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Solution of the Two-vector Problem of Resource Saving on Board of the Ship

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Abstract: Recently, the International Maritime Organization has taken a number of design decisions aimed at reducing the consumption of marine diesel fuel, carbon dioxide and sulfur dioxide emissions. The latter can be achieved by introducing the ship's energy efficiency management plan into maritime practice, minimizing the operational coefficient of the ship's energy efficiency, and transferring maritime transport to low-sulfur fuel. In addition to the above measures, this article proposes an integrated technology for the purification of exhaust gases from ship power plants (EG SPP) and utilization of the heat of exhaust gases from the SPP. The analysis of the known technical solutions for the purification and utilization of the heat of the exhaust gas of the power plant is carried out, their shortcomings are revealed and the ways of developing a resource-saving technology are outlined. As a result of the research carried out, the main components that lead to an increase in the efficiency of sea cargo transportation and the protection of the environment have been identified. Due to the implementation of the developed integrated technology, the damage to the air basin from the EG SPP is reduced by five times.

Keywords: “Greenhouse” Effect, Utilization of Exhaust Heat, Catalytic Cleaning, Fuel Consumption, Marine Environment, Emissions

1. Introduction

Energy efficiency is generally understood as rational use of energy or the use of less energy to ensure the required level of product manufacture during technological processes in production and transport. Over the past decades, the issue of energy efficiency has received increasing attention. This is due both to the depletion of hydrocarbon resources of a non-renewable nature, and to the "concern" for the protection of the marine environment, which has been increasing recently, especially in the resolutions of the International Maritime Organization.

The International Energy Agency has prepared a significant number of materials on the implementation of energy efficient technologies in the transport industry [1]. This is explained by the fact that transport is a technogenic sphere with the highest level of consumption of material and energy resources.

The correlation of «greenhouse» gas emissions from ship power plants into the atmosphere and energy efficiency is as follows. The International Maritime Organization (IMO) has introduced an indicator that characterizes the energy efficiency of a vessel / voyage and, at the same time, the environmental safety of navigation, is determined by the ratio of the mass of carbon dioxide formed during the combustion of marine fuel to the mass of the transported cargo and the distance traveled by the sea passage. To convert the amount of fuel consumed by the ship into carbon dioxide emissions it is necessary to multiply the fuel mass by the coefficient K = 3.114 - 3.72, depending on the type of marine fuel [2].

One of the methods of increasing the energy efficiency of shipping, according to the resolution of the International Maritime Organization MEPC.213 (63), is the heat utilization method, that is, modern systems must use the heat of waste gases of ship power plants of the main and auxiliary power plants in the production of energy or in shafts.

These requirements are set out in the Ship / Voyage Energy Efficiency Management Plan (SEEMP) developed by IMO [2-5].

In the total balance of operating costs of ship power plants, the share of consumed diesel fuel is 70-80%. Therefore, improving the energy efficiency of ship power plants (SPP) is the most important task. The efficiency of ship power plant until the early-mid 70s of the last century was insignificant (the efficiency of the main engines barely reached 37% at the exhaust gas temperature of 375°C) and even with their relatively low power. This necessitated the creation and widespread use of ship systems for deep utilization of heat, the demand for was due to a sharp "jump" in fuel prices at the end of the third quarter of the last century. All this stimulated the development of technical solutions that contributed to a significant increase in the efficiency of the main engines.

To date, the efficiency main engines reached a maximum of 45% with a decrease in the temperature of the exhaust gases and an increase in the proportion of low-grade heat of the cooling water.

This is resulting from:

1. application of constant boost pressure, which led to a decrease in exhaust temperature and significantly reduced the proportion of losses with exhaust gases;
2. the use of highly efficient turbochargers, which, together with the previous factor, made it possible to reduce the EG SPP temperature to 240°C;
3. an increase in the temperature of the fresh water cooling the cylinders to 75 - 80°C.

In the systems used, the efficiency of "exhaust" heat recovery reaches 60% due to the use of efficient utilization boilers, heating of feed water, and turbine generators [6].

A specific feature of modern diesel engines (in contrast to the pre-crisis period) is their operation on heavy fuel [7], with the exception of their start-up and work on maneuvers.

Modern highly efficient low-speed engines are characterized by increased efficiency - 45% and a reduced specific consumption of marine diesel fuel 152 g / kW per h, which is due to various schemes for increasing their energy efficiency [8].

There are several ways of heat utilization: waste gas energy utilization, coolant heat utilization, engine oil heat utilization, reduction of harmful substances in the exhaust gases of marine diesel engines [9, 10].

