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ANALYSIS OF RECYCLING OF NON-FERROUS METALS AS A PART OF RECYCLING OF SEA-GOING SHIPS

Об'єктом дослідження є процеси рециклінгу кольорових металів при утилізації морських суден. Рециклінг є основним напрямом розвитку кольорової металургії, оскільки, як показує світовий досвід, використання вторинної сировини економічно ефективніше та екологічно безпечніше, ніж використання первинних ресурсів. Одним з найбільш проблемних місць є відсутність утилізаційних підприємств і сучасних екологічних технологій утилізації в Україні. При дослідженні були використані метод аналізу при вивченні динаміки виробництва міді в світі і метод класифікації при розгляді властивостей, застосування кольорових металів в суднобудуванні, а також при виявленні потенційних споживачів кольорових металів.

Проаналізовано властивості кольорових металів, що застосовуються в суднобудуванні, та показано їх застосування в конструкції судна. Проведено аналіз підприємств України, які є основними потенційними споживачами кольорових металів як вторсировини. Найбільше в Україні підприємство з обробки кольорових металів – ПАТ «Завод з обробки кольорових металів» (м. Бахмут) – використовує в якості сировини тільки лом кольорових металів. Отримано обґрунтування ролі вторинного брухту при розвитку виробництва кольорових металів в Україні. Проведено аналіз динаміки виробництва міді в світі. Підкреслено, що методика, яка застосовується в Україні для оцінки вигоди різних класів рециклінгу застаріла і не дозволяє правильно розрахувати дохідну і видаткову частини, оцінити ризики. Завдяки змінам комплексного підходу при оцінці економічної ефективності використання у виробництві нових технологій прийняття державної програми з утилізації морських судів може забезпечити збільшення річного прибутку, період окупності витрат, прибутковості, відсотку рециклінгу кольорових металів.

Ключові слова: *рециклінг кольорових металів, утилізація морських суден, вторинна сировина для металургії.*

1. Introduction

The rapid development of the world economy over the past decades has led to a significant reduction in the life cycle of complex technical systems. A similar trend is observed in world shipping. So, if only recently, many shipping companies have successfully operated ships of 30 years or more, today, according to the data of the Scandinavian bank DANISH SHIP FINANSE [1], the average age of ships sent for recycling is 26 years. In 2017, there were cases of sale to scrap of ships younger than 10 years. In 2017, about 1 thousand ships were disposed of, and, according to forecasts, by 2020 their number will increase to 3 thousand ships per year. According to Resolution A.962 (23) of the IMO (International Maritime Organization), recycling is the best option for removing all dead ships.

Problems of non-ferrous metallurgy in Ukraine can't be solved only through the supply of raw materials for the production of non-ferrous metals. As the world experience shows, the development of metallurgical production based on the use of secondary raw materials is economically efficient and environmentally safe. Specialists engaged in the study of the turnover of metals have long concluded that the amount of primary natural resources needed for the production of metals is limited. Therefore, the obtaining of secondary materials from metal waste is a real necessity for the further development of the Ukrainian economy [2, 3]. The raw material base for this is the tremendous resources of the amortization scrap, which can be involved in the turnover in the process of the future large-scale renovation of obsolete fixed assets of all spheres of the economy, including water transport. In addition, it is important to note that the production of metal using scrap metal is not only an economic benefit, but also a concern for the environment. For example, when using ferrous scrap in steelmaking, emissions to the environment are half that of iron ore and coke.

Obviously, one of the important aspects here is the recycling of scrap ship. Now scrap is not considered by most Ukrainian enterprises as a separate scrap metal, whereas ship scrap is a separate article in the supply of black scrap all over the world [4].

Secondary processing is most often colored and ferrous metals. Thus, recycling is modern ecological technologies plus real savings [5].

When recycling sea-going ships, first of all, non-ferrous metals and their alloys are chosen. Therefore, it is important to study the recycling of non-ferrous metals in the recycling of sea-going ships, which is the main direction of growth of metal gathering and raw materials for non-ferrous metallurgy.

2. The object of research and its technological audit

The object of research is the processes of recycling non-ferrous metals in the recycling of sea-going ships.

The ship is a complex engineering structure and, when the time comes to take a decision on the termination of operation, it becomes a waste.

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Recycling is the process of returning a useful waste into the life cycle, which combines many processes associated with the recycling and separation of useful components from domestic and industrial wastes [5]. Recycling is called:

1. Reuse.
2. Manufacture of new materials and goods from secondary raw materials.
3. Allocation of useful fractions from waste and recycling of what is recognized as non-recyclable waste.
4. Obtaining energy from the burning or pyrolysis of industrial and domestic waste.

Thus, waste recycling is part of what is called recycling. In the modern world, it is becoming increasingly promising, as the planet's natural resources are close to exhaustion. In developed countries, recycling of wastes has been done for a long time and seriously, the best laboratories are working on the development of efficient technologies, the view of waste as a final product of use is changing in society.

