The results of using of preliminary fuel treatment of water-fuel mixture in self-ignition engines

O Klyus
Maritime University of Szczecin, Waly Chrobrego 1-2, 70-500 Szczecin, Poland
e-mail: olegklus@o2.pl

Abstract. The paper discusses of implementing preliminary fuel treatment that take place in the fuel injector. Preliminary treatment results of mixture diesel oil fuel with water (up to 2.5%) in the direct injection diesel engines show the best ecological and economic results comparison of standard factory-made fuel equipments.

1. Introduction
Attempts to obtain technically optimal economical and ecological parameters in piston diesel engines face a number of difficulties, mainly concerning the arrangement of the engine working process. We can achieve lower fuel unit consumption, i.e. increased engine efficiency, by raising maximum temperatures of the cycle, which leads to increased toxic emissions of exhaust gases, mainly nitrogen oxides. Common Rail injection systems with electronic control of fuel injection characteristics are used in newly built engines, while exhaust components are equipped with catalytic reactors, solid particle filters and others. Still the simultaneous reduction of fuel consumption and level of toxic emissions remains a major problem. The same refers to engines currently operated in ships, whose construction does not leave much space for essential improvements in fuel, exhaust and other systems.

The Maritime University of Szczecin conducts research on medium and high speed self-ignition engines used in fishing boats and vessels which focuses on the use of preliminary fuel treatment directly in the injector body. Such treatment is possible in new design engines leaving factories as well as those in operation. As it is known, the reduction of nitrogen oxide emissions is facilitated by the lowering of the cycle temperature, which can be obtained by introducing water into the cylinder. It is interesting to use pre-treatment of fuel in the form of a mixture of diesel oil and water.

2. Preliminary fuel treatment
In order to present the problem of fuel pretreatment, let us consider an indicator diagram which describes the working process in the self-ignition engine. Considering a diesel engine indicator diagram we can observe that the basic time interval directly affecting economical and ecological engine parameters is the self-ignition delay time; its shortening may lead to both a slower increase of pressure and decreased maximum temperatures in the combustion chamber while a range of effective work remains at the same level.

Analysing the relations defining self-ignition delay time we can see that it depends on such factors as pressure and temperature in the combustion chamber, rotation speed of the shaft and engine kinematics as well as activation energy [2]. It should be noted that in attempts to improve economical
and ecological performance of new and used engines there is no practical possibility to change parameters such as pressure or temperature, and basic design features. One possible direction to affect these self-ignition engine parameters is to decrease values of activation energy.

For polyatomic molecule compounds (to which hydrocarbon fuels belong) activation energy is defined as the minimum kinetic energy by which the potential energy of a system should be greater for a chemical reaction to occur. Activation energy depends on molecule structure and bond strength. In the work [1] the behaviour of paraffin hydrocarbons \( \text{C}_n\text{H}_{2n+2} \) is discussed in this context. In these hydrocarbons the energy of breaking \( \text{C}–\text{H} \) bonds is greater than the energy of breaking \( \text{C}–\text{C} \) bonds, that is why the more carbon atoms there are in a molecule, the less activation energy is needed to break the bonds. This explains a high stability of isooctane \( \text{C}_8\text{H}_{18} \), used as reference fuel to determine octane ratings of other fuels. To facilitate overcoming the activation energy, we can deliver more energy to the reaction environment (e.g. by heating) or use a substance that easily reacts with the substrate (low activation energy), and thus formed compound easily converts into a product (also low activation energy). A catalyst is a substance that facilitates a conversion from a reactant into a product and, notably, is not consumed in the reaction. It follows that the presence of a catalyst (e.g. metals of the platinum family) and its contact with fuel before injection into the combustion chamber is desired.

The presence of a catalyst in the fuel system has another justification. Chemical properties of fuels used in self-ignition engines can be changed. In paraffin hydrocarbons, the most common group among diesel fuels, paraffin can be dehydrogenated in the presence of a catalysts. In the relevant reactions paraffin hydrocarbons change into olefins \( \text{C}_n\text{H}_{2n} \) and hydrogen molecules are released. Hydrogen, with its high diffusion coefficient, high flammability, high rate of combustion and a wide range of mixture combustibility, reduces self-ignition delay time in the conditions prevailing in the combustion chamber.

The presence of hydrogen in the injected fuel may affect chemical and physical phenomena. For instance, the self-ignition delay time depends on such physical factors as the diffusion rate of fuel, oxidizer and active nuclei of reaction.

It is known that a catalyst will be more effective if it is used in high temperature and the fuel has turbulent flow along catalyst surfaces [3]. For this reason we propose 'preliminary fuel treatment' that consists in depositing a catalytic material on the surface of an atomizer needle. The injector has the highest thermal load of all engine elements. To create turbulent fuel flow, the needle surface has properly situated passages. The part of the atomizer needle connecting the precision surface and the conical tip was chosen for preliminary fuel treatment. Such solution makes deposition of a catalyst (e.g. by electro-spark alloying) and machining of turbulizing passages technologically feasible in new as well as used injectors.

