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The impact of fuel properties on shape of injected fuel spray

Abstract: The debate on alternative fuels includes quality of combustion process depends on the properties of these fuels. The physicochemical parameters of fuel determine besides other the shape of the fuel jet, which effects on creation of mixture with air. The paper proposes a simplified method for assessing the shape of injected fuel spray based on the analysis of digital photos taken with the ordinary camera. Differences in the core of spray, jet angle and the presence of fuel droplets were presented for three different fuels. The results, described only briefly in this paper, can be helpful during the fuel injector designing or to test the engines.

Keywords: *internal combustion engine, fuels, research*

Wpływ właściwości paliw na kształt wtryskiwanej strugi

Streszczenie: W dyskusji nad paliwami alternatywnymi przewija się zagadnienie jakości procesu spalania uzależnione od właściwości tych paliw. Parametry fizykochemiczne paliw decydują między innymi o kształcie strugi wtryskiwanego paliwa, co przenosi się na sposób tworzenia mieszaniny z powietrzem. W pracy zaproponowano uproszczoną metodę oceny kształtu strugi wtryskiwanego paliwa na podstawie analizy zdjęć wykonanych kamerą cyfrowego. Wykazano zróżnicowanie w rdzeniu strugi, kącie rozpylenia oraz obecności kropel paliwa dla trzech różnych paliw. Uzyskane wyniki, opisane tylko skrótowo w niniejszej pracy, mogą być pomocne na etapie konstruowania wtryskiwaczy lub podczas badań silnikowych.

Słowa kluczowe: *silnik spalinowy, paliwa, badania*.

1. Introduction

Combustion process in diesel engine is largely dependent on way of formation of the air-fuel mixture which ignites spontaneously. Fuel-air mixture is formed in the gas phase, so the fuel evaporation time is an important parameter of the combustion process. Time of fuel evaporation depends on temperature and pressure in space where fuel exist as well as area of evaporation. So, the size and amount of fuel droplets determine the range and speed of initial spray in the injection process.

The problem of formation and evaporation of the droplets is widely described in the literature [4, 5, 6, 9, 15, 19, 21, 25, 26] and show the analysis of this issue as very complicated and time-consuming. Incorrect assessment of the boundary conditions could lead to unauthorized inference. Therefore, the authors undertook to introduce an optical method - estimation of fuel properties on the basis of recorded images via analysis of the fuel spray flowing from the injector. Researchers emphasize that the definition of the correlation between such a relatively simple and rapid visualization studies and engine tests would significantly reduce the cost of design and research [1, 4, 5, 6, 11, 17, 23].

Constructed chamber in which the original fuel injector was placed and subsequent phases of the injection were recorded by the camera Canon 40D, 100mm, f/2.8. The study employed three types of fuels: diesel fuel with a low sulphur content ONM S-50, rapeseed oil methyl ester EMKOR of FAME group and pure (called “kitchen” [18]) canola virgin oil (OR100).

The results confirmed the hypothesis about the possibility of using a relatively simple method to assess the quality and quantity of fuel spray. It makes possible to use recorded images in designing process of injectors or during engine tests.

2. Fuels and research methodology

Prior to testing, essential physical and chemical properties of fuels were identified. Chosen properties are shown in Table 1. Fuel, marked as ONM S-50 was a standard diesel fuel with reduced sulphur content. Fuel, called EMKOR was a liquid from the group of fatty acid methyl esters made of rapeseed oil. Symbol of OR100 was used to mark pure rapeseed oil, the same as in the kitchen use. The use of pure rapeseed oil as an engine fuel was demonstrated by the authors in numerous studies [14, 17, 22, 23, 24]. Measured calorific values for tested fuels show that they meet the energy demands placed on fuels for diesel engines [10, 11, 13, 20].

The fuels were injected into a special chamber with atmospheric conditions i.e. pressure of 1000 hPa, ambient temperature 23 °C and a relative humidity of 65%. It meant no reverse pressure like in actual combustion chamber in the engine. "Open" chamber was deliberate intention of authors who want to demonstrate the possibility of proper inference of fuel jet on the basis of a simplified visual testing.