In Ukraine, recycling is still a new concept, although the situation has begun to change – the state has paid attention to the economic profit that can return to the turnover of valuable components of waste.

In Europe, recycling and reuse of waste began to be actively engaged in the 90s, and today they have a powerful processing industry, which is actively developing. The economic stimulus for development is that the use of secondary raw materials, in particular from the recycling of sea and river ships, allows increasing investment efficiency than the use of primary resources. Recycling and reuse of waste can significantly reduce water pollution and emissions of various harmful substances into the atmosphere.

One of the most problematic places is the lack of modern environmental recycling enterprises in Ukraine.

3. The aim and objectives of research

The aim of research is showing the importance and prospects of using recycled scrap of non-ferrous metals obtained during ship recycling for the metallurgical production of Ukraine.

To achieve this aim, it is necessary to solve such problems:

1. To analyze the main properties of non-ferrous metals and alloys used in the construction of sea-going ships, and indicate their use in the ship design.
2. To analyze potential consumers of non-ferrous metals and alloys as recyclable materials in Ukraine.
3. To analyze the world copper production and show its dynamics.
4. To analyze the existing system for assessing the economic efficiency of using new technologies, inventions and rationalization proposals in production in Ukraine.

4. Research of existing solutions of the problem

Among the main directions of solving problems arising in the recycling of sea-going ships, the following can be singled out:

– problems of development of recycling (metal recycling) of maritime transport [1–5]. In particular, the paper [1] shows the dynamics of fleet growth for 2000–2016, the distribution of orders by countries, the cost of building ships. Also, issues related to the recycling of maritime transport, the prerequisites for the creation of a recycling enterprise and questions of the impact of scrap on modern metal production were considered [2]. The analysis of the state of legislative, organizational and technological levels of ship recycling in Ukraine is carried out, prospects of development of the enterprise on the basis of available shipbuilding and ship-repair plants of the south of Ukraine are determined [3]. The authors [4] develop a modern methodology for conducting a long-term analysis of the financial and economic activities of the heat recovery enterprise. In [5], the importance of the problem related to the management of production wastes is pointed out. The concept of a waste management system includes the development of a set of measures aimed at increasing the technical level of waste processing by creating enterprises which activities are aimed at using secondary resources in their production;

– issues of necessity and importance of metal recycling [6–9]. For example, in [6] it is noted that the amount of primary resources necessary for the production of metals is limited. The obtaining of secondary materials from scrap metal is a real necessity for the further development of the economy. The dynamics of scrap consumption in metallurgy in Ukraine, EU countries and the USA [7] is shown. Special attention is paid to the acuteness of the problem of recycling of industrial waste, the search for new scientific and technical, organizational and economic, legislative solutions in this area [8]. The annually volume of metal products is estimated in Russia and Ukraine, it is emphasized that Ukraine produces copper only from scrap [9];

– issues of economic justification for recycling [10, 11]. It is shown that recycling is a good policy only if the environmental impact and resources used for collecting and processing the material are less than the environmental impact and the resources needed to provide virgin material [10]. Also, potential synergies obtained from an integrated environmental quality system and qualitative advantages using ISO 9000 and 14000 certificates are shown [11];

– issues of application of modern, environmentally safe technologies for ship recycling [12–15]. The author [12] proposes a model of the environmental management system of a recycling enterprise based on the Shewhart-Deming cycle. Also, a method has been developed to form an effective portfolio of the organization's projects, taking into account limitations on the degree of air pollution, sea water and sewage from the implementation of a project. The issues of preparing a «green passport» containing information on potentially hazardous materials used in ship construction are considered [13]. An assessment of the environmental hazard in the storage of ships based on an analysis of environmental risk is given [14]. The issues of greenhouse gas emissions during metal recycling are considered, the magnitude of which depends on the choice of technologies and energy used in the metal reduction process [15];

– study of environmental strategies for waste management [16–19]. The authors [16] provide an overview of the methods used to support waste management solutions. It is indicated that various methods can be described as methods of system analysis. However, it is also clear that research will always be open to criticism, as they simplify reality and include uncertainties. The authors [17] analyze the ecological input-output and show its application to the regional planning of solid waste management. It is noted that the model can reflect the direct and indirect influence of regional solid waste production and specific relations with the development of the regional economy. The authors [18, 19] present the results of research into the processes of institutional and technological transformation in the sector of recycling of secondary metallurgical raw materials. Also, the issues of creation and trends of development of the national recycling system of secondary metallurgical resources are considered;

– ways of recycling and processing of industrial wastes [20–23].

