.] // Proceedings of the Florida State Horticultural Society. – 2003. – Vol. 116. – P. 98–105.*
18. *Zaker, M. Natural Plant Products as Eco-Friendly Fungicides for Plant Diseases Control – A Review / M. Zaker // The Agriculturists. – 2016. – Vol. 14, No. 1. – P. 134–141.*
19. *Kirillov, N.A. Perspektivy ispol'zovaniya osadkov stochnykh vod dlya povysheniya produktivnosti malogumusnykh pochv [Prospects for the Use of Wastewater to Increase the Productivity of Low-Humus Soils] / N.A. Kirillov, N.A. Fadeyeva // Ekologicheskiy vestnik Severnogo Kavkaza. – 2015. – Vol. 11, No. 1. – P. 79–83.*
20. *Van Veen, J.A. Fate and Activity of Microorganisms Introduced into Soil / J.A. Van Veen, L.S. Van Overbeek, J.D. Van Elsas // Microbiology and Molecular Biology Reviews. – 1997. – Vol. 61, No. 2. – P. 121–135.*
21. *Usage of Perlite in Polluted Sandy Soils for Potato Crop / E.M. Draghici [et al.] // Revista de Chimie. – 2016. – Vol. 67, No. 11. – P. 2281–2286.*
22. *Philon, V.I. Issledovaniye prirody gumusovykh veshchestv, podverzhennykh neposredstvennomu vozdeystviyu mineral'nykh udobreniy [Investigation of the Nature of Humic Substances Subject to the Direct Influence of Mineral Fertilizers] / V.I. Philon // Agrokhimiya. – 2004. – No. 8. – P. 61–65.*

Features of Conclusion of the International Treaty on the uSpace Geocosmic Program Implementation

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The general rules and regulations concerning the process of drafting and concluding international treaties, their entry into force, and other formal procedures necessary to attribute legal force to treaties are considered. The specifics of the application of these rules to the international treaty on the uSpace geocosmic program implementation, involving the industrialization of near space and transferring a harmful part of the Earth's industry into orbit are analyzed. The features and problems of the process of concluding this treaty are highlighted and solutions are proposed.

Keywords: *General Planetary Vehicle (GPV), international law, international treaty, uSpace geocosmic program.*

Introduction

At the present stage of development, humanity has faced many environmental challenges, the bulk of which is associated with the growth of production capacities and, as a result, an increase in the amount of substances polluting the biosphere, i.e., industrial waste. Many relevant studies are devoted to this problem, but only some of them consider it systematically. The concept of engineer A. Unitsky looks the most comprehensive and elaborated. In his works, he reasonably concludes that there is a single way out of the dead end which modern humanity has entered. At the same time, his approach can be called radical, since it proposed to provide the technosphere with an ecological niche outside the biosphere, namely, to transfer the harmful part of industrial production outside the planet Earth [1, 2].

It should be noted that this plan cannot be implemented using rockets due to their high cost, low transportation capacity and extremely negative impact on the Earth's ecology [1]. The General Planetary Vehicle (GPV), which is the main structural part of the uSpace geocosmic program, is proposed as the most suitable alternative of cargo delivery to outer space for the purposes of industrialization [1].

The analysis carried out by the author earlier [3] leads to the conclusion that the construction of the GPV involves the direct and indirect participation of a large number of subjects of international relations, whose rights, duties and responsibilities should be defined and legally consolidated by concluding an international treaty. Such documents are the basis of relations between subjects of international law and contribute to the development of international cooperation in various fields [4]. The purpose of the treaty is a clear definition of the rights, obligations and responsibilities of the parties. Therefore, it is important for the document to have legal force, i.e., to be mandatory, so it is necessary to follow the appropriate conclusion procedure.

This article examines the procedure for concluding an international treaty, describes the stages of this process and analyzes the specifics of applying general rules to the international treaty on the uSpace program implementation.

General Characteristics of the Process of Concluding an International Treaty

An international treaty is the result of a rule-making process on an international scale, a final document containing the coordination of the free will of the participating entities, but at the same time it is a source of international law regulating the relations of the parties by establishing their rights and obligations [5].

Since international treaties contain norms of international law and form the legal basis of interstate relations [6], in recent years their number has exceeded 500,000 [7] and continues to increase. These documents differ in goals, subject of regulation, scope, number of participants and other characteristics, but the conclusion procedure does not depend on this and is considered unified. The procedure for concluding international treaties is established by the main international act regulating the area under consideration – the Vienna Convention on the Law of Treaties of 1969 (hereinafter referred to as the Vienna Convention).

This document provides for three stages of concluding an international treaty (Figure 1) [8].

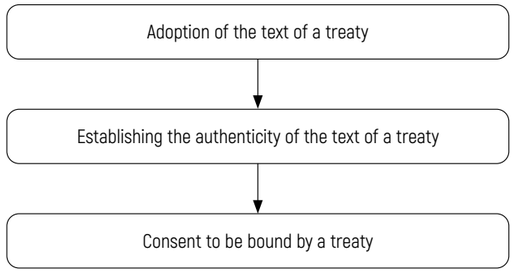

Figure 1 – Stages of concluding an international treaty (in accordance with the Vienna Convention)

In the scientific literature, in addition to these stages, the nomination of a contractual initiative and the preparation of the text of a treaty are also reasonably distinguished [9].

As part of the analysis of the process of concluding the international treaty on the uSpace program implementation, it is necessary to additionally consider if representatives of subjects of international law have the power to conclude relevant agreements. Such an approach is of great importance, since the subjects of international law, i.e., the parties between whom the treaty on the uSpace program implementation will be concluded, are states and international organizations. An individual or a group of persons always acts on their behalf; this representative must be duly authorized to express the will of the subject of international law, since only in this case will the actions of the authorized person entail legal consequences for the subject represented by him.

Article 7 of the Vienna Convention defines that a person is considered as representing a state for the purpose of adopting or authenticating the text of a treaty or for the purpose of expressing the consent of the state to be bound by a treaty if:

- he produces appropriate full powers;
- it appears from the practice of the states concerned or from other circumstances that their intention was to consider that person as representing the state for such purposes and to dispense with full powers [8].

In addition, the above article contains a list of persons who are considered to represent their state by virtue of their functions and without the need to produce full powers:

- Heads of state, Heads of Government and Ministers for Foreign Affairs, for the purpose of performing all acts relating to the conclusion of a treaty;
- heads of diplomatic missions, for the purpose of adopting the text of a treaty between the accrediting state and the state to which they are accredited;
- representatives accredited by states to an international conference or to an international organization or one of its organs, for the purpose of adopting the text of a treaty at such a conference, in such an organization or in such an organ.

At the same time, "full powers" means a document emanating from the competent authority of a state designating a person or persons to represent the state for negotiating, adopting or authenticating the text of a treaty, for expressing the consent of the state to be bound by a treaty, or for accomplishing any other act with respect to a treaty (article 2 of the Vienna Convention) [8].

Stages of Concluding the International Treaty on the uSpace Program Implementation

The process of concluding an international treaty includes several stages. The author of this article has chosen their expanded version (Figure 2).

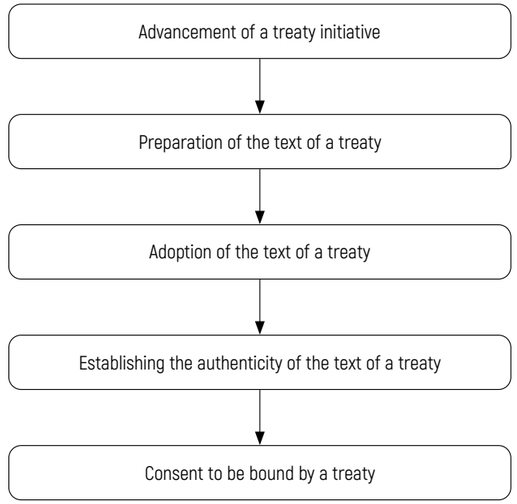

Figure 2 – Stages of concluding an international treaty

Advancement of a Treaty Initiative

An international treaty initiative is, in fact, a proposal coming from one or more subjects of international law to conclude a certain treaty that will contribute to the achievement of some global or regional goal.

However, it should be understood that persons who have the right to initiate the conclusion of an international treaty do not always act on their own conviction. That is, there is a preliminary stage of an intra-state or intra-organizational contractual initiative, within the framework of which recommendations and proposals on the conclusion of an international treaty are made by an authorized person of the state or an international organization. Thus, the initiators may be representatives of science, the public, politicians and other persons (groups, associations, movements), but acquiring the status of an official international treaty initiative requires the approval and assistance of the leadership of the state or international organization.

Based on the above, we can conclude that in order to initiate the execution of the international treaty on the uSpace program implementation, it is necessary to enlist the support of a full-fledged subject or group of subjects of international law. At the same time, as a positive point, it should be noted that due to the globality of the uSpace program, its elaboration and validity, scientific and economic potential, as well as the ability to solve many global and regional problems of our time, there is a sufficient number of subjects who may be interested in such an initiative. Exactly, in [10] the author identifies the following most probable parties to the treaty on the implementation of programs: United States of America, Democratic Republic of Sao Tome and Principe, Gabonese Republic, Republic of the Congo, Democratic Republic of the Congo, Republic of Uganda, Republic of Kenya, Federal Republic of Somalia, Republic of Maldives, Republic of Indonesia, Republic of Kiribati, Republic of Ecuador, Republic of Colombia, Federative Republic of Brazil.

Preparation of the Text of a Treaty

Preparation of the text of a treaty is the stage of concluding an international treaty at which a document is created.

In international legal practice, three ways of developing and approving a document are used (Figure 3) [4].

We assume that the method in which diplomatic channels are used cannot be applied in the process of concluding the international treaty on the uSpace program implementation due to its global scale, which means a great number of likely participants – primarily, the equatorial countries, through the territory of which the GPV takeoff and landing overpass should pass. Given the complexity and specificity of the document, the most suitable option for preparing the text of a treaty in this case is a combination of the first and second methods. Such a process will be clearly regulated by the procedural acts of the event.

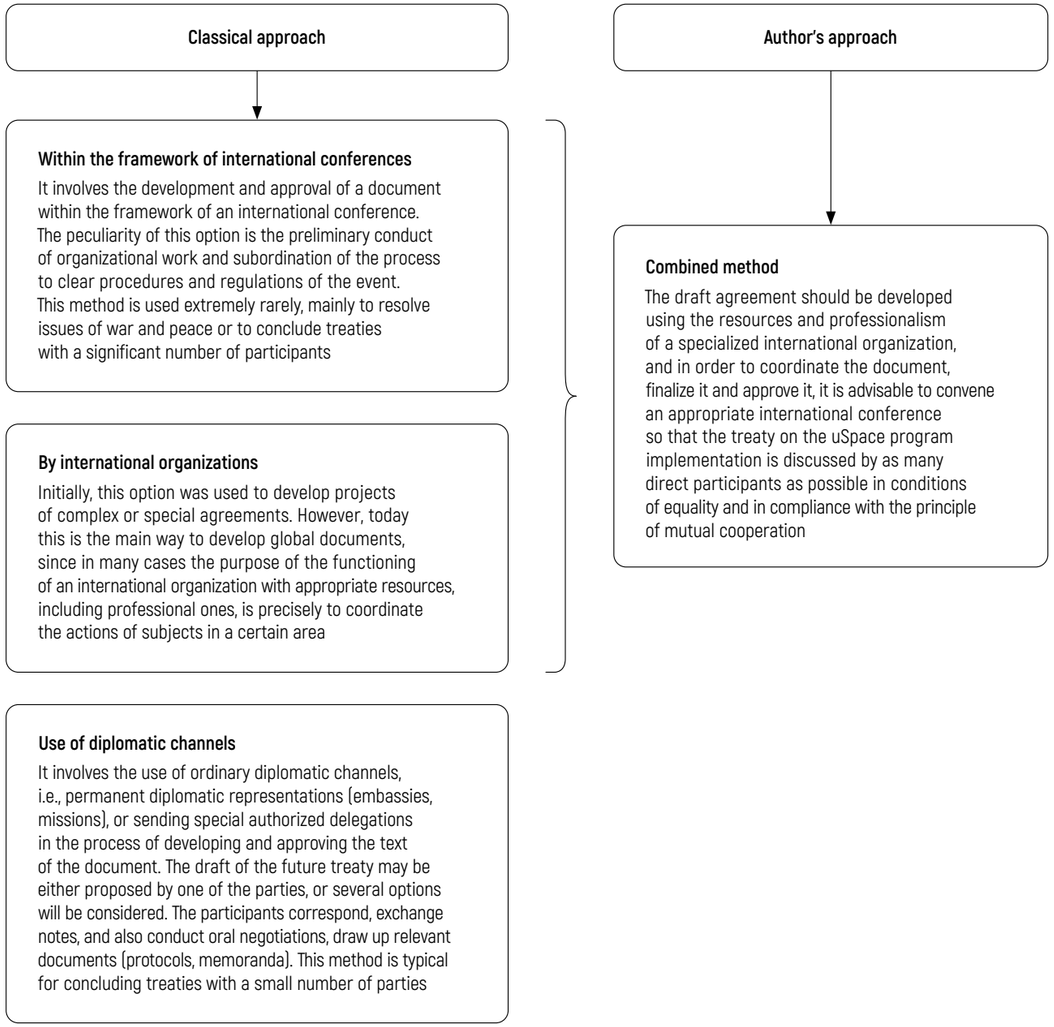

Figure 3 – Ways of preparing the text of an international treaty

Adoption of the Text of a Treaty

The adoption of the text of a treaty can be called the stage that completes its preparation, however, due to its significance and the importance of the decision taken, it is reasonable to consider this stage separately. An international treaty is finally agreed upon by the project development participants, its final version in form and content is adopted. Article 9 of the Vienna Convention provides for two ways of adopting the text of an international treaty (Figure 4) [8].

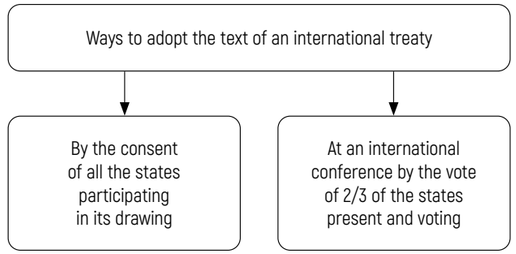

Figure 4 – Ways to adopt the text of an international treaty

As mentioned above, to discuss the international treaty on the uSpace program implementation, it is required to convene an international conference. That is why, in this situation, the second of these methods of adopting the text of a treaty should be used. It is worth noting that the ideal option seems to be the unanimity of the participants, however, given the current political situation and the current state of international cooperation, this will be extremely difficult to achieve, and therefore establishing the need for a qualified majority of 2/3 of the votes seems appropriate.

Establishing the Authenticity of the Text of a Treaty

At this stage, there is a formal confirmation that an international treaty is final, so further amendments to it are unacceptable; the authenticity of the text is also established, including those in different languages (if necessary).

Article 10 of the Vienna Convention suggests two possible options for the procedure for establishing the authenticity of the text of a treaty:

- as a result of the application of the procedure provided for in a treaty itself or agreed by the participants;
- by signing *ad referendum* or initialing the text of a treaty or the final act of a conference containing this text by representatives of the parties to the agreement [8].

Ad referendum (Latin – subject to approval) means that a treaty is signed by a duly authorized representative of the state in advance and needs confirmation from that state [11].

Initialing is a form of confirmation of the agreement with the text of a treaty developed as a result of negotiations by applying their initials by representatives of the parties at the end of the text, and sometimes on each page of it [11].

Taking into account previously substantiated proposals for establishing the authenticity of the text of the international treaty on the uSpace program implementation, the most appropriate ways are to sign an *ad referendum* or initialing the final act of an international conference, since this will allow to receive informed approval from each participant in the future.

Consent to Be Bound by a Treaty

The expression of consent to be bound by a treaty is the final stage of concluding an international treaty, which means its entry into force. Until then, participants are not considered bound by obligations under such a document.

Article 11 of the Vienna Convention defines the following ways of expressing consent to be bound by a treaty:

- signing;
- exchange of documents;
- ratification;
- approval (acceptance);
- accession;
- any other method agreed upon by the participants [8].

The expression of consent to be bound by an international treaty by signing implies its entry into force immediately after the signatures of all authorized representatives of the parties are affixed to its text.

When expressing consent to be bound by an international treaty by exchanging documents, the parties to the agreement send each other certain documents, such as letters or notes, which confirm agreement with the terms of a treaty and indicate that the subject has assumed the relevant rights and obligations.

Ratification is reasonably considered to be the most authoritative way of expressing consent to be bound by an international treaty, since it is a separate act of the highest state authority (president, parliament) of the party to the agreement, adopted according to a certain procedure subject to the norms of national legislation.

On approval (acceptance) as a way of expressing consent to be bound by an international treaty, one should speak

in two senses. In the first case, we are talking about a situation where one of the parties to the agreement is an international organization for which the ratification procedure is impossible. Then the procedure for approval by the supreme governing body of such an organization is applied in accordance with the adopted rules. In the second case, an act is issued by an authorized state body, but not by the highest one, and according to less strict rules than ratification.

The method of accession is used if an entity that did not participate in the preparation of the text of the document, i.e., was not among the original participants, wishes to express consent to be bound by an international treaty for itself.

Taking into account the specific nature of the uSpace program, as well as its global scale, the most appropriate ways to express consent to be bound by the international treaty on the uSpace program implementation are ratification for the initial membership of states (approval – for international organizations) and accession for those entities that realize the need for cooperation in the future. The application of ratification will allow to properly confirm and consolidate the intentions of the participant at the national and international level, while the possibility of accession is required due to the fact that in the process of implementing the uSpace program, an increasing number of subjects will understand and accept the necessity and exclusivity of the implementation of the solution proposed by A. Unitsky.

Conclusions and Future Work

The analysis carried out in this article for concluding an international treaty, the stages of such a process and the specifics of applying the general rules to the international treaty on the uSpace program implementation allows to draw the following conclusions.

The norms, rules and procedures concerning the conclusion of agreements that exist today and are applied in international practice are sufficient for the treaty on the uSpace program implementation to become part of international law. However, it is worth taking into account the specifics of the program under consideration, primarily related to the global scale, complexity and intersectoral nature. In this regard, a certain procedure for concluding a treaty seems to be the most appropriate:

1) in order to put forward an initiative to conclude the treaty on the uSpace program implementation, it is necessary to receive the support of a state or an international organization as a full subject of international law;

2) drafting of the treaty should be entrusted to specialists in various fields within the framework of the activities of a specialized international organization;

3) an international conference should be organized to coordinate the text of the treaty on the uSpace program implementation, as well as its completion and approval;

4) authentication of the text of the treaty should be formalized within the framework of the above-mentioned conference in its final act by signing *ad referendum* or initialing the document;

5) it is necessary to express the consent of the participants to the binding nature of the international treaty on the uSpace program implementation by ratifying (approving – for international organizations) the agreement, while providing for the possibility of joining new entities.

