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ACTA INNOVATIONS

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Contents

Nadiia Bielikova
Research Center for Industrial Problems of Development of the National Academy of Sciences of Ukraine
1-A Inzenernyi Ln., Kharkiv, Ukraine, nadezdabelikova@gmail.com
https://orcid.org/0000-0002-5082-2905

Ivan Yaroshenko
Research Center for Industrial Problems of Development of the National Academy of Sciences of Ukraine
1-A Inzenernyi Ln., Kharkiv, Ukraine, ndc_ipr@ukr.net

PROSPECTS FOR THE DEVELOPMENT OF INNOVATIVE NANO- AND BIOTECHNOLOGIES

Abstract
Nano- and biotechnologies are the key elements of the complex of NBIC-technologies, developed within the concept of continuous growth of innovations in the context of the transition to the sixth technological mode. The purpose of the article is to study the prospects for the development of nano- and biotechnologies in various sectors of the economy, as well as explore opportunities for accelerating the commercialization of research results in these areas. The article's relevance is confirmed by the strengthening of the role of nano- and biotechnologies in the sphere of innovation development of countries worldwide. The results of the study have shown that the nanotechnology market has a divergent structure, and the basic characteristic of nanoproducts is their interdisciplinary nature. The world leaders in the production and commercialization of nanotechnologies are the United States, China, Japan, Germany and South Korea. Biotechnologies are developing rapidly as well. Worldwide, the largest number of biotechnologies is created in areas such as health care (biomedicine and biopharmaceuticals), industry and agriculture. The leading countries in the field of development and commercialization of biotechnologies are the United States, France, Germany and South Korea.

Key words
biotechnologies, nanotechnologies, innovations, economy

Introduction

Most countries are now implementing the concept of continuous innovation development as part of the transition to the sixth technological mode. This statement is confirmed both by the large number of publications that consider issues concerning the development of complex NBIC-technologies and the continuous increase in the expenses to develop and assimilate new technologies. Erasing the boundaries between innovative technologies in different sectors of the economy forms a new unique phenomenon — complex nano- and biotechnologies as a tool for improving the population's quality of life. Thus, the relevance of the topic of this article is determined by the strengthening of the role of nano- and biotechnologies in the innovation development of countries worldwide. Issues concerning the development and introduction of nano- and biotechnologies are considered in works by authors such as M. De Wild, S. Berner, H. Suzuki et al. [1], K. E. Drexler [2], R. N. Kostoff, I. A. Stump, D. Jonson [3], U. Roos [4], P. Vettiger and G. Cross, M. Despont et al. [5].

The purpose of this article is to study the prospects for the development of nano- and biotechnologies in different sectors of the economy, as well as the opportunities to accelerate their commercialization. The development of nano- and biotechnologies can be characterized as being explosive, encompassing many branches of the economy. As L. Melnyk [6], Ponomarenko et. al.[7] and others have noted, almost all significant innovative inventions in the field of nano- and biotechnologies have been created over the past 15-20 years.

The term "nanotechnology" was first proposed in 1974 by Japanese professor Norio Taniguchi of Tokyo University in his report "On the Basic Concepts of Nanotechnology" given at the International Conference on Precision Engineering in Tokyo [8]. The term was used to denote the large set of knowledge, approaches, techniques, specific procedures and materialized results of nanoparticles. Let's consider in more detail the main types of nanoproducts and priority areas of their use now and in the future. Taniguchi [9] gave the following classification of nanoproducts:

https://doi.org/10.32933/ActaInnovations.32.1 • ISSN 2300-5599 •

- primary products: nanoobjects, nanosystems and ultrapure substances created using nanotechnologies, including basic raw materials and semi-finished products for the nanoindustry, in particular nanopowders and nanomaterials;
- products that contain nanoproducts (goods), nanotechnological components (nanoobjects, nanosystems, and ultrapure substances), including those produced using primary nanotechnological products;
- nanotechnological works and services, works and services provided by applying nanotechnologies or technologies for using primary nanotechnological and/or nano- containing products.

Expert analysis of the nanoproduct market [9] predicts a promising future for products manufactured using nanotechnology starting from 2015 and which belong to the fourth generation, the main feature of which is the use of heterogeneous molecular nanostructures (each complex molecule is a special nanostructure with a peculiar architecture and high functionality).

The basic trends in the development of nanotechnology and nanoproducts of the fourth generation include the following:
1. Developing atomic and molecular engineering based on still unknown laws of self-organization of matter.
2. Designing macromolecules with given properties.
3. Creating nanosized mechanical devices.
4. Ensuring a directed and multilevel self-organization of atomic structures with quantum mechanical control of assembly processes.
5. Creating nanodevices for medical supervision and treatment.
6. Ensuring direct human-computer interaction, implying contact between human nerve endings and electronic networks, etc.

The interdisciplinary nature of the latest generation of nanoproducts is confirmed by the wide range of possibilities for their application in various branches of the economy. For example, new high-strength construction materials based on nanotubes (fullerene, nanofibers), as the main carrier component or filler in composite materials can use nanoparticles to strengthen automobile tires, polymers, paint coatings, glass and concrete. Nanoparticles can be used to help lubricate components and as additives to oils to carry out work under extreme conditions and increase the functional characteristics of rubbing parts of mechanisms. Hydrogen fuel tanks are adapted to create chemical cells, in particular lithium batteries. Contrast agents are widely used for magnetic resonance imaging based on paramagnetic atoms located in the fullerene-based scaffold, since they are less toxic than the commonly used chelate complexes and permit obtaining more clear images.

Although the US, China, Japan, Germany, and Korea remain the world leaders, Ukraine has relative experience in nanotechnology development and implementation. According to the data [10], Ukraine occupies 36th place in the world ranking by the number of publications indexed in the Scopus database in the field of "Nanoscience and Nanotechnology" during 1996-2014 (Table 1).

Table 1. Ranking of various countries by the number of publications indexed in the Scopus DB in the field of "Nanoscience and Nanotechnology", 1996-2014

Rank	**Country**	**Publications**	**Citable publications**	**Citations**	**Self-Citations**	**Citations per publication**	**Hirsch index (H)**
1	USA	67227	66236	2 077860	768154	39.03	405
2	China	49009	48560	853015	481098	26.98	239
3	Japan	21558	21378	426211	117370	22.6	192
4	Germany	20800	20560	497244	111477	28.68	221
5	Republic of Korea	19306	19158	321226	78223	24.23	178
6	France	13314	13169	243083	53670	21.87	155
7	UK	13101	12848	331524	59921	29.85	203
8	India	11458	11303	141484	40710	20.39	119
9	Taiwan	9533	9444	143996	31617	20.1	122
10	Italy	8555	8435	149249	33933	22.01	129
11	Spain	7392	7310	139582	29868	25.77	125
13	Russia	6646	6601	54186	14393	11.07	84

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17	Netherlands	4829	4775	148042	19681	37.91	152
18	Sweden	3594	3554	84848	13756	30.22	117
19	Belgium	3460	3428	68064	10547	23.21	98
24	Poland	2368	2327	25334	5796	12.78	58
25	Austria	2124	2105	52402	7275	31.36	81
26	Denmark	1775	1750	39335	6090	31.06	83
29	Greece	1656	1622	25385	5001	18.21	67
36	Ukraine	1195	1187	12219	2301	12.24	47

Source: [10]

The presented data suggest that the number of publications in different areas of development of nanotechnologies will continue to grow among the leading countries and worldwide. If the trend continues, Ukraine's role in the world of nanotechnology will remain insignificant. China and the USA will occupy leading positions, with China being significantly ahead of the rest of the world.

Today, the world's largest industry that involves biotechnologies, according to the number of research projects, is healthcare, particularly, biomedicine and biopharmaceuticals. Production processes is the second largest industry that applies biotechnologies in terms of the number of research and development, and third — agriculture.

The United States is the leader in terms of absolute expenditure both on biotechnology research and development in the business sector with US companies spending nearly USD 39 billion on research in biotechnologies in 2014. The other top countries in terms of this indicator include France, Switzerland, South Korea and Germany. The USA is 5th place in terms of expenses on biotechnology for business enterprise expenses of research and development (BERD), behind Switzerland, Denmark, Ireland, and Estonia. Slovakia, which occupies the lowest position in terms of absolute expenditure, outperforms South Korea, Germany, Japan, Canada, Russia, Austria, Australia, Finland, South Africa and Mexico.

Particular attention should be paid to consideration of the expenses on biotechnology research and development of public companies in leading European countries. According to the ranking of the leading European countries in terms of R&D expense by public biotech companies, the largest investment in biotechnology research is done by public companies in the UK. Germany occupies 8th place, so it is clear that a large part of biotechnology research in this country is conducted on the basis of private companies, which places Germany, along with Britain at the top of the list of the most developed European countries in the field of biotechnology.

It should be noted that the size of government support for research in specific fields of biotechnologies depends on the chosen bioeconomic strategy adopted by the government of a particular country. The United States, Germany, and Japan have developed detailed strategies to accelerate the processes connected with the use of biomass and other innovative biotechnologies. Other countries, such as Canada and Italy, operate more pragmatically and, through their strategic documents, are trying to strengthen the existing private sector and public-funded research. A more detailed analysis of strategic documents of countries in terms of their place in the system of government support for the development of biotechnologies is presented in Section 4.1. Today, the issue of satisfying mankind's ever-increasing needs in the presence of limited resources is particularly acute. One of the tools to handle this difficult task is biotechnologies, which can fundamentally change the overall approach to production of goods and services, as well as the interaction between man and environment based on using the potential of living organisms.

Today, the United States is the undisputed flagship in the field of biotechnology. According to experts from Ernst & Young, the total market value of the US biotechnology sector is over USD 889 billion, with total annual revenues amounting to USD 107.7 billion [11]. The sector provides jobs for almost 132,000 people. The statistics refer to public companies only since information about private companies is generally kept confidential.

Moreover, in terms of revenue, the ranking of the 10 largest biotechnology and pharmaceutical companies in the world include five US companies: Johnson & Johnson, Pfizer, Merck, Abbott Laboratories, and Amgen, which combined receive 51% of the total revenues of the top ten such companies.

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The prospects of the biotechnology sector are evidenced by the salaries of biotech researchers in the United States. In 2015, the average annual salary of a biotechnologist in the country was USD 82,150 and the average hourly earnings for work by such a specialist was USD 24 [12, 13]. To-date, the average annual wage in the USA is USD 46,120 [14] and therefore the annual remuneration for the work of specialists in biotechnologies is almost twice the country's average annual income. The average salary of a starting investigator in the field of biotechnology is currently about USD 75,000; specialists with work experience from 5 to 10 years can count on an annual salary of approximately USD 82,000; if a person has great experience in biotechnology (10-20 years), his/her salary per year is about USD 91,000; biotechnology experts with more than 20 years of experience in the industry receive an average salary of USD 96,000.

When examining the structure of revenues and employment in the EU's bioeconomy, it should be noted that currently the greatest productivity of labor is observed in the areas of application of biotechnologies that are only now being formed — those concerning biofuels and bioelectricity. However, agriculture, the industry that is the second largest in terms of the number of employees has the lowest productivity, which suggests that using biotechnologies does not necessarily imply a significant increase in revenue, since this industry is an initial element in the value-added chain.

An analytical review of the biotechnology sector in the United States and Europe shows that the key player in the international biotech market is the United States, in terms of all major monetary and quantitative indicators. Biotechnology R&D expense in the United States is more than five times higher than similar public expense in European countries. The net income of public companies in the biotechnology sector in the United States is 15 times higher than in Europe, and the number of such companies in the United States is almost twice the number of biotech companies as in Europe. Moreover, the bio-based economy of the United States engages almost twice as many specialists as the biotechnology sector in Europe (Table 2).

Table 2. Comparative characteristics of the biotechnology sector in the USA and Europe

Information about public companies in billions of US dollars	USA	Europe
Revenue	107.7	25
R&D expense	33.9	6.2
Net income	15.6	1
Market capitalization	889.3	182.2
Number of employees	131690	72160
Number of public companies	436	234

Source: [11]

Aside from the United States and European countries, four countries — Canada, Australia, India, China, and Japan — have taken a prominent place in the arena of global biotechnology.

Above all, Canada's success in biotechnology development is due to the system approach of public authorities to support all the industry's driving forces. This involves developing strategic documents (such as "2020 Biodiversity Goals and Targets for Canada"), raising public awareness to understand the need for introducing biotechnologies, and providing support to specialists in biotechnologies, including the promotion of immigration of experts in the industry within the BioTalent Canada project.

The above-mentioned project is a national information platform, designed to promote the development of highly professional labor resources in the country's bioeconomy. BioTalent Canada regularly conducts research on the labor market, identifies "bottlenecks" and develops recommendations that would positively affect the balance between the supply and demand of human resources in the field of biotechnology. For example, as of 2013, 33.2% of Canadian biotech companies pointed out that their employees lacked necessary practical skills and considered it to be one of the most serious challenges for their country's bio-based economy in the 3-5 years that followed. Therefore, one of the most important factors in the development of Canada's bio-based economy is labor resources, which is why the state and companies are actively investing in the training of professionals in the field of life sciences.

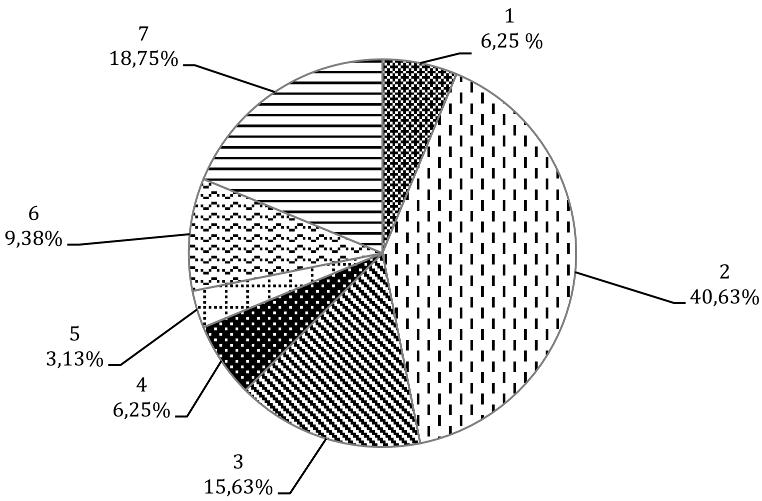
https://doi.org/10.32933/ActaInnovations.32.1 • ISSN 2300-5599 •

Australia also follows a similar policy concerning the development of a bio-based economy. In the sphere of legislation, the Biotechnology Ministerial Council adopted a document called the "National Biotechnology Strategy of Australia" and the Australian Department of State Development, Trade and Innovation created a strategy aimed at supporting and developing competencies of specialists in the field of lawmaking, project management and scientific and technical activities in the fields of bioinformatics and biostatistics. Similar to the BioTalent Canada information platform, in Australia the Bio-Link Education Center successfully operates a platform aimed to help with obtaining education in biotechnology (including from abroad), as well as assists in the recruitment of specialists. Moreover, this organization collaborates with biotech companies from Australia and abroad to commercialize achievements in biotechnology. Furthermore, Australia has borrowed the experience of the United Kingdom in the creation of innovative clusters in the field of biotechnology. For almost 30 years an organization called "AusBiotec" has been functioning in the country, uniting more than 3,000 scientists.

Particular attention should be paid to the special tax regime for innovative biotech companies in Australia: a reduced income tax rate (10%) has been introduced, which in turn stimulates the modernization of the industry and facilitates the commercialization of its achievements. Biopharmaceutical companies are provided a possibility of compensation of up to 43.5% of the total amount of R&D expenses. Due to this, clinical trials in Australia are 60% cheaper than in the United States. Moreover, in 2016 the Australian government allocated USD 250 million to promote the commercialization of biotechnology in the country [15].

The result of Australia's system approach to the implementation of a biotechnology strategy is the transformation of Australia into a global center that brings together leading researchers, companies, investors and partners into a holistic biotechnological ecosystem. Presently, Australia is among the top five countries in terms of biotechnology, with Australia's GDP share of biotechnology being the largest in the world [16].

Prospects for the development of nano- and biotechnology in Ukraine depend on their commercialization and support mechanism. The analysis of 32 projects from Ukraine, which was implemented by The 7th Framework Programme for the "Biotechnology" and "Biofuel" directions, shows such results (Figure 1).



1 - food biotechnology; 2 - biomedicine; 3 - industrial biotechnology; 4 - agricultural biotechnology; 5 - environmental biotechnology; 6 - biofuels; 7 - complex biotechnology.

Figure 1. Distribution of biotechnology and biofuels projects with Ukraine's participation in the 7th Framework Programme [17]

Most Ukrainian biotechnology projects are related to biomedicine technologies: research of cancer, bubonic plague, HIV cell membrane antigen splitting and others. Noteworthy integrated biotechnology development projects are: INCOMAT (study of surfaces and coatings of new biomaterials), PERCERAMICS (development of the innovative type of ceramics for the production of bone bioimplants), OPTIMISC (biotechnology for bioenergy). Due to Ukraine's participation in The 7th Framework Programme, important problems of the development of national biotechnologies are being solved, however, all projects are implemented under co-financing. From this perspective, the development of an effective national mechanism for state support for the development of biotechnology is gaining importance and relevance. In the authors' view, the mechanism should include the concept of biotechnology development, legislative and regulatory support and specific tooling. The concept of nano- and biotechnology development should be based on the principles of biotechnology development with priorities established for state support and development methods. In the field of the legislative and regulatory support it is necessary to amend a number of laws governing the development of science and technology, that is, to create new methods and regulatory acts to regulate the development of biotechnology.

The specific tooling includes program-targeted financing instruments, the development of technology parks and technology clusters, and establishing tax and financial instruments. The broad analysis of the world's experience in the field of nano- and biotechnology makes it possible to draw the following conclusions:
1) the undisputed leader in the industry is the United States, which has managed not only to develop all types and sub-sectors of biotechnologies known today, but has successfully commercialized them;
2) the biotechnology sector is identified as one of the most promising innovative directions of development of EU countries. Within the EU there are 3 conditional clusters that differ in types of biotechnologies in accordance with their economic, geographical and historical features;
3) the pathway of all countries that have achieved remarkable success in the bioindustry is based on a systems approach and start precisely with the development of strategic documents identifying the top priority sub-sectors of biotechnologies most fitting for the particular country and optimal methods to ensure their development and improvement;
4) establishing a mechanism for effective interaction between academia and business as well as clustering and merging research centers in order to accelerate the development of innovation are the key factors that contribute to the commercialization of results of biotechnological research;
5) based on the experience of BioTalent Canada and the Australian Bio-Link information platforms, it is possible to conclude that one of the most important investments in the development of the bioindustry is the comprehensive support and training of specialists in the field of biotechnology.

Summary and conclusions

The rapid development of nano- and biotechnologies worldwide is supported by a steady increase of R&D funding which accounts for a significant share of the total amount of R&D expenses in developed countries. Both developed and developing countries have their own specific concepts and strategies for the development of nano- and biotechnologies, which specify the priority areas to receive government support for innovative research. Presently, the undisputed leaders in the practical implementation and commercialization of nano- and biotechnologies are the United States, Switzerland, and the United Kingdom, which is confirmed by their having the highest total revenues of companies in this sector. In light of the analysis of the current expanding state of the global market and current financial incentive possibilities available for Ukraine, the authors highly suggest full governmental support of the introduction of biotechnologies in the Ukrainian economy. The need is for immediate support and stimulation specifically of the development of biotechnologies in the fields of medicine and pharmacy, which will create jobs and ensure the existing social procurement and development of the country's pharmaceutical industry. Moreover, taking into account Ukraine's energy dependence and the availability of its own technologies, the development of biotechnologies in the field of biofuels is recognized as being highly promising for the country. The article complements citations [1–9] by clarifying the promising areas for the development of nano- and biotechnologies based on an analysis of the scientific activity of the inventors. A new contribution is the proposed components of the mechanism of co-commercialization of innovative biotechnologies for Ukraine, which can be marketed in other countries.

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Kinga Boroń
Częstochowa University of Technology
al. Armii Krajowej 19, 42-200 Częstochowa, Poland, boron.kinga@wip.pcz.pl

EVALUATION OF POROSITY OF ALZN5MG CASTINGS MADE BY SQUEEZE CASTING TECHNOLOGY

Abstract
The paper shows the results of research aimed to assess the impact of high squeeze pressure on the porosity of AlZn5Mg alloy castings, including its distribution in slab-type castings with dimensions of 25 x 100 x 200 mm. The research was carried out on castings made by two methods: squeeze casting and gravity casting. The pressing was conducted at a pressure of 100 MPa at an initial mould temperature of 200°C. The research identified the middle and outer parts of the casting. Experimental research was preceded by numerical simulation of the casting solidification, then a porosity assessment was carried out using the hydrostatic weighing method, which was supplemented by structural observations. The results of the research showed a two-fold decrease in the porosity in the middle part of the casting which is most exposed to the occurrence of shrinkage voids formed in the final clotting phase. Structural tests revealed the occurrence of dispersed porosity in castings, mainly of shrinkage and / or shrinkage-gas origin. The impact of pressure of 100 MPa during solidification caused fragmentation of the primary structure of castings, which resulted in a higher grain density.

Key words
squeeze casting, AlZn5Mg, porosity

Introduction

Aluminum and zinc alloys have a chemical composition of from 5% to 14% zinc, as well as magnesium, copper, manganese, chromium and titanium. These alloys are called zinc durales and are characterized by the highest strength properties in comparison with other aluminum alloys. Tensile strength of Al-Zn alloys in precipitation-hardened state reaches 700 MPa, while yield strength 600 MPa, with relatively small elongation of 2 ÷ 5%. AlZn alloys are rarely used due to low resistance to elevated temperature and structural degradation, as well as low corrosion resistance, mainly stress corrosion. To increase the corrosion resistance of zinc durales, they are clad with pure aluminum. The advantage of aluminum alloys with zinc is their ease of welding and low ignition propensity, which makes AlZn alloy castings suitable for use with steel [1,2]. In contrast to other precipitation-hardened aluminum alloys, AlZn alloys are not sensitive to the cooling rate during supersaturation [3]. They can be hardened both cold and hot. During aging of Al Zn Mg alloys, metastable disperse phases are isolated in the following sequence [4]: supersaturated α solution $\rightarrow$ GP zones $\rightarrow$ η' phase $\rightarrow$η ($MgZn_2$) $\rightarrow$T ($(AlZn)_{48}Mg_{32}$). GP zones in classic dural (Al-Cu) occur in the form of flat coherent discs, whereas in Al-Zn and Al-Zn-Mg alloys they usually take on a spherical shape [5-8]. Dispersive phase η' or GP zone particles provide high strength properties of castings at low temperatures and at 25°C. Characteristic properties of the AlZn5Mg alloy include sufficient castability, low resistance to hot cracking, poor tightness, very good machinability, good weldability, good polishability, good susceptibility to decorative anodising, very high strength (after precipitation hardening) at room temperature, low strength at elevated temperatures (above 100°C) and good plasticity. Despite the many advantages of this alloy, work is still in progress to increase its properties by using different casting methods and heat treatment. The presented research focuses on the use of the squeeze casting method. It is a method combining forging, pressure casting and die casting [9-11]. The combination of these three methods allows the production of products with many advantages such as fine grained structure, smooth surface or obtaining castings with high shape and dimensional precision. However, the main advantage of this method compared to pressure casting is the significant elimination of shrinkage and gas porosity and the possibility of heat treatment of castings [12].

Research material and methodology

For testing purposes, standardized (according to PN-EN 1676: 2002) AlZn5Mg aluminum alloy was used, from which slab-shaped castings were made. In order to identify potential spots of shrinkage porosity in the analyzed casting, experimental tests were carried out with a numerical simulation of solidification in NovaFlow&Solid software at initial conditions: mould temperature 200°C, temperature of the liquid alloy 720°C (entirely the

https://doi.org/10.32933/ActaInnovations.32.2 • ISSN 2300-5599 •

same), the material of the mould was made of carbon steel however, at the point of touch of the cast-mould the fourth type condition was adopted.

The metal charge was melted in the PIT50S / 400 crucible induction furnace. The castings were made on a PHM-250c hydraulic press (Figure 1) equipped with a metal mould with dimensions of 100x200x50mm recess and the ejector slab (Figure 2). Slab-shaped castings with dimensions of 100x200x25mm, were produced by the squeeze casting method and for comparison by the gravity method. Time of impact of the stamp on the casting of 60 seconds was based on preliminary research and literature data [12].

Figure 1. Hydraulic press
Source: Author's

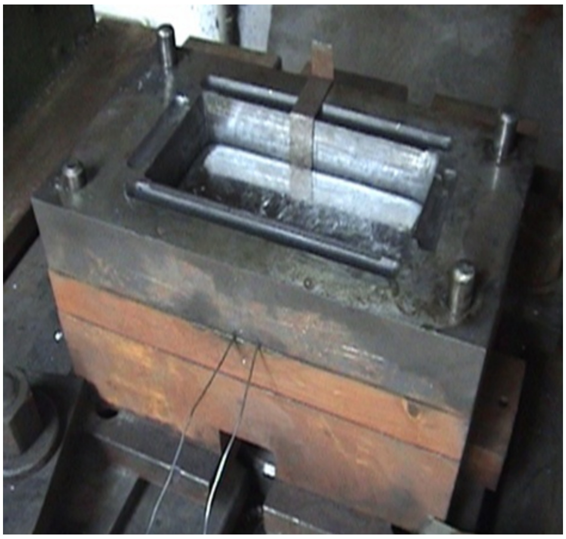

Figure 2. Mould cavity
Source: [12]

The pressing process was carried out with the following parameters:
- mould temperature - 200°C,
- temperature of the metal charge - approx. 710°C
- squeezing pressure - 100 MPa
- time of impact of the stamp on the casting - 60 seconds.

Gravity casts were also made on a hydraulic press with the difference being that no pressure was applied, when the pressing ram was in the point of contact with a liquid alloy, the hydraulic system was turned off and the cast solidified without external pressure. Research was conducted on a total of 8 casts of the slab method, 4 gravity casts and 4 casts by direct compression. For the research on porosity, from each casting, 2 rectangular samples of 25x25x100 mm were taken. Samples were cut from the center of the slab (internal samples) and from its edges along the shorter side (external samples) (Figure 3) to analyze the porosity distribution in the cast. After taking porosity measurements, metallographic examinations were made and microstructural observations of the tested alloy were carried out.

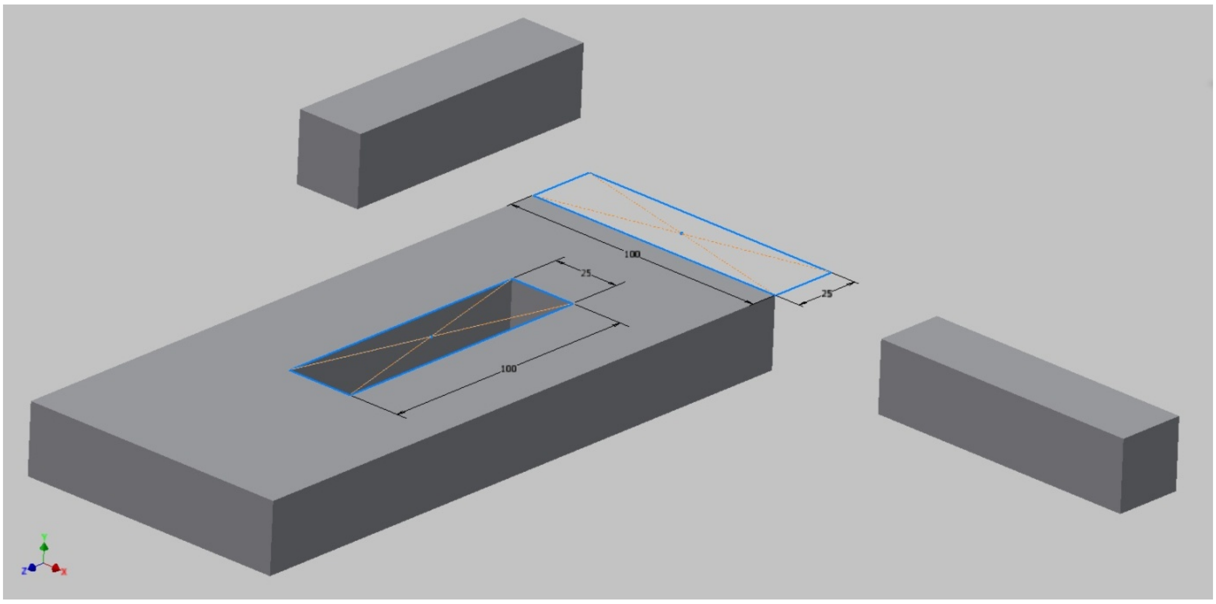

Figure 3. Scheme of cutting out samples from a casting slab
Source: Author's

Evaluation of the porosity of the castings was carried out using the hydrostatic weighing method according to BN-75 / 4051-10 standard. Samples were weighed in air and water, and their density was determined from the following formula:

$$\rho_P = \frac{m_1}{m_1 - m_2} \cdot \rho_W \quad (1)$$

ρ_P – sample density,
m_1 – weight of the sample in the air,
m_2 – weight of the sample in water,
ρ_W – water density.

Then, the porosity of the tested samples was calculated:

$$P = (1 - LG) \cdot 100\% \quad (2)$$

LG – the gas number specified by the expression:

$$LG = \rho_P / \rho_{TS} \quad (3)$$

ρ_{TS} – theoretical density of the alloy defined by the expression:
A, B, N – content of individual components in% by mass
ρ_{TA}, ρ_{TB}, ρ_{TN} – theoretical density of individual alloy components

The last point of the research was the observation and evaluation of microstructures. Observations were made on the samples prepared from the porosity measurement samples.

Results and discussion

Numerical simulations of solidifications of the slab casting were carried out in the following conditions:

- mould temperature - 200°C,
- liquid alloy temperature - 720°C (homogenous for the entire cast),
- mould material - carbon steel.

At the point of touch of the cast-mould the fourth type condition was adopted. The thermophysical properties of the alloy and matrix were downloaded from the program NovaFlow&Solid database.
Number of unit cells 1,236,492. The characteristic size of the unit cell was 1.4 mm. The wall thickness of 25 mm was used for calculations.

On the basis of conducted numerical simulations of solidification (Figure 4-7), local thermal nodes were identified and potential places of shrinkage of porosity in the analyzed cast were determined.

