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MICROEMULSION AS A MEANS OF NO_X REDUCTION IN EXHAUST EMISSION OF DIESEL ENGINES

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Abstract

Currently produced internal combustion engines used in transportation, must meet very stringent legislative requirements EURO VI, for the limited emissions of exhaust gases: CO, HC, NO_x, PM, PN. One of the most toxic components and the most difficult to eliminate are nitrogen oxides NO_x, which currently permissible amount in the exhaust gases shall be 80 mg/km. This result must be achieved, moreover, with the fulfilment of the limits for other exhaust components, and above all, the contents of particulate matter (PM, PN). It should be pointed out, that the mechanisms of the NO_x and PM formation are opposed to each other; reduction of the NO_x amount is generally associated with an increase in PM and vice versa. Therefore, issues of lowering the amount of NO_x in the exhaust gases devote a lot of scientific work and engine research. Currently the most effective method of reducing the NO_x is the selective catalytic reduction (SCR), which requires the additional installation of sophisticated equipment in the vehicle. Therefore, methods easier to implement and to operate are sought. One such method is the use of a microemulsion to supply as fuel to diesel engines, consisting of an emulsion of diesel oil, water and surfactant (surface-active compound). The use of the microemulsion results in that already in combustion chamber forms less of NO_x, and therefore reduction of NO_x in the exhaust system is easier. The publication presents results of SB 3.1 engine research on the engine test bench. The research was comparative in nature and thus, in the first stage of research conducted, the engine was fuelled with diesel oil, then the area of engine load and engine speed characteristics, in which the NO_x emissions are greatest, was determined, and next, when engine was fuelled with various microemulsions, the engine investigation was conducted in this area. The microemulsions of diesel fuel and water comprise 10%, 20% and 30% water, selectively. The results of investigations show that, when the engine is fuelled with microemulsions, both NO_x and PM, as the main component of diesel engine exhaust - soot (smoke) can be reduced at the same time. The article also discusses the differences between emulsions and microemulsions, and how they influence the combustion in the engine combustion chambers.

Keywords*: internal combustion engines, engine emissions, internal combustion engine fuels, microemulsions.*

1. Introduction

Internal combustion engines are the source of high emissions to the atmosphere of various substances: gaseous, liquid and solid, mainly carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbons (HC), nitrogen oxides (NO_x), particulate matter (PM), the issue of which is subject to legislative restrictions, and a number of other substances emissions, which, as found in smaller quantities, were not yet on the list of restrictions. Among the emissions of harmful pollutants, NO_x are among the most harmful, the most difficult for the disposal, having the longest time of natural decomposition [7, 8, 9].

Moreover, with the hydrocarbons, in the presence of sunlight, they form smog, which is detrimental to the living organisms and plants. Harmfulness of NO_x is reflected in the legislation on allowable NO_x emissions during the tests.

This limit is currently 80 mg / km, according to the Euro 6 requirements, which apply to all new vehicles from 9/1/2015. Additionally this level of NO_x emissions must be maintained together with limited emissions of particulate matter (PM, PN). It should be noted that the emissions of NO_x and PM, PN emissions and opposed, because the reduction of NO_x emissions is bound with an increase in PM emissions, and vice versa.

Currently, one cannot obtain an adequate level of various exhaust components emissions using only the adjustment procedure. It is necessary to use complex catalytic systems. Namely, for an adequate level of NO_x emissions, the catalyst storage system, which is used mainly in the light vehicles (LDV), or the system of selective catalytic reduction (SCR) is required. The latter system is most effective in reducing the NO_x; however, it requires the installation of a complex reducing agent metering system. Therefore, the new solutions are being sought, easier in implementation and usage [14, 15, 16, 17].

One way to reduce NO_x emissions is the use of a diesel oil and water microemulsion to fuel diesel engines (CI) [1, 3, 4]. The use of a microemulsion has the advantage that one can obtain simultaneous reduction of NO_x and PM. Although the method of adding water to reduce NO_x emissions has been known for long, but there were technical difficulties with obtaining a stable and homogeneous emulsion, which prevented practical application. It was not until mastering the methods of piezoelectric quartz injection allowed the production of a microemulsion, which is characterized by suitable fragmentation of droplets, their uniform dispersion and clarity.