When conducting further research, it is supposed to analyze the ways to ensure the fulfillment of obligations assumed by the participants of the international treaty on the uSpace program implementation, the limits of permissible legal coercion, as well as possible forms of liability in case of violation of the terms of the treaty in question.

References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Unitsky, A.E. Tsivilizatsionnaya yomkost' kosmicheskogo doma po imeni Planeta Zemlya [Civilizational Capacity of the Space Home Named Planet Earth] [Electronic resource] / A.E. Unitsky. – Moscow: Mir nauki, 2022. – 136 p. – Mode of access: https://izd-mn.com/PDF/08MNNPM22.pdf?ysclid=la98apfobr284127861. – Date of access: 11.05.2022.*
3. *Kazakevich, A.P. Pravovyye aspekty mezhdunarodnogo sotrudnichestva v oblasti osvoyeniya kosmosa [Legal Aspects of International Cooperation in the Field of Space Exploration] / A.P. Kazakevich // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 102–115.*
4. *Lukashuk, I.I. Forma mezhdunarodnykh dogovorov [The Form of International Treaties]: Study and Practical Guide / I.I. Lukashuk. – Moscow: Spark, 2001. – 112 p.*
5. *Struktura mezhdunarodnykh dogovorov Sodruzhestva Nezavisimykh Gosudarstv [Structure of International Treaties of the Commonwealth of Independent States] [Electronic resource] // Internet-portal SNG. – Mode of access: https://e-cis.info/cooperation/3216/78098. – Date of access: 14.05.2022.*
6. *Vasil'yeva, L.A. Mezhdunarodnoye publichnoye pravo [International Public Law]: Study Guide / L.A. Vasil'yeva, O.A. Bakinovskaya. – Minsk: TetraSistems, 2010. – 576 p.*
7. *Vidy mezhdunarodnykh dogovorov [Types of International Treaties] [Electronic resource] // ICC Russia. – Mode of access: https://iccwbo.ru/blog/2016/vidy-mezhdunarodnykh-dogovorov. – Date of access: 21.05.2022.*
8. *Vienna Convention on the Law of Treaties [Electronic resource] // United Nations. – Mode of access: https://legal.un.org/ilc/texts/instruments/english/conventions/1_1_1969.pdf. – Date of access: 21.05.2022.*
9. *Meyer, T. From Contract to Legislation: The Logic of Modern International Lawmaking / T. Meyer // Chicago Journal of International Law. – 2014. – Vol. 14 (2). – P. 559–623.*
10. *Kazakevich, A. Terms of Treaty Between Participating Countries of the uSpace Program / A. Kazakevich // Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the IV International Scientific and Technical Conference, Maryina Gorka, Sep. 18, 2021 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2022. – P. 117–123.*
11. *Borisov, A.B. Bol'shoy yuridicheskiy slovar' [Big Law Dictionary] / A.B. Borisov. – Moscow: Knizhnyy mir, 2010. – 848 p.*

Artificial Intelligence and Human Alienation from Mind: Causes, Mechanisms, Consequences

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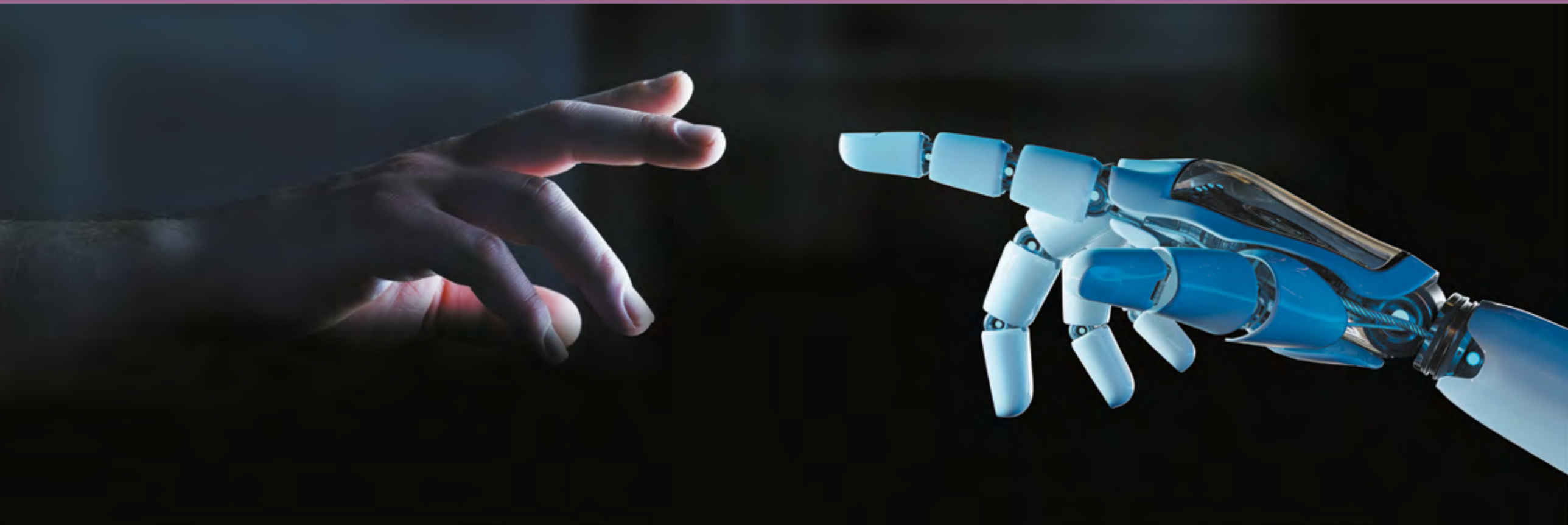
Modern trends that have developed with the introduction of artificial intelligence technologies into everyday life are considered: a description of the calculator effect, the paradox of a civilized person is provided; statistical data on changes in the Flynn effect over the past century are presented. The importance of creating a complex and unique Universe in which a hierarchy of collateral subordination will be established for the harmonious development of civilization is substantiated.

Keywords: *alienation from mind, artificial intelligence, calculator effect, digital totalitarianism, digitalized human, informational garbage, natural and digital thinking, paradox of a civilized person, waste of thinking.*



Introduction: Phenomenon of Alienation as a Result of Civilizational Development

Modern civilization is focused on the problems of artificial intelligence. This relatively new phenomenon opens up amazing, previously unseen opportunities, prospects, solutions for humanity. People are trying to find application of this tool in all areas – from household appliances to space exploration. And everywhere it comes to finding a way to partially or completely replace a person with algorithms, as well as with machines that perform them. Although formally and technologically such a situation is largely new, it reflects the essence of our Earth's technogenic (industrial) civilization and embodies the fundamental attitudes characteristic for it.

The "civilization" concept comes from the French *civilisation* (originally – transformation of a criminal process into a civil one), then from *civiliser* – to civilize, from *civil* – civilian, then from Latin *civis* – citizen [1]. Many are familiar with the saying "*Civis Romānus sum!*" ("I am a Roman citizen!"). In antiquity, it was a formula for self-affirmation, the superiority of one group of people over all others as bearers of special rights and privileges. Even the poorest Roman citizens received free bread and access to entertainment, and therefore remained the elite. On the other hand, such a special position was based on their inclusion in the legal system – a system of laws that applied only to the Romans and required a special court for them, while others were outside the law and were deprived of any legal protection.

Civilization begins where the law appears. It is it (no matter whether formalized or non-formalized) that regulates the relations inherent to a civilized community, which differ from relations based on instincts or personal experience of a single individual in the animal world. At first, it is a law of tradition or nature, then – a legal law that has not only a limiting function, but also contributes to the transfer of practically valuable knowledge. The procurement of fire, the manufacture of tools – the entire material basis of civilization rests upon knowledge of the laws of nature and the implementation of the algorithms of actions prescribed by them. The law and the algorithm as a sequence of operations are largely identical concepts. The Latin word *lex* (law) in one of the meanings is the order of actions [2].

The main mechanism of self-preservation and development of civilization is the maintenance of those engineering (industrial) technologies that lie in its foundation. Without hunting and gathering technologies, skinning and fire procurement, as well as without other algorithmic actions, the rules of which are preserved and passed down from generation to generation, social development as an increase in the level of complexity of the organization of society would be impossible. The ordering tool in this regard is certain algorithms that subjects in civilizational processes obey. So, the laws of primitive tribes were built around the need to maintain fire. The industrial society serviced the machines. A person of the 21st century becomes at the service of artificial intelligence: performs functions related to the development of computing machine capabilities, the expansion of its fields of application, as well as its maintenance, while simultaneously being a consumer of digital products. Here, in the process of alienation of labor described by K. Marx, a new dimension opens up.

Until now, the alienation of labor has been built up in several stages: alienation from the instruments of production (they are owned by the capitalist, not the worker); alienation from the results of activity (products do not belong to the worker); alienation from the processes of performing physical labor procedures and from one's own physicality (the human body actually turns out to be part of industrial equipment). This was followed by alienation from the ancestral essence (from ties with ancestors and relatives, with whom neither the land as an object of labor, nor the ownership of tools of labor are no longer united) and alienation of people from each other. With the advent of artificial intelligence algorithms, a person is alienated from the elements of thinking and conscious abilities, from his own individual mind. Let us designate such a phenomenon as the calculator effect not only because these electronic devices process numbers quickly and efficiently and perform complex computational operations, but also because they are all the same – impersonal, like any other machine.

Calculator Effect

The calculator effect is that in the process of performing mental operations, such as counting, some actions are carried out by a mathematical (digital) algorithm instead of a person. As a result, thinking becomes fragmented. During the formation of the concept of an object, the cognition of which is aimed at thinking, essential stages become missing. The idea of the world becomes devoid of integrity, as the person himself is alienated from thinking. Interestingly, one of the most successful calculator brands is called Citizen. The word comes from the Latin *civitas* (city), which goes back to the same roots as *civis* (citizen) and *civilisation* (civilization). The calculator is the same machine algorithm that replaces an individual in his main component as a biological being endowed with intelligence – in the thinking ability.

The described effect applies not only to computing activities. Algorithms are integrated into absolutely all mental operations: comparison, analysis, synthesis, abstraction, generalization. Getting to the destination, a person uses a navigator and may not even think about which part of the city he is in. There is a case when Japanese tourists in Australia drove a car into the ocean, although they planned to get to an island near the shore. They followed the navigator's instructions [3]. Similarly, in the process of reading the news and searching for the right information, we are increasingly being led by algorithms that record our preferences and issue recommendations for studying only those topics that, from the viewpoint of artificial intelligence, may be of interest to us. Thus, the development of personality stops due to its disconnection from creativity and turning into a consumer of standardized and redundant information.

In communication, we are increasingly replacing entire conversation blocks with demonstration videos and memes. Algorithms make us coffee, do cleaning, build cars and already learn how to drive them, launch rockets into space, process volumes of data in seconds that a person cannot consider even in a lifetime. With the advent of new technologies, society became more powerful, but there was less and less room in it for the individual in his natural manifestations. Let us call it the paradox of a civilized person. The less he is, the better and more powerful he is. The more we subordinate our lives to the laws, the better we execute them. For an ideal performance, it would be good for us to disappear altogether – first reducing to the "golden billion", then to the "diamond million", which will then inevitably degrade as a society and become zero, like Ancient Rome.

Natural and Digital Thinking

Civilization includes the installation of replacing the individual with algorithms and machines, since man is a natural being. In the same way asphalt replaces grass; tractors and cars – horses; communication on the Internet – live contact. Civilization is aimed at replacing the natural with man-made. The creation of artificial intelligence in this context is a necessary stage in the development of the so-called civilized (but not civilizational) community. And the root cause is as follows: everything is based on engineering and technology. They exist according to the same principles as Live Nature (living organisms): at the entrance they have raw materials and energy, at the exit they have products (services) useful to humans and technological waste according to the scheme: (raw materials + energy) – product (service) = waste. The difference is that the waste of technical production cannot be used by technology or life to the fullest, as it happens with the waste of living organisms.

The entire biosphere, a small part of which is a human, is formed from vital waste: biohumus, which contributes to the fertility of previously lifeless soils; oxygen, which we breathe and which ensured the creation of an ozone layer saving life on the planet; carbon dioxide, thanks to which a greenhouse effect appeared, which increased the average temperature on the planet by 32 °C, without what neither the biosphere nor us would exist, since all the oceans would remain covered with ice [4]. The wastes of the technosphere, on the contrary, damage the biosphere, as they are poisonous antagonists and take away the space that previously belonged to it – in the air, water and soil.

Thus, any technogenic civilization (terrestrial humanity is no exception here) does not just replace Live Nature, but also fights with it and destroys it – first on a material level, and then on a spiritual and social level. According to the same logic, material and information raw materials turn into digital products, as well as into material and informational waste, which increasingly fill up the living space and living thinking with a digit. This is the calculator effect – the material subject of an industrial object creating a digital product and informational waste, i.e., digital garbage.

The analogy between the thinking process and technical production may seem controversial to someone. Nevertheless, in our opinion, it deserves consideration if we want to give a comprehensive assessment of artificial intelligence. It is necessary to understand that it is a product of technology, not nature. Therefore, artificial intelligence must somehow absorb and refract principles of operation of technology.

The raw material for thinking is information or data (quantitative and qualitative). Through their processing, we form ideas, beliefs, knowledge, worldview, goal-setting and build our actions on their basis. A by-product of thinking (waste) also turns out to be information, i.e., a digit.

However, it undergoes changes in the thinking process. Compared with informational raw materials, informational waste significantly changes its structure, becomes orderly according to the formal parameters of cognitive activity. In the same way, raw materials change their structure in technological cycles. For example, a product such as thermal and electrical energy is obtained from coal. The waste will be flue gases, ash, slag, sludge, etc. The chemical elements of which they consist were also contained in coal, but now they are structured and correlated in a different way. At the same time, if coal existed as a matter harmoniously integrated in nature, then from the moment its extraction from it and through changing its structure, we get substances that violate the natural balance. It is worth noting that a similar process in nature does not lead to the same results. Waste products of all living organisms in the biosphere of the planet are effectively integrated into food chains. Approximately the same situation occurs when comparing natural thinking with digital thinking.

It is proposed to understand natural thinking as the activity carried out directly by the human brain; the digital one – by computer algorithms. The specifics of the waste or by-products of the first is as follows:

- they may remain not recorded in any way;
- the energy used for their production has a natural origin and is embedded in the natural energy exchange;
- being recorded, they can effectively integrate into the thinking processes of other subjects.

The specifics of the by-products of digital thinking:

- they are mandatory recorded on digital media;
- the energy used for their production is of artificial origin and disrupts the natural energy exchange that has developed in the Earth's biosphere;
- a significant part of them is not integrated into the thinking processes of subjects of natural thinking, but, on the contrary, violates and destroys them, which is described in more detail above through the "calculator effect" concept.

Let us consider the above with an example. Take the algorithm that generated the cover of Cosmopolitan magazine. Allegedly, the neural network completed the task in 20 s, based only on a textual description as initial data: "...wide-angle shot from below of a female astronaut with an athletic feminine body walking with swagger toward camera on Mars in an infinite Universe, synthwave digital art" [5]. In addition to the cover itself, which seemed the most successful to the research group, at least a dozen more images were created. This is just waste. Electricity was spent on their production. They are not needed by anyone and will never be used. Nevertheless, they take up space on a server or computer hard disk, can be thrown into the Internet and there, along with the necessary and important information, they will turn out to be just noise, an obstacle to finding the right material. In other words, they become noospheric informational garbage, invading the processes of natural thinking and polluting it in the same way as waste from technological production pollutes the biosphere.

Informational Garbage

The result of the fact that a person began to transfer a significant part of mental and creative operations to artificial intelligence algorithms for execution is an overflow of the informational field with informational garbage. According to the authors, this leads to the degradation of natural thinking in the same way as the oversaturation of the biosphere with material waste of the technosphere leads to its destruction.

Informational garbage produced by subjects of natural intelligence mostly appears when digital algorithms are included in the thinking and creative processes. Thanks to the latter, the creation of intelligent products is significantly facilitated: computer programs correct grammatical errors, can independently compile texts, perform graphic image processing, make collages and carry out visual data editing, process and generate new audio tracks. Since the creation of an intelligent product is significantly simplified, its quantity may exceed the actual needs. As in technological process: a product that is not consumed turns out to be a by-product, ceases to be a product and becomes a waste.

The processes of creating non-recyclable waste of thinking are cumulative. On the other hand, the products of natural thinking are forced to compete with the products of digital thinking. This is another mechanism for replacing a person. In the end, an individual can be completely displaced. Firstly, there will be no need for the products of his thinking and creative abilities. Secondly, these abilities themselves will be unsuitable for efficient work in the new conditions. In the abundance of informational garbage, we may be unable to find the informational raw materials we need for thinking.

The Need to Control and Limit the Application Scopes of Artificial Intelligence

According to the authors' opinion, the main essence of the described crisis of natural thinking is the loss of the integrity of people's ideas about reality, defragmentation, clip perception, ever increasing dependence on gadgets and algorithms, alienation of a person from entities previously inherent only to him and deconstruction of the very idea of him in the logic of dehumanization and transhumanism. Both in the case of the antagonism of the technosphere and the biosphere, and in the confrontation of techno- and biothinking, it is possible to resolve the situation in principle only through the separation of these systems in space or, more precisely, in the sphere of use. Therefore, just as it is important to bring out the harmful part of the technological industry into near-Earth orbit [6], so it is necessary to distinguish the areas of application of natural human (i.e., biological) and artificial engineering (i.e., machine) intelligence. For example, leaving everything related to cultural, political, legal, social, educational, scientific and other creative activities for the former one. For the latter – only technological aspects and assistance to a person (but without decision-making) in the informational (computational) part that does not relate to the concepts "consciousness", "humanity", "personality", "worldview", "spirituality", "morality", "ethics", "virtue", "culture", "goal setting", "planning", etc. Artificial intelligence is for technology; natural intelligence is for humans. However, the question remains: how to make this separation? It turns out that, as in the case of the task of transferring the industry into space, limiting the application scope of artificial intelligence requires political will and international purposeful interaction.

It should be noted: the professional community engaged in the study and development of artificial intelligence is well aware of the degree of danger posed by developments in this area. First of all, of course, attention is paid to the threats associated with the use of algorithms in the production of military equipment. The UN has been calling for international regulation of developments involving the creation of "thinking" algorithms for several years. "People should have good reason to trust that AI systems can bring individual and shared benefits, while adequate measures are taken to mitigate risks. An essential requirement for trustworthiness is that, throughout their life cycle, AI systems are subject to thorough monitoring by the relevant stakeholders as appropriate" [7], the Recommendation on the Ethics of Artificial Intelligence states. Nevertheless, so far these words remain unheard, on the contrary, the state programs of the USA and China continue to develop technologies, in fact, having entered a new arms race.