The energy efficiency of a ship depends not only on the effective efficiency of the main engines, it is also determined by the energy consumption for the drives of auxiliary mechanisms, the heat and power supply system. Recovering "waste" heat on ships can lead to significant fuel savings while at the same time achieving reductions in CO_2 emissions. Moreover, this will reduce the cost of cargo transportation, as well as improve the living conditions of the crew without additional power costs. Secondary energy resources on ships are significant and the issues of their utilization remain unresolved.

The efficiency of the use of systems for deep utilization of the heat of exhaust gases has decreased due to a significant decrease in the temperature of the exhaust gases, therefore, it can be argued, that the possibilities of increasing the efficiency of marine diesel engines by utilizing the combustion products of the initial heat are practically exhausted. Therefore, recently among scientists who have studied this problem [8], the idea has arisen that the use of integrated heat utilization systems does not give anything but difficulties in their maintenance and repair.

In most ships (with the exception of tankers carrying oil products and requiring significant heat input for heating oil products), the amount of heat that can be used in utilization boilers significantly exceeds the ship's needs. The excess heat of exhaust gases, over heat supply and other needs (except for heating the cargo), increases with an increase in the capacity of the ship's power plant. Therefore, modern large sea vessels use the so-called deep heat recovery systems (DHR), where the generated steam is used for heat supply and electricity generation.

So, the energy recovery plant, consisting of: a waste heat boiler, a turbine generator, a condenser and other elements that make up a conventional steam turbine power plant, can completely replace the auxiliary boiler and a diesel generator in the main running modes. If the steam consumption exceeds the steam capacity of the waste heat boiler, then the auxiliary one is switched on, which generates the required amount of steam.

2. Materials and Methods

In maritime transport, the real scheme of utilization of thermal energy of exhaust gases from the SPP includes the following stages:

1. Heat recovery in waste heat boilers with the production of low-parameter steam and hot water.
2. Desalted water production unit.
3. Recovery, regeneration of the efficiency of heat transfer surfaces covered with soot deposits and, accordingly, leading to a decrease in heat transfer, by blowing with "live" steam.
4. Emissions of waste "live" steam into the air basin together with soot deposits.

Disadvantages of the currently operating systems for the utilization of heat of exhaust gas of the SPP:

1. Low heat transfer efficiency.
2. Air pollution when blowing with "live" steam soot.
3. Air basin and marine environment pollution with soot deposits.

In works [11, 12], the idea of an integrated technology was formulated for the first time, which includes the actual quantitative cleaning of exhaust gases from ship power plants and deep utilization of the heat of exhaust gases from the power plant. The idea of an integrated technology has been formulated, including the actual quantitative cleaning of exhaust gases from ship power plants and deep utilization of the heat of waste gases from a power plant [11, 12]. Moreover, the complex process is carried out without additional energy and material costs. In fact, the proposed technology allows to solve the following problems:

1) increase the energy efficiency of the vessel / voyage by 25%;
2) reduce by several orders of magnitude the absolute damage to the air basin, the marine environment from the exhaust gases of the SPP;
3) reduce carbon dioxide emissions by 75%;
4) stop using expensive and scarce low-sulfur marine diesel fuel;
5) receive target products and energy in the form of

high-parameter steam and heated water from the exhaust gases of the power plant.

As an alternative solution, an innovative technology for utilizing the heat of exhaust gases from the SPP is proposed.

A comprehensive scheme for the purification of the EG of SPP from toxic compounds and utilization of heat of the EG of SPP for ships is shown in Figure 1 [11-15]:

