EXPERIMENTAL INVESTIGATION ON INJECTION CHARACTERISTICS OF RAPESEED OIL AS FUEL FOR DIESEL ENGINES

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Abstract. Complete fuel combustion is highly dependent on the quality of fuel atomization and distribution in the combustion chamber. The main purpose of the research was experimental investigation of injection characteristics of rapeseed oil and its various blends with mineral diesel fuel. The attention was focused on the injection characteristics, which significantly influence the characteristics of the engine performance and exhaust emissions. The following parameters of the injection characteristics have been investigated experimentally: sound velocity in fuel, maximum injection pressure, injection duration and spray characteristics. The experimental investigation results indicate that differences in the physical properties of diesel fuel and rapeseed oil have significant influence on the injection characteristics. The increase of rapeseed oil amount causes sound velocity in fuel to increase, that leads to advanced injection timing. It was determined that rapeseed oil affects the increase of the maximum injection pressure and injection duration. The comparison of rapeseed oil and mineral diesel fuel sprays development shows that when injecting identical fuel quantity diesel sprays were longer than that of the rapeseed oil.

Keywords: diesel engine, rapeseed oil, injection characteristics.

Introduction

The depletion of petrol, the growing demand for fuel, instability of world fuel prices and concerns about global warming are factors that focus the interest in renewable energy sources, biofuels, in particular. Along with popular in Europe RME, rapeseed oil (RO) could also be used for local tractor and self-propelled agricultural machinery powering. Potential advantages and problems of using rapeseed oil for compression ignition engine fuelling have been discussed by many researchers [1-6]. Straight vegetable oils as fuel for diesel engines offer some advantages: they are produced in rural areas and can contribute to the local economy by lower production and transportation costs [1].

However, use of RO as fuel in diesel engines causes some problems related to differences in the physical properties of diesel fuel and rapeseed oil. The RO have an average viscosity 10-15 times greater than that of diesel fuel at ambient temperature [2]. High viscosity affects the fuel flow through the fuel pipe, injection characteristics, filtration properties and low temperature behavior particularly. The crude oil filtration capacity through the fuel filter at ambient temperature of 20 °C is only approximately 4 % related to diesel fuel [3]. The viscosity of rapeseed oil reduces rapidly and its filtration properties improve with diesel fuel addition into RO. Mixing of RO with diesel fuel improves filtration through a fine porous paper element and the flow capacity increases 1.7 to 11.8 times for fuel blends with 25 to 75 % admixture of mineral diesel fuel.

At the Latvia University of Agriculture a low temperature behavior test of rapeseed oil and its blends with diesel fuel was conducted [4]. The fuel blends with 5 %, 10 %, 25 % and 50 % mineral diesel fuel admixture were tested. Besides, the viscosity and cold filter plugging point (CFPP, °C) were determined. It was determined experimentally that the CFPP changes nearly linearly depending on the amount of the diesel fuel premixed in the RO. For 95 % RO and 5 % arctic class 2 diesel fuel blend CFPP temperature was measured as being equal to 15 °C and for 50 % RO and 50 % the same diesel fuel blend was -20 °C. The CFPP temperature is not so much affected by the crystal formation process, but by the critically increased rapeseed oil viscosity, which aggravates the fuel filtration process.

The engine power may decrease due to lover RO heat value and fuel consumption can be higher. Earlier tests showed that when using RO the engine minimum brake specific fuel consumption increases approximately by 10-15 % compared with that of diesel fuel. However, the fuel energy conversion efficiency for both diesel fuel and rapeseed oil was very similar.

The high viscosity and low volatility of vegetable oils leads to deposit formation on the noses of the nozzle, the walls of the combustion chamber and the piston head [5]. The intensity of the deposits depends on the type of the engine, its performance conditions and the quality of oil.

Complete fuel combustion in diesel engines is highly influenced by the fuel atomisation quality and its distribution in the combustion chamber. To improve the diesel engine performance on rapeseed oil it is important to find out the changes occurring in the fuel injection equipment performance related to the case of using fuel with standard properties.