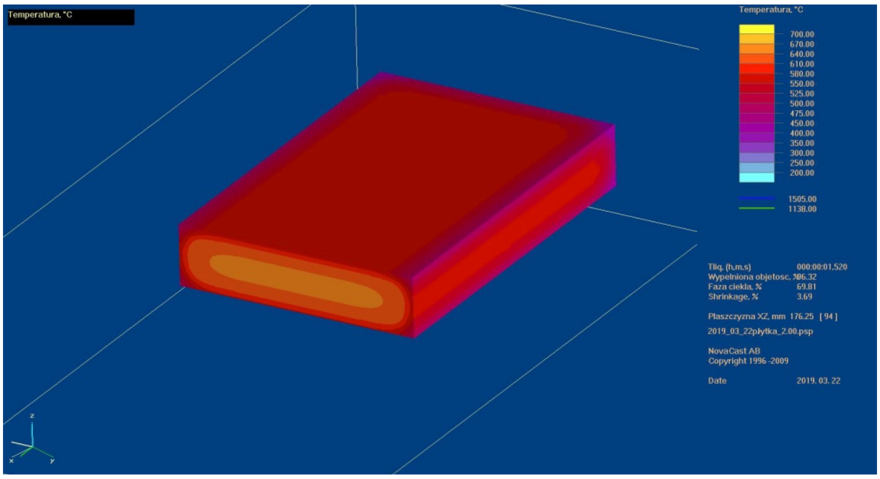

Figure 4. Area of liquid phase share in the middle period of solidification
Source: Author's

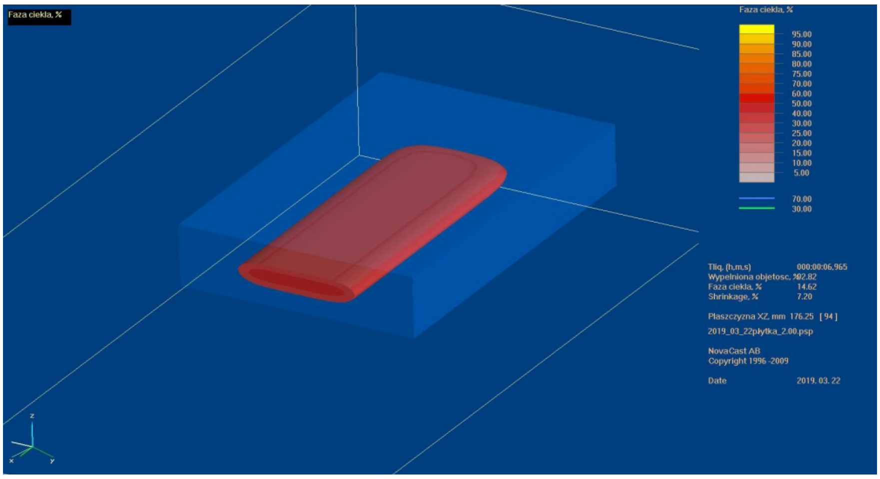

Figure 5. Area of liquid phase share in the final solidification phase - residual liquid
Source: Author's

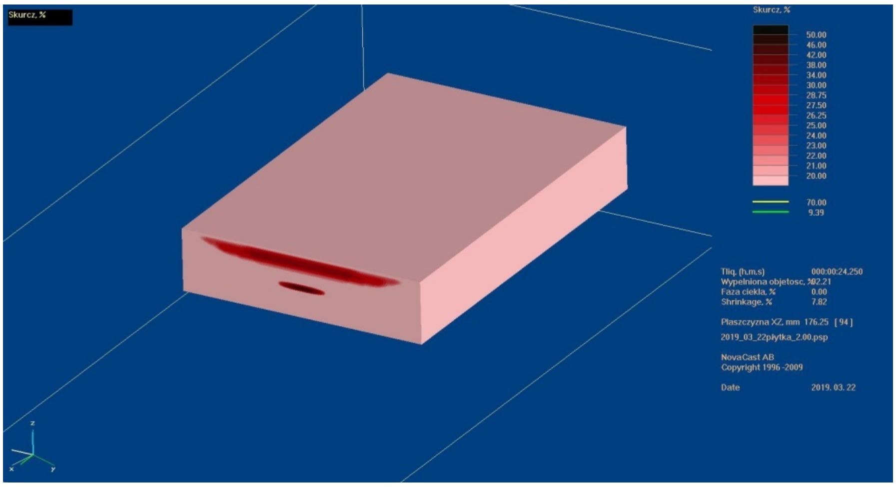

Figure 6. 3D distribution of the shrinkage in the cast after solidification
Source: Author's

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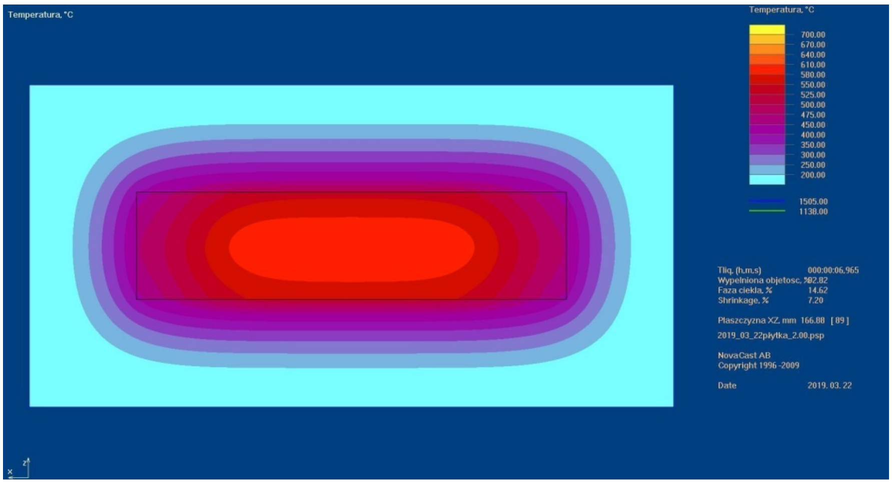

Figure 7. Temperature field in the slab casting and metal mould after solidification
Source: Author's

The results of the solidification simulation showed that the cast solidifies the quickest on the edges, in the corners and on walls with a smaller surface area. From Figure 4, it can be observed that with a liquid phase of about 50%, the temperature in the central part of the cast was about 640°C, on the edges and walls about 580°C while the fastest heat dissipation comes from the corners where the temperature is around 450°C. The share of the liquid phase in the final phase of solidification, shown in Figure 5, is residual liquid which determines the area particularly exposed to shrinkage porosity. This area is the central part of the casting which gives off heat longest and solidifies last. The lack of liquid metal supply to this part of the casting results in the creation of a longitudinal void with dimensions of approx. 23 x 2.5 x 85 mm. Visualization of contraction effects in the center of the tested plate and in the area extending from the upper surface to the interior of the casting is presented in Figure 6. Considering the wide temperature range of solidification of the AlZn5Mg alloy, it should be assumed that diffused porosity will occur in these places. Numerical simulations also show that the total solidification time of the casting is 24.25 s, and the maximum temperature difference between the center and the edge of the plate is about 100°C. The matrix overheating zone up to 300°C in one casting production cycle is at the level of 150 mm. This area is the middle part of the cast, in which the heat dissipation time is longest and it solidifies last. The results of the solidification simulation, shown in Figures 5-7, reveal the occurrence of shrinkage effects in the central part of the tested slab and in the area extending from the upper surface to the center of the casting. Considering the wide temperature range of AlZn5Mg alloy solidification, it should be assumed that dispersed porosity will occur at these locations. The results obtained after the computer simulation were supported by the results of porosity tests and microscopic observations. The main conclusion which results from the conducted research, is the fact that the technology of squeeze casting reduces the porosity of the tested alloy two-fold in the middle part of the casting and in external areas the effects of compression were a reduction of porosity by approx. 0.3%.

The results of weight measurements of internal and external samples calculated on the basis of dependence (1) - (3) of actual density are summarized in Table 1. Figure 8 shows the average values of porosity in the specified parts of the slab, cast by gravity and squeeze casting methods.

Table 1. Testing results of the weight, density and porosity of internal and external casts by gravity and squeeze casting

Gravitational casting									
External samples					Internal samples				
Sample symbol	Weight in the air g	Weight in water g	Density g/cm^3	Porosity %	Sample symbol	Weight in the air g	Weight in water g	Density g/cm^3	Porosity %
4G_1Z	108.12	68.60	2.74	1.23	4G_1W	102.31	63.91	2.66	3.82
4G_2Z	105.45	66.82	2.73	1.45	4G_2W	116.45	73.26	2.70	2.67
4G_3Z	110.57	69.98	2.72	1.67	4G_3W	118.92	74.68	2.69	2.96

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4G_4Z	112.56	71.29	2.73	1.53	4G_4W	107.56	67.16	2.66	3.89
Squeeze casting									
4P_1Z	116.80	74.13	2.74	1.18	4P_1W	107.89	68.36	2.73	1.48
4P_2Z	107.97	68.58	2.74	1.05	4P_2W	116.23	73.47	2.72	1.87
4P_3Z	107.56	68.28	2.74	1.14	4P_3W	106.81	67.68	2.73	1.47
4P_4Z	104.19	66.09	2.73	1.28	4P_4W	110.07	69.57	2.72	1.89

Source: Author's

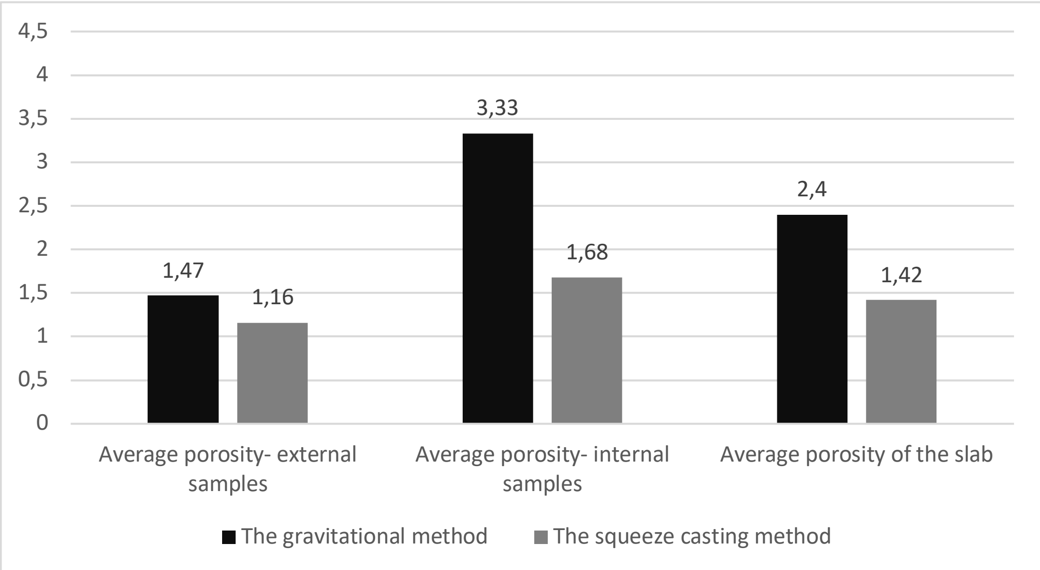

Figure 8. Average porosity of the AlZn5Mg alloy casting
Source: Author's

The graph clearly shows the average porosity in the entire slab area decreased significantly, in particular for internal samples where the porosity in the middle part decreased more than two-fold using the squeeze casting method. The obtained test results also confirm observations of the microstructure (Figure 9). In the case of gravity casts, around the primary crystals, visible interdentritic voids were created, while the squeeze casting method effectively lowered shrinkage microporosity and grain phase α primary crystals.

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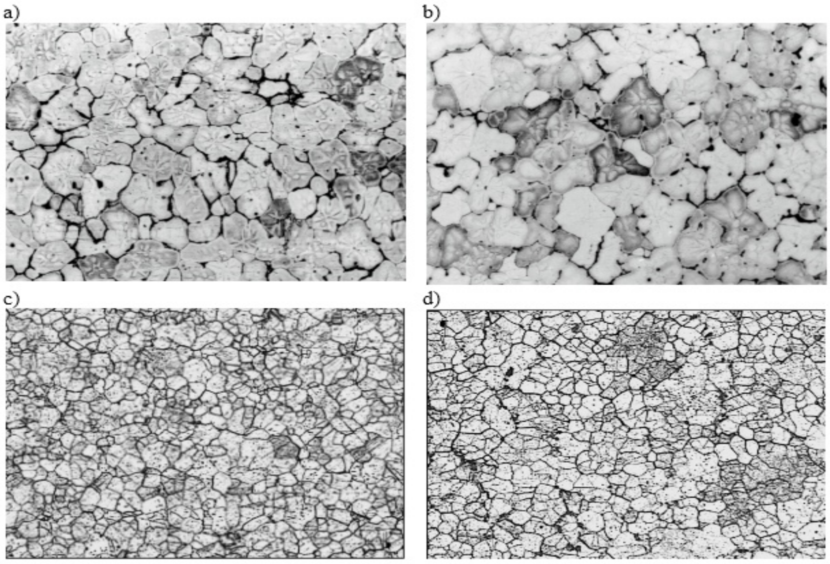

Figure 9. AlZn5Mg alloy structure, magnification 50x:
a) gravitational casting - edge of the slab
b) gravitational casting - the center of the slab,
c) squeeze casting - plate edge,
d) squeeze casting - the center of the slab
Source: Author's

Structural tests revealed the occurrence of dispersed porosity in castings, mainly of shrinkage and / or shrinkage-gas origin. The AlZn5Mg alloy shows a monophasic dendritic structure (where the morphology of crystallized crystals depends on the solidification conditions), while in the final solidification stage, in the middle part of the slab, due to the lack of liquid metal supply around the primary crystals, visible voids were created, and formed at the grain boundary in the tested alloy. In gravity castings, the primary phase crystallizes dendritically with only first-order branches with clearly rounded dendritic tips.

However, in squeeze casting the α phase takes on a typically granular form. The pressing process also causes greater supercooling of the alloy, which in turn results in greater nucleation intensity [13,14] and very clear fragmentation of the grain structure of the alloy [Figure 9c, 9d]. In all the alloys tested, increased porosity was revealed on samples taken from the middle part of the slabs. When assessing the effect of pressure on solidification of the casting, it can be concluded that the grains are finely disintegrated, which is the result of faster heat dissipation during mould casting (no shrinkage gap) and a greater tendency of the alloys to nucleate the primary phases under high pressure conditions. The reduction in the shrinkage porosity of squeeze casting is primarily associated with their plastic flow in the liquid state as well as partly in the solid state as a result of local stress generated by the stamp [15]. It should also be noted that the phenomenon of plastic flow in the final phase of solidification and subsequent cooling of castings has a very positive effect on dimensional accuracy and shape mapping and surfaces of castings. A clear reduction of porosity in Al alloy castings produced by the squeeze casting method in comparison to gravity castings was also found in other studies [16]. It is believed that the very low porosity of pressed castings and the high level of primary graining favors the processes which occur during the hardening of the precipitated alloy and, as a result, obtains higher mechanical properties of squeeze casting casts in comparison to casts produced by gravity.

Conclusions

On the basis of conducted tests of castings made of AlZn5Mg aluminum alloy produced by the squeeze casting method and gravity method, it can be stated that after numerical simulations of solidification of slab-type casting, it was observed that the area particularly exposed to shrinkage porosity is the middle part and area extending from its center to the upper surface. Due to the wide temperature range of solidification of the tested alloys, there is dispersed porosity in the casts, and the shape of the formed voids depends on the solidification morphology. Squeeze casting technology allows more than a two-fold reduction of porosity in the middle parts of the slab, while in the outer parts of the slab a reduction of 0.3%. The average porosity

https://doi.org/10.32933/ActaInnovations.32.2 • ISSN 2300-5599 •

of the castings for the whole slab made by squeeze method is more than twice less than that produced by gravity. The pressure impact of 100 MPa during solidification causes the fragmentation of the primary structure of the castings, which is manifested by a higher grain density.

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Olga Ivanova
Research Center for Industrial Problems of Development of the National Academy of Sciences of Ukraine,
1a Inzhenernyi Ln., Kharkiv, Ukraine, laptevaou@gmail.com

Viacheslav Laptiev
Simon Kuznets Kharkiv National University of Economics
9a Nauky Ave., Kharkiv, Ukraine, vlaptev777@gmail.com

TAX INCENTIVES FOR INNOVATION IN THE ENERGY SECTOR

Abstract
The article considers the current issues of stimulating innovation in the energy sector and rational use of energy resources. A three-level system of problem-oriented management of human resources for stimulating innovation in the energy sector is proposed. The system considers the impact of the human factor on innovative development at the national, regional and enterprise levels. Also, the need to encourage enterprises to hire highly qualified specialists in the sphere of energy saving and energy efficiency is proven. The role of the tax policy in state regulation of the rational use of energy resources and stimulation of innovation in the energy sector is substantiated. The tax incentives for the rational use of energy resources applied in the world practice are grouped. Features of the application of tax incentives (accelerated depreciation, tax credits, tax holidays, and tax reduction) for energy efficiency and energy saving of households and business entities are analyzed. Directions for stimulating innovation in the energy sector for the efficient use of energy resources are offered.

Key words
stimulation of innovation, tax incentives, state regulation, energy sector, energy efficiency, human resources

Introduction

Innovation is a force for progress in any sphere of human activity. Innovative development is an important factor for increasing the level of competitiveness of the country's national economy, its territorial units and business entities. Intensive development of international cooperation in the context of integration puts forward demands for the state's stimulation of innovative development in all spheres of the economy and creation of conditions for conducting innovative activity. An important role in this process is assigned to human resources, which, on the one hand, provide legislative and organizational mechanisms for stimulating innovation at the national and regional levels, and, on the other, ensure the development and implementation of new ideas and technologies. One of the sectors in which innovation is the key to increasing the competitiveness of the national economy and the standard of living of the population is the energy sector. Socio-economic development of the national economy under conditions of shortages of energy resources is impossible without development and implementation of a balanced state policy of stimulating the rational use of energy resources and innovations in the spheres of energy saving and energy efficiency. The development of directions for the rational use of energy resources stimulates the increase of financial stability, energy and environmental security, and, as a result, ensures the country's economic security and increases its competitiveness.

Research of problems in state regulation of the rational use of energy resources has been carried out by such scientists as L. Bretschger, V. Mykitenko, L. Petkova, D. Palamarchuk, H. Sanders, K. Hassett, M. Filippini, H. Hunt and I. Sotnik. Tax issues in the implementation of resource-saving measures have been investigated by A. Amosha, S. Aptekar and Y. Ivanov. Research in the field of energy efficiency of the economy has been engaged V. Zhovtyansky, M. Kulik, A. Sukhodolya, J. William, etc. The role of human resources in innovative development has been considered in the scientific works and research of D. Bell, M. Blaug, P. Burd'e, I. Kamenev, A. Korickij, Ju. Korchagin, B. Milner, V. Sinov, etc. However, the potential for innovation in the sphere of energy efficiency and energy saving is enormous and requires effective mechanisms of state support. Issues of the duality of the human factor in the process of applying tax incentives for innovative development, including in the energy sector, require further research.

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The human factor and state stimulation of innovative development

Specialists in the sphere of energy saving determine the state policy in this area as "the process of implementing particular actions by state authorities with the aim of influencing the national economy in order to ensure efficient and rational use of fuel and energy resources" [1]; "a system of purposeful actions by government departments with a view to formulating mechanisms of public administration to influence the national economy in order to ensure efficient and rational use of fuel and energy resources" [2]; "an organized and purposeful activity or inactivity of government departments to regulate the use of primary energy and its transformation in the national economy" [3]. The last definition more fully reflects the essence of this concept but does not focus on mechanisms that stimulate the rational use of energy resources, which is also a subject to regulate.

State regulation of the rational use of energy resources and energy innovation should be viewed as a process of targeted influence (stimulation, support) by the state with the help of instruments (tax, budgetary, monetary, etc.) (Figure 1) [4] through the system of bodies authorized by them on tax subjects with the purpose of their rational use of energy resources.

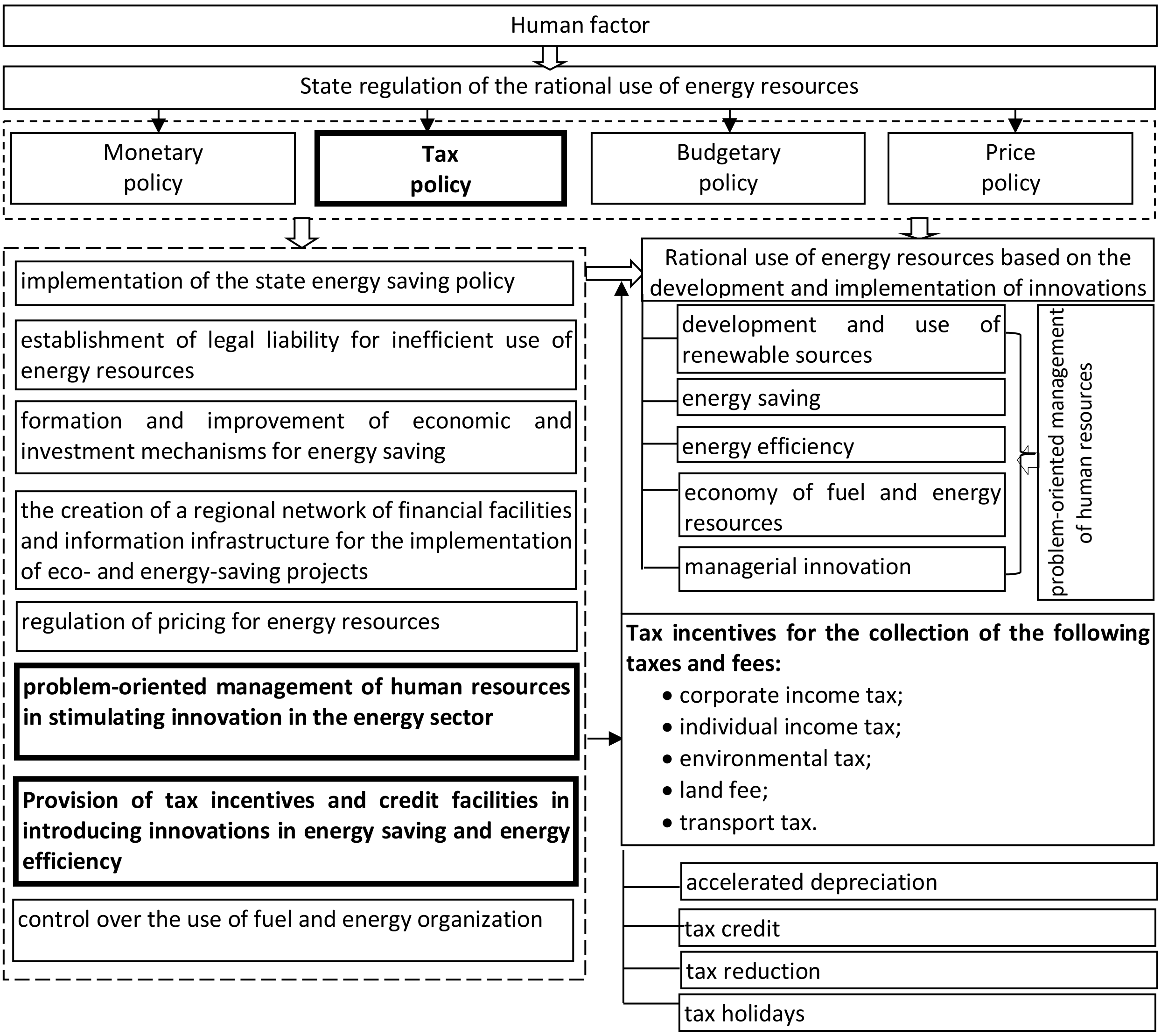

Figure 1. The role of the tax policy and human factor in state regulation of the rational use of energy resources and innovations in the energy sector
Source: Author's

The country's energy saving potential lies in [4; 5] increase of its own energy carriers production; reduction of irrational use of energy resources; introduction of new energy-efficient projects and programs at the national

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and regional levels; introduction of resource-saving technologies in all sectors of the economy and the social sphere.

For national economies to achieve sustainable development, efficient use of energy resources is timely and relevant for several reasons:

- economic - this is evidenced by the relatively high energy consumption in the manufacturing sector in developing countries, which makes the cost of products uncompetitive on world markets;
- political - this is manifested in the issues of energy dependence of countries, which, for example, is about 50% on average in the EU countries (Austria – 64.7%, Germany – 61.4%, France - 50%, Italy - 18%, Japan 7%) [6; 7];
- environmental - the production of energy resources results in a negative impact on the environment.

Given these reasons, considering today's needs, promoting rational use of energy resources is one of the most important priorities for the country's socio-economic development. To ensure sustainable development of the economy and stimulate the efficient use of energy resources, a set of government regulation measures is used in world practice. Innovative development includes a number of factors that affect the innovation process and effectiveness of innovation, the most important of which is the human factor. Based on a problem-oriented approach to human resource management, the influence of the human factor on innovative development in the energy sector can be divided into a three-level system (Fig.3). This approach involves choosing the methods and tools for human resource management that are most adaptive, flexible and timely for addressing specific problems at the methodological and practical levels.

Levels	Directions and instruments of state support for innovation		Role of the human factor
Macro level (National)	legislative, financial, institutional, information support, etc.	Laws and regulations; innovative target programs; transfer of knowledge in the sphere of energy saving and efficiency; twinning; coordination of interaction of science, education and business in the sphere of innovations in the energy sector, stimulating business to introduce innovations, etc.	competence of personnel of public authorities in the sphere of stimulating innovative development; ability to justify the economic feasibility of applying instruments to stimulate innovation
Meso level (regional)	Organizational, information, infrastructure, financial support	effective linkages between the research sphere and the real economy; regional competitions of innovative vouchers, business incubators, technoparks, etc.	competence of personnel of regional authorities in developing mechanisms for stimulating innovation in the region
Micro level (company)	staffing; direct financial support, tax support instrumentss	tax benefits; staffing for development and innovation; energy management programs; outsourcing; subcontracting	availability of personnel for developing and implementing innovations as well as management personnel for developing energy management

Figure 3. The three-level system of problem-oriented management of human resources in stimulating innovation in the energy sector
Source: Author's

At the macro level, for the implementation of regulatory, legal, financial, institutional and other support for innovative development, there is a need for competent personnel that can develop mechanisms for stimulating innovative development in the country; can justify the expediency of using instruments to stimulate innovation; are able to effectively coordinate the cooperation of science, government, education and business to achieve

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the goal. To reach this goal, it is necessary to: conduct training and professional development of state employees; twinning and exchange of experience in organizing state support in the sphere of energy efficiency and renewable energy; provide internships abroad and participation in international programs, grants, etc.

At the meso level, the human factor manifests its duality. On one hand, at the regional level innovative development is influenced by the qualifications and competencies of the personnel of regional authorities. These include those who take part in elaborating regional innovation development programs, the mechanisms for the operation of innovative clusters, technology parks, etc., as well as coordinate interaction between science, educational institutions and business in the preparation and search for specialists in the field of development and implementation of innovations among enterprises. On the other hand, the availability of intellectual and scientific potential in the region determines the directions of its innovative development.

At the micro level, in the context of support for innovation in the energy sector, on the state's part, it is necessary to implement a policy of direct financing and tax incentives for entrepreneurs who through innovation create new job opportunities and attract highly qualified specialists within the sphere of innovation. For example, the experience of the Netherlands in tax incentives for innovation is to provide a 50% exemption from social contributions to personnel employed in R&D. In world practice, reduced rates of the single tax and profit tax are applied when using the technology of outsourcing. On the part of the entrepreneur it is important to interact with the authorities and scientific and educational institutions in the implementation of innovative activities; development of managerial innovations in the sphere of human resource management.

Instruments for stimulating innovation and energy efficiency in the energy sector

Foreign experience shows that under market economy conditions, economic methods of state regulation are preferable, the most effective among which can be employment of the country's tax system. The fact that the tax system plays a significant role in stimulating (or hindering) resource conservation is also noted by S. Aptekar [8] as well as by other scientists.

According to the World Energy Council report [9], which assesses energy efficiency policies in 90 countries worldwide, economically developed countries use fiscal measures more than other countries. In foreign countries, the following fiscal measures are mainly used: tax credits, accelerated depreciation, tax reduction. Tax incentives, as a means of stimulating the efficient use of energy resources, are most widely used in the US, Japan and a number of European countries since the late 70s to early 80s after the global energy crisis. It was at that time that the economically developed countries intensified the elaboration of measures to stimulate energy saving. A number of European Union directives that regulated the energy saving process in general and methods to stimulate it were adopted. Among them there can be singled out the Council's recommendation on the rational use of energy in industrial enterprises [10], on the promotion of energy efficiency investments [11], and on the promotion of the use of biofuels and other renewable fuels for transport [12].

The world practice of taxation shows that tax incentives for the efficient use of energy resources can be applied in the collection of such direct taxes and fees such as: corporate income tax; individual income tax; environmental tax; land fee; transport tax. The process of stimulating the efficient use of energy resources in the context of direct taxes and fees occurs through the provision of tax incentives (in some cases subject to certain restrictions) for industrial enterprises and households for the use of energy-efficient and energy-saving technologies and alternative energy sources. The main objectives of this process should be singled out for two groups of subjects: business entities and households (Table 1).

https://doi.org/10.32933/ActaInnovations.32.3 • ISSN 2300-5599 •

Table 1. The objectives of applying tax incentives for efficient use of energy resources depending on the subject

Objectives for business entities	Objectives for households
reducing the amount of corporate income tax by the full amount of the targeted expenditures incurred, or a part thereof; by the full or partial amount of the increment of corresponding expenses in the reporting period in relation to the established base	reducing the amount of individual income tax when using alternative energy sources or implementing activities related to energy saving
reducing the cost of industrial products through the use of less energy-intensive production technologies, which will increase the profit of the enterprise and improve its competitiveness in world markets	
providing fixed assets renovation due to application of accelerated depreciation. Higher rates and a shorter (compared with the usual order) depreciation period allow the payer to increase in each tax period the use of such fixed assets of the amount of accrued depreciation, reduce the taxed item	reducing government spending on energy and increasing the country's energy independence by cutting off energy consumption by households
stimulating the use of environmentally safe technologies of industrial production, which should allow to reduce harmful emissions into the atmosphere and discharges into water bodies	reducing harmful emissions into the atmosphere

Source: Author's

The world practice of stimulating the efficient use of energy resources demonstrates the application of various tax incentives to achieve the goal. Thus, based on the Worldwide tax summaries: Corporate Taxes 2017/18 report (published by PwCIL [13]), the Energy Charter's report "Investments in Energy Efficiency. Elimination of barriers" [14], in the article the application of tax incentives to stimulate the efficient use of energy resources in countries that employ such instruments is systematized (Table 2).

Table 2. Features of using incentives to stimulate the efficient use of energy resources in individual countries when collecting the corporate income tax

Country	Application features
	Accelerated depreciation
Australia	Accelerated depreciation is available for capital expenses for the exploration of geothermal energy sources. Such expenses are entitled to immediate 100% write-off [13].
Argentina	Accelerated depreciation (write-off of expenses within three years) is available for exploration of alternative energy sources (e.g. wind power) [10].
United Kingdom	The opportunity to write off up to 100% of the cost of the relevant technologies and equipment within a year from the date of acquisition [15]. The right to accelerated depreciation is available only for products that are included in the Energy Technology List, the criteria for which are reviewed and approved annually, taking into account the latest developments [16]. The List itself [17] is updated monthly and contains a detailed list of products specifying the manufacturer and model numbers. There are also four categories of products not included in the list of energy technologies, but are entitled to accelerated depreciation (non-listed products): equipment based on the use of automatic control and orientation, which is specifically designed for measuring and analyzing data on energy consumption; equipment for combined heat and power generation (cogeneration) high-efficiency light modules; insulation of pipelines [11].
Ireland	Accelerated depreciation of 100% in the first year is provided for expenses for some energy-saving equipment. The following categories of equipment are entitled to accelerated depreciation: related to information and communication technologies; related to provision of heat and energy supply; electric cars and vehicles using alternative fuel systems; heating, ventilation and air conditioning, lighting systems; motors and drives; energy management systems of buildings; freezing and cooling systems; electro-mechanical systems; equipment of restaurants and hotels [18].

Continuation of Table 2

Country	Application features
Liechtenstein	Energy-saving equipment and systems using solar energy are depreciated at a rate of 50% [5].
Luxembourg	Special accelerated depreciation of 80% of the value of fixed assets is available for assets that contribute to energy savings [13].
Singapore	Amortization deductions of 100% are available for capital expenses for energy-saving equipment [13].
Tax credit	
USA	The tax credit is established at the federal level in the amount of up to USD 2,000 for all new energy-efficient houses. This benefit can be applied by home producers if energy consumption is 50% less compared to the requirements envisaged by the International Energy Conservation Code (IECC). A USD 1,000 tax credit is provided for homes that consume energy 30% less than the requirements set by the IECC. A 30% Manufacturing Tax Credit is applied for investment in new, expanded or refined prospective energy projects in production. Applicants received tax incentives, depending on the expected commercial viability of the project and the ranking of their project compared to other projects [18].
PRC	Enterprises that buy and use specified by the state equipment that is intended for energy saving have the right to a tax credit of 10% of the investments in such equipment. Any unused amount can be transferred and accounted for in the following five years [13].
Luxembourg	A complementary tax credit is granted in the amount of 12% of the increase in investments in tangible assets during the tax year. Regardless of this, the company can receive a tax credit of 8% on the first EUR 150,000 of new investments in tangible energy-saving assets, which are depreciated, and 4% on the amount of the corresponding investment exceeding EUR 150,000 [20].
Spain	Companies are entitled to a 30% tax credit on investments in equipment to preserve and improve the environment and conserve energy. Equipment that qualifies for a tax credit is listed in the Basque List of Environmental Technologies [20].
Hungary	A tax credit is granted in the amount up to 80% of the tax payable [20].
Tax reduction	
USA	The Energy Efficient Commercial Buildings Tax Deduction [21] is applied at a rate of USD 0.30 - 1.80 per square foot (0.093 m^2), depending on the technology and the degree of energy reduction.
Australia	A tax discount of 150% of the actual cost of energy audits, not exceeding BBD 25,000 (USD 12,500) is provided for each year within five years, and additional write-off of 50% of the cost of improvement of premises or installing systems for generating electricity from renewable sources. The condition for obtaining a discount is the absence of debts for the payment of the profit tax, VAT, land tax, and national insurance premiums [13].
Belgium	Enterprises that implement energy-saving investments can claim a tax discount of 14.5% of the amount of qualifying investments. In case of insufficiency or absence of taxable profit, investment deductions can be transferred without any restrictions in time or amount [15].
Netherlands	For investments in energy efficient assets, a tax discount of 41.5% of the total annual amount of investments exceeding EUR 2,300 is foreseen [15].
Tax holidays	
Fiji	The income received by the taxpayer from a new type of activity for the processing of agricultural raw materials in biofuel can be exempted from the profit tax for a period of ten years. Exemption from the income tax for five years may be available to a taxpayer who participates in renewable energy and cogeneration projects [13].
Honduras	Renewable energy producers have the right to a tax holiday on corporate income tax for five years [22].
Indonesia	Industrial enterprises in the sphere of renewable energy have the right to exemption from corporate income tax for a period of five to ten years from the commencement of industrial activity, after which it is possible to reduce tax liabilities by 50% for another 2 years [21].