Table 1 Selected properties of the tested fuels

Properties	Standard diesel fuel	Oil plant fuel	
	ONM S-50	EMKOR	OR100
Density at 20° C, 10^3 kg/m^3	817	882	914
Kinematic viscosity at 40° C, mm^2/s	1,83	4,75	34,56
Cetane number	51,7	51,3	49
Calorific value, MJ/kg	43,2	38,7	37,2
Surface tension σ - 10^{-2} ,N/m	3,64	3,52	3,38

The study was based on a cyclic, optical recording of the injection process. All captured images of individual fuel sprays were digitally elaborated to improve the image quality, which leads to better show structure of spray (shape of the core, edge, range, presence of vapour or droplets) and allowed to compare with each other.

The end of the injector was mounted horizontally in the chamber and the system was calibrated, so that the injection pressure was 210 bar for entire time of tests. The different sprays were compared in terms of shape and method of flow from injector nozzle. It can be assessed:

- the angle of the spray,
- the shape of the spray core,
- the range of jet,
- the number, size and the manner of occurrence of fuel droplets,
- the presence of fuel vapour and fuel mist appearance,
- way of fuel flow at the start,
- the last phase flow i.e. closing the injector needle and so called "Cutting" of jet.

Each fuel was tested multiple in sequence research to eliminate random errors.

3. Results

3.1. ONM S-50 diesel fuel

The first tested fuel was diesel oil ONM S-50 with reduced sulphur content. Pictures No. 1-4 show the phases of the fuel injection. The first three of them were made in positive technology and the last one is a negative picture, which provides higher quality image, showing the steam volatile of the spray and fuel droplets.

Fig. 1 The initial phase of the injection for ONM S-50 (see vapours from the previous injection)

Fig. 2 Average advanced phase of the injection for ONM S-50

Fig. 3 Phase of full injection for ONM S-50 (see small vapour from the previous injection)

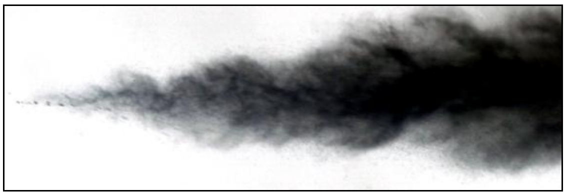

Fig. 4 Final phase of injection with visible droplets of ONM S-50 directly at the nozzle

Looking at these photos of ONM S-50 fuel it is clear that it has a homogeneous structure, in which there is accumulation of fuel in the central part so-called spray core and a very scattered jet determining the wide-angle scattering and not too far range. This image may provide a proper dispersion of the fuel dose, providing the ability to evaporate completely before reaching the nearest wall of the cylinder. It has a very big impact on the proper operation of the engine. Comparing the resulting images of injections of ONM S-50 fuel with the presented in the bibliography [6, 19], one can assume it is in line with those that occur in the real engine operation. Therefore, these images were used for comparative studies as bases – entry images.

3.2. Fatty acid methyl esters of rapeseed oil - EMKOR

The next tested fuel was the methyl ester of rapeseed oil. The sequence of test images correspond to previous in chapter 2.1.

Fig. 5 The initial phase of the injection for EMKOR (visible vapours from the previous injection)

Fig. 6 Average advanced phase of injection for EMKOR

Fig. 7 Phase of full injection for EMKOR (see small vapour from the previous injection)

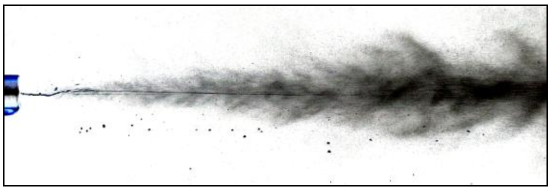

Fig. 8 Final phase of EMKOR fuel injection with visible jet fuel in the spray core and droplets everywhere

