ENERGY PROBLEMS OF THE WORLD COMMUNITY: PRESENT, FUTURE

Valeriy Leonov[1]

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Abstract. Man-made systems use energy resources to produce energy and commercial products. Conventionally, energy resources can be divided into renewable and non-renewable. In the balance of energy resource use, non-renewable resources prevail (90%), and renewable resources account for only 10%. Non-renewable energy resources are depleted, since their high consumption combined with the imperfection of modern man-made systems. Renewable energy sources are not able to completely replace non-renewable energy resources. Hence the goal of the work – what energy source can replace non-renewable energy in the near and long term. In this case, it is advisable to consider a set measures, namely, the creation of resource-saving technologies, the search for and use of natural alternative energy sources, the of man-made systems to non-hydrocarbon energy. For the long term, it is advisable to consider the idea of creating an energy basis based on raw materials with a high reserve factor, cheap and environmentally friendly. Based on research and development, a base will be created for organizing large-scale production of chemical and petrochemical industries. This proposal will allow for a smooth replacement of depleted, expensive, environmentally hazardous non-renewable traditional energy with a new efficient and safe energy base. To achieve a quick and effective result, it is proposed to comprehensively use known reliable technologies in conjunction with new scientific ideas and preferences. Within the framework of the new project, proposals for organizing integrated production of carbon-containing and nitrogen-containing compounds are considered. Within the framework of the project for creating the energy of the future, the idea of replacing the antagonistic two-vector system with a unidirectional one-vector model of economic efficiency and environmental safety of the functioning of technogenic systems is considered.

[1] Doctor of Technical Science, Professor
ORCID: https://orcid.org/0000-0001-5590-8807

1. Introduction

A significant part of the world's energy is based on the use of non-renewable raw materials, the reserves of which are limited and running out. The world community is faced with an urgent problem – what to do when non-renewable resources run out and, most importantly, what to replace them with, what source. There is information on alternative energy in the scientific literature, but it is unsystematic, irregular and not aimed at practical implementation.

Within the framework of Non-renewable energy, while time still allows, it is necessary to accelerate the development of resource-saving technologies and their implementation, use alternative energy sources, prepare a scientific base for the production of energy of the future.

In this section of the scientific monograph, the first time, a raw material triad is proposed, including water, carbon dioxide, nitrogen, on the basis of processing which it is necessary to organize the production of electrical energy and petrochemical synthesis products.

2. Statement of the Problem

A significant part of the world's energy is based on the use of non-renewable raw materials, the reserves of which are limited and running out. The world community is faced with an urgent problem – but, it is easy to assume that significant volumes of processed hydrocarbon marine fuel are required to carry out these shipments. The works [1, p. 248; 2, p. 24; 3, p. 79] provide scientific and practical recommendations for ensuring environmental safety of sea freight transportation, c the studies [4, p. 193; 5, p. 111] examine fundamental issues of saving marine fuel, and the articles [6, p. 75; 7, p. 55; 8, p. 38] provide practical recommendations for increasing the economic efficiency of sea freight transportation.

There is information on alternative energy in the scientific literature, but it is unsystematic, irregular and not aimed at practical implementation. Within the framework of Non-renewable energy , while time still allows, it is necessary to accelerate the development of resource-saving technologies and their implementation, use alternative energy sources, prepare a scientific base for the production of energy of the future. In this section of the scientific monograph, for the first time, a raw material triad is proposed, including water, carbon dioxide, nitrogen, on the basis of processing which it is necessary to organize the production of electrical energy and petrochemical synthesis products. It should be noted that published scientific and technical works contain virtually no information on the projected reserves of non-renewable and alternative energy sources, new energy bsources and, accordingly, there are no long-term forecasts for the functioning of man-made systems using new environmentally friendly energy resources. Therefore, it is currently not possible to analyze published works on the topic of this article.

3. Purpose and objectives of the study

To analyze the current balance of energy resource use. To develop practical recommendations for the use of traditional and alternative energy sources in order to improve the economic efficiency and environmental safety of man-made systems in the long term.

Based on our own research work, a raw material triad of future energy has been proposed, on the basis of which technologies for obtaining environmentally friendly fuel and petrochemical synthesis products have been developed.

4. Presentation of the main material

4.1 Types of energy resources of the Planet

Energy resources of the Planet play a significant role in the life of the world community, ensuring the sovereignty and security of states.

Classification of energy resources is given in the textbook [9, p. 122]. and includes the following types:

1. Eternal energy of the first and second types.
2. Renewable energy.
3. Non-renewable (traditional) energy.

Over the past 50 years, the dominant role on a global scale falls on non-renewable (traditional) energy (90%), and the remaining 10% – in total on Eternal energy of the first and second types and Renewable energy.

At the same time, the reserves of Non-renewable (traditional) energy are limited.

The literature provides time forecasts of explored reserves of traditional energy in the range from 50 to 100 years. In this paper, no preference will be given to these forecasts. But at the same time, it is impossible not to notice that exploration and production of non-renewable energy is smoothly moving from the continents to the sea shelves, to the depths of the world's oceans, the Arctic, and hard-to-reach deposits. And this is a fairly reliable marker of the depletion of world energy reserves in class 3 (third) and, accordingly, this leads to an intensive increase in their cost and military-political conflicts. The degree of useful use of non-renewable energy does not exceed 15%, and most of them, 85%, are converted into material and energy waste, which lead to global environmental problems and, in particular, the climate crisis ("greenhouse" effect) on the Planet [10, p. 10]. Within the European Union, preference is given to the transfer of man-made systems from traditional energy sources to Renewable and Eternal energy – "green" energy. Thus, in Germany, energy complexes for energy production using coal and nuclear fuel as raw materials were closed. The result of this translation is negative and the issue of resuming the use of coal in power generating systems is already being considered.

The work provides a comparative characteristic of traditional, non-renewable energy in comparison with "green" energy. Solar and wind energy are considered as an object of "green" energy [11, p. 5].

The main disadvantages of using solar energy:

1) low concentration of energy per unit of solar battery surface, which requires significant useful areas of the Earth;

2) constant cleaning of solar panels, preventive maintenance and repair are required;

3) dependence on meteorological and seasonal conditions, force majeure events;

4) the productive degree of action of solar panels is 10-15 years;

5) the resulting solid waste – spent solar panels are 400 times more toxic than spent nuclear fuel, there is no technology for the disposal of spent solar panels, and their burial in solid waste landfills poses a great danger to the environment and the biosphere;

6) solar panels are destroyed and become unusable from hail, external mechanical sources, force majeure events;

7) the payback period of industrial solar batteries is more than 12 years.

