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EFFICIENCY IMPROVMENT OF SHIPS OPERATION BY WATER-FUEL EMULSION USING

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Досліджена технологія використання водопаливних емульсій під час роботи суден, що обслуговують нафтовидобувні платформи. При аналізі процесу паливопідготовки розглянуто основні теоретичні методи та результати моделювання горіння каплі водопаливної емульсії. Показано, що присутність води при певних умовах може позитивно впливати на процес горіння, що приводе до поліпшення характеристик одержуваного факела горіння і тепловиділення палива

Ключові слова: емульсія, двигун судна, суміш води і дизеля, диспергування, температура спалаху, концентрація води, концентрація компоненти

Исследована технология использования водотопливных эмульсий при работе судов, обслуживающих нефтедобывающие платформы. При анализе процесса топливоподготовки рассмотрены основные теоретические методы и результаты моделирования горения капли водотопливной эмульсии. Показано, что присутствие воды при определенных условиях может положительно влиять на процесс горения, приводя к улучшению характеристик получаемого факела горения и тепловыделения топлива

Ключевые слова: эмульсия, двигатель судна, смесь воды и дизеля, диспергирование, температура вспышки, концентрация воды, концентрация компоненты

1. Introduction

In most cases, when operating of ship power plants, the ships do not use clean fuel, but the fuel emulsion with the presence of the water component [1]. The presence of water in fuel in most cases cannot be avoided. The natural processes of moisture condensation from the environment, a technical failure in the sealing units and seals the fuel

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and ballast tanks, etc., lead to the ingress of water into fuel components.

Without exception, all the vessels include in their design a fuel processing loop. Its implementation may vary depending on the ship's design, but there are always basic elements: hydraulic lines, injection equipment, filtration systems, components separation, etc.

An unambiguous conclusion about the negative effects of water in fuel on qualitative and quantitative parameters of the combustion process can be done. It is known that during combustion (chemical oxidation) of fuel due to the emergence of these intermediate chemical compounds like alcohols, small additions of water lead to the improvement of the quality of the combustion process [2]. In particular, in this case, increasing the dispersion of the torch and the concentration of harmful component (black carbon, toxic oxides of nitrogen and sulfur, etc.) can decrease in the flue gases, temperature of flue gases, etc.

The relevance of the work in this direction is determined primarily by the need to improve the efficiency of vessel operation by the use of new technologies of preparation of water-fuel mixtures and their subsequent combustion in the main engine of the vessel.

2. Analysis of scientific literature and the problem statement

According to the classification of works [3, 4], moisture in diesel fuel can be divided into two types: internal and external.

Internal (colloidal) moisture in the fuel is always there and is uniformly distributed per unit volume. Its amount is determined by the natural composition of the fuel and the relative humidity of atmospheric air. It also applies to the hydration moisture – the water that is chemically bound with mineral impurities of the fuel.

A characteristic feature of internal moisture is the impossibility of its removal by any of the prior methods [3–5]. The only way for the internal moisture of the fuel is high temperature, which in application to the ship operating conditions corresponds to only one process – the combustion of fuel in ship main engine (SME).

Exterior moisture in the fuel is a variable quantity. The main sources of its occurrence can be divided into atmospheric, technological and technical.

There are many methods of separating water from fuel, but the real practical use on courts have only been received by gravitational method, centrifugal separation and filtration. Each of them has its own advantages and disadvantages, but their efficiency depends on the surface tension s at the interface of water and fuel, which, in turn, as shown in Fig. 1, is determined by the temperature of the mixture [5, 6].

During the processing of a large number of ship certificates of quality supplied to ships diesel fuel (Shell Eastern Petroleum, Petronas Penapisan, Central Star Marine Supplies, Intertek Ltd., Total, Ryuseki Corporation), it was found that vessels serving oil platforms, only work on light diesel. Most of its figures indicate a lack of common normative values. So, for example, the temperature fluctuation range of the outbreak has varied widely from 61 to 78.5 °C.

Manufacturers and suppliers do not use the total output figure for the number of the volume concentration of water in the fuel. The lack of uniform standards increases the requirements for proper organization of the combustion process inside the working cylinders of SME [7].