The main existing and prospective ways of recycling and processing of industrial wastes are considered and the notion of industrial wastes is given [20]. And also their classification according to various criteria and possibilities of complex use of wastes of the industry as a whole in the industry, and on an example of metallurgical, fuel and energy and chemical complexes are considered. The ways of recycling and processing are characterized. The prospects and possibilities of new high technologies in aluminum recycling (for example, the use of low-temperature plasma, ultrasound) are shown [21]. The author [22] draws attention to the use of other technologies as well – to the processes of high-temperature processing, the introduction of non-traditional additives into the metal, etc. indicates that the processing of metals is most often positioned as an effective way to solve the problem of the scarcity of natural resources and reduce the environmental impacts associated with the extraction of metal. However, there are relatively few available data on the productivity of the reprocessing process, which makes it more difficult to estimate the reserves of secondary resources. The paper [23] describes the current situation in the management mechanism of the industrial sector responsible for the processing of secondary resources in different countries, examines various concepts for improving the mechanism:

– trends and prospects for development of metal recycling [24–28]. In [24], a brief review of the state and prospects for the development of metal recycling in Russia and the world is given. Data on trends in the development of markets for the most large-scale metal consumption volumes are collected and analyzed. The results of research on the dynamics of socio-economic processes in the world are generalized. The results of studies on the evaluation of the efficiency of recycling of zinc-containing raw materials are systematized. [25] emphasizes on the importance of aluminum recycling for present and future generations in terms of saving energy and other resources, reducing emissions to the atmosphere of harmful emissions. Advantages of using aluminum in the creation of vehicles, construction, packaging, energy recovery from renewable sources and its distribution are described. The conclusion is made that in the conditions of constant growth of the planet's population, aluminum is an important part of the solution of the stability problem of the future. The role of aluminum in development of human civilization is discussed [26]. It is shown that the growing diversity of aluminum products and their applications from year to year will lead to the fact that the world demand for aluminum will double in the period between 2010 and 2020. This demand will be met both at the expense of primary and secondary metals. At the same time, two-thirds of the demand will be met by the supply of primary aluminum, which, from 40 million tons in 2010, will increase to more than 70 million tons by 2020. The dynamics of prices for primary aluminum over the past 20 years has been analyzed, medium-term forecast [27]. It is shown that under the conditions of significant fluctuations in prices for primary aluminum, the dominant trend in the development of aluminum-producing corporations is the implementation of a binary vertically integrated scheme that combines aluminum smelting and recycling in parallel batches. The author [28] considers some features of technology and the organization of recycling of aluminum and its alloys. Analysis of the features of melting technology in a rotor furnace and organization of recycling of aluminum and its alloys shows that modern production provides high process efficiency, ensuring high quality of alloys;

– evaluation of recycling efficiency [29–33]. In particular, in [29] the problem of developing modern requirements for the recycling of cars is being solved. An indicator of the recycling efficiency is proposed, which will allow carrying out the most important measures for countries with different levels of economic development for the recycling and processing of waste. In [30] important scientific and practical results in the field of recycling are presented, which open up new possibilities in the field of saving material and energy resources in transport. A recycling efficiency index is proposed [31], taking into account the economic efficiency of the process, the prevention of environmental damage and the amount of cash waste. The work of the authors [32] is devoted to the problem of efficient use of secondary resources formed during the industrial process of an industrial enterprise. And in [33] the classification of recycling processes is given and recommendations are given on the use of various methods of economic evaluation of these processes;

– issues of the urgency of recycling non-ferrous metal scrap in non-ferrous metallurgy [34–37]. [34] states that the use of secondary resources is one of the most important directions for reducing environmental pollution. A parallel is made between the processes of obtaining primary and secondary aluminum. The positive and negative aspects of each method of production are determined. The authors [35, 36] present a modern system of secondary processing of secondary metals in the Republic of Belarus, as well as identify the features of the secondary metals market and identify some problems in its functioning. The authors of [36] point out that the life cycles of products and products from exploitation to return to nature act as a technological chain for the return of matter and energy to nature. It is proposed to distinguish two streams of return of matter into nature: lithogenic and technogenic materials. At the same time, consumption flows and waste streams in the system of circulation of technogenic substances are balanced during the year. It is shown that the development of the waste processing industry remains due to the progressive growth in the amount, in particular industrial waste [37]. Technogenic deposits are not involved in the processes of technogenesis,

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enhance environmental problems, it is possible to find a solution in the world of consumer demand, developing a strategy for processing and eco-democracy;
– the issues of the properties of non-ferrous metals used in the creation of ships, and the issues of their production [38, 39]. Thus, in work [38] it is shown the mastering of the technological processes of fire refining of copper and the manufacture of copper wire rod from metal waste and the production of brass rod by the method of hot pressing (extrusion) from a continuously cast round billet. The search for more efficient means for processing non-ferrous scrap metal continues, for example, the continuous extrusion process will provide environmental benefits and energy savings [39].

