The scrubbers on the Marine transport vessels: technical, economic and environmental characteristics

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***Abstract*—The use of scrubbers on ships is one of the strategic alternatives in order to meet the current International Maritime Organization (IMO) requirements for sulfur oxide content in marine fuel exhaust. In this regard, various researches of scrubbers' characteristics are being carried out today and considered as an important scientific & practical issue of a number of sciences – technology, economics, ecology and others. The approaches' ambiguity to technical feasibility and economic efficiency of scrubbers' use is the research's problem due to their energy intensity, time losses during installation on existing ships, and high operating costs. The purpose of the research is to identify and consider the basic technical, economic and environmental characteristics of scrubbers in the context of other ways to meet the IMO requirements. In accordance with the purpose, the main scrubbers' advantages and disadvantages in comparison with other alternatives to meet the IMO requirements are presented. The structure and principle of scrubber operation, their types depending on the technology of neutralizing sulfur oxides are considered. The potential of using exhaust gas cleaning systems with opened and closed loop scrubbers in modern marine shipping are identified. Also, technical requirements for the air cleaning systems operation and emission monitoring, including quality criteria for desulfurization of exhaust gas by scrubbers are indicated. On the basis, the scrubbers' technical feasibility and the potential of their use in the world modern shipping are assessed so that to provide the implementation of the relevant environmental requirements of the IMO.**

Keywords*—scrubbers, exhaust gas cleaning systems (EGCS), fuel oil sulphur limits, opened loop scrubber system, closed loop scrubber system, EGCS technical manual, onboard emission testing, onboard exhaust gas monitoring.

I. Introduction: Importance and Relevance

In recent decades, the world community has been taking all possible measures to improve the environment. Today, the most actively discussed issue is the compulsory reduction of sulfur emissions, nitrogen and carbon oxides by the marine fleet ships. Sea transport is one of the dirtiest of all types of vehicles, both in terms of the emission share, estimated by experts at 5.5% of all emissions into the environment on the planet [1], and in terms of the emission severity consequences for human health, aquatic biomass, coastal agriculture, etc. This is due to the fact that the marine transport vessels are equipped with powerful engines that consume high-sulfur fuel oil – diesel fuel, fuel oil of various compositions – and, as a rule, are not originally equipped with exhaust gas cleaning systems.

About 63% of the global freight traffic volume today is carrying out by sea that determines fuel consumption at the level of 5-6 million barrels per day [1]. In order to prevent the catastrophic consequences of the marine fuel use for the environment in 2010, Annex VI of the MARPOL 73/78 Convention established the maximum sulfur content in marine fuel at 3.5% and designated the Sulpfur Emission Control Areas, where the limit was reduced to 0.1 % [2]. Since January 1st, 2020, the International Maritime Organization (IMO) has set a global limit for sulfur in fuels at 0.5% level.

This fact affects the essential conditions for the sea-going vessels operation, which leads to significant transformations in shipbuilding and in the field of sea transportation, as well as in the fuel and ship equipment production. The transformations' nature will be determined by the choice of strategic alternatives to meet the IMO environmental requirements. One such alternative is the scrubbers on marine transport vessels – special exhaust gas cleaning devices. The main criteria for the scrubbers' use expediency are their environmental and technical characteristics, i.e. the power to reduce SO_x and CO_2 emissions properly to allowable levels, in the way to keep the economic efficiency of maritime transport shipping under the restrictions. The purpose of the research is to identify and consider the basic technical, economic and environmental characteristics of scrubbers in the context of other ways to meet the IMO requirements.

The fundamental scientific and practical problem that has to be solved by the researchers is the lack of a universal method that can effectively achieve the purpose to implement the relevant IMO requirements in the process of ship's exhaust gas emissions to air and water, both for solid contaminants and for gaseous ones. Using any of the alternatives is limited by the high cost and constructive and technical complexity.