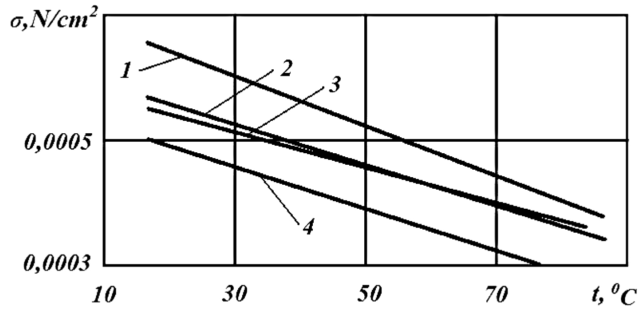

Fig. 1. The dependence of surface tension of fuel oil on temperature: 1 — 40 cSt fuel oil ; 2 — fuel oil emulsion with a moisture content of 10 %; 3 — fuel oil emulsion with a moisture content of 30 % ; 4 — fuel oil emulsion with a moisture content of 40 % [12]

From a scientific point of view, many of the issues associated with the theory of burning moist fuels, remain open and require further in-depth research. For example, there are no results that describe how a drop of the emulsion consisting of water and diesel is destroyed, when released into the field of high temperatures [3].

Of particular importance for improving the overall efficiency of the work are theoretical and experimental results on the description of the process of burning moist fuels [6]. Ultimately, such studies can help to formulate baselines and evaluation method of the degree of influence of the water concentration in the fuel on workflows in ship power plant (SPP).

Taking into consideration technical problems associated with the operation of ships in flooded fuel, and the lack of results, describing the work of marine diesel engine at various concentrations of water in the fuel, it is possible to assert that an urgent task requires a solution. It consists in developing a method for increasing the efficiency of vessel operations through the use of new technologies of preparation of water-fuel mixtures and their subsequent combustion in SME.

3. Goal and objectives of the study

The aim of the research was to improve technical and economic performance of ships by developing a new technology that allows to obtain and use water-fuel emulsion in working SME without the reduction of the main indicators of the power they develop.

To achieve this goal, the following tasks were solved:

– to formulate basic equations, on the basis of which it is possible to investigate the process of combustion of water-fuel emulsion;

– to determine by theoretical and experimental way the main indicators of the working process of the developed technology of preparation of water-fuel emulsion and to show how they can be used in the practice of the operation of vessels;

– to determine the boundaries of the numerical ranges of the stability zone of the combustion flame depending on the flame temperature and the concentrations of water components fed in the combustion of water-fuel emulsion.

4. Materials, equipment and methods of researches of influence of water concentration on the indicators of combustion of water-fuel emulsion

The studies were carried out using distilled water and brands of diesel fuel: Marine diesel oil, euro 2M Diesel, Gas Oil, Marine Gas Oil, Diesel Gas Oil ENEOS.

During the experiments in the preparation of water-fuel emulsions for measuring concentrations of complex components calibrated at the factory cylindrical measuring cups 1 precision class with a capacity of 100 ml with a scale division of 1 ml. were used.

With ultrasonic preparation of water-fuel emulsion, the ultrasonic generator IL 10-2.0 calibrated by the manufacturer was used. Its main characteristics are: supply voltage at a frequency of 50–60 Hz is equal to 220 V /–10 %; single-phase; operating frequency of 16–25 kHz; max power: 2.2 kW; Efficiency at load Cos φ=0.86, at least 92 %; the type of connected transducers – magnetostrictive.

During the mechanical preparation of water-fuel emulsion tubing with a diameter of 50 mm and a single-stage pump brand DESMI (Denmark) a series of NSA with the features: capacity 5–10 m^3/hour; maximum head: 10 m water were used.

The change in the temperature and the composition of exhaust flue gases depending on the fuel moisture was measured at the SRS mode of the load, equal to 80 %. The measurements were performed using a universal digital 717R flue gas analyser Flue Gas Analyser (USA).

In the work, to study such characteristics of the emulsion, as resistance to delamination and flash, analytical method and theory of statistics were used. To study the combustion process, the diffusion theory of combustion with the scheme of the given film and numerical approximation methods were used. To conduct field studies of the effect of the degree of water content of the emulsion on the stability of the process of combustion the theory of similarity and the method of experiment planning were used.

5. Results of researches of influence of water concentration on the burning characteristics of water-fuel emulsion

According to [5, 8], the equation of momentum conservation in the jet, the longitudinal velocity component was recorded in the form

$$\frac{\partial V_x^2}{\partial x}+\frac{\partial V_x V_y}{\partial y}=0, \quad (1)$$

where V_x, V_y are the projection of the velocity components, m/s; x, y – coordinates, m.