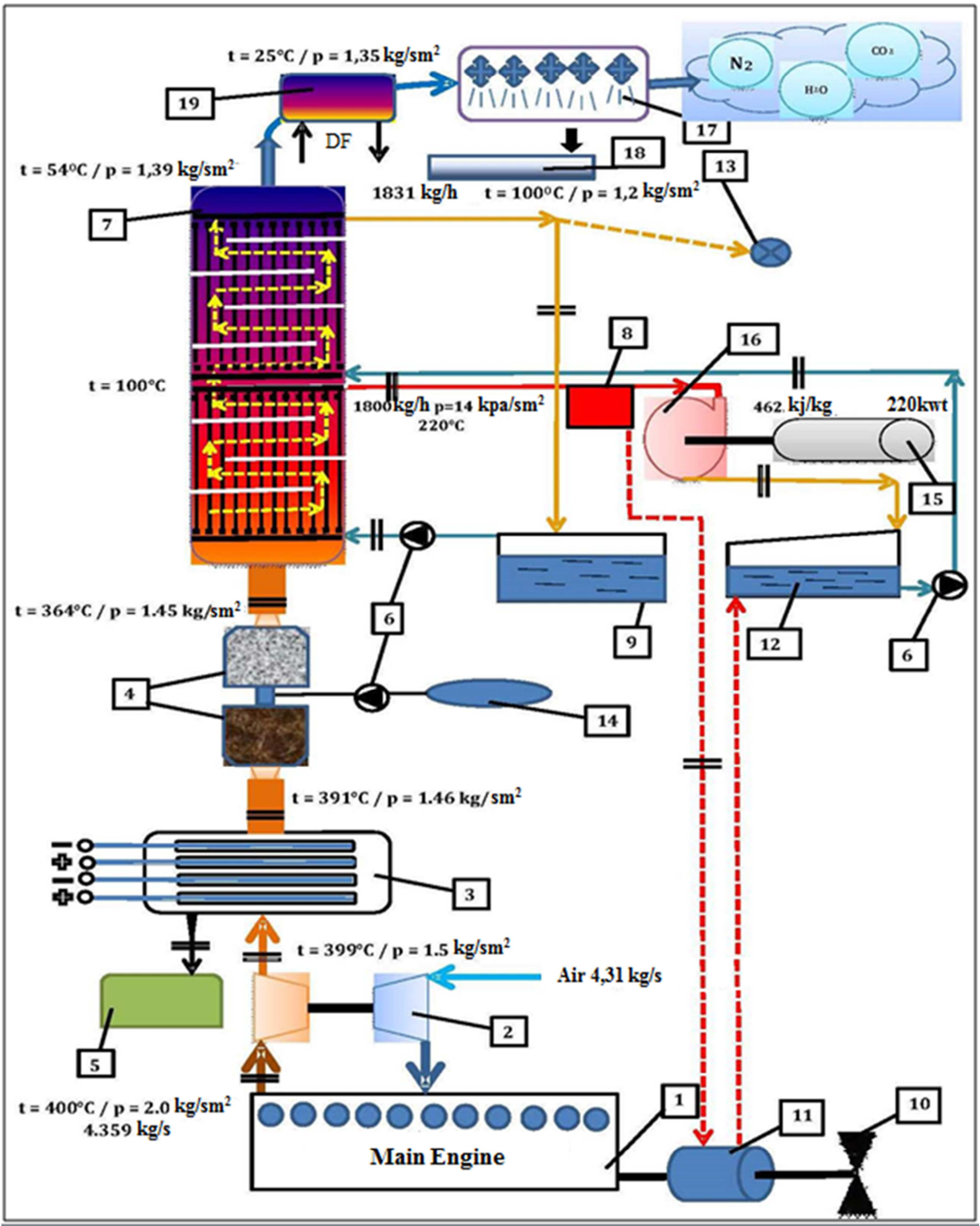

Figure 1. *A comprehensive scheme for the purification from toxic compounds and utilization of heat of the EG of SPP for the vessel «OXL SAMURAI» [11-15].*

1. EG of SPP - after the main ship engine (1) at a temperature of 400°C enter the turbine (2) and then the electrostatic precipitator (3), the catalytic reactor apparatus (4), which is equipped with oxidation and reduction catalysts. At a temperature of 363.6°C, the exhaust gases of the SPP enter the economizer (7), where heat exchange with water circuits occurs, then at a temperature of 54°C they enter the refrigerator-condenser (19), in which the temperature drops to 25°C, the scrubber (17), where sulfuric acid is formed, the latter is collected in a container (18).
2. Condensate circuit - from the tank (12) at a temperature

of 25 - 45°C, the condensate is delivered by the pump (6) to the primary heat exchange circuit, where it is heated to 100°C and fed to the main distribution tank (9), from where it is automatically discharged to the secondary circuit of the economizer (7), in which steam is generated with a pressure of 14 kgf / sm^2, which is used to drive a steam turbine unit (16) and / or generate electricity using a generator (15), or steam is supplied to a steam turbine unit (11), where it is used as an additional power for the ship's propulsion system. After the transfer of energy to the turbine (16 or 11), the exhaust steam in the form of condensate returns to the tank (12).

3. Air circuit - passes through the discharge section of the twin turbine, the heat exchanger for engine cooling and enters the marine engine as part of the fuel-air medium.

To cool the treated exhaust gas of SPP to 15-25°C in a refrigerator-condenser (19) and obtain additional energy savings, it is proposed to use the original diesel fuel as a coolant [12, 13].