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Continuation of Table 2

Country	Application features
Malaysia	Upon applications granted before 31 December 2015, full exemption from the income tax for ten years is given to companies engaged in the production of energy from renewable sources (biomass energy, hydro-energy, or solar energy), and energy service companies [13].
Sri Lanka	From 1 April 2013, a ten-year tax exemption for the profits and incomes of enterprises from the cultivation of renewable energy crops on agricultural lands is provided [15].

Source: [7; 10; 11; 13; 15; 16; 17; 18; 20; 21; 22]

According to Table 2 and 3, the most widespread instrument/incentive/measure for stimulating energy efficiency in industry in the world practice is accelerated depreciation (about 60%) and a tax credit (about 40%). At the same time, the main rate of accelerated depreciation in most countries is 100%, which allows taxpayers to reduce the taxed item by the entire amount of certain capital expenses in the first year. Also, rates of 80%, 50% and 33.3% are applied, i.e., the maximum period during which certain capital expenses reduce the taxed item is 3 years.

The practice of applying a tax credit testifies to the amount of the loan from 4% to 100% of the corresponding expenses. The possibility of reducing tax liabilities without the need to pay them in the future makes the tax credit attractive to taxpayers, as evidenced by statistics on the application of a tax credit by sector: industry — 32%, households — 36% [19].

Table 3. Applying tax incentives to stimulate the efficient use of energy resources in certain countries when collecting corporate income tax

Countries	accelerated depreciation	tax credit	tax holidays	tax reduction
Australia	+			+
Argentina	+			
Belgium				+
United Kingdom	+			
Hungary				
Honduras			+	
Indonesia			+	
Ireland	+			
Spain		+		
PRC		+		
Liechtenstein	+			
Luxembourg	+	+		
Malaysia			+	
Netherlands	+			+
South Africa				+
Russia	+			
Singapore	+			
USA		+		+
Uruguay			+	
Fiji			+	
Sri Lanka			+	

Source: [7; 10; 11; 13; 15; 16; 17; 18; 20; 21; 22]

A tax reduction is mainly popular in developed countries and is used in the USA, Australia, Belgium, South Africa and the Netherlands. Quite often, a tax reduction includes not all relevant expenses but only a certain percentage, or there is a restriction in the form of a certain amount of expenses.

Tax holidays are seldom used for stimulating the implementation of energy efficient equipment and increasing the energy efficiency of production in economically developed countries. They are applied in China, Fiji, Honduras, Indonesia, Malaysia, Sri Lanka and Uruguay. Most often, tax holidays are granted for a period of 3 to 10 years in the amount of 40% to 100% of tax liabilities.

Among instruments of tax regulation of the rational consumption of energy resources for individual taxes and fees there are:

- instruments using the value added tax (differentiated VAT rates, increase of the VAT rate for traditional fuel and energy resources, VAT exemption, reduction of the VAT rate). Thus, for example, the average value of the base VAT rate in EU countries is 21.3%, and the average level of the reduced VAT rate is 6.4%;
- instruments using the excise tax (increase of the excise tax rate for traditional fuel and energy resources, excise tax exemption for biofuels and bioethanol, reduction of the excise tax rate for biofuels and bioethanol). Thus, in Great Britain the share of taxes in the price for fuel (the excise tax and VAT) reaches 55%, which is much higher than that in the USA. A zero rate for electricity is a powerful incentive for the production and use of electric vehicles. In Germany, the excises for motor fuel provide about 10% of tax revenues to the federal budget;
- instruments using the duty (exemption from / reduction of the import duties for equipment and materials that contribute to rationalizing the consumption of fuel and energy resources);
- instruments using the environmental tax (expansion of the circle of environmental taxpayers, reduction of rates / exemption from the environmental tax for payers introducing technologies or processes that facilitate rationalizing the consumption of fuel and energy resources, increase of environmental tax rates on actual emissions to air);
- instruments using land fees (land tax credit, increase of tax (reporting) period, tax holidays, deferment or payment in installments of tax obligations on land fees for individuals carrying out activities that promote rationalizing the consumption of fuel and energy resources).
- instruments using the personal income tax (a tax credit, tax reduction, tax holidays for the personal income tax on the implementation of activities that promote rationalizing the consumption of fuel and energy resources, deferment and payment in installments of tax obligations for those introducing more advanced technologies or processes).

Consequently, there is a sufficient number of tax incentives for the efficient use of energy resources, the implementation of which would allow rationalizing the consumption of fuel and energy resources.

Summary and conclusions

The systematization of the world experience in the sphere of using tax incentives for energy efficiency and the application of a systematic approach to the problems of tax regulation of rational energy consumption have made it possible to identify directions, the simultaneous use of which will contribute to the formation of additional financial benefits. These directions include:

- stimulating rational consumption of energy resources;
- encouraging rational consumption of energy by business entities (legal entities), individuals (private households);
- promoting R & D in the sphere of rationalization of energy consumption;
- stimulating production of goods (equipment, materials, etc.) and services, the use of which will allow rationalizing the consumption of energy resources;
- stimulating production of energy resources from renewable sources;
- stimulating attraction of highly qualified specialists in the field of development and implementation of innovations in the energy sector (for example, the use of reduced rates for social contributions, the stimulation of employment).

To promote rational consumption of energy resources, it is possible to use the majority of existing taxes and fees and such instruments of tax regulation such as changes in tax rates, tax exemption, reduction of the taxed item, spending restrictions, tax credits, accelerated depreciation, tax reduction, deferment or payment in installments, tax holidays, etc.

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Ewa Kochańska
Research and Innovation Centre Pro-Akademia
Innowacyjna 9/11, 95-050 Konstantynow Lodzki, Poland, ewa.kochanska@proakademia.eu
https://orcid.org/0000-0002-4735-7969

Iwona Adamkiewicz
Research and Innovation Centre Pro-Akademia
Innowacyjna 9/11, 95-050 Konstantynow Lodzki, Poland, iwona.adamkiewicz@proakademia.eu
https://orcid.org/0000-0003-2272-802X

Lais Bertozo
FIEC System - Federation of Industries of the State of Ceará System
Av. Barão de Studart, 1980, Aldeota, Fortaleza, Brazil, lbertozo@sfiec.org.br

SELECTED PROBLEMS OF WATER, ELECTRICITY AND WASTE MANAGEMENT IN BRAZIL IN THE CONTEXT OF ITS IMPACT ON CLIMATE CHANGE MITIGATION

Abstract
The article discusses selected problems related to environmental protection in the context of climate change in the Ceará region of North-Eastern Brazil. The authors analyse the lack of water and negative impact of climate change on fish processing in the region. Also, the opportunity to use fish waste to increase profitability of the local fish processing SMEs thanks to implementation of climate-friendly technologies such as the production of fertilisers and energy for their own needs is discussed.

Key words
environmental protection, climate change, waste and water management, Brazil

Introduction

There is a close relationship between development of civilization based on new technologies, increasingly complex systems of society organization and the progressive exploitation of the natural environment, and as a consequence, climate change.

Method of research

The main research method was content analysis and a bibliographic search. This made it possible to conduct a sensible analysis of the phenomenon of climate change caused by economic development, which is manifest in the growing amount of waste, including organic waste as well as the increasing demand for electric energy under conditions of continually decreasing yearly rainfalls and ongoing lowering of the groundwater level. The database for the research was based on official statistical data of Brazilian state and regional institutions such as the FIEC System (Federation of Industries of the State of Ceará System), international organizations, reference publications, analytical monographs, annual statistical bulletins, reports of world organizations, the European Union and Brazilian institutions and authors' own research. Field research was performed and information collected from PISCIS, a small Brazilian company typical of the area under study, specializing in fish processing. To obtain quantitative data at the regional level and to calculate the impact of implementation of waste-to-energy technology for mitigation of negative effects of climate change, mathematical modelling was used. The evolutionary features of the dependence of economic development on a local scale as well as climate change was taken into consideration. Multi-parameter modelling was used to calculate the impact of the use of waste-to-energy technology on PiSCIS's development.

The general research methods used were specific to positive economics. The main paradigm of positive economy is to explain economic phenomena based on objective knowledge of reality and to present empirical data and analyse the effects of changes in economic conditions or variants of economic policy without formulating value judgments. Positive economics focuses on developing the most universal tools and methods of economic analysis in order to generalize economic processes and economic mechanisms as comprehensively as possible. These

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include description, comparison, statistical review, system analysis, results of field research, case analysis and others that help to characterize the development of this phenomenon in a more comprehensive manner.

Results

Water management in Brazil in the context of mitigation of climate change effects

Climate change, and especially the progressing water shortage in the Ceará region and Jaguaribara basin have a direct economic and social impact on the development processes in general and on the business of many companies located in this region, especially on the production of a various range of agricultural and fish products, e.g. tomatoes or viscera fish oil. The State of Ceará is one of the driest in Brazil. The rainfall in this region takes place from January to June and is at an average level of 400 mm in the interior to 1,200 mm on the coast.
Figure 1 shows the state of Jaguaribara river and Castanhão reservoir in 2012.

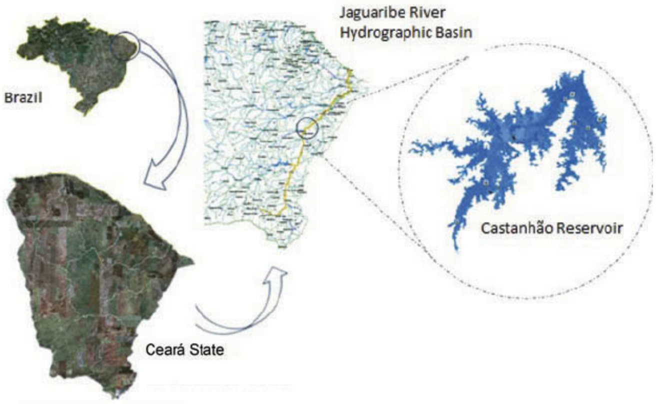

Figure 1. Map of the Castanhão Reservoir in the Jaguaribe River basin, Ceará State, Brazil [1]

Brazil may be experiencing its worst drought cycle in over a century as the region braces itself for its 7th consecutive year of insufficient rainfall. Almost 100% of the region has been affected by severe droughts, and half of the Northeastern cities, including Fortaleza and Jaguaribara, have declared states of emergency. The last time the region experienced six consecutive years of drought was between 1979 and 1983, but even then, it rained more than now.

Water management comes first in the list of problems to be solved by the state. The most important issues associated with low rainfall and high temperatures are thin soils hindering water storage, high evapotranspiration and a large rural population that is dependent on intensive fish production. In response to the deteriorating situation of water management, tanks with a total capacity of 13,560 m^3 (4,700 tanks) were installed throughout the country in which water from the rainy season is stored. [2].

Another example of the water crises is the effect on the rapidly growing Fortaleza, the largest city of Ceará, which does not have large water reservoirs and it is necessary to transfer water to the city from the nearby Jaguaribe basin. Frequent and devastating drought and economic activity have caused the Jaguaribe basin itself to require intensive intervention by the construction of large water reservoirs. In 2003, the Castanhão reservoir with a capacity of 6,700 m^3 was built [3]. Castanhão's construction provides flood protection in the river basin and temporary storage for the proposed inter-base transfer from the São Francisco River [4]. Complementary to Castanhão are two additional main tanks in the pool, such as Orós (1,940 m^3) and Banabuiú (1,601 m^3). Together, these 3 reservoirs account for over 75% of the basin's storage capacity of the state (Figure 2).

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Figure 2. Map of the Jaguaribe basin and the three main reservoirs and rivers [5]

Brazil's semiarid region is the most densely populated semi-dry region in the world. Long-lasting droughts have had a significant negative impact on the social and economic aspects of this part of the region, therefore, preventive actions have been taken, such as damming the rivers and construction of water reservoirs in order to neutralize the effects of prolonged drought. Despite these efforts, in 2019 reserves of only 3.75% capacity were registered in Açude Castanhão.[6]. The problem is not only the amount of water but also the deterioration of the water's quality due to increasing concentrations of dissolved salts and decreasing oxygen levels (Figure 3).

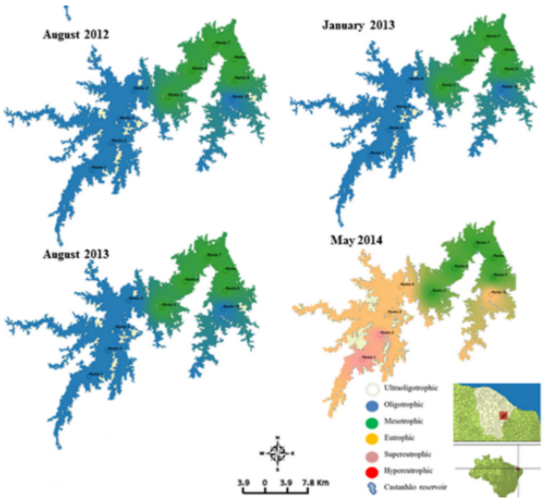

Figure 3. Trophic state index changes in the Castanhão reservoir in NE Brazil, during the period of Nov. 2011 - May 2014 [7]

Another side to the problem is the increased frequency and intensity of extreme rainfall which causes augmented nutrient inputs from the watershed. In the Ceará region, the amount of annual rainfall has been steadily decreasing, which has resulted in an increase in the frequency and duration of extended periods of drought which in turn has led to nutrient accumulation, increase of algal density and frequency of cyanobacteria blooms, thus rendering these systems much more vulnerable to eutrophication. This has had a negative effect on the tilapia population in Açude Castanhão and has resulted in loss of fish valued at 18 million Brazilian Reals (approx. USD 4.3 mln) [8]. These occurrences confirm changes in the climate and emphasize the need to take them into account as significant drivers with impact on the environmental and socio-economic conditions of the company's development.

Figure 4. Satellite pictures of the Castanhão reservoir 2011 and 2019 [9]

Therefore, tilapia production has suffered a significant reduction [8] and consequently the production of oil from fish viscera has been considerably reduced as well. Drought periods during following years besides having reduced the tilapia population, have also resulted in the concentration of potential pollutants in Açude Castanhão. The installation of the PISCIS company in the Ceará region is an example of intensively developing fish cage/container aquaculture, which negatively affects water quality, in particular during extended drought periods. PISCIS company / PISCIS Industry Trade LTDA is a good example of a business entity operating in the Ceará Region, which has been forced to change their production profile due to climate change.

PISCIS was founded in 2009 by a private entrepreneur. In the beginning, the company worked with small volumes of fish waste (viscera of tilapia), however, with the expansion of tilapia production activity in the region, the company quickly grew and PISCIS processed ca. 8 tonnes daily of tilapia viscera collected from local fisheries of Açude Público Padre Cícero commonly known as Açude Castanhão. In the following years, the company became well known regionally and nationally for the transformation of tilapia residues into oil and received various local and national awards for sustainable development. In parallel, the company established itself on the market with the commercialisation of viscera oil for animal feed industries. In addition, it sold oil to Petrobras Biocombustiível from Quixadá to produce biodiesel [2]. The progressive growth of PISCIS was also possible due to the continuous increase in prices for viscera oil (Figure 5).

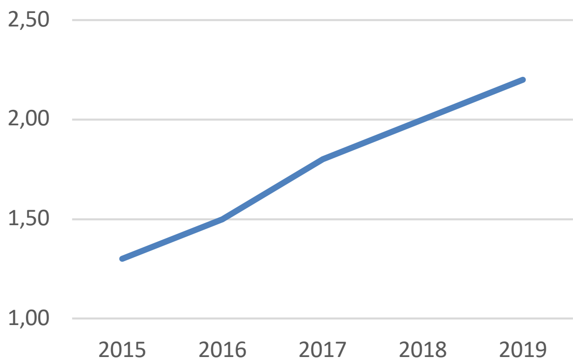

Figure 5. Prices of viscera oil (R$/L) [10]

Additionally, during the same period, the company started a new project that would help fish farming of tilapia in a sustainable way. Tilapia is the most popular fish in Brazil and Nile tilapia (Oreochromis niloticus) is one of the most readily available varieties in the country. During 2015, some 219,000 tonnes were caught (slaughtered and sold) [4]. This number had increased by 9.7% compared to 2014 and almost 10 times more since 1998 when 30,000 metric tons were sold. The largest producing regions are in Ceará, mainly in the municipality of Jaguaribara. However, from 2015, Castanhão region has been affected by drought and, consequently, the activity of tilapia production declined, and the production of oil diminished as well. In PISCIS aquaculture the strong influential factors are the cost of feed (accounting for 60% of the total production cost) and the most limiting factor is the lack of water availability. High stocking density and rearing of aquatic fish and shrimp requires wastewater treatment. Because of the water situation and wastewater treatment requirements, while waiting

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for rebuilding of natural water reservoirs, the company has diversified the production and has been investing in the production of shrimp and tilapia by water container technology using a biofloc system (Figure 6)

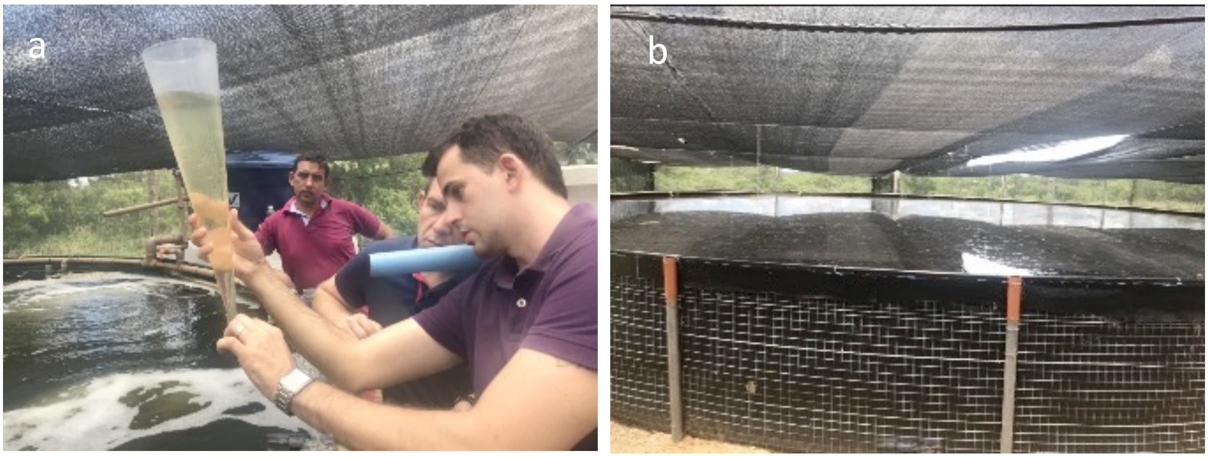

Figure 6. Biofloc technology used by PISCIS: a) evaluation of water quality, b) fish farming container

Biofloc is a wastewater treatment technology that enhances water quality by balancing nitrogen and carbon in the system and which has gained vital importance as an approach in aquaculture. Thanks to this technical solution, there is no direct dependency on the Castanhão water, and waste water is minimal. The Biofloc system has been developed to save and effectively manage water and to improve environmental control over aquatic fish and shrimp production. PISCIS fish farming activity is based on water containers (1 m height, 30 m diameter). The biofloc technology provides many benefits: water use efficiency, reduction of environmental impact, limited or zero water exchange, higher productivity of fish and thanks to feed conversion in the eco-friendly culture systems of fish and shrimp as well as provides higher biosecurity. However, there is one serious disadvantage, namely biofloc increases energy demand for mixing and aeration of the pools [11]. Currently PISCIS company has capacity to process 8 tonnes of fish per day. In the future, they plan to produce ca. 174 tonnes per year [10]. Time needed to grow one batch of fish under standard conditions is approximately 6 months. PISCIS farms currently produces 8 kg of aquaculture per 1 m^3 of containers, but in the future, thanks to implementation of more effective system operation, it is expected that the productivity is going to increase to 30 kg per 1 m^3 of containers. Therefore, there are numerous opportunities related to the effective use and potential of fish farming [12]. Special support is expected from the EU, within the Low Carbon Business Action Brazil Programme and transferring of the European technologies.

Waste management in Brazil in context of mitigation of climate change effects

The main challenge of waste management worldwide for the coming years is the transition to a circular economy, which aims to use the unavoidable waste produced as a resource by recycling and upcycling processes that minimise the amount of waste generated. In Europe, positive trends in waste management can be observed because of an increasing level of waste recycling as well as the reuse and simultaneous decrease in the amount of waste generated. For example, at the beginning of this century, the amount of waste generated in Poland (excluding municipal waste) was 130 million tonnes. In 2017, approximately 114 million tonnes were generated that indicates a decrease of approximately 10%. The amount of waste generated annually has remained at a similar level, while the GDP has been constantly growing.

As the fifth largest waste producer in the world, Brazil faces major waste management challenges. Every day, 198,000 tons of municipal waste is produced, of which about 58% ends up in sanitary landfills, 24% in controlled landfills, and 17% goes to various landfills. It is especially necessary to solve the problem of the other 42% of waste that goes to unknown places that lack proper systems and procedures necessary to protect the environment from damage and degradation. Brazil lacks adequate social support as well as necessary infrastructure expenditure and the necessary political will to implement new regulations. Improper disposal practices continue to be common practice in all Brazilian states [13]. In 2010, Brazil implemented a national solid waste policy. Its main goal was to reduce the total amount of waste generated at a national level, as well as to increase sustainable solid waste management through activities such as:

- incentives for the recycling industry;

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- promotion of social inclusion;
- non-generation, reduction, reuse, recycling and solid waste treatment;
- intensification of environmental education actions;
- rationalisation of natural resources in the production of new items;
- technical capacitation;
- appropriate final disposal of waste;
- clear channels set up between the different classes of government agencies and between them and the business sector, aimed at technical and financial cooperation.

Regulations regarding waste include types of waste such as: public, domestic, industrial, mining, agroforestry, transportation, construction, and health industries waste. Responsibility for paying for or providing management of waste now falls on its producers.

The Low Waste regulation also mandated:
- solid waste plans to be prepared by all 5,570 municipalities in the country by 2012;
- closure of all dumpsites by 2014;
- reduction of organic waste by 53%;
- increase in recycling of 45%;
- raising waste-to-energy production to 300 MWh by 2031;
- social inclusion of 75% of waste pickers by 2031.

As of now, the country lags far behind all these targets. For instance, only 40% of municipalities had submitted Solid Waste Management (SWM) plans by 2015 and approximately 3,000 dumpsites are still open, mostly in the North, Northeast and Midwest regions. To achieve the reduction of carbon dioxide associated with landfill waste and protect the environment from human-generated waste, it is necessary to improve the overall recycling rate, which is currently at 6%, whereas the target for 2030 is 45%. However, an analysis of the way Brazilians deal with waste management problems, including the technical and organisational processes and the need to change social perception of waste as a valuable resource, one may come to the conclusion that it will take a long time. The Brazilian waste management budget is very low at 3 euros per month per inhabitant, which can be compared to cities like Barcelona - 19 euros or Tokyo at 43 euros. [15].
Major infrastructure investments are needed. Sanitary landfills are the most popular destination of waste in Brazil: nearly 60% of all kinds of waste are isolated from the environment in sanitary landfills. It is worth noting that only 23% of them are controlled. Needless to say, the present-day situation of waste management in Brazil is challenging (Table 1**,** Table 2)**.**

Table 1. Final destination of waste in Brazil in 2016 and 2017 [16]

Sanitary Landfill		Controlled Landfill		Open air dumps	
2016	2017	2016	2017	2016	2017
59%	59.1%	23.5%	22.9%	17.5%	18%

Table 2. Number of cities: by type of final disposal in 2016 [16]

Type of disposal	Brazil	North	Northeast	Midwest	Southeast	South
Sanitary Landfill	2 239	90	449	159	817	703
Controlled Landfill	1 772	108	484	159	634	357
Open air dumps	1 559	252	861	149	217	131
TOTAL	5 570	450	1 794	467	1 668	1 191

The Ceará region has begun implementing a recycling program to reduce waste in landfills. A good example is the city of Fortaleza, where in 2016 the implementation of a recycling strategy based on social values and actions aimed at changing the behavior of residents was undertaken. Transport and energy credits have been proposed for residents of 24 districts who properly segregate waste. The campaign covered 9,000 residents and 830 tons of waste were recycled, thus reducing landfills. The next planned step is to introduce the program to another 100 districts. As more than 50% of solid waste in Brazil constitutes organic waste, it provides a natural base for promoting bioenergy and biogas production development [17].

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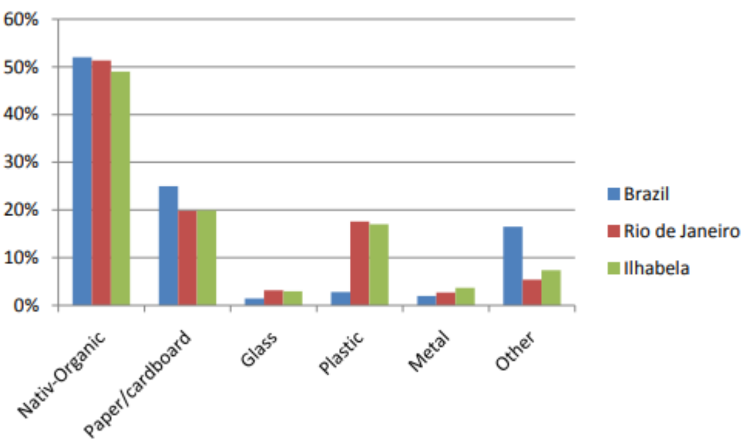

Figure 7. Composition of solid waste in selected Brazilian cities [17]

Energy management in Brazil in the context of mitigation of climate change effects

Brazil has been one of the largest energy consumers in the world for decades. In 2017, it took 8th place, and economic growth generates a further increase in primary energy consumption. The installed generating capacity in 2017 was 157 GW and increased by 4.5% compared to 2016 [18]. The country remains dependent on two sources of energy: natural gas and hydro energy. In June 2017, the installed power of renewable sources was 100 MW from photovoltaics (PV), up from about 1 MW in 2012. The government expects Brazil's overall solar capacity to exceed 8 GW by 2024. As of December 2018, wind power plants reached an installed power of 14.2 GW.

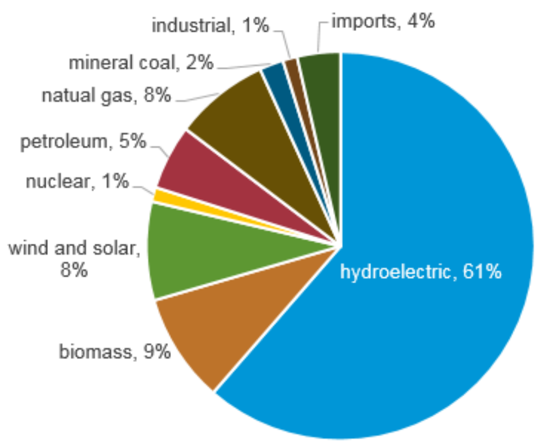

Figure 8. Power generation supply in 2017 [19]

Hydropower accounts for a high share of Brazil's energy mix and amounts to 60.8%. Climate change will therefore have a major impact on their operation and limits the possibility of increasing their share as a security for Brazil's energy system. In addition to climate change, Brazil's water potential is seriously affected by such factors as agricultural intensification, industrial development and urbanization. During 2014-2016, a serious water crisis occurred in the Southeast as a result of chronic drought. Since 2014 these factors have caused a decrease in energy produced from this source. This crisis was accompanied by an increase in energy production from sources such as fossil fuels, wind, solar and biogas [20]. Wind and solar energy technology development are challenging, however, despite the favorable natural conditions (areas with high solar irradiation and areas with good wind capacity) use of these sources is insufficient, showing a clear need for more investment. In addition, most of the equipment required for the installation of photovoltaics, concentrated solar thermal plants or wind energy plants have to be imported, which implies high costs. The Brazilian Electricity Regulatory Agency distinguishes the following types of biomass: municipal solid waste (UW), agro-industrial waste (AIW), forest residues, animal waste (AW). Biogas plants are responsible for only 9% of electricity production in Brazil, which means the operation of 127 biogas plants using, among others, agricultural residues. In 2016, the installed biogas production capacity was 450 MW [18]. No biogas plant is located in the Ceará region (Figure 9).

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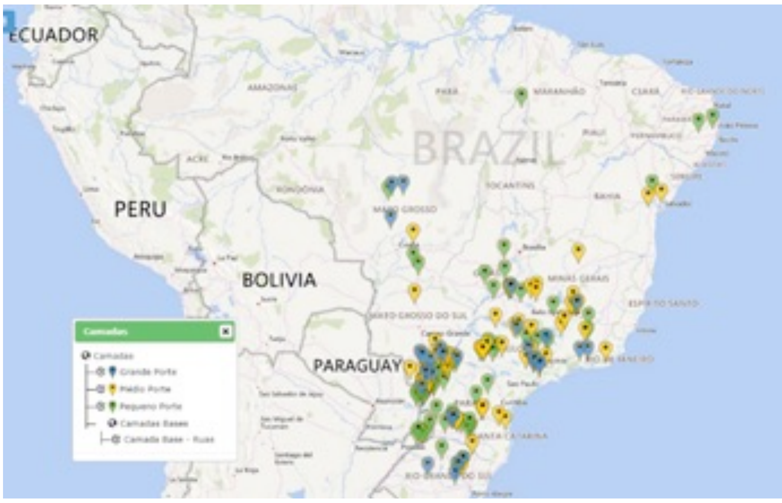

Figure 9. Map of generation centres of biogas production in Brazil [21] The blue, yellow and green markers indicate the unit size, classified as large (more than 12 000 m^3/day), medium (from 2 000 to 12 000 m^3/day) and small size (less than 2 000 m^3/day), respectively.

While in Brazil energy is generated from an increasing variety of energy sources, the average cost of energy bills has increased. Between 2012 and 2017, the average energy cost in the country increased by 53%, which is 12% above the inflation rate. The electrical energy tariffs in Brazil are somewhat complex. The current energy prices in the state of Ceará are presented below, according to the supply of voltage [22]:
For low voltage consumers (below 75 kW of installed power)**,** there is a monomial tariff of 0.1678 EUR/kWh, including taxes and charges. For public lighting supply, the tariff is 0.098604 EUR/kWh. For the 836,002 low-income consumers (23.7% of total), with an annual consumption of 1,069,998.58 MWh, their tariff is subsidised by the other consumers, according to the following rule:

- Monthly consumption between 30 kWh and 100 kWh => 65% tariff reduction
- Monthly consumption between 100 kWh and 220 kWh => 10% tariff reduction
- Monthly consumption above 200 kWh => no tariff reduction

Other consumer categories that can have subsidies as well:

- Aquaculture and irrigation: 60% to 73% tariff reduction
- Water-sewage utility: 15% of energy tariff reduction.

For high voltage consumers (from 2.3 kV to 25kV and above 75 kW of installed power), there are binomial (power and consumption tariffs) and seasonal (according the daily peak demand) tariffs, as shown in essential terms as follows (green tariff):

- Peak consumption period = 0.411 EUR/kWh
- Off-peak consumption period = 0.101 EUR/kWh
- Use of distribution system = 4.76 EUR/kW

Some consumers are allowed subsidies:

- Rural consumers: 10% of power demand and 10% of energy tariff
- Aquaculture and irrigation: 70% to 90% tariff reduction
- Water-sewage utility: 15% for power demand and 15% of energy tariff
- Free Energy Market using renewable sources: 50% of power demand tariff.

Between 2014 and 2018, the electrical energy prices in Ceará state for low and high voltage consumers increased by 35% and 54%, respectively.

Table 3. Energy demand in in Ceará state [22], [23]

Low Voltage (residential)	TUSD[1] (R$[2]/kWh)	TE[3] (R$/kWh)	Energy (R$/kWh)	Growth (%)
2018	239,36	253,09	492,45	4,0

2017	225,05	248,64	473,69	-0,3
2016	224,23	251,04	475,27	13,7
2015	193,94	224,02	417,96	16,4
2014	184,12	175,1	359,22	

*without taxes and charges

Increase in the Energy Tariff – five years 37%

Rate exchange (R$ to EUR) 4.35 05/04/2019

1)TUSD - Tariff of Use of Distribution System
2) R$ - current Brazilian currency (Reals)
3)TE - Tariff of Energy

Table 4. Energy prices in 2014-2018 [22]

High Voltage (commercial and industrial)	TUSD (R$/kWh)	Growth (%)	TUSD (R$/kWh)	TE (R$/kWh)	Energy (R$/kWh)	Growth (%)
2018	13,59	13,5	36,41	240,25	276,66	4,8
2017	11,97	22,1	26,45	237,44	263,89	-3,5
2016	9,8	6,6	34,07	239,46	273,53	12,6
2015	9,19	74,4	29,89	212,93	242,82	34,9
2014	5,27		13,7	166,34	180,04	

*Green tariff
*without taxes and charges

*off-peak
Increase in the TUSD – 5 years (use of Power Distribution System) 158%

Increase in the Energy Tariff – five years 54%

Rate exchange (R$ to EUR) 4.35 05/04/2019

An annual revision of the energy tariff is planned with the prospect of an increase in energy tariffs of 8.62% in 2019.