The magnitude of the transverse velocity component V_y in the moving stream can be found on the value of the longitudinal component V_x as

$$V_y=-\int\frac{\partial V_x}{\partial x}dy. \quad (2)$$

The equation of heat transfer in the jet has a view

$$V_x\frac{\partial T}{\partial x}+V_y\frac{\partial T}{\partial y}=-l^2\frac{\partial V_x}{\partial y}\frac{\partial^2 T}{\partial y^2} \quad (3)$$

a two-dimensional equation of thermal balance of the jet can be written in the form

$$\Delta TV_y+\frac{\partial}{\partial x}\int_0^y \Delta TV_x dy+c^2x^2\frac{\partial V_x}{\partial y}\frac{\partial T}{\partial y}, \quad (4)$$

where T – temperature, °C; 1 is the path length of mixing, m; c – the heat transfer coefficient, W/(m^2K).

In the course of its movement, a jet of water emulsion fuel will be expanded at the expense of the arising of stress [5]. For the axisymmetric jet and two components corresponding to the tangential and normal stress can be defined as

$$\tau_{xy}=\tau_{yx}=\mu\left(\frac{\partial V_x}{\partial y}-\frac{\partial V_y}{\partial x}\right), \quad (5)$$

$$\tau_{xx}=-\frac{2}{3}\mu\left(\frac{\partial V_x}{\partial x}-\frac{\partial V_y}{\partial y}\right)+2\mu\frac{\partial V_x}{\partial x}, \quad (6)$$

where τ is the stress, Pa; μ – dynamic viscosity, Pa×c.

When driving in the jet, a spray of the emulsion is characterized by a different fractional composition. In accordance with the work [9], it can be described by the expression, identical in form to the statistical Gaussian law

$$n_k=N^{-a^2 d_i^2}, \quad (7)$$

where n_k is number of droplets, whose diameter is greater than the current diameter d_i; N is the total number of droplets produced during spraying per unit mass of fuel; a – the distribution coefficient.

Time of burning of single drops of fuel is determined by the law [10]

$$t_b=\frac{\left(d^2-d_i^2\right)}{k_{ev}}, \quad (8)$$

where k_{ev} is the evaporation constant, C/mm^2.

When considering the process of combustion of water-fuel emulsion, the diffusion theory of combustion with the scheme of the given film was used [11–15]. In it, the main characteristics of the combustion process are determined not only by diffusion transfer of fuel vapor and oxygen to the place of combustion, but occurring kinetic resistance to burning. It was assumed that in the space bounded by the surface of the drop and the film are water vapor, fuel vapors and combustion products. During the burnout fuel-water core drops its diameter, and the diameter of the sphere of combustion is constantly decreasing too. Such combustion process is described using four equations of the heat balance.

The first equation describes the heat balance in the area of the internal space limited by the surface of the fuel droplets and the outer surface of the spheres of burning

$$\Delta M_F\left[q_{ev}-C_{fv}\left(t_d-t_b\right)-C_w\left(t_d-t_b\right)\right]= =\frac{4\pi r^2 dt_i}{dr}, \qquad (9)$$

where C_{fv} is the concentration of fuel vapor, %; C_w is the concentration of water vapor, %; r – variable radius (from zero up to the radius of the sphere surface combustion), m; t_d – the drop temperature, °C; t_b – current temperature, °C.

The second equation represents material balance in the region of the internal space limited by the surface of the fuel droplets and the outer surface of the spheres of burning

$$\Delta M_F=-4\pi r^2\left(DC_{fv}\frac{d\vartheta_{wv}}{dr}-VC_{fv}\vartheta_{wv}\right), \qquad (10)$$

where J_{wv} – relative content of water vapor in combustion products, %; V –speed of movement of the fuel vapors, m/s.

The third equation is a recording of thermal balance in the region between the combustion zone and the surrounding space

$$\Delta M_F\left[q_{ev}-C_{fv}\left(t_d-t_a\right)-C_w\left(t_d-t_a\right)\right]= =-4\pi r^2\frac{dt_i}{dr}, \qquad (11)$$

where t_a – ambient temperature, °C.