The developed technology is intended directly on board the vessel and allows, in comparison with the known proposals, to solve the following main topical issues of shipping within the framework of SEEMP and Energy efficiency operanional index of the vessel (EEOI) [2-5]:

1) use cheap heavy fuel on board IFO 180,380 (3,5% weight «S»);
2) to increase the economic indicators of the vessel, voyage due to the utilization of the heat of the exhaust gas of the power plant and the receipt of target products;
3) ensure the ecological safety of the sea environment during the operation of ships, regardless of their project, type, cargo and route;
4) ensure the minimum value of the Operating Energy Efficiency Factor of the vessel / voyage;
5) reduce emissions of carbon dioxide, the main component of "greenhouse" gases.

According to the Resolution of the International Maritime Organization, from 01.01.2020, all maritime transport was switched to low-sulfur marine fuel, with the exception of sea vessels equipped with systems for cleaning exhaust gases of ship power plants from sulfur compounds, as well as sea vessels on which research is being carried out to develop new systems for cleaning waste SPP gases from sulfur compounds. In connection with the above, as well as the fact that in the technology presented by us for the utilization of the heat of the exhaust gases of the SPP, the purification of the exhaust gases of the SPP gases occupies a significant part of the technology, it seems appropriate to analyze and generalize the modern technologies for the purification of the exhaust gases of the SPP from sulfur compounds.

The company «Wartsila» to reduce the emission of Sulphur dioxide from EG SPP offers the following technological directions – the transfer of maritime transport to the low-Sulfur fuel, the use of liquefied natural gas, scrubber cleaning [16]. In the directions mentioned above, «Wartsila» gives preference to the scrubber cleaning from Sulphur dioxide. In work [17] researches on scrubber cleaning from sulphurous anhydride are carried out and it is defined that the maximum degree of cleaning from SOx makes 95%, and from solid particles (soot) – 60%. Researches on scrubber cleaning from sulphurous anhydride are carried out and it is defined that the maximum degree of cleaning from SOx makes 95%, and from solid particles (soot) – 60% [17]. It remains unclear under what conditions the above results have been achieved, with or without circulation of the reactive absorbent, whether the degree of purification obtained is sufficient for the safe release of purified gases into the atmosphere.

In work [18] the analysis and generalization of use of catalysts for neutralization of toxic substances and connections is conducted. The analysis and generalization of use of catalysts for neutralization of toxic substances and connections is conducted [18].

In work [19] computational studies on the emission reduction components of "greenhouse" gases in the operation of the courts are conducted. Computational studies on the emission reduction components of "greenhouse" gases in the operation of the courts are conducted [19]. Carbon dioxide, methane, nitrous oxide are the key components of "greenhouse" gases. The calculation was carried out on the condition that the average air temperature should not exceed 2 degrees Celsius in accordance with the Protocol of the Climate Summit (2015, Paris, France). The method of calculation of emission components of "greenhouse" gases released during combustion of marine fuel in the conditions of the regular route and port handling.

In work [20] as a result of survey of shipping companies and ship owners the most effective technologies which will allow to optimize EEOI and to reduce considerably emission of carbon dioxide were revealed. As a result of survey of shipping companies and ship owners the most effective technologies which will allow to optimize EEOI and to reduce considerably emission of carbon dioxide were revealed [20]. The analysis of the possible use of alternative marine fuel, which will reduce carbon dioxide emissions and increase the EEOI.

However, it should be noted that the transfer of ships to alternative fuels will require significant modernization of SPP and large investments, considerable time for modernization.

In works [21, 22] for the first time studies have been conducted to minimize operating EEOI when changing the main parameters of a real sea crossing – the distance of the transition, the mass of the load, speed of the vessel. For the first time studies have been conducted to minimize operating EEOI when changing the main parameters of a real sea crossing – the distance of the transition, the mass of the load, speed of the vessel [21, 22]. On the basis of the developed mathematical model in these works the basic conditions for minimization of EEOI were formulated and, accordingly, recommendations on reduction of carbon dioxide emission – the main component of "greenhouse" gases were developed.

The cruise company "Carnival Corporation" [23, 24] has developed its own technology for cleaning EG SPP, which allows to reduce to a minimum the content of Sulfur compounds and solid particles (EGCS technology). EGCS technology works during sea crossings, and during stops of the vessel or when maneuvering in port. "Our system is a state-of-the-art, environmentally-friendly technology, and its application attests to the willingness of Carnival Corporation to comply with international norms and regulations," said M. Kachmarek, Vice President of Carnival Corporation [25].

EGCS technology allows to clean EG SPP only from two pollutants –SOx and solid particles (soot).