"Escape from Freedom" Mechanisms in Industrial and Post-Industrial Society

The optimism that is being found in society in connection with the expansion of the application scope of artificial intelligence deserves special consideration. In our opinion, this process involves the same mechanisms, which E. Fromm defined as "escape from freedom" [8] and which previously caused the emergence of totalitarian regimes, and now can result in the emergence of a new type of social structure – digital totalitarianism or digital fascism. Before describing it, we will give a few quotes from this German sociologist relating to the processes and states of the psyche that lead to social unfreedom and alienation from mind.

The scientist writes: "The new freedom is bound to create a deep feeling of insecurity, powerlessness, doubt, aloneness and anxiety. These feelings must be alleviated if the individual is to function successfully" [8]. For the most part, people "cannot go on bearing the burden of 'freedom from'; they must try to escape from freedom altogether unless they can progress from negative to positive freedom. The principal social avenues of escape in our time are the submission to a leader, as has happened in Fascist countries, and the compulsive conforming as is prevalent in our own democracy," continues E. Fromm [8]. "Often he is well adapted only at the expense of having given up his self in order to become more or less the person he believes he is expected to be. All genuine individuality and spontaneity may have been lost" [8]. "By becoming part of a power which is felt as unshakably strong, eternal and glamorous, one participates in its strength and glory. One surrenders one's own self and renounces all strength and pride connected with it, one lose one's integrity as an individual and surrenders freedom; but one gains a new security and a new pride in the participation in the power in which one submerges. One gains also security against the torture of doubt" [8].

These quotes describe the situation that developed in the 20th century and led to the emergence of fascism in Europe. However, all these statements and observations are true for the 21st century, too. The only difference is that the "unshakable eternal and beautiful force" is not the state, a political party with its ideology or a great personality of the leader, but artificial intelligence algorithms and digital technologies lying in their base. The modern individual, who in liberal countries is given a great negative "freedom from", being unable to transform it into something positive, is ready to renounce his "I" in order to gain confidence and be involved in the great power of digital thinking.

A mass person turns out to be ready to transfer to artificial intelligence the right and duty to make decisions in as many areas as possible. Let our digital friends plot the route for us, run businesses and stock markets, diagnose diseases and give recommendations for their treatment, choose music to listen to, books and news to read, movies to watch, count votes in elections and conduct trials, making supposedly objective and impartial decisions. We will only possess and use all this, be great because of the greatness of the incredible computing power that will be at our disposal. With the help of algorithms, we will be able to improve genetic parameters before the birth of a child, and then improve the human body by implanting chips and taking drugs that will expand our capabilities. We will be able to instantly master complex professions and gain the necessary knowledge, for example, through augmented reality systems and neural networks integrated into glasses, mastering new languages or learning to fly a helicopter. However, we ourselves, i.e., our "I", will become maximally leveled at the same time. On the one hand, we will become consumers, on the other – slaves, since a slave is only a tool serving the subject of thinking and decision-making. The slave himself does not think and does not makes decisions.

Digital totalitarianism is no longer an anti-utopia, but a new reality, the space of existence of which is steadily growing, threatening to engulf the entire modern human civilization. Totalitarianism (from Latin *totalis* – whole, total, complete ← *totalitas* – wholeness, completeness) is a political regime implying an absolute (total) control of the state over all aspects of public and private life. The widespread introduction of gadgets and artificial intelligence algorithms is doing a better job of providing control tools than any police service that has ever operated.

Digital totalitarianism is much more awesome than all previously existing systems of this kind because the subject of power and control in it is impersonal. Instead of a person (a politician, a policeman or a neighbor in a communal apartment), artificial intelligence performs the functions of control and making a number of decisions about encouragement or punishment – supposedly neutral and objective. The layman cannot see any evil intentions in his actions, which means that he cannot but accept what is happening for granted, as some natural forces, which, however, are not such.

The presented author's analysis shows that the pessimistic scenario of the development of events does not necessarily imply the uprising of machines and the physical destruction of people by them. Probably, people will be eliminated in a different way – mentally. We will simply cease to be thinking beings, delegating this quality to machines, and thereby cease to exist as a species. The history of a reasonable person will end by this, he will be replaced by a digitalized, bio-digital convergent.

Digitalized Human

A digitalized human is a potentially new species of living beings, a species of the genus *Homo* from the family of hominids in the group of primates. Under certain circumstances, he will be able to have a special physiological structure, as well as appearance, behavior. His defining distinctive feature is the introduction of various kinds of chemicals and electronic devices into the body; the mediation of most of the mental processes by artificial intelligence algorithms integrated into the global information network. In fact, residents of technologically developed countries already have many signs of a digitalized human, the emergence of which is due to the increasing role of gadgets, as well as the information received and processed with their help. The decisive step in the context of the proposed evolutionary leap should be the integration of biological and digital technologies into the unified system of regulation of human status and behavior. Today we are already close to this in terms of the technical feasibility of such a system [3]. If it is formed up, the probability of the appearance of global digital totalitarianism will increase by orders of magnitude.

In order to more clearly see the trend of replacing a person with a computer in the field of intellectual activity, we present some statistical information [9], reporting that during the 20th century the level of intelligence on average increased significantly. This phenomenon is called the Flynn effect – a statistical occurrence that is expressed in a gradual increase in intelligence quotient (IQ) over the years, both in particular countries and in the whole world. This process seems paradoxical: this growth has been observed for decades, therefore, it is difficult to explain it by evolutionary-genetic factors as a literal "wisening" of the human race.

J. Flynn showed [9] that from 1934 to 1978 the average IQ of US residents increased by 15 points – about three

points for each decade. Similar studies in other countries have yielded similar results. Thus, a New Zealand psychologist described a 20-point increase in IQ of Dutch conscripts from 1952 to 1982. However, experiments conducted after 2000 demonstrated a decline in the Flynn effect: IQ growth slows down, stops or even gives way to a decline. In 2004, the data on IQ of Norwegian conscripts showed that after the mid-1990s, growth stopped and was replaced with a decline. Studies by T. Tisdale and D. Owen, conducted in 2005 and in 2008, demonstrated that the IQ test results of Danish conscripts grew from 1959 to 1979 by three points per decade; during 1979–1989 increased by only two points; during 1989–1998 – by 1.5 points; during 1998–2004 decreased by the same 1.5 points. In the future, the situation only worsened. It is important that the turning point, when, after a long period of growth, people's intellectual abilities began to decline, chronologically coincides exactly with the beginning of the computerization of society. Natural thinking in the presence of an alternative (replacement) turns out to be simply redundant.

Civilizational development reaches its culmination, gaining the possibility to replace not only the natural environment surrounding an individual, but also the individual himself in his natural dimension. Taking into account the fact that humanity, due to this, gets at its disposal new unprecedented computing capabilities, and a digitalized human may seem superhuman to someone, this situation is sometimes assessed as progressive. Some believe [3] that it is good to transfer the function and the right to make key decisions to a sufficiently developed artificial intelligence. However, before agreeing with such statements, it is necessary to figure out whether artificial intelligence is capable of fulfilling the role promised to it and which it is already taking over.

Fundamental Limitations of Artificial Intelligence

What is intelligence and artificial intelligence?

We consider the automatic car control system to be an intelligent system and, moreover, we are sure that an automated car is controlled by artificial intelligence. Is it really so? Is there really a smart house in which we can open a window with the help of a smartphone, although it is uncomfortable to live in this house, and sometimes it is dangerous for health? Is it possible to call a smart city a place where millions of people live and work, where "smart" "green" electric cars kill hundreds of residents, including children, on the streets every year, as previously they were killed in car accidents by environmentally dirty cars equipped with an internal combustion engine? The soil is covered with asphalt under electric cars; being in them, just like in ordinary cars, you will need to stand in traffic jams for hours and breathe carcinogenic fumes from asphalt heated in the sun and tire and roadway wear products.

A natural question arises: on what basis is electric energy considered the safest and most environmentally friendly for those electric cars? In fact, it is safe only at the place of its consumption, and not at the place of its production. No need to go far for examples:

- the environmental disasters in Chernobyl and Fukushima are the result of industrial production of electric energy obtained from the atom;
- acid rain, global warming and the destruction of the protective ozone layer of the planet are a by-product of thermal power plants;
- flooded thousands of square kilometers of fields and forests are the result of the construction of hydroelectric dams, which not only block the migration routes of fish, but also grind all living things with their turbines, sending down a nutritious broth for the reproduction of pathogenic microflora [10];
- wind turbines that kill millions of birds [11] because they do not see the rotating turbine blades. In addition, the blades, in which speed of movement can reach the speed of sound, create an intense noise and vibration (from low-frequency to high-frequency, as a result of which earthworms (a source of soil fertility) are dying in the area) and make life unbearable for people even a few kilometers from such supposedly "green" power plants;
- humming wires of high-voltage power lines, under which it is impossible to grow and graze cattle. Moreover, it is dangerous to live and work nearby because of a strong alternating electromagnetic field [11].

One can argue about how composite a mechanism of an electric car is and how difficult it is to control it with six simple actions: "gas", "brake", "forward", "backward", "left", "right". And why is involvement in driving a car becomes the main and defining feature of something insanely "smart", nicknamed "artificial intelligence"? However, since the very concept of intelligence came from a *Homo sapiens* – the pinnacle of perfection of living matter, it is necessary to find the essence of this term not in mathematics and physics, not in philosophy and business, but in the "Life" concept, i.e., in living organisms.

The basic structural unit of any living organism is the DNA molecule, in which all its genetic information is recorded. There are hundreds of billions of parts in this molecule – atoms of various chemical elements [12] embedded in well-defined places in a molecular-spatial structure of the highest complexity. There are only a few thousand parts in an electric car. So, from an engineering point of view, the DNA molecule is unimaginably complex – it is millions of times more complicated than an electric car. DNA is even more complex than all innovative technologies combined, created by thousands of generations of people of our civilization (about 100 bln people who lived on the planet in total) over a long human history (more than a million years, since the invention of the first bonfire): bolts and nuts, bridges and skyscrapers, internal combustion engines and turbines, rockets and airplanes, cars and railways, computers and smartphones, as well as thousands and thousands of other engineering technologies.

The DNA molecule is also more complex than the entire inanimate part of our vast Universe (i.e., without planet Earth), stretching for tens of billions of light-years, consisting of trillions of trillions of planets, stars, galaxies and clusters of galaxies. After all, the Universe, which, according to one of the theories, emerged randomly from the singularity as a result of the Big Bang, was formed over billions of years (during the expansion of energy and matter in three-dimensional Space) under the influence of physical laws that arose in the singularity, which we then called the laws of physics. They are the "genes" that created our Universe. Such dead (i.e., inanimate) physical "genes" can be described by much simpler mathematical formulas than the genes of the DNA molecule that give life. The formation of planets, stars, galaxies and their clusters occurred mainly under the influence of just one of the features of matter – its inherent gravity [13]. It is this main "gene" of the growth and development of the Universe that has fulfilled its important mission: it has collected hydrogen into stars and ignited them, including the Sun; created black holes that formed galaxies around them; collected rocks and stardust into planets, including the Earth, on which life was born, perhaps the only one in the boundless Universe.

The industry consists of its industrial "bricks" – units, mechanisms, equipment, various technological processes and materials, with which factories, power plants, roads and other industrial systems of countries, regions and the Earth's technogenic civilization as a whole are then built. At the same time, its entire industrial power – the terrestrial technosphere – in its intellectual potential, as well as the entire intellectual potential of all people who lived on Earth and created this technosphere for thousands of generations, as justified above, is very much inferior to the intelligence of the Creator who invented such a "simple brick" of any living organism (but not life and the biosphere in general) as the DNA molecule.

Every living cell of any living organism is millions of times more complex than DNA, and, for example, there are about 40 tln of them in an adult human body alone [14]. All the tissues, organs and systems of our body are composed of these cells (there are about 230 types of them): 850 muscles, 208 bones, 230 joints, 10 main systems, 78 organs, dozens of glands, billions of endocrine cells that produce thousands of completely different secretions, hormones and biologically active organic substances that regulate the most complex biochemical reactions – metabolism in cells and organs. In addition, the human body is endowed with a most complex internal transportation system – more than 100 bln blood vessels alone with a total length of about 100,000 km with 25 tln "vehicles" [15], i.e., red blood cells (if all red blood cells are placed in one line, close to each other, it will stretch for almost 200,000 km), and also has its own informational network – nerve fibers with a total length of about 150,000 km. At the same time, there is a huge number of all kinds of links (energy, informational and productional) both inside the body and with the outside world, the exact number of which is impossible to calculate: it is likely to be more than googol, but this number is unimaginably large.

Undoubtedly, the Creator was an engineer (but not a banker, politician, economist, philosopher, priest or oligarch), and the human body is more complicated in its engineering complexity than anything that our technocratic civilization has created in the entire history of its existence, by myriads of myriads of times, and it is impossible to define this complexity more precisely than abstract "myriads".

Let us imagine a person lying in a coma. His body functions normally, organs and systems work properly, while the work of this hyper-complex creation is controlled by his brain without anyone's help. However, such person does not have consciousness. Is it possible to say that in such a state he has intelligence? Of course not.

Conclusion: Possible Scenarios for Further Development

We began to use the term "artificial intelligence" to refer to primitive process control systems, like a car, with the help of primitive machines – hardware-computers, which are, in fact, high-speed calculators. At the same time, it should

be noted that such an "intelligence" has no consciousness, spirituality, worldview, morality, ethics, virtue, culture, goal-setting. After all, it is obvious that the ability to count quickly and manage any processes, both technological and vital, is not included in the concepts "mind" and "intelligence".

The main reason for the emergence of ideas that the digit should guide the individual, society and humanity as a whole, according to the authors, is the desire of the "global elite" to obtain super profits with uncontrolled and irresponsible management of humanity, reduced to the level of a digital biorobot-convergent, where each digitized humanoid being will become only a faceless ant or a working bee in a hive.

From an engineering point of view, an attempt to create a "brave new world" of inclusive capitalism is no better than the idea of creating a world in which, for example, an incredibly complex virus, such as COVID-19, will control the flight of a primitive Boeing aircraft. Specialists in the field of digital technologies, and they supposedly "know everything and can do everything", will easily "teach" the necessary piloting skills. The fact that the simplest virus made up by the Creator is incredibly more complicated than any of the most elaborate man-made machine, which is described in detail above, is at least confirmed by the fact that we know how to design and manufacture aircraft from scratch and then improve them, including autopilot-ing, so that they fly even better. But the virus is something different, a person is not able to construct it from scratch, from atom to atom, he can only somehow modify a natural virus, completely unaware of the long-term consequences of such an engineering transformation.

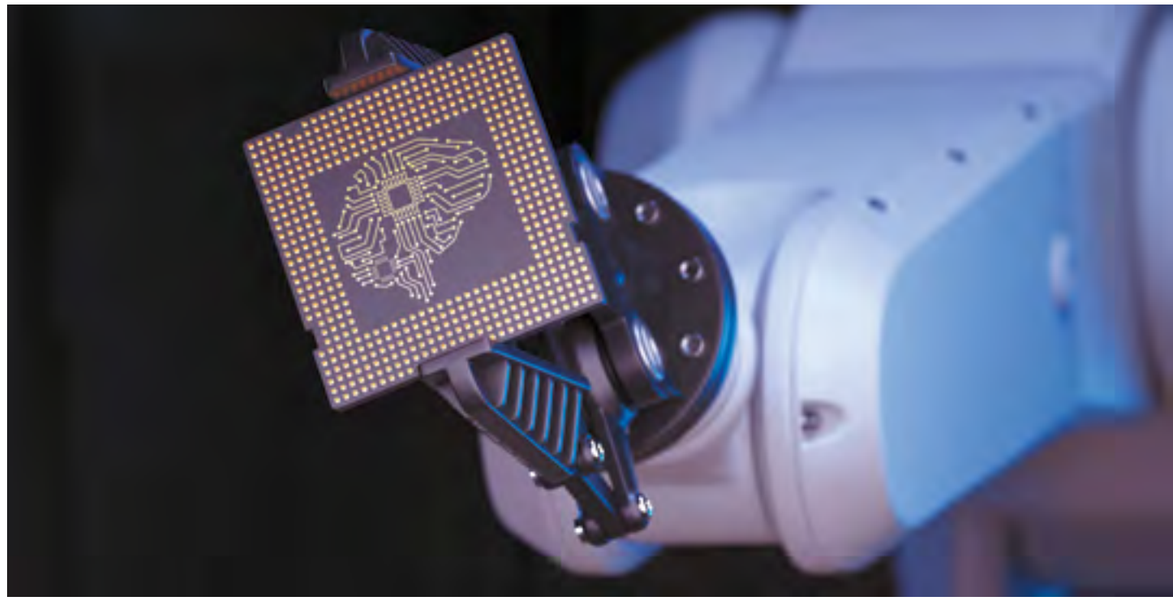
It is well known that the management of simple systems should be handled by more complex ones, and not vice versa, as it is planned to do in the virtual universe currently being created. In addition, the control system should be more complicated to manage by many, many orders of magnitude. Obviously, the mentioned airplane cannot be controlled, for example, by a mosquito, millions of times more complex than a virus, and even a monkey, even more complicated. The "successes" of the so-called "artificial intelligence" (they are all imaginary, not real) are due not to the fact that it is supposedly very "smart", but to the fact that it was generated and accompanied by the creator – a human intellectual. Moreover, not by him alone, but by a society, and not just the society of some single African tribe, but by that of the entire Earth's technocratic (i.e., industrial) civilization.

It was civilization that gave each person the main components of his personal intellect – awareness, spirituality, morality, culture, goal-setting, knowledge, including scientific knowledge, created over thousands and thousands of generations of the development of *Homo sapiens* and the Earth industry as a whole, which, in fact, allowed the development of a high-speed computing digital machine. This means that a stillborn (because it is not alive), unreasonable and spiritless child of the technological progress called "artificial intelligence" should by no means be guided by its creator – a person with a real living intelligence. Otherwise, everything will be like in the story with an airplane controlled by a virus, a mosquito or a monkey: after taking off, such a "smart" device will certainly crash, at least for the simple reason that, even after learning how to control the equipment, a mosquito will not learn how to use it reasonably.

The essence of civilization, which consists in establishing an order parallel or alternative to the natural one, can be implemented in the ultimate perspective only in three scenarios. The first is the global oppression of all living things and the displacement (replacement) of it with artificial ones. The second is the rejection of the civilizational (technological) path of development and the return to the wild, accompanied by the triumph of nature. The third is the establishment of a balance between nature and artificial forms of arrangement of matter and thought. The latter scenario is possible only with a strict distinction between the technosphere and the biosphere, including segmentation of the areas of application of digital and natural thinking. Space is for industry, Earth is for life. Artificial intelligence is for technology, human intelligence is for human society.

