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THE OPTIMALISATION OF CHOOSING THE COMPOSITION OF FUEL-WATER EMULSION APPLIED FOR FEEDING MARINE COMBUSTION ENGINES

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Abstract

Delivery of water to cylinders is one of the basic ways of limitation of nitrogen oxides concentration in exhausts gases from the diesel engine and is justified in many published results of researches. In effect of engine's supply by fuel-water emulsion, simultaneously with decrease of nitrogen oxides, the changes of concentration of hydrocarbons, carbon oxides, solid particles, and changes of basic engine's working coefficients determining its performance and load of crank and cylinder-piston set.

In article, the results of researches of water delivery, in form of fuel-water emulsion to cylinders on changes of exhausts blackening; so on the changes in emission of toxic compounds in exhausts were introduced. In addition, the problem of choosing composition of fuel-water emulsion and way of its preparation were taken into consideration.

Keywords: Marine Diesel Engine, toxic exhausts emission, fuel-water emulsion.

1. Introduction

More and more frequently applied manner of active affecting on the combustion process to decrease the emission of nitrogen oxides is delivery of water to the cylinders. One way of water delivery to the cylinder is an injection of the fuel-water emulsion by standard but more efficient injector [3,9].

In the authors' opinion, applying fuel-water emulsion assures effect of the greatest reduction of NO_x concentration, simultaneously with full control of influence on the combustion process. Among all things it occurs because injected water (which is a component of fuel) is delivered directly to the flaming zone in cylinder, which is the area where nitrogen oxides directly form [1,9].

The essential issue is selection of the composition and manners of obtaining the fuel-water emulsion. In case of selecting composition of the fuel-water emulsion for concrete engine (with specific features of exploitation process) it is a significant problem of such a selection of emulsion, that the effect on the exploitation parameters of engine was possibly low at desirable level of ZT emission [4,5,6,7,].

Additionally, it is essential to obtain a significant stability of the emulsion, which is low by nature. Attempts of improving this situation concern applying various methods of obtaining the fuel-water emulsion. Depending on applied method, there is a group of control parameters, which are characteristic for every of the methods. These parameters determinate properties of the physics condition of received emulsion [4,5]. Among them temperature is a significant factor. It determinates dispersive extend of the emulsion, but simultaneously it affects on the unfavorable process of forming derivative emulsion.

2. Own researches

As it was mentioned before, the run of the exploitation process depends on the concrete use of engine. In case of a marine combustion engine of the main propulsion, changes of load of and engine rotational speed occur in a broad range and they are described by the propeller characteristic. To intensify this process there were carried out tests on the Sulzer 6AL20/24 engine test stand, loading the engine according to the propeller characteristic.

Performed tests have justified published data, which concern the effective limitation of the nitrogen oxides emission by providing water to the cylinders along with emulsion supplying the engine (Fig. 1), and also these data, which proved favorable influence on general efficiency (Fig. 2) and thermal and mechanic load in the crank and cylinder-piston set.

The run of propeller curve (Fig. 1) is characteristic to the medium-rotor engine and it is a result of conditions and parameters of a combustion process in the engine cylinders. Input low values of the NO_x concentration is a result of low number of local areas in the combustion chamber at $\lambda = 1,0$, where spread of the combustion in initiated and appears high values of temperature, which are favorable to forming nitrogen oxides in the engine cylinder.