The main stages of EGCS [26]:

1. Cooling the EG SPP with the disposal of excess heat of the EG SPP.
2. Wet scrubber cleaning (absorption process) EG SPP from SOx and solid particles with an absorbent of 50% NaOH solution mixed with sea water.
3. Cleaning of worked off liquid absorbent from solid particles.
4. Reset the worked off absorbent with SOx compounds, alkali, solid particles in the marine environment.
5. The release of cleaned EG SPP from SOx and solid particles into the atmosphere.

In our opinion, the basis of EGCS technology is the wet scrubber cleaning (stage 2) EG SPP of sulfur compounds with the help of absorbent-50% NaOH solution mixed with seawater-at a pressure of 10 bar with the help of special spray devices that convert the absorbent into a fine mist phase. As a result, the interaction of SO_2 and SO_3 contained in EG SPP with sodium hydroxide, respectively, formed sulfite and sodium sulfate. At the same time, the degree of purification from SO_2 and SO_3 in EG SPP is at 98% level. In the process of wet scrubber cleaning, in the opinion of the authors of the project, solid particles from EG SPP are absorbed by the absorbent. This is questionable because the solids are hydrophobic and therefore must be released to the atmosphere.

A rather complex technological task is a stage 3 of purification of the worked off absorbent from solid particles, after this stage, the spent absorbent containing sulfite, sulfate, sodium hydroxide, solid particles is discharged into the marine environment.

The flow diagram of EGCS technology is shown in figure 2.

Exhaust gas (pos. 16) after SPP (pos. 17) is supplied to the economizer (pos. 15), in which the EG temperature decreases below 50 degrees Celsius, then enters the lower part of the absorber (pos. 10), where is the counter flow in a spray form, a mist is supplied as the absorbent, containing 50% by weight. of sodium hydroxide (lye) mixed with sea water. As a result of the interaction of sulfur oxides with alkali sulfites and sodium sulfates are formed, dissolving in the absorbent, in the opinion of the authors, solid particles (soot) are transferred. In general, quite complex in composition and aggressive worked-off absorbent after the absorber (pos. 10) sequentially moves to the container (pos. 8) for averaging, particle cleaning system (pos. 4), the quality analyzer (pos. 3) and further discharged into the marine environment (pos. 18). The scheme provides recycling of spent absorbent after the tank (pos. 8) part of the spent absorbent pump (pos.6) through the condenser (pos. 7), the quality analyzer (pos. 9) fed to the upper part of the absorber (pos. 10). The purified EG SPP (pos. 13) is thrown out into atmosphere.

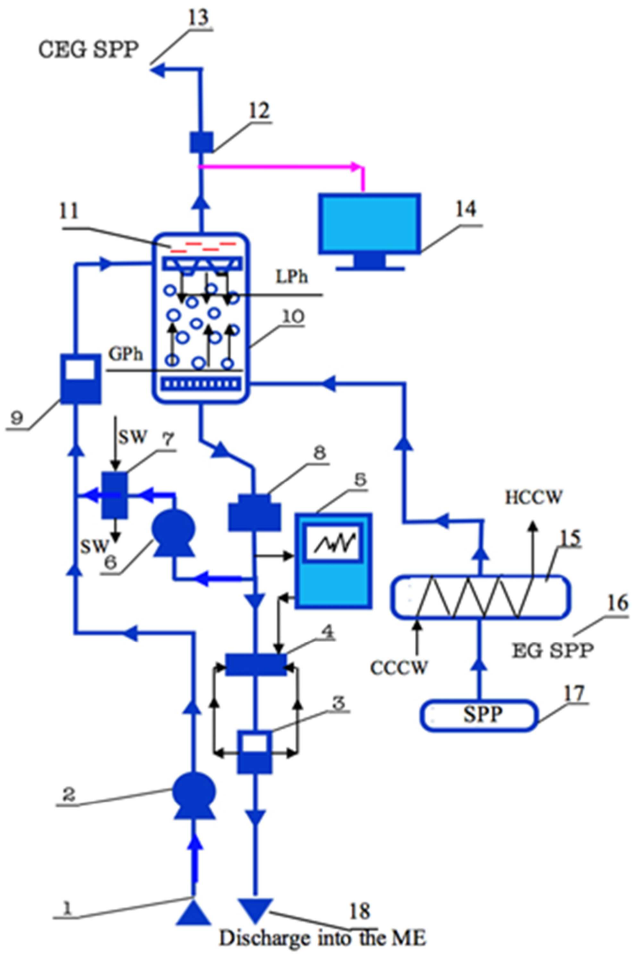

Figure 2. *The flow diagram of EGCS technology.*

It is of scientific and practical interest to consider an alternative technical solution for cleaning EG SPP from toxic components developed by us [27]. It is of scientific and practical interest to consider an alternative technical solution for the purification of EG SPP from toxic components [27].