In [40], the authors develop a formal model of the international network of material products, which is a mechanism for international processing. Attention is focused on the case of a developed and developing country. The model demonstrates that taking environmental externalities into account leads to higher levels of recycling. It is shown that international recycling is mainly caused by regional differences in the quantity and quality of factors and the economic efficiency of processing. And also, that industrially developed countries are relatively well supplied with recyclable waste. The recovery factor usually exceeds the recycling factor. In developing countries, the opposite is true.

The authors of [41] discuss the need for recycling and processing of non-ferrous metals. The sources of scrap are analyzed and the corresponding processing of scrap is investigated, processing procedures, in particular aluminum and copper, are revised.

The results of the analysis allow to conclude that the problem of ship recycling (recycling of non-ferrous metals) in Ukraine was not solved in the XX century and more acute passed into the 21st century. Secondary raw materials are the most necessary element in the melting of metal. Through the use of recyclable scrap metal, a significant reduction in the cost of the entire production occurs. Savings are visible in everything, and in the costs of material of charge type and in energy costs, and much more. In addition, the recycling and reuse of scrap metal reduces the burden on the use of natural resources in this area, especially since they are already quite depleted to this day. All these factors listed above are a significant argument in metal processing.

5. Methods of research

The following scientific methods were used in the study:
– method of analysis in studying the dynamics of copper production in the world;
– method of classification when considering the properties, the use of non-ferrous metals in ship-building, and when identifying potential consumers of non-ferrous metals.

6. Research results

Non-ferrous metals and their alloys are selected, first of all, for ship recycling.

Aluminum has a low mass and increased resistance to corrosion. Due to this, aluminum alloys are increasingly used in shipbuilding, both for the manufacture of individual ship structures and for the construction of hulls.

The most common are aluminum alloys with magnesium and manganese (AMg, AMC), which are processed by pressure. Of these, bulkheads, ventilation pipes, chimney hoods, pipelines are manufactured, and superstructures, cuttings, boats, masts, outriggers and other important details are made of AMg5B alloy [42].

Copper in its pure form is used in some cases for the manufacture of ship pipelines. Copper alloys – brass and bronze are much more often used.

Bronze is an alloy of copper with tin or with aluminum, manganese, iron. Bronze has good corrosion resistance and low coefficient of friction. Copper is used to manufacture sliding bearings, padding of propeller shafts, seacock casings, worm wheels and other details.

Brass is copper-zinc alloy – the cheapest copper alloy, which has sufficient strength, corrosion resistance, ductility, electrical and thermal conductivity. Brass pipes are made for heat exchangers, t-pipes, plugs, details of portholes, oil cans, electrical parts, propellers, etc. [42].

Antifriction alloys are made on the basis of tin, lead and aluminum. These alloys are used in ship-building for casting of sliding bearings, which are characterized by low coefficient of friction, high plasticity, minimal wear and heat.

Titanium and its alloys are the latest progressive construction materials. These alloys are characterized by high strength, ductility, low specific gravity (45 g/cm^3), high melting point and high corrosion resistance.

Titanium alloys are well welded by electric welding in an argon or helium atmosphere. Titanium alloys are forged, stamped and rolled, which allows them to make and profile materials.

Titanium and its alloys are relatively expensive materials, but as the technology of their production improves, their cost quickly decreases. These materials are increasingly used in ship-building to manufacture particularly critical parts of the hull and its elements (for example, the hull of the Komsomolets submarine) [42, 43].

The main potential consumers of non-ferrous metals as recyclables are the enterprises of Ukraine listed in Table 1.

In Ukraine, mainly unrefined copper alloys are produced from scrap. A considerable number of enterprises are engaged in the production of copper and copper alloys. Among them, one of the largest is OJSC «Non-Ferrous Metals Processing Plant» (NFMPP) (Bakhmut). The capacities of NFMPP allow to produce up to 100 thousand tons of products from copper and its alloys annually. In addition to copper, the company produces brass and copper-nickel rolled products.

Table 1

Ukrainian enterprises producing non-ferrous metals [44, 45]

Produced Metal	Enterprise
Aluminum	Zaporizhzhia aluminum production plant, Mykolaiv alumina plant, Intersplav (Dnipro), Obimet (Odesa), Ukrchermet (Kharkiv)
Copper	Ukrcolorprom (Dnipro), Ukrchermet (Kharkiv), Non-Ferrous Metals Processing Plant (Bakhmut), Zaporizhzhia Non-ferrous Alloys Plant
Zinc	Ukrzinc (Kostiantynivka)
Nickel, chrome	Pobuzhsky Ferronickel
Titanium, magnesium	Zaporizhzhia Titanium and Magnesium Plant, Irshansk Mining and Processing Enterprise, Volnogirsk Mining and Metallurgical Plant, Fiko (Kyiv), Titanium Institute (Zaporizhzhia), Oriana (Kalush)

The main products of the plant are sheets, ribbons, pipes, rods, electrical wire rod, wire, as well as sanitary fittings and household goods. As a raw material, scrap of copper and its alloys is used. The latter once again emphasizes the importance of metal recycling and non-ferrous scrap of scrap produced by the recycling of sea-going ships.