The fourth equation represents material balance in the region between the combustion zone and the surrounding space

$$\Delta M_F\left[\vartheta_{o-f}+\vartheta_o\right]=4\pi r^2 D\rho_o\frac{d\vartheta_o}{dr}, \qquad (12)$$

where J_{o-f} is the ratio of the flow rate of the oxidant (oxygen) and fuel flow; J_o – the relative content of the oxidant (oxygen) in the combustion products, %; D – diffusion coefficient, m^2/s; r_o – the density of the oxidizer (oxygen), kg/m^3.

The value of the water concentration in the fuel is the main factor influencing the process of its combustion in the SME [3]. During the experimental study of this effect new results were received, which may have a significant impact on the operational characteristics of the vessel. An example of such data is Fig. 2–4.

In Fig. 2, it is shown how the flash point of the emulsion, which was based on marine diesel brand Diesel euro 2M and water at various concentrations is changed.

The change in the fuel consumption of the SME and the temperature of leaving flue gases depending on the water concentration in the emulsion is shown in Fig. 3, 4. As it can be seen in the graphs Fig. 3, the shown data correspond to different load modes of the SME (80 %, 50 % and 30 %) at a constant number of revolutions.

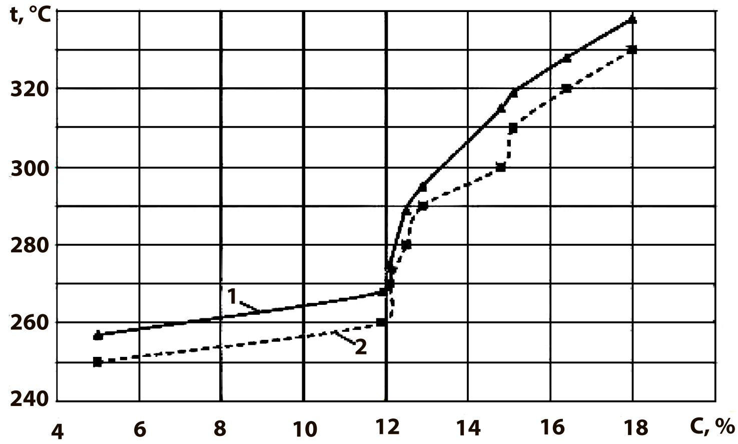

Fig. 2. The effect of the concentration of water on the flash point of the emulsion on the basis of marine diesel engine brand Diesel euro 2M: 1 — mechanical preparation of the emulsion; 2 — ultrasonic preparation of emulsions

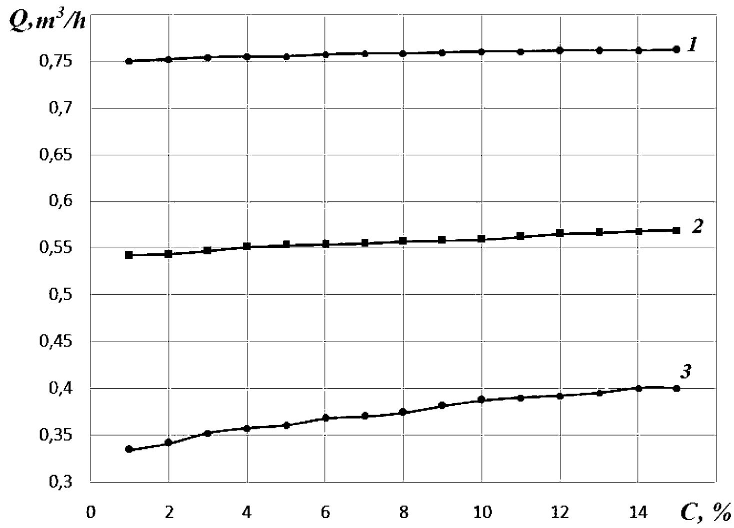

Fig. 3. The change in the flow rate of the emulsion depending on water concentration: 1 — the load on the SME 80 %; 2 — the load on the SME 50 %; 3 — the load on the SME 30 %