IMO aims to create a highly efficient, environmentally safe, trouble-free ship that meets the high level of Energy efficiency constructional design index (EECDI) in the 2020-2025 years [4, 5, 28].

To implement this general direction, the complete solution of technological tasks for purifying EG SPP, and heat utilization shall be offered.

The main stages of the complex process are:

1. Quantitative high-temperature purification of EG SPP from soot.
2. Catalytic purification, neutralization of toxic substances and compounds contained in the EG SPP.
   a. By means of catalytic oxidation.
   b. Method of catalytic reduction.
3. Dual circuit technology for utilization of excess heat of the EG SPP.

4. Cooling the EG SPP to the temperature of 20-30 degrees Celsius.
5. Absorption of sulfuric anhydride condensate to produce sulfuric acid.

The technology of heat recovery of the EG SPP provides:

1) the continuity of the utilizing process of the EG SPP;
2) the increase in the efficiency of SPP, voyage, minimizing the EEOI.

There is a brief description of the process below (Figure 1):

EG SPP from the main marine engine (1) at a temperature of 400 degrees Celsius enter the turbine (2) and then go into the electro filter (diffusional filter) (3), catalytic reactor unit (4), which is equipped with oxidation and reduction catalysts. At a temperature of 363.6 degrees Celsius, the EG SPP enter the economizer (7), where heat is exchanged with water circuits, then at a temperature of 54 degrees Celsius enter the refrigerator-condenser (19), in which the temperature decreases to 25 degrees Celsius, into the scrubber (17), where sulfuric acid is formed, the latter is collected in a container (18).

It should be noted that the technical solutions proposed and implemented on cruise ships by “Wartsilla” and “Carnival Corporation” are not original and new. As early as fourteen years ago, in the work of Raevsky [29], various industrial technologies for desulphurization of exhaust gases from a power plant were considered.

This article [29] was initiated by a number of regulations and amendments adopted by the International Maritime Organization and the European Union at that time, namely Regulation No. 5 of Annex VI to MARPOL 73/78 and EU Directive 2005/30 / EC introduced severe restrictions on the content sulfur compounds in fuel (no more than 1.5%, and since 2010 - no more than 0.1% by weight). The work was initiated by a number of regulations and amendments adopted by the International Maritime Organization and the European Union at that time, namely Regulation No. 5 of Annex VI to MARPOL 73/78 and EU Directive 2005/30 / EC. strict restrictions on the content of sulfur compounds in fuel (no more than 1.5%, and since 2010 - no more than 0.1% by weight) [29]. The use of fuels with a higher sulfur content was allowed only with equipment for cleaning exhaust gases from SOx. A technology based on the process of absorption of sulfur compounds by sea water has been proposed to clean the exhaust gases of the power plant from sulfur compounds [29].

In [29] it is indicated that technical solutions for the purification of exhaust gases from sulfur oxides using the process of absorption by sea water on ships equipped with ship power plants with a capacity of 1200 to 5000 kW allow achieving the maximum efficiency of gas purification from SOx at the level of 80 %. Technical solutions for the purification of exhaust gases from sulfur oxides using the seawater absorption process on ships equipped with ship power plants with a capacity of 1200 to 5000 kW, allow achieving the maximum efficiency of gas purification. from SOx at 80% [29]. The question arises whether this degree of purification of exhaust gases is sufficient in comparison with the emissions of exhaust gases from the ESP when using low-sulfur marine fuel (no more than 0.1% by weight).

The technology [29] provides for the purification of waste seawater waste after the absorber from suspensions (?) and oil products (?).

The work [29] presents the results of using wet scrubbers on various ships with seawater spraying of gases by analogy, as currently offered by the companies "Wartsila", "Carnival corporation". The results of the use of wet scrubbers on various ships with a spray of gases with seawater by analogy, which are currently offered by the companies "Wartsila", "Carnival corporation" are presented [29]. The only difference is that the companies "Wartsila", "Carnival Corporation" add sodium hydroxide (NaOH-50% wt.) to the seawater used as an absorbent. This raises questions (???), what is the novelty of technical solutions offered by “Wartsila”, “Carnival Corporation”.

The developed technology is designed to be implemented directly on board the vessel and allows, in comparison with known proposals, to solve the following main issues of navigation in the framework of improving the energy efficiency and environmental safety of the vessel/voyage, minimizing EEOI:

1) use on board the vessel cheap high-sulfur heavy fuel IFO 380 (3,5% sulphur compounds by mass.);
2) improve the economic performance of the ship, the voyage through the utilization of the heat of the EG SPP and obtaining target products;
3) to ensure the environmental safety of the marine environment in the operation of ships, regardless of their design, type, cargo and route.

