Reducing harmful air emissions from vehicles, ships and stationary facilities operating in the Arctic

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Abstract. The paper proposes a method for reducing harmful emissions into the Arctic atmosphere during the operation of diesel engines using electromagnetic waves of ultra-high frequency (UHF) and ultrasound. Experimental studies were conducted, which confirmed the reduction of NOx emissions by 50%. In order to implement the method, a multipurpose fuel unit is being developed.

1 Introduction

Severe climatic conditions, hard-to-access locations, and difficulties with power supply have led to widespread use of diesel engines in the Arctic. Vehicles, construction machinery, all-terrain vehicles, most ships, diesel locomotives, mobile and stationary power plants operating in the Arctic are equipped with diesel engines. Given the plans of the Russian Federation for the development of the Arctic region, it is necessary to take into account the following factors. First, there is no alternative to diesel-powered machinery operating today in the Arctic for the next decades. The Arctic ecosystem is very fragile and susceptible to anthropogenic impact [1]. The diesel engine is one of the main sources of harmful emissions into the atmosphere [2]. The combustion of fuel in the cylinders of diesel engines generates various substances that are relased into the atmosphere with exhaust gases. Their composition depends on the design of the diesel engine, its power and operating modes, as well as the quality of the fuel used [10]. Exhaust gases emit water (H2O), oxygen (O2), carbon dioxide (CO2), carbon monoxide (CO), unburned hydrocarbons (HC or CH) and nitrogen oxides (NOx). nitrogen oxides (NOx) are currently considered the most dangerous for humans, flora and fauna and the ecology of the area as a whole. They are dangerous when inhaled into the lungs of humans and animals; besides, when released into the atmosphere, they precipitate so-called acid rain - aqueous solutions of nitrogen oxides. Such precipitation negatively affects the entire fragile ecosystem of the Arctic, destroys a thin layer of soil in the tundra, and negatively affects the life of aquatic organisms. aqueous solutions of nitrogen oxides are also formed by contract of nitrogen oxides contained in the exhaust gases with snow and water.

2 Research

The employees of the Department of Thermodynamics and Thermal Engines of Gubkin National University of Oil and Gas are dealing with the issues of reducing harmful emissions into the atmosphere during the operation of diesel engines [9, 14]. Taking into account that engineers have been interested in studying the effects of electromagnetic waves on various substances, including fossil fuels, for more than a decade, the department has been conducting research and development work in recent years to assess the possibility of using electromagnetic waves of ultra-high frequency (UHF) and ultrasound to improve the efficiency of diesel engines. The expected scientific result of the study is an assessment of the possibility of practical application of the features of thermohydrodynamic and physico-chemical processes occurring in the cylinders of diesel engines using a water-fuel-mixture as fuel, when the fuel-water mixture is exposed to microwaves and ultrasound to reduce harmful emissions and fuel consumption. Analysis of works on the formation of nitrogen oxides allows to distinguish several mechanisms of NOx formation. Fast nitrogen oxides NOx are formed as a result of collisions of nitrogen molecules with hydrocarbon radicals in the combustion zone at pulsating temperature. If the fuel contains nitrogen-containing compounds, fuel nitrogen oxides are formed during their low-temperature oxidation. This process is accompanied by low temperatures of 1000-1200K. Thermal nitrogen oxides NOx are formed during the high-temperature oxidation of nitrogen in the air [16].

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Atmospheric nitrogen is oxidized at high temperatures (> 2000K) in the zone of combustion products behind the flame front. The main provisions of the thermal theory of nitrogen oxides formation are:

Nitrogen is oxidized by atmospheric oxygen in the zone of combustion products behind the flame front.

The amount of NOx is determined not only by the maximum possible combustion temperature, but by the number of nitrogen and oxygen atoms in the zone of combustion products, and does not depend on the type of fuel, provided that the fuel itself does not contain nitrogen.

The cooling rate of the exhaust gases significantly affects the content of nitrogen oxides in them.

The maximum combustion temperature affects the concentration of nitrogen oxides only in lean mixtures, while in rich mixtures this concentration is limited by the decomposition kinetics.

When the temperature exceed 1700 K, thermal nitrogen oxides become predominant over all others.