The main disadvantages of using wind power plants:

1) low concentration of wind energy per unit of the Earth's surface occupied by the wind power plant, which requires significant useful areas of the Earth;

2) a source of infrasound radiation;

3) mechanical destruction of the blades due to high "sail" (blade radius within 100 – 200 m);

4) death of birds, damage to the blades;

5) long payback period, more than 12 years, of an industrial installation;

6) dependence on meteorological and seasonal conditions;

7) expensive maintenance, prevention and repair;

8) used and/or damaged blades, due to the complexity of their composition, including wood, fiberglass (glass wool) and plastic polymers, cannot be recycled, and their disposal at landfills is expensive and dangerous for the environment and the biosphere.

Limitations in energy production – if all energy production is transferred to solar and wind power systems, they will not be able to cover 90% of the energy generated by the use of non-renewable, traditional energy.

On the other hand, the activation of international "climate" organizations under the auspices of the UN (Union Nation) to combat the "climate" crisis on the Planet requires a legislative ban on the use of traditional hydrocarbon raw materials with the transfer of man-made systems to "Green" energy. This experiment on an industrial scale led to negative results and, together with the destruction of the Northern Streams of natural gas, led to a sharp increase in prices for traditional hydrocarbon raw materials, and all these factors led to stagnation of the economies of industrialized countries and to the bankruptcy of well-known industrial firms. The above is quite consistently demonstrated by the analysis of the final decisions of the climate summits over the past 27 years (1997 – Japan, 2015 – France, 2024 – the Republic of Azerbaijan), given in the work [12, p. 159]. All the final decisions are practically no different from each other and are unsuitable for practical use in terms of regulating the climate on the Planet, which is what the authors of the final decisions of the climate summits relied on. Without going into the reasons for the failure of Green Energy, we can summarize this section:

1) within the framework of the functioning of technogenic systems on traditional hydrocarbon raw materials, class 3, a platform for the use of alternative energy sources should be created;

2) create a research and development base for the use of alternative energy sources in the context of research on model and pilot industrial installations;

3) develop a feasibility study for the operation of man-made systems on alternative energy sources;

4) develop design and estimate documentation, a working project for the main unit;

5) create a main industrial unit, launch it, develop it, formulate conclusions, develop an act on the results of commissioning work for the industrial unit.

4.2 Development of resource-saving technologies, analysis of alternative energy sources

As follows from the above, the era of hydrocarbon energy carriers – class 3 is approaching its "sunset", and new energy sources, in particular Green Energy, are not yet ready for industrial operation in man-made systems. Therefore, in this section, in the order of exchange of opinions and discussion, it is proposed to consider two directions within the framework of the functioning of traditional non-renewable energy resources:

1) development and implementation of resource-saving technologies;

2) search for alternative energy sources.

4.3 Resource-saving technologies

The basic principles of developing resource-saving technologies are given in the textbook [9, p. 187]. We have introduced a criterion for the quantitative assessment of resource-saving technologies – the coefficient of performance (COP), %, which is determined by the ratio of the energy converted into the target product to the total energy converted into the target product and waste of technogenic systems.

Depending on the value of the COP, %, resource-saving technologies are conventionally divided into the following types [9, p. 233]:

1) modern technologies (COP – 15%);

2) low-waste technologies (COP – 45%);

3) resource-saving technologies (COP – 75%);

4) waste-free technologies (COP – 100%).

Purpose of resource-saving technologies:

1) reduce the consumption of non-renewable energy resources, reduce the load on class 3 resource reserves;

2) reduce ecological and economic damage to the environment, biosphere;

3) improve technical and economic indicators of man-made systems.

It should be noted that recently the environment, especially the world's oceans, has been intensively polluted with plastic waste, which leads to significant environmental and economic damage. The work provides an analysis of the pollution of the marine environment with plastic waste, describes the consequences of this pollution and proposes technical solutions for the rational disposal of plastic waste [13, p. 142].

The monograph, developed under the editorship of Professor V. Ye. Leonov, provides examples of resource-saving technologies developed and implemented on an industrial scale. Particular attention should be paid to large-scale production of methanol according to the "short" scheme M-100 – 100,000 tons/year, integrated with the production of acetylene by the method of high-temperature oxidative pyrolysis of methane [14, p. 355].

In maritime transport, in order to increase the efficiency of maritime cargo transportation and ensure their environmental safety, we have proposed a method of ballastless transitions using optimal logistics schemes in the conditions of Southeast Asia in conjunction with the development and operation of multi-purpose universal vessels [15, p. 195].

Thus, at present, modern technologies with a low efficiency level of only 15% are used, which characterizes these technologies as the most expensive, economically unprofitable and ecologically dangerous for the environment, biosphere, and humans.

Therefore, in our opinion, it is advisable to direct scientific research to the development and practical implementation of low-waste, resource-saving and waste-free technologies.

4.4 Alternative energy sources

As a result of the analysis and generalization of literary sources and our own research, the following types of alternative energy resources can be distinguished:

1) extraction and processing of hydrogen sulfide dissolved in the marine environment into electrical energy, petrochemical synthesis products directly on offshore platforms, these issues can be found in detail in the textbook [9, p. 287];

2) extraction and processing of bottom sea crystalline hydrates into electrical energy, petrochemical synthesis products directly on offshore platforms;

3) scientific research on the development of new effective technical solutions for the optimal use of solar and wind energy;

4) communication, collection and use of "mine methane" for fuel and energy purposes;

5) use of tidal phenomena, storm waves at sea for generating electricity.

4.5 Development of energy resources of the future

After the implementation of the stages described in Section 2, it seems appropriate to consider the prospects of the energy of the future. The main criteria for choosing a base for the production of energy of the future are:

1) availability and cheapness of the feedstock;

2) high multiplicity of the stock of the feedstock;

3) the presence of a sufficiently reliable research base for the production of energy and petrochemical synthesis products.

These criteria are fully met by the basic triad of the energy of the future (Figure 1), namely – water (occupies 75% of the Earth's area), carbon dioxide (contained in atmospheric air, sea water, bottom sediments, rocks), nitrogen (79% by volume), contained in the air. Based on this triad, the directions of research work on the syntheses of organic and inorganic compounds will be proposed below.

5. Hydrogen Production from Water

Currently, two methods of hydrogen production from water are known:

1) "iron-steam" (Fe-H2O) method;

2) electrochemical method.

However, these methods of hydrogen production are not implemented in industry due to their low economic indicators and non-compliance of the processes with the second law of thermodynamics.

These methods are used only for special purposes and when other methods cannot be applied. Thus, on submarines, an electrochemical method of water decomposition is used to produce oxygen.

We conduct research and development work in laboratory conditions on the catalytic conversion of water vapor into hydrogen in differential and integral type installations. Positive results have been obtained, a positive decision on the patent.

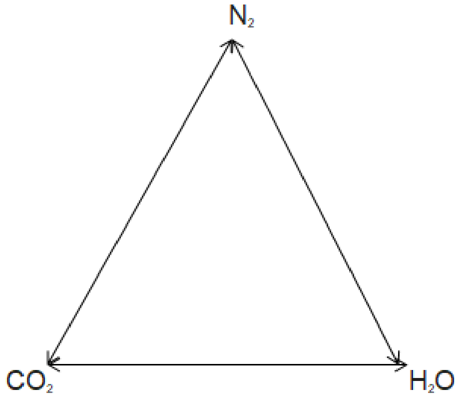

Figure 1. The Basic Triad of Future Energy

6. Production of carbon-containing compounds

Methanol – refers to large-scale production, currently methanol is obtained by catalytic hydrogenation of carbon monoxide, the main raw material is natural gas.