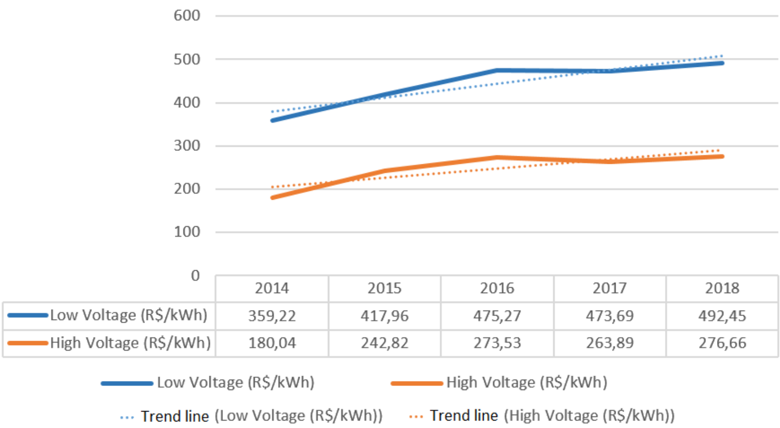

Figure 10. Energy prices for low voltage (residential) and high voltage (commercial and industrial)

The energy taxes and charges applied in electrical energy tariff in Ceará State are 27% of ICMS (Ceará State Tax) and 6.5% of PIS and COFINS (Federal Taxes). The exception are low-income consumers that are exempt from taxes unless they reach 140 kWh of consumption per month. The breakdown of the tariff is shown in Figure 11.Figure 11

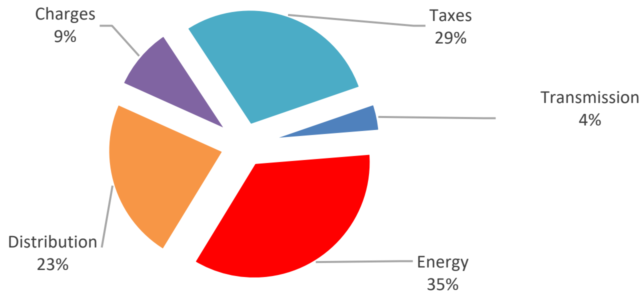

Figure 11. Ceará´s electrical energy tariff cost structure [21]

Water and waste management in Brazil's Ceara Region in context of its impact on mitigation of climate change effects

Waste to energy projects (WtE) usually involve utilisation of waste, including organic waste, to recover energy that can be available in the form of electricity, fuel or any other by-products. The main environmental benefit obtained from biogas plants is a major contribution to a decrease in air pollutants and GHG emissions in the atmosphere. This is possible through the controlled capture of methane, replacement of fossil fuels with biogas and the CO_2 emissions that are avoided [24]. The process at a typical WtE biogas plant creates some residues that have to be monitored and accordingly treated to avoid any harmful effects it may have on the environment. The specific residues of the previously mentioned company PISCIS – fish waste - may be converted to electricity and useful by-products such as fertiliser for agriculture. In the context of the negative effects of climate change, droughts and lack of water, specific problems arising from waste management and particularly the high costs of electricity in the northeast of Brazil, the use of organic waste can be a way to mitigate all of the above problems.

Uncertainty and impact of research results on science, economy, environment and society

To limit the negative impact of climate change in the Ceara Region, the wide implementation of waste management to local SMEs, should be taken into consideration, for such companies as PISCIS. As a result, the following potential positive environmental impacts can be identified:

1. reducing the amount of landfilled organic waste;
2. saving fossil fuels for energy purposes and reduction of CO_2 emissions due to production of energy from renewable sources;
3. saving natural resources and valuable elements such as phosphorus for the production of fertilisers.

An analysis of the monthly amount of waste produced by the PISCIS company varies depending on the business model adopted. In one scenario, PISCIS considers that the company will breed and sell whole fish. As a result, waste from this production component is wastewater from biofloc tanks and dead fish. An additional source of fish residue is waste from the production of oil from tilapia's viscera. So far, the company has been collecting the viscera of tilapia from nearby fishing companies. In the second scenario, fish farming is planned, followed by filleting, which entails a significant increase in amounts of fish waste. Implementation of the WtE project by the PISCIS company might significantly reduce the annual amounts of organic wastes by 100.44-189.72 tonnes (depending on the chosen development scenario) [10].

The next result of implementation of the climate-friendly project and technology is the possibility to save fossil fuels for energy purposes as well as reduction of CO_2 emissions due to using energy of renewable sources, particularly thanks to establishing micro biogas plants. For the PISCIS company, implementation of the WtE project will determine biogas production in the amount of approximately 6 m^3/day to 125-140 m^3/day depending on the applied approach, with a content of methane at a level of 60-65%, which corresponds to electricity and heat or cold production. The efficiency of the cogeneration unit within the most profitable scenario is approximately 31%, and about 6-7 % of energy produced is considered to be used for biogas installation for own needs. The cold production, within one of the scenarios is approx. 26,499 kWh with thermal efficiency of cogeneration unit of 34%. The main goal of the WtE project is organic waste utilisation, although the saving of resources and CO_2 emission avoided are the important results of implementation of the biogas installation as well. Within many of the WtE projects based on organic waste processing, the production of digestate is present. The average dry matter content can be 4%. If biogas production is based on agricultural organic waste, the produced digestate can be used as fertiliser for agricultural production, bringing benefits for the neighbouring rural territories and improving the environment by replacing the use of artificial fertilizers. The most important effects, related to the use of digestate, are its impact on the increase in the yield of plants fertilised with digestate, which will improve the economic results of agricultural activity and additional reduction of the need for mineral fertilisers. This in turn reduces the costs of vegetable or crop production. Simultaneously, the use of digestate reduces the expenditure incurred on agriculture production carried out on the farms

Finally, implementation of the climate-friendly projects of the biogas production installation in the SMEs in Ceara Region, Brazil, can serve as an example of a tool for mitigation of climate change, better management of organic waste and increase of energy efficiency.

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Yelyzaveta G. Koniaieva
V.N. Karazin Kharkiv National University, Department of Foreign Economic Relations and Touristic Business
4 Svobody Sq., 61002 Kharkiv, Ukraine, sunnybigday@gmail.com

Vitalina A. Babenko
V.N. Karazin Kharkiv National University, Department of Foreign Economic Relations and Touristic Business
4 Svobody Sq., 61022 Kharkiv, Ukraine, vitalinababenko@karazin.ua
https://orcid.org/0000-0002-4816-4579

DETERMINING PRIORITIES OF SCIENTIFIC AND TECHNICAL COOPERATION BETWEEN UKRAINE, THE EU AND CHILE IN THE FIELD OF NON-CONVENTIONAL RENEWABLE ENERGY SOURCES

Abstract
As many programs of scientific and technical cooperation of various fields are being successfully implemented between Ukraine and the EU, the author has set the goal of intensifying relations between Ukraine and Chile in the field of green energy. The cooperation Ukraine has had with the EU serves as an example of future cooperation between Ukraine and Chile. The text explores Chile's experience in the field of green energy and, through the comparative example of such cooperation between Ukraine and the EU countries, shows that such interaction is a worthwhile endeavor. Based on an analysis of research materials, one of the priority areas of scientific and technical cooperation is the use of non-traditional renewable energy technologies. In Ukraine, and the EU, as well as Chile, there are objective factors (natural, resources, socio-economic, environmental-technological) that concern their development. It is interesting to note Ukraine's scientific experience and implementation of these technologies and the organizational and economic support of them as priorities in the context of national and regional policy. All aspects of international scientific and technical cooperation, including through the exchange of intellectual products, make it possible to increase the effectiveness of forms of state support, the innovation, production and business activities of Ukraine and the corresponding development of producers and consumers' motivation towards using non-conventional forms of renewable energy technology.

Key words
Cooperation between Ukraine and the EU, scientific and technical cooperation between Ukraine and Chile, non-traditional renewable energy, innovative susceptibility.

Introduction
The chosen priorities of international scientific and technical cooperation influence economic development of the global economy. With the continued emergence and development of the global economy, scientific and technical cooperation is constantly broadening and acquiring new forms. However, when implemented, such cooperation becomes a relatively independent phenomenon that obeys its own laws and which have their own specifics in realizing the potential of international economic relations in general [1]. This is one of the active forms of international economic relations, which determines the growing dynamics in modern conditions and international scientific and technical cooperation. This is an intangible form of economic relationships and conditions through the mutually beneficial exchange of scientific and technical knowledge, intellectual property, experience and programmes of scientific and technical development, engineering services, etc. Together, this plays an increasing role in the intensification of scientific development and production of the subjects of world economic relationships.

Related work
The research analysis indicates significant attention paid to the problem of establishing priorities for the development of scientific and technical cooperation within the framework of international economic relations. The topic was actively studied and developed by many prominent academics such as Sidorov V. [2, 6], Babenko V. [3, 4, 5], Matyushenko I. [7] and others. The field of non-conventional energy source technologies in the process of effective global and domestic development has been studied by academics such as Dyuzhev V. [8], Voitko S. [9], Dzhedzhula V. [10] and Vytvytska O. [11], Matyushenko I. [12] and others. However, taking into account each state's objective conditions and the needs and prospects for their scientific and technological development, a number of issues, in particular, the problems of determining priorities for scientific and technical

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cooperation need further study and methodological elaboration. A theoretical, methodical, and integrated approach is needed for the formation of these priorities to determine the corresponding measures needed to implement them and increase innovation regarding the production and economic activities necessary for the use of non-conventional energy source technologies.

Objective and method

The objective of this article is the development of approaches for determining priorities of international scientific and technical cooperation in relation to the conditions of Ukraine, the EU and Chile that correspond to the needs of overcoming the crisis of this socio-economic phenomena based on the intensification of scientific and technical cooperation. Theoretical, methodological and logical methods of analyzing primary sources including statistical materials, regulatory documents and scientific publications for descriptive and structural analysis were used to assess the initial state of the basic level of scientific and technical cooperation within the framework of international economic relations and methods of forming trends in their development.

Features and problems of the dynamics of innovation in Ukraine

The systemic economic crises during the 90s, 2000s and 2013-2015 resulted in destructive changes in the scientific and industrial potential of Ukraine. The level of science and industry has decreased as well as a strong concern has arisen over the quality of education, which is based on objective (contradictory) trends (see Table 1.).

Table 1. The dynamics of the main scientific and production indicators of the Ukrainian economy, 2008 vs 2017

No.	Year	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Indicators											
1	**GDP (PPP), bln. dol.**	405,2	346,5	351,6	378,5	386,4	392,6	373,4	340,6	353,3	368,7
2	**GDP per capita (PPT), dol.**	8816	7569	7712	8328	8517	8676	8733	7997	8331	8713
3	**GDP growth rate, %**	2,2	-15,1	0,3	5,5	0,2	0,1	-6,6	-9,8	2,4	2,5
4	**Unemployment rate, %**	6,4	8,8	8,1	7,9	7,5	7,2	9,3	9,1	9,3	9,4
5	**Number of students, mln. ppl.**	2,763	2,599	2,491	2,311	2,170	2,052	1,689	1,605	1,586	1,538
6	**Dynamics of R&D costs, % of GDP**	0,9	0,9	0,8	0,9	0,8	0,7	0,8	0,8	0,6	0,6
7	**Dynamics of patent applications, pcs.**	2434	2825	2434	2556	2649	2491	2856	2457	2271	2233
8	**Articles in scientific journals, pcs.**	5489	5907	5633	6074	6400	6716	7450	7417	7455	7375
9	**Researchers in R&D, pal./mln.**	1432	1349,7	1332,2	1261,9	1234,7	1165,2	1026	1006	1008	992

Source: Author's based on [13]

The following is a more detailed analysis of considered indicators.

1. During 2008-2016 Ukraine's GDP at current values, decreased by $ 94.8 billion (50.4%). During 2008-2016 the per capita GDP in Ukraine grew by $ 1,974.0 (48.5%) to $ 2,099.0. The average annual decrease in per capita GDP at current values was -$246.8 or -8.0% (11). Ukraine's GDP in 2008 was equal to $ 188.1 billion and ranked 45th

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in the world, near the same level as Singapore's GDP ($ 192.2 billion) and Chile's GDP ($ 179.6 billion). Compared to 2013, Ukraine's GDP fell from $ 183.4 billion in 2013 to $ 112.1 billion in 2017 [14].

2. Per capita GDP, even taking into account purchasing power parity (PPP) for 10 years has not shown any tendency to increase. In addition, the statistics of the Ukrainian population reveal many problematic issues. This includes immigration, Ukrainians working abroad, the total absence of a population census and other matters, which controversially reflect on this indicator.

3. Ukraine's total GDP, taking into account PPP for 10 years, decreased by 10%. Moreover, during periods of crises (2008–2009, 2013–2015) there was a significant decrease. GDP growth was driven by the retail, non-manufacturing sector. That is, weakly associated with innovative scientific and technological development. The table shows that Ukraine's GDP in 2010 showed an increase of 4.1% after a sharp drop of -14.8% in 2009. The change in the GDP of Ukraine in 2010-2014 was characterized by a significant growth of 4.1% and 5.2% (2010-2011 respectively) and minimal growth of 0.2% of Ukraine's GDP in 2012 and 2013. Ukraine's GDP in 2013 still held its positions, but from the end of the year up to the present, there has been a drop (-6.8 % - 2014, -14.6 % - 2015) [15].

4. The unemployment rate for the period 2008–2017 rose significantly by 46%, which means a worsening of the crisis in the Ukrainian economy, while, despite some recovery in the Ukrainian economy after the 2014–2015 crisis, the unemployment rate in Ukraine remains high at 9,3% in 2016 and 9.5% in 2017 [16].

5. The main problem of higher education in Ukraine is that in 90% of cases it does not guarantee a high school graduate appropriate work in his/her specialty**.** Ukrainian higher education does not correspond to today's realities; it does not meet the demands of the labour market, the needs of the economy, and, most importantly, it does not meet the requirements of the students themselves. Up to 85% of university graduates in Ukraine do not work in the speciality that they acquired at university [17].

6.. According to the Global Competitiveness Index [18], the United States spends $ 405 billion (up to 2.7% of GDP) on science annually followed by China, where research funding amounts to $ 338 billion per year (2.1% of GDP at purchasing power parity). Japan allocates $ 160 billion (3.67%) for this purpose. By way of comparison: in Ukraine during 2015, the budget for support research was 16 billion hryvnias ($ 666 million), or only 0.8% of the GDP. In terms of the total investment in research Ukraine was ranked 76th in the world.

7. A decrease in patent applications from 2008 to 2017 in Ukraine was evident while the general tendency worldwide was an increase.

8. Against this background, the trend of growth of articles stands out separately. The main growth is in publications in foreign journals, which actually involves the use of intellectual resources to solve the problems of the development of advanced economies. However, during this time, the scope of application of intelligent products has significantly decreased in Ukraine.

9. The number of R & D researchers in Ukraine for the period 2008-2017 decreased by about 40%. In fact, complex factors led to a reduction in GDP in general and per capita.

Based on the above conditions, scientific and technical cooperation with more developed scientific and production entities (for example, the EU) contributes to the migration of the intellectual resources of Ukraine - from the direct emigration of Ukrainian scientists to the transfer of intellectual property directly to the scientific and production structures of the EU.

This is confirmed by the calculations of international innovation indices. The top ten Innovation Index, according to the data for the beginning of 2016, includes South Korea, Germany, Sweden, Japan, Switzerland, Singapore, Finland, the USA, Denmark and France. At the same time, South Korea's GDP grew by 2.3% last year, Germany - by 1.7%, Sweden - by 4.1%, Singapore - by 2.1%.

Ukraine is in 41st place, between Latvia and Bulgaria. Although, if the data of another annual study - the Global Innovation Index, is correct, Ukraine is in 64th place, between Serbia and the Seychelles. In 2013 Ukraine was in place 71, 2014 - 63, 2015 - 64, 2016 - 56, and 2017 - 50 [19].

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Based on the above characteristics of the dynamics of factors of the scientific and production potential of Ukraine, in the authors' opinion, an interconnected analysis with the dynamics of the development of scientific and technical cooperation between Ukraine and the EU is needed. Table 2 presents data on the sustainable dynamics of the development of various programmes of scientific and technical cooperation Ukraine with the EU.

Table 2. The list of programmes in the framework of scientific and technical cooperation between Ukraine and the EU

No.	Programme	Characteristics
1	**FP7 - Seventh Framework Programme for research and technological development**	There are two main strategic objectives of The Framework Programmes for Research: 1. to strengthen the scientific and technological base of European industry; 2. to encourage its international competitiveness, while promoting research that supports EU policies.
2	**Erasmus Mundus**	This Programme aims to enhance quality in higher education through scholarships and academic co-operation between the EU and other countries. Erasmus Mundus comprises three actions: 1. Joint programmes. 2. Partnerships. 3. Attractiveness projects.
3	**Tempus**	The Tempus Programme finances interuniversity cooperation in the field of development and improvements of curricula, university governance, interaction between academics and civil society, cooperation between education and business, as well as structural reforms in higher education.
4	**TACIS (Technical Assistance to the Commonwealth of Independent States and Georgia)**	The objective of the programme is to help individual states to develop effectively-functioning market economies based on private ownership and initiative, and to encourage the development of pluralistic democratic societies.
5	**Jean Monnet Programmed under the Lifelong Learning Programme**	The European Commission's Lifelong Learning Programme enables people at all stages of their lives to take part in stimulating learning experiences, as well as helping to develop the education and training sector across Europe.
6	**INSC - Instrument for Nuclear Safety Cooperation (from 2007 onward since it replaces the Tacis Nuclear Safety Programme) - funded though ENPI European Neighborhood and Partnership Instrument**	Via the INSC the following specific objectives are: 1.The promotion of an effective nuclear safety culture and implementation of the highest nuclear safety and radiation protection standards, and continuous improvement of nuclear safety. 2. Responsible and safe management of spent fuel and radioactive waste and remediation of former nuclear sites and installations. 3.The establishment of frameworks and methodologies for the application of efficient and effective safeguards for nuclear material in third countries
7	**ENPI CBC (Cross-Border-Cooperation) Poland-Belarus-Ukraine Programme**	For 15 years supports the cross-border development processes in the borderland of Poland, Belarus and Ukraine by co-funding diverse projects. All projects funded within the Programme are non-profit ones and contribute to the improvement of quality of life of inhabitants of eastern Poland and western Ukraine and Belarus.
8	**Hungary-Slovakia-Romania-Ukraine ENPI Cross-border Cooperation Programme 2007-2013**	This Programme offers a wide range of opportunities to potential Beneficiaries through four priorities - Economic and social development, **enhancement of environmental qualities, increased border efficiency** and **support for people to people cooperation.**
9	**Joint Operational Programme Romania-Ukraine-Republic of Moldova 2007-2013**	Is a cooperation programme financed by the European Union through the European Neighbourhood and Partnership Instrument 2007-2013. The programme aims to create "bridges" among the three countries involved, in order to help the border areas overcome their similar development challenges, by working together and finding common solutions
10	**Euroatom**	Euratom aims to pursue nuclear research and training activities with an emphasis on continually improving nuclear safety, security and radiation protection, notably to contribute to the long-term decarbonisation of the energy system in a safe, efficient and secure way.
11	**Eurostudent VI**	The main aim of the EUROSTUDENT project is to collate comparable data on the social dimension of European higher education. It focuses on the socio-economic background and on the living conditions of students, but it also investigates temporary international mobility.
12	**Horizon 2020**	Horizon 2020 is the biggest EU Research and Innovation programme. It is the financial instrument implementing the Innovation Union, a Europe 2020 flagship initiative aimed at securing the global competitiveness of Europe.

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13	**COSME**	The programme for the Competitiveness of Enterprises and Small and Medium-sized Enterprises is improving access to finance for SMEs.
14	**Black Sea Basin Joint Operational Programme 2007-2013**	There are 8 participating countries in the Black Sea JOP, i.e. Armenia, Bulgaria, Georgia, Moldova, Turkey, Ukraine, Romania, and Greece. The Black Sea JOP aims at creating a stronger and more sustainable economic and social development of the Black Sea Basin regions.
15	**INOGATE Interstate Oil and Gas Transport to Europe - funded though ENPI European Neighborhood and Partnership Instrument**	The international energy co-operation programme between the European Union, the littoral states of the Black & Caspian Seas and their neighbouring countries, which have agreed to work together toward the achievement of the following four major objectives: 1.Converging energy markets on the basis of the principles of the EU internal energy market taking into account the particularities of the involved countries. 2. Enhancing energy security by addressing the issues of energy exports/imports, supply diversification, energy transit and energy demand. 3. Supporting sustainable energy development, including the development of energy efficiency, renewable energy and demand side management. 4. Attracting investment towards energy projects of common and regional interest.
16	**Nuclear Safety Co-operation Instrument (NSCI)**	An Instrument to support the promotion of a high level of nuclear safety, radiation protection and the application of efficient and effective safeguards regarding nuclear material in third countries.
17	**South East Europe Programme**	This programme aims to develop transnational partnerships on matters of strategic importance, in order to improve the territorial, economic and social integration process and to contribute to the cohesion, stability and competitiveness of the region. For this purpose, the Programme seeks to realize high quality, result-oriented projects of strategic character, relevant for the programme area.
18	**Central Europe Programme**	This programme aims to improve capacities for regional development in innovation, carbon dioxide level reduction, the protection of natural and cultural resources as well as transport and mobility.

Source: [20]

In our opinion, the growth dynamics of programmes should be compared with the dynamics of the main scientific and production indicators of Ukraine. The main trends are presented in Figure 1.

From Figure 1, it is clear that against the background of the growth of the dynamics of various programmes within the framework of scientific and technical cooperation between Ukraine and the EU, there is a tendency to reduce the basic economic, scientific and technical indicators. Thus, we can conclude that, as of 2018, that the growth trends of the scientific and production potential of Ukraine does not confirm the trend of strengthening this vector, and in fact, there is a downward trend.

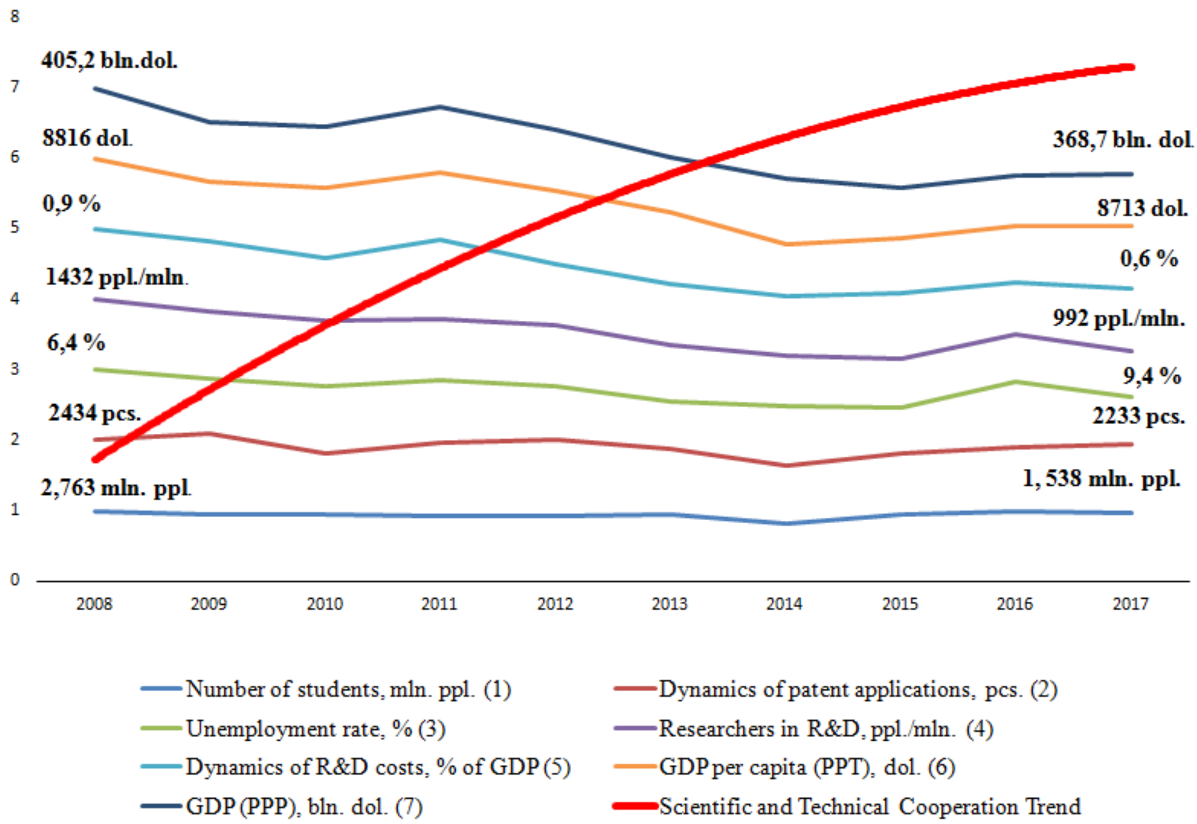

Figure 1. Comparative characteristics of the relationship between the growth of scientific and technical cooperation programs between Ukraine and the EU and the main trends in the development of the Ukrainian economy
Source: Author' materials based on Table 1

Nowadays, there is a growing increase in the share of energy source generation from renewable sources. Since the 2000s, this trend in the development of this energy sector has become more and more stable and is projected to continue to increase in the coming decades. Systemic oil and gas crises, the complication of international political relations in the struggle for energy resources and the emergence on the energy markets of innovative investors such as Apple, Microsoft, Google and Elon Musk with his SolarCity have helped contribute to this [21]. All this has given a significant impetus to the dynamic development of the global market for renewable energy sources, including the EU, in which these stable prerequisites indicate its strengthening in the foreseeable future. Consequently, today the global market for renewable energy sources is developing dynamically (see Figure 2), and there are no serious prerequisites indicating a change in this trend in the future. A positive point is that Ukraine has responded to the trend reflected in Table 3.

In our opinion, there is ae need for Ukraine to seriously consider the development experience of non-conventional renewable energy in the EU. Along with this, there is a need to make a comparative study of the positive results of non-conventional renewable energy usage in other developing and poor countries, which are also being reformed according to the priorities of the development of world experience of non-conventional renewable energy technologies.

Determining priorities of scientific and technical cooperation between Ukraine and Chile in the field of non-conventional renewable energy technologies

Considering the conditions of the modern innovative economy, economic relations may have a priority not as much in commodity items, but in intellectual and organizational communication systems of their realization. This relates to the exchange of experience, licenses, know-how and rapid expansion of scientific, technical and technological cooperation. It is through these means that it is possible to solve the issues of raising the technological level of various industries and the national economy as a whole such as the needed tasks of accelerated technological re-equipment, the need to expand export opportunities and reduce imports and need to develop technical and economic ties between countries based on specialization and cooperation in the production of various types of products [22].

One of the potential areas is the exchange of experience, knowledge and technologies in the field of the formation and implementation of the strategy for the development of non-conventional renewable energy (NCRE). For this, the prerequisites are considered according to the following reasons:

- both in Ukraine and in Chile there are various climatic conditions that have potential for the development of certain types of NCRE;
- both in Ukraine and in Chile there are sufficient potential sources of NCRE;
- both Ukraine and Chile have a comparable research and production potential that can be used to implement NCRE technologies;
- during the same period, both Ukraine and Chile have embarked on the path of development of NCRE since the 2000s.

However, as presented in Table 3, the growth rate of NCRE in Chile is significantly higher than in Ukraine.

The table shows that in Chile, the growth rate of NCRE generation based on solar, wind energy and bioenergy is much higher than in Ukraine as illustrated in Figure 2 below.

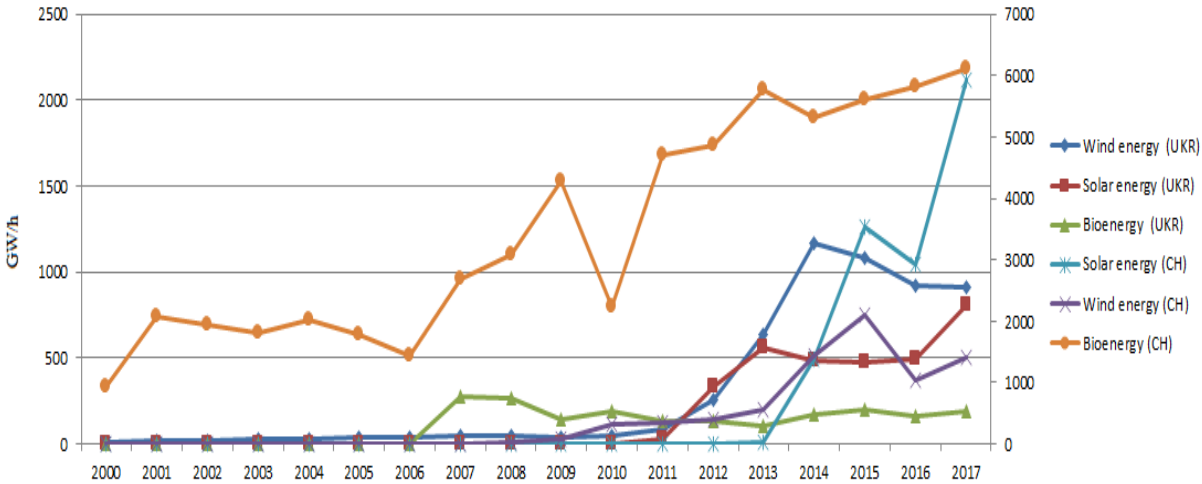

Figure 2 Comparative dynamics of energy production from various NCRE sources in Chile and Ukraine for 2000-1017
Source: Author's based on [15, 23-27]

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Table 3. Dynamics of actual energy production from NCRE (2000-2017) in Ukraine / Chile, GW/h

NCRE sources	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**Growth rate**
Wind energy	6	16	22	31	33	38	35	45	45	41	49	89	258	637	1172	1084	924	915	152,5
	0	7	7	7	7	7	7	9	38	79	332	338	409	554	1443	2114	491	804	202,7
Solar energy	0	0	0	0	0	0	0	0	0	0	1	30	334	563	483	475	164	190	26,8
	0	0	0	0	0	0	0	0	0	0	0	0	0	8	490	1261	1029	1419	264,4
Biomass energy	0	0	0	0	0	0	0	281	264	139	188	134	134	106	169	199	1041	2115	0,7
	941	2068	1944	1807	2031	1790	1431	2696	3083	4274	2249	4703	4874	5761	5327	5615	5812	6124	6,5
Total NCRE production	6	16	22	31	33	38	35	326	309	180	238	253	726	1306	1824	1758	1579	1909	119,3
	941	2075	1951	1814	2038	1797	1438	2705	3121	4353	2581	5041	5283	6323	7260	8990	7882	9658	8,8
Average NCRE production	2	5,3	7,3	10,3	11	12,6	11,6	109	103	60	79,3	84,3	242	435	608	586	526	636	
	314	692	650	605	679	599	479	902	1040	1451	860	1680	1761	2108	2420	2996	2627	2746	

Source: Author's materials based on [15, 23-27]

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In the process of analysis, the dynamics of average values and trends of total indicators of NCRE production of Chile and Ukraine show the field of growth of potential innovative susceptibility to NCRE technologies in the process of mutual scientific and technical cooperation between the subjects of international economic relations.

To justify the prospects of international cooperation between Ukraine and Chile, we made an analysis of the comparative dynamics of the volume of NCRE production. Based on these sources, there are comparative figures for the period from 2000 to 2017. According to Table 3, graphs presented in Figure 2 clearly reflect the dynamics of these processes. As the starting conditions for the development of NCRE were relatively similar, then considering the entire period, we can conclude that the growth rates of various types of renewable energy in Chile significantly exceed those in Ukraine.