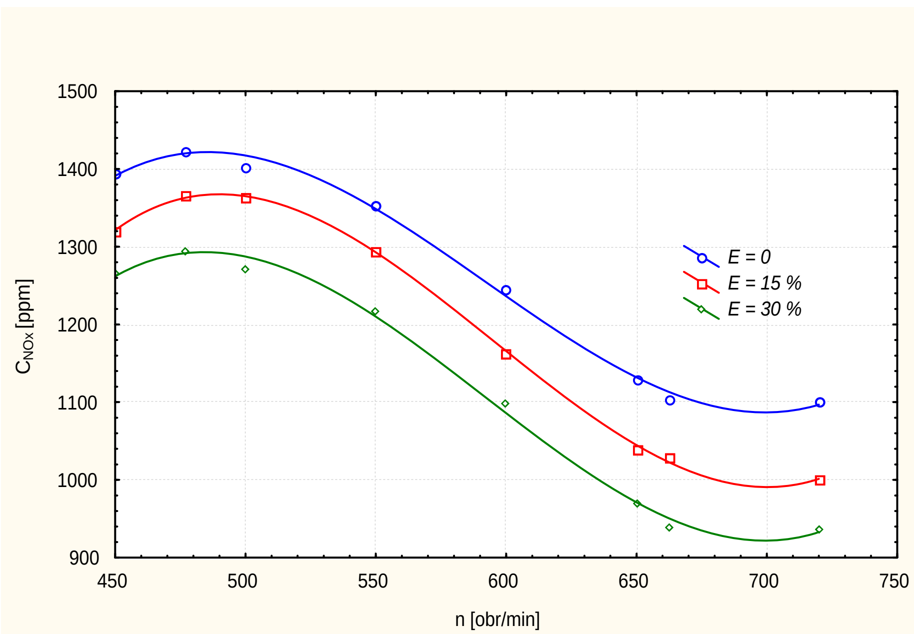

Fig.1. Propeller characteristic of the nitrogen oxides concentration in exhausted gases in the Sulzer 6AL20/24 engine, depending on the water content in supplying emulsion
where: C_{NOx} – NO_x concentration [ppm], n – engine speed [rpm], E – concentration of the emulsion [%]

A low load accompanies high value of air-excess coefficient. Increase of the nitrogen oxides concentration to the maximal value is a result of the increasing number of local zones in the combustion chamber at high temperature value.

Along with the further increase of load, engine rotation speed increases and affects on the improvement of homogeneous mixture in the cylinder, which is provoked by a movement of the piston, more even and placid combustion of he mixture at lowering number of high temperature zones. Despite the increasing load values and mean temperature of exhausts, nitrogen oxides concentration decreases even to 30% in proportion to the maximal value, which occur at relatively low load of the engine.

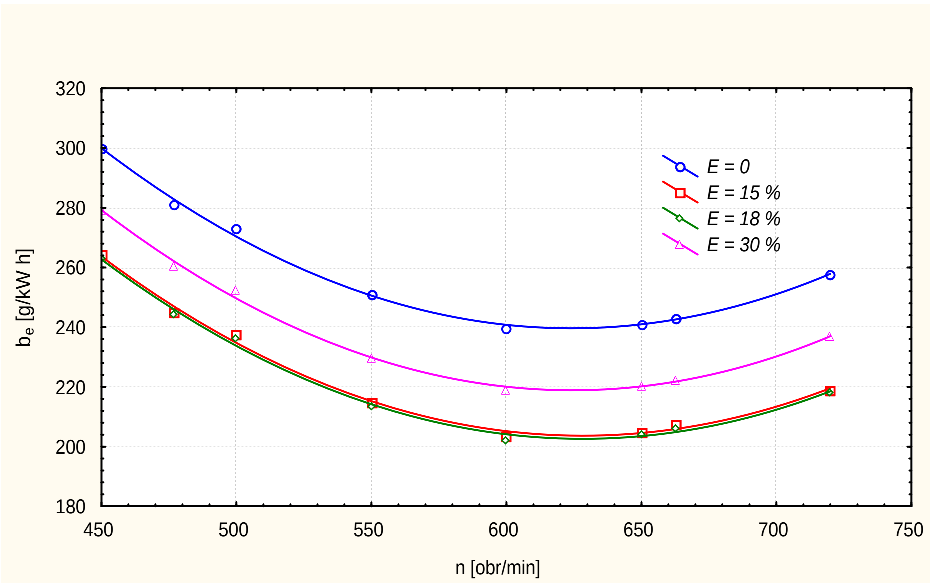

Fig. 2. Propeller characteristic of the unit fuel consumption in exhausted gases in the Sulzer 6AL20/24 engine, depending on water content in the supplying emulsion
where: b_e – unit fuel consumption [g/kW·h], n – engine rotation speed [rpm], E – concentration of emulsion [%]

The issue of selecting composition of the fuel-water emulsion is a broad issue and it could be taken under consideration depending on the amount of accepted standards. Analyzing changes of the nitrogen oxides concentration, presented in Fig. 1, it is noticeable, that decrease of the NO_x concentration (the main purpose of applying the fuel-water emulsion) it takes place in the whole considerate area of the engine's work. In relation to this, the selection of water content in the fuel-water emulsion could take place on the basis of one standard, what certainly would be the greatest decrease of the concentration or emission of NO_x.

This standard could be described by the dynamic signal change index d_p defined as [5]:

$$d_p = 1 - \frac{X_m - X_o}{X_o} \tag{1}$$

where: X_o – initial value of signal (NO_x concentration at supplying by pure fuel),
X_m – current value of signal (NO_x concentration at supplying by emulsion).

As a result, quantities described as maximal values of dynamic signal change index had to be regarded as optimal.

Presented solution is certainly imperfect, because during the supplying engine by the fuel-water emulsion energy parameters of engine have changed, and among them also unit fuel consumption. Because of this, greater amount of the simulation standards should be accepted to analyze the problem.