The purpose of the research was to investigate the fuel injection equipment performance peculiarities when operating on rapeseed oil and its blends with diesel fuel: changes in the sound velocity in fuel, changes in the injection pressure and duration, changes in fuel spray development.

Materials and methods

Five types of test fuels were used in this study, i.e., neat diesel fuel (DF), pure rapeseed oil (RO), 25 % RO and 75 % DF, 50 % RO and 50 % DF, 75 % RO and 25 % DF blends.

The fuel was injected by an in line fuel injection pump UTN-5 through five holes injection nozzles. The diameters of the injection orifices were 0.34 mm. The injectors needle lifting pressure was set to 17.5±0.5 MPa. The injection system was mounted on Motorpal type NC108-1291 test bed for a conventional fuel injection pump. The injection pressures at the pump and at the injector were measured with Kistler piezoresistive pressure sensors Type 4067 with the accuracy ±0.5 %; pressure range 0-100 MPa. The injection duration was determined by measurement of the nozzle needle movement using the Wolff Controls Corporation Hall effect position sensor ASMB 470004-1. The maximum nozzle needle lift was 0.28 mm. The measuring signals of the pressure and needle lift sensors were transmitted to the Kistler type 4665 and type 5247 amplifier modules respectively mounted on the signal condition platform Compact 2854A. The data acquisition and processing system was based on personal computer equipped with a 12-bit A/D converter.

The fuel injection characteristics were tested at the injection pump camshaft speed of 1100, 750 and 400 min^{-1} that correspond to the rated, peak torque and idle speeds of the engine. The fuel injection equipment performance modes are given in Table 1.

Table 1

Performance modes of fuel injection equipment

Mode	***n*, rpm**	***q*, $mm^3 \cdot stroke^{-1}$**	**Mode**	***n*, rpm**	***q*, $mm^3 \cdot stroke^{-1}$**
1	1100	70 (q_{rated})	5	750	80 (q_{Mmax})
2	1100	52,7 (75 % q_{rated})	6	750	60 (75 % q_{Mmax})
3	1100	35 (50 % q_{rated})	7	750	40(50 % q_{Mmax})
4	1100	7 (10 % q_{rated})	8	400	12

The measurement of the sound velocity in fuel was based on the principle of pressure wave propagation within a long high pressure tube, an instrument by two piezoresistive pressure sensors located at both ends of the tube (Fig. 1). The distance between pressure sensors was 2871 mm.

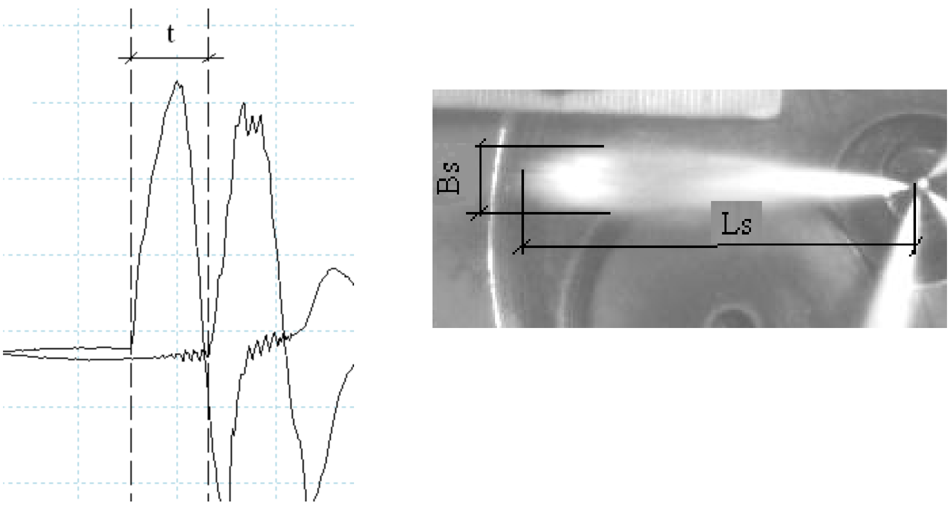

Fig. 1. **Principe of sound velocity and fuel spray parameter measurement**

The speed of pressure wave propagation (sound velocity in fuel) was calculated:

$$a = l / t \quad (1)$$

where a – pressure wave propagation speed (sound velocity in fuel), m·s^{-1};
l – distance between pressure sensors, m;
t – time spent for pressure wave propagation from the injection pump to the injector, s.