References

1. *Civilization [Electronic resource] // Wiktionary. – Mode of access: https://en.wiktionary.org/wiki/civilization. – Date of access: 01.09.2022.*
2. *Perevod: s latinskogo na russkiy [Translation: From Latin to Russian] [Electronic resource] // Slovari i entsiklopedii na Akademike. – Mode of access: https://translate.academic.ru/lex/la/ru/. – Date of access: 01.09.2022.*
3. *Kharari, Yu.N. 21 urok dlya XXI veka [21 Lessons for the 21st Century] / Yu.N. Kharari. – Moscow: Sindbad, 2019. – 416 p.*
4. *Izmeneniye klimata: posledstviya, smyagcheniye, adaptatsiya [Climate Change: Consequences, Mitigation, Adaptation]: Educational and Methodical Complex / M.Yu. Bobrik [et al.]. – Vitebsk: VGU im. P.M. Masherova, 2015. – 424 p.*
5. *The World's Smartest Artificial Intelligence Just Made Its First Magazine Cover [Electronic resource] // Cosmopolitan. – Mode of access: https://www.cosmopolitan.com/lifestyle/a40314356/dall-e-2-artificial-intelligence-cover/. – Date of access: 01.09.2022.*
6. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
7. *Recommendation on the Ethics of Artificial Intelligence [Electronic resource]. – Mode of access: https://unesdoc.unesco.org/ark:/48223/pf0000380455. – Date of access: 17.11.2022.*
8. *Fromm, E. Escape from Freedom / E. Fromm. – New York: Avon Books, 1965. – 334 p.*
9. *Valuyeva, Ye.A. Effekt Flinna: obzor sovremennykh dannykh [The Flynn Effect: Overview of Current Data] / Ye.A. Valuyeva, S.S. Belova // Psikhologiya. Zhurnal Vysshey shkoly ekonomiki. – 2015. – Vol. 12, No. 4. – P. 165–183.*
10. *Bark, I. Zhertvy ekologicheski chistoy energii: skol'ko ptits gibnet ot vetrogeneratorov [Victims of Eco-Friendly Energy: How Many Birds Die from Wind Turbines] [Electronic resource] / I. Bark. – Mode of access: https://www.techinsider.ru/science/579664-vyyasnilos-skolko-ptic-gibnet-ot-vetrogeneratorov/. – Date of access: 01.09.2022.*
11. *Dams and Development: A New Framework for Decision-Making: The Report of the World Commission on Dams [Electronic resource]. – Mode of access: https://archive.internationalrivers.org/sites/default/files/attached-files/world_commission_on_dams_final_report.pdf. – Date of access: 01.09.2022.*
12. *Nachala sovremennogo yestestvoznaniya [The Beginnings of Modern Natural Science] [Electronic resource] // Slovari i entsiklopedii na Akademike. – Mode of access: https://estestvoznanie.academic.ru/396/ДНК.– Date of access: 01.09.2022.*
13. *Gul'karov, I. Kakova rol' gravitatsii vo Vselennoy [What Is the Role of Gravity in the Universe] [Electronic resource] / I. Gul'karov. – Mode of access: https://www.kontinent.org/article.php?aid=5335a2abd1aa7. – Date of access: 01.09.2022.*
14. *Kletka [Cell] [Electronic resource] // Entsiklopediya Krugosvet. – Mode of access: https://www.krugosvet.ru/enc/biologiya/kletka. – Date of access: 01.09.2022.*
15. *The Heart & Blood Vessels Explained [Electronic resource] // Hirslanden: Swiss Hospital Group. – Mode of access: https://www.hirslanden.com/en/international/focus/heart/heart-bloodvessels.html. – Date of access: 01.09.2022.*



Legal Aspects of the Use of Artificial Intelligence in the Implementation of the uSpace Geocosmic Program

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UDC 004.8:349:346.7

This work is the first attempt in domestic and foreign legal doctrine to comprehend and systematically analyze the use of artificial intelligence (AI) in the implementation of the uSpace geocosmic program. The research methodology includes the use of general scientific, interdisciplinary and special legal methods. This explains the relevance of the topic, its scientific significance, novelty and the author's approach. The theoretical and legal aspects of AI have been reviewed, and possible ways of using it during the implementation of the uSpace program have been disclosed. A comparative legal analysis of the current trends in the legal regulation of AI at the international level has been carried out. The most serious problematic issues of using AI in the light of public and private law have been identified, and prospective ways to resolve them have been shown. The formulated conclusions and proposals are aimed at innovative regulation of social relations that mediate the use of AI in the implementation of the uSpace program, and serve as the basis for further scientific research of a special orientation.

Keywords: *artificial consciousness, artificial intelligence (AI), artificial intelligence system, artificial intelligence technologies, uSpace geocosmic program.*

Introduction

As is rightly noted in the literature, the development and industrialization of near space by rockets is largely futile. This is explained by a number of scientifically substantiated facts, among which are the extremely expensive nature of rocket launches and the low transport productivity of the modern global rocket and space industry. An important factor is also the presence of very obvious cause-and-effect relationships between inefficient rocket astronautics and the emergence of global environmental problems, such as the destruction of the ozone layer, environmental pollution, adverse changes in the physical parameters and chemical composition of the atmosphere, the occurrence of ionospheric turbulence, etc. [1]. The way out of this situation seems to be the use of alternative methods of industrialization of near space, which are distinguished by improved characteristics in the field of productivity, safety and ecology. From the point of view of both theoretical and applied science, it is necessary to recognize the solutions and methods developed within the framework of the uSpace geocosmic program as the most fundamental and justified way of alternative space exploration.

This program includes many components, which we will discuss below. An unquestionable advantage in terms of its implementation is the introduction of artificial intelligence systems in various spheres of public relations, which is reflected in the studies of national and foreign authors [2–7]. The use of artificial intelligence (AI) entails many systemic problems. Among them are problems of law that are closely related to cognitive science, neuroscience, philosophy, ethics, morality, virtue, information and public security, as well as a number of other complex and interdisciplinary areas.

Noting the unquestionable importance of introducing the issues of using AI in the above studies, including those published in the collections of articles of the conference on non-rocket space industrialization [8, 9], it should be said that this topic was not the central link of scientific research. AI is often mentioned fragmentarily by the authors in the context of the general direction of scientific activity, and the issues related to it are mostly descriptive or explanatory. It is worth noting the absence of interdisciplinary works reflecting a systematic approach to the use of AI in the solutions and methods offered by the uSpace program, as well as the absence of doctrinal studies on the legal aspects of its application.

Below are the results of a scientific study of the legal aspects of the use of AI in the implementation of the uSpace program in the context of the identified issues, and possible options for overcoming the most significant gaps in the legal doctrine associated with the use of AI technologies have been proposed.

Theory of Artificial Intelligence

The Concept of Intelligence and Cognitive Functions

When studying the "artificial intelligence" concept, it is first necessary to understand what is meant by intelligence. With regard to the word "intelligence" there is no terminological unity, which is due to the interdisciplinary nature of this concept, its connection with many areas of human knowledge – philosophy, science, psychology, etc. The term "intelligence", as well as a number of others, such as "consciousness", "psyche", "mind", "reason", is extremely difficult for a person to understand and evaluate. This is largely determined by the fact that the subject and object of research here coincide in one person, the intelligence studies and analyzes itself, which is an insoluble philosophical and scientific problem. At the same time, for the present it is obvious that for its solution it is required to reach a new qualitative, not quantitative level. That is, progressive and non-standard scientific methods should be the basis, and not an increase in the accuracy of measuring instruments.

Nevertheless, the concept of intelligence can be found in doctrinal sources. So, Encyclopaedia Britannica defines human intelligence as "mental quality that consists of the abilities to learn from experience, adapt to new situations, understand and handle abstract concepts, and use knowledge to manipulate one's environment" [10]. The Great Russian Encyclopedia interprets intelligence as a general cognitive ability, which manifests itself in how a person perceives, understands, explains and predicts what is happening, what decisions he makes and how effectively he acts (primarily in new, complex or unusual situations) [11].

Man, being a creature with a developed intelligence, has a number of cognitive (higher mental) functions, which include perception, imagination, memory, thinking, speech, spatial orientation, understanding, calculation, learning (self-learning), reasoning, etc. The human intelligence also has a creative function, i.e., the ability to create something new that did not exist before (creativity).

The Concept of Artificial Intelligence

There are different representations of the "artificial intelligence" concept. It can be interpreted as a software and hardware complex (an artificial intelligence system); property inherent in an artificial intelligence system; technology group; scientific field. The said terminological apparatus is systematically presented in Figure 1.

Based on these data, we can conclude that AI is primarily a property of an intelligent system, just as intelligence is a property of the human psyche. The fundamental goal of AI is to mimic the human cognitive functions we listed earlier at a level comparable to or above that of a human. AI is often identified with an artificial intelligence system, which is a software and hardware complex based on AI technology (computer vision, intelligent decision support, etc.).

Artificial Intelligence and Artificial Consciousness

One of the key philosophical problems of the modern digital society is, of course, the issue of strong and weak AI. The postulates underlying the identified problem serve as a kind of reminder of what significant risks the creation of AI entails.

Strong and weak AI is a hypothesis in the philosophy of AI, according to which its individual forms can actually justify and solve problems. The theory of strong AI suggests that computers can acquire the ability to think and be aware of themselves as a person (in particular, to understand their own thoughts), although not necessarily that their thought process will be similar to a human. The theory of weak AI rejects this possibility [14].

These theories correlate with the term "artificial consciousness", which refers to a non-biological, man-made machine that is aware of its own existence [15]. The risks of a machine acquiring artificial consciousness are difficult to predict. They range from a person acquiring a devoted friend to the destruction of all mankind. The key problem in this case is the fact that in cognitive science today there is no real methodology for determining whether a robot has synthetic consciousness, and its development is not expected in the near future. If at some point in time an artificial consciousness arises in a robot, the society may find out about it too late, which will become one of the central problems, including those in legal science.

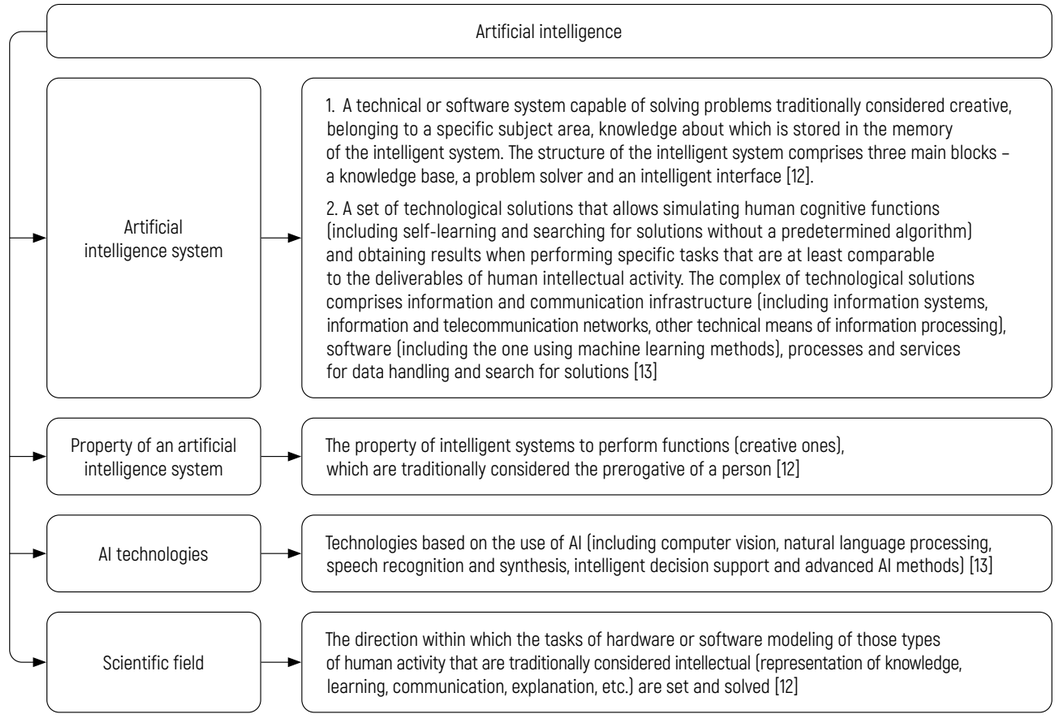


Figure 1 – Artificial intelligence. Terminological apparatus

The Problem of Using Artificial Intelligence

The Problem of Using Artificial Intelligence Through the Prism of Public Law

We will consider the issue of using AI in the public sphere, first of all, using the example of the branch of constitutional law (Figure 2) [16–18].

It is noteworthy that world practice already knows symbolic examples of recognizing AI as possessing the status of a person. So, the world-famous anthropomorphic robot Sophia was awarded the citizenship of Saudi Arabia [19, 20], which is highly ambivalently assessed by representatives of the scientific community and human rights organizations.

The emergence of synthetic consciousness and the potential recognition of AI's status of an "electronic personality" entails significant risks for all of humanity. It is obvious that intelligent systems with artificial consciousness will have their own beliefs, goals and motives that may run counter to the interests of a person, his ideas about morality, virtue, ethics and the place of AI in the system of social relations. We can assume that *Homo sapiens* will not be needed by intelligent systems at all, because, acting as the creator of AI and being the dominant species among living creatures on the planet, it will in many ways limit AI in actions and rights, try to use it in its own interests, because the main goal of AI is imitation of human cognitive functions for the benefit of society.

In connection with the foregoing, the recognition of AI's status of a person, even symbolic, is premature today. Moreover, such steps, of course, require the prior adoption of certain control and response measures. In the context of the implementation of the uSpace program, the unquestionable importance of AI as a human assistant, but not as a controlling person or manager, is emphasized.

In order to ensure the right to privacy, it is necessary that legislation reflects the restrictions on the creation and use of AI, up to a complete ban on certain technologies related to total surveillance. This approach is currently being actively discussed in the European Union when adopting a Regulation on AI [21].

From the position of criminal law, a number of problems can also be identified (Figure 3).

In the context of the implementation of the uSpace program, the monographic study by I. Mosechkin arouses special interest [22]. Considering ways to improve the protection and regulation of AI in criminal law, the author proposed a fundamentally new approach to the criminal law qualification of illegal acts, the object of which is public relations in the field of traffic safety and transport operation.

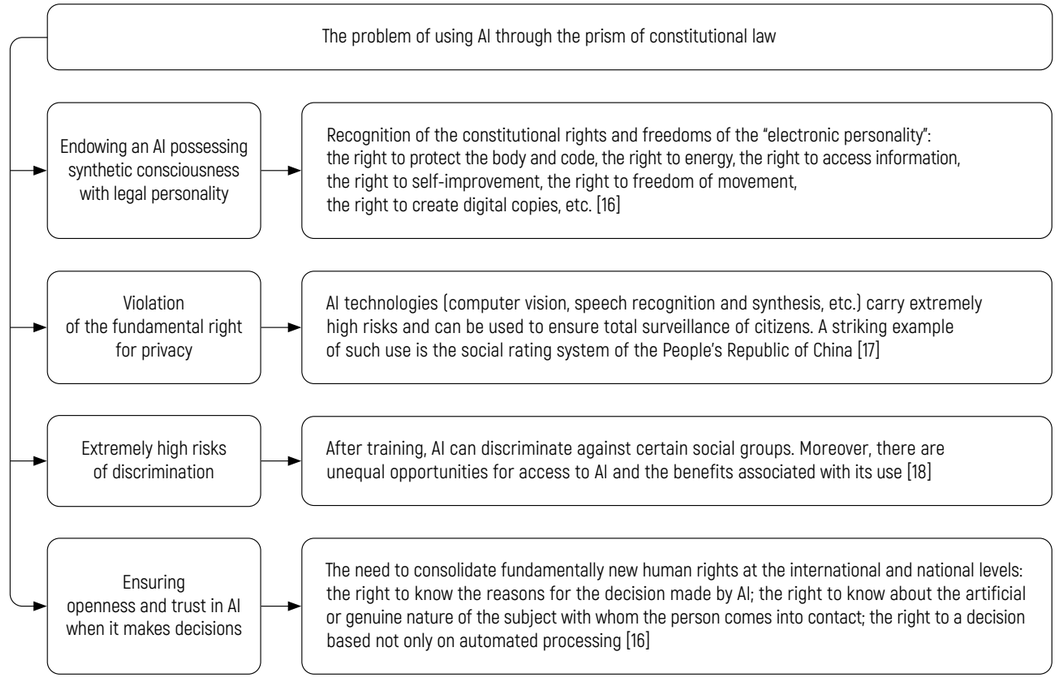


Figure 2 – The problem of using AI through the prism of constitutional law

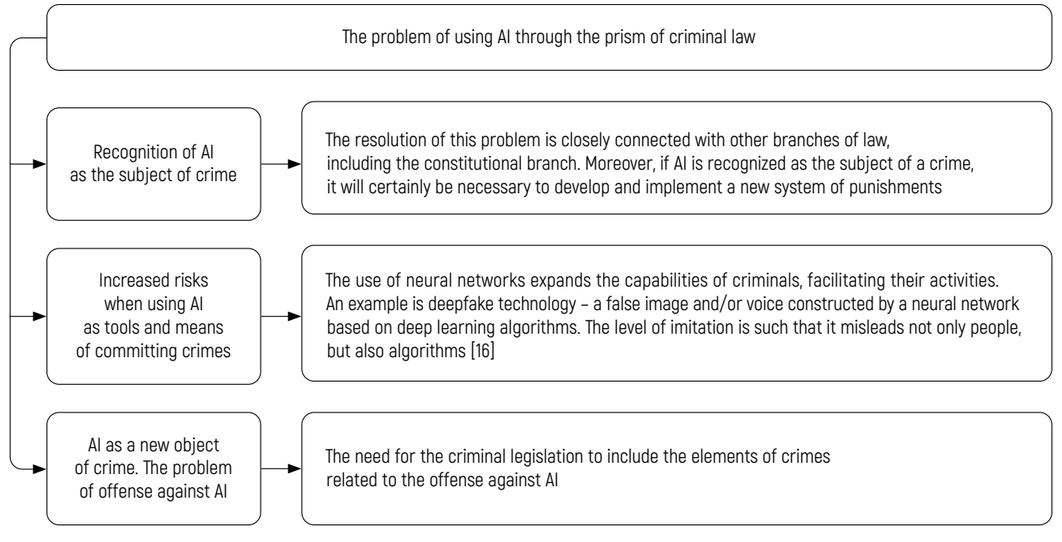


Figure 3 – The problem of using AI through the prism of criminal law

According to I. Mosechkin, it seems expedient to include in the criminal legislation the elements of crimes that commit offence against artificial intelligence systems of unmanned vehicles (UVs). The said elements include the commitment of the following unlawful acts:

- creation, distribution and/or use of computer programs for the purpose of destroying, blocking, modifying or neutralizing the means of protecting the UVs;
- illegal access to software and hardware of UVs;
- violation of the rules for the operation of software and hardware of the UVs or the rules for accessing them, which resulted in damage.

The Problem of Using Artificial Intelligence Through the Prism of Private Law

Let us analyze the problems of AI application in the private sphere using the example of the branches of civil law (Figure 4) and labor law (Figure 5).