A specific problem of the research is the approaches' ambiguity to the question of the technical feasibility and economic efficiency of scrubbers' use due to their energy intensity, time losses during installation on existing ships, high operating costs, and low environmental friendliness of some types of scrubbers. Some large shipping companies, such as Maersk and Mediterranean Shipping Company, have repeatedly stated that they were not ready to invest to scrubbers' installation [3; 4].However, in 2018-2020, there has been an increase in purchases of these water treatment facilities all over the world, since the high-sulfur fuel oil continues to take a significant share in the fuel structure of these and many other shipping companies [5]. So, the relevance of multidisciplinary researches related to improving the environmental, technical, and economic efficiency of using scrubbers still remains very high.

II. RESEARCH METHODOLOGY

A. Scientific Background of the Research

The technical characteristics and features of scrubbers' production, installation and operation on marine transport vessels are well covered in the scientific and technical literature, in particular [6–9]. Today, the greatest interest of scientists and shipping companies is a comparison of the scrubbers' technical and economic parameters with other ways of meeting the IMO requirements [10–14]. According to experts, the most obvious strategic alternatives to the scrubbers' use are: 1) use of low-sulfur fuel [15; 16], 2) transition to technologies with liquefied natural gas (LNG) [17], 3) use of alternative fuels (for example, methanol) and energy sources (for example, wind, solar energy, wave energy, etc.) [18; 19], 4) innovative design and technical schemes, fundamentally new concepts of environmentally friendly ships (for example, the concept «NYK Super Eco Ship 2030» [20; 21]). A number of scientists objectively prove the strengths of scrubbers both from technical [9–11] and from economic point of view [12].

At the same time, the governments of many states are guided exclusively by innovative ways of developing the environmental friendliness of shipping [22; 23]. The scrubbers' comparative advantages and disadvantages overview is presented in Table 1.

TABLE I. THE MAIN ADVANTAGES AND DISADVANTAGES OF USING SCRUBBERS IN COMPARISON WITH OTHER STRATEGIC ALTERNATIVES TO MEET THE IMO REQUIREMENTS

Alternative	**Technical and economic features of the alternative**	
	Advantage	***Disadvantages***
Low sulfur fuels, distillates	- Ecological efficiency due to the low sulfur content that meets the IMO requirements, - relative availability of the fuel on the market	- High market price if to compare with HSFO, - high production cost if to compare with HSFO, limited current production, - low viscosity and worse lubricating properties, - incompatibility of different sorts of fuel
Scrubbers	- Ability to use available HSFO, - do not require changes in the design of engines, - various design options for exhaust gas cleaning systems, - proven ecological efficiency of most types of scrubbers	- High purchase and installation costs, including time costs by reason of ship downtime, - decrease of useful area of the vessel, - increase of crew workload through the service and emission monitoring efforts, - increase of operating costs, - for some types of scrubbers (closed and hybrid), hazardous alkaline substances are required, which requires additional equipment for storage and collection of toxic waste, - legal restrictions for scrubbers' use in some areas of the world
LNG	- Good environmental performance, in particular the complete elimination of sulfur emissions, - low cost if to compare with sulfurous fuel (about 1.5 times lower), - higher energy efficiency compared to other types of fuel and the engine`s wear reduce, - rapid development of LNG infrastructure in developed regions of the world	- High investment costs, preferential feasibility of installation on new ships, - long production cycle for ship building / equipping, - a small number of ship power plants in the world using LNG at present, - special requirements for storage and transportation of fuel
Other fuels and energy sources	- Environmental acceptability, - lower cost and availability in some cases	- Specificity (not universality) of marine fuel systems, - limited use in general
Innovative technical solutions	- Ecological efficiency in a wide range of parameters, - improvement of the vessel's technical characteristics	- High investment costs and risks for shipping companies, - long duration of the innovation cycle (approximately 10 years and more)

As Table 1 shows, LNG-based technologies and innovative technical schemes are strategically promising options, however, in the mid-term, it is unlikely that we will be able to take full advantage with them. As we expect the goal of the IMO environmental requirements is the gradual complete withdrawal of high-sulfur fuels from use in shipping. The scrubbers' use is a kind of transitional stage between HSFO and more environmentally acceptable fuels, a vital stage that global shipping must go through. Scientists believe that if today's experience in operation and maintenance proves the feasibility of using scrubbers, so they can become a widespread technology in the long term perspective [24].