2. Microemulsions

Microemulsions are thermodynamically stable, transparent dispersion of diesel fuel and water, stabilized at the phase borders by surface-active compounds - surfactants. The difference between emulsions and microemulsions consists primarily of a particle size (emulsions 100-600 nm, the microemulsions of 5-140 nm) and clarity, low viscosity, thermodynamic stability and spontaneous formation of the microemulsion. In emulsions there is a strong interaction between molecules of surfactants which form a continuous phase boundary, whereas for microemulsions the surfactant particles are separated by constituent particles of the microemulsion, so that the system is transparent and stable, even during prolonged storage. This means that each diesel fuel particle is surrounded by a continuous water film. Water is the fuel non-active ingredient, but its presence reduces the temperature of combustion. At the high temperatures prevailing in the combustion chamber, the water molecules are overheated; with some droplets remain in a liquid state. Evaporation inside the drop results in a pressure difference, which leads to „micro blasting”. This phenomenon is beneficial for the mixing process of fuel and air. As a result, the combustion process occurs at lower temperatures, and combustion is more complete [7, 8, 9].

The water content in the fuel oil microemulsion must be optimized in terms of other toxic components of exhaust gas emissions and the performance and efficiency of the engine. Fuel in the form of microemulsion is characterized by a lower calorific value and a higher density.

In the research of Diesel engine there was a reduction the NO_x emissions with an increase in water content in the emulsion, whereas in the case of carbon monoxide, hydrocarbons and particulates, the reduction was observed to their proportion in case of microemulsion water content increase up to 20%. At higher water contents, their emissions was increased, which was probably caused by excessive lowering of temperature in the combustion chamber. This is an interesting issue, which may be the subject of further studies on the mechanism of the microemulsion combustion.

3. The research test stand and the subject of research

The researches were conducted on a single cylinder research compression ignition engine type SB 3.1, and its parameters are listed in Table. 1 [2]. The engine was loaded by means of Heenan-Froude eddy current brake type NK 11 CVA [10, 11, 12, 13].

The fuel consumption tests, which are the basis for determining the engine efficiency, were carried out using the volumetric method. NO_x concentrations were determined using the LCD type analyser; model PM2000, from Pierburg GmbH, Neuss BRD.

The engine smoke was analysed by filtration through opacimeter type AVL 415 with a measuring range of 0-10 FSN (Filter Smoke Number), production AVL Austria.

Table 1. Technical-operational parameters of SB 3.1 engine

Cylinder diameter	127 mm
Piston stroke	146 mm
Displacement	1.85 dm^3
Compression ratio	15.8
Nominal power	22.7 kW
Nominal rotational speed	2200 rpm
Maximum torque	117.7 Nm
Maximum torque speed	1400 rpm
Specific fuel consumption	220.3 g/kWh
Injection starting angle	26° BTOC

Schema of the test stand is shown in Fig. 1.

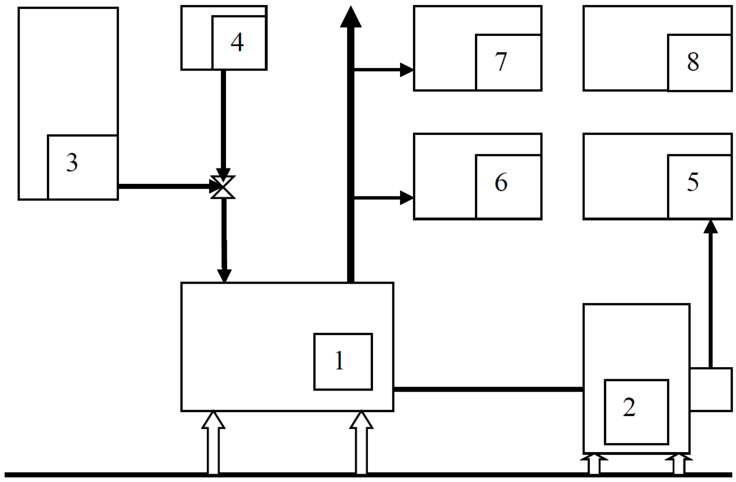

Fig. 1 Schematic of the engine test stand: 1. Engine, 2. Eddy current dynamometer, 3. Diesel oil supply, 4. Supporting installation, 5. Engine speed and load transducers, 6. Exhaust gas analysers, 7. Smoke meter, 8. Atmospheric conditions transducers

Subject of the research were micro emulsions of diesel oil with different water content: 10%, 20%, 30%, which were supplied to the engine. The research was determined power, torque and engine speed, the concentration of nitrogen oxides in exhaust gases and smoke opacity (S). Based on engine parameter measurements results, the operating efficiency (η) of the tested engine was determined [18, 19].

