The prospects for the use of hydrogen as a fuel in maritime transport

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Abstract: *In diesel engines, the fuel mixture consisting of liquefied gas and hydrogen is prepared, and a process corresponding to the gas-diesel cycle is implemented, where methanol or diesel fuel are used as an explosive fuel, as a result of which the self-ignition delay period is reduced, and the fuel combustion duration during active combustion is reduced as well. That is, the limits of the working mixture combustion are expanded (hybrid combustion), the mixture formation process is improved, and the cycle carried out in the engine is closer to the Otto cycle, which improves the environmental and efficient indicators of diesel engine compared to the gas-diesel engine, where diesel fuel is used as an explosive fuel, which makes it possible for diesel engine to run: only on liquefied gas; only on hydrogen, only on a diesel fuel or on a combination of different fuel mixtures.*
KEY WORDS: *HYDROGEN FUEL; DIESEL ENGINE; METHANOL; EXPLOSIVE FUEL; HYBRID COMBUSTION.*

1. Introduction

Climate change caused by global warming poses a grave threat to humanity. Delays in reducing emissions of "greenhouse gases" causing global warming will significantly increase the risks of the worst impacts of climate change. According to thorough research by the world's leading experts, 15% of the main "greenhouse gas" of anthropogenic origin in the Earth's atmosphere - carbon dioxide - is released from the transport sector, and the road transport (cars, buses, motorcycles, etc.) is responsible for the largest share of these emissions.

Against the backdrop of "decarbonization" of other sectors of the economy, i.e. the reduction of "greenhouse gas" emissions, the share of emissions from vehicles may increase further if appropriate measures are not taken to reduce them. On October 1, 2021, the world leaders' summit (the 26th conference) held in the city of Glasgow, Great Britain, was focused on this issue, where the problems of a warming environment were discussed. Particular attention was given to the issues of reduction of greenhouse gases and released thermal energy in the environment. All participants noted that by 2030, the parameters mentioned above should be at least halved. From this point of view, partial gradual replacement of internal combustion engine vehicles with hybrid and electric drive vehicles will significantly contribute to the reduction of "greenhouse gas" and heat energy emissions from the road transport sub-sector. The creation and use of electric cars - i.e. "decarbonization" of road transport is the first priority for the governments of many countries. Today, tens of billions of US dollars are allocated worldwide for the development of vehicles running on alternative fuels and advanced technologies. According to the forecast of the Japanese company Nissan, by 2025, every tenth car in the world will be powered by an electric engine, and the electric and other "green cars" will make up one third of global auto sales. There is practically no air pollution in the city with an electric car, because the exhaust does not contain harmful pollutants such as soot, volatile organic compounds, hydrocarbons, carbon monoxide, ozone, lead and nitrogen oxides. In this case, the utility (clean air) is conditional, because the energy consumed by the electric car or electric motor (in the case of a hybrid drive) can be produced using non-renewable energy resources (fossil fuels) elsewhere, and the carbon dioxide emissions also depend on how the electric car or electric motor consumes electricity.

The use of electric motors is particularly effective in the case when its power supply is generated from "clean" renewable energy, or when environmentally "clean" organic fuels are used for its generation, where various combinations provide the so-called "hybrid combustion" process while maintaining the effective parameters of the engine, which will significantly reduce the quantities of "greenhouse gases" in exhaust gases.

Three main conceptual approaches are distinguished when predicting the prospects for the development of modern transport engine building sector:

1. Introduction of alternative energy sources (Stirling engines, steam engines, air turbine engines, Wankel engines, electric engines, engines on solar batteries, etc.);
2. Use of alternative fuels (natural gas and other gaseous carbon fuels, fuel shales, synthetic fuels, coal dust and suspensions, alcohols, ethers, hydrogen, biofuels, etc.);
3. Improvement of the existing piston internal combustion engines, especially improving their operation process.

The advantages and disadvantages of the above directions are analyzed in the papers [1,2]. Here we only note that the last two conceptual approaches directly depend on the improvement and development of the piston internal combustion engines. It is clear that it's time to answer the question: does the piston internal combustion engine have an alternative and will it maintain its monopoly position in transport energy use? To answer this question, we must start from the fact that the piston engine is a widespread source of energy that has practically covered almost all areas of human activity and, as already mentioned above, it is directly related to two global problems of civilization - energy and environmental problems. Therefore, in order to answer the question, in addition to the above-mentioned problems, the acceptable social aspect is also taken into account [1,3].