Analysis of these photographs (No. 5-8) shows a variation with respect to jet of standard ONM S-50 fuel (fig. No. 1-4). Because of its high viscosity, EMKOR fuel (see Table 1) has a smaller spray angle. It is also associated with a higher density at the same ambient temperature and lower surface tension, which forms a spray. The larger range of the spray core is due to a higher viscosity, which makes higher pressure in the pipes. It is also known that in that case, just before opening (get-up) the injector needle, injection system seals by itself. The flow rate is greater as well as the critical speed of droplets. In can be concluded that the amount of fuel is smaller than the previous one and the average diameter of the droplets by Sauter [6, 9, 12, 13] is also smaller, so the decay time is also less which leads to an increase in fuel spray penetration.

3.3. Pure canola virgin oil – OR100

The third tested fuel was pure rapeseed oil which has been found in other studies [4, 9, 12, 16] as an alternative fuel for diesel engines.

All images were obtained by the same configuration as mentioned in chapters 2.1 and 2.2.

Fig. 9 The initial phase of the injection for OR100 (visible vapours from the previous injection)

Fig. 10 Average advanced phase of OR100 injection

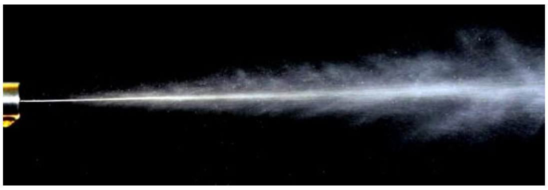

Fig. 11 Phase of full injection of OR100 (see small vapour from the previous injection)

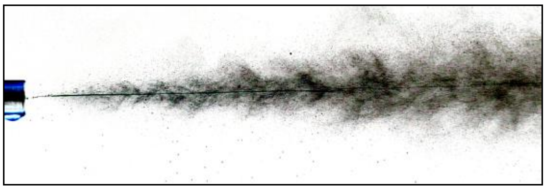

Fig. 12 Final phase of injection with visible droplets and spray core of OR100

Pure rapeseed oil (OR100) has got a higher viscosity than the previously discussed fuels. It is about 12 times greater than the standard diesel fuel. It is similarly with density. Lower the surface tension than others is also affected by the construction of spray. Visible in the pictures No. 9-12 spray of

OR100 fuel has small angle scattering - smaller than the other fuels. Range of the spray core is greater than the other. The liquid dispersion is at a greater distance from the nozzle than in the case of the previously tested fuels. Spray is not so homogeneous like for other. It is far more accumulated within the core. The reason of that is the high level of viscosity. Believe that in real conditions of engine operation, the jet evaporation time will be longer, which will result in increased spray range up to the area of the walls of the combustion chamber, where fuel mist can condense. The result is obvious, namely, it will lead to the formation of deposits disrupting combustion process. It will be expected of other things such as ignition temperature increases and changes in toxic exhaust emissions [1, 2, 3, 7].

4. Conclusions

The objective of that project has been achieved by showing simplified optical method to assess fuel sprays and for resulting about design and research of combustion engines. The shape, size and range of the injected fuel spray is closely related to physicochemical properties of the fuel.

With a base view of diesel spray it can be assess the qualitative and quantitative characteristics of streams other fuels.

It was noted changes in:

- the angle of the fuel sprays,
- shapes,
- ranges,
- scatter dose,
- formation of jets,
- a "cut-off" spray - when you close the injector nozzle.

The most important differences between sprays are: the presence of the spray core as the liquid stream and the spray angle as well as the presence of fuel vapour. Differences in these characteristics leads to necessity of modification in the injector nozzle or to changes in environmental conditions such as the pre-heating. The changes in management of combustion process using the different characteristics of injection should be considered.

Nomenclature

ONM S-50	standard diesel fuel with low sulphur content
EMKOR	commercial name of rapeseed methyl ester
OR100	pure canole virgin oil

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