There are known methods for obtaining methanol by partial oxidation of natural gas, "dry" high-temperature distillation of wood.

We are conducting research and development work in laboratory conditions to obtain methanol by catalytic hydrogenation of carbon dioxide according to the reaction:

$$CO2. + 3\ H2. =. CH3OH. +. H2O. + Qr. \qquad (1)$$

Aliphatic alcohols C2 - C5+ – in the stage of research and development work in laboratory conditions, the reaction of catalytic methanol hydrocarbonylation – "CH3OH + H2 + CO2";

Diimethyl ether (DME) is an environmentally friendly refrigerant that can be used in refrigeration equipment, refrigeration units on ships, as a propellant instead of dangerous refrigerants based on fluorochlorocarbon. Research work has been carried out in laboratory conditions, on pilot plants, the process is based on the reaction of methanol dehydrogenation in the presence of a catalyst based on active aluminum oxide:

$$2\ CH3OH = (CH3)2O + H2O. \qquad (2)$$

The process of obtaining DME from methanol has been prepared for industrial implementation.

Formaldehyde (CH2O) – the process of obtaining formaldehyde by the method of partial catalytic oxidation of methanol in the presence of a silver catalyst has been mastered in industry.

Carboxylic acids

In industry, synthetic acetic acid is obtained by the method of catalytic carbonylation of methanol on a rhodium catalyst (Monsanto, USA).

At the stage of scientific research work in laboratory conditions, the process of obtaining formic acid from carbon dioxide and water.

– Hydrocarbons – methane is obtained by the Sabatier reaction by the method of catalytic hydrogenation of carbon dioxide;

– synthetic gasoline C2 - C5+ is obtained by catalytic conversion of methanol on zeolite catalysts.

7. Production of nitrogen-containing compounds

Ammonia – Large-scale production of ammonia is based on the Haber-Bosch process with the interaction of nitrogen and hydrogen in the presence of iron-containing catalysts. Promising is the synthesis of ammonia from nitrogen and water vapor in the presence of a catalyst.

Urea is an effective mineral fertilizer, the industrial process is based on the A.I. Bazarov reaction as a result of the interaction of ammonia and carbon dioxide.

Nitric acid – the production of nitric acid has been mastered on an industrial scale by the method of catalytic (platinum and/or platinum-rhodium contacts are used as a catalyst) oxidation of ammonia to nitrogen oxides with subsequent absorption of the latter by water to form nitric acid.

It seems interesting to conduct exploratory studies on the synthesis of nitrogen oxides from nitrogen and water vapor with subsequent absorption of nitrogen oxides by water to nitric acid.

Ammonium nitrate is used as a mineral fertilizer, for the production of explosives. In industry, it is obtained as a result of the interaction of ammonia and nitric acid.

Urea-formaldehyde resins are obtained in industry by the interaction of urea and formaldehyde.

Thus, a triad of the raw material base of the energy of the future is proposed, based on industrial experience and our own research and development work, research areas in the field of energy of the future are proposed.

I would like to invite the authors and research teams to continue the list of research and development areas of the energy of the future for subsequent analysis and selection of the most effective areas of research and development.

The problem of resource conservation is inextricably linked with the development and practical implementation of innovative efficient technologies.

Based on our own research and development work, analysis and generalization of scientific and practical materials, new technical solutions and technologies for maritime transport have been developed, some fragments of which are given below. The choice of the maritime transport industry is primarily due to the fact that maritime transport accounts for more than 80% of the total volume of world transport. In addition, the new technical solutions developed can be successfully i mplemented in other industries.

8 Research work on the feasibility of switching maritime transport to low-sulfur marine fuel

8.1 Research on optimizing the concentration of sulfur compounds in marine fuel

8.1.1 Calculation studies of absolute damage to the air basin depending on the concentration of sulfur compounds in marine fuel

As a result of combustion of hydrocarbon fuel in ship power plants (SPP), exhaust gases are formed that contain various toxic substances and compounds, the main ones being carbon monoxide, hydrocarbons, soot, heavy metal compounds, carbon, sulfur and nitrogen oxides, carboxylic acids, aldehydes, ketones, carbon dioxide.

In the future, hydrogen, methanol, hydrogen sulfide, bottom solid gas-crystal hydrates, aliphatic alcohols C1-C5+, carbon dioxide, water will be used as fuel for MPP. Absolute damage to the air basin caused by exhaust gases of the SPP, Y, UAH/year, is determined by the formula [9, p. 228]:

$$Y = \gamma \times \sigma \times f \times M \qquad (3)$$

The calculation studies were carried out for the conditions of the port of New York (USA), in two directions – with catalytic cleaning of exhaust gases of the SPP from sulfur compounds and without cleaning (in the range from 0 to 5% by weight).

According to theoretically substantiated data, it can be stated that from the position of the voyage economy and damage to the air basin, the transition from high-sulfur to low-sulfur fuel is inappropriate: the cost of low-sulfur fuel is 157 times higher than the prevented damage to the air basin caused by the transition from high-sulfur marine fuel to low-sulfur (Appendix VI MARPOL 73/78) [16, p. 327]. Even if we imagine a complete absence of sulfur compounds in marine fuel, then even in this ideal case the absolute damage to the air will exceed 11,000,000 UAH per year. At the same time, when using high-sulfur fuel containing 4.5% by weight of sulfur compounds, but in combination with catalytic cleaning of exhaust gases of the SPP, all other things being equal, the absolute damage to the air will be only 3,000,428,544 UAH per year, which is 5.4 lower than when using the same high-sulfur marine fuel (4.5% by weight of sulfur compounds, but without the use of a catalyst), and 3.7 times lower than the absolute damage received with absolutely desulfurized marine fuel. Thus, based on the research work we have conducted, it follows that the transition of sea transport to low-sulfur marine fuel is not justified, both from the standpoint of economic indicators of sea passage and in terms of protecting the marine environment.

8.1.2 Research on optimizing the concentration of sulfur compounds in marine fuel

Recently, the International Maritime Organization (IMO) has been working to reduce the concentration of sulfur compounds in marine fuel in Special Control Zones in order to reduce the level of environmental pollution, and since 2020, the entire merchant fleet has been transferred to low-sulfur fuel. In addition, the emission of sulfur dioxide in the exhaust gases of Ship power plants (EG SPP) is regulated – no more than 6 g / kW × h.

In case of exceeding the emission of sulfur oxides of more than 6 g / kW×h in the EG SPP, the IMO recommends cleaning the exhaust gases of the SPP from sulfur compounds on board the vessel.