2.Preconditions and means for resolving the problem

The steady increase in the number of piston engines, as well as their specific power and rotation frequency, makes them the main consumers of natural fuels. It is clear that, from this point of view, the creation and introduction of highly efficient engines is not a radical solution to the global energy problem. On the other hand, the piston engines, as the main consumers of natural fuel resources, are themselves the main violators of the natural ecological balance of the earth. The piston internal combustion engines emit harmful substances into the atmosphere such as: nitrogen oxides [NOx], solid particles (the main component of which is soot), carbon monoxide [CO] and hydrocarbon compounds [CmHn]. The so-called "engine with zero harmful emissions" running on traditional fuels remains a source of carbon dioxide [CO_2], which is limited by the so-called "greenhouse effect" law. Therefore, the creation and implementation of such an engine cannot completely solve the environmental problems. These problems become even more complicated when the ways of solving energy and environmental problems are not only different from each other, but also often contradict each other. A clear example of the conflict of goals in the realization of these tasks is the expansion of the temperature limits of the cycle, which, according to the Carnot cycle, is followed by an increase in the efficiency and a decrease in fuel consumption. In fact, this is achieved by means of the upper limit of the cycle, that is, by increasing the maximum temperature of the cycle, because it is practically impossible to significantly change the lower limit of the cycle (charge temperature during injection). An increase in the maximum temperature of the cycle, in turn, contributes to the formation of nitrogen oxides, as a result of which their quantities in

the exhaust gases increases. This means that there is a conflict between fuel economy and environmental friendliness, in other words, between efficiency and quality [1,4].

There are two main ways to simultaneously solve the environmental and energy problems of the piston engine-powered vehicle engines:

1. It is possible to reduce fuel consumption and toxic emissions by limiting the number of moving vehicles, that is, by reducing the number of engines in operation or by using low power engines;
2. Replacement of piston engines by alternative power equipment that does not use polluting petroleum products (fuels).

Let us analyze the capacities of these directions: the first way - reducing the number of vehicle movements and using small-capacity engines is directly related to the social aspect. The second way involves replacing the piston engines by an alternative source of energy that does not use polluting petroleum products. Today, a real alternative to piston engines of various energy sources is the electric motor, which is installed in the battery- electric cars.

Also, the hybrid motors, which are equipped with electric and piston engines, require a powerful battery. In such cars, during acceleration, the electric motor transmits energy to the shaft of the piston engine, and during braking, the electric motor runs in a generator mode, that is, it takes kinetic energy from the moving vehicle and charges the battery. Obviously, such a hybrid motor cannot be an alternative to a piston engine, and it can be viewed as a special factor for improving the energy and environmental situation. The fact that replacing the piston engine by an electric motor is considered to be a real and radical way can be clearly seen on the example of those megacities that have developed a network of tramway and-trolleybus transport, land and underground electric transport, and electrified railways for intercity and international traffic. In the future, public transport will include a significant number of intra-city electric vehicles (such a trend is especially noticeable in the USA). Nevertheless, the problem of private transport remains unsolved, because the electric car cannot respond to the natural human demand to "travel wherever I want and whenever I want". In this case, it is not only about the absence of the batteries, whose energy capacity can be compared with the energy capacity of traditional fuels of piston engines. Here, of course, we cannot exclude a scientific breakthrough in the field of electric energy storage, but if it still happens and cheap and easy-to-use electric cars with a long mileage appear on the market, then there will not be enough electricity from existing hydro and nuclear power plants to charge their batteries. This is indicated by the fact that the total power generated by piston engines in the world is several times higher than the installed capacity of all power plants. On the other hand, an electric motor can be successfully used to to improve the piston internal combustion engine. Hybridization of these engines make it easier to avoid the well-known disadvantage of the piston internal combustion engine, the existence of a relatively low efficiency at low loads, which can practically be increased when driving at low speeds by using an electric motor. Along with this, the further development of transport energy use puts on the agenda the need to use non-petroleum, non-traditional (alternative) fuels in order to solve energy and environmental problems, we note here that the adaptation of the piston engine to alternative fuels, first of all, implies the improvement of the combustion process. Thus, we can conclude that the further improvement of the combustion process in piston engines will remain relevant also in the future.