The research has comparative nature, and therefore, at first, the tests were conducted on diesel fuel powered engine, and following tests were conducted on the microemulsion-fuelled engine. In tests of diesel fuel powered engine, it turned out that the NO_x emission maxima occur while the engine rotational speed equals 1600 rpm, and therefore, the following series of tests for microemulsion-fuelled engine were carried out at this engine rotational speed.

Accordingly, the presence of water in the microemulsion has changed the combustion heat and the fuel density, in relation to the diesel oil. The parameters were as follows:

Diesel fuel: density 0.830 g/cm^3; calorific value 42000 kJ/kg.

Microemulsion of 10% water: density 0.887 g/cm^3; calorific value 37800 kJ/kg.

Microemulsion of 20% water: density 0.899 g/cm^3; calorific value 33600 kJ/kg.

Microemulsion of 30% water: density 0.910 g/cm^3; calorific value 29400 kJ / kg.

Fuel properties refer to the actual values resulting from the measurements, because due to the presence of surfactants of unknown chemical compositions for the microemulsions, it was not possible to determine these values by calculation. Therefore, the density of the microemulsion is greater than would result just of the presence of water.

4. Results of the researches

The research was of comparative nature and, therefore, during first phase of SB3.1 diesel oil fuelled engine research was conducted on a wide range of engine loads and speeds. By contrast, due to the small quantities of manufactured microemulsions, the tests when engine was fuelled with microemulsions were carried out only in the largest recorded range of the NO_x emissions, and thus, at the rotational speed of 1600 rpm.

On Figure 2 is presented the contour characteristics of a NO_x emissions in the exhaust of the diesel oil fuelled engine; NO_x = f (n, Pe). The drawing shows, that the maximum value of NO_x appear in the speed range of 1150-1600 rpm.

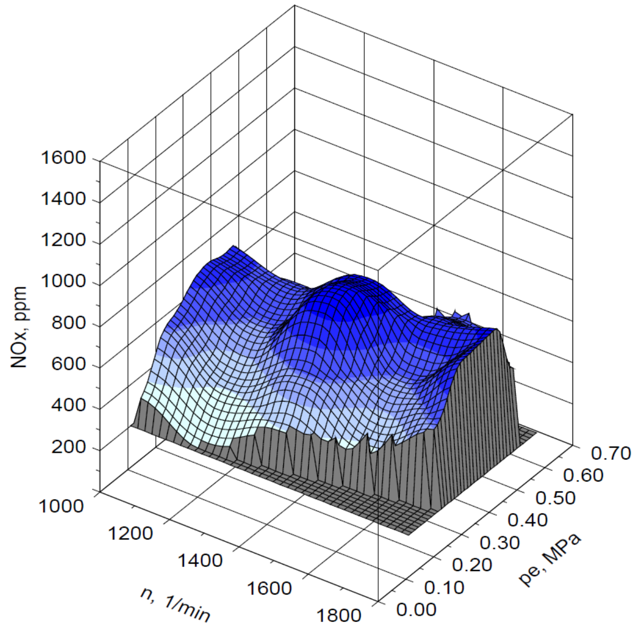

Fig. 2. NO_x emission (NO_x) versus engine speed (n) and engine load (Pe – mean effective pressure) Source: Report on the research of emulsion of water and hydrogen peroxide [10]