This recommendation raises two main questions:

1) it is not entirely clear what system of purification of exhaust gases of the power plant from sulfur compounds should be used, by whom and when the recommended purification system was legalized, what technique, methodology is incorporated into the purification method, where this purification system has been tested, what results have been obtained, is there design documentation for the purification system, are there test reports and an environmental impact assessment?

2) on the basis of what data was the $SO2$ emission limit of 6 g / (kW × hour) adopted.

The answer to the first question sounds like a good wish, from which it is not clear to the navigator, the mechanic, what should be done in the current situation in the unit if the $SO2$ emission limit of 6 g / (kW × hour) is exceeded?

To answer the second question, it is necessary to conduct a more detailed scientifically based analysis.

Sulfur compounds contained in marine fuel are a complex composition, including mercaptans, sulfides, ethers, alcohols, acids. When sulfur compounds are burned (oxidized) in the cylinders of marine power plant engines, sulfur compounds are quantitatively converted into sulfur dioxide. To simplify the research, we will assume that all sulfur compounds contained in marine fuel are methyl mercaptan. The adopted simplification will in no way affect the qualitative and quantitative characteristics of the results obtained.

The oxidation process of methyl mercaptan ($CH3SH$) in the cylinders of marine power plants is described by the following stoichiometric equation:

$$CH3SH + 3O2 = SO2 + 2H2O + CO2 + QR \qquad (4)$$

Below is an example of calculating sulfur dioxide emissions depending on the concentration of methyl mercaptan in marine fuel.

Based on practical data, we will take the specific consumption of marine fuel (average) as 0.175 kg/kW×h, and in each specific case it is required to take the specific consumption of marine fuel according to the passport characteristics of the main SPP.

With the concentration of methyl mercaptan ($CH3SH$) in marine fuel of 3% by weight, the mass of methyl mercaptan ($CH3SH$) in marine fuel will be equal to $0.175\times3/100=0.00525$ kg/kW×h. Then, according to the stoichiometric equation (4), the material balance calculations carried out, the emission of sulfur dioxide with the exhaust gases of the SPP will be: 0.00525 × 1.33 = 0.00698 kg SO2/kW×h. Similar calculations of sulfur dioxide emissions with exhaust gases of the SPP were carried out at concentrations of methyl mercaptan, % by weight, in marine fuel: 0.1; 0.5; 1.0; 2.0; 3.0; 3.5; 4.0. Based on the calculations performed, Figure 2 was constructed showing the dependence of sulfur dioxide emissions on the methyl mercaptan content in marine fuel.

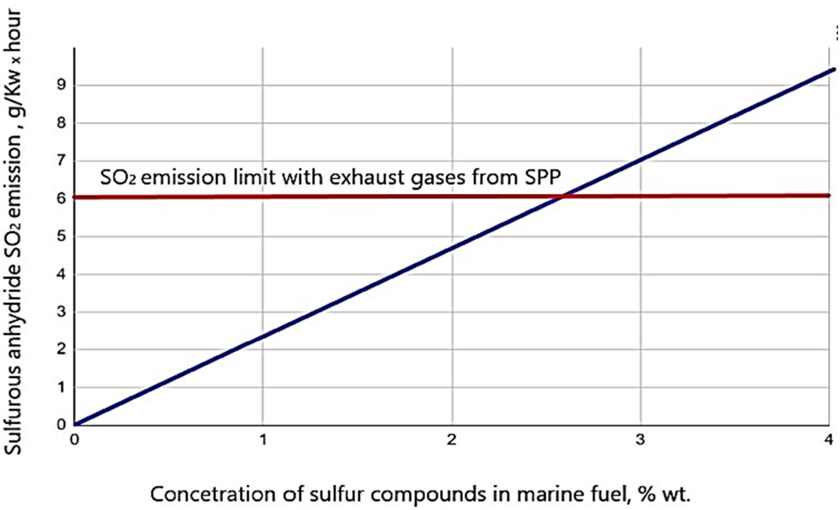

Figure 2. Dependence of sulfur dioxide emission in the exhaust gases of the SPP on the concentration of organic sulfur compounds in the marine fuel

Based on the obtained calculation and experimental data (Fig. 2), we will analyze how justified was the requirement to limit the content of sulfur compounds in marine fuel to no more than 0.1% by weight in the SECA, ECA zones (until 01.01.2020), no more than 0.5% by weight from 01.01.2020 worldwide. With a concentration of sulfur compounds in marine fuel of 0.1% by weight, the emission of sulfur dioxide from the exhaust gases of the SPP is 26.08 times less than the permissible limit

(6 g / (kW × h)) and with a concentration of sulfur compounds in marine fuel of 0.5% by weight. the emission of sulfur dioxide from the exhaust gas of the power plant is 5.17 times less than the permissible limit (6 g / (kW × hour)). Thus, in both cases (0.1% by weight and 0.5% by weight of sulfur compounds in marine fuel) there is a significant reserve from the prescribed limit on sulfur dioxide emissions. This raises a reasonable question: is it worth underestimating the concentration of sulfur compounds in marine fuel, because the process of desulfurization of marine fuel requires significant material and energy costs, which inevitably leads to an increase in the cost of marine fuel and, as a result, leads to a decrease in the economic efficiency of sea freight transportation.

What can be proposed?

1) the lines in Figure 2 intersect at a point corresponding to a concentration of sulfur compounds in marine fuel of 2.6% by weight. in this case, the established limit on sulfur dioxide emissions from the exhaust gas of the SPP-6g/(kW × h. will not be exceeded;

2) without harming the air basin, the concentration of sulfur compounds in marine fuel can be increased from 0.5% by weight to 2.6% by weight, i.e. more than five times, which will significantly reduce the cost of marine diesel fuel;

3) with a concentration of sulfur compounds in marine fuel of 3.5% by weight (without additional purification of marine diesel fuel), sulfur dioxide emissions will exceed the established limit by 1.36 times, which will require purification of the exhaust gas of the SPP from excess sulfur dioxide emissions to the established limit, but this in total is a low price for marine fuel containing 3.5% by weight. sulfur compounds, – and additional purification of the exhaust gas of the power plant from sulfur dioxide, will improve the efficiency of sea freight transportation [1].

Based on the research and design developments, it has been proven that by meeting the requirements of the International Maritime Organization for maximum emissions of sulfur oxides during the operation of ships of no more than 6 g / kW × h, it is possible to increase the permissible limit for the content of sulfur compounds in marine fuel from 0.5% by weight to 2.8% by weight (increase by 5.6 times), while the cost of marine fuel will be reduced by 1..55 times or by 242 US dollars / mt.

In this case, the economic efficiency of sea freight transportation will be increased.

8.2 Research on purification of exhaust gases of marine power plants from sulfur compounds

An analysis of technical solutions for purification of exhaust gases of marine power plants from sulfur compounds and those implemented on individual vessels was conducted.