Figure 1 presents a scheme and Figure 2 includes a photograph of the suggested electro-spark alloying of catalyst application on an atomizer needle.
The technological process anticipates an introduction of a thin steel wire into the spark area, on the surface of which the catalytic material from the platinum metals group was applied. Since the catalyst efficiency improves at extending a contact surface of the catalyst with fuel, it has been proposed additionally that turbulizing passages shall be cut on the same surface where the catalyst is applied. Due to the turbulizing passages, fuel flow is forced and increases the contact frequency of the fuel and the catalyst material. Figure 3 presents a grinding process of turbulizing passages on the atomizer needle. The form of the passages presents intersecting left-hand and right-hand threads. Except for turbulizing effect, in that case, it is possible to obtain a homogenization effect [4].

3. Laboratory tests
Particle size distribution in an atomized fuel jet was determined at the first stage of the tests for the proposed method of preliminary fuel treatment. For that purpose a laser diffraction method was applied with the use of an instrument, made by Malvern, of Spraytec type and of a common rail injector test bench of Bosch EPS200A type (Figure. 4). As a research facility, an injector for engine of 359 type equipped with three hole atomizer was selected. The selection of this injector was justified by the fact that most of fishing vessels is equipped with engines with direct fuel injection and 359 engine constitute their representative part. Apart from the study, the atomized fuel jets were directed to one of
the jets in the area of laser beam. Therefore, separating of two remaining jets from that area did not constitute a technical issue. The figure 5 presents the photographs of the measurement process of particle distribution and the suggested system for fuel discharge from two fuel jets.

![Figure 4](image-url) Test stand for particle distribution in atomizer fuel jet

![Figure 5](image-url) Measurement of particle distribution in the laser beam area and separation of two remaining jets from the laser beam area

As it was mentioned earlier, the research used a mixture of diesel oil and water (up to 2.5%). The selected laboratory tests results are presented in Table 1.

| No | Sample composition | Calorific value [J/g] | HFRR Friction coefficient [-] | Lubrication film [%] |
|----|---------------------|------------------------|-------------------------------|---------------------|
|    | Diesel fuel | Water |                            |                     |                     |
| 1  | 100               | 0      | 43443                        | 187                 | 0,137               | 92                 |
| 2  | 98,5              | 1,5    | 41289                        |                     |                     |                    |
| 3  | 98                | 2,0    | 42989                        |                     |                     |                    |
| 4  | 97,5              | 2,5    | 42980                        | 220,5               | 0,145               | 71                 |
The laboratory tests results (Figure. 6) proved an improvement of fuel atomization characteristics – at the application of primarily treatment the value of a mean Sauter diameter decreased, the number of particles of smaller diameter increased [4].

Figure 6. Particle size distribution in atomized fuel jet

| Date-Time | File | Sample | D10 (%) | D50 (%) | D90 (%) |
|-----------|------|--------|---------|---------|---------|
| 3 Oct 2011-... | P17 W1 | RYBY01 | 9.86 | 27.87 | 71.73 |
| 3 Oct 2011-... | P17 W2 | RYBY01 | 9.31 | 24.14 | 80.92 |
| 3 Oct 2011-... | P17 W3 | RYBY01 | 11.79 | 29.66 | 70.64 |

[V]=Volume [N]=Number

4. Field tests
The field tests were conducted on a four stroke self-ignition engine with direct fuel injection, 359 type (Figure. 7). The set of instruments included an option to measure both the operational parameters and the ecological ones during the work according to a speed characteristics.

Figure 7. Test stand with 359 type engine

Figure 8, 9 and 10 present a speed characteristics in a form of a power, a unit fuel consumption and nitrogen oxides emission (using analyser type IMR3000).
Figure 8. Speed characteristics of power of 359 diesel type

Figure 9. Unit fuel consumption characteristics
Analysis of the obtained results shows that the use of pre-treatment of water-fuel mixture does not affect the engine's power, while it helps reduce both the emission of nitrogen oxides (on average by 12%) and unitary fuel consumption (by 8%).

5. Conclusions
It is possible to increase the efficiency of self-ignition engines and at the same time reduce the level of toxic emissions by implementing preliminary fuel treatment. The method consists in applying a catalytic coating deposited on a part of atomizer needle. The catalyst is more effective when put on specially made turbulizing passages forming crossing grooves or threads. The relevant method, consisting in depositing a metal of platinum group by electro spark alloying and making turbulizing passages, is technologically feasible in the process of making new injectors as well as by modifying those in use. Low temperatures of the process do not cause any changes or thermal strains of the precision pair, and portable equipment allows to make minor constructional changes directly at operator's base. The results of laboratory and field tests indicate that the use of preliminary fuel treatment reduces fuel consumption (by 8% on average), and the level of toxic emissions in exhaust gases (nitrogen oxides by 15%).

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