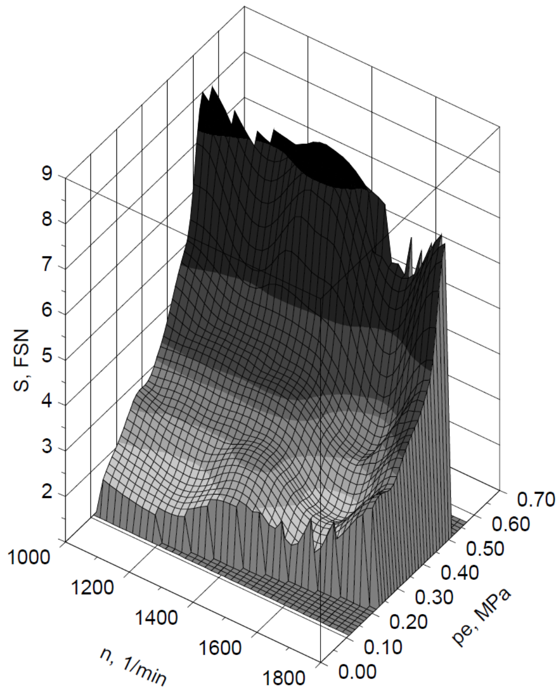

Fig. 3. Soot emission (S) versus engine speed (n) and engine load (Pe – mean effective pressure) Source: Report on the research of emulsion of water and hydrogen peroxide [10]

On Figure 3 is presented the contour characteristics of the engine exhaust opacity (S) as a function of engine speed (n) and engine load, when engine is fuelled by diesel oil: S = f (n, Pe). As we can see in the figure that the maximum values of the smoke appear in the area of the engine speed 1000 rpm and 1300 to 1600 rpm.

Figure 4 shows in the diagram the difference in the maximum and minimum concentration of NO_x in the engine exhaust gases, when the engine is fuelled with diesel oil and with microemulsions with different water contents

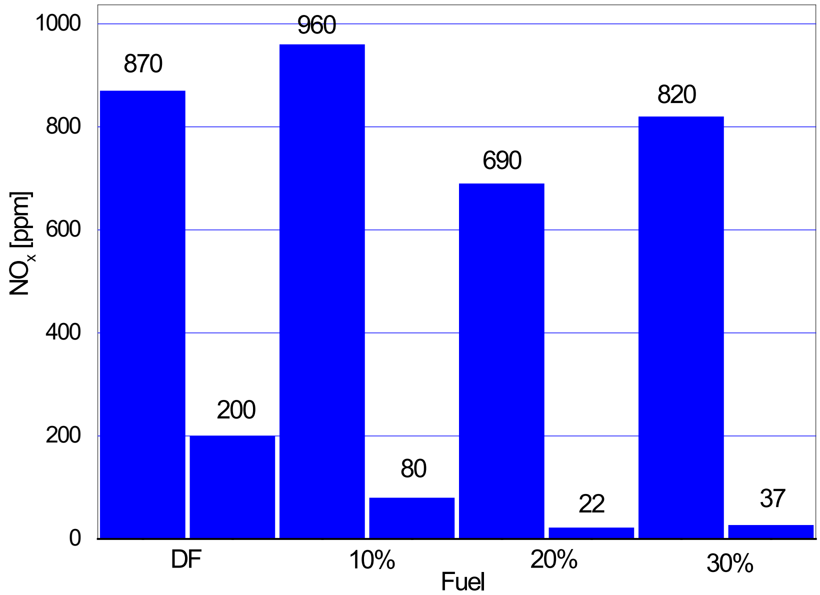

Fig. 4. The maximum and minimum concentration of NO_x (depending on the engine load) in the exhaust gases of the SB 3.1 engine at a speed of 1600 rpm and supplying the engine with diesel oil and various microemulsions

Figure 5 shows in the diagram the difference in maximum and minimum engine exhaust soot emissions at the engine rotational speed of 1600 rpm for different engine loads for the SB 3.1 engine, fuelled in tests with diesel oil and various oil and water microemulsions.