An alternative is homogeneous self-ignition, known as homogeneous charge compression ignition (HCCI). Sometimes the term "controlled auto ignition (CAI) is used. Such an alternative engine is a combination of a diesel engine and an Otto thermodynamic cycle engine [3]. The intense competition between the diesel and gasoline engines has contributed to the fact that there were and are many attempts (including many successful ones) to organize new, alternative operation processes that could combine the positive properties of these fundamentally different engines in a single engine. From the characteristics of the operating cycles of the diesel and gasoline engines, it is clear that the engine with the HCCI process is a hybrid of these two types of engines. The need for such clarification is clear, because the hybrid engines are usually called the car's power unit, which consists of a piston engine and an electric motor [5]. Naturally, there are other possibilities of organizing the operating cycle with parallel signs, recently the A2CD version has attracted attention. It is practically an engine with the HCCI process, for the creation of which there are different approaches. For example, the DaimlerBenz company created a diesel engine with a homogeneous mixture in the combustion chamber. Hybrid engines created on the basis of diesel and Otto engine operation processes are called "Diesotto".

Methanol fuel can be viewed as an additive to motor gasoline. The optimal addition of methanol to liquid fuel with a high octane component varies from 5 to 20%; At such concentrations, the gasoline-alcohol mixture is characterized by satisfactory properties and provides a noticeable economic effect. At the same time, the introduction of methanol increases the octane number of fuel (on average by 3-8 units for a 15%-additive), which leads to compensation of the degradation of energy efficiency by increasing the compression ratio. Also, methanol improves the process of fuel combustion due to the formation of radicals that activate oxidation chain reactions. Combustion studies of the gasoline-methanol mixtures in the single-cylinder engines with standard and stratified mixture formation systems have shown that the addition of methanol reduces the ignition delay period and the duration of fuel combustion. In this case, heat removal from the reaction zone decreases, and the combustion limit of the mixture expands and becomes the maximum for pure methanol. One of the most serious problems hindering the use of methanol additives is a low stability of the gasoline-methanol mixtures and their particular sensitivity to water. The difference in the density of gasoline and methanol and the high solubility of the latter in water lead to the fact that the introduction of even a small amount of water into the mixture leads to its immediate stratification and the water-methanol phase precipitation. The tendency to delamination increases with decreasing temperature, increasing water concentration and decreasing the content of aromatic substances in gasoline [5] .

The comprehensive analysis given above allows us to conclude that the piston internal combustion engines still remain the most economical, but environmentally unreliable devices. It should also be noted here that the further development of internal combustion engines depends primarily on the use of such alternative fuels that will significantly improve environmental pollution processes, although it is possible that the engine's economic performance for these conditions will be less or close to that of the base engine (fuel consumption will increase). At the modern stage, key findings from the study show that fuel gasoline-methanol mixture gives good results in this regard, in particular, environmental and power indicators are improved, but specific fuel consumption increases.

By analogy with the gasoline-methanol fuel mixture combustion, the possibility of implementing the combustion process of compressed natural gas and methanol mixture (hybrid combustion) is considered, which will improve both the engine's environmental and efficiency indicators compared to gaseous fuel consumption. The effect can be achieved by the fact that the gas-methanol mixture is more stable, its density is higher, and the burning rate increases significantly, which is distributed almost evenly in the entire volume of the combustion chamber, because the methanol fuel mixture is placed layer by layer in the volume, thus ensuring a stable hybrid combustion process. Implementation of such a process will improve the efficient operation of the positive-ignition engines. Figure 1 illustrates how the mixing process should be implemented in the case of using gaseous and methanol fuels. Here, the spraying of methanol in the intake manifold, the beginning of gaseous fuel entry, and the process of external mixing are taking place simultaneously until the end of the compression process. A spark is then supplied with some advancing and the hybrid combustion process takes place, as is done in the Otto cycle. Figure 2 illustrates the theoretical representation of the indicator diagram, from which it can be clearly seen that in the case of the hybrid combustion process, the pressure value is higher than in the case of using direct

gas fuel, and it approaches the case of using high octane gasoline. It should also be noted that the fuel mixture of natural gas and methanol makes it easier to increase the compression ratio by 3-5 points and to compensate fully the efficient indicators.