The IMO scientists and specialists make a great scientific contribution to the development and approbation of technologies to protect the environment from sea transport emissions. In particular, regulation 4 of MARPOL 73/78 Annex VI allows the use of an alternative compliance method at least as effective in terms of emission reductions as that required by MARPOL Annex VI in the context of fuel oil sulphur limits. More detailed administrative and technical aspects of the scrubbers' use are set out in Resolution MEPC.259 (68) 2015 Guidelines for Exhaust Gas Cleaning Systems [25], which also corresponds to Resolution MEPC.184 (59) [26].

B. The research Objectives

To achieve the research goal, the following tasks are set:

- to consider the scrubbers' internals and operation principles, their types depending on the technology of exhaust gas cleaning on ships;
- to identify the potential of different scrubbers' types using in modern maritime shipping;
- to outline the technical requirements for the operation of air cleaning systems and emission monitoring, including quality criteria for HSFO to be cleaned by scrubbers;
- to assess on the whole the technical feasibility of scrubbers' use and their power to meet the IMO requirements at the present stage of shipping development.

III. Theoretical Aspects of the Research

A. A Mechanism of Marine Scrubbers in Outline

In outline, scrubber is a device for capturing solid and gaseous impurities from a gas mixture by wetting with a liquid. Gas and dust collection is due to hydrodynamic, electrostatic and diffusion processes resulting from the flow turbulence. Taking into account the peculiarities of the ongoing physical and chemical processes, the scrubber is a tower that provides counter-current movement of heavy dirty air and a liquid. Dirty air is supplied to the lower part of the scrubber through the inlet pipe, rises along the tower's body under the influence of pressure, and gets under the multi-level nozzle spraying of a liquid (water or absorbent substances). As a result of chemical reactions, harmful impurities are deposited in a special receiver in the form of sludge, and the purified gas is removed through a gas duct in the upper part of the tower.

Depending on ship's working parameters, such as the working area, the number of engines, the power of the engines, the volume and composition of the exhaust gases, etc., scrubbers of various sizes, spatial orientations, numbers of inlets and working mechanisms are used. However, the scrubber's type depending on the technology to neutralize the sulfur oxides is more important for the environment then other parameters.

A. Types of Scrubbers: Exhaust Gas Cleaning Technologies

In recent years, we can observe a wide spread of devices for «wet» cleaning (wet method of dust and gas capture) because of enough high air cleaning efficiency, relatively low production costs, and the possibilities of using them in a non-standard and hazardous conditions (high temperature, high humidity, risk of spontaneous combustion and explosion of gases, etc.).

The simplest and the cheapest scrubbers are the opened loop scrubber system. The natural alkaline properties of seawater are capable to neutralize sufficiently sulfur oxides, if the fuel oil contains sulfur up to 3.5%. The general working scheme of opened loop scrubber is in Figure 1.

As we can see in Figure 1, the seawater is let on board through a pumping system to a scrubber tower where it is sprayed to neutralize sulfur oxides. The washwater is discharged into a residue tank for separation of solid substances from combustion products, which are then collected in a sludge tank through the hydrocyclones. Thus, the washwater is treated before to be discharged overboard, although practice shows that on large vessels, large flows of washwater do not allow its high-quality purification, and the water is discharged overboard together with harmful substances dissolved in it. According to paragraph 10.4.1 of MEPC.259 (68) Resolution, the wash residues contained in the sludge tank should be delivered ashore to adequate reception facilities. Such residues should not be discharged to the sea or incinerated on board.

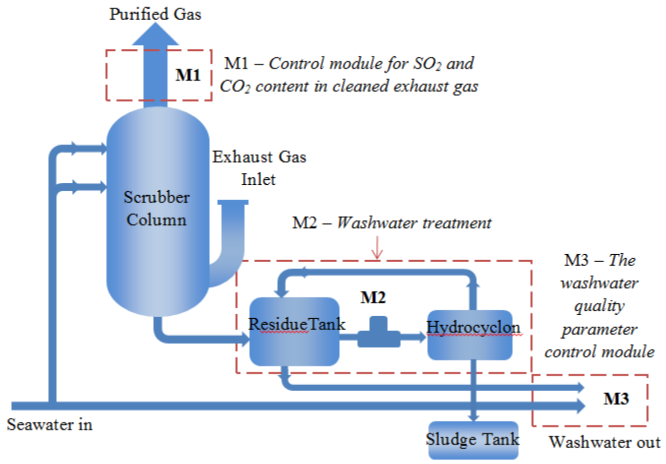

Fig. 1. Working scheme of the opened loop scrubber system.