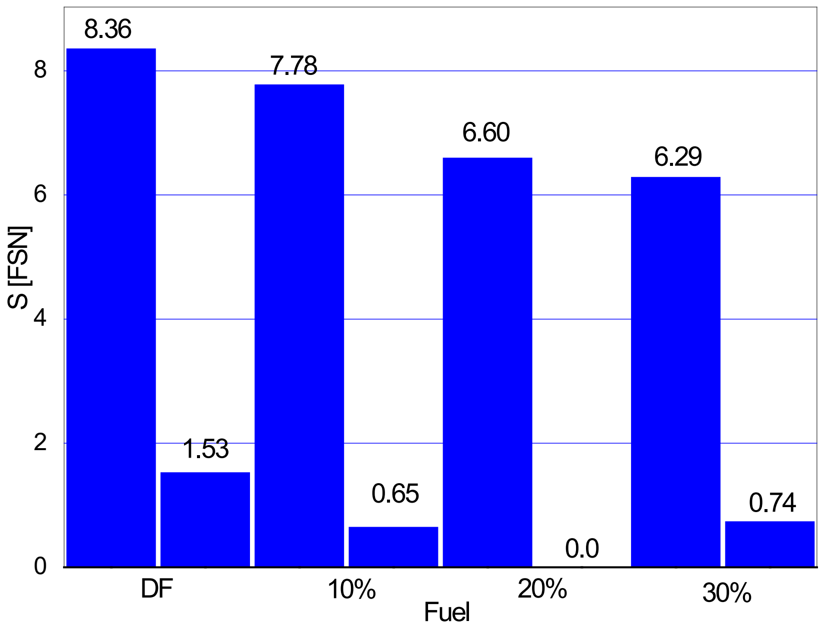

Fig. 5. Maximum and minimum values of soot emissions (S) for different engine loads. Engine SB 3.1 was fuelled with different fuels (diesel oil and microemulsions); engine speed 1600 rpm

Figure 6 shows the relative values of the maximum NO_x emissions of the SB 3.1 engine, the engine fuelled with various microemulsions, relative to the engine NO_x emissions when fuelled with diesel oil. Engine speed 1600 rpm.

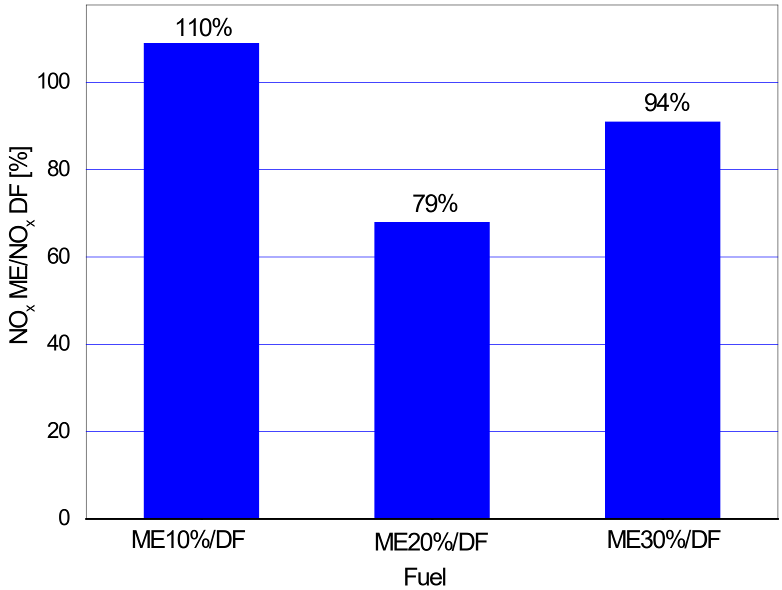

Fig. 6. Relative values of maximum NO_x emissions for engine SB 3.1 (fuelled with different microemulsions) relative to NO_x emissions when fuelled with diesel oil. Engine speed 1600 rpm

Figure 7 shows the relative values of the exhaust soot emissions of the SB 3.1 engine, the engine fuelled with various microemulsions, relative to the exhaust soot emissions when fuelled with diesel fuel. Engine speed 1600 rpm.

Relative changes in general efficiency when the SB 3.1 engine was fuelled with diesel oil and various microemulsions (10% and 20% water), at a rotational speed 1600 rpm and for different engine torque values are shown in Fig. 8. The efficiency of an engine was determined from the following formula:

$$\eta = \frac{3600}{g_e \cdot W}, \tag{1}$$

where: g_e is the specific fuel consumption [g/kWh], W is the fuel calorific value [MJ/kg].

Analysis of the results shows, that by increasing the amount of water in the microemulsion, the value of the minimum NO_X emissions levels are lowered in the entire load range, while the maximum value of NO_X emissions decreased only, when water content in the microemulsion was greater than 10%. It is clear, too, that engine exhaust opacity was significantly lower, when engine was fuelled with microemulsions, than under diesel oil fuel, throughout the whole engine load range, at the rotational speed of 1600 rev / min. The efficiency of the SB 3.1 engine, when fuelled by microemulsions was slightly lower, than when running on diesel oil, which is the result of increasing the amount of heat, required to evaporate the water in the combustion chamber and a lower combustion temperature. The isentropic exponent k is also reduced. However, the main task of the fuelling the engine with a microemulsion is the decrease of the toxic components in exhaust gas, particularly NO_X. This task, looking on the results of tests of fuelling the engine with microemulsions, was fulfilled, although studies have shown that there is no simple relationship between the amount of water in the microemulsion and the emission of NO_X or exhaust gas smokiness. Therefore, achieving practical results requires optimization between the amount of water incorporated in fuel, the toxicity of exhaust and engine performance. In this respect, one cannot rely on one parameter only.