NFMPP is the only enterprise in Ukraine producing flat and round rolled products from copper, its alloys and other non-ferrous metals. Currently, the plant produces more than 1000 sizes of products from 100 brands of metals based on copper, nickel, zinc [43].

In addition to NFMPP, processing of copper and its alloys in Ukraine involves in such enterprises as:

– «Ukrcolorprom» (Dnipro);
– «Ukrchermet» (Kharkiv);
– «Forum» (Zaporizhzhia);
– «Enei» (Kyiv);
– «Katekh-Electro» (Kyiv);
– «Aquaton» (Rivne);
– «Ecporesource» (Kyiv) and others.

As noted, Ukraine produces copper only from scrap, but recently there were plans to start own production. The quality of copper ore found in the Zhirichi field in the Volyn region is very high [46]. This deposit has unique characteristics, in particular, the content of pure metal in the ore reaches 5.1 %.

World production of primary copper (Fig. 1) in 1900 was only 495 thousand tons, in 1997 – 11.526 million tons, and in 2015 – 22.848 thousand tons. Between 1900 and 1960, copper production in the world grew by 3.2 % per year, from 1960 to 1970 – 3.4 % per year, in the 1970s – by 2.6 %, in the 1980s – by 2.2 %, in the 1990s – by 3.1 %, and in the 2000s – by 2.3 % per year.

A special role in the world copper market, along with the United States, in the last decades began to play Chile and the countries of Southeast Asia. So, over the past 30 years, Chile has grown into the largest producer of refined copper in the world. The production of refined copper in this country grew by 1858 % in 2012 in relation to the level of 1960 (177 thousand tons). The production of refined copper in Asian countries grew by almost 2000 % over the same period, mainly due to increased production in Japan and China. Chile, traditionally the world's leading supplier of copper ore and concentrates, increased its share of world copper production from 13 % in 1978 to 29 % in 1997 and to 30 % by 2015. In 2015, Chile produced 5700 thousand tons of copper (in the form of ore and concentrates). The countries of Africa, on the contrary, reduced the extraction of copper [47].

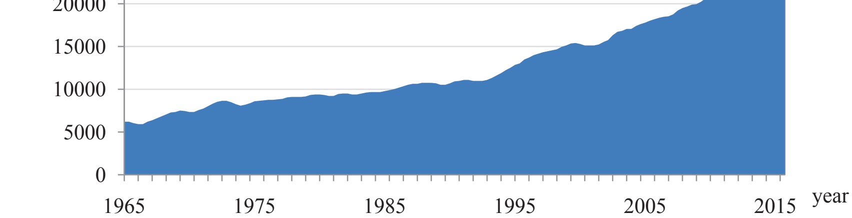

Fig. 1. Dynamics of primary copper production in the world by years from 1996 to 2015

The existing system of assessing the economic efficiency of using new technologies, inventions and rationalization proposals in production was developed in the late 70s of the last century. The methods of this evaluation system do not allow to correctly estimate the benefits of different recycling classes, calculate the revenue and expenditure parts and assess the risks.

The current evaluation system takes into account:

– compliance with environmental standards;
– consideration of all positive and negative conditions in the spheres of production and operation;
– estimate of time costs;
– multi-variant estimation of costs and benefits of the final result;
– consideration of risks at all stages of recycling;
– commensurate the cost of secondarily and primarily produced products [46].

The main indicators, which are taken into account in a comprehensive assessment – annual profit, a period of recoupment of costs and a profitability index, including indicators of profitability, profitability and efficiency of capital investments, are recorded in the journal.

In developed countries, recycling still accounts for 60 % of all production and consumption waste, and the remaining 40 % is still buried in landfills or, as waste ships, flooded, left abandoned off the rivers and seas. In Ukraine, this indicator remains at the level of 20–30 %.

7. SWOT analysis of research results

Strengths. The economic incentive for the development of recycling of non-ferrous metals obtained from the recycling of sea-going ships is that the use of secondary raw materials makes it possible to increase investment efficiency, in contrast to the use of primary resources. Recycling and reuse of waste can significantly reduce water pollution and emissions of various harmful substances into the atmosphere.

Weaknesses. The weak points of the research object include the absence of recycling enterprises in Ukraine certified for EU requirements.

Opportunities. The opportunities for further research include exploring the possibility of creating an environmentally friendly recycling enterprise, for example, on the basis of a shipyard.

Threats. The development of recycling requires state support at all levels – sectoral and regional, which should be enshrined in legal acts and be accompanied by budgetary financing.

8. Conclusions

1. It is shown that non-ferrous metals and their alloys are widely used in ship construction. In particular, the most common are aluminum alloys with magnesium and manganese. Copper alloys are often used – brass and bronze. Particularly critical parts of the hull and its components are made of titanium and its alloys. Thus, it is possible to obtain a scrap of non-ferrous metals when ship recycling.