The washwater discharge overboard means a direct impact on the environment. In order to prevent such impact, the closed loop scrubber systems are used. The closed systems take not seawater for cleaning gases, but the process water of the vessel. The seawater is used only for cooling (Fig. 2).

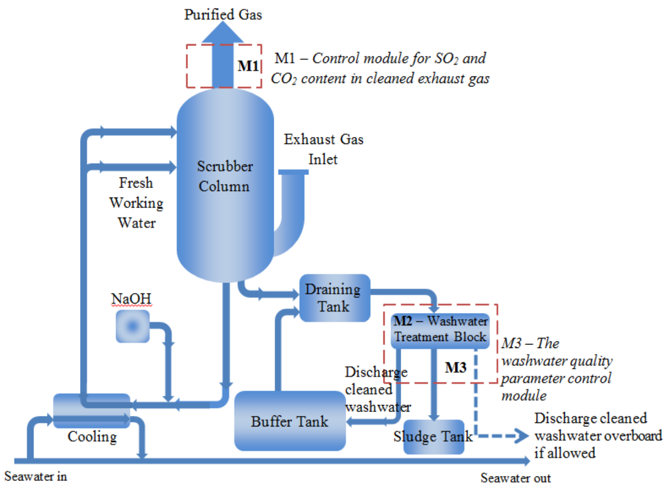

Fig. 2. Working scheme of the closed loop scrubber system.

The process water circulates from the process water tank to the scrubber tower and back. Water absorbs the sulfur, heat, dust and solids in the exhaust gas.

To neutralize sulfur oxides, the alkaline components such as NaOH are used. The sulfur neutralization is proceeding by absorption: when the NaOH solution encounters sulfur oxides, the chemical reactions releasing the carbon dioxide and sodium sulfate Na_2SO_3 take place. Na_2SO_3 has moderate toxicity. The alkali and other reagents come from special chemical tanks. The storage and use of the chemicals on board are under the strong control.

Na_2SO_3 dissolved in water with solid particles is sent through the bottom of the scrubber to the water treatment block. After multi-stage mechanical and chemical treatment, the washwater flows into the external buffer tank (in rare cases – overboard), and solid contaminants – into the sludge tank. The buffer tank is emptied systematically; therefore, the volume of the tank must be calculated taking into account the time the scrubber functions without the treated water discharge.

IV. APPLIED RESEARCH ASPECTS

A. Perspectives of Using Different Types of Scrubbers in Modern Maritime Shipping

The absence of direct washwater discharge overboard makes the closed-loop scrubbers much more effective method of removing sulfur oxides from exhaust gas than open-loop scrubbers. Table 2 covers the main advantages and disadvantages of different types of scrubbers.

TABLE II. MAIN ADVANTAGES AND DISADVANTAGES OF OPENED AND CLOSED LOOP SCRUBBER SYSTEMS

Scrubber type	**Technical and economic features of scrubbers**	
	Advantage	***Disadvantages***
Opened loop system	- Simple construct scheme in production and operation, - lower price, - unlimited use of seawater, - no hazardous reagents in the scrubber cycle	- Not suitable for use in seawater with low alkalinity, as well as in fresh water, - low ecological efficiency by reason of washwater discharge to the sea
Closed loop system	- Enough high ecological efficiency, both in terms of cleaning gases from sulfur and in terms of washwater discharge to the sea, - ability to operate in almost any physical conditions	- Complex construct scheme in production and operation, - higher price, - need for additional water to ensure the scrubber cycle, - storage and use of hazardous reagents, - need for more significant work efforts of the crew to maintain the scrubber and empty the buffer tank, - need for wide working area for scrubber

The obvious ecological failures of opened loop scrubber systems make many countries to impose active bans and restrictions on them. Due to fast-changing regulations with regards to bans and prohibitions, vessels should always confirm with local port authorities and agents, whether there is an active ban on open loop scrubbers and if consequently washwater from open loop scrubbers may be discharged or not. On July 1 2020 the following active prohibitions and restrictions related to opened scrubbers existed (Table 3).