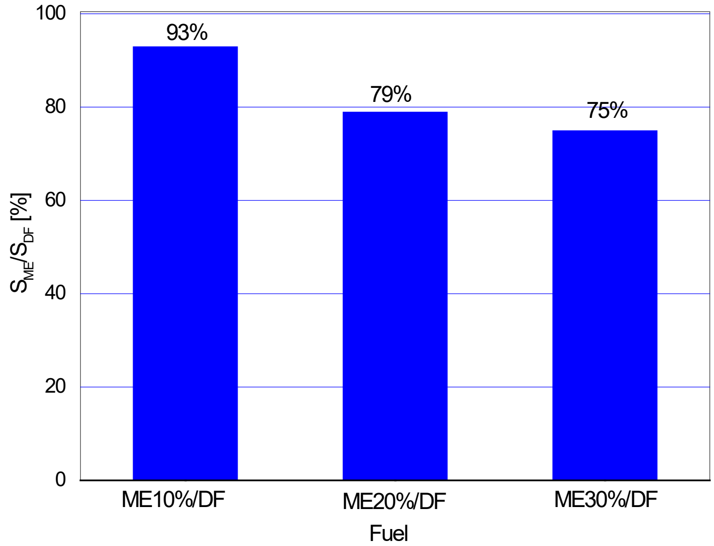

Fig. 7. Relative values of maximum soot emissions for SB 3.1 engine, fuelled with different microemulsions, relative to engine emissions when fuelled with diesel oil; engine speed 1600 rpm

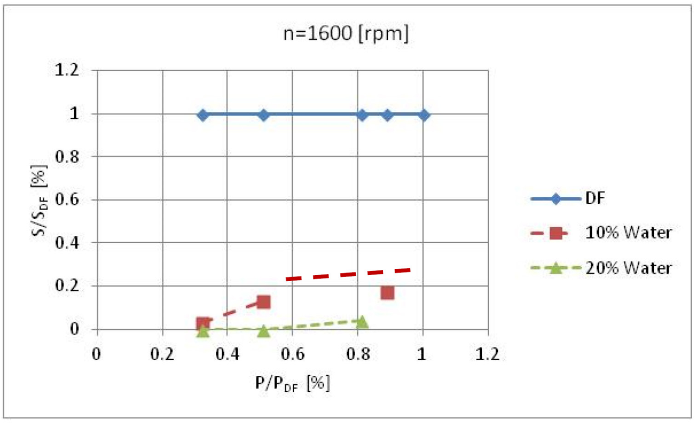

Fig. 8. Variations of relative effectiveness values versus relative engine load (torque) for different fuels (Diesel oil ON, microemulsion 10% water, microemulsion 20% water); engine speed 1200 rpm

5. Conclusions

According to the results of laboratory and motoring tests, which were comparative studies, conducted in a fairly limited range, you can draw the following conclusions:

1. Developed microemulsions can be successfully used to fuel diesel engines; they exhibit stability of properties, high homogeneity, and clarity.
2. Measurements of NO_x in the microemulsion fuelled engine exhaust gases showed a marked reduction in the minimum NO_x emissions in the lower range of low engine loads and a reduction of the NO_x emissions maximum values at high engine loads, if the microemulsion water content was above 10%.
3. The lowest values of NO_x emissions in the engine exhaust were observed for microemulsions containing 20% water.
4. In the entire engine operating range, when the engine was fuelled with various microemulsions, the smoke opacity of the engine exhaust has decreased, especially at low loads, where even zero emissions of soot was observed.
5. When engine was fuelled with microemulsion, there was a slight decrease in overall engine efficiency, whereby it was lower, than the water content in the microemulsions.
6. There is no simple relationship between the amount of water in the microemulsion and the engine performance and the obtained content of NO_x and smoke in exhaust, suggesting the need for optimization research.