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2. The list of potential consumers of scrap of non-ferrous metals and alloys in Ukraine, which could use it as a secondary raw material for the production of metal, is given. Thus, the prospects for the recycling of non-ferrous metals in the recycling of sea-going ships for development of non-ferrous metallurgy in Ukraine are shown.

3. It is shown that the production of primary copper in the world is increasing. In particular, in almost twenty years the volume of copper produced doubled (in 1997 – 11.526 million tons, and in 2015 – 22.848 million tons), which indicates the demand for this metal in industry. Despite plans to start own extraction of copper ore, in Ukraine copper is produced only from scrap. It is possible to obtain secondary raw materials from the details of copper and its alloys used in the ship design, with its disposal.

4. It is shown that the existing system of assessing the economic efficiency of using new technologies, inventions and rationalization proposals in Ukraine does not allow to evaluate the recycling efficiency. The methods of this evaluation system do not allow to correctly estimate the benefits of recycling classes, calculate the revenue and expenditure parts, and assess the risks. For this purpose it is necessary to use an integrated approach. This approach takes into account the annual profit, the payback period of costs and the profitability index, including the profitability, profitability and efficiency of capital investment.

References

1. Sudno. Novosti zarubezhnogo sudostroyeniya // LiveJournal. 2016. URL: https://shipway1.livejournal.com/ (Last accessed: 16.04.2018).
2. Neobkhodimost i znacheniye pererabotki metallolomа. URL: http://krasmet.net.ru/neobhodimost_i_znachenie_pererabotk (Last accessed: 16.04.2018).
3. Yuzov O. V., Sedykh A. M. Mirovyye tendentsii obrazovaniya i ispolzovaniya resursov metallolomа // Metallurg. 2003. No. 5. P. 55–56.
4. Pizintsali L. V., Aleksandrovska N. I., Kosharskaya L. V. Predposylki razvitiya sistemy utilizacii loma v Ukraine na primere zheleznodorozhnogo i morskogo transporta // Sbornik nauchnyh trudov DonIZHT. 2014. Vol. 37. P. 157–162. URL: http://ea.drti.donetsk.ua:8080/jspui/bitstream/123456789/1241/1/28Pizintsali.pdf (Last accessed: 11.04.2018).
5. Recikling – informaciya k razmyshleniyu. URL: http://www.cct-spb.ru/index.php/home/news/86-recycling-info (Last accessed: 11.04.2018).
6. Pizintsali L. V. Ukraina – problemy utilizacii sudov // East European Scientific Journal. 2016. No. 8. P. 100–104. URL: https://eesa-journal.com/wp-content/uploads/2016/04/EESJ_8_7.pdf (Last accessed: 11.04.2018).
7. Voynichenko V. Razdelka sudov: mirovoy opyt poslednikh desyatiletiy // Sudokhodstvo. 2016. No. 1 (145). P. 52–57.
8. Bolshakov O. P. Perspektivnyy analiz deyatelnosti sovremennogo utilizatsionnogo predpriyatiya: PhD thesis. Saratov, 2013. 156 p. URL: http://www.dissercat.com/content/perspektivnyi-analiz-deyatelnosti-sovremennogo-utilizatsionnogo-predpriyatiya#ixzz3lGKXu6zQ (Last accessed: 16.04.2018).
9. The Role of Input–Output Analysis for The Screening of Corporate Carbon Footprints / Huang Y. A. et al. // Economic Systems Research. 2009. Vol. 21, No. 3. P. 217–242. doi:10.1080/09535310903541348
10. Tekushchee i perspektivnoe potreblenie metallov v Rossii i Ukraine / Gerasimchuk I. et al. // Entsiklopediia marketinga. 2003. URL: http://www.marketing.spb.ru/mr/industry/consuption_metal_02_7.htm (Last accessed: 11.04.2018).
11. Municipal Solid Waste Recycling Issues / Lave L. B. et al. // Journal of Environmental Engineering. 1999. Vol. 125, No. 10. P. 944–949. doi:10.1061/(asce)0733-9372(1999)125:10(944)
12. Pizintsali L. V. Podgotovka «zelenogo pasporta» kak procedury mezhdunarodnyh trebovanij k organizacii predpriyatij po utilizacii sudov // Visnik ONMU. 2015. Vol. 2 (44). P. 177–185. URL: http://meb.com.ua/onmu/201544.pdf (Last accessed: 11.04.2018).