TABLE III. OVERVIEW ON ACTIVE OPENED LOOP SCRUBBER BANS

Opened loop scrubbers can be used or not	**Areas**
Using open scrubbers and / or washwater discharge can be allowed under certain restrictions	Lithuania, Netherlands, Sweden, Hawaii (USA)
The discharge of scrubber washwater is prohibited	Bahrain, China, Belgium, Estonia, Finland, Germany, Port of Gibraltar, Egypt (Suez Canal), Ireland, Italy (Ravenna), Latvia (Ventspils), Malaysia (excluding transit zones), Norway, Russia (Baltic ports), Singapore , Spain, United Arab Emirates, Connecticut (USA), Massachusetts (USA), Uruguay
The use of open loop scrubbers is prohibited, including discharge of scrubber washwater	Argentina, France, Lebanon, Mauritius, Oman, Pakistan, Panama, Portugal, Saudi Arabia, UK (multiple ports)
The use of open loop scrubbers is prohibited. The use of closed loop scrubbers needs permission of the destination authorities	Hong Kong
All types of scrubbers are prohibited	California (USA)

- *The Overview is drawn up on each state's (port's) law basis.*

Of course, the law specificity of the prohibitions and restrictions may differ on each territory. However, as we can see in Table 3, there is a global trend towards tightening local regulations for air pollution and ships' wastewater discharge prevention. The USA, China and some European countries are especially active in these bans.

The most severe requirements were put forward by the California Air Resources Board: within 24 nautical miles from the coast of California there is a limit on the sulfur content in fuel oil at the 0.1% level, as well as a ban on all types of scrubbers. This fact leaves ships with no other ways than the use of low-sulfur fuel, which is also not the best technical and economical alternative. Low and ultra-low sulfur fuels typically contain catalytic particulates that cause severe engine abrasion unless the particulates have been removed from fuel during the expensive production process. Also when alternating fuels with different sulfur content takes place, there is a risk of their incompatibility that leads to emergence of sludge in fuel tanks and filters. Consequently risk of fuel equipment failures increases [27]. These problems add hazard in the ships operation process.

So, in the near future the opened loop scrubbers' use is rather limited, and they are losing their technical and economic glamor for shipping companies. The low-sulfur fuels are gradually coming, but they carry high risks and costs for producers and shipping companies. The vessels' engine technically competent operation envisages the efficient use of fuel energy, protection of equipment from wear and regular emergency repairs. So today we can talk about the necessity of closed-loop scrubbers, as well as hybrid, dry and some other ecologically acceptable types of scrubbers.

B. Today's Practice of Using Scrubbers: Technical Requirements and Emission Monitoring

Such significant technical devices as scrubbers are used under great control, take hard efforts of the crew, should meet technical requirements and conform to guidelines. The 2015 Guidelines For Exhaust Gas Cleaning Systems (EGCS) adopted by MEPC.259 (68) Resolution, aims to establish the requirements for testing, certification and monitoring of exhaust gas cleaning systems on sea vessels to meet the IMO standards. Any EGCS installed on ships can be certified, if regular checks of emission parameters (automatic or manual) are mandatory, the work of water treatment systems meets technical requirements and emission quality criteria. In this case, section 2.6 of the International Air Pollution Prevention Certificate should be duly completed and approved in accordance with the Annex VI of MARPOL 73/78.

Resolution MEPC.259 (68) provides two schemes of EGCS operation: A – certification of each EGCS unit with the operational parameter standards specified by the manufacturer, and daily random emission quality checks; B – continuous emission monitoring with parameter checks for their compliance with the approved standards.

Regardless of the scheme selected on ship, certain onboard procedures must be followed to demonstrate compliance with emission limits.