As a result of the analysis, it was determined that the most significant results in the technology of purification of exhaust gases of marine power plants were achieved by the companies "Carnival Corporation" and "Wartsilla" (Finland). The purification technology is based on the absorption of sulfur dioxide by sea water mixed with alkali.

As an alternative solution for purification of exhaust gases of marine power plants from sulfur compounds, we proposed a new complex technology, fundamentally different from that developed by "Wartsilla" and "Carnival Corporation". A comparison of two process flow charts was performed based on eleven main parameters, recommendations were developed for the implementation of a system for purification of exhaust gases of marine power plants from sulfur compounds on sea vessels using cheap high-sulfur marine fuel on board ships.

An alternative technology for cleaning exhaust gases of power plants from toxic compounds has undeniable advantages in comparison with the technology developed by Carnival Corporation and Wartsilla – in terms of the depth and range of the spectrum of harmful toxic substances and compounds for cleaning exhaust gases of power plants, utilization of heat from power plant exhaust gases, the amount of prevented damage to the air basin, protection of the marine environment, continuity of the process regardless of specific situations of a sea passage, control of the processes of cleaning and utilization of heat from exhaust gases of power plants is automatic, autonomous from the navigation bridge. The decision of the Session of the Marine Environment Protection Committee of the International Maritime Organization prescribes the use of low-sulfur fuel containing no more than 0.5% by weight of sulfur compounds on ships worldwide from 01.01.2020. This IMO requirement does not affect ships equipped with power plant exhaust gas cleaning systems, as well as ships associated with research into power plant exhaust gas cleaning systems. Thus, the analysis of known technical solutions for cleaning the exhaust gases of the SPP has been carried out, among which it is worth noting such companies as "Carnival Corporation", "Wartsilla", which developed a scrubber cleaning of the exhaust gases of the SPP from sulfur compounds (scheme No. 1). The technology of the process of cleaning the exhaust gases of the SPP from toxic compounds, developed by a group of specialists of the Kherson State Maritime Academy under the leadership of Professor Leonov V. Ye. (scheme No. 2) is described.

A comparison of two technological schemes was carried out according to eleven indicators. As a result, an undeniable advantage of scheme No. 2 was determined.

We consider it expedient to conduct a Feasibility Study of the two schemes given above (possibly more) under the auspices of the Marine Environment Protection Committee of the International Maritime Organization in order to objectively select the optimal technology for cleaning the exhaust gases of the SPP for implementation in marine transport.

8.3 Research on minimization of the ship's operational energy efficiency index (EEOI)

EEOI is determined using the equation given in [14, p. 147].

We were the first to develop and propose for practical implementation an equation for determining the fuel consumption of a ship, depending on the SPP power, ship speed and weather conditions during the passage [15, p. 187]:

$$Rsf=f(Nspp)\times f(Vs)\times Pm\times Nspp\times t. \quad (5)$$

Research and development work on minimization of the Vessel's Operating Energy Efficiency Ratio was conducted on four different projects of real vessels, in real conditions of sea (transoceanic) passages depending on the passage distance, cargo mass, and vessel speed. According to the developed methodology, using mathematical modeling methods based on the obtained real research results in sea conditions, calculation studies were conducted to minimize the Operating Energy Efficiency Ratio of the Vessel/Voyage. The results of the research and development work are summarized and presented in the form of diagrams. It follows from the data obtained that regardless of the types of vessels and the designs of ship power plants used, the nature of the dependence of EEOI on the vessel's speed, the mass of the transported cargo, and the distance of the sea passage is described by the same qualitative patterns.

Thus, for the first time we have developed a mathematical model for minimizing the Operating Coefficient of Energy Efficiency of a Vessel, based on which for any type of vessel it is possible to determine with sufficient accuracy and reliability the area of minimization of EEOI depending on the speed of the vessel, the power of the vessel used, the mass of the transported cargo, and meteorological conditions. The adequacy of the developed mathematical model was checked on various types of vessels, and a sufficient degree of accuracy and reliability of the developed mathematical model was shown. The purpose of developing a mathematical model to determine the area of minimization of EEOI is to determine the conditions for conducting a voyage under which economic efficiency and environmental safety of a particular voyage are ensured.

8.4 Research on the development of ozone-safe refrigerants for refrigerators

Ozone-depleting substances (ODS) refrigerants are used to produce aerosol packaging (46%), refrigeration equipment and air conditioners (27%), foam plastics (11%), fire extinguishing agents (14%), and also using "chlorine-fluorine-carbon" (CFC) as a solvent (2%). Freons are also used in heat pumps as a coolant.

One chlorine atom can destroy 150,000 ozone molecules, i.e. chlorine atoms act as a catalyst for the decomposition of ozone. Other gases that destroy ozone include hydrocarbons and nitrogen monoxide (II).

Currently, about 80% of aerosols produced in the world are based on the use of hydrocarbon propellants. Cyclopentane is widely used as a foaming agent. In refrigeration technology, the introduction of ozone-safe substances is accompanied by the greatest difficulties. This is due to the very high thermodynamic and technical and operational characteristics of refrigerants in the temperature range from minus 46 ° C to 24 ° C. However, the transfer of aerosol products and foaming technology to hydrocarbons does not solve, but only softens the problem of ozone layer degradation, by analogy, hydrocarbons also destroy the ozone layer. Is there an alternative to ODS and hydrocarbons? In our opinion, it is dimethyl ether (DME), the ozone safety of which is due to the symmetrically located CH3 groups equivalent in bond energy relative to the oxygen atom. DME is a fairly stable chemical compound, under normal conditions – a gas, liquefies at a pressure of 12 atm. and higher. In its physicochemical properties, DME is close to the propane-butane fraction. Hazard class – fourth. Even if a stable DME molecule loses both radicals (CH3), atomic active oxygen will remain, which will be a source of ozone. Thus, both from a technical and environmental point of view, especially as an ozone donor, DME can effectively replace ODS and hydrocarbons in the near future.

The raw material base for obtaining DME is quite wide, with a large reserve factor – coal, natural and associated gases, gaseous waste from metallurgical enterprises, petrochemical waste, gas condensate, mine methane, biogas, shale gas, hydrogen sulfide, carbon dioxide, water.

DME can be obtained from waste from the production of synthetic methanol, formalin, from dimethyl sulfate at elevated temperatures (250–300 °C) using copper oxide as a catalyst, by the esterification reaction of methanol in the presence of sulfuric acid. All these factors determine the low cost and environmental safety of DME in comparison with currently used ODS.

The proposed technologies for obtaining DME are distinguished by the novelty of technical solutions, there are author's certificates and patents.

The developed technologies meet modern requirements of resource conservation, low waste and meet the International environmental requirements of ISO 14001, and the manufactured product dimethyl ether does not lead to the destruction of the ozone layer of the Planet [14, p. 357].

Conclusions, proposals and recommendations.

