SECTION 4. SHIPBUILDING

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PRIMARY WAYS FOR IMPROVING THE ENVIRONMENTAL PERFORMANCE OF MARINE DIESEL ENGINES

ОСНОВНІ НАПРЯМИ ПОЛІПШЕННЯ ЕКОЛОГІЧНИХ ХАРАКТЕРИСТИК СУДНОВИХ ДИЗЕЛЬНИХ ДВИГУНІВ

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Marine internal combustion engines (MICE) form the backbone of modern maritime transport, with diesel engines powering nearly 96% of the world’s shipping tonnage. However, the intensive operation of such engines is accompanied by significant amounts of harmful emissions. Exhaust gases contain carbon dioxide (CO_2), nitrogen oxides (NOx), sulfur oxides (SOx), unburned hydrocarbons (HC), and particulate matter (PM). These substances have a negative impact on both the environment and human health. That is why the issue of making ship engines more environmentally friendly is one of the most pressing issues in shipbuilding and energy today. Harmful emissions are regulated at the international level. The main document is the MARPOL Annex VI Convention, which was adopted in 1997 and entered into force in 2005. It sets standards for reducing NOx and SOx emissions and limits the sulfur content in fuel.

These emissions have a negative impact on:

– Global climate change;
– Overall air, water, and soil pollution;
– Human health (cancer, cardiovascular and respiratory problems).

Today, great efforts are being made to develop diesel engines and new additional technologies to reduce these harmful emissions. Artificial intelligence is already being applied to support development and solve problems, starting from the engine design stage. Particular attention is focused on engine management, fuel injection and combustion control, exhaust gas recirculation, catalytic treatment and exhaust gas filtration, as well as the use of alternative fuels. To improve the performance of internal combustion engines, it is necessary to increase the effective power and torque of the engine and reduce fuel consumption and harmful emissions, especially NO_X, and reduce smoke.

NO_X concentrations can be reduced by reducing the fuel combustion temperature, which can be achieved, for example, by a lower oxygen content or a higher inert gas content in the intake air (as with EGR) or by better premixing to achieve a partially homogeneous saturated mixture before combustion begins. Smoke formation can be reduced by better mixing, with a local relative air/fuel ratio below 0.6. Oxidation can be improved by maintaining a high temperature for a sufficiently long period of time in the presence of oxygen.

Another effective method is selective catalytic reduction (SCR), which is based on injecting urea (AdBlue) into the exhaust gas stream. As a result of a chemical reaction, NOx is converted into harmless nitrogen and water. The SCR system can reduce NOx emissions by 80–90% but requires the use of special reagents and has increased maintenance requirements [1].

To reduce particulate emissions, filters (DPF) are widely used, which trap up to 95% of soot and ash. Such systems require regeneration, which can be done passively or actively. The best results are achieved when combining DPF with catalytic converters.

A separate promising area is the use of alternative fuels. Liquefied natural gas (LNG) allows SOx emissions to be virtually eliminated, NOx emissions to be reduced by 80–85%, and CO_2 emissions to be reduced by approximately 20%. The use of methanol, ethanol, and biofuels is also being considered. Biofuels are considered carbon neutral, but have problems with oxidative stability. Hydrogen fuel is also promising, but its full-scale use requires a thorough modernization of engine designs and storage systems.

In the search for the "best diesel engine" design, there are many compromises and conventions, and the development process is quite complex. Despite this, the general guidelines that can be provided are as follows:

– Gas flow control in cylinders, such as controlled swirl and turbulence through variable intake geometry, multi-valve cylinder heads, and optimized combustion chamber shape;

– Improved injection system with vertical nozzle, injection speed shaping, such as pre-injection and split injection, achieved by injection pressure up to 2000 bar using an electronic system;

– Improved and controlled combustion process due to reduced temperature (better Exhaust Gas Recirculation (EGR) control, EGR cooling, better pre-mixing), avoidance of oversaturated zones, and faster oxidation start;

– Improved fuel quality and use of alternative fuels with lower sulfur and aromatic hydrocarbon content and higher cetane number.