After calculating the pressure wave propagation speed the fuel bulk modulus E_F was determined:

$$E_F = a^2 \cdot \rho \quad (2)$$

where ρ – fuel density, kg·m^{-3};
a – pressure wave propagation speed, m·s^{-1}.

Fuel spray development was visualised by using a high speed video camera Photron FASTCAM-1024PCI. The time between separate images was equal to 0.1 ms because 10000 frame rate was selected. Fuel was injected into the chamber with ambient pressure and temperature. The analysis of spray images allowed determining the spray tip penetration ant spray width as it is shown in Fig. 1. The spray tip penetration was defined as the maximum axial distance, which the spray can reach from the nozzle tip.

Results and discussion

At the beginning of the fuel delivery the pressure wave propagates with sound velocity from the injection pump to the injector. The speed of pressure wave propagation changes the start of actual fuel injection, i.e., increases or decreases injection delay. The diagrams in Fig. 2 show, that sound velocity in the fuel increases with the increasing rapeseed oil content in the fuel blend. A higher sound velocity is related to higher density and correspondently higher bulk modulus of rapeseed oil. When injecting pure rapeseed oil the pressure wave propagation speed was by 3.6 % higher comparing with that of mineral diesel fuel. This may mean that in the case of RO injection will start earlier. However, this difference is not big. For example, when using a high pressure pipe with the length of 0.55 m the difference would be equal to 0.18° of the crankshaft angle only at the engine rated (n=2200 min^{-1}) performance mode.

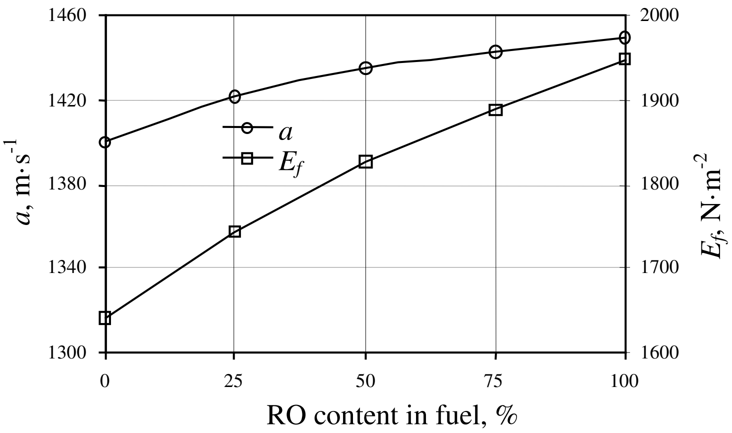

Fig. 2. **Sound velocity in fuel (*a*) and fuel bulk modulus (E_F) as a function of rapeseed oil content in fuel**

The fuel-air mixing quality depends also on injection duration, i.e., on the time during which the injector is opened and fuel is sprayed into the combustion chamber. The analysis of the graphs in Fig. 3 shows, that the injection duration increases with the increasing rapeseed oil content in the fuel due to decreasing throughput of the nozzle. Earlier tests [7] showed that when injecting pure RO the maximum throughput of the nozzle decreases by 21 % relative to that of diesel fuel. When operating under full load and rated speed the injection duration of rapeseed oil was approximately by 19 % longer than that obtained in the case of using mineral diesel fuel. This increase of injection duration compiles 2° injection pump camshaft angles or 4° engine crankshaft angles. When running under medium load (q = 75 % q_{rated} and q = 50 % q_{rated}) at the same speed the injection duration increases by 2-3° crankshaft angles.