Based on research and development work, technical proposals have been developed for the technology for obtaining an ozone-safe refrigerant - dimethyl ether – in two ways:

1. Catalytic dehydration of aliphatic alcohols.
2. Catalytic hydrogenation of carbon monoxide.

As a result of the analysis, it was determined that the proposed technologies for obtaining dimethyl ether and its use are environmentally safe for the ozone layer of the Planet and economically feasible. The developed technologies are recommended for implementation on refrigerated sea vessels and in other industries using refrigerants.

8.5 Research on the safe and harmless use of ship ballast water.

Marine ballast water is indispensable for the safe and efficient operation of modern maritime transport, ensuring the stability of ships sailing empty and loaded.

However, ballast water poses a serious threat to the environment and the economy, as well as to human health, marine flora and fauna [9, p. 457].

The concept of "biological, marine invasion" first arose when in 1988 Canada informed the IMO Marine Environment Protection Committee that marine organisms alien to this ecosystem had been discovered in the Great Lakes.

The transfer of alien marine organisms to new natural conditions with ships' ballast water has been identified by the Global Environment Facility as one of the most significant threats to the World Ocean. In recent decades, due to the rapid development of shipping, cases of the dispersal of living organisms by ships to various areas of the World Ocean have become more frequent. The transfer of alien organisms by ships can be carried out with their ballast water and sediments.

According to estimates by the International Maritime Organization, the annual global turnover of ballast water is about 12 billion tons.

The discharge of ballast water into the marine environment is potentially dangerous, and the severity of this problem is reflected in the UN Convention on the Law of the Sea of 1982, Article 196 of which recommends "to take measures to prevent and control pollution of the marine environment resulting from the intentional or accidental introduction of organisms, alien or new to the marine environment, which are likely to cause significant and harmful changes thereto."

As a result of the analysis and generalization of scientific, technical and patent materials, we have identified the following methods of treating ballast water – Ballast Water Treatment (BWT) – and their neutralization:

1. High-temperature destruction.
2. Ultraviolet treatment of BWT.
3. Treatment with chlorine-containing compounds.
4. Ultrasonic treatment of BWT.
5. Biological treatment of BWT.
6. Physicochemical treatment of BWT.
7. Combined treatment of BWT.

8. Use of inert gases in the treatment of BWT.

However, the listed methods have significant drawbacks:

Low efficiency, high capital investments and energy costs (p. 1, 8).

Repeated pollution of the marine environment with ballast water (p. 3, 5).

Negative impact on the ship's crew (p. 2, 4).

Low specific productivity of the methods (p. 1-5, 8).

The requirement for large sizes of working production areas and the formation of side compounds (p. 3, 5, 8), which is unacceptable in conditions of limited space on board a ship and a sea passage.

Based on scientific research, we have developed an innovative technology for the sanitary treatment of ballast water with its subsequent reuse. Unfortunately, we will not be able to describe the developed technology, since an application for an invention and a patent have been filed.

8.6 Research into the feasibility of using oxygen on board a ship instead of atmospheric air as an oxidizer for marine fuel

In the total consumption's of world hydrocarbon resources, the share of marine transport is more than 15%, and this share has a steady upward trend.

When burning one conventional unit of mass (CUM) of marine hydrocarbon fuel, approximately 20 CUM of atmospheric air are consumed, while the emission of carbon dioxide, the main component of "greenhouse" gases, increases more than three times compared to the consumption of marine fuel.

Currently, almost all man-made systems use atmospheric air for oxidation (combustion) processes (in general, this share exceeds 99%): the spectrum is quite wide, from a gas stove in the kitchen to marine power plants and aircraft engines.

Atmospheric air, with a small degree of error, includes two main macrocomponents: approximately, % vol.: nitrogen 79.03, oxygen – 20.92, the rest is carbon dioxide, argon, xenon, krypton, ozone, helium, hydrocarbons in total – 0.05. In Ship power plants (SPP) for the processes of oxidation (combustion) of fuel, only oxygen contained in the source air is consumed, and not completely (in the exhaust gases of the SPP, the residual oxygen concentration fluctuates within 4.5-8.5% vol.), and nitrogen in this case is an inert gas. Under the conditions of combustion of marine diesel fuel in the MPP – pressure 25-35 atm., temperature 800-1000 ° C in the engine cylinders from nitrogen and oxygen in the air, nitrogen oxides are formed, which negatively affect the air basin, the marine environment and lead to new problems, i.e. to the need to standardize nitrogen oxides in exhaust gases and clean the exhaust gases of the SPP from nitrogen oxides.

Since in the case of using air to oxidize Ship diesel fuel (SDF), nitrogen acts as an inert gas, then a significant amount of energy resources (marine diesel fuel) is spent on its heating (up to 800-1000 ºC), compression (up to 25-35 atm.). Moreover, in all SPP designs, an excess of air against the theoretical (stoichiometric) is provided in order to increase the degree of oxidation (combustion) of marine diesel fuel.

The task is set to replace the oxidizer atmospheric air with oxygen, to analyze the processes of oxygen production, to propose an economically, energetically efficient and environmentally friendly method of obtaining oxygen. As a final result, when replacing air in the SPP with oxygen as an oxidizer for the SDF, the distribution structure of the consumption of 1 ton of SDF will change as follows (t, %):

1) for the production of useful work – 0.50 t, 50%;

2) when burning SDF in the SPP for organizing the cycle "heating-compression-throttling, cooling" of the exhaust gases of the SPP – 0.05 t, 5%;

3) for the formation of material and energy waste during the combustion of SDF in the SPP – 0.45 t, 45%.

Of course, a certain reserve is hidden in point 3 – the formation of material and energy waste during the combustion of SDF in the SPP, the value will be much lower.

Thus, if oxygen is used instead of air, the share of the completed useful work will increase by 25% and will be 50%, while in air only 25%, i.e., the contribution to the useful work of the SPP will increase twofold. In addition, the emission of nitrogen oxides will be completely eliminated.

In the case of using oxygen, the load on the SPP for the oxidizer will decrease from 20 tons (in the case of using atmospheric air) to 4.2 tons (in the case of using oxygen), i.e. almost 5 times, and this will lead to a decrease in the dimensions of the SPP, heat losses, and consumption of the SDT.

When using oxygen instead of air as an oxidizer of marine diesel fuel, the following problems will be solved:

1) reduction in the consumption of marine diesel fuel due to a twofold increase in the share of useful work;

2) reduction in the emission of toxic components with the exhaust gases of the SPP in accordance with the reduction in the consumption of marine diesel fuel;

3) reduction of the weight and dimensions of the ship's power plant;

4) reduction of the heat losses of the power plant in accordance with the reduction of the weight and dimensions of the ship's power plant;

5) emissions of nitrogen oxides with the exhaust gases of the power plant are completely eliminated;

6) as the feedstock for obtaining oxygen, it is recommended to use water and carbon dioxide, which have a high index of reserve multiplicity (more than 1012) and a high concentration of oxygen in their composition – 3.5 times more for carbon dioxide and 4.3 times more for water compared to atmospheric air.