Finally it was assumed that participation of water in the fuel-water emulsion g_w defined as:

$$g_w = \frac{d_w}{d_f + d_w} \tag{2}$$

where: d_w –dose of water injected at engine cycle,

d_f – dose of fuel injected at engine cycle

will be optimal, if the unit fuel consumption b_i minimizes as well as nitrogen oxides e_{NOx}. at unlimited point of the propeller characteristic.

Basis on what is above presented, the purpose function was accepted (function of working quality index) in the form of [5]:

$$F(g_w, n) = \frac{C}{\left(\frac{e_{NO_x}}{e_{NO_x 0}}\right)^2 + \left(\frac{b_i}{b_{i0}}\right)^2} \tag{3}$$

where: C – constant,

n – engine speed [rpm]

b_{i0}, e_{NOx0} – values for given n and $g_w = 0$.

The injection of water $g_{w,opt}$ would be optimal, when:

$$F(g_w, n) = F(g_w, n)_{max} \quad \text{for } n = idem \tag{4}$$

Presented solution also seems to be not fully satisfying, because it omits such significant elements as physical properties of the fuel-water emulsion, which, as it was proved in the authors' papers [3,4,6,7,10], change in broad range and have influence in certainly significant way on the combustion process and NO_x concentration as well.

These quantities: dynamic viscosity, dispersion extend and stability - for the fuel-water emulsion at change of temperature and pressure changes significantly for quality of pulverization and influenced on energy effort, which is connected with blending and delivery of the emulgated fuel.

Streams of pulverized fuel is characterized by the extend of dispersion, an angle of the obtuse stream, diameter and the range of drops. Along with an increase of temperature of the fuel-water emulsion, these quantities increase, what shows that conditions are more favorable to blending in cylinder filled by the fuel with load. It shows also possibility of fast evaporation and then combustion of fuel included in the fuel-water emulsion. As it is known, intensity of the evaporation increases in proportion to the surface of drops.

Viscosity of emulsion mainly depends on the content of water, the extend of dispersion, temperature and properties of emulgator. Changes are significant in comparison to viscosity of diesel fuel. Rapid increase of viscosity till the stage of gel occurs only at water content above 40% [8].

For the sake of stability, but first of all combustion very important is an extend of dispersion and a homogenous of the emulsion. There are various methods of obtaining a high extend of the dispersion and generally they result from the same way of forming the fuel-water emulsion. However, the basic condition is that the diameter of water particles can not be greater than the diameter of drops of pulverized emulsion. Therefore, the extend of dispersion depends on quality of pulverized emulsion in cylinder of engine. On this condition, drops of the pulverized emulsion contains water, coated by hydrocarbons and emulgator. It is assumed, that diameter of water drops should not exceed 10 μm, and its main part should fit in the range of 2 - 3 μm .If emulsion contains water drops greater than diameter of drops appeared as a result of pulverization by the injector, in engine cylinder comes to the direct contact of water and walls of the combustion chamber, which effects in the deterioration of conditions of the combustion process.

One of the features of emulsion stability is its resistance to influence at low and high temperatures. Particularly sensitive are these emulsions with high content of water. Exceeding limitation values of temperature leads to the inversion of stages or the decline of emulsion into the separate components of fuel and water [7,10].

As it was mentioned before, the formation of emulsion does not occur spontaneously, but it requires supplies of energy from the external souce. The most effective method to emulgate water in fuel feeding the self-ignition engine is to insert diesel fuel under the surface of fuel. To production the emulsion are applied rotation devices: disc disperser, agitator, ultrasonic, cavitation and injection device, helicoidal mixer.

In case of helicoidal mixer the properties of obtained fuel-water emulsion depend on the setting parameters of mixer [2], which are: rotation speed, height of slot in the mixer and efficiency, understood as total mass of fuel and water, which flow through the helicoidal mixer. Also important is temperature of the emulsion formation, a parameter, which could be easily controlled as well as the rotation speed. First of all, dispersion of the emulsion and its stability are determined by these parameters.

Thus, purpose function, defined by the equation (3), should contain the term, which describe value of dispersion of emulsion. In relation to this, the new form of purpose function is following:

$$F(g_w, n) = \frac{C}{\left(\frac{e_{NO_x}}{e_{NO_x 0}}\right)^2 + \left(\frac{b_i}{b_{i0}}\right)^2 + \left(\frac{1}{i_{H_2O}}\right)^2} \tag{5}$$

where: i_{H2O} –number of water drops on the control survey of the fuel-water emulsion [7,10].
Suggested solution is also imperfect, it does not consider particular terms of the equation. In fact, influence of the particular terms is not equal. To take under consideration these differences, it is necessary to convert vector coordinates of the purpose function $F(g_w, n)$ into a singular function $H(g_w, n)$:

$$H(g_w, n) = wF(g_w, n), \tag{6}$$

where:

$$w = [w_1, w_2, ..., w_m] \in R^m, \tag{7}$$

is such a normalized verse form vector of significances, that the coordinates are:

$$w_i \in [0,1], \qquad i = 1, 2, ..., m, \tag{8}$$

and:

$$\sum_{i=1}^{m} w_i = 1 . \quad (9)$$

At this stage values of significances are intuitively accepted and in relation to this, the purpose function would be following:

$$H(g_w, n) = \frac{C}{0{,}4 \cdot \left(\frac{e_{NO_x}}{e_{NO_x 0}} \right)^2 + 0{,}4 \cdot \left(\frac{b_i}{b_{i0}} \right)^2 + 0{,}2 \cdot \left(\frac{1}{i_{H_2O}} \right)^2} \quad (10)$$

Considering the fact, that low amount of samples were analyzed, in this paper was not carried out the complete analysis of function $e_{NOx} = h(g_w, n)$ i $b_i = h(g_w, n)$. The analysis was limited to description of extreme values of the function established n for g_w, treating received results as values of working quality index– h. Standard of optimum would be fulfilled, analogous to (4), when values of work quality index h were accepted as maximal values.

The results of analysis of selecting the water content in emulsion, accepting the above mentioned standards are presented in Fig.3.

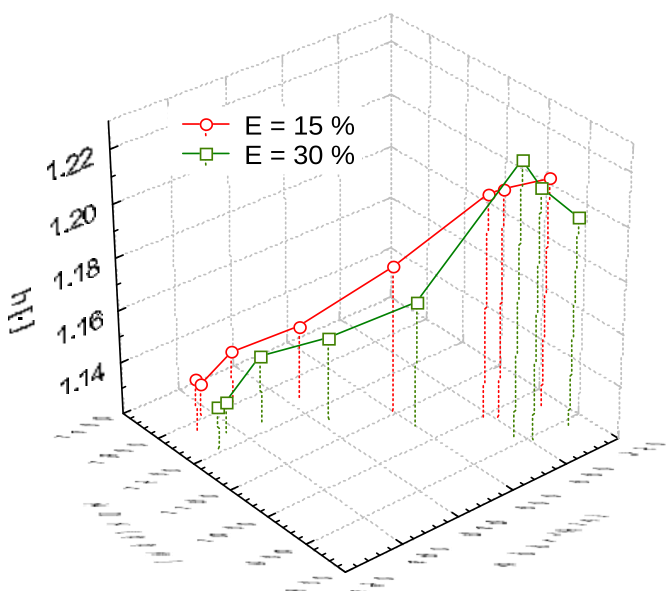

Fig. 3. Relation of working quality index h to nitrogen oxides concentration and engine speed in engine Sulzer 6AL20/24 type powered by fuel-water emulsion

Analyzing Fig. 3 it should be remarked that working quality index h had the highest values for both types of emulsion: 15% and 30% of water content. The extreme value has occurred at n = 650 rpm and load T = 3,18 kNm. The influence on such condition undoubtedly has a very favorable run of the unit fuel consumption in this area of engine's work (Fig. 2).

Aside from just mentioned decrease of the nitrogen oxides concentration, it is a result of the fact, that applying the fuel-water emulsion causes a number of effects on a run of the combustion process in the cylinder. Among other things, presence of water in the combustion area is a reason of decreasing temperature of the combustion products, but simultaneously specific volume of exhausted gas increases. In comparison to exhausted gas, the low molecule mass of the vapour causes considerable increase of pressure, as well as effective power of the engine.

In performed tests with application of 30% fuel-water emulsion a low increase of mean indicated pressure was remarked at the practically invariable maximal pressure of the combustion. It results in the increase of indicated power [1,6]. Dose of fuel per circuit of emulsion increased due to the decrease of energy, referred to a volume unit injected to the cylinder in comparison to analogues dose of pure fuel. However, after subtracting a mass of water included in the emulsion, consequently to the change of mean indicated pressure, consumption of fuel was reduced.

This resulted in increase of general efficiency of engine for about 2%.

3. Conclusions

In conclusions should be remarked, that presented above material does not completely solve problem of selection components of fuel-water emulsion for various conditions of using the engine. This is only an attempt at formalizing a problem in the essential scope to prepare input data for the principal tests, which authors plan to carry out for statistically significant population, using the multiply regression. Such obtained results will be purposely used to devise supply system of marine combustion engine by the fuel-water emulsion, which composition would be dynamically formed depending on a current load, what come out of the exploitation conditions. The minimal nitrogen oxides emission at the possibly greatest general efficiency of engine obviously remains a standard of selecting composition of the fuel-water emulsion.

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