13. Boons F., Berends M. Stretching the boundary: the possibilities of flexibility as an organizational capability in industrial ecology // Business Strategy and the Environment. 2001. Vol. 10, No. 2. P. 115–124. doi:10.1002/bse.277
14. Reineke T. Umweltshute in der Schiffahrt, die Herausforderung fur das nachste Iahrtausend // Schiff und Hafen: Seewirt., Kommondobruck. 1999. Vol. 7. P. 36–40.
15. Dixon T. R. Shipping and enviroment: the view from shoreline // The Journal of Environmental Education. 1991. Vol. 10, No. 2. P. 55–66.
16. Connolly R. A., De Coste J. V., Jaupp H. L. Marine Exposure of Polymeric Materials and Cables after Fifteen Years // ASTM J. Materials. 1970. Vol. 5, No. 2. P. 339–362.
17. Pizintsali L. V., Shahov A. V. Ekologicheskii menedzhment predpriyatii po utilizacii morskih sudov // Zbirnik naukovih prac' Institutu geohimii navkolishn'ogo seredovishcha. 2016. Vol. 26. P. 50–59. URL: http://www.igns.gov.ua/wp-content/uploads/2017/02/MAKET--26-final_6.pdf (Last accessed: 11.04.2018).
18. Shimova O. S., Sokolovskiy N. K. Osnovy ekologii i ekonomika prirodopolzovaniya: textbook. Minsk: BGEU, 2001. 367 p.
19. Akimova T. A., Khaskin V. L. Ekologiya: handbook. Moscow: YuNITI, 1998. 445 p.
20. Mavrishchev V. V. Osnovy obshchey ekologii: handbook. Minsk: Vyshcha shkola, 2000. 317 p.
21. Muravey L. A. Ekologiya i bezopasnost zhiznedeyatelnosti: handbook. Moscow: YuNITI-DANA, 2000. 447 p.
22. Kachalov A. A. ISO 14001:2004. Sistemy menedzhmenta okruzhayushchey sredy. Moscow: IzdAT, 2005. 665 p.
23. Aba E. K., Badar M. A. A Review of the Impact of ISO 9000 and ISO 14000 Certifications // The Journal of Technology Studies. 2013. Vol. 39, No. 1. P. 42–50. doi:10.21061/jots.v39i1.a.4
24. Standards, conformity assessment, and trade: Into the 21st century. New York: National Academies Press, 1995. 238 p. URL: https://www.nap.edu/read/4921/chapter/1 (Last accessed: 16.04.2018).
25. Razvitiye sistem ekologicheskogo menedzhmenta v Rossii: proceedings. Moscow: Ekolayn, 2001. 87 p.
26. Boschet A.-F., Wahliss W., Lack T. J. Inland Waters. Annual topic update 1998. Topic report No. 2. European Environment Agency. Copengagen: EEA, 1999. 31 p. URL: https://www.eea.europa.eu/publications/92-9167-199-1 (Last accessed: 16.04.2018).
27. Yarlington L. J. Spill prevented in concrete Ships off kiptopehe // Proc. Mar. Safety Councl. 1992. Vol. 49, No. 3. P. 60–62.
28. Solodskiy S. A. Snizheniye vrednykh vydeleniy pri dugovoy svarke metallov: proceedings // Ekologiya i bezopasnost v tekhnosfere: sovremennyye puti i resheniya. 2015. P. 124–126. URL: https://books.google.com.ua/books?id=lZ49CwAAQBAJ&printsec=frontcover&dq=isbn:5447552206&hl=ru&sa=X&ved=0ahUKEwjim7b1jL_aAhXMx6YKHUExCWIQ6AEIJzAA#v=onepage&q&f=false (Last accessed: 16.04.2018).
29. Gopanyuk N. A. Otsenka negativnogo vozdeystviya predpriyatiy po remontu transportnykh sredstv na okruzhayushchuyu prirodnuyu sredu: handbook. Moscow: MGIU, 2007. 192 p.
30. Chelnokov A. A. Osnovy promyshlennoy ekologii. Minsk: Vysheyshaya shkola, 2001. 339 p.
31. Plastinin A. E. Otsenka ekologicheskoy opasnosti sudov vnutrennego plavaniya. podlezhashchikh utilizatsii: Abstract's PhD thesis. Nizhny Novgorod, 2004. URL: http://earthpapers.net/otsenka-ekologicheskoy-opasnosti-sudov-vnutrennego-plavaniya-podlezhaschih-utilizatsii (Last accessed: 16.04.2018).
32. Vasilchenko Z. A., Kovaleva V. I., Lyashenko A. V. Metodicheskoye posobiye po primeneniyu kriteriyev otneseniya opasnykh otkhodov k klassam opasnosti dlya okruzhayushchey sredy. Moscow: FGU «TsEKA», 2003. 38 p.
33. Kolotyrkin Ya. M. Elektrokhimiya i problemy ekologii // Rossiyskiy Khimicheskiy Zhurnal. 1993. Vol. 37, No. 4. P. 61–66.
34. Damgaard A., Larsen A. W., Christensen T. H. Recycling of metals: accounting of greenhouse gases and global warming contributions // Waste Management & Research. 2009. Vol. 27, No. 8. P. 773–780. doi:10.1177/0734242x09346838