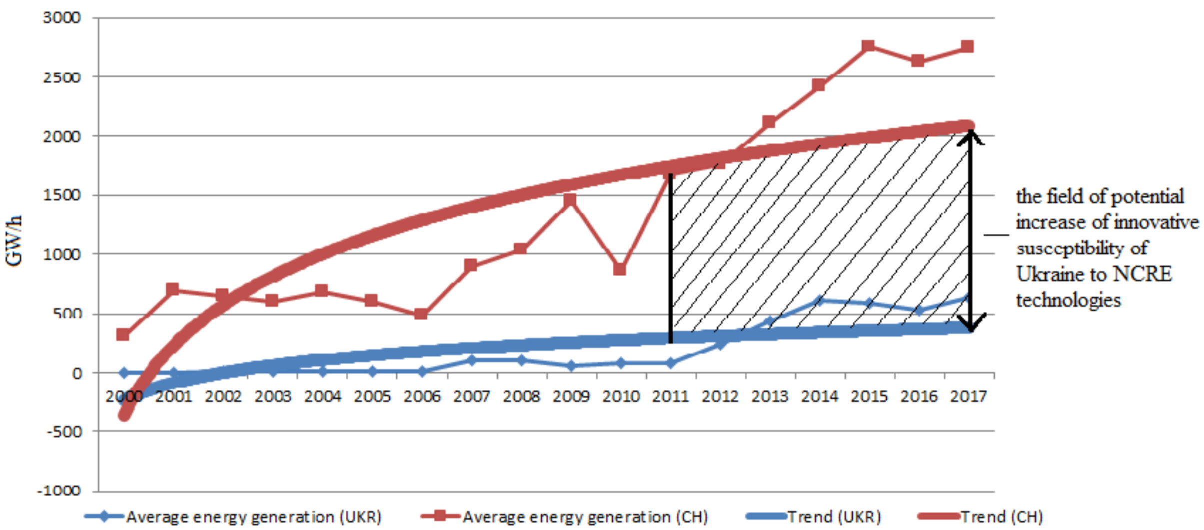

Figure 3 Dynamics of average values, trends in NCRE production over the years (2000-2017) and the growth prospects of innovative susceptibility to NCRE in the process of scientific and technical cooperation between Chile and Ukraine
Source: Author's materials *based on [15, 23-27]*

By the analysis of the comparative dynamics of trends in NCRE production, we can conclude that the Chilean dynamics substantially exceed those of Ukraine, which implies the need of a corresponding analysis of the conditions and forms of state support for these processes. Figure 2 presents the interpretation of the dynamics of NCRE development based on mathematical methods, in particular the logarithmic smoothing of graphs and their corresponding transformations into averaged trends. This made it possible to graphically visualize the field of potential innovative susceptibility of the development of the use of NCRE technologies by business entities in Ukraine.

This field of innovative susceptibility represents a segment of the innovative information for the formation of priorities in the international scientific and technical cooperation in the field of NCRE. In particular, regarding the current issues of convergent technologies, it also touches upon the issues of NCRE in terms of using elements of NBIC technologies within its framework. Among them, attention should be paid to:

1. Whether any party has elements of NBIC-technologies in the field of NCRE, then this immediately becomes a priority of international cooperation.
2. In fact, NCRE technologies already use elements of NBIC technologies. For example, solar collectors have the prospect of using nano-coatings and biotechnologies provide unconventional energy generation technologies from organic waste.
3. A promising direction from the point of view of NBIC is the creation of energy-saving complexes based on a combination of generating technologies on a traditional and non-traditional basis. This is especially important for improving the efficiency of existing traditional energy generation [28].

For example, it is possible that energy-saving complexes based on, for example, a house gas boiler, may systematically include a solar power system and a heat pump, which as experience has shown, will allow a reduction of the average annual consumption of fossil fuels by 40%. At the same time, elements of NBIC technologies are being used to some extent. All this shows serious scientific production and organizational-

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economic prerequisites for the formation of the priorities of scientific and technical cooperation between Ukraine and Chile in the field of NCRE.

Conclusions

On the basis of a phased analysis of the formation of priorities for development in Ukraine, we propose an approach for analysing the integrated development of national economies. This will allow a more reasonable approach to the selection of priorities for intergovernmental cooperation, including the growth of relevant areas of development. The results of the analysis, within the framework of interstate cooperation between Ukraine and the EU, allow to determine promising directions for development the field of NCRE sources between Ukraine and Chile. The author's exploration of cooperation of Ukraine with Chile in the field of green energy has proven that such cooperation is possible from the example of successful scientific and technical cooperation between Ukraine and the EU countries. In general, in Ukraine the development of certain areas of NCRE (such as solar and wind power) began within the framework of world trends (including the EU) much earlier than in Chile. However, until now there have been no institutional changes in the attitude towards NWE technologies in Ukraine [20].

In Chile, during 2007 – 2017, institutional changes occurred in the sphere of innovation susceptibility to NCRE technologies, which affected a wide range of factors, including political, legal, and socio-economic factors. Separately, it is possible to single out a complex of factors of scientific and technical cooperation with various advanced actors of the global economy on the issue of NCRE.

Accordingly, within the framework of world development, including trends in the EU, there is a prospect for the development of scientific and technical cooperation between Chile and Ukraine on NCRE issues, including:

1. The formation of priorities and the role of state programs of scientific and technical cooperation in the development of the national economies.
2. Organisational and economic forms of scientific and technical cooperation in the field of NCRE between Chile and Ukraine taken from the example of such cooperation between Ukraine and the EU.
3. The experience of state support of the subjects of the producer-consumer NCRE cycle, taking into account the best international practices, including the EU.
4. Forms of development of producer and consumer motivation; selection of the priorities for NCRE technologies taking into account the experience of advanced economies, including EU countries.
5. Exchange of intellectual products (technology, licenses, know-how, etc.).

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Igor Yu. Matyushenko
V.N. Karazin Kharkiv National University,
School of International Economic Relations and Travel Business
app. 380, 6 Svobody Sq., 61022 Kharkiv, Ukraine, imatyushenko@karazin.ua
https://orcid.org/0000-0001-9866-9025

Olesia V. Azarenkova
V.N. Karazin Kharkiv National University,
School of International Economic Relations and Travel Business
app. 380, 6 Svobody Sq., 61022 Kharkiv, Ukraine, azarenkova.olesia@gmail.com

PROSPECTS OF CONVERGENT TECHNOLOGIES USAGE IN SOLVING THE GLOBAL ENERGY PROBLEM

Abstract
The article summarizes the main findings regarding a study on global problems, with an emphasis on global energy problems and possible solutions. To find solutions to global problems, the conditions of the new industrial revolution were taken into account, the features of technological development of economies in countries worldwide were investigated and, namely the essence of economic paradigms aimed at solving global problems was determined. Convergence of NBIC-technologies as a key factor of the new industrial revolution were characterized, and the process of converging knowledge, technologies and society as a mechanism for solving global problems was studied. Trends in the development of scientific and technical, innovative activities in Ukraine and countries worldwide were determined. In particular, the main directions for development of converging and advanced production technologies that are most promising for developed countries, developing countries and Ukraine are presented.

Key words
biotechnology, biofuels, convergent technologies, global energy problem, nuclear energy, alternative energy, energy security, thermonuclear energy

Introduction

The most significant trend that has shaped the face of the world since the turn of this century has been the formation of a global economic system that erases the boundaries of national economies and which is bound by strong trade, financial, political, social and cultural relations. In the second half of the twentieth century mankind faced many severe global problems. These included processes and phenomena that cover the sphere of interaction between nature and society, as well as relations between worldwide social communities - peoples and states. The need to find solutions to mankind's global problems has been generated by threats of a highly dangerous nature that put the further existence of mankind in peril. After the economic crisis of 2008-2009, the most developed countries of the world considered convergent technologies as the main tool for solving global problems, based on the mutual influence and mutual penetration of the constituent parts of these technologies (foremost nano-, bio-, informational and cognitive technologies). The scientific tasks of using convergent technologies to solve global problems have been studied by O. Sartakova [1], K. McCormick, N. Kautto [2], D. Yergin, I. Buntov, V. Khaustova, etc. [3-16] and other researchers.

Method of research

Content analysis and bibliographic retrieval were used as the main methods of research, which allowed making a meaningful analysis of classic papers and works of modern economists devoted to studying Ukrainian trends in convergent technologies' scientific research. General scientific methods make up a methodological foundation of the research. They include description, comparison, statistical reviews, system analysis and others, which help characterize this phenomenon's development in a more comprehensive way. The methods of dialectic cognition, structural analysis and principles of logic which allow making authentic conclusions regarding the investigated topic were also applied. Official statistical data of state institutions and international organizations, publications of reference character, analytical monographs, annual statistical bulletins, World and Ukrainian institutions and universities' reports all served as the information basis for the research.

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Results and Discussion

The term "global problems" was first used in scientific research by scientists of the Rome Club in the 1960s and such general global problems have the following essential features:

- they concern not only individuals, but all of mankind;
- they cannot be solved by individual countries, but require a purposeful and organized effort by the entire world community;
- they are closely related to each other, cover all aspects of people's lives, and therefore require a comprehensive solution [14].

Over the past 50 years, a large number of foreign and domestic scientists have devoted their studies to these problems and their corresponding transformation and influence on the development of particular countries. On the basis of modern studies by Ukrainian scholars, the main global problems that relate first of all to the material sphere can be combined into the following four groups:

- depopulation and aging of the population;
- lack of food and the exhaustion of stocks of a number of raw materials and fuels;
- environmental problems, new energy and energy saving;
- slowing down of scientific and technological progress and lagging behind the leading countries of the world in the transition to a new technological structure (Figure 1) [9-11].

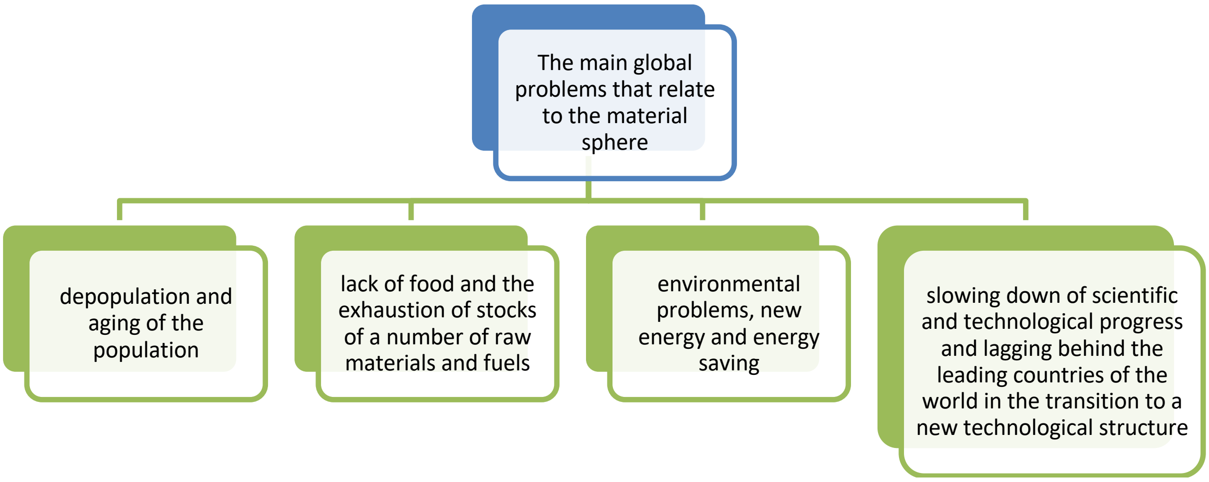

Figure 1. The main global problems that relate to the material sphere
Source: [9-11]

The energy problem is definitely counted in the category of being of global concern. Its research should take into account the level of development of science, technology, economics, social relations and the specifics of the interaction of energy supply and economic growth. This approach avoids narrow-minded estimates and unreasonable generalizations used to distinguish between techno-economic, social and other groups of factors increasing and exacerbating the energy problem, the differentiation of its manifestations for particular periods, groups of countries and industries are covered. Above all, there has been a general deterioration of the natural and geographical conditions for the continued extraction of mineral fuels and, as a consequence, a significant increase in the cost of exploration, extraction and transportation of energy over long distances. Areas of oil and gas supplies are becoming increasingly distanced from the main centers of their consumption. Satisfaction of rapidly growing energy needs is still carried out extensively - involving in the circulation of new energy resources and their costs which are not always justified. Overall, the transition to energy-saving technologies is limited to the wealthiest nations. In the vast majority of developing countries, this process, which requires a significant amount of investment, is delayed. An important factor in the globalization of the energy problem is its close connection, both direct and indirect, with other global problems the world now faces. Modern energy is mainly based on non-renewable energy sources, which, with limited resources, are exhaustive and cannot guarantee the sustainable development of the world energy supply over the long term, and their use is one of the main factors that has led to the crisis in deterioration of the environment. There is an increase in the total world consumption of primary energy, mainly due to the constant growth of the world's population and increase in specific energy consumption. Today a reliable energy supply is one of the most significant factors for stable economic development. The quality and uninterrupted operation of energy supplies depends on the level of

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energy service provided the population, the country's national security and global security in general. The Global Energy Institute's (GEI) International Index of Energy Security Risk provides a look at energy security risks across different countries for the years 1980 through 2016; it is calculated for 25 countries that make up the Index's large energy user group. Norway remained the most energy secure country among the large energy user group in 2016, a position it has held since it took over first place from the United Kingdom in 2006. Unfortunately, Ukraine continues its unbroken record (since 1992) of being the least energy secure country among the large energy user group [28].

The key challenges for energy security include:
- energy intensity, that is, how much energy is spent on production of a unit of GDP;
- natural gas imports - this risk has intensified for most countries that are large consumers of energy. This is due to the fact that the increase of gas extraction, with the exception of the USA, is observed only in countries with high political risks, as well as the fact that the needs of gas in developed countries are increasing;
- volatility of prices and supplies of oil and petroleum products.

Modern researchers and international organizations [14] traditionally distinguish three main criteria for assessing the degree of manifestation of the global energy problem:
- ACCESSIBILITY - the degree to which people have access to modern and affordable energy;
- AVAILABILITY - the reliability and security of energy supply systems, as well as the rather high degree of infrastructure development;
- ACCEPTABILITY - environmental safety of production, transportation and consumption of energy.

Proceeding from the foregoing, one can distinguish the main levels of the manifestation of the global energy problem (Figure 2):

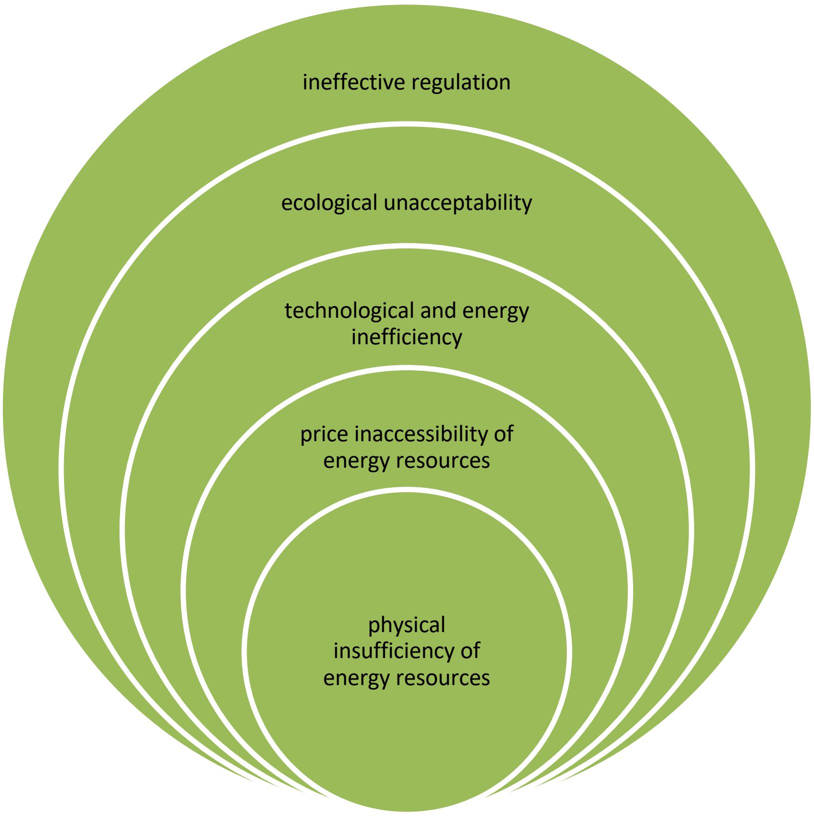

Figure 2. Levels of the global energy problem
Source: Author's

When identifying Ukraine's position in comparison to other top energy-consuming countries, it is obvious that Ukraine is extremely dependent on imports of energy products. Ukraine ranks last among 25 countries - large consumers of energy in terms of the energy intensity and energy consumption (see Table 1).

Table 1. Energy efficiency indices for top energy consuming countries, 2016

Index	1st place	25th place	Ukraine
Risk Score	Norway	Ukraine	25
Petroleum Import Exposure	Canada	Japan	16
Natural Gas Import Exposure	Australia	France	16
Coal Import Exposure	Australia	Netherlands	15
Total Energy Import Exposure	Canada	Japan	17
Fossil Fuel Import Expenditures per GDP	Canada	Ukraine	25

Source: [29]

Ukraine has low rates in the category of volatility of prices and markets, which means that it is not able to operate and reduce risks to the economy from changes in energy prices. This makes enterprises very sensitive to changes in gas, electricity or oil prices. (see Table 2).

Table 2. Energy expenses and prices influence

Metrics	Index	1st place	25th place	Ukraine
Energy Expenditure Metrics	Energy Expenditure Intensity	UK	Ukraine	25
	Energy Expenditures per Capita	India	Netherlands	7
	Retail Electricity Prices	South Africa	Italy	14
Price & Market Volatility Metrics	Energy Expenditure Volatility	UK	Ukraine	25
	GDP per Capita	Norway	India	24

Source: [29]

Compared to other top energy consuming countries, Ukraine has sufficient diversification in the electricity market. Regarding electricity, it should be noted that the problem in the electricity market is not the lack of energy resources to ensure energy, but rather imperfect tariff and regulatory policies, domestic monopolies and ageing of power grids (see Table 3).

Table 3. Energy Use Intensity and Electricity Power Sector

Metrics	Index	1st place	25th place	Ukraine
Energy Use Intensity Metrics	Energy Consumption per Capita	India	Canada	9
	Energy Intensity	Denmark	Ukraine	25
	Petroleum Intensity	Germany	Thailand	22
Electricity Power Sector Metrics	Electricity Capacity Diversity	Spain	Norway	8
	Non-Carbon Generation	Norway	Indonesia	8

Source: [29]

Although Ukraine ranks on the top of the rating in terms of transport costs *per capita* and CO2 emissions, it is nearly last place in terms of energy intensity of transport and emission intensity (see Table 4).

Table 4. Transport and Ecology

Metrics	Index	1st place	25th place	Ukraine
Transportation Sector Metrics	Transport Energy per Capita	India	USA	2
	Transport Energy Intensity	Japan	Ukraine	23
	CO_2 Emissions	Denmark	Indonesia	9
Environmental Metrics	CO_2 per Capita	India	Canada	4
	CO_2 GDP Intensity	Denmark	Russia	24

Source: [29]

To guarantee high level of energy security, i.e. the state in which the country, its economy and population will have uninterrupted availability of energy sources at an affordable price it is required to use the most prospective energy technologies (see Fig.3) [8].

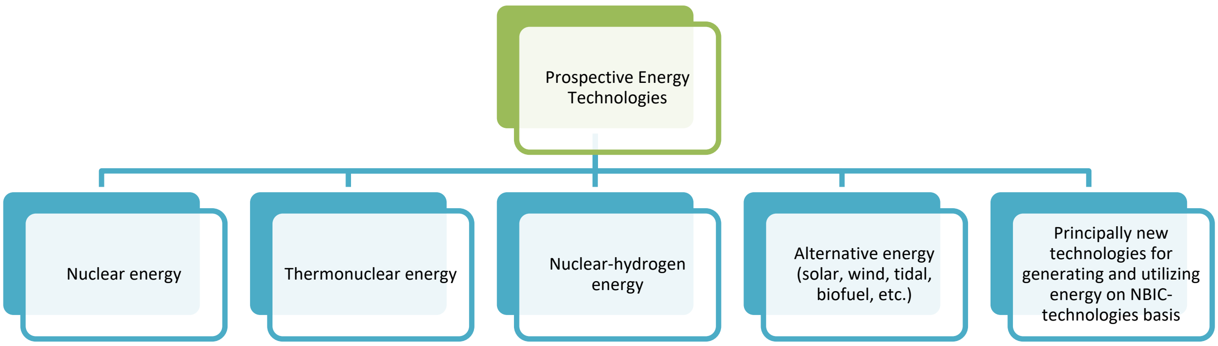

Figure 3. The most prospective energy technologies
Source: [8]

The most significant alternative to hydrocarbons is nuclear power based on the separation of uranium-235. On the other hand, the use of fission reactors (NPPs) inevitably creates two other global problems - the utilization of high-level spent fuel (HLW) and other radioactive waste, as well as nuclear safety. Today worldwide about 200 thousand tons of spent HLW, 1 million tons of waste of average activity and very active water and more than 10 million tons of waste of low activity have been accumulated. Each year, these figures increase by 5% [13]. Since the early 1950s, it was unreasonably believed that the future of mankind was connected with the solution of the thermonuclear problem. The essence of thermonuclear energy is the use of energy released during fusion (synthesis) of light nuclei. The problem faced is confining the plasma and preventing contact with the walls of the camera. The advantages of nuclear fusion include:

- nuclear fusion can provide not only mankind's current energy needs (16 TB), but also produce a much greater amount of energy;
- as a fuel, it requires a very small amount of substances that are common in nature;
- thermonuclear plants are able to produce as much as 200 MWh of electricity, which is equivalent to burning 70 tons of coal, even if it is not ideal, and a more efficient model of the installation will provide 2.5 GW of fusion energy after the conversion and use of a certain particle for plasma heating and the work of superconducting electromagnets and other systems will provide 1.5 GW of electrical output;
- high internal fusion energy;
- the absence of high-level radioactive waste that remains active for a long time [14].

The disadvantages of thermonuclear reactors are the technological complexity of the self-sustained fusion reaction, as well as the fact that there are no effective technical solutions that can convert the energy released during fusion into electricity. Examples of thermonuclear devices already in use in the developed world are: (1) The International Thermonuclear Experimental Reactor (ITER), a gigantic tokamak that will operate on the basis of deuterium-tritium fuel at a total cost of USD 10 billion (and may increase to USD 16 billion), which is being built in France; (2) National Ignition Facility (NIF or literally - "national ignition complex") - an alternative project worth USD 3.5 billion, which started in the USA in 2009. The complex includes 192 high-power lasers, the rays of which focus on a tiny sample of deuterium and tritium (although the US government is considering the future of the NIF more in the context of defense rather than energy). Today the problem of thermonuclear energy engineering is more technical and economic than physical, because for creation of real economically profitable power plants it is necessary to solve two principal tasks:

- the continuation of development of new materials that are able to withstand strict operating conditions;
- the creation of new technologies related to remote control, shell designs, fuel cycles, etc. [7, 8].

Andrea Rossi [15], the Italian inventor of the so-called E-Cat generator (or energy catalyst), promises LENR (low energy nuclear reactions) or "cold nuclear synthesis" to solve the global energy problem. Its fuel is nickel and hydrogen powder, and the source of energy is the nuclear reaction between them. As a result, the original compact version of the E-Sat generator was transferred on the basis of licensing agreements with China and South Korea for further large-scale production and sale at a unique low price of USD 500 for the reactor [13, 15]. Hydrogen (atomic-hydrogen) power engineering, in particular, the production of metallic hydrogen and other exotic substances, is the next potentially effective direction of future energy development [8]. Perspective directions of use of metallic hydrogen are:
(1) in power engineering and microelectronics;
(2) safe storage of hydrogen fuel;
(3) research of various alloys of metallic hydrogen with heavier elements.

The main results of the research in this direction are presented by Matyushenko and colleagues [3, 7].
Among the large variety of alternative energy sources, solar energy is primarily allocated. Renewable solar power has been technologically developed for many decades, and the efficiency of solar cells has increased significantly, however today solar energy still has not become a powerful energy resource. Unlike living nature, where solar energy accumulates through photosynthesis is still not available for artificial reproduction of the bioorganic structure of a green leaf, and this natural process is stimulated using a semiconductor structure [7, 8].
It has become obvious that systems that mimic objects of nature can be done by "launching the future" on the basis of the convergence of NBIC-technologies [16]. The main areas of the use of NBIC-technologies in the energy sector, in specific generation (conversion, production), accumulation, transfer and conservation of energy, include [17]:

- photovoltaic (solar cells), hydrogen (fuel elements) transformation, thermoelectricity (thermoelectric devices) Improvement of hydrocarbon energy (catalysts, additives);
- LEDs - Significant energy savings can be obtained by a transition to LED technology, including using organic OLED LEDs based on various forms of green fluorescent protein (GFP) that can also be used to create monitors, televisions, different kinds of displays, and more. GFPs are completely safe for the environment and require very little energy.

Considering Russia's aggression, for Ukraine, the problem of survival and sustainable development is directly related to the trends of world energy and the need to minimize dependence on hydrocarbons, may have the opportunity to become an energy-independent state through the improvement of nuclear technology and the use of unconventional energy sources. The National Academy of Sciences of Ukraine has provided scientific and technical support for nuclear power engineering, has created the Nuclear Physics and Energy Department of the National Academy of Sciences of Ukraine (NASU). One of the most important tasks has been the active study of perspective directions of development of nuclear energy in Ukraine and the development of appropriate proposals for the State Energy Strategy [18, 19]. The results of the programmes execution are listed in Table 5.

Table 5. The most significant results of the NASU target comprehensive programs for scientific research on nuclear energy

Year	Sector of the program	The most significant result	Practical utility
2004-2010	Nuclear energy	promising results of research, ready for further implementation, including the technologies of obtaining new titanium based metallurgy materials for spent fuel tanks and production of hafnium of nuclear purity for neutron-absorbing elements, were obtained.	
2011-2012		methods of high-frequency creation and heating of plasma were developed;	new methods of application of functional coatings;

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		the behavior of energetic particles in magnetic traps was investigated; new methods of diagnostics of high-temperature plasma have been developed; carried out experimental studies of the behavior of structural materials of the first wall and the diverter in the conditions of extreme corpuscular and energy loads that are inherent in the thermocouple reactor.	modification of materials by powerful currents of the plasma; plan-coagulation sources of extreme ultraviolet and X-ray radiation; plasma ozonizers; low-temperature plasma ozone-ultrasound sterilizers; helicopter technical sources; plasmochemical reactors; vaporplastic waste recycling technology; the creation of new, promising environmentally friendly, plasma technologies for industry, medicine, rural society and environmental protection

Source: [18, 19]

Ukraine has also joined the international thermonuclear program by signing an Agreement on Cooperation between the Cabinet of Ministers of Ukraine and the European Atomic Energy Community in the field of controlled thermonuclear fusion, ratified by the Law of Ukraine of March 7, 2002, No. 3104-III (3104-14), according to which the main fields of cooperation include:

- experimental and theoretical studies of plasma content, transfer, heating and plasma control processes (including the development of appropriate high-frequency systems) and diagnostics in toroid magnetic devices;
- studies on plasma theory, in particular, the physics of fast ions and alpha particles in toroidal magnetic devices, and the study of turbulent plasma and nonlinear wave interactions in plasma;
- thermonuclear fusion technology;
- Applied Plasma Physics;
- policy on programs and plans [20].

However, as Ukraine was not formally involved in the unification of the countries involved in the construction of the reactor, its participation has been limited to solving auxiliary tasks within the framework of cooperation with the laboratories of Europe and Russia. In 2013, the Presidium of the National Academy of Sciences of Ukraine approved the Conception of the Target Complex Program of the National Academy of Sciences of Ukraine "Prospective studies on plasma physics, controlled thermonuclear fusion and plasma technologies" for 2014-2016 [22]. The main objective of this program is to increase the efficiency of research in plasma physics, controlled thermonuclear fusion (CTC) and plasma technologies aimed at identifying new physical principles of the structure of complex plasma systems and on this basis creating the physical foundations of new high-and low-temperature plasma technologies.

Table 6. The most significant results of the NASU target comprehensive programs for scientific research on thermonuclear energy

Year	Sector of the program	The most significant result	Practical utility
2014-2016	Thermo-nuclear energy	realization of a number of projects in the following areas of research: - fundamental problems of plasma theory; - controlled thermonuclear fusion; - plasma electronics and collective methods of accelerating charged particles; - low temperature plasma and technology based on it; - plasmodynamics; - cosmic plasma	Modeling of physical processes in large thermonuclear installations with diverter configurations such as ITER One-dimensional analytic-on model of diffusion-convective transfer of charged nucleation synthesis products in a toroidal plasma Experimental installation "Plasma-Dyelle-Tricycle Multi-speed Accelerator" Modeling of

			peculiarities of the influence of longitudinal magnetic field

Source: [22]

Today, all countries are looking for new efficient and environmentally friendly alternative energy sources. Among renewable energy sources hydrogen has a special place in solving this problem, both from the point of view of high specific energy intensity, and from the point of view of the absence of environmental pollution in its use, since it burns only oxygen and its byproduct is water. As a result, hydrogen energy is viewed today as the most realistic alternative to modern energy resources, which are largely based on the combustion of hydrocarbons. At the same time, hydrogen can be obtained from natural gas, coal, biomass and virtually all renewable and non-traditional types of energy resources. The development of modern technology of fuel cells (PCs) allows heat-generating machines to convert hydrogen into electricity without polluting the environment. In order to solve the problems of the development of hydrogen energy, fundamentally new technological solutions are needed in the direction of obtaining, storing and using hydrogen.

To address these issues and engage in research with the wider scientific community during 1995-2005 a number of international and national programs on hydrogen energy were created. First of all, this was the initiative of the International Energy Agency (IEA), which supports more than 40 relevant international programs. International organizations such as the International Organization for Cooperation and Development (OECD), the International Partnership for the Advancement of Hydrogen Energy (IPHE), the World Energy Network (WE-NET) and others promote the development of hydrogen energy. Additionally, in 2003, the European Commission established the "Technology Platform for Hydrogen and Fuel Cells," which began operations in January 2004. A number of hydrogen projects have also been funded by the EU under the auspices of the 6th and 7th Framework Programs, as well as the Horizon 2020 Program.

To create the foundations of hydrogen energy research in Ukraine, the Resolution of the Presidium of the National Academy of Sciences of Ukraine dated December 29, 2010 No. 356 approved the Targeted Integrated Program "Hydrogen in Alternative Energy and New Technologies" for 2011-2015 [23].

The main results of this program's implementation from 2011-2015 for solving global problems were presented in the study [7, p. 518-523]. Thus, as a result of the program's implementation the following were established:

- scientific basis of new hydrogen production technologies based on the use of renewable energy sources, organic wastes, non-condensed solid fuels;
- laws of the interaction of hydrogen with light hydride-forming metals, intermetallides and composites on their basis, as well as the influence of atomic structure, electronic structure and surface condition on hydrogen adsorption characteristics of hydrogen storage materials were investigated;
- materials with a hydrogen content of more than 4 wt. % that are capable of absorbing and releasing hydrogen in the conditions necessary for their use in road transport;
- developed new high-performance functional and construction materials for high-temperature oxide-ceramic fuel cells (PCs) and low-temperature PC-based polymeric membranes, ZrO2 monoblock ceramic fuel cells and improved electrode materials, new proton-conducting polymer membranes with increased thermal stability;
- experimental prototypes of said oxygen-hydrogen fuel cells were created and investigated;
- proposed technologies for the use of hydrogen processing materials in order to modify their structure, increase mechanical and other operational properties;
- scientific foundations of destructive hydrogenation-recombination of intermetallic compounds and alloys containing hydride-forming metal were developed, as well as principles of the assessment of the working capacity of structural materials during their operation in a hydrogen medium;
- fundamental research was carried out and methods for minimizing the harmful effects of hydrogen on welded joints were proposed.

The process of looking for new ways to use energy resources of renewable energy accumulated by living substances through photosynthesis such as, biofuel, which is of high importance nowadays. Soon approximately 10% of total energy consumption may be covered by means of the products of photosynthesis. During the implementation of integrated programs "Biomass as a fuel material" ("Biofuels") and "Biological resources and the newest bioconversion technologies" in 2007-2015. To expand the use of alternative fuels by the use of biofuel, the scientific institutions of the National Academy of Sciences of Ukraine continued to work on prospective bio-resources, development and implementation of the latest bioconversion technologies for the production of liquid biofuels and expansion of their use, improvement and development of the latest chemical technologies for the production of biodiesel, utilization of agricultural, forestry, food processing and household waste as raw materials for bio-fuels [6].

Modern achievements in the field of optoelectronics have led to the creation of LED light sources with energy efficiency, which is 8-12 times greater than the energy efficiency of incandescent lamps. The use of such sources can significantly reduce electricity consumption for lighting and maintenance of the electricity grid, increase environmental safety, simplify the creation of automated lighting control systems and light signal equipment. To ensure a significant reduction of electricity consumption for lighting, improve its quality, reduce the burden on the environment by developing and introducing into the economy of Ukraine a new technology of "solid" lighting the Resolution of the Cabinet of Ministers of Ukraine dated 07.09.2008 No. 632 "On Approval of the State Target Scientific and Technical the program with development and introduction of energy saving LED light sources and lighting systems on their basis" for 2009-2013, a production program was introduced lighting at [24, 25].
The most significant results of the implementation of this program for 2009-2013 for solving global problems are presented in the study [7, p. 524-530] and in Table 7 in the most generalized view.