- The SO_x Emissions Compliance Plan (SECP) must be developed and approved. The SECP specifically describes how continuous monitoring of the scrubber's operating characteristics (under Scheme A) and continuous monitoring of emission measurements (under Scheme B) assure compliance with the IMO sulfur emission requirements on ship.
- Onboard monitoring of emission check devices should be undertaken and include: sensors used for monitoring; positions in which parameters were measured; analyzers and more. Onboard Monitoring Manual is an important component of the ship's documentation approved by the shipping company headquarters related to the sulfur emission regulation.
- The technical manual of the EGCS must be approved and include a description of the device, limit and operating values of its technical parameters, requirements for washwater treatment, a list of corrective actions in case of exceedances of the applicable maximum allowable emission values, or washwater discharge criteria, etc.
- The exhaust emission measurement procedure should meet the NOX Technical Code 2008 [28] requirements. In particular, SO_2 should be measured using analysers operating on non-dispersive infrared or non-dispersive ultra-violet principles. An exhaust gas sample for SO_2 should be obtained from a representative sampling point downstream of the EGC unit and stored under specified temperature and humidity conditions.
- A device for recording and processing emission data should have specific construct and functionality. In particular, any EGCS should automatically record its operating parameters, for example, pressure and flow rate of washwater, temperature and pressure of exhaust gas before and after cleaning, the volume of supplied chemicals, etc.

Compliance with the technical requirements during scrubber operation and emission monitoring makes the process of gas cleaning unified and controlled. According to opinion of leading marine gas cleaning systems manufacturers, such as Wartsila, Alfa Laval, Yara Marine Technologies and others, modern innovative technologies used in production of scrubbers allow ships to comply with current legislation of most countries and the IMO requirements: in the closed loop they can remove more than 99% of sulfur and 80% of solid particles [21; 29]. Experts assure that, despite the high cost of installing gas cleaning systems, scrubbers can pay off in several years. Today maritime shipping companies are focusing their efforts on increasing the efficiency of gas cleaning while reducing the energy intensity of this process, reducing the usable area occupied by treatment equipment, and minimizing waste [29]. This is the technical and economic superiority of scrubbers at the current stage of shipping development.

C. Quality Criteria for Cleaning HSFO by Onboard Scrubbers

The result of the exhaust gas cleaning process is the neutralization of harmful substances, i.e. their transformation into substances with moderate or low toxicity. The final substances and the properties of their environment let estimate the quality of gas cleaning. To estimate the quality of cleaning process there is a monitoring system controlling emission both to air and to the sea. To control final air emissions the ratio of SO_2 (ppm) to CO_2 (% v/v), corresponding with fuel oil sulphur content, is used. To control the discharge to seawater, indicators of washwater acidity pH, polycyclic aromatic hydrocarbons (PAH) level, water turbidity, content of nitrates and some other substances are used. Nowadays the Marine Environment Protection Committee has fixed the following limits for the specified parameters (Table 4) [25].

TABLE IV. THE CLEANING QUALITY CRITERIA FOR MARINE SHIPS' SCRUBBERS

Parameters	The values	Methods of taking and measuring
Ratio emission SO_2 (ppm) к CO_2 (% v/v)	For 0,5% fuel oil sulphur content: 21,7 For 0,1% fuel oil sulphur content: 4,3	At the exit from the gas duct in the upper part of the scrubber tower (see the M1 control module in Fig. 1). CO_2 and SO_2 are measured with a non-dispersive infrared analyzer. SO_2 is also measured with a non-dispersive ultraviolet analyzer
The washwater pH	- Not less than 6.5, - difference between input and output - no more than 2 pH units	At 4 m from the overboard discharge point with the ship stationary (M3 control module in Fig. 1). Direct measurements with acid-OH indicators or a potentiometric pH meter, as well as calculations according to approved formulas are used
The washwater PAH	Not more than 50 μg / L higher than at the inlet (for a drainage rate of 45 t / MWh)	Downstream of the water treatment equipment (M3 module in Fig. 1), but upstream of washwater dilution, if used, prior to discharge. Fluorescent measurement technology is used
The washwater turbidity	No more than 25 FNU or 25 NTU than input	Downstream of the water treatment equipment (M3 module in Fig. 1), but upstream of washwater dilution, if used, prior to discharge. Photometric measurement technique is used

Parameters	The values	Methods of taking and measuring
Nitrates	60 mg / l (for a drainage rate of 45 t / MWh)	Regular measurements at every EGCS examination. Measurement methods correspond to standard methods of seawater analysis

The parameter measurement is organized in emission quality control modules (monitoring zones): in Figures 1, 2, 3 they are indicated by dotted lines.