35. Environmental and economic assessment methods for waste management decision-support: possibilities and limitations / Finnveden G. et al. // Waste Management & Research. 2007. Vol. 25, No. 3. P. 263–269. doi:10.1177/0734242x07079156
36. Huang G. H., Anderson W. P., Baetz B. W. Environmental Input-Output Analysis and its Application to Regional Solid-waste Management Planning // Journal of Environmental Management. 1994. Vol. 42, No. 1. P. 63–79. doi:10.1006/jema.1994.1061
37. Gurevich I. M., Zelichenko A. Ya., Kulik Yu. G. Tekhnologiya sudostroyeniya i sudoremonta: handbook. Moscow: Transport, 1976. 416 p.
38. Pupan L. I., Kononenko V. I. Perspektivnyye tekhnologii polucheniya i obrabotki materialov: handbook. Kharkiv: NTU «KhPI», 2008. 261 p.
39. Perov V. N. Tekhnologiya utilizatsii sudov: handbook. Nikolayev: UGMTU, 2002. 24 p.
40. Metallicheskie materialy // Flot.com. URL: https://flot.com/publications/books/shelf/chainikov/25.htm?print=Y (Last accessed: 11.04.2018).
41. Morozov D. Eksportnaya poshlina na lom spasla ukrainskuyu metallurgiyu v proshlom godu (Part 2). URL: http://uaprom.info/article/6212-denis-morozov-eksportnaya-poshlina-lom-spasla-ukrainskuyu-metallurgiyu-proshlom-godu-chast.html (Last accessed: 11.04.2018).
42. PAO «Artemovskiy zavod po obrabotke tsvetnykh metallov». URL: https://pao-artemovskij-zavod-po-obrabotke-tsvetnyh.uaprom.net (Last accessed: 13.04.2018).
43. Proizvodstvo tsvetnykh metallov v Ukraine // Biznes-katalog. URL: https://www.ua-region.info/kved/Ind.27.4 (Last accessed: 14.04.2018).
44. Metallurgicheskoye proizvodstvo // Biznes-katalog. URL: https://www.ua-region.info/kved/Ind.27 (Last accessed: 14.04.2018).

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EFFICIENCY ESTIMATION OF CATION-EXCHANGE RECOVERY OF HEAVY METALS FROM SOLUTIONS CONTAINING THEIR MIXTURES

Об'єктом дослідження є промивні стічні води гальванічних виробництв, що містять катіони важких металів. Найбільш поширені реагентні методи очистки гальванічних стоків не забезпечують необхідний ступінь очищення води, супроводжуються втратою цінних компонентів і утворенням значних об'ємів токсичних шламів. Іонний обмін є перспективним в створенні технологій очистки стічних вод гальванічних виробництв.

Одною з найбільш голових проблем іонообмінної технології є процеси регенерації іонітів, а, зокрема, утилізації відпрацьованих регенераційних розчинів. Найбільш перспективним при відновленні регенераційних розчинів є електрохімічний метод. Проте, електроекстракція цинку та нікелю практично неможлива з кислих розчинів без розділення електродного простору мембраною. Крім того, стоки гальванічних виробництв містять суміші іонів важких металів. Це ускладнює процес очистки стічних вод та повернення цінних компонентів у виробництво.

В ході дослідження використовували сильнокислотний катіоніт КУ-2-8 в Na^+-формі для вивчення процесів сумісної сорбції іонів важких металів. Регенерацію катіоніту проводили розчинами сірчаної та соляної кислот. Еектроекстракцію цинку та нікелю з кислих регенераційних розчинів здійснювали в двохкамерному електролізері з аніонообмінною мембраною МА-41.

Отримано результати, які свідчать, що в умовах концентрування важких металів на катіоніті КУ-2-8 досягнути ефективного розділення їх неможливо. Встановлено, що іони важких металів сорбовані індивідуально і в сумішах з іншими іонами важких металів ефективно десорбуються розчинами сірчаної та соляної кислот.

Використання двохкамерного електролізера, на відміну від проведення процесів електролізу без розділення електродного простору, дозволило практично повністю вилучити іони цинку та нікелю з кислих регенераційних розчинів. А також отримати розчин сірчаної кислоти в анодній камері в концентрації 239–651 мг-екв/дм^3.

Ключові слова: *очищення стічних вод, електроекстракція катіонів важких металів, метод іонного обміну.*

1. Introduction

The issue of pollution of natural water bodies refers to global environmental problems. It is known that the toxicity of the aquatic environment is formed due to the receipt of harmful substances of anthropogenic origin, the accumulation of significant amounts of them and their violation by the influence of natural geochemical cycles of the matter cycle.

Among the most common highly toxic substances in fresh water bodies, one of the leading places is occupied by heavy metals. A characteristic feature of these ions is that