Table 7. The most significant results of the NASU target comprehensive programs for scientific research on optoelectronics

Year	Sector of the program	The most significant result	Practical utility
2009-2013	Optoelectronics	- Creation of materials, technologies and methods of control, thermoregulation of LED light sources; - Manufacture of LED emitters and their systems; - Creation of means of diagnostics and certification of LED light sources; - Realization of pilot projects on introduction of energy-saving LED lighting systems	Technology allowed: - to organize the modern production of LED light sources, which include: energy saving LED lamps; lighting devices for the needs of housing and communal services; special fire and explosion-proof lamps for mines; street light fixtures; ceiling light fixtures for illumination of administrative buildings (including budgetary institutions), industrial objects; LED illumination systems for illumination of buildings, constructions and artistic-decorative purposes; special lighting systems; lighting systems for transport; - to ensure the industrial production of energy-saving LED light sources, whose energy consumption is 8-12 times less than that of incandescent lamps, with a life span of over 50 thousand hours; - to save about 400 million kWh of electricity per year for each million LED lamps.

Source: [6, 7]

Conclusions
The paper shows that today, when mankind is faced with a range of global problems, the activity of the state and society should be aimed at solving these problems, the main problem related to the material sphere can be combined into four groups:

- depopulation and aging of population;
- lack of food and exhaustion of stocks of some types of raw materials;
- environmental problems, lack of fuel energy and energy saving;
- slowing down of scientific and technological progress and lagging behind the leading countries in transition to a new technological wave.

Since 1992, the first year for which data are available for Ukraine, the country has been ranked last with by far the worst energy security index scores of any country in the large energy user group. Its scores over the period from 1980 to 2016 averaged 177 % higher than those for the OECD.

The authors have concluded that due to the exacerbation of energy and environmental problems, the prospect of the gradual exhaustion of fossil hydrocarbons in most countries of the world thereby raise the issue of the

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need for widespread use of the latest convergent technologies in the development of nuclear energy, the creation of thermonuclear energy and the increased use of renewable energy sources as well as the search for new efficient and environmentally tolerant energy carriers. It was shown that in 2004-2010 the State Program for Fundamental and Applied Research on the Issues of the Use of Nuclear Materials, Nuclear and Radiation Technologies in the Sphere of Economic Development was carried out to solve the problems of nuclear power of Ukraine (the actual level of funding for this program was about 52 % of the prescribed amount). In 2011-2015, a complex program "Scientific and technical support for the development of nuclear energy and application of radiation technologies in the branches of economy" was carried out at the institutes of the National Academy of Sciences of Ukraine, in which a number of important applied developments were obtained, namely:

- new methods for the application of functional coatings; modification of materials by powerful plasma flows;
- plasma sources of intense extreme ultraviolet and X-ray radiation;
- plasma ozonizers;
- low-temperature plasma ozone-ultrasound sterilizers;
- helicoid technological sources; plasma chemistry reactors;
- steam-plasma technology of waste processing;
- creation of environmentally friendly plasma technologies for industry, medicine, agriculture and environmental protection.

It was determined that the scientific institutes of the National Academy of Sciences actively participate in joint research with EU and Russian laboratories on the development of technology for controlled thermonuclear fusion, including in 2014-2015 as part of the integrated program "Prospective studies in plasma physics, controlled thermonuclear fusion and plasma technologies ". The most important results were:

- gaining new knowledge about the physical phenomena occurring in high-temperature plasma, including its interaction with solid surfaces;
- development of the fundamental aspects of thermonuclear energy for the future;
- development of physical principles and equipment for advanced ion-plasma technologies for industrial processing of materials, environmental protection, agriculture, medicine, diagnostics of substances, etc.;
- development of plasma electronics, plasmodynamics and physical foundations of collective methods of accelerating charged particles; an impetus for the development of the high-tech manufacturing industry, which is currently almost completely imported.

It has been established that from 2006-2015 Ukraine continued intensive fundamental and applied research within the framework of the programs "Fundamental problems of hydrogen energy", as well as "Hydrogen in alternative energy and new technologies" on the development of technologies for hydrogen production, which included:

- the creation of appropriate materials and highly effective processes that can lead to a significant reduction in the cost of both hydrogen itself and auxiliary systems, especially fuel cells,
- promotion the widespread commercialization of hydrogen energy technologies;
- coordination with the general tendency of increasing use of alternative energy and maximum possible decentralization of energy supply.

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Andrzej Piotrowicz
AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Department of Physical Chemistry and Metallurgy of Non-Ferrous Metals
30 Mickiewicz Av., Krakow, 30-059 Poland, andpio@agh.edu.pl

Stanisław Pietrzyk
AGH University of Science and Technology, Faculty of Non-Ferrous Metals, Department of Physical Chemistry and Metallurgy of Non-Ferrous Metals
30 Mickiewicz Av., Krakow, 30-059 Poland

DISSOLUTION OF MANGANESE (IV) OXIDE FROM TANTALUM CAPACITOR SCRAP BY ORGANIC ACIDS

Abstract
The dissolution of MnO_2 from tantalum capacitor scrap using organic acids in various process conditions was studied. The initial materials were of two types: LTC (leaded tantalum capacitors) and SMDTC (surface-mounted device tantalum capacitors). The research materials were prepared by pyrolysis, grinding and sieving and the preparation processes were characterized. Dissolution of MnO_2 was carried out with the use of sulfuric acid solutions with the addition of acetic, ascorbic, citric and oxalic organic acids. Results show that the addition of organic acids significantly improves dissolution yields (72-94 vs 90-99 % for H_2SO_4 and acid mixtures, respectively). In practice, a concentration of organic acid above 1 M results in the complete removal of MnO_2.

Key words
tantalum capacitors, tantalum recycling, eco-friendly recycling, transition metals recovery

Introduction

The publication of a list of critical raw materials for the European Union (EU) [1, 2] shows that tantalum is one of them. Tantalum has many uses, such as for heat exchange, as a superalloy additive, for sputtering and others, but the most important use is for tantalum capacitors (TC) which are characterized by a high electrical capacity. TCs are crucial for the development of the high-tech electrical/electronic industry, especially for the manufacture of portable devices and energy control and storage systems. Tantalum is mostly imported to the EU, and recycling of this metal is poorly developed in the EU – therefore, scientific efforts should be made to increase tantalum recycling efficiency.

A tantalum capacitor essentially consists of three components:

- an internal tantalum sinter covered with manganese(IV) oxide, graphite and silver with tantalum wire, hereinafter referred to as an anode,
- an outer layer of epoxy resin
- electrical leads, metal pads and solders.

Figure 1 shows a schematic of an anode. The metallic tantalum powder is sintered with tantalum wire – the whole is a sinter covered with the following layers: tantalum(V) oxide (Ta_2O_5), manganese(IV) oxide (MnO_2), graphite, metallic silver and epoxy resin. Metallic tantalum powder is a substrate for the production of a dielectric layer – Ta_2O_5. The use of powder increases the surface area, which in turn increases the electrical capacity. MnO_2 is a cathode and silver provides chemical protection. To prevent undesirable reactions between the cathode and silver, there is a graphite layer between them. Epoxy resin containing halogens increase the decomposition temperature and serves as a mechanical protection and electrical insulation [3,4].

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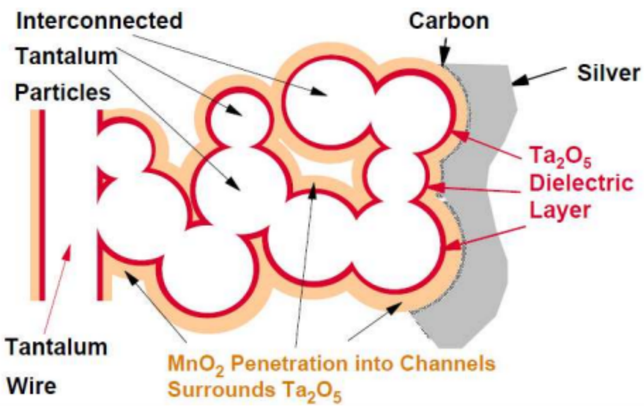

Figure 1. Schematic representation of the structure of a tantalum capacitor and the cathode connecting layers (the whole is encapsulated in epoxy resin and is a three-dimensional structure, no electrical leads are marked)
Source: [3]

There are two types of TCs (Figure 2):
- leaded tantalum capacitors (LTC) and
- surface-mounted device tantalum capacitors (SMDTC).

Despite the differences in the external structure, which results from the mounting method to the electric circuit (though-hole or surface-mounted technology), the internal structure is almost identical (Figure 3).

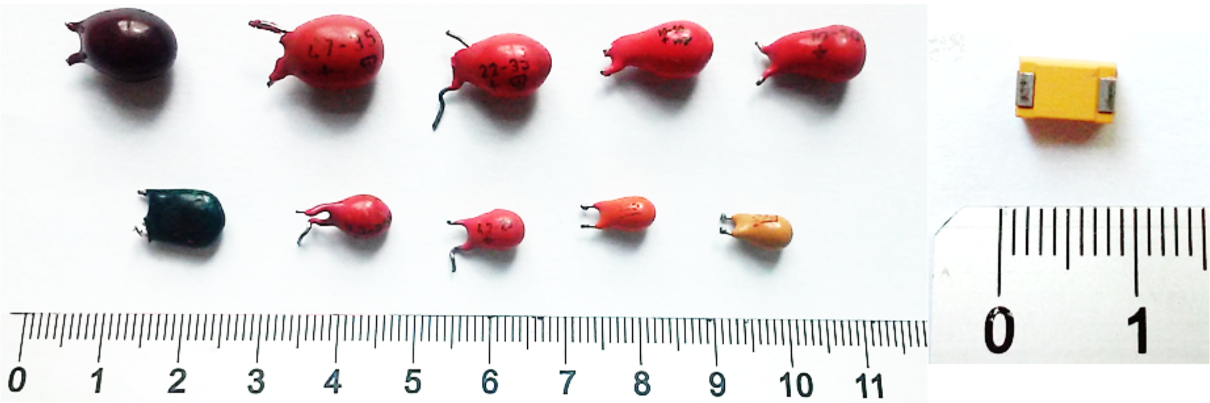

Figure 2. Tantalum capacitor scraps used in this work – LTC (right) and SMDTC (left)
Source: the Author's own materials

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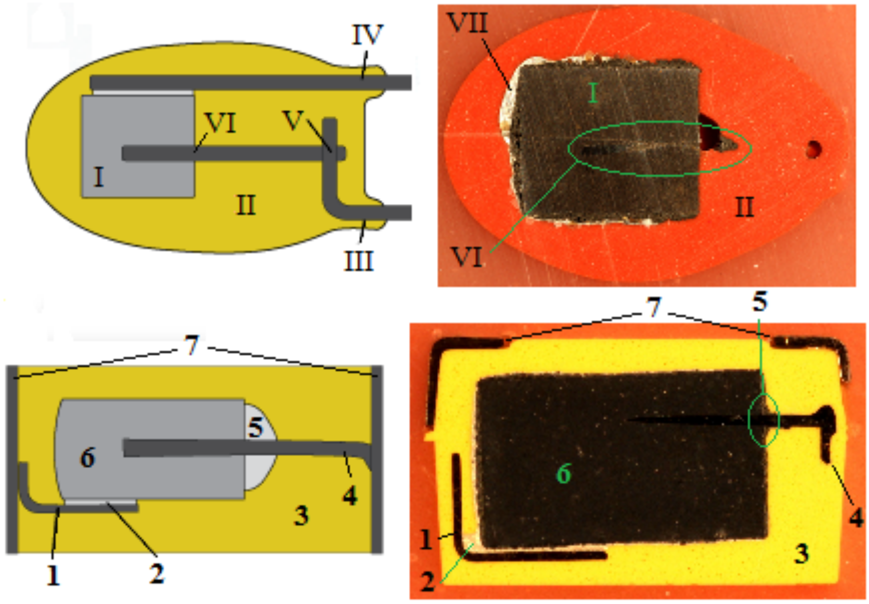

Figure 3. LTC and SMDTC schemes (left side at the top and at the bottom) and optical images of a section through the internal structure of LTC and SMDTC (right side at the top and at the bottom): I, 6 - anode; II, 3 - epoxy resin encapsulant; III - positive lead; IV - negative lead; V – weld; VI, 4 – anode wire; VII – silver paint; 1 and 7 – lead frames; 2 - silver filled epoxy; 5 - teflon washer
Source: [5] and Author's materials (optical images)

Tantalum recycling from capacitor scraps

Many studies of recycling tantalum from scrap electric and electronic equipment show that it is possible to effectively recover tantalum by various piro- and/or hydrometallurgical methods such as: mechanical-magnetic separation and alkali/acid treatment [6], tantalum solubility in a Cu-Fe alloy [7], chlorination of tantalum by iron chlorides [8,9,10], chemical reduction of oxidized tantalum [10,11], recovery with ionic liquids [12], supercritical water treatment [13], steam gasification with sodium hydroxide [14], vacuum pyrolysis [15,16] and others. This work [17] strictly concerns the removal of MnO_2 from manganese material, which may be a tantalum capacitor with hydrochloric acid or a mixture of sulfuric acid and hydrogen peroxide. Both methods cause either the emission of dangerous compounds ($MnCl_4$, and hence, chlorine), or are long-term (over twelve hours). In the authors' previous work [11], the possibility of tantalum recycling through the reduction of oxidized anodes (consisting mainly of Ta_2O_5) by magnesium was studied. Incomplete manganese removal can contaminate the end product, giving phases with Ta, oxygen and a reducing agent (Figure 4), thus lowering the efficiency of the reduction process. Therefore, before tantalum oxide reduction, it is necessary to remove the Mn.

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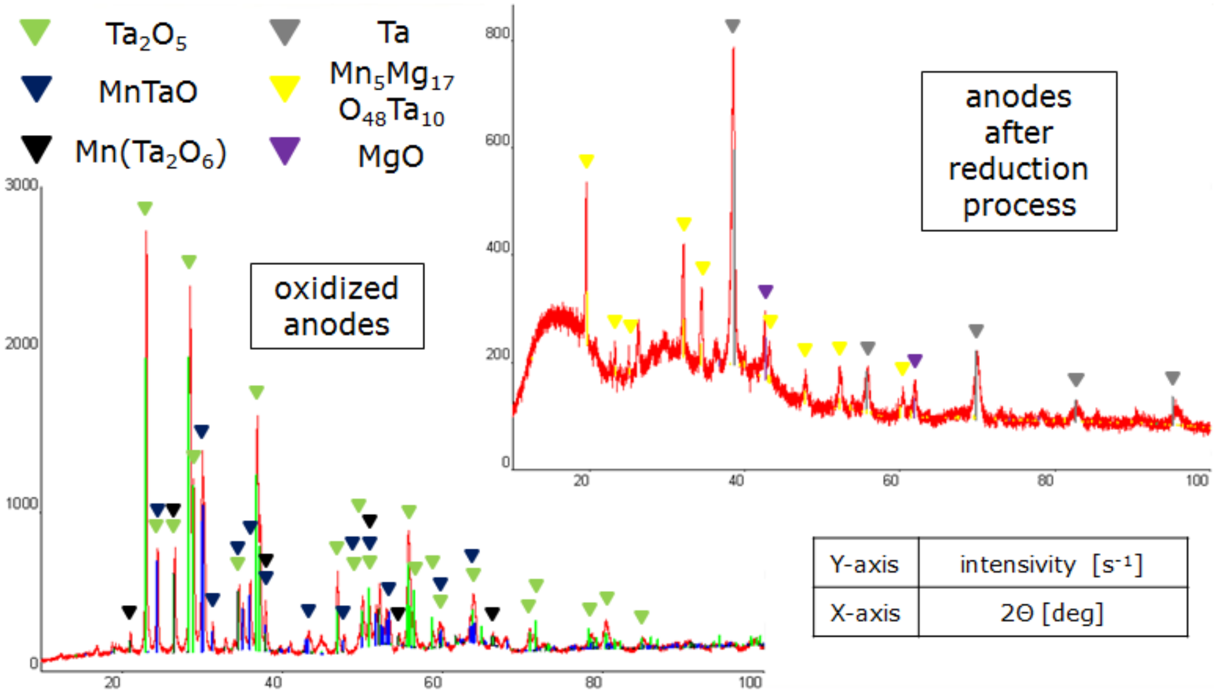

Figure 4. X-ray diffraction analyses of the oxidized anodes before and after thermal reduction by magnesium (left and right, respectively); apart from the MgO and metallic tantalum, in the end product there are also manganese-containing phases (reflection peaks under the yellow markers)
Source: based on [11]

Dissolution of manganese (IV) oxide in organic acid solutions
The dissolution kinetics of manganese oxides in sulfuric acid is described by Gudunov et al. and Artanomona et al. [18,19]. Chen et.al. [17] presented the results of a study on the removal of MnO_2 from TC by reducing the leaching reaction of H_2SO_4 + H_2O_2 and hydrochloric acid (HCl) + H_2O_2. Studies on dissolving MnO_2 by using H_2SO_4 also containing organic acids (OA) such as oxalic [19,20], ascorbic and citric acids [20] have been carried out. Manganese removal occurs by reducing leaching, in which the OAs are used as the reducing agents. In comparison to removing Mn only by H_2SO_4, the addition of OA improves the removal efficiency [20].

Objective
The objective was to study the possibility of removing MnO_2 from TC scrap by a dissolution process in the following sulfuric and organic acid solutions: acetic ($C_2H_4O_2$), ascorbic ($C_6H_8O_6$), citric ($C_6H_8O_7$) and oxalic ($C_2H_2O_4$). A series of laboratory tests were carried out to determine the optimal conditions and parameters such as acid concentration, duration, temperature and liquid-to-solid ratio. After the hydrometallurgical treatment, the end product was expected to obtain a manganese-free tantalum concentrate.
Materials from two types of tantalum capacitor scraps were used: LTC and SMDTC which were appropriately prepared by pyrolysis, grinding and sieving. Each of these steps was described and parametrized.

Experiment
The research plan is presented in Figure 5. Initial materials were LTC and SMDTC scraps from a domestic source. For a determination of the contents of the components, which are conventionally divided into epoxy resin, electrical components (electrical leads and lead frames) and anodes (a source of Ta and Mn), some part of the scraps were dismantled and the mass fractions were calculated.

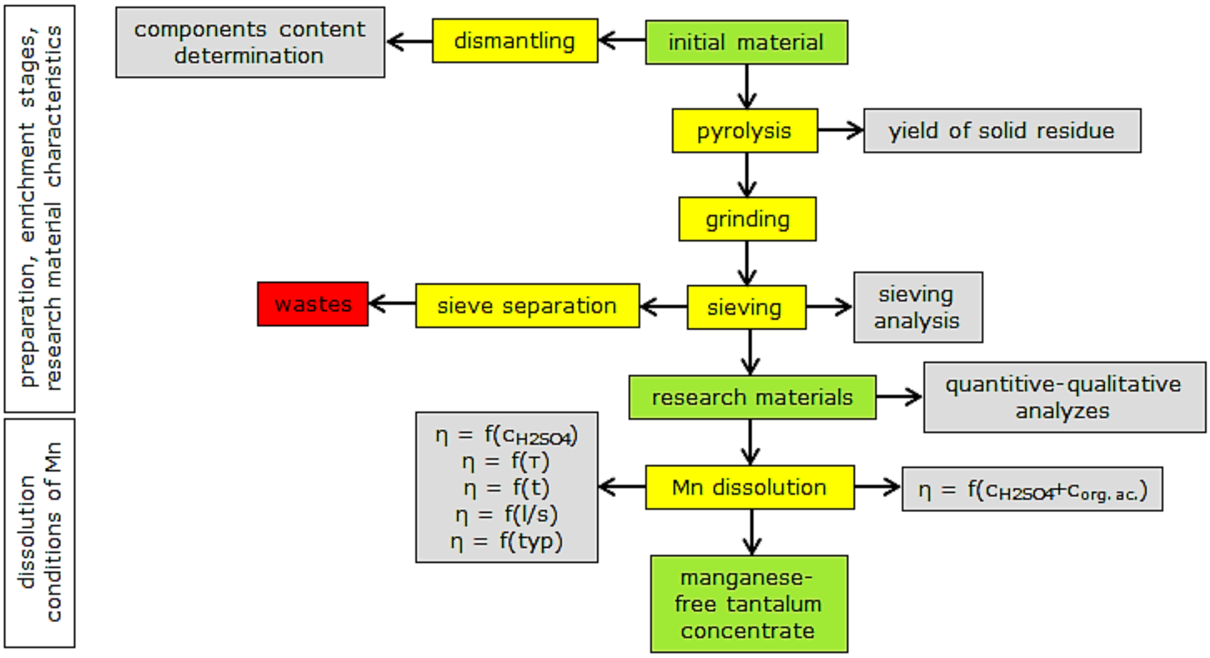

Figure 5. Diagram of the present research: green – research materials, yellow – study steps, grey – analyses and calculations
Source: Author's materials

For research purposes, both types of capacitors were prepared separately in the following order:

- first, capacitor scraps were pyrolized in an electric furnace at 400 ^{0}C in a nitrogen atmosphere (99.2%) for 45 min;
- after this, the solid residues were grinded in a laboratory grinding machine for 5 min;
- finally, the grinded materials were manually sieved on square mesh sieves for 10 min and some parts such as electrical components were separated.

The aim of the pyrolysis was the removal of most of the epoxy resin, other volatile carbon compounds and halogens without changing the oxidation state of other components, such as Ta and Mn. Waste materials, such as electrical leads and lead frames were removed by sieving. The yield of solid residue (R), which was used to evaluate the pyrolysis process, is given according to the formula [15]:

$$R = \frac{m_{SR}}{m_{IM}} \cdot 100\% \qquad (1)$$

where: m_{SR} – the mass of solid residue after pyrolysis, m_{IM} – the mass of initial material, both in g. Sieve analysis was performed on the basis of particle size distribution and the average particle size was calculated. Some particle-size classes, which were later treated as waste were discarded, and the rest, which was the appropriate research material for the dissolution study of manganese, was subjected to quantitative and qualitative analyses. The content of elements was determined by an energy dispersive X-ray fluorescence analysis (EDXRF, MiniPal4 PANalytical) and X-ray powder diffraction analysis (XRD, Rigaku Miniflex II).

Laboratory tests of MnO_2 dissolution were carried out by leaching using solutions of H_2SO_4 (95 %) with/without the following OAs (99.5 %): acetic (3), ascorbic (4), citric (5) and oxalic (6), according to reactions [18-20]:

$$MnO_2 + H_2SO_4 \rightarrow MnSO_4 + \frac{1}{2}O_2 + H_2O \qquad (2)$$

$$MnO_2 + H_2SO_4 + \frac{1}{4}C_2H_4O_2 \rightarrow MnSO_4 + \frac{2}{3}H_2O + \frac{1}{2}CO_2 \qquad (3)$$

$$MnO_2 + H_2SO_4 + \frac{1}{10}C_6H_8O_6 \rightarrow MnSO_4 + \frac{7}{5}H_2O + \frac{3}{5}CO_2 \qquad (4)$$

$$MnO_2 + H_2SO_4 + \frac{1}{9}C_6H_8O_7 \rightarrow MnSO_4 + \frac{13}{9}H_2O + \frac{2}{3}CO_2 \qquad (5)$$

$$MnO_2 + H_2SO_4 + C_2H_2O_4 \rightarrow MnSO_4 + 2H_2O + 2CO_2 \qquad (6)$$

The quantities of the OAs were stoichiometric in relation to H_2SO_4 according to the chemical equations. The acid solutions were heated with a laboratory hot plate (Figure 6). After reaching the given temperature, the research material was added into the beaker. Mixing speed was 200 rpm. After the reaction time had elapsed, the mixture was filtered through a glass funnel; the solid residue was rinsed with distilled water and 92 % ethanol. A composition analysis was performed for this solid residue. The dissolution yield (η) was determined by the formula:

$$\eta_x = \frac{C_{x,0} - C_{x,\tau}}{C_{x,\tau}} \cdot 100\% \quad (7)$$

where: $C_{x,0}$ – initial concentration (x is element), $C_{x,\tau}$ – concentration after the process (both in %) - determined by EDXRF analysis.

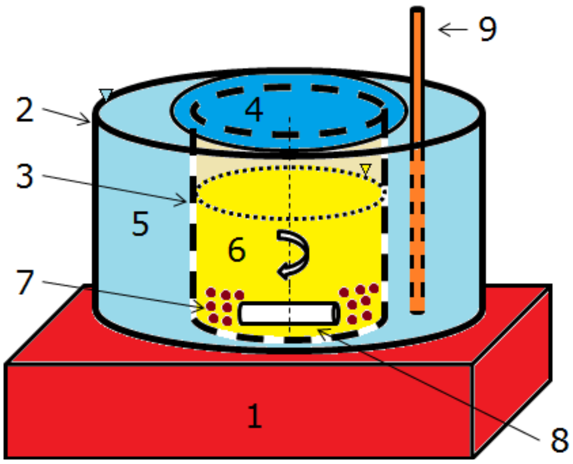

Figure 6. Scheme of apparatus for dissolution study: 1 – hot plate, 2 –bath, 3 – beaker, 4 – watch glass, 5 – water, 6 – acids solution, 7 – research material, 8 – magnetic stirrer, 9 – thermocouple
Source: Author's materials

Results

Table 1 shows the components' mass fractions of initial materials. The anode is a significant part of the capacitors (± 40 and 58 % for SMDTC and LTC, respectively). In SMDTC, the share of epoxy resin and anode was more or less similar, but electrical components had a large share. The presented mass fractions are not universal; they concern only the TC scrap in this work.

Table 1. Component mass fractions of the TCs used in this study

capacitor type	epoxy resin	electrical leads/metal pads and lead frames	anode
	wt [%] (±0.1)		
LTC	37.1	5.1	57.8
SMDTC	36.9	23.2	39.9

Source: Author's materials

The pyrolized materials retained their original shape, however became black due to the coke content (Figure 7). Yields of the solid residue of pyrolysis (R), depending of the type of TC, are presented in Table 2. Although this parameter value for SMDTC can be compared with literature data [15,16] and corresponds with them, there is no data for LTC. The higher R for SMDTC can be explained by the high quality of epoxy resin (more silicon and halogens).

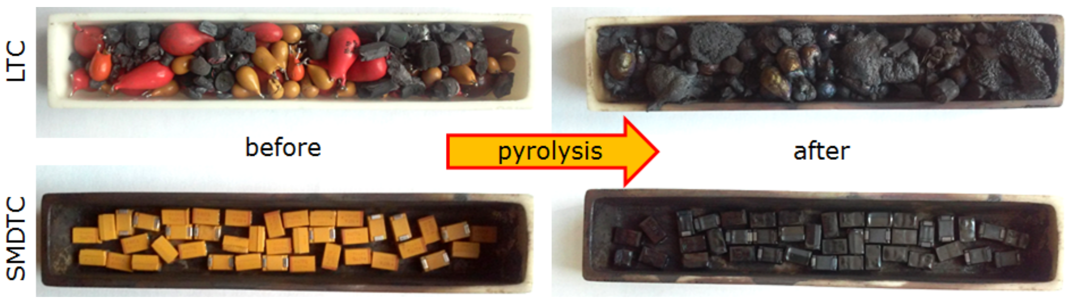

Figure 7. Materials' appearance before and after pyrolysis process
Source: Author's materials

Table 2. Yields of solid residue after the pyrolysis process

capacitor type	mass of initial material m_{IM}	mass of solid residue after pyrolysis m_{SR}	yield of solid residue R
	[g] (±0.001)		[%] (±0.1)
LTC	139.492	122.812	88.0
SMDTC	16.678	15.848	95.0

Source: Author's materials

Figure 8 shows the fractions obtained after grinding and sieving. Fractions >0.4 mm and 0.315-0.4 mm were electrical leads and tantalum wires – their longitudinal shape and the fact that they do not grind easily, enabled their easy separation. Fractions <0.315 mm, representing 92-99 %, were a fine powder – these fractions constitute the research material for testing the Mn dissolution. Figure 9 shows the particle size classes, particle size distribution and cumulative curve, on the basis of which the average particle size was determined to be 0.127 and 0.055 mm for LTC and SMDTC, respectively.

Figure 8. Fractions of pyrolized and ground tantalum capacitors
Source: Author's

The chemical compositions of research material are presented in Table 3. While in LTC the main component is tantalum, in SMDTC it is SiO_2. There was much SiO_2, MnO_2 and solder elements in the LTC, as well as Cu in SMDTC. The materials also included Fe and Ni from partially ground electric leads and metal pads. Elements and components such as Pb, Sn, Cu and perovskites may have come not so much from the TC as from the entire electrical scrap from which they originated.

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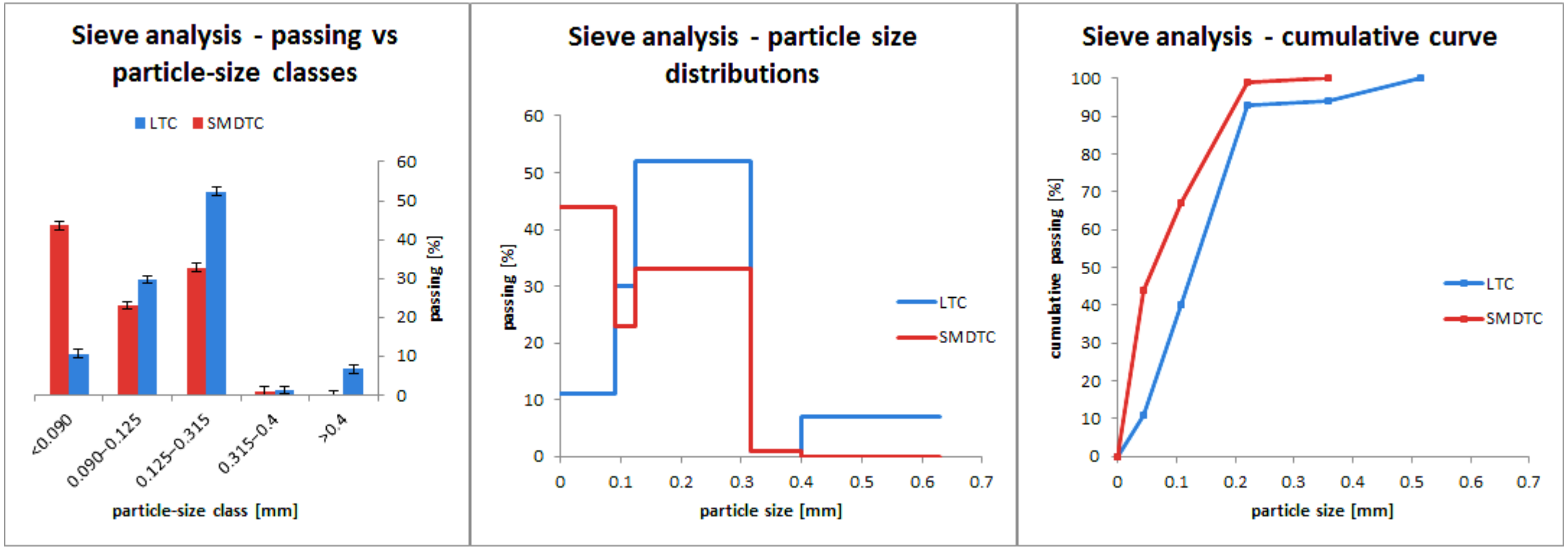

Figure 9. Sieve analysis of pyrolized and ground tantalum capacitors: on the left – particle-size classes in passing function, in the middle – particle size distributions, on the right – cumulative curve

Source: Author's materials

Table 3. Chemical compositions of research material for dissolution study – results of EDXRF and XRD analyses; the carbon content is not included, the Ta content has been converted to Ta_2O_5

	SiO_2	MnO_2	Fe	Ni	Cu	Ag	Ta_2O_5	Sn	Pb	TiO_2	BaO	CaO
source	epoxy resin	catode	electric leads and lead frames			silver layer	wire, sinter and dielectric	solder		perovskites		
type	wt [%]											
LTC	13.50	13.54	3.08	0.45	nd	6.41	39.10	14.71	8.28	0.607	0.40	nd
SMDTC	33.24	12.87	3.58	0.12	19.61	6.83	22.41	nd	nd	0.690	nd	0.65

Source: Author's materials

In any case, it was observed that, during the dissolution studies, a part of the material floated on the free surface. This was most likely hydrophobic silica and pyrolytic coke particles. After leaching, the filtrate took on a light flesh color (Mn ions presence). Fe, Ni and Cu, as well as Mn, were simultaneously dissolved (although it was not a priority) and dissolution yields of these elements are also included (Table 4). Analysis of the effect of H_2SO_4 concentration on dissolution yields (Figure 10A) showed that both Mn, Fe and Ni pass into solution at low c_{H2SO4}. In the cases of Mn and Fe, the equilibrium is set at c_{H2SO4} about 2 mol·l^{-1} and in the case of Ni – at a lesser acid concentration of about 1 mol·l^{-1}. The effect of time on η_{Mn} is insignificant (Figure 10B); for τ = 180 min and more, η_{Mn} reached a maximum value. In the range of 60-120 min, a significant increase in η_{Fe} was observed, and almost after 120 min, most of the Fe dissolved. As shown in Figure 10C, in the temperature range of 30-60 ^{0}C η_{Mn} was constant; in the whole temperature range η_{Fe} was high. In the studied l/s (Figure 10D), this parameter had no effect on the η_{Mn}. The highest value of η_{Fe} was reached for l/s = 20 ml·g^{-1}. Figure 10E shows the dissolution yield depended on the type of capacitor (LTC or SMDTC). In the case of SMDTC the results were lower. This is due to the fact that the acid also reacts with Cu. Based on the above results, subsequent tests with the addition of an organic acid on the dissolution yield were carried out at the following constant parameters: τ = 120 min, t = 30 ^{0}C, l/s = 20 ml·g^{-1} and for LTC.