From the perspective of labor law, the use of AI technologies also entails many risks (Figure 5).

The development of neuroprosthetics technologies and the creation of hybrid systems – cyborgs, in our opinion, is a key problem in the doctrine of labor law. This is due to the fact that cyborgs will have significant advantages in being hired, in most cases they will become the most sought-after personnel. In connection with the above, it seems necessary to provide for social guarantees in the legislation for persons who do not have such neuroimplants.

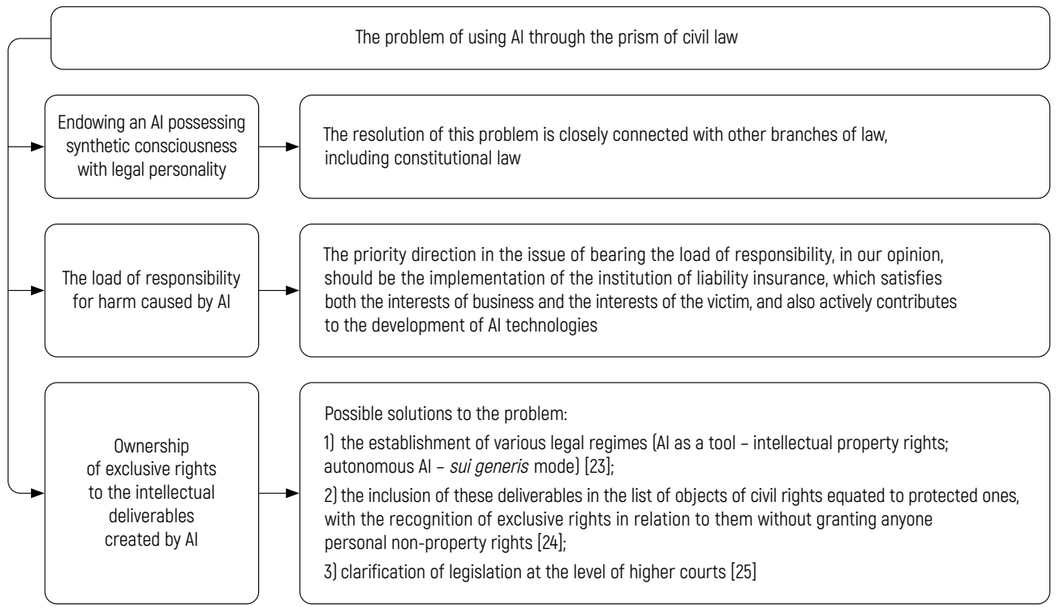


Figure 4 – The problem of using AI through the prism of civil law

Regulation of Artificial Intelligence at the International Level

Legal Regulation of Artificial Intelligence

The social relations emerging in the digital field are significantly ahead of the processes of their legal regulation – this is a global trend.

To date, there are no international treaties, the subject of which is the regulation of public relations for the creation, implementation and testing of AI. Only separate legal documents have been adopted that are not recognized by international treaties, which form the basis for the future regulation of AI.

Among these acts it is necessary to highlight:

1) UNESCO draft Recommendation on the Ethics of Artificial Intelligence, 2021 [26].

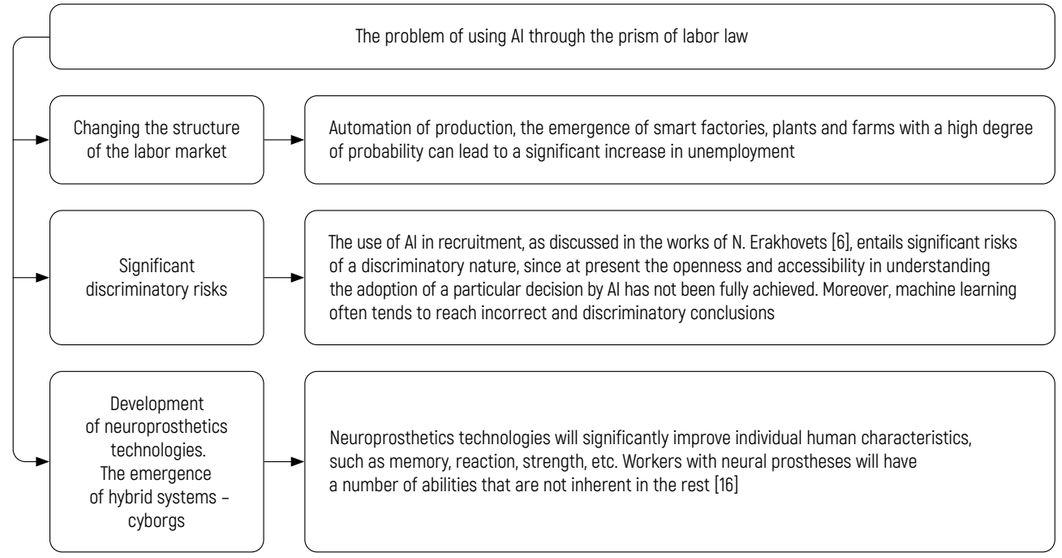


Figure 5 – The problem of using AI through the prism of labor law

The main goal of developing this document:

- laying the foundation that will allow the use of AI for the benefit of all mankind, the individual, society, the environment and ecosystems and prevent them from being harmed;
- encouraging the use of AI-based systems for peaceful purposes.

The document provides detailed explanations of AI values, such as respect, protection and promotion of human dignity, rights and freedoms of man; well-being of the environment and ecosystems; ensuring diversity and inclusiveness, etc.

This project also reinforces the key principles of activity in the field of AI: proportionality and non-harm; safety and security; fairness and non-discrimination; privacy; transparency and explainability; control and subordination to a person, etc.;

2) Recommendation of the OECD* on Artificial Intelligence, 2019 [27].

The document defines the following principles for the use of AI: inclusive growth, sustainable development and well-being; equity and human-centered values; transparency and explainability; reliability and safety; accountability (responsibility).

This act also provides recommendations for national governments in the field of AI regulation: ensuring long-term public and private investment in research and development of AI; creating a digital ecosystem for AI; creating a favorable political environment for AI; building human capacity and preparing for labor market transformation; developing international cooperation for trustworthy AI.

Thus, the international legal regulation of AI today is represented exclusively by the norms of "soft law", which are advisory in nature. This trend is explained both by the novelty of the subject of legal regulation, and by the desire of each individual state to achieve personal gain without the establishment of strict regulations by the world community. By the way, a similar situation is developing in the field of legal regulation of space exploration, which is reflected in the works of A. Kazakevich [28].

At the same time, a number of the principles described above are declarative. Thus, computer vision systems are used to spy on citizens, which directly violates the principle of privacy, while the principle of transparency and explainability of decision making by AI cannot be fully implemented because AI creators often lose control over its learning process and cannot explain the decisions it makes.

* Organization for Economic Co-operation and Development, founded in 1948, headquartered in Paris.

Technical Statutory Regulation of Artificial Intelligence

The legal regulation of AI lags far behind the technical one, in which the International Organization for Standardization (ISO) has taken a leading position. Since 2017, Committee on Artificial Intelligence has been functioning in the ISO, which has so far published 11 standards in this area, focused on AI bias, AI decision-making, its reliability, as well as assessing the reliability of neural networks, AI computational approaches, scenarios for its use and big data. The ISO Committee on Artificial Intelligence is developing 27 more standards that will form the basis of future AI projects around the world. These standards can be found on the official ISO website [29].

The diagram of AI regulation at the international level is presented in Figure 6.

Possible Ways of Using Artificial Intelligence in the Implementation of the uSpace Geocosmic Program

The uSpace geocosmic program is a concept of non-rocket exploration of near space using the General Planetary Vehicle (GPV), implementation of which will ensure the preservation of the biosphere by moving the industry (technosphere) outside the planet Earth (beyond the boundaries of the biosphere).

In addition to the GPV, the uSpace program provides for the development and construction of the GPV takeoff and landing overpass (uWay), Equatorial Linear City (ELC), Industrial Space Necklace "Orbit" (ISN "Orbit"), EcoCosmoHouse (ECH).

The uSpace program is an integral part of the EcoSpace program, which is aimed at implementing such eco-oriented areas as Unitsky String Technologies (uST), linear cities (uCities), EcoHouse, uEnergy, uGreen.

Some issues of using AI systems in the implementation of the uSpace program were raised by researchers in papers published at the conferences "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" [8, 9].

Thus, M. Akbari considers AI as one of the technologies of Industry 4.0, acting as a leading driver of innovation in supply chains for geospace systems [5]. N. Yerakhovets suggested using AI as a modern tool for the formation of human capital for the implementation of complex projects with an enclosed social system [6]. The search for a possible integration of a single digital economic model for managing the EcoCosmoHouse object with blockchain, AI and quantum data encryption technologies was declared one of the key areas for further scientific research by a team of authors consisting of A. Unitsky, A. Kushnirenko, A. Kostyuk and E. Kulik [7].

Engineer A. Unitsky in his monograph "Civilization Capacity of the Space Home Named Planet Earth" [2] analyzes the positive and negative aspects of AI as an integral part of the digitalization process of society and economy.

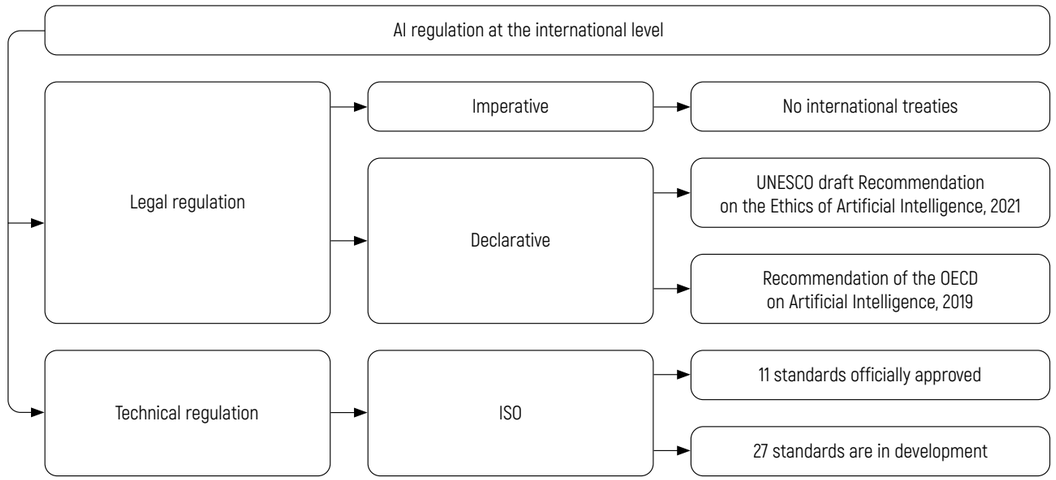


Figure 6 – Diagram of AI regulation at the international level

The author points out the crucial importance of the ethical use of intelligent systems in the implementation of the EcoSpace program, in which AI should take the place of an assistant and adviser to a person, but not a controlling body. Moreover, the basic principle of the implementation of the uSpace program is defined: the concepts of "artificial intelligence", "smart city", "smart factory", "smart vehicle" should be based not on the availability of a program code and technical complex, but rather on increased requirements to human security, productivity, environmental protection, etc. Otherwise, AI will purely be a brand, behind which there is no fundamental scientific and technical base.

In our opinion, the use of AI in the context of the uSpace program implementation should become one of the key areas for future research by the authors in accordance with their industry-wise specifics. The authors' solutions presented in the Table below can be used as a basis for special scientific research.

Conclusions and Future Work

The use of AI in the context of the implementation of the uSpace geocosmic program is a key area of research and economic activity. Intelligent systems can be successfully applied in various solutions and methods developed within the framework of the uSpace program, in accordance with their industry specifics (transportation, production, agriculture, construction, etc.). In the course of this study, the theoretical aspects of the implementation of AI have been analyzed, and the ways of its application in the context of the fulfillment of the uSpace program have been outlined.

Table – The use of AI in the context of the uSpace geocosmic program implementation*

Sector of the economy	AI technologies	Applications in uSpace
Transport	Use of UVs and intelligent transport management systems Route building optimization Ensuring vehicle traffic safety and preventing vehicle breakdowns by predicting malfunctions Robotization of logistic hubs and warehouses	Implementation of uST transport solutions: • in uCities; • in the ELC; • within the framework of the uST orbital string-rail roads located at the ISN "Orbit"
Agriculture	Increasing the efficiency of selection processes by taking into account genetic and phenotypic parameters Increasing yields due to the elaborated autonomous crop care system Reducing maintenance and repair costs by predicting equipment breakdowns	Reconstruction of the terrestrial biosphere: flora, fauna, living fertile soil, terrestrial biogeocenoses within the orbital autonomous multifunctional cluster "EcoCosmoHouse" Creation of smart farms, greenhouses and orangeries
Production	Improving the quality and reducing the cost of product design due to the complex modeling of the parameters of the future product Automation and optimization of production processes and the supply chain by reducing production errors and minimizing the impact of the human factor Effective demand forecasting	Creation of smart industries and factories – TechnoCosmoHouses (TCHs)
Construction	Improving the quality of the construction process by detecting construction errors Modeling and analysis of potential hazards (fire risks, destruction risks, etc.)	Construction: • GPV; • GPV takeoff and landing overpass; • ELC; • multifunctional transport, infrastructure and industrial-residential complex at the ISN "Orbit"

* When describing the possible ways of using AI in the context of the uSpace geocosmic program implementation, the materials of the Roadmap for the Development of "End-to-End" Digital Technology "Neurotechnologies and Artificial Intelligence" were used [30].

When studying the issues of legal regulation of AI at the global level, it was concluded that there are no international treaties in this area, that AI is regulated via "soft law", and that there is a declarative nature and difficult implementation of certain principles and recommendations. As part of the study of the use of AI through the prism of private and public law, a number of legal gaps have been identified, and separate options for overcoming them have been proposed, in particular in the field of intelligent control systems of UVs.

At the same time, the greatest concern in the field of AI is caused by: the emergence of AI's synthetic consciousness and the potential recognition of the AI's status of an "electronic personality"; the emergence in the near future of hybrid systems – cyborgs, which will have significant advantages over people who do not have neuroimplants, which will result in the processes of social stratification and discrimination.

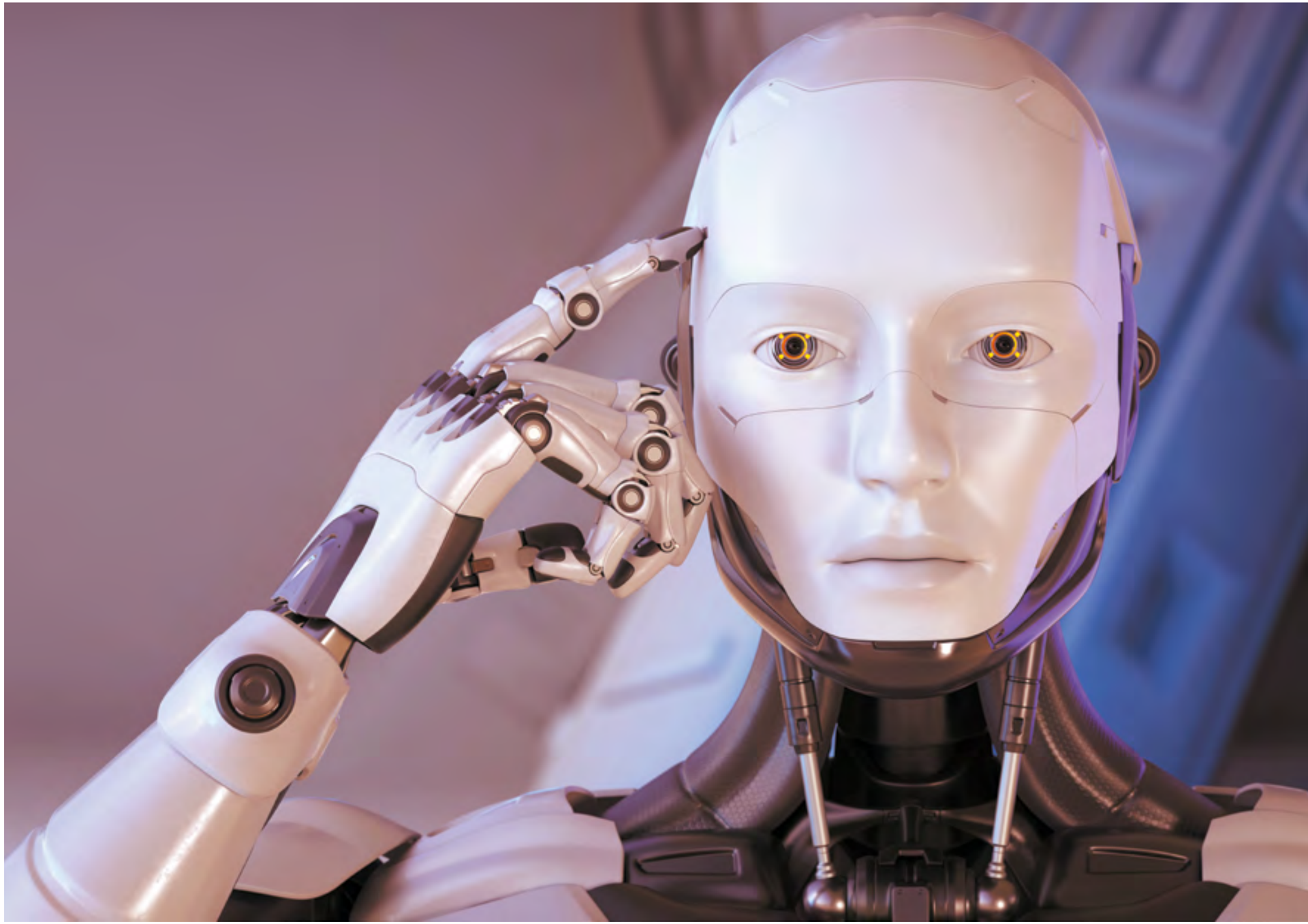
In the context of the implementation of the uSpace program, it is necessary to emphasize the unquestionable importance of using AI as a human assistant, but not as a controlling body or manager. The fundamental principle of fulfilling the uSpace program: the concepts of "artificial intelligence", "smart city", "smart factory", "smart vehicle" should be based not on the fact of the presence of a program code and a technical complex, but rather on increased requirements for human safety, productivity and environmental protection.

It is necessary to specify the following lines of further scientific research within the framework of the problems described in this article: ways to use AI in the implementation of the uSpace program in accordance with industry-wise specifics (biotechnology, engineering, industrial production, energy, agriculture, etc.); industry-wise legal research, the subject of which is the use of intelligent systems in the implementation of the uSpace program; nature of artificial consciousness; legal status of "electronic personality" and the cyborg; regulation of AI at the supranational level, in particular in the European Union; institute of liability insurance in the area in question.