Diesel exhaust also contains sulfur salts and other abrasive and corrosive substances (Zheng et al. 2004). There has been debate about whether EGR should be used for diesel engines due to increased wear on the cylinder-piston group (CPG). Intensive use of EGR can also reduce energy efficiency and operational stability at certain engine speeds. Despite this, concerns about increased wear and reduced performance have been somewhat overshadowed by strict emission standards. Therefore, the current state of affairs largely concerns how actively EGR should be used at different speeds and loads. It should be noted that increased CPG wear associated with EGR continues to be a problem that affects engine durability and performance [2].

Currently, EGR is still the most viable technology for significantly reducing NOx. Energy-efficient cleaning systems that work simultaneously with NO_X and particulate matter are still in the early stages of development.

It is known that high EGR rates cause a significant increase in PM emissions. From this perspective, the use of an ultra-fine particulate filter system can be considered an effective solution.

This is because the particulate filter provides high efficiency, approximately 90% reduction in TC emissions, and thus provides increased flexibility for NO_X control using EGR.

Two different EGR configurations:

– Low-pressure system (LPS), shown in Fig. 1;
– High-pressure system (HPS), shown in Fig. 2.

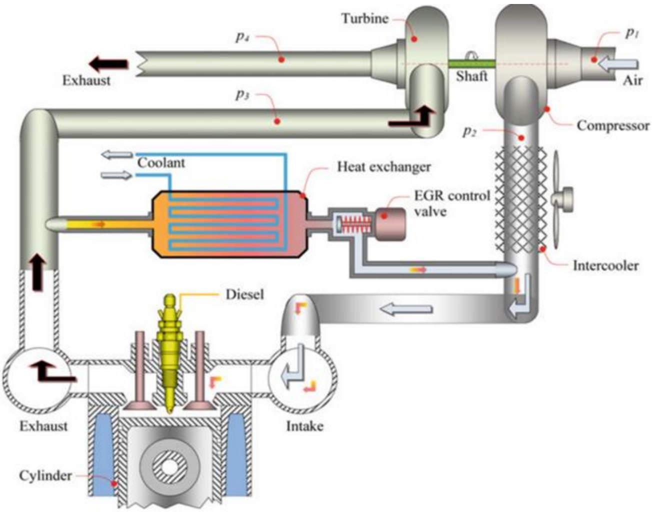

Fig. 1. Low-pressure system (LPS)

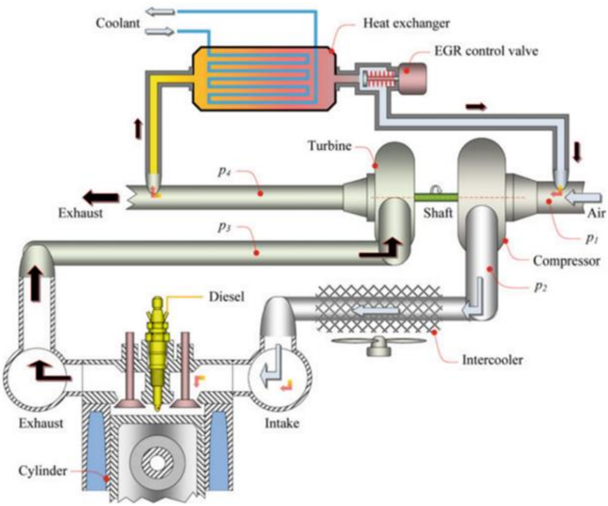

Fig. 2. High-pressure system (HPS)

Conclusions. Diesel engines remain essential in transportation, but their emissions (CO_2, NOx, HC, PM) create serious environmental problems. To reduce them, continuous improvements are needed: optimization of the combustion process, efficient fuel injection systems, the use of EGR, catalytic converters, particulate filters, and alternative fuels. Further development of these technologies is critical to reducing harmful emissions and improving environmental safety.

Low-pressure system's advantages:

– Allows cooler exhaust gases to be fed into the cylinders, which reduces NOx more effectively;
– Reduces soot and smoke formation;
– Operates at high loads and engine speeds;
– Improves fuel economy through more even gas distribution.

High-pressure system's advantages:

– Fast system response to changes in engine load.
– More effective NOx reduction at low and medium speeds.
– Easy to implement and relatively low cost.
– Works well at low exhaust gas temperatures.

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