So, module M1 represents the monitoring zone of SO2 and CO2 content in the cleaned exhaust gas. The control system is connected to the scrubber control system for data logging and reporting. Typically, it includes an exhaust gas-sampling probe, a sample storage cabinet, and an analysis and calculation block.

Module M3 is the quality monitoring zone for washwater parameters. EGCS automatically controls the flow of treated water based on its quality. While using the opened loop scrubber washwater is pumped from the M2 drain-cleaning module to the M3 control module and, if it meets the quality requirements, is discharged overboard. If the treated water does not meet the requirements, it should be redirected to the buffer tank. In the case of closed loop scrubber, washwater is directed to the buffer tank regardless of the values of the measured parameters.

All emission measurements are recorded, stored in a memory device and ready to be presented for reading to regulatory authorities. According to Annex VI to MARPOL 73/78, the emission monitoring system may be inspected by the authorities of port the ship is arriving. Thus, exhaust gas and washwater cleaning as well as continuous exhaust gas and washwater monitoring allow achieving the compliance with the ecological standards and keeping economic efficiency in the further development of shipping.

V. Conclusions

Based on the research we can draw the following conclusions.

1. From 01.01.2020, the new IMO requirements for the 0.5% sulfur content in fuel were specified. Sulpfur Emission Control Areas also maintains the 0.1% sulfur limit for marine fuel. The use of scrubbers is one of the obvious alternatives to meet the IMO requirements in a strategic perspective. The main advantage of scrubbers is the ability to use relatively cheap and readily available HSFO even under environmental constraints. However, the high purchase and installation costs, the growth of operating costs limit the scrubbers' use; form ambiguous viewpoints to their use among shipping companies.

In the context of a multi-alternative approach to meeting the IMO requirements, which implies a significant time and resources investment for any of the alternatives, the use of scrubbers is a transitional stage between HSFO and more environmentally friendly fuels, a chance to meet the international ecological standards without heavy losses in energy efficiency and economic profitability in coming years.

2. Scrubbers are common multi-format devices for air cleaning in industry and transport, including marine shipping. Depending on the sulfur oxides neutralization technology there are scrubbers with opened and closed loops. Closed scrubbers do not allow washwater to be discharged overboard, even after cleaning, but collect it in buffer tanks. Because of this, despite their more complex design and higher cost, closed loop scrubbers are a much more environmentally acceptable method of removing sulfur oxides from exhaust gas than opened scrubbers.

3. The obvious ecological failures of opened loop scrubber systems lead to bans and restrictions for their use in some areas. So, there is a complete ban of opened scrubbers in 12 countries. There is a ban on water discharge overboard in 19 countries' port areas. The largest number of bans has been fixed in recent years. The trend of toughening environmental regulations in ports and territorial waters of different countries continues.

4. Today's practice of using scrubbers on sea vessels is based on the mandatory compliance with technical requirements and the high quality emission monitoring. First, we are talking about development, approval and execution some technical documents on each vessel in relation to each unit of the air cleaning system: SO_x Emissions Compliance Plan, Onboard Monitoring Manual, EGCS Technical Manual. The NO_x Technical Code 2008 requirements for gas emission measurement, for devices recording and analyzing emission data must also be compiled. To check the emission quality, a number of parameters is used. Their values information is collected on board in control modules.

5. According to EGCS manufacturing companies, the latest scrubbers can remove over 99% sulfur and 80% solid particles. Due to the scrubber manufacturers' efforts in way to increase gas cleaning efficiency, to reduce energy consumption and to minimize cleaning process waste, in the near future we can talk about the technical and economic superiority of scrubbers in comparison with other alternatives that can meet the IMO requirements. The ability to operate on high-sulfur fuel oil and at the same time to comply with environmental standards through the continuous emission monitoring determines the expediency of using scrubbers at the present stage of shipping development.

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