Ways to reduce harmful emissions from the operation of power plants in special environmental control areas

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Abstract. The article examines the specifics of operating power plants in special environmental control areas, following the restrictions of the International Maritime Organization introduced in 2020. It focuses on innovative technologies such as the use of low-sulphur fuels, the implementation of SCR technology, the development of new logistical solutions and the use of new fuels. The method for controlling the emission of sulphur oxides into the atmosphere from power plants must be an integrated one, combining primary and secondary measures. Primary activities include purification of fuel from pollutants - improvement of fuel quality (enrichment of feedstock, use of alternative fuels); suppression of formation of harmful substances during combustion by improving fossil fuel combustion processes (by improving furnace designs, technological methods and regime measures, organization of mixture formation and combustion processes, improvement of fuel injection system). Secondary measures include technologies for capturing pollutants from flue gases, including methods designed for coarse and fine flue gas cleaning (flue gas recirculation, catalytic flue gas cleaning, wet methods, dry methods, absorbers for the cleaning of combustion products of sulphur oxides, cyclone-foam apparatus). The solution to the pollution of the World ocean, and in particular the special environmental control zones, by sulphur emissions from diesel engines primarily depends on the development of highly effective technologies to reduce its concentration at the diesel plant outlet.

1. Introduction

Research and development in the field of diesel modernization have, until recently, focused on the economics of the power plant, then on reliability and, with engines switching to heavy fuel grades, on environmental friendliness [1]. Over the past three decades, however, leading diesel fuel producers have been focusing their research on improving the environmental performance of engines running on high-viscosity (heavy) fuels, because of the significant amount of harmful substances released into the atmosphere after the combustion of these fuels. In turn, the poor condition of atmospheric air leads to an increase in respiratory diseases, cancer and certain nosologies, which the World Health Organization has categorized as indicative of environmental factors. These circumstances, as well as the prospect of global environmental complications, make it necessary to impose strict restrictions in areas of special control on the sulphur content of fuels.
Annex VI of MARPOL as well as resolutions of the International Maritime Organization MEPC.203 (62) and MEPC.213 (63) determine the importance of ensuring the required fuel quality. At the same time, international environmental legislation in the shipping sector is changing regularly. For example, from 1 January 2020, the Marine Environment Protection Committee of the International Maritime Organization will limit from 3.5% to 0.5% the maximum sulphur content in fuel for ships outside the SECAs (Sulphur Emission Control Areas), which include the North Sea and the Baltic Sea including the English Channel, the East and West Coast of North America, the Caribbean and the Gulf of Mexico in the USA. At the same time, the specified special marine areas have higher requirements with more stringent emission standards (NOx up to 3.4 g/(kWh), SOx down to zero) [2].

Since it is possible to influence the formation of a number of hazardous components contained in exhaust gases through the special organization of processes in the engine cylinder, the emission of sulphur-containing components entirely depends on the sulphur content of the fuel used [11]. Consequently, solutions for the reduction of sulphur oxide emissions require special solutions. Currently, the global average sulphur content of marine fuels is around 2.7%, so a new limit of 0.5% is expected to reduce sulphur emissions from ships by more than 80% [3].

Given the new requirements, shipowners operating in special areas will be forced to abandon the use of conventional fuel oil as fuel. Accordingly, ship owners in Canada, Europe and also the USA are already prioritising liquefied natural gas as their fuel of choice. The Philippines and Japan opted for dimethylether and methanol. In addition, some shipowners are analysing the possibility of using scrubbers to reduce sulphur content.

Thus, issues related to the specifics of power plant operation on ships navigating in special environmental control areas in the context of the IMO's 2020 restrictions are of particular relevance and practical significance, which makes this article relevant.

International cooperation in the field of protection of the marine environment from pollution has been researched by scientists such as A.S. Belous, V.S. Efremov, V.V. Demidenko, V. A. Kiseleva, S.M. Nunuparova, I.V. Leusenko et al.

The key aspects of engine and fuel improvement in the context of meeting International Maritime Organization requirements have been addressed by M.A. Gosudarev, V. H. Zakharov, V. P. Zachesova, E. A. Zing.

The work of foreign researchers, who comprehensively approached the study of promising technologies to improve the environmental performance of power plants, deserves special attention. Among them, we can single out Kontovas Christos A., Chen Dongsheng, Ma Dongfang, Zanatta Marco, Zhen Lu, Ergin Selma, Durmaz Murat, etc; Kontovas Christos A., Chen Dongsheng, Ma Dongfang, Zanatta Marco, Zhen Lu, Ergin Selma, Durmaz Murat, etc.