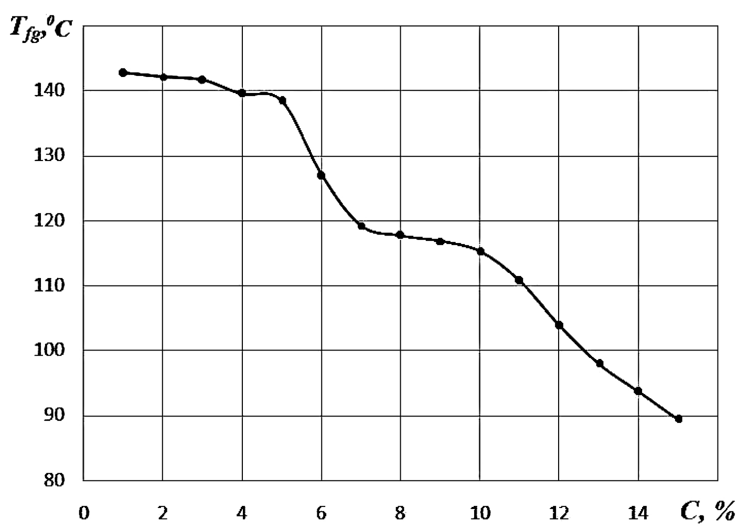

Fig. 4. The influence of water concentration in water-fuel emulsion on the temperature of leaving flue gases when the load on the SME 80 %

6. Discussion of the results of the research of influence of water concentration on the burning characteristics of water-fuel emulsion

On the basis of systematic experimental data of the work [8], and simulation results based on equations (1)–(12), it was found that, taken in the same cross sections of the moving turbulent jet profiles of the impurity concentration coincide with the temperature profiles in the same sections. In this case, the distribution of water components in the emulsion, which is injected into the working cylinder of the SME, can be studied in the field of temperatures obtained by the jet.

Analysis of the expression (7) showed that in the jet of sprayed water-fuel emulsions the distribution of the resulting drops of fuel in terms of size is different. The most probable droplet diameter after high-quality spray of water-fuel emulsion is 50–100 μm. From 20 to 90 % of the droplets in the jet get in this interval.

The quality of the preparation of water-fuel emulsions has an impact on its performance. So, in Fig. 2 it is shown that curve 1, corresponding to the mechanical method of preparation of emulsions, differs from curve 2, which corresponds to the emulsion obtained using the ultrasonic generator. On the chart, all the results correspond to the averaged values of the flash temperature.

The results given in Fig. 3 show that the increase in the concentration of water components in the emulsion led to an increase in its consumption in the SME. The graph shows that this change is not characterized by constancy. The worst case corresponds to the stroke of the modes at low load on the SME. In this case, water components did not result in fuel economy, because at its maximum value equal to 15 % the flow reading increased by 16.5 %.

On average course, when the load on the SME was 50 % at water concentration equal to 15 %, the growth of consumption amounted to just 4.7 %.

The best effect in fuel economy when using water-fuel emulsion was achieved when the load on the SME was equal to 80 %. In this case, when the humidity of the fuel equal to 15 % the change in fuel consumption in comparison with a moisture content of 1 % amounted to only 1.57 %. In real conditions, during the course of the 80 % mode load on the SME it is possible to obtain fuel economy of 13.42 % or in real units of measurement it is 0.102 m^3/h. At the cost of USD 800 per tone and diesel light density of 860 kg/m^3 the derived value of saving fuel costs is 1684.22 USD per day.

In Fig. 4, which shows the change in flue gas temperature, it is seen that increasing the moisture content of water-fuel emulsion directly reduces this characteristic of the workflow of the SME. The temperature drop is mainly due to additional consumption of thermal energy for combustion of water-fuel emulsion in the torch and leads to a total decrease of total heat losses at the exit of the SME. By analogy with economic effect from reduction of fuel consumption on travel with a load of SME in 80 %, the positive effect of the temperature balance was achieved. The moisture changes in the source of water-fuel emulsion with 1 % to 15 % resulted in having a negative gradient in the temperature differential at the exit of the chimney equal to –52.7 °C. This figure is very high and shows prospects for the use of water-fuel emulsions in the conditions of work of the courts.

7. Conclusions

1. As a result of studying the process of combustion of water-fuel emulsion in the SME, it was found that the presence of water in fuel is not a negative factor. With proper use of new production lines, it can lead to an increase in the main operational indicators of the SPP.

2. The quality of the preparation of the emulsion has an impact on its performance, and the increase in the concentration of water components in the emulsion leads to an increase of its consumption in the SME. The best effect in fuel economy when using water-fuel emulsion is achieved when the load on the SME is equal to 80 %. In this case, it is possible to obtain fuel economy of 13.42 %.

3. The increase in the concentration of water in the emulsion reduces the temperature of leaving flue gases. If you change the humidity from 1 % to 15 % the temperature drops by 52.7 °C. This figure is very high and shows prospects for the use of water-fuel emulsions in the conditions of work of the courts.

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