Table 4. Element contents and dissolution yields data depending on process parameters, a dissolution study with only H_2SO_4

parameter	constant parameters		MnO_2		Fe		Ni		Cu	
			wt, %	η, %	wt, %	η, %	wt, %	η, %	wt, %	η, %
c_{H2SO4}, mol·l^{-1}	▪ τ = 120 min ▪ t = 30 ^{0}C ▪ l/s = 20 ml·g^{-1} ▪ RM = LTC	0.2	3.80	71.9	1.78	42.3	0.32	30.0		
		0.4	1.84	86.4	0.89	71.2	0.18	60.0		
		0.9	1.33	90.2	0.60	80.6	0.13	70.8		
		1.8	0.90	93.4	0.36	88.3	0.14	68.4		
		3.2	0.83	93.9	0.34	88.9	0.13	70.4		
		6.3	0.76	94.4	0.32	89.5	0.12	72.8		
τ, min	▪ c_{H2SO4} = 1.8 mol·l^{-1} ▪ t = 30 ^{0}C ▪ l/s = 20 ml·g^{-1} ▪ RM = LTC	60	1.13	91.6	1.17	62.0	0.22	52.0		
		120	0.90	93.4	0.36	88.3	0.18	60.4		
		180	0.22	98.4	0.48	84.5	0.20	56.0		
		240	0.19	98.6	0.50	83.7	0.12	74.4		
t, ^{0}C	▪ c_{H2SO4} = 1.8 mol·l^{-1} ▪ τ = 120 min ▪ l/s = 20 ml·g^{-1} ▪ RM = LTC	30	1.00	92.6	0.98	68.3	0.14	68.4		
		60	0.90	93.4	0.36	88.3	0.15	67.6		
		80	0.27	98.0	0.48	84.4	0.12	74.4		
l/s, ml·g^{-1}	▪ c_{H2SO4} = 1.8 mol·l^{-1} ▪ τ = 120 min ▪ t = 30 ^{0}C ▪ RM = LTC	10	0.68	94.9	0.93	69.9	0.18	60.4		
		20	0.90	93.4	0.36	88.3	0.14	68.4		
		30	1.17	91.3	0.73	76.1	0.15	66.4		
		50	0.74	94.5	0.73	76.3	0.11	76.0		
capacitor type, -	▪ c_{H2SO4} = 1.8 mol·l^{-1} ▪ τ = 120 min ▪ t = 30 ^{0}C ▪ l/s = 20 ml·g^{-1}	LTC	0.90	93.4	0.36	88.3	0.14	68.4		
		SMDTC	2.17	83.1	1.21	66.1	0.10	21.4	17.94	22.8

Source: Author's

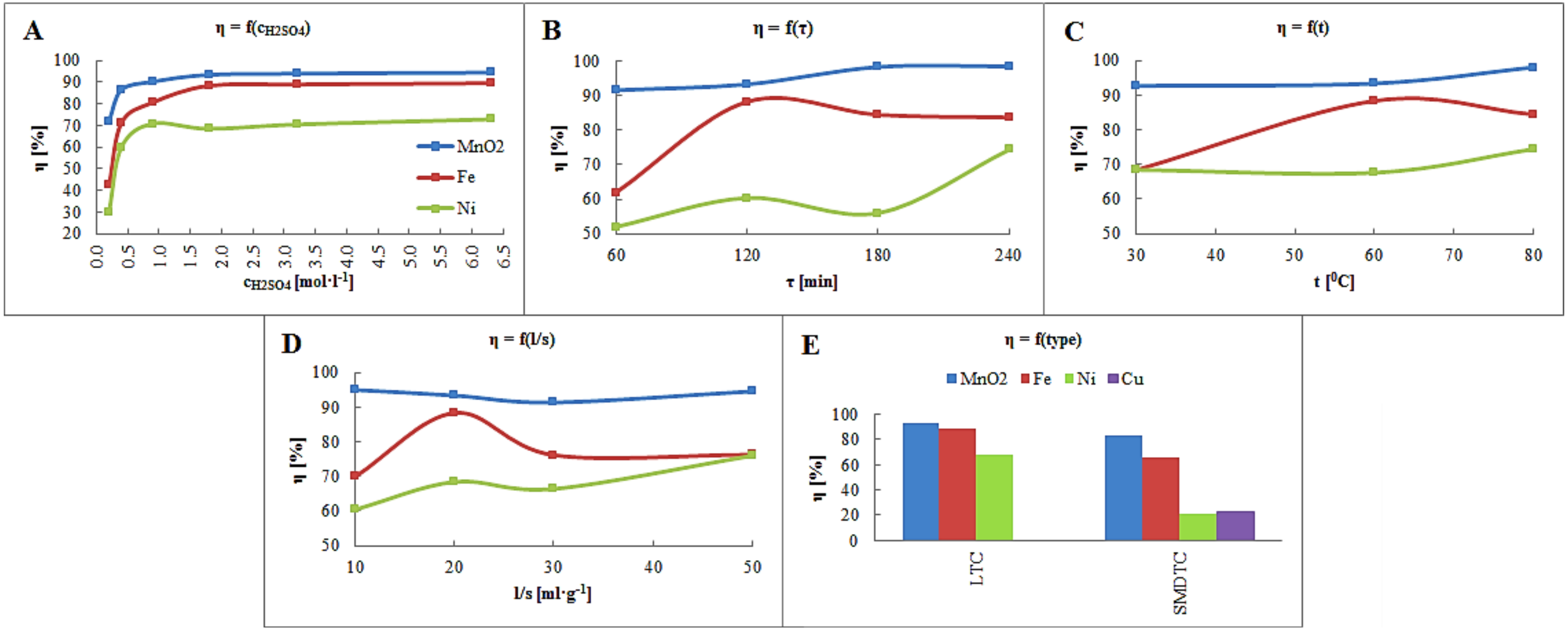

Figure 10. Effect on dissolution yields of MnO_2, Fe and Ni: A - H_2SO_4 concentration, B - time, C - solid/liquid ratio, D - temperature, E - capacitor type; based on the data in Table 5
Source: Author's materials

Table 5 shows the results of reductive leaching by use of the following OAs: $C_2H_4O_2$ (Figure 11A), $C_6H_8O_6$ (Figure 11B), $C_6H_8O_7$ (Figure 11C) and $C_2H_2O_4$ (Figure 11D) respectively. In almost all cases, the equilibrium of manganese dissolution was set at an acid concentration of about 1 M, except for the $C_2H_2O_4$, where already at 0.2 M η_{Mn} it reached a constant value. Maximum η_{Mn}, in comparison to leaching with H_2SO_4 only, was almost always higher. Therefore, due to the very good results of manganese dissolution in the entire concentration range, it is recommended to use low concentrations of this acid, especially, so that the solubility of $C_2H_2O_4$ in the aqueous solutions is lowest in comparison with the other OAs. Dissolution yields of iron for $C_2H_4O_2$ and $C_6H_8O_7$ were similar to those of leaching with H_2SO_4 only. The lower η_{Fe} values were in the case of using $C_6H_8O_6$, where the equilibrium was set for the whole range of concentration. Whereas the situation was different when using $C_2H_2O_4$: η_{Fe} and η_{Ni} (also for $C_6H_8O_6$) decreased with increased concentration. The reason for this is the very low solubility of the formed nickel citrate, iron and nickel oxalates. As in the case of only H_2SO_4, the additional use of OAs results did not give η_{Ni} results higher than 80 %. However, it should be noted that the nickel concentration in the initial material was very low (0.45 %).

Table 5. Element contents and dissolution yields data depending on process parameters, a dissolution study with H_2SO_4 and organic acids solutions; organic acid concentrations are stoichiometric in relation to H_2SO_4 according to reactions (3-6)

organic acid	constant parameters	$c_{OA.}$, mol·l^{-1}	MnO_2		Fe		Ni	
			wt, %	η, %	wt, %	η, %	wt, %	η, %
$C_2H_4O_2$	τ = 120 min, t = 30 ^{0}C, l/s = 20 ml·g^{-1}, RM = LTC	0.2	1.27	90.6	0.73	76.4	0.13	70.4
		0.4	1.04	92.3	0.53	82.9	0.13	72.0
		0.9	0.60	95.5	0.54	82.3	0.13	70.8
		1.8	0.45	96.7	0.48	84.5	0.12	73.6
		3.2	0.30	97.8	0.35	88.6	0.11	76.4
$C_6H_8O_6$		0.2	1.37	89.9	0.90	70.6	0.20	56.0
		0.4	1.07	92.1	0.87	71.6	0.17	61.6
		0.9	0.13	99.1	0.79	74.3	0.17	61.2
		1.8	0.28	97.9	0.77	75.1	0.20	56.6
		3.2	0.43	96.8	0.74	76.1	0.22	52.0
$C_6H_8O_7$		0.2	1.42	89.5	0.91	70.3	0.20	56.0
		0.4	1.17	91.3	0.83	73.1	0.17	62.4
		0.9	0.46	96.6	0.49	84.0	0.15	67.2
		1.8	0.42	96.9	0.38	87.6	0.14	69.2
		3.2	0.37	97.3	0.27	91.2	0.13	71.2
$C_2H_2O_4$		0.2	0.19	98.6	0.48	84.4	0.13	70.8
		0.4	0.22	98.4	0.58	81.2	0.12	72.8
		0.9	0.24	98.2	0.82	73.4	0.16	64.0
		1.8	0.24	98.2	1.00	67.5	0.17	62.0
		3.2	0.25	98.2	1.18	61.8	0.18	60.0

Source: Author's

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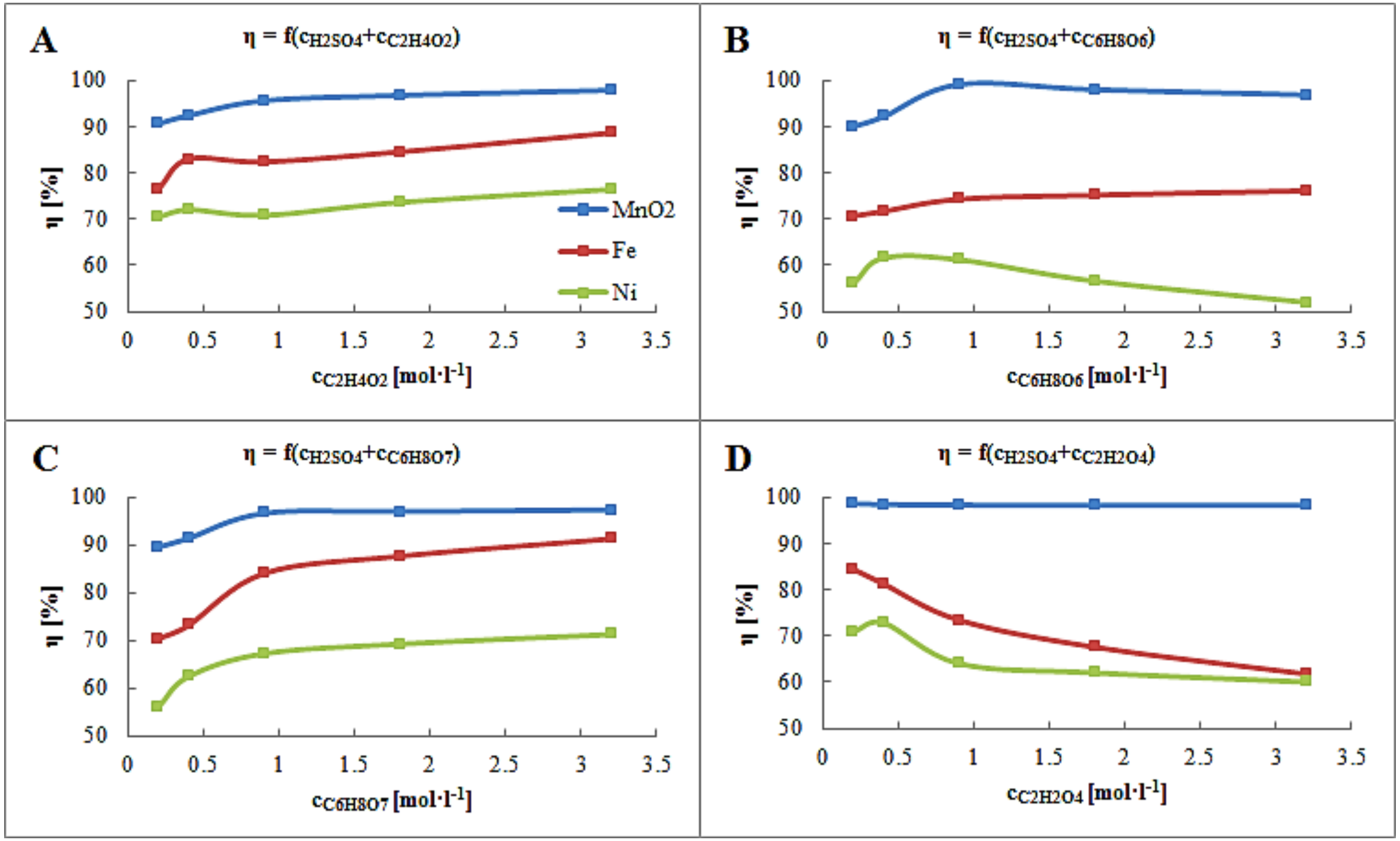

Figure 11. Effect of organic acid concentration on dissolution yields of MnO_2, Fe and Ni: A - $C_2H_4O_2$, B - $C_6H_8O_6$, C - $C_6H_8O_7$, D - $C_2H_2O_4$; based on the data in Table 5
Source: Author's materials

Application of manganese dissolution in tantalum recycling

Figure 12 shows the potential use of manganese in the development of a tantalum recycling method based on literature and this work. The process of manganese removal by a hydrometallurgical method enables the convenient treatment of a solution for the recovery of manganese salts or oxides, which are widely used in industry and organic acid regeneration. Although organic acids can pose a threat to health or life (especially corrosive/toxic acetic and oxalic acids; ascorbic and citric acids are generally considered harmless), they are safer than mineral acids, and their utilization is not a major challenge. Many stages of tantalum material enrichment have been considered: from sorting and dismantling to electrostatic separation. Their use enables the removal of ballast components such as coke and silica, thereby increasing the tantalum content and manganese in the concentrate. As regards the recovery of copper and silver, some studies [11,21] have indicated that the best solution for silver removal is nitric acid; leaching with sulfuric acid in the presence of H_2O_2 is not so effective [21]. There is a possibility of collective leaching of Mn, Cu and Ag, however, subsequent stages of separation of individual elements are required. If selective leaching is used, a portion of nitric acid can be replaced by a safer and environmentally friendly mixture of H_2SO_4 and OA. Material that contains only tantalum after the removal of contaminated materials such as manganese and other ferrous materials provides a good base for magnesiothermic reduction.

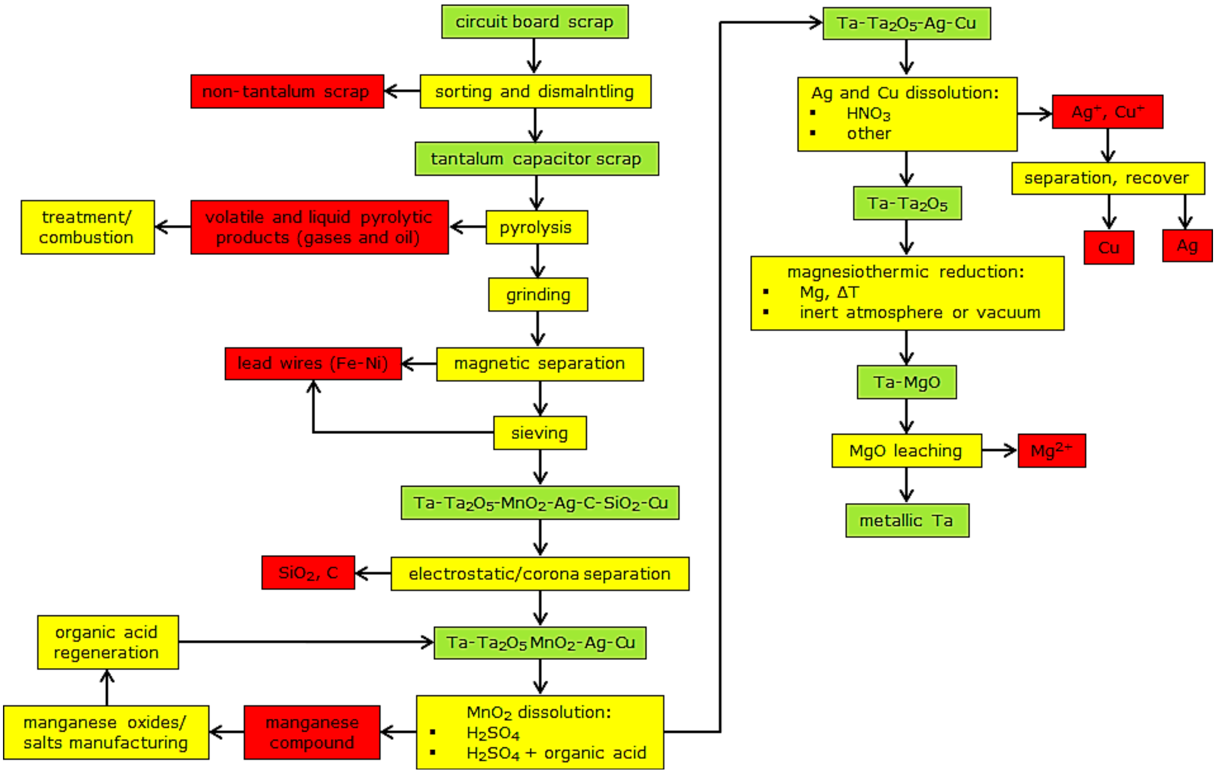

Figure 12. A proposition for the use of manganese dissolution in the process of recycling tantalum from scrap electrical/electronic equipment : green – containing-tantalum material (main stream), yellow – a process stage, red – a secondary valuable material or waste; this includes the steps of the enrichment process (mechanical, magnetic, electrostatic), hydro- and pyrometalurgical processes and regeneration and recovery of valuable materials Source: based on [6,10,11,15,16] and this work

Summary and conclusions

A tantalum capacitor is a complex electronic subassembly in terms of structure and composition with an epoxy resin encapsulant, terminals and anode. The anode has a multi-layered three-dimensional structure and consists of metallic tantalum (sinter and wire), Ta_2O_5 (dielectric layer), MnO_2 (cathode), graphite (anti-diffusion layer) and silver (chemical protection). Moreover, in leaded capacitor scrap may be tin and lead, derived from the solder, and in the capacitor to surface-mounted technology there may be contaminates derived from perovskite-based dielectrics. All together this means that tantalum recycling from scrap capacitors is a challenge.

Pre-treatment processes, such as pyrolysis, grinding and sieving, are good methods for the enrichment of tantalum concentrate originating from scrap for hydrometallurgical treatment. The material remaining after

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these processes is a powder, devoid of some part of the resin, as well as most of the iron and nickel. The obtained research materials contained significant amounts of silica (13.5-33 %) and manganese (about 13 %), which are impurities, and high tantalum concentrations (22-39 %).

Manganese removal based on its dissolution in sulfuric acid is an effective method, although the addition of organic acids, such as $C_2H_4O_2$, $C_6H_8O_6$, $C_6H_8O_7$ and $C_2H_2O_4$ increases the dissolution yield. In the studied ranges of process parameters, such as acid concentration, time, temperature and solid/liquid ratio, the optimal parameters were: τ = 120 min, t = 30 ^{0}C, l/s = 20 ml·g^{-1}. Additionally, iron and nickel can simultaneously be removed with manganese. The effect of the addition of organic acid on the dissolution yield is significant, otherwise a lower concentration of acids is required. Exceptionally high η_{Mn} were observed in the cases of $C_6H_8O_7$ and $C_2H_2O_4$. However, in the latter case, a decrease of η_{Mn} relative to iron and nickel was noted along with an increase of acid concentration.

The use of manganese dissolution can be implemented to the tantalum recycling process. Due to the lack of manganese, subsequent stages of tantalum recycling may be more effective. In addition, the manganese dissolution in a mixture of sulfuric and organic acids is selective, i.e. metals such as silver can be leached and recovered in another processing step.

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Krzysztof Powała
Department of Environmental Engineering, Faculty of Process and Environmental Engineering, Lodz University of Technology
Poland, krzysztof.powala@edu.p.lodz.pl

THE INFLUENCE OF SELECTED POLYMERS ON CONCRETE TIGHTNESS - CURRENT STATE OF KNOWLEDGE

Abstract
Today's construction market of materials, contractors and building users, places new demands on individual building materials. Undoubtedly one such material is concrete, which is used in almost all construction projects as a binder for building materials. Therefore, it is necessary that this material is constantly subjected to new tests to find ways to improve its properties. Therefore, many scientists attempt to improve properties such as compressive strength, flexural strength and water resistance. One method is to modify the cement matrix with polymers.

Keywords
cement, leakage, phase change material, waterproof

Introduction

Polymers were already in use in the 1980s, however, there were problems not only with the possibility of mixing polymers with cement as well as the costs of production. The idea was temporarily abandoned but resurfaced about 25 years later. The idea of using polymers in cement has begun to show reliable results and with continued progress and decreasing production costs may cause a major revolution in the building materials market in the near future. Based on today's research, scientists are obtaining good results in improving cement's flexural strength, compressive strength, water tightness and resistance to low temperatures.[1] Another important aspect is the thermal insulation obtained by adding polymer to mortar. For this purpose, phase-change materials such as paraffin are often used. Regarding measurements for the use of polymers and then paraffin, it is reported in the literature, that the water-tightness of the cement is important. Polymers added to cement allows to achieve a layer that is watertight to some extent. When using paraffin, the concept of adding polymer is similar except that the polymer admixture creates a layer to prevent cement paraffin from leaking. It can be assumed that if a good quality polymer is used, it will create a suitable impermeable layer. Such a layer will allow the paraffin to remain inside the material if the state of aggregation changes.[2] Cement modified in this way will obtain good insulating properties. This work is a literature review, the results of research on the various types of polymers is presented below.

Types of reinforced cement

On the basis of over a dozen years of research on the application of polymers in cement, we managed to draw some interesting conclusions. First, it was possible to group polymers based on their use in cement. Therefore, we can distinguish three groups: polymer impregnated concrete (PIC), polymer concrete (PC) and polymer modified concrete (PMC). "Polymer impregnated concrete was first produced in the 1960s. PIC is made by impregnating the cement with a low viscosity monomer which is them later polymerized. The advantage of this solution is increased tensile and bending strength. Also, this solution increases durability to weather conditions. Thanks to such properties PIC was eagerly used in places of joining the structure, as a support for pipes, as well as in places with high stresses" [3]. Concrete polymers were already in use in 1958, which included aggregate as well as a polymer binder. Interestingly, this cement does not contain water. Polystyrene as well as various types of acrylics and epoxies were the most commonly used monomers. Various types of resins were also used, as well as sulfur, which is considered to be a polymer. Concrete with the addition of sulfur is used primarily in places where resistance to acidic compounds is required. Such material is characterized by high durability, which is why it was often used as a repair material. Unfortunately, PC is characterized by high thermal expansion which can cause the part being repaired to fragment. Unfortunately, PC has been supplanted by Portland concrete, which is cheaper to produce as well as cures faster. Polymer concrete is mainly used for the construction of tanks, drains, curbs as well as floor tiles.

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The third type of concrete is polymer-modified concrete. It consists of Portland cement and modified cement with polymers such as acrylic, SBR and others. The polymers in PMC amount to only 20%, however, oftentimes it gives poor results. This type of cement is characterized by high strength as well as low permeability. Thanks to this type of cement, compression can be increased, thus reducing the chances of cracking. With this technology, the consumption of polymer is smaller, which means it is cheaper to produce than PC.

Requirements and selection of polymers (General concept of using polymers)
Research based on mixing polymer together with cement is primarily carried out to find ways to improve their properties. This is important due to the nature of the facilities where improved cement will be used, which is mainly construction projects such as bridges and overpasses where the cement will be exposed to high stresses. Therefore, the added polymers must meet several important conditions so that the intended structure remains intact as long as possible.

One important condition is the thermal stability of the polymer. Due to the prevailing temperatures in summer and winter, it is important that the polymer used is thermally stable. During higher temperatures followed by cold, irreversible effects can occur and cause deformations in the material. This is an undesirable feature that eliminates the use of polymer. It is estimated that polymer has a greater tendency to expand than metal.

Polymers are a good insulating material characterized by low thermal conductivity which varies from 0.15 [W/m*K] to 0.3 [W/m*K] and in some cases may be even lower. Therefore, polymers may play an additional insulating role.

Another issue is the resistance of the polymer to weather conditions. Based on local weather conditions an appropriate polymer, or additional substances that will stabilize the polymer can be selected. As mentioned previously, the temperature affects the polymer's expansion. However, in addition to the surface temperature, polymer can also be affected by ultraviolet rays, high energy radiation and the chemical environment in the form of acid rain. Each polymer will react differently to external factors, for example, causing discoloration of a wall as well as cracking or destruction of the wall from the inside. Depending on the materials used It is important to properly preserve external surfaces, however, the aging process cannot be entirely eliminated.

Another important feature of the polymer is the degree of permeability through the material layer. Polymers are used successfully as sealing agents in various forms for both vertical and horizontal surfaces. This will be described in more detail in a later part of the text

Another feature of polymers is their flammability. Unfortunately, any organic or synthetic polymer is flammable. Depending on the composition, polymers give off toxic substances that threaten human health. However, both synthetic and natural polymers are used in construction within a certain range of fire safety. In non-combustible conditions, polymers can produce adverse effects to the properties of the surface. Therefore, when using materials such as polymers that are located in the fire risk zone of the buildings concerned, an appropriate sign designating the degree of fire hazard should be posted.

The greatest enemy of cement is the corrosion of reinforcement bars caused by continuous temperature changes. Research has determined that the durability of concrete depends on its porosity. The less porous concrete is, the stronger it becomes. The porosity affects the penetration of water, therefore admixtures of plasticized blends have been proposed. Due to the addition of such substances, the durability of cement is clearly increased.

To reduce the penetration of water, various types of additives are used. They are divided into normal water reducers and large range reducers. The first group are derived from waste during the production of pulp and can reduce the share of water to 10%. The second group is admixtures in the form of polymers. The use of reducers with a large range can reduce the use of water up to 40%. The use of this type of substance not only causes higher durability but also allows the use of such reinforced cement in inaccessible places by increasing the feasibility of application.

The influence of water on cement functions in the following way. When cement particles are dry, a small amount of water will cause electrical charges to merge, which in this case, causes the water to dissipate incorrectly for the cement. The use of polymers prevents cement particles from being combined, which after some time can be

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isolated as a small deposit. The operation is based on combining particles that can have both a positive and a negative charge which, in contact with other molecules, leads to flocs. The polymers used in such a mixture act as dispersants, i.e. they prevent particles from combining by giving the particles negative charges, which leads to the repulsion of particles. A kind of shell is formed around the cement particle, pushing other particles further away. Thanks to this action, the water molecules cannot combine cement particles into larger agglomerates. After the polymer is added, the fresh concrete is in an easy to apply liquid form, which preserves all properties of concrete without strengthening after solidification.

When characterizing concrete, the workability of the concrete mix should be mentioned. Workability is referred to as the cement's ability to spread easily in a given place. In short, workability indicates if the cement is in a sufficient enough liquid enough or not. Cement is often brought to a construction site in liquid form and it is important that it remains in this form. In some cases, the workability becomes reduced and some water is added to increase workability. To avoid such situations, the polymer is added to the concrete on site or more appropriately at the beginning of mixing to prevent aggregation of the cement. However, this can be economically costly, especially the addition of large doses of polymer.

During the process of concrete curing, it is important that the mixed and prepared cement cures as much as possible in the most saturated environment possible. If too little water is added to the mix it may cause self-drying of the concrete. This is a dangerous phenomenon that can lead to undesired shrinkage of the concrete and, consequently, to cracks. Such concrete does not have high strength properties nor is it resistant to weather conditions. In some cases, appropriate self-hardeners are added to avoid this problem taking place. Self-hardeners usually take up absorbent polymers. They prevent cement from cracking too quickly, reduce permeability and increase durability. The principle of operation of such polymers is quite simple as they can absorb a large amount of water because such polymers have an ionic nature.

Using polymers in concrete - mechanical properties
The literature review shows the results of the use of several polymers as an example for further studies on their effect on waterproofness of cement. One of the best polymers, which is styriene-butiadene rubber, has been considered. One of the most important advantages of this polymer is its ability to create a surface containing a smaller amount of pores than in the case of unmodified cement. This is important because in many cases it is the polymer that fills the pores thus ensuring waterproofness even with a low content of up to 2%.

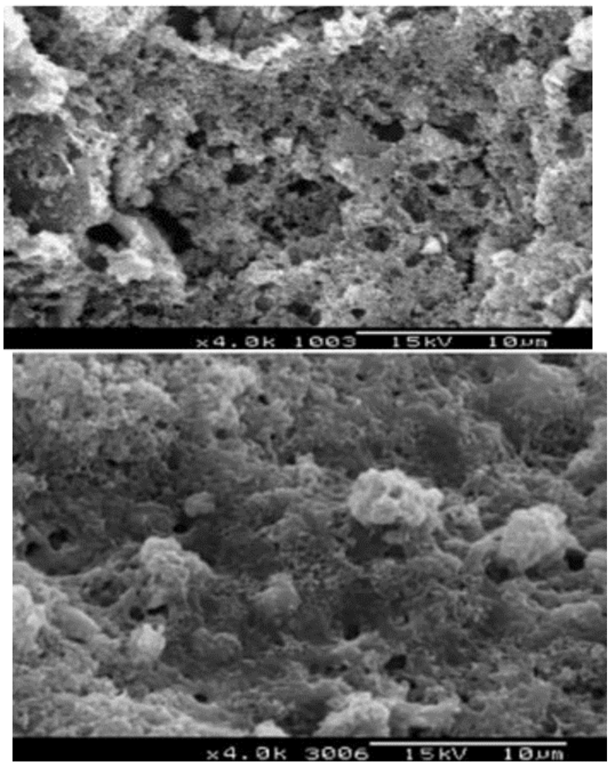

Fig.1 Cement structure with 0% (top) and 5% polymer (bottom) (SBS) [4]

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In Figure 1, the cement structure using SBS in the amount of 5% is not uniform but the surface is much more sealed than in the case of non-upgraded cement. As a result, not only water-tightness but also other properties are significantly improved. The highest density is obtained at 2% of the SBS content, after which it decreases and then increases once again at a content level of 8%. The compression strength is similar, the highest value is achieved at 2% content, then it decreases and again increases at 10%. A polymer concentration of approx. 2% allows for the highest flexural strength. The polymer has better retention properties, which increases the porosity of the mortar. As can be seen, SBS is one of many examples that improves the properties of cement. Figs. 2 and 3 show the change in compressive and flexural strength depending on the amount of polymer in the cement.