8.7 Integrated marine unit for disposal of oil-containing waters.

The main sources of marine pollution with hydrocarbons:

– discharge of oil-containing waters (OCW) from ships – emergency, after tanker washing;

– ship collisions, berthing, grounding;

– wastewater from man-made systems.

Cleaning of OCW is a rather complex technical task, which is characterized by high capital investments, consumption of energy and material resources, and cost of cleaning.

The goal of the work is to develop a mobile, efficient, self-propelled unit for cleaning and recycling of OCW, which will reduce damage to the marine environment and improve the economic performance of the voyage.

Sorbents have been developed to absorb hydrocarbons (HC) from the marine environment, 1 g of sorbent absorbs 50 g (HC).

The self-propelled unit is designed to receive OCW from ships, as well as to clean marine waters from emergency discharges of oil and oil products (Fig. 3).

Stages of the process of cleaning, utilization of HC, implemented on a self-propelled unit:

1) separation (section A), the degree of purification α1 is 25-35%;
2) pressure high-speed flotation (section A), α2 is 70-85%;
3) adsorption of HC on a unique sorbent (section A) α3 is 99.99%;
4) regeneration of the saturated HC sorbent (section A).

To create a shipping station, it is proposed to use a tanker, the bow of which is made in the form of a truncated cone and equipped with a ramp on which a unit of brush plates rotating in a vertical plane is installed.

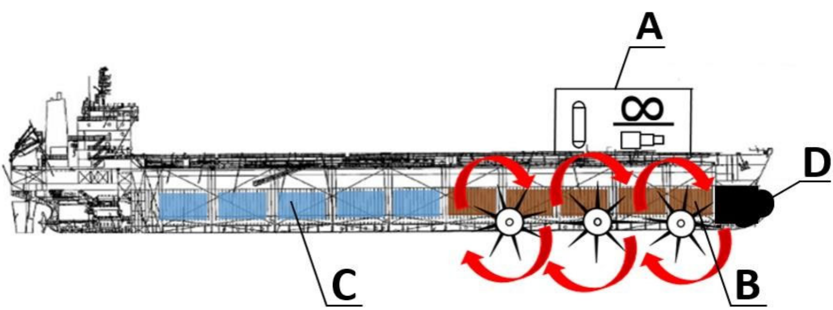

Figure 3. Floating self-propelled station for cleaning and recycling of HC (model VL-152)

The hydrocarbons separated from oil-containing sea water are collected in section D.

The uniqueness of the development lies in the implementation of paragraphs 3, 4 of the above stages of the process, which compare favorably with those known in the world and are protected by patents.

As a result of the implementation of a self-propelled recycling unit, two important problems are solved:

1) the damage to the marine environment from hydrocarbons is reduced [16];

2) economic efficiency is increased.

Thus, as a result of the studies, the following generalizations can be made:

1. An analysis and generalization of scientific and technical materials on the purification of oil-containing waters was carried out, which showed the shortcomings of existing methods, both in terms of the speed of

purification and the degree of purification, the lack of mobility for collecting hydrocarbons from the sea surface, and rolling them off from scheduled ships, low economic indicators of the process.

2. A modern technology for cleaning and recycling oil-containing waters is proposed for its implementation as part of a self-propelled unit based on the use of tankers and chemical gas carriers previously operated in the sea and river fleet.

3. The creation of a self-propelled marine unit will reduce the risk of damage to the marine environment, increase energy efficiency due to the disposal of "waste" hydrocarbons and reduce the cost of cleaning NW. A result of the conducted own research, analysis and generalization of the published materials it is necessary to draw certain final conclusions.

Man-made systems use mainly energy resources of non-renewable nature (90%), the reserves of which are depleted, which can lead to a global catastrophe. Attempts to transfer man-made systems to "Green" energy were unsuccessful for a number of reasons, detailed in this article. For the rational use of the remaining non-renewable energy resources it is proposed to transfer man-made systems to resource-saving, waste-free technologies with a simultaneous search and use of natural alternative energy sources. For a more distant perspective for the first time a triad of basic energy is proposed, including nitrogen, carbon dioxide and water. The reserve multiplicity of the elements of this triad has a high index, is practically unlimited and environmentally safe. On the basis of the specified triad large-tonnage technologies for the production of carbon-containing and nitrogen- containing compounds of chemical and petrochemical synthesis are proposed. Within the limits of non-renewable energy use, research and development, design and construction, and installation work by new enterprises will enable a smooth transition of man-made systems from traditional non-renewable energy to new energy with a high reserve factor and environmentally friendly

9. The main conclusions are given below:

1. The balance of the world energy is dominated by non-renewable, hydrocarbon raw material base, the reserves of which are running out.

2. In order to save the raw material base of the third class, it is proposed to switch to resource-saving technologies and use alternative energy sources.

3. A raw material triad of the energy of the future is proposed, including water, carbon dioxide, nitrogen.

4. Based on the proposed triad, the directions of research work on obtaining organic and inorganic compounds are presented.

5. In the future, it is advisable to develop research work on the receipt of fuel, electricity, petrochemical synthesis products based on cheap processing, available, with a large rate of reserves of new energy resources.

References:

1. Tran T.A. (2017). Research of the Srubber Systems to Clean Marine Diesel Engine Exhaust Gases on Ship. *Journal of Marine Science: Research and Development*. Nu 3, p. 243-252. DOI: https://doi.org/10.4172/2155-9910.1000243

2. Anders B. Laursen (2018). Availability of Elements for Heterogenious Catalysis : Predicting the Industrial viability of Novel Catalysts. *Chinese Journal of Catalysis*. Vol. 3, Nu 5, pp. 16-26. DOI: https://doi.org/1016/S1872-2067(17)62979-6

3. Winnes H. (2015). Reducing GHG Emissions from Ships in port areas. *Reaearch in Transportation Business and Management*. Nu 4, p. 73-82. DOI: https://doi.org/10.1016/jrtbm.2015.10.008

4. Rehmatulla N., Calleya J., Smith T. (2017) The Implementation of Technical Energy Efficiency and CO2 Emission Reduction Measures in Shipping. *Ocean Engineering*. Vol. 139. P. 184–197. DOI: https://doi.org/10.1016/j.oceaneng.2017.04.0

5. Leonov V.E., Serdyuk A.D. (2020) Issledovaniya т o parametricheskoj svyazi EEOI sudna v usloviyah realnogo morskogo rejsa [Investigation of the Parametric Connection of EEOI and the Ship in the Condition of a Real Sea Flight]. *Nauchnye problemy vodnogo transporta* [Journal Scientific Problems of Water Transport]. Nizhniy Nobgorod : Volga State University of Water Transport. Iss. 65, pp. 105-116. DOI: https://doi.org/10.37890/jwtvi65.133

6. Pivovarov L.A. (2013). Razrsbotka Plana Upravleniya Energoeffektivnosty Sudna (PUEES) dlya Tankerov [Development of a Ship Energy Efficience Management Plan (SEEMP) for tankers]. L.A. Pivovarov // Sb. Materialov Mezhdinarodnoi Nauchno-Practichn. Konferencii [Collection of Materials of the International Scientific and Practical Conference]. Kherson: ITS KHGMA/KSMA// Vol. 1, p. 73-77.