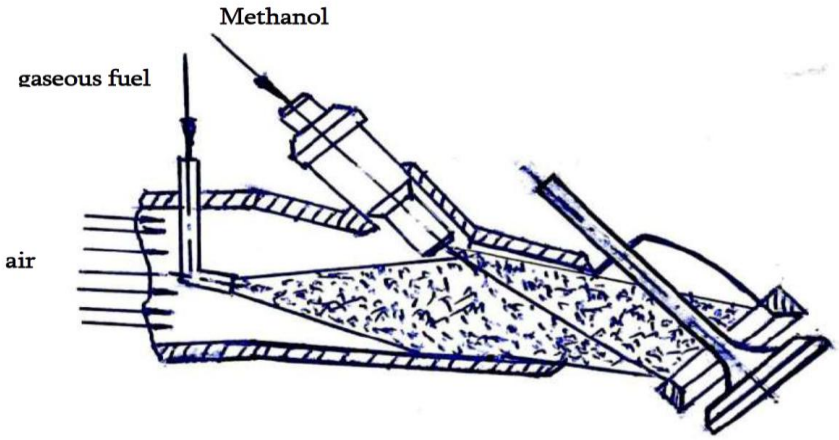

Fig.1. *Scheme of the formation of gas-methanol or hydrogen-methanol working mixture*

From an extensive literature review, it appears that in the near future it is planned to convert the water transport diesel engines to run on compressed of liquefied gas. In this case, if the working mixture consisting of liquid gas-and-methanol or hydrogen-and-methanol is prepared, as discussed above, that is, the gas-diesel process is implemented, where the selection of explosive fuel is important, for this purpose, methanol can be used, because it reduces the period of delay of self-ignition, the duration of fuel combustion, and the combustion limits of the working mixture are expanded (hybrid combustion), resulting in improving the mixture formation process, and the cycle implemented in the engine approaches the Otto cycle, which increases environmental and efficiency indicators of diesel engine in comparison with that of a gas-diesel engine, where diesel fuel is used as an explosive one.

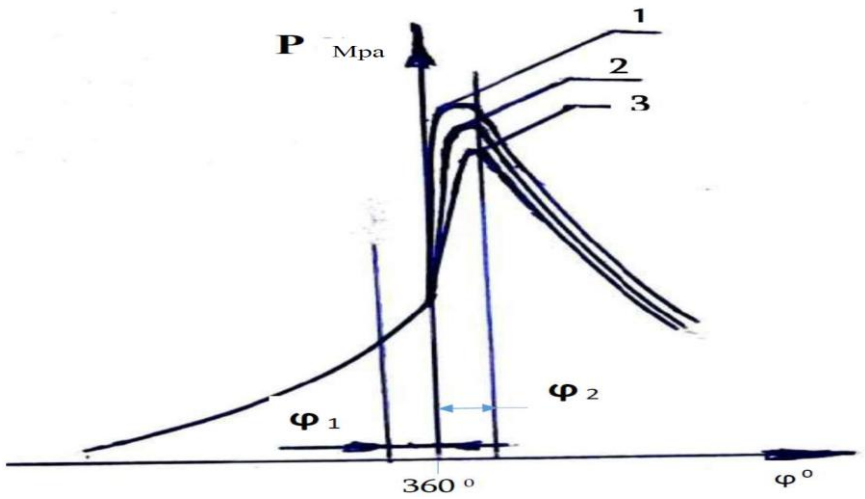

Fig. 2. *The theoretical indicator diagram: 1-Hydrogen-liquid gas fuel mixture; 2- Natural gas-methanol fuel mixture; 3- Natural gas fuel mixture.*

3. Conclusion

Based on the analysis, it can be concluded that the use of methanol (hybrid combustion) improves the environmental and efficient indicators of the engine with forced ignition compared to that of the engines running on a gas fuel. It should also be noted that the diesel engine operation is closer to the Otto cycle, where the heat losses are reduced, which ensures the improvement of the environmental and efficient characteristics of engines.

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