References

1. *Unitsky, A. String Transport Systems: On Earth and in Space / A. Unitsky. – Silakrogs: PNB Print, 2019. – 560 p.: il.*
2. *Unitsky, A.E. Tsivilizatsionnaya yomkost' kosmicheskogo doma po imeni Planeta Zemlya [Civilization Capacity of the Space Home Named Planet Earth] [Electronic resource] / A.E. Unitsky. – Moscow: Mir nauki, 2022. – 136 p. – Mode of access: https://izd-mn.com/PDF/08MNNPM22.pdf?ysclid=la98apfobr284127861. – Date of access: 10.09.2022.*
3. *Badulin, K. Innovative Business Models of the EcoSpace Program Complex / K. Badulin // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 85–89.*
4. *Kabanov, E. Blockchain as a Single Information and Economic Basis of the Equatorial Linear City, Its Transport Systems and General Planetary Vehicle / E. Kabanov // Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – P. 91–95.*
5. *Akbari, M. Poyavleniye tekhnologiy Industrii 4.0 kak klyuchevykh drayverov innovatsiy v tsepyakh postavok dlya geokosmicheskikh sistem [Emergence of Industry 4.0 Technologies as Key Drivers of Innovation in Supply Chains for Geospace Systems] / M. Akbari // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 246–257.*
6. *Yerakhovets, N.V. Optimal'naya komandnaya matritsa dlya dostizheniya tseley konkretnogo kollektiva [Optimal Command Matrix to Achieve the Goals of a Particular Team] / N.V. Yerakhovets // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 266–283.*
7. *Yedinaya tsifrovaya ekonomicheskaya model' dlya upravleniya ob"yektom "EkoKosmoDom na planete Zemlya" [Unified Digital Economic Model for Managing the Object "EcoCosmoHouse on Planet Earth"] / A.E. Unitsky [et al.] // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 360–375.*
8. *Non-Rocket Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the II International Scientific and Technical Conference, Maryina Gorka, Jun. 21, 2019 / Astroengineering Technologies LLC; ed. A. Unitsky. – Minsk: Paradox, 2019. – 240 p.*
9. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*
10. *Human Intelligence [Electronic resource] // Britannica. – Mode of access: https://clck.ru/rcTWa. – Date of access: 22.06.2022.*
11. *Intellekt [Intelligence] [Electronic resource] // Bol'shaya rossiyskaya entsiklopediya. – Mode of access: https://bigenc.ru/c/intellekt-47cb87. – Date of access: 22.06.2022.*
12. *Averkin, A.N. Tolkovyy slovar' po iskusstvennomu intellektu [Explanatory Dictionary of Artificial Intelligence] [Electronic resource] / A.N. Averkin, M.G. Gaaze-Rapoport, D.A. Pospelov. – Mode of access: https://clck.ru/rcTpY. – Date of access: 22.06.2022.*
13. *O provedenii eksperimenta po ustanovleniyu spetsialnogo regulirovaniya v tselyakh sozdaniya neobkhodimykh usloviy dlya razrabotki i vnedreniya tekhnologiy iskusstvennogo intellekta v sub"yekte Rossiyskoy Federatsii – gorode federal'nogo znacheniya Moskve i vnesenii izmeneniy v stat'i 6 i 10 Federal'nogo zakona "O personal'nykh dannykh" [On Conducting an Experiment to Establish Special Regulation in Order to Create the Necessary Conditions for the Development and Implementation of Artificial Intelligence Technologies in the Constituent Entity of the Russian Federation – the City of Federal Significance Moscow and Amending Articles 6 and 10 of the Federal Law "On Personal Data"] [Electronic resource]: Federal Law, Apr. 24, 2020, No. 123-FZ // Konsul'tantPlyus. Rossiya / Consultant Plus Inc. – Moscow, 2020.*
14. *Averkin, A.N. II i kognitivnyye nauki [AI and Cognitive Sciences] [Electronic resource] / A.N. Averkin // Pyatyye Pospelovskiye chteniya "Iskusstvennyy intellekt segodnya. Problemy i perspektivy". – Mode of access: https://clck.ru/rcV7w. – Date of access: 22.06.2022.*
15. *Artificial Consciousness: What Is It and What Are the Issues? [Electronic resource] // Future of Work Hub. – Mode of access: https://clck.ru/rcUq6. – Date of access: 22.06.2022.*
16. *Filipova, I.A. Pravovoye regulirovaniye iskusstvennogo intellekta [Legal Regulation of Artificial Intelligence]: Study Guide / I.A. Filipova. – 2nd ed. – Nizhny Novgorod: Nizhegorodskiy gosudarstvennyy universitet imeni N.I. Lobachevskogo, 2022. – 275 p.*
17. *Circular of the State Council on Printing and Distributing the Outline of the Plan for the Construction of the Social Credit System (2014–2020) [Electronic resource] // The State Council. The People's Republic of China. – Mode of access: http://www.gov.cn/zhengce/content/2014-06/27/content_8913.htm. – Date of access: 22.06.2022.*
18. *Artificial Intelligence and Human Rights in Australia / B. Solomon [et al.] // Artificial Intelligence for Better or Worse. – Melbourne: Future Leaders, 2019. – P. 87–114.*
19. *Saudi Arabia Gives Citizenship to a Non-Muslim, English-Speaking Robot [Electronic resource] // Newsweek. – Mode of access: https://clck.ru/rcUWQ. – Date of access: 22.06.2022.*
20. *Saudi Arabia Bestows Citizenship on a Robot Named Sophia [Electronic resource] // TechCrunch. – Mode of access: https://clck.ru/rcUTL. – Date of access: 22.06.2022.*
21. *Proposal for a Regulation of the European Parliament and of the Council Laying Down Harmonised Rules on Artificial Intelligence (Artificial Intelligence Act) and Amending Certain Union Legislative Acts [Electronic resource] // EUR-Lex. Access to the European Union Law. – Mode of access: https://clck.ru/rcWBe. – Date of access: 22.06.2022.*
22. *Mosechkin, I.N. Iskusstvennyy intellekt v ugolovnom prave: perspektivy sovershenstvovaniya okhrany i regulirovaniya [Artificial Intelligence in Criminal Law: Prospects for Improving the Protection and Regulation] / I.N. Mosechkin. – Kirov: Vyatskiy gosudarstvennyy universitet, 2020. – 111 p.*
23. *Koryachenkova, Yu.O. Iskusstvennyy intellekt: vyzovy dlya prava intellektual'noy sobstvennosti [Artificial Intelligence: Challenges for Intellectual Property Rights] / Yu.O. Koryachenkova // Mezhdunarodnyye otnosheniya: istoriya, teoriya, praktika: Materials of the XI Scientific and Practical Conference of Young Scientists of the International Relations Faculty of the Belarusian State University, Minsk, Feb. 4, 2021 / Belarusian State University; eds Ye.A. Dostanko [et al.]. – Minsk: BGU, 2021. – P. 132–137.*
24. *Sesitskiy, Ye.P. Problemy pravovoy okhrany rezul'tatov, sozdavayemykh sistemami iskusstvennogo intellekta [Problems of Legal Protection of Results Generated by Artificial Intelligence Systems]: Ph.D. Legal Sc. Diss.: 12.00.03 / Ye.P. Sesitskiy. – Moscow, 2018. – 218 p.*

25. *Yadrevskiy, O.O. Osnovnyye napravleniya sovershenstvovaniya zakonodatel'stva ob avtorskom prave v svete razvitiya tsifrovykh tekhnologiy [The Main Directions of Improving Copyright Legislation in the Light of the Development of Digital Technologies] / O.O. Yadrevskiy // Zhurnal Belorusskogo gosudarstvennogo universiteta. Pravo. – 2021. – No. 3. – P. 23–31.*
26. *Draft Recommendation on the Ethics of Artificial Intelligence [Electronic resource] // UNESCO. – Mode of access: https://clck.ru/32k7cY. – Date of access: 22.06.2022.*
27. *Recommendation of the Council on Artificial Intelligence [Electronic resource] // OECD Legal Instruments. – Mode of access: https://clck.ru/rcUgf. – Date of access: 22.06.2022.*
28. *Kazakevich, A.P. Pravovyye aspekty mezhdunarodnogo sotrudnichestva v oblasti osvoyeniya kosmosa [Legal Aspects of International Cooperation in the Field of Space Exploration] / A.P. Kazakevich // Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – P. 102–115.*
29. *Standards by ISO/IEC JTC 1/SC 42: Artificial Intelligence [Electronic resource] // ISO. – Mode of access: https://clck.ru/rcUdY. – Date of access: 22.06.2022.*
30. *Dorozhnaya karta razvitiya "skvoznoy" tsifrovoy tekhnologii "Neyrotekhnologii i iskusstvennyy intellekt" [Roadmap for the Development of "End-to-End" Digital Technology "Neurotechnologies and Artificial Intelligence"] // KonsultantPlyus. Rossiya / Consultant Plus Inc. – Moscow, 2022.*



Outer Space, Education and Economy in the 21st Century: A Cybernetic Approach

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The problem of shortage of highly qualified personnel for the space industry of the Russian Federation has been reviewed. According to the author, in order to successfully explore space, the relevant specialists have to be trained from school. The demand for them should also be formed by the state, the strategy of which needs to include the study of the Universe, the desire to bring life to other planets. Such a system can be implemented through the introduction of an economic model that has a management and planning mechanism based on a cybernetic approach. A description has been provided of this model, its practical application and the effect it has on the development of the space industry as a whole and the training of personnel for this area.

Keywords: *digital economy, dynamic interindustry-intersectoral balance model (DIIBM), education, full employment, future professions, industry, space industry.*

Unemployment Among Graduates from Institutions of Higher and Secondary Vocational Education

Successful space exploration requires highly qualified specialists, whose training must begin from school. Since an early age, children should seriously study the Universe in order to become astronomers, design engineers, robotic engineers, space biologists and professionals in aviation and space medicine.

In the Russian Federation today, the training of specialists is not linked with either the goal or the strategy for the development of the space industry, which was updated by the State Space Corporation "Roscosmos" in 2021 and is aimed at ensuring the strategic security and independence of the state with space efforts and resources; improving the quality of life, the infrastructural unity of the country and the digital transformation of the economy; obtaining new knowledge about the Universe and the origin of life on Earth; access to unlimited space resources. Obviously, the implementation of these goals requires a large number of relevant personnel. However, only a few of higher education institutions are engaged in the training of such specialists (Bauman Moscow State Technical University, Moscow Aviation Institute, Voronezh State Technical University, Institute of Electronic Engineering and Instrumentation of Yuri Gagarin State Technical University of Saratov, Baltic State Technical University "VOENMEH" D.F. Ustinov, South Ural State University, Samara National Research University, Orenburg State University, Reshetnev Siberian State University of Science and Technology, Omsk State Technical University, Amur State University), as a rule, in one speciality – "rocket systems and astronautics". Moreover, the knowledge obtained in them lags even behind the existing technological development.

The declared goal of achieving excellence and leadership in the development of artificial intelligence generates a bias towards the training of IT specialists, while the material spheres of production, which includes the space industry, remain outside the attention of state policy. As a result, there is an acute shortage of senior and middle-level personnel for industrial enterprises, an overabundance of specialists in the distribution chain and, consequently, youth unemployment.

This is a serious problem, since every year tens of thousands of graduates leave educational institutions of various levels, who are trying in vain to find a job in their chosen major. Speaking about the classification of youth unemployment, it should be noted that it depends on educational programs. Thus, among those who graduated from higher education programs, 13.8 % of men and 11.5 % of women become unemployed. The highest value of this indicator was recorded among graduates of secondary vocational education programs (15.8 % of men and 14.5 % of women) and training programs for skilled workers and employees (15.3 % of men and 22.2 % of women) [1]. This statistic is catastrophic for our country [2].

Young people are less often choosing working professions, building a career in other areas, changing the major received at a college or technical school, due to the absence of demand in the market and the lack of job security after graduation. In addition, today there is no longer a rigid link between education and production, often undergraduate training in higher education institutions is nominal in nature, and students of technical colleges in rare cases, before graduation, apply their knowledge in practice outside of educational laboratories, if such have been preserved.

Let us review the reasons that prevent Russian graduates, which include young people trained in engineering specialities (in particular, for the rocket and space industry), from finding a job and guaranteeing a comfortable life, as well as benefiting society with their work activities.

Personnel Problems in the Space Industry of the Russian Federation

Competitiveness and successful development of the space industry directly depend on innovations and new technologies, the decline of which is recorded in the Russian Federation. This trend was the reason that the country began to lose its leadership position in the international arena, taking in 2022 (based on the results of seven months) the third place in terms of the number of launches of space rockets [3]. China and the United States were ahead again.

Obviously, the success of competitors is due not so much to technology as to the activities of scientists. Here it is extremely important to note the contribution of young scientists and inventors to the development of the industry, because they are the main source of innovative ideas and technologies [4].

Unfortunately, in the last decade, the departure of promising personnel abroad has increased, despite attempts by the authorities to stop it. Young people leave mainly for the United States and the countries of the European Union [5]. Innovations depart along with scientists, which, in turn, leads to stagnation in the Russian scientific and industrial complex.

Forbes magazine provides the following statistics on the number of young engineers in the Russian Federation: annually, the country produces an average of 454,000 specialists, which makes it the absolute leader among the other 124 states included in the study (does not contain data for China and India). The United States, which holds the position next to Russia, produces almost half as many engineers – 238,000. The remaining eight places from the top ten countries are occupied by: Iran – 234,000, Japan – 168,000, South Korea – 147,000, Indonesia – 140,000, Ukraine – 130,000, Mexico – 114,000, France – 105,000, Vietnam – 100,000 [6].

According to the report of the Federal State Statistics Service, only slightly more than half (about 55 %) of graduates go on to work in their profession. Considering the narrow area of expertise of rocket and space specialities, it is safe to say that this percentage is even lower among them [7].

Thus, the rocket and space industry is experiencing a shortage of qualified personnel. One of the most important factors that reduce the prestige of engineering and technical professions, including those in the area in question, is the low level of wages at the beginning of the career, therefore in Russia there is an outflow of such specialists to other industries [8], which, unfortunately, are not related to the real sector of the economy and are subject to deep transformation under the influence of market mechanisms.

Transformation of Economic Sectors

A very fast and chaotic transformation of economic sectors is currently taking place. Due to the constant emergence and destruction of economic ties, the spontaneous distribution of investments in more profitable industries (computer technology, manufacture of clothing, internet trading), the lack of a single goal for the development of the state economy, professions are constantly disappearing and new ones are emerging, sometimes not requiring knowledge and skills to work in material production sectors, which are the basis of any economy.

With the development of information technologies, the products of which parasitize on the surplus value created in the sphere of material manufacturing, the emergence of a number of new professions servicing the IT sphere is predicted. The professions of the future, according to the futurists from the Russian Agency for Strategic Initiatives, include a time manager, a game master, an operator of medical robots, an urban gardener, an eco-leader, an eco-auditor, a digital waste disposal operator, an operator of automated agricultural machinery, a cross-logistics operator, a clothing processing specialist, a cryptocurrency bank operator, an augmented and virtual reality engineer, a cross-cultural communication manager, a robotics concierge (in tourism) [9]. These professions have nothing to do with the real sector of the economy, which provides people with material benefits: they are not strategically important for the life support and sovereignty of the country, since they do not produce products (do not perform work, do not provide services) that are strategically important for the defense capability and security of the state, protection of morality, health, rights and legitimate interests of citizens of the Russian Federation.

By defining the development of digital technologies and artificial intelligence systems as one of the priority areas for achieving leadership in this domain [10], the development of other industries is disproportionate, including the space industry, for which information technology performs only an auxiliary function.

Implementation of a Dynamic Interindustry-Intersectoral Balance Model to Ensure Full Employment Among Youth

It is worth reminding that in order to achieve space, and hence industrial leadership, it is necessary to restore and increase the volume of industrial production. We are talking here about the entire industry, since its sectors are linked into many production chains that serve the implementation of strategic space goals.

To bring the labor market in the segment of graduates of technical schools and colleges from the Brownian motion to the trajectory of ensuring full employment, as well as to supply the space industry with highly qualified personnel of various levels, it is necessary to change the approach to the strategic planning of the economy. First of all, it is required to outline the goal – the growth of the social product, which is created only in material production and entails the growth of the public good. After setting the goal, there will be a need to determine the capabilities of sectors, including the space industry, to achieve it, which involves calculating the availability of labor resources in the sectors.

There is already a tool capable of doing such calculations. It was created at the Department of Strategic Planning and Economic Policy of Moscow State University. This is an artificial intelligence system built on the basis of the dynamic interindustry-intersectoral balance model (DIIBM) and using cybernetic feedback from all business entities. Unlike predictive mathematical models, which suffer from a number of errors due to the incompleteness and insufficiency of the statistical data used and the formalization of the algorithms, the DIIBM has strict requirements for the collection and processing of information, complex algorithms that describe the actions of all participants in economic relations. As an example, the Figure below shows the logic of calculations of the DIIBM for solving the problem of optimizing air transportation. The principle and architecture of neural networks may not be useful here; perhaps the work of programmers will be needed to create a fundamentally new approach, architecture, code and programming language.

With the help of algorithms of iterative balance calculations according to the real-time model, the correlation of professional training opportunities with the requirements of the space industry and other sectors of the economy is achieved under the condition of full employment, which is incorporated in the DIIBM [11]. Within the framework of short-, medium- and long-term plans, created on the basis of the DIIBM, there is a coordination of the volumes and directions of training in various majors in vocational training institutions and the number of employees in the respective enterprises. The dynamic model covers all sectors of the economy: industrial and non-industrial ones.

Thanks to such planning, it is possible to increase the interest of young people in professions in demand by the space industry through social support too – a kind of investment in labor resources: providing housing for young professionals, free programs for advanced training and additional professional education, direct financial support for young families, development of the general level of culture and morality, etc. The costs of these activities are also included in the model and calculated in accordance with the strategic objectives of the state and feedback from citizens.

Such calculations in the context of secondary vocational and higher education are especially necessary for managers of industrial enterprises and other business units related to the space industry, as they must be sure that, while planning their activities for the short-, medium- and long-term, they will receive from higher and secondary vocational education institutions the required number of personnel ready for qualified work, requiring not retraining, but an organically built mentoring system at an industrial enterprise. Since planning according to the model is alive, the issue of retraining in a major is solved much easier and faster than using modern predictive models.

Conclusions

The answer to the question "What should education be like for the space industry in the 21st century?" is the following statement: one that will provide the state with leading positions in the study and exploration of outer space, comprising those with the help of non-rocket geocosmic systems [12]. To win the designated positions, it is necessary to restore and develop all segments of industrial production on the territory of the Union State, including the use of domestic robotics and automation systems.

If the state sets further space exploration as one of the strategic goals, automatically there will be a need for planning, which can only be carried out with the help of DIIBM. Competent planning will comprehensively provide economic entities engaged in the implementation of the space goals of the Union State with employees of the required qualifications, and provide young professionals, who have received specialized education, with high-quality jobs, which will give them confidence in the future.