Analysis of the conditions of formation of nitrogen oxides leads to the conclusion that reducing the temperature in the combustion zone is the determining factor ensuring the the reduction in NOx formation. To solve the problem of reducing the temperature in the combustion zone, it is proposed to supply a certain amount of water to the engine cylinders together with the fuel, which, when evaporating, will ensure a decrease in temperature and, as a consequence, a decrease in NOx content in the diesel exhaust gases. Analysis of thermodynamic processes in the diesel engine cylinder insicates the possibility of using water in the combustion zone in order to reduce fuel consumption. For this purpose, it is proposed to treat the fuel water mixture before feeding it into the diesel engine cylinders with microwave waves and ultrasound [7, 9,].

It is commonly known that the fuel-air mixture is the smallest droplets of fuel in the air. Let us assume that, along with fuel droplets, water droplets are also entered in the fuel-air mixture, after which this three-component mixture was exposed to microwaves with a frequency of 2.45 GHz. When waves of this frequency affect water, water molecules in the form of an electric dipole begin to actively vibrate in the electromagnetic microwave field, which leads to the heating of water. The result of this effect will increase the temperature of water droplets and, subject to heat transfer, increase the average temperature of the mixture, which will ensure better evaporation of the fuel, and, as a consequence, increase the efficiency of the heat engine. Besides, an increase in water temperature will lead to an increase in internal pressure inside the water droplet surrounded by fuel on the outside. However, water droplets will retain their integrity up to a certain point under the action of surface tension forces. When placing such droplets in the cylinder of a diesel engine and disrupting the surface layer of the droplets (e.g., under the action of a flame front, mutual collision, additional treatment with microwave radiation), micro explosions of water droplets occur, which, after instantaneous explosion and evaporation, destroy and reduce fuel droplets, increasing the fuel burning surface. This will increase the pressure in the combustion chamber, and, as a consequence, increase the power and efficiency of the heat engine with the same amount of fuel consumed [5].

When running engines on the fuel-water mixture, it is especially important to ensure that water droplets suspended in the fuel are evenly distributed throughout the entire volume of the mixture. to achieve maximum homogeneity of the fuel-water mixture before feeding it into the cylinder, it is possible by pre-treating it with ultrasound. This will lead to the fragmentation of water droplets suspended in the fuel, their uniform distribution throughout the volume and the formation of a fuel-water emulsion.

The aim of the study was to assess the possibility of reducing nitrogen oxide emissions into the atmosphere and reducing fuel consumption when the fuel-water mixture treated with microwaves and ultrasound is fed into the diesel engine cylinders. For experimental verification of the proposed hypothesis, a laboratory bench equipped with a Kipor KM178 diesel engine was designed and manufactured. In addition to the standard fuel supply system, an experimental fuel supply system was designed and manufactured as a separate unit for preparation and feeding into the engine cylinder of the fuel-water emulsion treated with ultrasound and microwaves [4]. Schematic diagram of the experimental fuel supply system is shown in Figure 1.

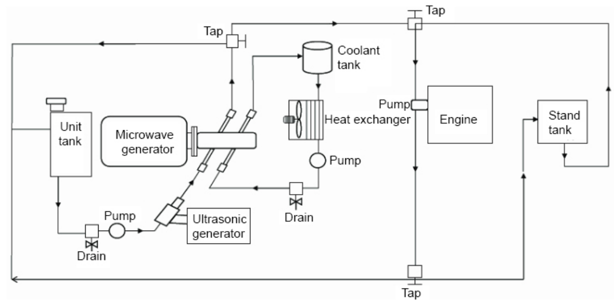

Fig. 1. Schematic diagram of the experimental fuel supply

General view of the bench with the engine, loading device and fuel supply unit is shown in Figure 2.

Fig. 2. General view of the bench

In the course of the experiment, the main operating parameters of the diesel engine and the loading device were recorded by a system of sensors and displayed using a computer connected to the bench with the Research Engines 3.2 software as shown in Figure 3. The composition of exhaust gases was measured with a Testo t350XL gas analyzer.