Thus, the following ecological and economic problems of shipping are solved as a result of the performed complex innovative technology of purification and utilization of heat of the EG SPP:

1. Application on board of the vessel at sea cargo transportation of cheap high-sulfur diesel fuel in areas of special control SECA, ECA, and from 01.01. 2020. – around the world.
2. Sanitary cleaning of the EG SPP to a safe level is provided for all toxic components and, in particular, for sulphur compounds and solid particles.
3. Deep utilization of the heat of the EG SPP and their purification is carried out.
4. EG SPP after sequential processing directly on board of the ship turn the target commodity products.
5. Increases the economic efficiency of shipping, efficiency of voyage, ensures the protection of the marine environment.
6. The payback period of the integrated process unit does not exceed three years.

The analysis and generalization of technical solutions for purification of the EG SPP of «Carnival Corporation company» (EGCS technology) and suggested by authors is conducted in Table 1.

Table 1. *The analysis and generalization of technical solutions for purification of the EG SPP of «Carnival Corporation company» and suggested by authors.*

№	Indicators	Carnival Corporation	Variation +	Variation -	Suggested by authors	Variation +	Variation -
1.	Cleaning method of EG SPP	Scrubber cleaning - absorption		–	Electrodiffusion cleaning from soot, catalytic neutralization of EG SPP toxic compounds	+	
2.	Materials	50% mass NaOH with seawater, chemically cleaned water		–	Catalysts, chemically cleaned water	+	
3.	Purification of EG SPP	Cleans from SO_x compounds and solid particles (soot)		–	Cleans from all EG SPP toxic compounds	+	
4.	Repeated pollution of the environment	Marine environment is polluted by sulfite, sulfate, sodium hydroxide, soot		–	No repeated pollution of the marine environment	+	
5.	Heat utilization of EG SPP	Cooling EG SPP chemically cleaned water without heat recovery		–	Two-circuit heat recovery system is used	+	
6.	Power usage	Requires increased power consumption, main and standby generators are used		–	Energy sources are generated - the first circuit is steam (14 atm), the second circuit is heated water 40-85°C	+	
7.	Metal consumption of the installation	High		–	Low - five times lower compared to technology campaigns "Carnival Corporation", "Wartsilla"	+	
8.	Payback period of the installation	Three years	+		Less than three years	+	
9.	Operating mode of the installation	In ports, when maneuvering and sea crossings	+		In ports, when maneuvering and sea crossings	+	
10.*	Prevented damage to the air basin, $/year	2 000 000		–	10 000 000	+	
11.	Ecological compatibility of new technical solutions	Transfer of toxicants from the gas phase (EG SPP) to the marine environment		–	Transfer of toxicants (EG SPP) to the neutral compounds and target products, deep utilization of waste gas heat	+	
	TOTAL		Two (+) Nine (-)			Eleven (+)	

Note: Calculations on item 10 are made for M/V "OXL SAMURAI".

As a result of technical and economic analysis of two technological schemes of the «Carnival Corporation» company and technology developed by our group of specialists, our team should conclude that we have developed technological scheme which has undeniable advantages in comparison with the «Carnival Corporation» company, which is a consequence of the following scheme parameters: As a result of the technical and economic analysis of two technological schemes of the company "Carnival Corporation" and the technology presented in the article, it can be concluded that the latter has undeniable advantages over the "Carnival Corporation" of the company, which is a consequence of the following parameters of the scheme:

1) efficiency due to the cleaning and neutralization of all toxic compounds contained in the EG SPP, in comparison with only two toxicants by «Carnival Corporation» company;
2) ecological safety, due to the combined effect of neutralizing the toxic compounds contained in the EG SPP, and convert the final target in production while the technology by Carnival Corporation company is organized to transfer pollutants from the gas phase of the EG SPP into the liquid marine environment;
3) the value of the prevented damage to the air basin under similar conditions is five times greater in comparison with the technological scheme of «Carnival Corporation».

The decision of the Session of the Marine Environment Protection Committee of the International Maritime Organization requires to use the low-Sulphur fuel containing no more than 0.5% Sulphur-compounds of the mass on ships from 01.01.2020 worldwide. This IMO requirement does not affect vessels equipped with exhaust gas cleaning systems of SPP, as well as those vessels that conduct research on the development of effective methods of purification from sulfur compounds.