However, despite the importance and urgency of this challenge, and the advances already made in this area, we should note that solving the problem of ocean basin pollution, and in particular the special environmental control areas of sulphur emissions from diesel plant, involves primarily the creation of highly effective technologies to reduce its concentration at the diesel unit outlet, and this applies in full to ships under design and construction as well as those in service.

Therefore, issues relating to the use of new diesel production technologies, the cleaning of energy plant exhaust gases, the introduction of new modes of operation and conversion of ships, which will generally allow compliance with increased requirements in special environmental control areas, considering the new International Maritime Organization restrictions, require additional and more in-depth analysis, which generally constitutes the focus of the article.

In areas of special control of sulphur and nitrogen emissions under the International Convention for the Prevention of Pollution from Ships, one of the most pressing concerns is the environmental and safety aspects of bunkering operations.

2. Technologies for the improvement and operation of energy plants

Promising technologies, areas of improvement and operation of power plants that will reduce sulphur emissions in areas of special environmental control are shown in Table 1.
Table 1. Measures to meet sulphur emission reduction requirements under the International Maritime Organization's 2020 standards

| No. | Measures                              | SO₂ |
|-----|---------------------------------------|-----|
| 1   | Use of fuel with low sulphur content  | yes |
| 2   | Implementation of SCR technologies   | yes |
| 3   | Change in the operational modes of the power plant | yes |
| 4   | Alternative fuels: natural gas (liquefied), methanol, etc. | yes |

We will look in more detail at the proposals outlined in Table 1.

1. Use of fuel with low sulphur content The measure does not exempt from nitrogen oxide regulations, and the production of such fuels increases greenhouse gas emissions many times over. Thus, if the environmental situation improves in a certain zone of special control (Table 2) in other areas, the state of the environment may deteriorate significantly.

![Figure 1](image.png)

Figure 1. Nitrogen emissions from the use of different fuels. Source: DNV GL

Table 2. Fuel combustion emissions of medium-speed marine diesel engines manufactured after 2000 g/kWh [4]

| Type of fuel                | SO₂ | NO₂ | CO₂    | Solid particles |
|-----------------------------|-----|-----|--------|----------------|
| Fuel oil (3.5% sulphur)     | 13.0| 9-12| 580-630| 1.5            |
| Marine diesel fuel          | 2.0 | 8-11| 580-630| 0.25-0.5       |
| Refined diesel fuel         | 0.4 | 8-11| 580-630| 0.15-0.25      |
| Natural gas (liquefied)     | 0.0 | 2   | 430-480| 0.00           |

Low-sulphur diesel is about twice as expensive as conventional diesel, and there are indications of further increases in its cost, which may have a negative impact on market competitiveness compared to other modes of transport - a reallocation of freight flows to road and rail transport.

2. Installation of scrubbers (SCR technology). For vessels navigating in areas of special environmental control, owners can have exhaust gas cleaning systems - scrubbers - to reduce sulphur emissions. Using estimated fuel consumption and current fuel prices, the experts estimated that more than 630 IMO-registered vessels could benefit from the use of scrubbers.

However, we should note that the installation of scrubbers is a costly procedure. The Finnish Institute of Marine Research estimates that the capital cost of using this technology would increase by
about €50 per kW of shipboard power, and the operating cost by about €5-7. Additionally, there are absorbents inside the system that absorb the exhaust, resulting in the formation of sulphites and zinc sulphates. They are poisonous reagents that the ports are currently not storing, creating another environmental problem, as there are still no fully developed ways and methods of disposing of scrubber waste. In addition, the absorption efficiency of absorbents for sulphur-containing elements is directly related to their volume, and scrubbers on medium-sized ships can take up to one quarter of the effective area, which reduces the ship's cargo capacity and significantly reduces the shipowner's income.

In addition, for the passenger fleet as a whole, scrubber installation is a problematic operation.

3. Change in the operational modes of the power plant can reduce air pollutant emissions in areas of special environmental control. The rationality and effectiveness of this proposal were investigated by simulating speed reductions of 10 and 30% from above 10 knots. The results of the experiment concluded that the effectiveness of changing power plant operating modes as a way of limiting sulphur emissions varied significantly depending on the type of vessel. In particular, RoPax, RoRo vessels could achieve significant fuel cost savings without significantly increasing operating time. The resulting fuel savings were substantial, even at speeds as low as 10%. The relative reductions in SO₂, NOₓ and PM₂.5 emissions were estimated to be greater than the reduction in overall fuel consumption.