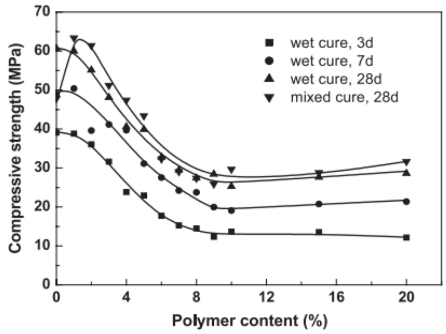

Fig.2 Compressive strength of polymer-modified mortars with different polymer/cement mass ratios
Source : [4]

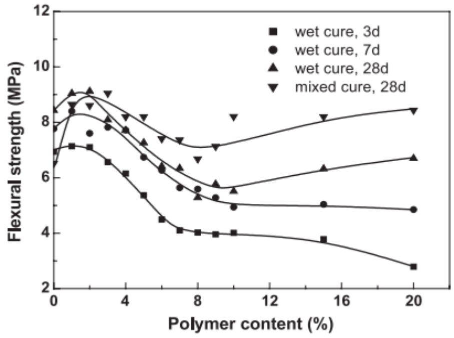

Fig.3 Flexural strength of polymer modified mortars with different polymer/cement mass ratios
Source: [4]

Other interesting polymers that can be successfully used in cement are styrene-acrylic ester and ethylene-vinyl acetate. Comparing them, we can draw the following conclusions. Styrene-butiadiene rubber improves flexural strength, tensile strength and water resistance. Styrene-acrylic ester reduces the modulus of elasticity and increases the strength of the mortar. Ethylene-vinyl acetate improves flexural strength and stretching [5]. The value of water adsorption decreases to the largest extent below 7%. However, when the polymer content is more than 7% in the cement, it is approx. 0.7 kg*m^{-2} and is better than ethylene-vinyl where the content is 0.8 kg*m^{-2}. However, it is not as good as SBR, where the value is 5% and is 0.7 kg*m^{-2}.

Water impermeability

The most important parameter that will allow the use of polymer in cement is its water impermeability. As mentioned before, this is the basis for extending the durability of cement. The main emphasis should be on cement reinforced with rods because corrosion can occur in such cement. This leads to many undesirable effects, mainly cracks. Such damaged cement quickly loses its properties, which is unacceptable in the case of structures that carry heavy loads. Therefore, scientists aim to solve the problem of water resistance. In concrete that is not reinforced with polymer, water penetrates the concrete deeply, which causes dampness to persist for a long time due to the high porosity of the cement. Freezing and thawing can therefore cause concrete to crack quickly. However, returning to the subject of solutions, it is worth noting the waterproofing properties of these polymers. The research of ethylene-vinyl acetate is an example.

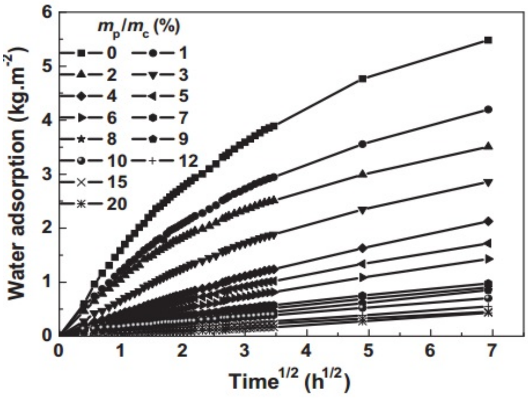

Fig.4 Relationship between the water capillary adsorption and time (m_p –amount of polymer; m_c – amount of concrete)
Source : [5]

As seen in Figure 4, the greatest impact on water resistance takes place at 7%. Note that the biggest jump takes place between 1-7% then later between 7 and 20%. This should be looked at from an economic perspective, as the more polymer in the mortar, the more expensive it will be. It is worth looking at the dependence at 20%. At this amount of polymer content, e.g. SBS, water practically does not penetrate the cement.

A very interesting study was made by Schulze [6]. His task was to compare selected polymers and choose the best one. These were RE 545 (vinyl-acetate-ethylene powder), RI 551 Z (ethylene-vinylchlorid-vinyllaurate), LL 512 (styrene / acrylic powder). As for water impermeability, the best was RI 551 Z, which at 2% the absorption level was almost 0.

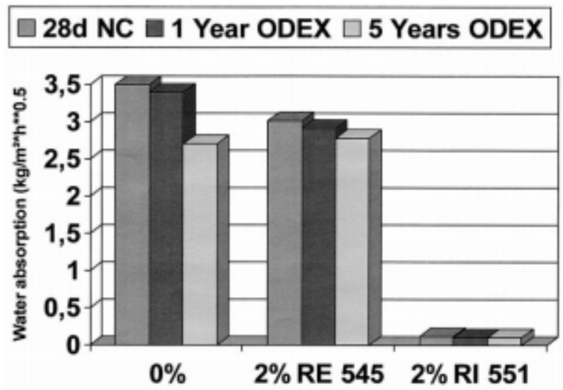

Fig.5 Water absorption for non-modified cement and with RE 545 and RI 551 (NC –normal climate, ODEX –outdoor exposure, RE 545 –vinylacetate-ethylene powder, RI 551 –ethylene-vinylchlorid-vinyllaurate)
Source : [6]

As shown, RI 551 polymer allows to achieve an impermeable surface even at a low content of 2%. It is a polymer which deserves further study as it gives very good results not only in the case of waterproofness but also flexural and compression strength. However, there is one disturbing factor using a polymer. Flexural strength in the case of external and internal samples for unmodified cement differs, because the same internal strength is obtained after 10 years whereas the external sample is obtained after 4 years. This is due to the low water content in internal conditions. Schulze's study [6] is important in the context of long-term research, as it allows to determine the decrease or increase in the value of given properties.

Discussion and conclusions

On the basis of the presented research it can be concluded that the addition of polymer during cement formation has advantages. It not only increases compressive strength, flexural strength and more importantly, water resistance, but also creates a more compressible surface providing new insulating properties. In the case of modern low energy buildings structures, such a material not only achieves the ability to retain heat but will also allow the use of less of other insulation materials, e.g. mineral wool. However, this solution also has several

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disadvantages. One is undoubtedly the price of polymer and the problems with mixing. Another important disadvantage is the length of time for external conditions to be established. With the use of an impermeable layer, compressive strength reaches its 100% capacity only after 10 years.

Nevertheless, there are many indications that cement reinforced with polymers will be widely used in the future. The conditions that must be met are primarily increased hardness, resistance to weather conditions but also the important economic aspect. First, the cement must be made more resistant to moisture, which causes corrosion of the steel inside the cement. The proper polymer must not only be efficient, but also chemically neutral. It is also important to determine the right amount of polymer to be added depending on the application. This especially concerns constructions where high strength is required, such as layers of concrete under supports and beams, as well as marine constructions or roof coverings most exposed to weather conditions. The main area of improvement or development of polymers may concern composites based on monomers. Hemp from the paper industry is also very promising. Another important issue is repair material in the form of various types of cement masses or pastes. In places where there has been damage such as where the cement is reinforced, repairs can be extremely difficult, because the corrosion process cannot be inhibited. Therefore, scientists should find a polymer that will not only fill the damaged section but also neutralize corrosion. In order to apply polymer technology scientists should strive to find an economically feasible solution.

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Piotr Antoniak
Wrocław University of Science and Technology, Faculty of Mechanical Engineering, Department of Mechanical Engineering and Tribology
ul. Łukasiewicza 7/9, 50-371 Wrocław, Poland, piotr.antoniak@pwr.edu.pl

Michał Stosiak
Wrocław University of Science and Technology, Faculty of Mechanical Engineering, Department of Maintenance and Operation of Logistics, Transportation and Hydraulic Systems,
ul. Łukasiewicza 7/9, 50-371 Wrocław, Poland, michal.stosiak@pwr.edu.pl
https://orcid.org/0000-0002-6111-1332

Krzysztof Towarnicki
Wrocław University of Science and Technology, Faculty of Mechanical Engineering, Department of Maintenance and Operation of Logistics, Transportation and Hydraulic Systems,
ul. Łukasiewicza 7/9, 50-371 Wrocław, Poland, krzysztof.towarnicki@pwr.edu.pl
https://orcid.org/0000-0002-4881-2548

PRELIMINARY TESTING OF THE INTERNAL GEAR PUMP WITH MODIFICATIONS OF THE SICKLE INSERT

Abstract
This paper presents the modifications that have been made to the sickle insert of the gear pump with internal gearing. This procedure allowed the obtainment of radial compensation. The test stand to plot the characteristics of the pump before, as well as after the first and second modification is discussed. The results of the measurements from the tests conducted are presented. The results obtained confirmed the achievement of radial compensation by cutting the appropriate channel in the sickle insert. As a result, it will be possible to obtain a higher discharge pressure for this type of pump and to increase its efficiency.

Key words
Gear pump, capacity, internal gearing, sickle insert.

Introduction

The pump is the main elementary component of the hydraulic system. Its operation is based on the conversion of external mechanical energy (for example, obtained from an electric or combustion engine) into hydraulic energy accumulated in the liquid. Its work comes down to sucking the liquid from the inlet, and then transferring it by the pump's working elements into the pressure port. Proper operation of the pump is guaranteed by a hermetically separation of the suction and pressure area. The impermeable separation of the two spaces allows the pressure of the transported liquid to be increased. The coupling of construction elements causes the rotation of the rotor simultaneously causing the displacement of the liquid mass. When the rotor stops, the flow of the working medium becomes unfeasible. The purpose of the pump is to provide two functions: transporting the liquid from the suction port to the discharge port, and increasing its pressure. The gear pump is one of the most commonly used positive displacement pumps in hydrostatic drive systems. The current development of hydraulic technology is based on the widespread introduction of electronic and automatic systems in machinery construction. An attribute of hydrostatic drive systems is the broad possibility of broad control of the speed and power of receivers. The placement of modern, multi-level electronic systems in hydraulic systems has contributed to smooth regulation and a significant reduction of their noise. Today's development of hydraulic drives is mainly based on the optimization of the construction of hydraulic drive system components. This mainly applies to two directions: a) minimizing their mass, which is associated with a reduction in their dimensions or the use of new lightweight and high-strength composite material [1], b) reduction of their noise [2]. The reduction of the dimensions or weight of hydraulic components while maintaining the current operating parameters (nominal pressures, efficiency, resistance to operating conditions) is included in the downsizing trend. The development trend aimed at minimizing dimensions has taken the name of microhydraulics. Over the last several years, significant development of microhydraulic systems has been noted in the literature [3], and the development of displacement micropumps contributed to this development. Requirements that have been

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set for them are: little geometric displacement, the ability to generate high pressures, small changes in efficiency along with an increase in generated pressure, possibly small flow pulsation resulting in low pressure pulsation, high efficiency and durability, resistance to oil contamination, and relatively low manufacturing costs. The above requirements are generally met by gear pumps. They can be used not only in hydrostatic drives, but also as metering elements for viscous liquids found in the automotive, chemical, food and pharmaceutical industries. [4]. It was adopted, although it is a contractual and constantly evolving, that microhydraulic elements are those in which the nominal flow is below 50 cm^3 / s (3 dm^3 / min) or the nominal size is WN <6 (for microhydraulic valves). Another trend in the construction of hydraulic components is the use of new materials, for example, for pump bodies, valves or hydraulic cylinders. Research is being carried out on the application of polyxymethylene (POM) in the construction of the above elements [5]. The main objective is to minimize the element's mass when achieving comparable operating parameters (for example, nominal operating pressures for actuators of 30 MPa and more). The advantages of hydrostatic drives include the exceptionally high density of the transmitted power stream in the drive system. Values of operating pressures of 35 ÷ 40 MPa are now something completely normal. At these pressures, power of 1 kW can be obtained from the spray liquid stream with a volume flow rate of only 30 ÷ 25 cm^3 / s (1.8 ÷ 1.5 dm^3 / min). The elements of the hydrostatic drive system have, therefore, compactness that is unachievable for other types of drive, i.e. a small mass per unit of power generated or transmitted. The development trends of hydrostatic drives are heading, among others, towards minimizing energy loss and mass, and increasing transferred power, thus increasing the power to mass ratio [6]. Weight reduction of high-pressure components and systems (including hydraulic ones) is particularly important in aircraft and mobile machines. On the other hand, micro-hydraulic systems have increased the requirements regarding the accuracy of operation of the receivers or silent operation. This requires an assessment of the impact of external mechanical vibrations on microhydraulic elements, and a search for ways to reduce this impact, for example, by the methods of vibration insulation of microhydraulic valves. An unquestionable advantage of hydraulic systems is the transfer of high power, which is associated with the generation of high pressures. Hydraulic gear units – pumps and motors – are widely used in hydrostatic drive systems [7]. Due to their simple construction, relatively low price and high durability, gear pumps are widely used. To ensure high pressure, axial and radial compensation are introduced. Radial compensation in external gearing pumps has been known for years. One Polish description shows a symmetrical version in the pump body on both sides of the pumping chamber, along the working chamber of two channels separated from the working chamber by flexible tongues. This radial compensation solution only applies to pumps with external gearing. In a German patent specification, one can find the introduction of radial compensation through the distinctive construction of the sickle pad. There are several design solutions that, irrespective of the type of design, consist of many elements. When the pressure in the pump pressure chamber increases, the insert elements are pressed against the surfaces of the tops of the meshing gears. To ensure high efficiency of the gear pump, it is essential to introduce both axial and radial compensation. Axial compensation is used most often because it is inexpensive and relatively easy to make. Because of the cost, radial compensation is used less often.

Materials and methods

Figure 1 shows a pump with internal gearing. The operation of the pump consists of rotating the outer gear (2). The next step is the rotation of the gearing rim (1) with the internal gearing. Between the wheel and the gearing ring there is a sickle insert (5), which closely touches the top of the gears. In order to secure the sickle insert, a safety peg (6) was placed in it. As a result of the rotation of the gear wheel (as in Figure 1), the liquid is transported in interdental gaps from the suction space (7) to the pressure space (4). Displacement of liquids occurs when the wheel gear enter the gap's interdental rim. After passing the teeth in the meshing, they come out of the interdental gaps and are filled with liquid in the suction space (7). Separation of the suction space from the pressing space is obtained through the contact between the gearing of the wheel (2) and the rim (1) (above) and the sickle insert (5) (below). The main properties of this type of pumps are: lower noise emission, more-even performance, and a more-compact design compared with pumps with external gearing. Thanks to the fact that the external and internal gears work together, a very high degree of gear coverage and favorable sealing at their contact point is obtained due to the increased circumference of the wheels in contact with the suction and pressure spaces. The advantage of high coverage results in smoother pump operation, reduced fill losses, reduced output and pressure pulsations, and lower noise levels. The result of this advantage is continuous work aimed at increasing the efficiency of these pumps and achieving higher pumping pressures [9].

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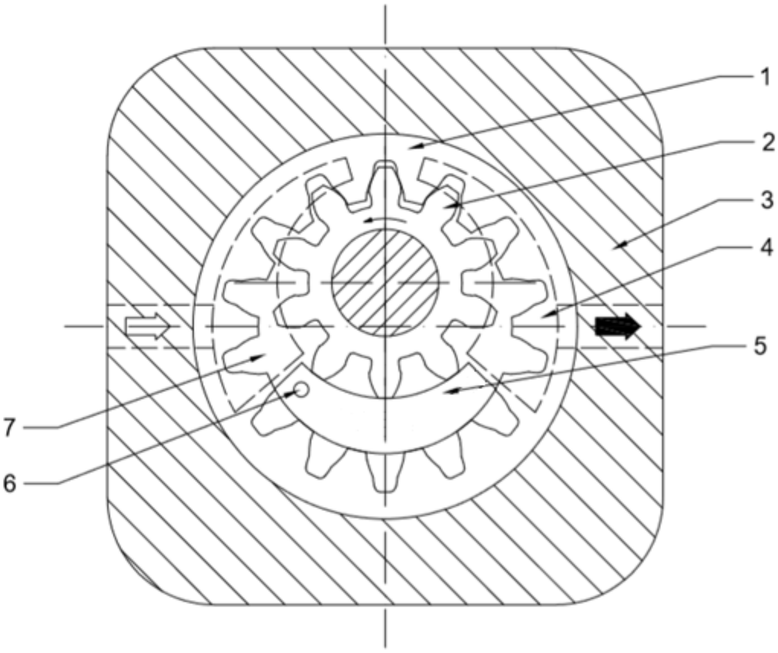

Figure 1. General scheme of a gear pump with internal gearing. 1 – gear wheel, 2 – gear wheel, 3 – pump body, 4 – pressure space, 5 – sickle insert, 6 – protection pin, 7 – suction space.
Source: Author's own work

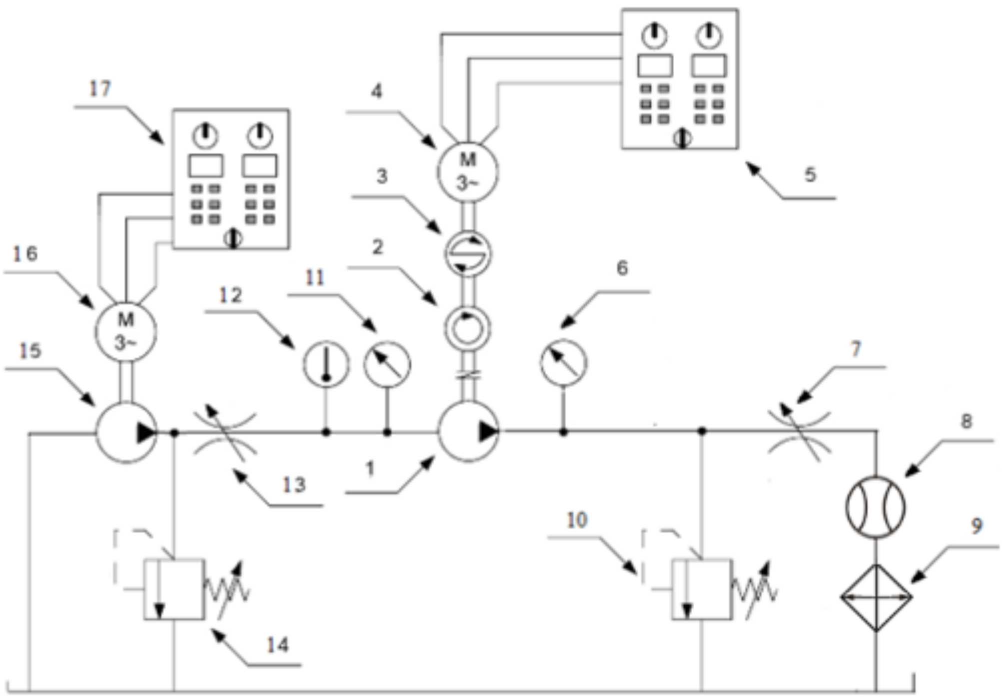

Figure 2. Hydraulic diagram of the test system. 1 – gear pump tested, 2 – tachometer, 3 – torque meter, 4 – electric motor, 5 – control cabinet, 6 – pressure transducer, 7 – throttle valve, 8 – flowmeter, 9 – cooler, 10 – safety valve, 11- pressure transducer, 12 – thermometer, 13 – throttle valve on the discharge line of the feed pump, 14 – safety valve on the discharge line of the feed pump, 15 – feed pump, 16 – electric motor driving the feed pump, 17 – control cabinet of the electric motor driving the feed pump.
Source: [10]

Figure 2 above shows a diagram of the measuring system. The supercharging pump (15) at the feed of the tested pump allowed the maintenance of constant pressure at the suction port of the tested pump, measured with a pressure transducer 11(WIKA A-10). To protect pump 1, a safety valve (10) is installed in the system. A throttle valve (7) was used to load the pump under test. A flow meter (8) (KRACHT VC0.2) was used to measure the actual pump performance, and a pressure transducer (6) (WIKA A-10) was used to measure the pressure. A torque meter (3) (HBM T22/10Nm) was used to measure the generated torque on the pump shaft. A magnetic sensor located on the shaft of the torque meter was used to measure the rotational speed of the pump. A flexible coupling was shown between the engine and the torque meter, as shown in Figure 2. A measuring system was used to record the torque and rotational speed in real time. The pump under test consists of two wheels. The gear wheel with external gearing has 13 teeth, and the gear wheel with internal gearing has 16 teeth. A test measurement was carried out, during which the correctness of the pump, safety valve and indications of all measuring instruments was checked. Following this, a series of correct measurements was made and pump characteristics were plotted. Three rotational speeds of the pump shaft were adopted for measurements, The tests were carried out at three rotational speeds of the gear pump shaft and the load was carried out for p_t from six to 20 bar in steps of one bar due to the pump body and modified plastic sickle insert. The recording of measurements was carried out after the pump operating conditions had stabilized. The tests were carried out at a constant working medium temperature of 333 K. The measurements were recorded using measuring instruments, partly connected to the computer, which facilitated the archiving of results. Microsoft Excel was used to process the measurement data.

Results and discussion

The results of the measurements are presented below.

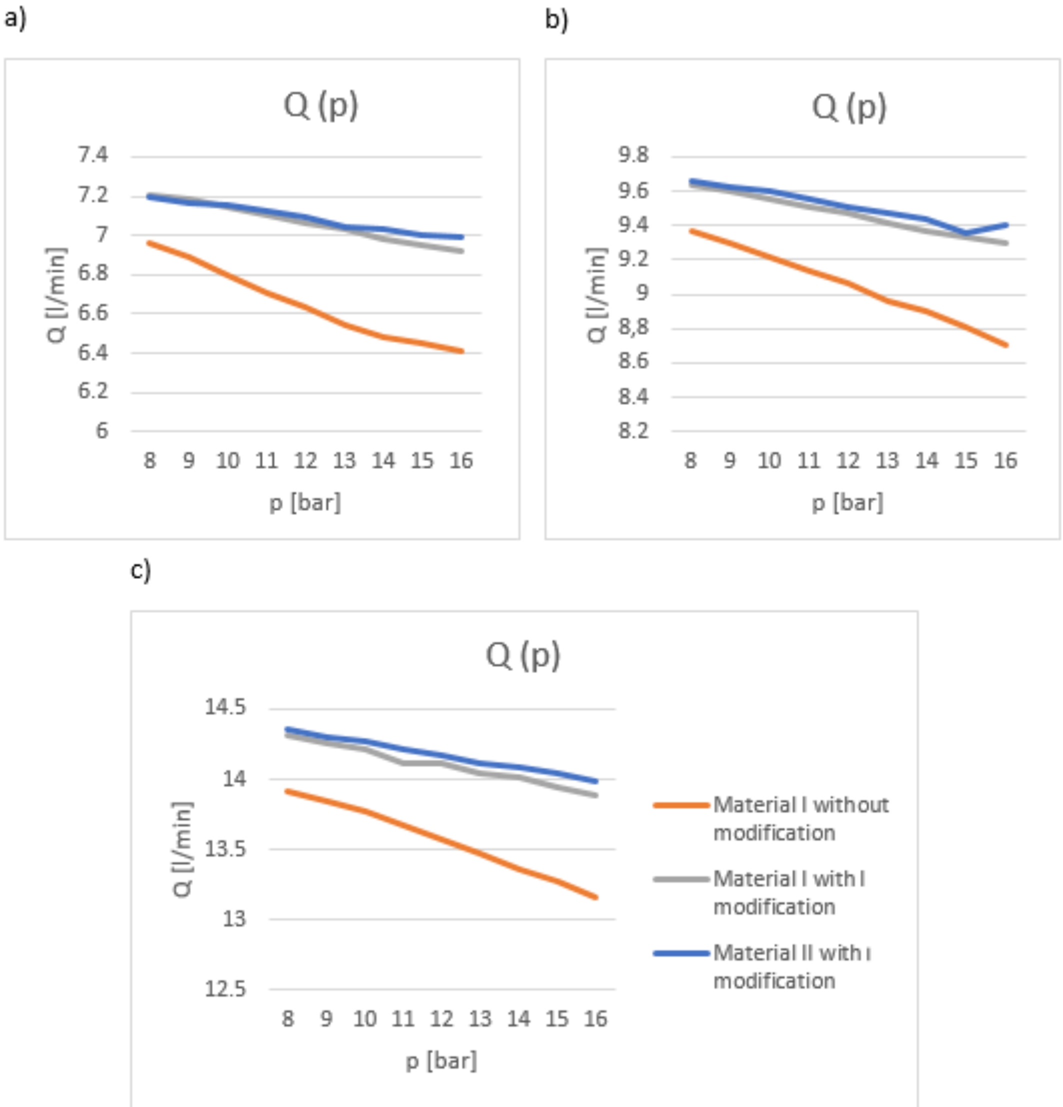

Figure 3. Characteristics of the gear pump with internal gearing with I modification sickle insert at different rotational speeds of the pump shaft: a) n = 750 [rpm] b) n = 1000 [rpm] c) n = 1500 [rpm].
Source: [10]

A hydraulic measuring system was built for basic measurements on the pump discharge line. The prototype pump differs from a conventional pump in modifications to the sickle insert. The modification consists of making the channel in a sickle pad, thanks to which two slides were created. Measurements were carried out on one pump construction; only the sickle pads were replaced during subsequent measurements. The base insert was made of POM plastic without modification, the next one was also made of POM plastic, but with modification, and another one made of PA plastic with modification. Each time the pump was assembled, its structural elements were bolted together with the same torque of 20 Nm. Analyzing the measurements, it can be stated that the modification introduced allows maintaining the pump capacity with increasing pressure. When the pump is operated with a base sickle pad without incisions, it can be stated that the flow rate decrease with increasing pumping pressure is higher than for a pump with a modified insert. During the operation of the pump with modified inserts, i.e. with notches, an increase in the pump's efficiency is noted compared with the operation of the pump with a base insert. Modification No. I consisted of creating a one half channel long sickle insert. Modification No. II consisted of creating a one-quarter hannel length of the sickle insert. After measurements and verification, it was decided to make longer channels with a length equal to half the length of the sickle insert. The following are the measurement results for both modifications and both materials for three rotational speeds.

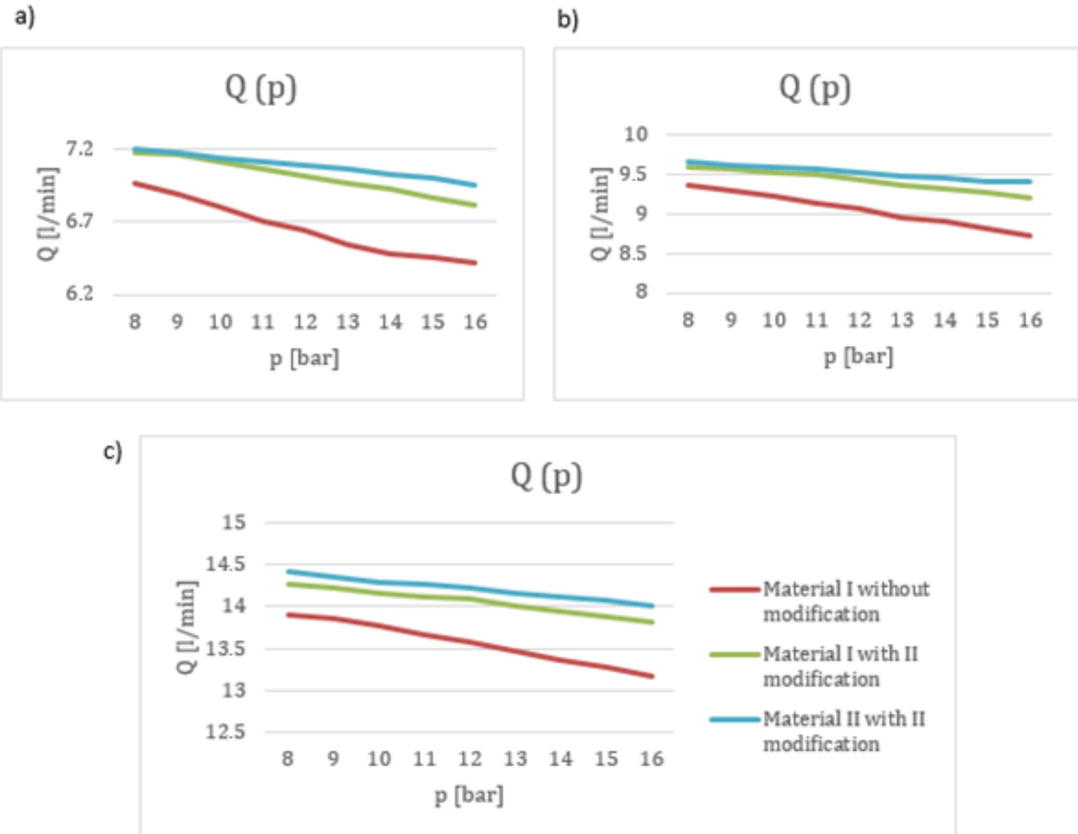

Figure 4. Characteristics of the gear pump with internal gearing with II modification sickle insert at different rotational speeds of the pump shaft: a) n = 750 [rpm] b) n = 1000 [rpm] c) n = 1500 [rpm].
Source: Author's own work

Comparing the measurements for two different modifications, it can be concluded that a small incision in the channel inside the insert causes an increase in volumetric efficiency compared with a conventional solution. In both cases, a higher efficiency is obtained for a pump with an insert made of material II.This is due to the properties of this material, mainly thermal expansion and specific heat and moisture absorption, which it is characterized by. Different thermal expansion changes the geometry of the gaps in the pump, which changes internal leakage. The applied modification has a positive effect on the characteristics of this gear pump, i.e. a slight decrease in efficiency as pressure increases. The feature presented refers to the two materials used; therefore, this is mainly due to its geometrical features, and to a lesser extent the material. The main reason for the decrease in performance as the pressure increases in conventional pumps is due to the increase in the gap between the surface of the insert and the surface of the gears. The incision in the sickle insert causes the guide

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to be pressed against the surface of the tops of the gears, reducing the gap as the pressure increases. This increases the volume efficiency. The measurements were carried out for a narrow pressure range with a relatively low value, so the differences are not very significant. A pump with a Plexiglas plastic body was used for the measurements, so higher pressure could not be generated at the pump discharge port. In the future, further measurements are planned for the steel pump. The above tests were carried out for a gear pump with compensation of radial clearances by introducing an incision in the sickle insert. This type of pump is used to generate the flow rate and generate pressure in the liquid stream in all types of hydraulic drive systems and lubrication systems. On this basis, it can be anticipated that the described modification can be readily implemented in pump designs.

Summary and conclusions

The current trend in the construction of hydraulic drive systems imposes the use of higher operating pressures. For this reason, pump manufacturers are required to introduce radial compensation to achieve higher discharge pressure. The modification presented consists of making a channel over the entire width of the insert, dividing it into two flexible slides. The channel inlet is located on the pump pressure side. When the pressure in the pressure chamber increases, the flexible tongues are pressed against the surfaces of the gear tops. To protect the insert from sliding, a pin located in the pump body was used. The advantage of the introduced design change is simple radial compensation, which results in a smaller decrease in efficiency as the discharge pressure increases. This solution is the subject of patent application No. P. 431145. The first modification consisted of making a channel with a length of one-quarter of the length of the sickle insert. After the measurements and verification, it was decided to make longer channels with a length equal to half the length of the sickle insert. The measurement results presented in the article confirm the correctness of the above conclusions. If the insert of material II is made, a higher volumetric efficiency is obtained. Pumps with modified inserts are characterized by higher volumetric efficiency values than pumps without. Based on the measurements carried out, another concept for the next modification of the sickle insert was created. The essence of this solution is to make a channel inside the sickle insert with two different widths The described solution is the subject of patent application No. P. 431146. The entrance to the channel chamber is located on the pressure chamber side. Inside the channel there is a piston, which on one side is supported by a spring, and on the other by the pressure prevailing in the discharge port of the pump. The piston moves as the pressure in the pump's pressure chamber increases. When the pressure drops, the piston will return to its original position by means of a spring. As a result of the sickle insert change, two flexible slides will be created in the sickle insert. Such a design change of the sickle insert will allow a reduction of the efficiency drop along with an increase of the pump discharge pressure, and will increase its efficiency irrespective of the change of pressure and pump rotation. While maintaining the hydraulic-mechanical efficiency, the overall performance of the modified device will increase. This contributes to further increasing the competitiveness of a gear pump with internal gearing pumps compared with a gear pump with external gearing. The described modification will allow the construction of high-pressure toothed micro-pumps with internal meshing. Micropumps are built on the basis of classic pumps. The requirements for micro pumps are: low geometric displacement, obtaining high pressures, small changes in efficiency with increasing pressure, high efficiency and durability, resistance to oil contamination, and low production costs. They are used in the drive systems and lubrication systems of machines and vehicles. They are distinguished by high working pressures reaching 35 MPa and volumetric efficiency exceeding 90%. Further unquestionable advantages are their long life and the ability to pump liquids at high rotational speeds, which places them first among positive displacement pumps. The elementary division of gear pumps divides them into gear pumps with external and internal gearing [11]. A special type of gear pump with internal gearing is a gerotor pump. Their distinctive feature is the absence of a sickle insert, thanks to which they are characterized by a very compact construction, resulting in smaller sizes and less mass. In addition, they are characterized by high efficiency, with small and light units, and are reliable and durable. Pumps commonly used in the industry are gear pumps with external gearing, which is due to their simple design and low price. The use of pumps with internal gearing is becoming increasingly popular [12].

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