7. MEPC 65/INF IMO Model Course on Energy Efficient Operation of Ships. (2013) London : World Maritime University. 71 p.

8. Guidelines for voluntary Use of the Ship Energy Efficiency Operational Indicator (EEOI) (2009). London ; IMO. 45 p.

9. Leonov V.Ye. (2016). Uchebnoe posobie. Ekologiya i okhrana okruzhayushchei sredi [Textbook. Ecology and environmental protection] // V.Ye. Leonov, A.V. Khodakovskii / Pod redaktsiei professora Leonova V.E. Kherson: Izdatelskii Tsentr KhGMA, 352 p.

10. Ship Energy Efficiency Management Plan (SEEMP). (2012) SEEMP Template for Owners and Operators. London : Lloyds Register. 12 p.

11. Leonov V. E (2023) Issledovanija protsessov povysheniya effektivnosti sudovykh morskikh grusoperevozok [Research on the Processes of Increasing the Efficiency of Ship Cargo Transportation by Sea]. *Tsifra. Ekonomika* [Cifra. Economy]. № 3 (3), pp. 3-12. DOI: https://doi.org/10.23670.ECNMS.2023.3.6

12. Leonov V.Ye. (2024) The Planetary «Climate» Crisis is a Problem for the International Community. VII International Conferense «Innovative Technologies in Science and Education. European Experience». Materials. Electronic publication. Dnipro: Jurfond, pp. 157-161. ISBN 978-966-934-625-4

13. Valeriy Leonov (2025) Pollution of the World Ocean with Plastic Waste-No More Plastic. International Scientific Conference. Theoretical and Practical Aspects of the Formation of the Scientific Area : Conference Proceedings, March 21-22. 2025. Riga, Latvia : Baltija Publishing, pp. 140-144. DOI: https://doi.org/10.30525/978-9934-26-536-5-30.

14. Leonov V.Ye. (2020). Sovremennye metody Issledovaniy i obrabotki eksperimentalnyh dannyh [Modern Methods of Research and Processing of Experimental Data]. Kherson: IC KhGMA. 698 p.

15. Leonov Valeriy (2024) Research on Optimization of Maritime Cargo Transportation in South East Asia. Science, Technology and Innovation in the Context of Global Transformation : Scientific Monograph. Riga, Latvia : Baltija Publishing, pp. 182-204. DOI: https://doi.org/10.30525/978-9934-26-499-3-10

16. MARPOL (2011). Consolidated edition 2011: Articles, Protocols, Annexes and Unified Interpretations of the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the 1978 and 1997 Protocols. London: CPI Group, 2011. 447 p. ISBN 978-92-801-1532-1.

Список літератури:

1. Tran T.A. (2017). Research of the Srubber Systems to Clean Marine Diesel Engine Exhaust Gases on Ship. *Journal of Marine Science: Research and Development*. Nu 3, pp. 243-252. DOI: https://doi.org/10.4172/2155-9910.1000243

2. Anders B. Laursen (2018). Availability of Elements for Heterogenious Catalysis : Predicting the Industrial viability of Novel Catalysts. *Chinese Journal of Catalysis*. Vol. 3, Nu 5, pp. 16-26. DOI: https://doi.org/1016/S1872-2067(17)62979-6

3. Winnes H. (2015). Reducing GHG Emissions from Ships in port areas. *Research in Transportation Business and Management*. Nu 4, pp. 73-82. DOI: https://doi.org/10.1016/j rtbm.2015.10.008

4. Rehmatulla N., Calleya J., Smith T. The Implementation of Technical Energy Efficiency and CO2 Emission Reduction Measures in Shipping.Ocean Engineering. 2017. Vol. 139. P. 84-197. DOI: https://doi.org/10.1016/j.oceaneng.2017.04.029

5. Леонов В.Е., Сердюк А.Д. Исследование параметрической связи EEOI судна в условиях реального морского рейса. *Научные проблемы водного транспорта.* Н. Новгород : Волжский государственный университет водного

транспорта 2020, Выпуск 65, С. 105-116. DOI: https://doi.org/10.37890/jwtvi65.133

6. Пивоваров Л.А. Разработка плана управления энегоэффективностью судна (ПУЭЭС) для танкеров. *Сб. материалов Международной научно- практической конференции.* Херсон : ИЦ ХГМА. 2013. том 1, с. 73-77.

7. MEPC 65/INF IMO Model Course on Energy Efficient Operation of Ships. (2013) London : World Maritime Iniversity. 71 p.

8. Guidelines for voluntary Use of the Ship Energy Efficiency Operational Indicator (EEOI) (2009). London ; IMO. 45 p.

9. Леонов В.Е., Ходаковский А.В. Учебное пособие. Экология и охрана окружающей среды. Под редакцией профессора Леонова В.Е. Херсон : Издательский Центр ХГМА. 2016, 352 с.

10. Ship Energy Efficiency Management Plan (SEEMP). (2012) SEEMP Template for Owners and Operators. London : Lloyds Register. 2012. 12 p.

11. Леонов В.Е. Исследования процессов повышения эффективности судовых морских грузоперевозок. *Cifra. Экономика.* 2023. № 3 (3). С. 3-12. DOI: https://doi.org/10.23670.ECNMS.2023.3.6

12. Leonov V.Ye. The Planetary «Climate» Crisis is a Problem for the International Community. VII International Conferense «Innovative Technologies in Science and Education. European Experience». Materials. Electronic publication. Dnipro: Jurfond. – 2024. p. 157-161. ISBN 978-966-934-625-4

13. Leonov Valeriy. Pollution of the World Ocean with Plastic Waste-No More Plastic. International Scientific Conference. Theoretical and Practical Aspects of the Formation of the Scientific Area : Conference Proceedings, March 21-22, 2025. Riga, Latvia : Baltija Publishing, 2025, pp. 140-144. DOI: https://doi.org/10.30525/978-9934-26-536-5-30.

14. Леонов В.Е. Современные методы исследований и обработки экспериментальных данных. Монография / Под редакцией проф. В.Е. Леонова. Херсон : ИЦ ХГМА. 2020. – 698 с.

15. Leonov Valeriy. Research on Optimization of Maritime Cargo Transportation in South East Asia. Science, Technology and Innovation in the Context of Global Transformation : Scientific Monograph. Riga, Latvia : Baltija Publishing, 2024, 204 p. DOI: https://doi.org/10.30525/978-9934-26-499-3-10

16. MARPOL Consolidated edition 2011: Articles, Protocols, Annexes and Unified Interpretations of the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the 1978 and 1997 Protocols. London: CPI Group, 2011. 447 p. ISBN 978-92-801-1532-