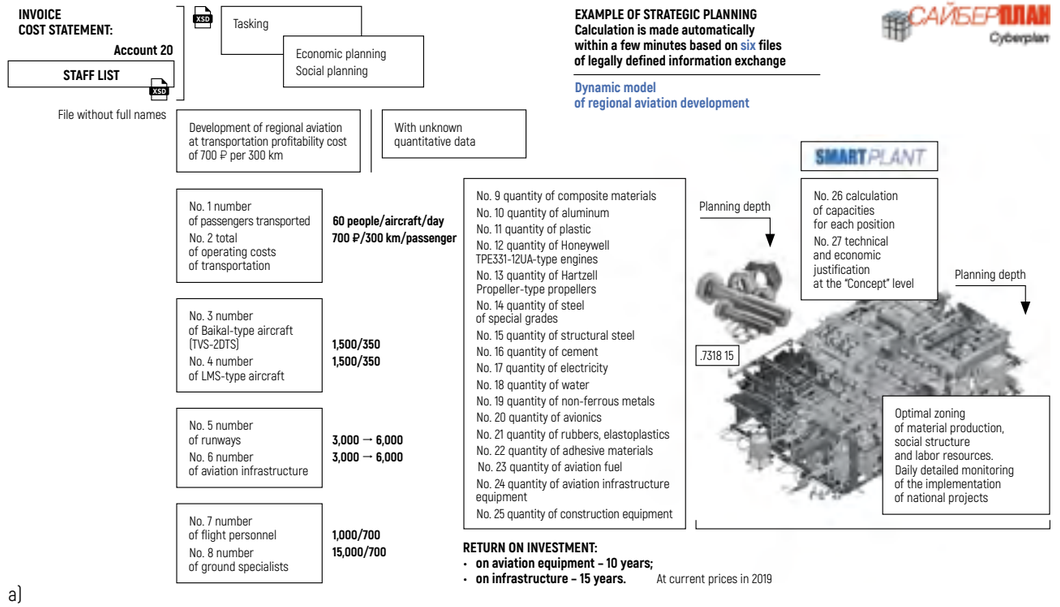

Figure – The logic of the DIIBM calculations for solving the problem of optimizing air transportation:
a – the logic of the dynamic model in the problem of developing regional air transportation;
b – the logic of setting tasks in the calculations of the dynamic model

References

1. *Tri fakta o trudoustroystve vypusknikov 2016–2018 godov [Three Facts About the Employment of 2016–2018 Graduates] [Electronic resource] // Federal'naya sluzhba gosudarstvennoy statistiki. – Mode of access: https://rosstat.gov.ru/folder/70843/document/88401. – Date of access: 12.08.2022.*
2. *Anferov, A.A. Statisticheskiy analiz trudoustroystva vypusknikov obrazovatel'nykh organizatsiy [Statistical Analysis of the Employment of Graduates of Educational Organizations] / A.A. Anferov, Ye.A. Dolgikh // Vestnik universiteta. – 2018. – No. 8. – P. 68–72.*
3. *Anikeyev, I. Rossiya zanyala 3-ye mesto v mire po kosmicheskim zapuskam [Russia Took 3rd Place in the World in Space Launches] [Electronic resource] / I. Anikeyev // Rossiyskaya gazeta. – 2022. – Aug. 10. – Mode of access: https://rg.ru/2022/08/10/rossiia-zanimaet-3-e-mesto-po-kosmicheskim-zapuskam.html. – Date of access: 11.08.2022.*
4. *Kuzina, A.A. Utechka kvalifitsirovannykh kadrov iz Rossii [Skilled Labor Drain from Russia] / A.A. Kuzina, A.A. Zavyalets, O.G. Lebedinskaya // Aktualnyye voprosy sovremennoy nauki: Collection of Articles Based on the Materials of the XV International Scientific and Practical Conference, Tomsk, Oct. 24, 2018: in 3 pt. – Ufa: Dendra, 2018. – Pt. 2. – P. 28–35.*
5. *Kapustin, A.I. Vliyaniye trudovoy podgotovki molodykh spetsialistov na kachestvo produktsii [Impact of Labor Training of Young Specialists on the Quality of Products] / A.I. Kapustin, R.S. Zagidullin // Otechestvennyy i zarubezhnyy opyt obespecheniya kachestva v mashinostroyenii: Collection of Reports of the II All-Russia Scientific and Technical Conference, Tula, Oct. 8–9, 2020. – Tula: TulGU, 2020. – P. 244–246.*
6. *Rossiya operezhayet SSHA po chislu bespoleznykh vypusknikov-inzhenerov [Russia is Ahead of the United States in the Number of Useless Engineering Graduates] [Electronic resource] // Novyye izvestiya. – 2019. – Jun. 30. – Mode of access: https://clck.ru/TEvrH. – Date of access: 05.01.2021.*
7. *Rabochaya sila, zanyatost' i bezrabotitsa v Rossii (po rezul'tatam vyborochnykh obsledovaniy rabochey sily). 2018 [Labor Force, Employment and Unemployment in Russia (Based on the Results of Sample Labor Force Surveys). 2018] [Electronic resource]: Statistical Compendium // Rosstat. – Mode of access: https://www.gks.ru/free_doc/doc_2018/rab_sila18.pdf. – Date of access: 12.08.2022.*
8. *Yudina, Z.A. Restrukturizatsiya raketno-kosmicheskikh predpriyatiy [Restructuring Rocket and Space Enterprises] / Z.A. Yudina, O.V. Patsuk // Proizvodstvennyy menedzhment: teoriya, metodologiya, praktika: Collection of Materials of the II International Scientific and Practical Conference, Novosibirsk, May 15, 2015 / ed. S.S. Chernov. – Novosibirsk: NGTU, 2015. – P. 185–190.*
9. *Atlas novykh professiy 3.0 [Atlas of New Professions 3.0] / eds D. Varlamova, D. Sudakov. – Moscow: Al'pina Pablisher, 2021. – 472 p.*
10. *Putin: lider v sfere iskusstvennogo intellekta stanet vlastelinom mira [Putin: The Leader in the Field of Artificial Intelligence Will Become the Ruler of the World] [Electronic resource] // RIA Novosti. – 2017. – Sep. 1. – Mode of access: https://ria.ru/20170901/1501566046.html. – Date of access: 15.08.2022.*
11. *Veduta, Ye.N. Mezhotraslevoy-mezhsektornyy balans: mekhanizm strategicheskogo planirovaniya ekonomiki [Interindustry-Intersectoral Balance: The Economy Strategic Planning Mechanism] / Ye.N. Veduta. – Moscow: Akademicheskiy Proyekt, 2016. – 239 p.*
12. *Bezraketnaya industrializatsiya blizhnego kosmosa: problemy, idei, proyekty [Non-Rocket Near Space Industrialization: Problems, Ideas, Projects]: Collection of Articles of the III International Scientific and Technical Conference, Maryina Gorka, Sep. 12, 2020 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A.E. Unitsky. – Minsk: StroyMediaProyekt, 2021. – 516 p.*

Resolution of the V International Scientific and Technical Conference “Non-Rocket Near Space Industrialization: Problems, Ideas, Projects”

On September 23–24, 2022, Maryina Gorka (Republic of Belarus) hosted the anniversary V International Scientific and Technical Conference “Non-Rocket Near Space Industrialization: Problems, Ideas, Projects”.

The conference program included a plenary and stand sessions, discussions, the work of sections. The total number of reports delivered was 26. Despite the existing restrictions caused by the ongoing pandemic and the escalated geopolitical confrontation against the background of events in Ukraine, representatives of academic and scientific circles, as well as public and commercial organizations of Belarus and countries of the near and far abroad showed great interest in the international forum.

The conference was held to summarize the results of research and practice work carried out in scientific and design organizations, design offices and engineering companies, as well as by individual researchers and enthusiasts in the following areas:

- solving global biospheric problems of our time with geocosmic means;
- prospects of technological development of near space within the EcoSpace program under the motto “Earth is for life. Space is for industry”;
- arrangement of large-scale cargo and passenger flows on the Earth – Near Space – Earth route, in order to develop the space industry in the interests of mankind;
- design features, search for biological and ecological solutions for the sustainable functioning of the Earth’s biosphere, the preservation of biodiversity on our planet and the development of hard-to-reach territories with unfavorable conditions for human life;
- specifics of self-sufficiency of linear ecocities;
- implementation of the EcoSpace program and its first local stage – the Program for Rebooting the Economy of the Union State of Russia and Belarus to the Biospheric Path of Civilizational Development – in order to consolidate the efforts of the global community to ensure the sustainable transformation of Earth’s technogenic civilization, as well as the coevolution of human and nature and the reorientation of all the entire planet’s industry towards the biospheric vector of civilizational development;
- conclusion of international treaties for the implementation of the uSpace geocosmic program;
- problematic aspects of the use of artificial intelligence in the EcoSpace program implementation from the point of view of private and public law, including the search for promising solutions;
- ways of creating and applying technologies for integrated information support and monitoring of the atmosphere, land and water surfaces of the planet in order to develop basic thematically oriented means intended to solve problems of managing the sustainable development of regions using the results of geocosmic activities.

Based on the sum total of the V International Scientific and Technical Conference “Non-Rocket Near Space Industrialization: Problems, Ideas, Projects”, the Organizing Committee and the participants reached a number of important decisions.

1. To note the extremely high importance of further advance in the topic of large-scale near space exploration and resetting the Earth’s industry towards the biospheric vector of civilizational development, including the cosmic one.

2. To emphasize the importance of the global geocosmic project – the General Planetary Vehicle (GPV) – as the only possible one from an engineering point of view, and hence the key transport and logistics solution for the industrial development of near space and the implementation of the EcoSpace program.

3. Given the scale and significance of the works presented at the conference, to point out the paramount importance and obvious urgency of the development of cooperation between the countries, international agencies, the world’s top companies, research organizations and universities in order to implement the EcoSpace program.

4. To recognize that humanity is now facing a momentous choice:

- either to implement the EcoSpace program, rebuilding the usual way of life and choosing an eco-oriented way of changing the traditional industry, which means:

a) to solve global economic and social problems on Earth with the help of biospheric technologies;

b) to turn the planet that nurtured our technogenic civilization into a blooming garden;

c) to relocate the ecologically dangerous industrial part of the technosphere beyond the limits of the Earth’s biosphere – into near space;

d) to prohibit blatant technogenic interference in planetary biospheric processes;

e) in the space home named Planet Earth, to stop all attempts to tame Nature, to the creation of which our civilization has no relation;

• or suffer a crushing defeat, condemning our children and grandchildren to face a global environmental catastrophe, which will lead to the subsequent degradation, extinction and death of the civilization that we know and are a part of.

5. To support the Program for Rebooting the Economy of the Union State of Russia and Belarus to the Biospheric Path of Civilizational Development that was presented at the conference plenary session as the first stage of the implementation of the large-scale EcoSpace program. To indicate that integration within the framework of the Union State opens up new opportunities and horizons for countries, allows them to refocus on the internal agenda, building a course to increase autonomy and sovereignty (including technological one), as well as to strengthen the economy. Within the framework of the Union State, new financial institutions must be created from the ground up, a government and a more advanced monetary system that are not influenced by unfriendly parties should be formed, various programs that provide for a comprehensive reorientation of the Union economy to new biospheric technological rails need to be implemented. It is worth noting that the designated Rebooting Program should be presented to the governments of Russia and Belarus after its extensive discussion and support by the progressive public of the Union State and other countries.

6. To emphasize that the sections "Social, Legal, Political and Financial Aspects of the uSpace Non-Rocket Space Exploration Program Implementation" and "Social Design and the Main Trends in the Development of Human Civilization on Earth and in Space" introduced into the structure of the conference have shown their effectiveness as a platform for lively discussion, expression of expert opinions on future design, social transformations of existing systems, the productivity of which has been repeatedly questioned and constructively criticized. In the process of discussing the specifics of global geocosmic and terrestrial projects, a vector for decisive actions in the direction of industrialization and large-scale exploration of near space was determined and a decision was made to expand this activity within the framework of creating a community of like-minded people – an international platform being an alternative to the existing destructive world ideological platforms.

7. To hold regular scientific, technical and practical workshops in this area, to attract a wide range of researchers involved in the problems of industrial development of near space.

8. To emphasize the high scientific and technical level of the reports submitted at the conference.

9. To publish a collection of conference materials. Participants, whose reports will be published, should prepare their work in the form of research articles in line with the requirements.

10. To conduct the next VI International Conference on the problems of non-rocket near space exploration in autumn 2023 in the Republic of Belarus.

The Organizing Committee expresses its gratitude to all the participants, speakers, guests, as well as sponsoring entities and individuals who made the conference possible: Astroengineering Technologies LLC, Unitsky String Technologies Inc., Unitsky's Farm Enterprise, which provided the venue and extensive assistance in holding the scientific forum, as well as to other organizations of international Unitsky Group of Companies.

We are glad to know that we share common values and act for the benefit of Humanity together with the United Nations Industrial Development Organization (UNIDO) and the Arctic Public Academy of Sciences. This is an important step towards full-scale cooperation for the implementation of the EcoSpace program and its space vector – the uSpace non-rocket space exploration program – in the logic of "Earth is for life. Space is for industry".

Organizing Committee
Sep/24/2022

Glossary:
Terms and Definitions

Abbreviation **uST** stands for the central brand of Unitsky Group of Companies (UGC); it combines the names of Unitsky String Technologies, the parent engineering company Unitsky String Technologies Inc., uST transport and infrastructure complex / Unitsky String Transport as the physical embodiment of uST transport and infrastructure solutions.

Active protection system (APS) is a generator of electrostatic field where negatively charged debris of space garbage create resonant vibrations in it.

Artificial atmosphere is a specially selected mixture of gases, which ensures regular breathing and gas exchange in living organisms, including humans, who are in an enclosed ecosystem; has the same quality as the Earth's atmosphere. The gas component of the EcoCosmoHouse (ECH) space is an artificial atmosphere.

Biofuels are various types of combustible products derived from plant raw materials. Their main advantages are renewability and accumulation of solar energy coming to the Earth.

Biological balance is the preservation of dynamic stability of natural complexes (biogeocenoses) over a long period of time, i.e., relative balance of stability of species composition, number and productivity of living organisms.

Biological diversity is the natural diversity of life in every manifestation, as well as an indicator of the complexity of the biological system, the diversity of its living components. Biodiversity is considered at the hierarchical levels of lifeorganization with the following main ones: molecular and genetic, organism and species, biogeocenotic and biospheric.

Civilization technogenic fork is a stage of development of the Earth's technosphere, which, when achieved, makes the technogenic human civilization face with a historically important choice of two mutually exclusive scenarios of action:

1) Earth's civilization continues to develop conventional technogenic vector, limited only by the planet size and resources. At the same time, resource consumption does not change dramatically because the world economy relies on obsolete and resource-intensive technologies (primarily, century-old transport and logistics technologies). As a consequence, the point of no return from degradation, extinction and death of human civilization will come in about two generations (in the third quarter of the 21st century);

2) the beginning of near space industrialization, gaining access to its unlimited resources, infinite space, matter and energy, as well as new technological resources: weightlessness, deep vacuum, technological purity (without dust and microorganisms) and cosmic radiation. Mandatory requirement: inefficient transport and infrastructure technologies, power industry, habitat (cities), infrastructure and agriculture used on the planet, which pose the greatest threat to the Earth's biosphere, must be replaced by better communications and eco-oriented technologies.

EcoCosmoHouse on Planet Earth (ECH-Earth) is a structure on Earth designed for autonomous and unrestricted long-term residence of a human settlement with calculated density. The inner enclosed space of the ECH-Earth has conditions for the development of ecosystems, has a necessary set of the planet's biosphere properties in this regard, and additional technological processes that are modeled to ensure human needs for existence (parameters of the atmosphere and habitat, food resources, etc.). The ECH-Earth is an Earth biospheric model of the ECH in terms of creation and arrangement of internal space and all relevant components (biosphere, technologies, process interconnections, etc.) with an enclosed cycle of matter (living and mineral), energy and information.

EcoCosmoHouse technological platform (ECH) is the construction of buildings in space with an internal inhabited space, isolated from the external aggressive space environment. There is an enclosed ecosystem of the Earth's type in the ECH, including artificially produced gravity, living fertile soil, flora and fauna (comprising microflora and microfauna), atmosphere with adjustable parameters (temperature, humidity, etc.) for unlimited long-term, autonomous, eco-comfortable living and activity of both individuals and groups of them and many thousands of settlements in equatorial orbits of the planet, as well as in open near space and deep space.

EcoHouse technological platform is an eco-oriented construction of residential and industrial buildings and structures on Earth with adjacent space open to the external natural (biospheric) environment, filled with natural and cultural (organic farming) ecosystems, in which atmospheric, soil and water parameters are regulated by the Earth's nature. The soil from under the buildings during their construction is transferred to the roofs and floors to be then enriched with living humus. Greening is based on the principle that all construction on the planet is meant to increase the area of fertile soil and its fertility.

EcoSpace is the program to provide for the development of eco-oriented biospheric technologies in order to transform the main sectors of the Earth's industry, infrastructure, power industry, transport and agriculture. It assumes bringing the hazardous part of the Earth's industry out into near space to secure the balance in a perfect world represented by BioSpace, TechnoSpace and HomoSpace triunity, which together form a complex of optimal conditions for sustainable growth and further development of the anthropogenic Earth's civilization in cosmic direction.

BioSpace is a restored and balanced planetary biospheric ecosystem open to space, which no longer experiences the devastating man-made effects of the Earth's technosphere and continues to evolve by the laws of evolutionarily established terrestrial nature. It comprises:

- natural and cultural (organic farming) ecosystems on the planet land, including aquatic ones (lakes, rivers, etc.);
- oceanic, marine and atmospheric ecosystems with the possibility of eco-friendly external control of weather, climate and other systems of the planet through natural methods;
- flora and fauna of terrestrial and aquatic ecosystems (including microflora and microfauna) with their biodiversity preserved and currently available;
- Earth's humanity with each individual being healthy and happy.

TechnoSpace comprises newly created industrial components:

1) Earth's industry which is based on novel eco-oriented technologies and consisting only of the technological industries necessary for humans within the Earth's biosphere;

2) space industry, including energy-consuming, resource-intensive, hazardous and other industries that are moved outside the Earth's biosphere, which acquire an absolute competitive price and quality advantage as part of the space technological environment;

3) GPV geocosmic transportation complex, providing environmentally friendly transport and logistics link between the Earth's and space components of the industrial TechnoSpace with cargo, energy, information and passenger flows of industrial scale;

4) artificial intelligence to manage the above components 1–3 under the multilevel control of HomoSpace.