7. It should be assumed, that the achieved results in terms of exhaust emissions of NO_x and smoke would also depend on the engine particular solutions.

Bibliography

[1] Bemert, L., Strey R., *Diesel-Mikroemulsionen als alternativer Kraftstoff*. 5. FAD Konferenz Herausforderung – Abgasnachbehandlung fuer Dieselmotoren. 7.11-8.11.2007 in Dresden

[2] Haller, P., Jankowski, A., Kolanek, C., Walkowiak, W., *Microemulsions as fuel for diesel engine*, Journal of KONES, Vol. 19, No. 3, pp. 165-170, 2012.

[3] Jankowski, A., *Influence of chosen parameters of water fuel microemulsion on combustion processes, emission level of nitrogen oxides and fuel consumption of ci engine*; Journal of KONES, Vol. 18, No. 4 2011

[4] Jankowski, A., *Laser research of fuel atomization and combustion process in the aspect of exhaust gases emission*, Journal of KONES, Vol. 15, No. 1, pp. 119-126, 2008.

[5] Jankowski, A., Sandel, A., Jankowska-Siemińska, B. Sęczyk, J. *Measurement of drop size distribution in fuel sprays by laser methods,* Journal of KONES Vol. 8 No. 3-4, pp. 334-345, 2001.

[6] Jankowski, A., Sandel, A., Seczyk, J., Jankowska-Sieminska, B., *Some problems of improvement of fuel efficiency and emissions in internal combustion engines*, Journal of KONES, Vol. 9, No. 3-4, pp. 333-356, 2002.

[7] Jankowski, A., *Some aspects of heterogeneous processes of the combustion including two phases,* Journal of KONES, Vol. 12, No. 1-2, pp. 121-134, 2005.

[8] Jankowski, A., *Study of the influence of different factors on combustion processes (Part one),* Journal of KONES, Vol. 16, No. 1, pp. 209-216, 2009.

[9] Jankowski, A., *Study of the influence of different factors on combustion processes (Part two),* Journal of KONES Internal Combustion Engines 2009, Vo. 16, No. 3 pp. 135-140, 2009.

[10] Kolanek, C. et al, Emulsje Raport, Wroclaw, 2007.

[11] Kolanek, C., Kułażyński, M., Kempińska, M., *Examination of the effects of water presece in Fuel on toxicity indices of a compression-ignition engine*. Journal of KONES, Warsaw 2007

[12] Kolanek, C., *Ograniczenie emisji NO_x z silników o zapłonie samoczynnym przez wprowadzenie wody do procesu spalania.* Ochrona środowiska 1(64)/97 Wyd. Oddziału Dolnośląskiego PZTIS, 1997.

[13] Kolanek, C., Sroka, Z. J., Walkowiak, W. W., *Exhaust gas toxicity problems in ship drives*. Polish Maritime Research. 2007.

[14] Jankowski, A., *Chosen Problems of Combustion Processes of Advanced Combustion Engine*, Journal of KONES, Vol. 20, No. 3, DOI: 10.5604/12314005.1136852, pp. 203-208, 2013.

[15] Jankowski, A., Kowalski, M., *Environmental Pollution Caused by a Direct Injection Engine,* Journal of KONES, Vol. 22, No. 3, DOI: 10.5604/12314005.1168461, pp. 133-138, 2015.

[16] Jankowski, A., *Reduction Emission Level of Harmful Components Exhaust Gases by Means of Control of Parameters Influencing on Spraying Process of Biofuel Components for Aircraft Engines,* Journal of KONES, Vol. 18, No. 3, pp. 129-134, 2011.

[17] Jankowski, A., *Test Stand for Modelling of Combustion Processes of Liquid Fuels,* Journal of KONES, Vol. 21, No. 2, DOI: 10.5604/12314005.1133885, pp. 121-126, 2015.

[18] Zurek, J., Jankowski, A., *Experimental and Numerical Modelling of Combustion Process of Liquid Fuels Under Laminar Conditions,* Journal of KONES, Vol. 22, No. 3, DOI: 10.5604/12314005.1134559, pp. 309-316, 2015.

[19] Zurek, J., Kowalski, M., Jankowski, A., *Modelling of Combustion Process of Liquid Fuels under Turbulent Conditions,* Journal of KONES, Vol. 22, No. 4, DOI: 10.5604/12314005.1168562, pp. 355-344, 2015.