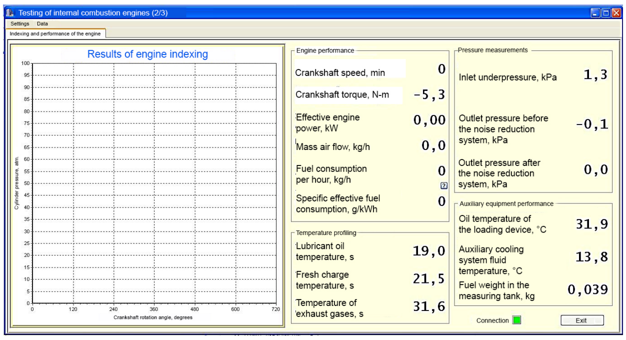

Fig. 3. Measurement results

Comparison of test results of diesel engine when idling with standard fuel and fuel-water mixture with different percentage of water treated with ultrasound and microwaves are presented in Figures 4 and 5.

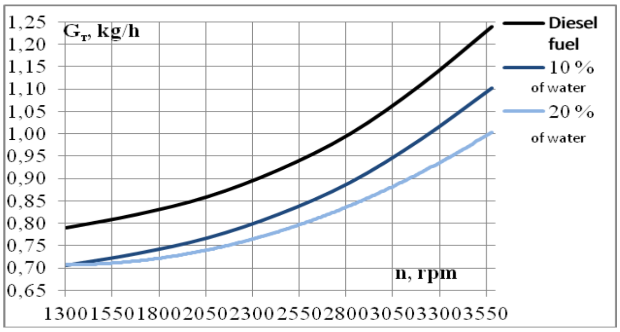

Fig. 4. Dependence of fuel consumption on the crankshaft speed

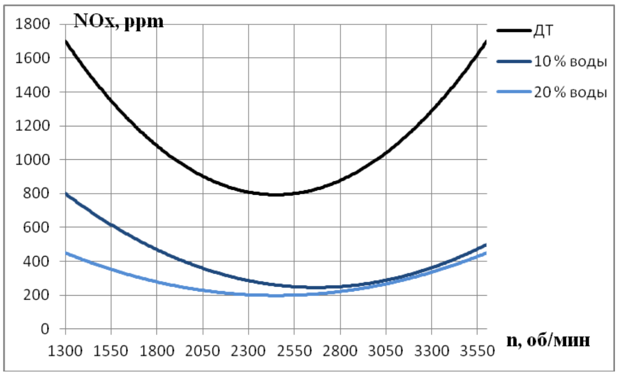

Fig. 5. Dependence of NOx concentration on the crankshaft speed

3 Conclusion

The main conclusions of the research work are as follows:

1. The use of fuel-water mixture treated with ultrasound and microwaves as fuel for the diesel engine can reduce the NOx content in exhaust gases by 40-50% and reduce fuel consumption by 3-10% when idling.
2. The use of the fuel-water mixture treated by ultrasound and microwaves significantly reduces the combustion temperature in the engine cylinder. When using pure diesel fuel, the temperature is 1900 - 2100 K, when using fuel-water emulsion containing 10 - 20% water, the temperature is 1500 - 1800 K. Calculations prove that lowering the combustion temperature to 2000 K and lower leads to a significant decrease in the concentration of nitrogen oxides. However, when the water content in the fuel-water mixture rises to 20%, the engine power decreases. Hence, it follows that it is preferable and optimal to run the engine on a fuel-water mixture containing 10% water.
3. The volume fraction of water equal to 10% ensures decrease in the calorimetric combustion temperature to 1700 - 1800 K, which is sufficient to normalize the content of nitrogen oxides in the exhaust gases.
4. In the course of experiments, it was noted that when using the fuel-water mixture, there is a decrease in the content of carbon monoxide, CO in the exhaust gases, as well as a decrease in soot formation.
5. All the studies were performed when the diesel engine was idling; therefore, further study of the load and speed modes of operation is of interest.

This paper presents a developed and experimentally tested method of reducing the content of nitrogen oxides in the exhaust gases of a diesel engine. The main advantages of the presented method include the possibility of its application at any facilities equipped with both new and long-operated diesel engines, without structural modifications in the engines themselves. The expected effect is achieved by installing a small-sized special fuel unit into the standard fuel system of the facility. An important factor in favor of this method is the possibility to modify facilities operating in the Arctic in the conditions of field workshops without sending them to manufacturers.

In conclusion, it should be noted that the development of technology will inevitably lead to the development of new engines that do not pollute the atmosphere. But achieving their widespread use will take a long time and during this period it is necessary to protect the Arctic atmosphere from harmful emissions of operating diesel engines.

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