HomoSpace is an advanced world socio-political system based on the consolidation of the international community of biological humans (but not digitized convergent biorobots) around a single governing center accumulating the territorial, financial, economic, scientific, human, military and political potential of all participating countries. This will open the gate to inexhaustible and accessible resources of space and through space-oriented economy of the technogenic civilization on Earth will create new socio-political and economic conditions for the most complete implementation of sustainable development of biological humanity, including social justice, equality, freedoms, harmonious development, as well as the right of every inhabitant of the planet for a worthy long and happy life. HomoSpace is developed and governed by people using artificial intelligence as an assistant and advisor (but not a leader). The main value of HomoSpace is the humane attitude of Man and his spirituality as a sociobiological quintessence created by the Universe (God) as a result of billions of years of life evolution in the space home named Planet Earth.

Ecosystem is a biological system (biogeocenosis) consisting of a community of living organisms (biocenosis), their habitat (biotope), as well as a system of connections that exchange substance and energy between them.

EcoTechnoPark is a demonstration and certification center for uST transport and infrastructure solutions, built in the Republic of Belarus (Maryina Gorka).

Equatorial Linear City (ELC) is the Earth's component of geocosmic transport and communication complex which locates the GPV takeoff and landing overpass (uWay) with the whole infrastructure required for the GPV to fly and for servicing global geocosmic cargo and passenger flows. This city represents a harmonious blend of cluster settlements with the natural environment of land and ocean areas of the planet. The settlements are interconnected by uST tracks and stretch along the equator.

Food solar bioenergy (FSBE) is power industry based on the integrated consumption and processing of biomass of greenery that has absorbed the energy of the Sun, to produce biofuels, animal feed and food for humans.

General Planetary Vehicle (GPV) is a geocosmic reusable torus-shaped spacecraft for non-rocket near space industrialization encircling the Earth in the equatorial plane; it ensures industrial cargo and passenger flows (millions of tons of cargo and millions of passengers per year) from the Earth to near-Earth equatorial orbits and back; it is based on the only possible (from the point of view of physics) environmentally safe and energy-efficient geocosmic transportation technology which uses only internal force of the system (space) and electric energy.

GPV takeoff and landing overpass (uWay) is a takeoff and landing, energy and communication overpass hub for geocosmic transportation, located along the equator and combined with a linear eco-settlement of new generation.

Industrial Space Necklace "Orbit" (ISN "Orbit") is a multiorbital transport, infrastructure and industrial-residential complex serving the Earth's humanity and covering the planet in the equator plane. It is a functional analogue of the Earth's ELC, however, located in space, as well as a range intended to protect from space threats (including meteorites) and a platform for the expansion of the Earth's civilization into deep space.

Linear city (uCity) is a cluster pedestrian urban settlement with its ground surface intended for people, animals and greenery; the development of residential, administrative, industrial and multifunctional clusters is implemented through the eco-oriented EcoHouse technologies; electricity and heat are supplied by the uEnergy technology; food supply is linked to the uGreen technology of organic farming. Transport, energy and information communications are arranged above ground on the second level (elevated version) according to the uST technology. Linear cities are characterized by the absence of devastating man-made effects on the biosphere, high efficiency of urban economy and its autonomy, as well as decent quality of life and working conditions for each resident.

Relict solar bioenergy (RSBE) is power industry based on the use of fossil brown coal and oil shale to produce clean energy and form living humus, which is necessary to restore the fertility of various types of soils.

Space-based solar power plant (SBSPP) is an orbital solar power plant using solar energy; it provides energy independence and biospheric environmental safety of the ISN "Orbit".

Space industrialization vector is a global re-equipment of the Earth's technosphere to eliminate its devastating man-made effects on the Earth's biosphere by transferring hazardous, energy- and resource-intensive industries into near space on low-Earth orbits. The space industrialization vector is also about using eco-oriented technologies to modernize that part of industry still on Earth and functioning in the biosphere.

Sustainable development is "the development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This concept was formulated by the UN World Commission on Environment and Development and is the basis of the UN goals and principles.

uEnergy technological platform is designed to generate green electric and thermal energy using:

- specially equipped thermal power plants for eco-friendly combustion of brown coal, shale, peat and other raw materials of organic origin in order to produce living fertile humus from their combustion waste;
- renewable energy sources, namely the solar energy on Earth and in space, as well as the energy of wind and sea currents;
- "hydrogen – oxygen" pair as a fuel accumulator for the optimization of the planet power industry and space transportation.

uGreen technological platform is organic farming in a new logic of recreation and intensification of natural biospheric processes by direct borrowing and using natural soil ecosystems with their microflora, microfauna and biogeocenosis, as well as in the logic of a complete rejection of any synthetic chemicals (fertilizers, plant protection agents, etc.), technologies of genetic modification and other elements of traditional intensive farming.

uMach is the concept of a hypervelocity uST transport and infrastructure complex. It is designed to travel at speeds over 1,000 km/h inside a forevacuum tunnel (with artificially reduced atmospheric pressure) to provide high-speed transportation for long (from 200 km) distances.

uNet transport and infrastructure network is an international transport, energy and information communication network created on the basis of uST transport and infrastructure solutions along uCities.

uSky Testing and Certification Center is a research and production cluster of uST transport and infrastructure solutions, built in the United Arab Emirates (Sharjah).

uSpace geocosmic program is a program of non-rocket near space exploration by means of the GPV, which will preserve the Earth's biosphere by taking the industry (technosphere) outside the planet Earth (outside the biosphere).

uST technological platform is the construction (along uCities) of a new kind of transport, infrastructure, energy and communication networks uNet, created on the basis of prestressed (string) Unitsky's structures. It is designed to provide all necessary communication links between objects (and continents) on Earth; between objects in near space moving on circular equatorial orbits; between objects on Earth and those deployed in near space.

uTerra is a biohumus produced from brown coal, ash, organic raw materials, inoculum and aerobic microorganisms to increase fertility and improve the quality of any soils, including desert sands.

Reviews
for the Collection of Articles of the V International Scientific and Technical Conference “Non-Rocket Near Space Industrialization: Problems, Ideas, Projects”

Review
by Hussain Al Mahmoudi,

CEO of the Sharjah Research Technology and Innovation Park and American University of Sharjah

The first works on the technological space exploration with the acquisition of additional energy, cosmic and raw materials can be found in the research of Russian cosmists. The papers of K. Tsiolkovsky, who essentially laid the scientific foundation for the development of practical astronautics, deserve special attention.

Among the successors of K. Tsiolkovsky is a Belarusian engineer, scientist and inventor Anatoli Unitsky, who has also devoted his life to space. Since 1977, he was gradually elaborating the ideas which engineering implementation is aimed at the non-rocket exploration of near space and the creation of comfortable and safe conditions for human life and work outside the planet Earth. The developments are conducted not only in the field of geospace logistics of passengers and cargo with the help of the General Planetary Vehicle (GPV), but also on creation of the residential EcoCosmo-Houses (ECHs) and industrial complexes in the transport and infrastructure system that is the Industrial Space Necklace “Orbit”. All ideas are reflected in the articles presented at the International Scientific and Technical Conference “Non-Rocket Near Space Industrialization: Problems, Ideas, Projects” (NRNSI) and published in this collection.

The presented studies are annually supplemented by amount of scientific data, thanks to the development of modern tools, among which are mathematical modeling programs, production of new composite materials and biological research. Such tools help in the implementation and testing of Anatoli Unitsky’s innovative ideas.

Recently, a number of researches have questioned the feasibility of far-reaching space exploration projects associated with the global negative effects of launching rockets that destroy the planet’s protective ozone layer. That’s why Anatoli Unitsky’s idea to create an ecologically clean geospace aircraft with a load capacity of 10 mln tons, while reducing the cost of cargo delivery to orbit by a thousand times, is the only possible solution to the large-scale exploration of near space with removing harmful industrial production from the Earth’s surface into orbit.

International cooperation in space exploration can provide real opportunities to transcend the boundaries of the Earth and pave the technological path to the stars that humankind has dreamed of for millennia.

I believe that the issues highlighted in this scientific collection of materials of the NRNSI-2022 conference about the creation of comfortable living conditions in the ECH, the development of biotechnological and energy industries, the design of the unique GPV systems with a length of 40,000 km (the length of the equator), and the legal and social aspects of the large-scale space exploration have great practical and scientific value for all mankind.

I recommend this collection to be published in the public press as presented.

Review
by Yuri Pleskachevsky,

**Corresponding Member
of the National Academy
of Sciences of Belarus,
Doctor of Technical Sciences,
Professor, Honored Scientist
of the Republic of Belarus**

The ideas and already particular implemented projects, published monographs, articles, including those set out in this collection, as well as public speeches by the engineer and inventor, philosopher and thinker Anatoli Unitsky are actually a draft roadmap for the movement towards a post-industrial Earth's civilization through the biospheric path of civilizational development and non-rocket near space exploration.

All the variety of problems, ideas, projects, facts and thoughts presented in the reviewed collection can be integrated with the following phrase given in the collection, which is, actually, the formula for the survival of modern technocratic civilization: "Earth is for life. Space is for industry". All aspects of human activity in the next century should be guided and consistently fit into this formula, which, when implemented, should become the formula for a new life of humanity. The ideas and already particular implemented projects, published monographs, articles, including those set out in this collection, as well as public speeches by the engineer and inventor, philosopher and thinker Anatoli Unitsky are actually a draft roadmap for the movement towards a post-industrial Earth's civilization through the biospheric path of civilizational development and non-rocket near space exploration.

It should be noted that the idea of transferring the most problematic industries from an environmental point of view to near-Earth space is not new. Back in the 60s of the last century, a prominent American scientist K. Ehricke in his writings on cosmonautics described the prospects for the development of the space industry in near-Earth space and on the Moon. As transport systems, he proposed the Shuttle – Spacelab platform as an intermediate tug and launch stage, as well as a rocket-type transport spacecraft and a fully reusable Shuttle with a returnable first stage of multiple use. However, over the years it has become increasingly obvious that Ehricke's ideas based on the use of rocket transport to move millions of tons of cargo into near-Earth orbit are uneconomical, unecological, non-technological, unsafe and therefore unpromising. This understanding came, among other things, and perhaps above all, thanks to the works by A. Unitsky, his associates and like-minded people, who have been gathering for the fifth time at conferences organized by A. Unitsky, which are becoming more representative and international in the full sense of the word with each stage, as evidenced by the materials of the reviewed collection.

The General Planetary Vehicle (GPV) has no analogues and is the largest engineering project of all known in the history of humanity. It is this project that can become a key transport and logistics solution for the implementation of the principles of the space industry and the realization of the no less global EcoSpace program. The first major step on this path may be the creation on the basis of the Union State of Russia and Belarus of a Center for rebooting the new world on the biospheric path of civilizational development. The detailed report by A. Unitsky on this topic contains particular steps already being brought to life today to create and successfully operate such a Center. The main projects and technologies implemented by the Center can and should serve as the basis for the functioning of EcoCosmoHouses, from which it is proposed to build a space industrial necklace of the planet Earth. A number of reports included in the collection are focused both on ensuring the sustainable functioning of all GPV systems from its "spinup" to its launch into near-Earth orbit, and to the specifics of creating production facilities in near space and providing specific working and living conditions in the EcoCosmoHouse for the GPV personnel and production workers. It is clear that there are still many unresolved problems and tasks on this path, including those not foreseen today, which will be the subject of discussion at subsequent conferences.

The glossary given in the collection deserves special mention. It enriches modern cosmology with new concepts and terms.

The Resolution of the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" given in the collection calls on the world community to recognize that humanity is currently facing a fateful choice: either to implement the EcoSpace program in all its aspects and elements, or to continue moving along the already outlined trends towards degradation, extinction and possible death of the current civilization.

I believe that this Resolution, as well as the materials of the reviewed collection, should be translated into many languages and sent to all heads of government and to all international organizations, posted on publicly accessible digital platforms on the Internet.

I recommend the collection of articles of the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" for publication in the open press in the presented form.

Review
by Michael Orloff,

**Doctor of Technical Sciences, Professor,
General Director and Scientific Supervisor
of the Modern TRIZ Academy,
Berlin, Germany**

The solutions by A. Unitsky, whether they relate to the creation of string elevated roads, new biotechnological, energy and food complexes or the exploration of near-Earth space, have system-forming properties on the scale of the entire civilization, and covering not only the planet, but also the near space, not only on the interval of some actual reality, but also for the future in hundreds and even thousands of years.

For more than 27 years, I have been a supporter and associate of A. Unitsky in his aspirations aimed at engineering, and at the same time at the social development of human civilization.

With each new report from the Belarusian scientist, I see not only the approval of his first fundamental ideas, but also their continuous improvement, refinement and manifestation of realistic outlines. The contours of a possible future in the inventor's vision appear more and more clearly, reasonably and in such multidimensional images that it causes not just respect for the systematic and dynamic development of his global projects, but goes out to the level of surprise and even shock from the artistic, aesthetic and, of course, humanistic value of the visualized structures.

The reports presented at the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" comprehensively cover key civilizational perspectives united by the fundamental concept of biospheric evolution, going back to the ideas of V. Vernadsky and inheriting his foresight. These main perspectives include:

1) relict solar bioenergy in interaction with other efficient and environmentally friendly types of energy production – nuclear, solar (photovoltaics, thermal), geothermal, hydrodynamic (dam, wave, tidal), etc.;

2) biospheric agriculture – without poisoning the fertile soil with chemicals and so-called fertilizers, with rationalization of the use of fresh water, preservation of a clean atmosphere, creation of waste-free enclosed cycles of reproduction of biological products;

3) technology for the construction of linear cluster-type cities – with access to trouble-free life support for the world's population of 10 bln or more people;

4) "second level" transport and infrastructure complexes – Unitsky String Transport with evolutionary development and transformation into a planetary transport network uNet;

5) non-rocket near space industrialization – the most complex creation of a future civilization, which was proposed by A. Unitsky.

The conference reports present convincing arguments and calculated data in all these areas. It is possible to express the general result of the analysis of the works done by highly qualified specialists of Unitsky's scientific engineering school by the statement of D. Gabor, physicist, Nobel Prize laureate: "The future cannot be foreseen, but it can be invented."

A great invention means a revolution in engineering and, of course, in society. And the solutions by A. Unitsky, whether they relate to the creation of string elevated roads, new biotechnological, energy and food complexes or the exploration of near-Earth space, have system-forming properties on the scale of the entire civilization, and covering not only the planet, but also the near space, not only on the interval of some actual reality, but also for the future in hundreds and even thousands of years.

I am confident that A. Unitsky fully deserves the status of a Nobel Prize laureate by his activities. It can be assumed that in the near future the development of the inventor will be appreciated. Although the most significant reward would be the implementation of his ideas and technical solutions for the benefit of civilization.

As in previous collections, the conference materials make a very positive impression. The topics of the articles are very diverse and touch upon the issues of designing, application of various materials, arrangement of bioproduction, use of artificial intelligence, legal regulation, modernization of the education system. The works are interesting, relevant, instructive, have scientific and practical value and demonstrate the great scope and potential for the development of Unitsky String Technologies.

Review
by Andrey Kuznetsov,

**Doctor of Biological Sciences,
Scientific Consultant
of the Federal Research Center
"A.O. Kovalevsky Institute
of Biology of the Southern Seas
of the Russian Academy of Sciences"**

The mankind will be forced to leave the planet Earth and move into the outer space due to the inevitable cooling of the Sun. Naturally, it is necessary to prepare for this in advance, especially since there are other powerful reasons, which are reported in this collection. It is worth noting that the idea of colonization of near space excited many minds. For example, A. Clarke, in his novel "The Fountains of Paradise" (1979), describes a space elevator that will make it as cheap as possible to bring cargo and passengers into Earth orbit. And this will be implemented in the 22nd century. In addition, the English science fiction writer proposed the idea of orbital satellites, which has already been implemented. That's why I tend to trust his time frame.

A logical chain of counteraction to the world bourgeoisie in its plans for inclusive capitalism, implying a reduction in the number of mankind to the "golden billion", and then to "diamond million" is built in the collection of materials of the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" around the concept of the General Planetary Vehicle, which is a structural part of the uSpace geocosmic program. The question is implicitly posed: "Do we want such a scenario for our children and grandchildren?" Of course not! Therefore, it is necessary to combine efforts to build a green harmonious paradise on Earth, relying on the achievements of the ancestors and fully applying and developing science.

The collection raises acute issues and provides interesting examples of the use of innovative technologies for the ennobling of our planet, such as the use of brown coal in the power engineering sector, the placement of greenhouses on the roofs of buildings, the determination of the parameters for technological lighting of plants, their microclonal propagation, callusogenesis, the cultivation of mycelium fungi on organic substrates, the creation of genetic banks of organisms, the prevention of premature aging, artificial intellect and the alienation of man from mind. As the authors emphasize, "the ordering tool in this regard is certain algorithms to which subjects in civilizational processes obey". The intelligent humanity needs to fight for the legal protection of these noble algorithms of the biospheric vector of development that requires political will.

Dear readers!

This collection was prepared following the results of the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects" held in Maryina Gorka on September 23–24, 2022. We hope that the material presented in this book will be useful to you.

Send your feedback, wishes and suggestions to: conf@ecospace.org.

Additional information on the topic of non-rocket space exploration is available at: www.ecospace.org/conferences.

Organizing Committee of the Conference
and Editorial Board for the Collection of Conference Materials

Non-Rocket Near Space Industrialization: Problems, Ideas, Projects: Collection of Articles of the V International Scientific and Technical Conference, Maryina Gorka, Sep. 23–24, 2022 / Astroengineering Technologies LLC, Unitsky String Technologies Inc.; ed. A. Unitsky. – Minsk: StroyMediaProject, 2023. – 320 p.
ISBN 978-985-7172-95-5.

The articles of the collection reflect the subject matter and content of the reports presented within the framework of the V International Scientific and Technical Conference "Non-Rocket Near Space Industrialization: Problems, Ideas, Projects". The participants of the 2022 conference considered the ways of solving global problems of our time by geocosmic means; announced the principles of designing a transport and infrastructure geocosmic complex and hypervelocity transport; studied the aspects of providing comfortable living in space settlements; discussed issues of a social, political and economic nature in the field of non-rocket near space industrialization. The collection contains the works of engineers, inventors, scientists, representatives of public organizations of Belarus, as well as countries of near and far abroad.

The publication is intended for specialists in the field of geotransport communications, fellows of government bodies, research institutes, teachers and students of educational institutions.

Scientific Publication

NON-ROCKET NEAR SPACE INDUSTRIALIZATION: PROBLEMS, IDEAS, PROJECTS

Collection of Articles of the V International Scientific and Technical Conference
(September 23–24, 2022, Maryina Gorka)

Signed to the print on May/05/2023. Format 60 × 84 1/8. Enamel paper. Offset printing. Conventional printed sheets 37.2. Circulation 200 copies. Order 384.

Publisher and printing execution: State enterprise "StroyMediaProject".
Certificate of state registration of publisher, manufacturer, distributor of printed publications:
No. 1/43 of Oct/03/2013, No. 2/42 of Feb/13/2014.
13/61 V. Khoruzhey Str., Minsk, 220123.

ISBN 978-985-7172-95-5

UDC 629.78
ISBN 978-985-7172-95-5