As well as the development of optimal logistical solutions (reduced traffic) will reduce journey time, which in turn will reduce the amount of fuel burned and thus lead to lower emissions.

For example, in the context of new requirements introduced in 2020 by the International Maritime Organization, dual-fuel engines with liquefied natural gas (LNG) capability are gaining technology for special environmental control areas [9]. Using LNG as a fuel reduces emissions by up to 90% [6]. However, the liquefaction process does not cause any additional emissions into the atmosphere. LNG is on par with methanol in terms of cost, so both fuels are financially viable. In addition, the use of LNG reduces shipowners’ dependence on fluctuating oil prices. The main disadvantage of LNG is the need for significant additional space on the ship for the installation of tanks [10].

An example of the use of methanol is the chemical tanker Lindanger. Methanol is considered a fairly promising marine fuel and can significantly reduce regulated emissions (carbon, sulphur, nitrogen, particulate matter). Methanol can be used both directly as a fuel and as a substance for the production of dimethyl ether. The unquestionable advantage of methanol is that it is environmentally friendly, as it does not contain sulphur and the emission of nitrogen oxides in the exhaust fumes is considerably lower compared to the combustion of diesel or fuel oil. We should pay attention to the fact that there are carbon dioxide and carbon monoxide emissions to the atmosphere as a result of the chemical reaction of methanol production [7].

For example, the Swedish company StenaLine uses only methanol as fuel in the power plants of ships operating in the SECA. In addition, the company developed a project to build a series of ships on methanol and to convert the 25 ships already in service to this fuel. Since spring 2015, StenaLine has commissioned the ferry Stena Germanica, whose ship power plants run on methanol.

Low-sulphur fuel oil can also serve as an alternative fuel for vehicles travelling in areas of special environmental control. Such fuel originates from low-sulphur crude oil or the desulphurization process. However, desulphurization is an expensive and complex process, which has a direct impact on the final price of this fuel oil. At the same time, ultra-low sulphur fuel oil has a complex chemical composition, which can cause additional complications and risks in the operation of power plants using it. These complications include increased aluminosilicate content in the fuel, incompatibility with other fuels, stress corrosion, reduced reliability of fuel systems due to reduced lubricity and viscosity of fuel at the engine inlet. Unstable fuels with low sulphur content pose threats to the safe operation of engines, namely reduced ignition quality, excessive engine deposits, increased visible particulate emissions and significant fuel system sludge formation. Reduced fuel stability can also lead to higher emissions. Low-sulphur marine fuels often produce large amounts of unburned hydrocarbons and cause visible particulate emissions (opaque smoke) [11].

There is particular interest in non-standard technologies for using and saving fuel in transport. The
DriveGreenHighway truck, for example, uses KawasakiHeavyIndustries technology to simultaneously reduce sulphur and nitrogen emissions, including an exhaust gas recirculation system and the use of water-fuel emulsions. The main engine on the EEVA VG freighter is an 8DZC engine equipped with an auxiliary fuel system for biofuel operation. The hybrid diesel-electric unit of the SeaspanSwift includes two gas-diesel engines as well as a block of 84 lithium polymer batteries, which allow the storage of electric energy and its use with the highest efficiency when required[8].

3. Conclusions
The solution to the pollution problem in the World Ocean basin relates to the development of meta-controlling measures to reduce sulphur and nitrogen oxide emissions from power plants. The method should be comprehensive, combining primary and secondary measures.

Primary activities include purification of fuel from pollutants - improvement of fuel quality (enrichment of feedstock, use of alternative fuels); suppression of formation of harmful substances during combustion by improving fossil fuel combustion processes (by improving furnace designs, technological methods and regime measures, organization of mixture formation and combustion processes, improvement of fuel injection system). Secondary measures include technologies for capturing pollutants from flue gases, including methods designed for coarse and fine flue gas cleaning (flue gas recirculation, catalytic flue gas cleaning, wet methods, dry methods, absorbers for the cleaning of combustion products of sulphur oxides, cyclone-foam apparatus).

Summing up the results of the study, we can draw the following conclusions. Compliance with the strict limits imposed by the International Maritime Organization in 2020 in the operation of power plants in special environmental control areas can be achieved through the use of innovative technologies in the production of fuels and their non-standard types, changes in modes of operation and through technological conversions of power plants. However, experience and practice have shown that a combination of different innovative technologies and approaches has the greatest effect.

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