The analysis of well-known technical solutions for EG SPP purification are performed, among which there are such companies as «Carnival Corporation», «Wartsilla», which have developed a scrubber cleaning method of EG SPP from sulfur compounds (Figure 2). The technology of the EG SPP purification from toxic compounds developed by a group of specialists of Kherson State Maritime Academy under the guidance of Professor Leonov V. Ye. (Figure 1) is suggested. The technology for cleaning the exhaust gas from the SPP from toxic compounds and utilizing the heat of the exhaust gas from the SPP was developed by a group of specialists from the Kherson State Maritime Academy (Figure 1). A comparison of the two processing schemes is done according to eleven parameters. As a result, the undeniable advantage of second technology is determined.

We consider it appropriate to conduct a feasibility study of the two technologies under the auspices of the Committee for the Protection of the Marine Environment of the International Maritime Organization with the objective to choose the technology for purifying EG SPP for implementation on maritime transport.

It is proposed to conduct a feasibility study of the two technologies presented in the article under the auspices of the

Committee for the Protection of the Marine Environment of the International Maritime Organization in order to select the most effective technology for cleaning the exhaust gas of the SPP for implementation in maritime transport. By the way, the number of technologies for analysis can be more than two.

3. Results

The developed technology is intended directly for functioning on board of the vessel and allows, in comparison with the known technical proposals, to solve the following main topical issues of shipping:

1. Use cheap heavy fuel on board IFO 180.-380 (3,5% weight «S»).
2. To increase the economic indicators of the vessel, voyage due to the utilization of the heat of the exhaust gas of the ship power plant and the receipt of target products.
3. Ensure the ecological safety of the sea environment during the operation of ships, regardless of its project, type, cargo and route.

Thus, as a result of the developed technology for the purification and utilization of the heat of the exhaust gases of the SPP, the following environmental and economic problems of navigation are solved:

1. The use of cheap high-sulfur diesel fuel on board a vessel for sea cargo transportation in the areas of special control of SECA, ECA, and from 01.01.2020 - all over the world.
2. Ensuring the sanitary cleaning of the EG of SPP to a safe level for all toxic components and, in particular, for sulfur compounds and solid particles (soot deposits).
3. Implementation of a comprehensive deep utilization of the heat of exhaust gases from the ship power plant and their cleaning.
4. Obtaining target marketable products and heat from the exhaust gases of the SPP after their sequential processing directly on board the ship.
5. To increase the economic efficiency of sea cargo transportation, the efficiency of the vessel / voyage, to ensure the protection of the marine environment.
6. The payback period of a complex resource-saving technological unit does not exceed three years.
7. The analysis, generalization of technical solutions for the purification of exhaust gases were conducted, as a result of the technical and economic analysis of the technological scheme, it should be concluded that the developed technological scheme has undeniable advantages [11-15] in comparison with the systems of exhaust gas of SPP heat recovery implemented in practice.

4. Discussion

In our opinion, the implementation of the developed project for the comprehensive heat recovery of waste gases from ship power plants is possible in one of the two directions presented below:

The implementation of the developed project of an integrated technology for cleaning and utilizing the heat of waste gases from ship power plants is possible according to one of the two scenarios presented below:

1. On existing ships, regardless of their type, purpose and gross tonnage.
2. On newly created ships, regardless of their type, purpose and gross tonnage.

Regardless of the direction adopted, the implementation process should be preceded by the following main stages:

1) development of a feasibility study of the proposed technology;
2) development of a business plan for the proposed technology;
3) development of the section "Environmental Impact Assessment" of the proposed technology;
4) development of a one-stage working project with the development of new equipment, and preferably the use of already mastered and manufactured equipment in industry;
5) start-up and pilot industrial tests of a new technology on a ship in a sea passage.

In all of the above stages 1-5, the authors of this article are ready to take direct part in agreement with a specific Customer.

In all the listed stages 1-5, technology developers are ready to take direct part in agreement with a specific Customer.

5. Summary

Sea transport, despite its obvious economic advantages over other modes of transport, has disadvantages, which are manifested in the high consumption of marine diesel fuel, significant emissions of material and energy waste and, as a consequence, damage to the air basin from the exhaust gases of ship power plants (EG SPP) ... Existing and mastered in maritime practice, the systems for utilizing the heat of exhaust gas from the SPP do not allow solving the above problems. In this scientific work, the goal is to solve two problems at the same time - economic and environmental. This is achieved through the following measures: * comprehensive purification of EG SPP from harmful toxic components; * utilization of the excess heat of the exhaust gas of the power plant with the production of steam, converted into the energy of the ship's motion and / or electricity; * the continuity of the process, both in the conditions of the sea passage, and in the conditions of the port; * production of targeted useful products from the harmful substances contained in the EG SPP. The solution of these complex tasks will make it possible to refuse from low-sulfur, expensive and scarce marine fuel and use high-sulfur, cheap marine fuel.

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