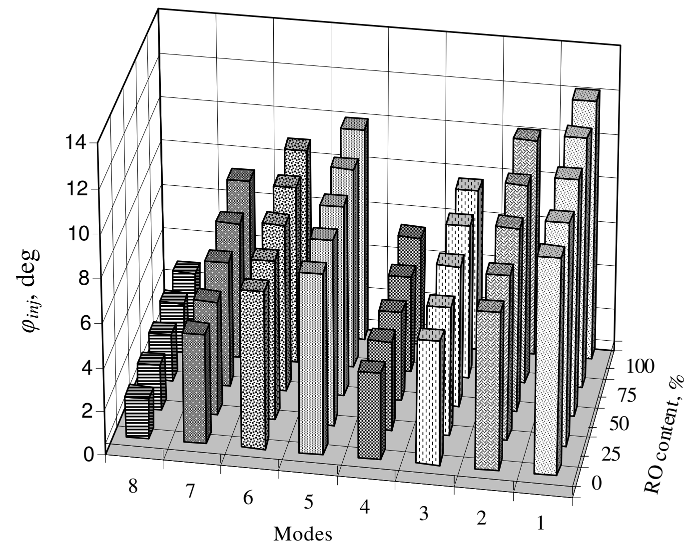

Fig. 3. **Fuel injection duration in degrees of crankshaft angle as a function of performance mode and rapeseed oil content in fuel**

At the peak torque conditions the injection duration was also approximately by 3° of camshaft angle higher. At idle speed conditions the injection duration increases approximately by 22 %, but the difference represents only 1° of the camshaft angle. Therefore, under all performance modes the injection durations are longer for all fuel blends and pure RO and their higher injection pressure does not compensate decreased throughput of the nozzle due to higher fuel viscosity.

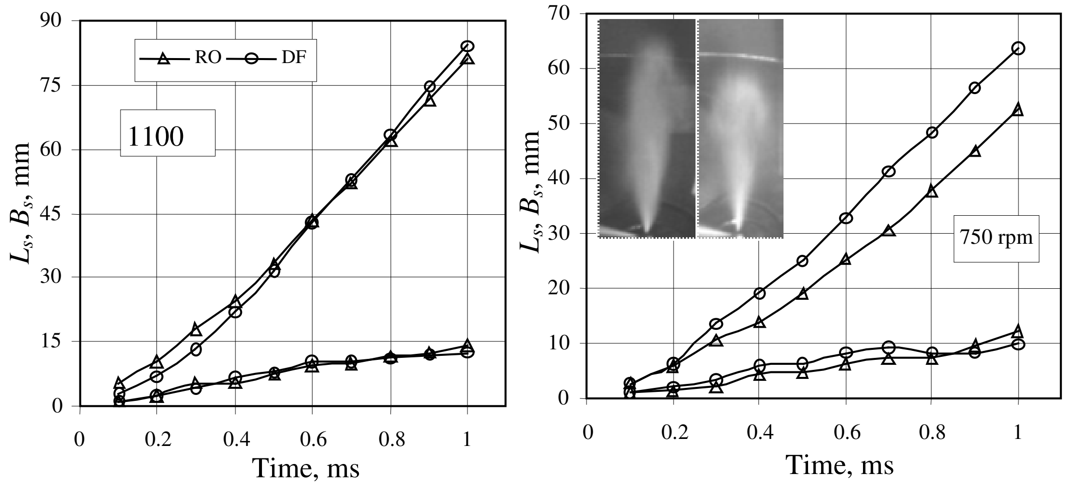

Fig.4. **Fuel sprays tip penetration L_s and spray width B_s as a function of time**

The speed of fuel sprays propagation and the extent to which they proceed the combustion chamber volume has an important influence on cylinder air utilization and fuel-air mixing rate. When the injection time is shorter than the break up time of the fuel spray, the spray tip penetration can be expressed as follows [8]:

$$S = 0.39\sqrt{\frac{2 \cdot \Delta p}{\rho_f}} \cdot t \quad (3)$$

where S – spray tip penetration, mm;
t – time after start of injection, ms;
Δp – pressure drop across the nozzle, Pa;
ρ_f – fuel density, kg·mm^{-3}.

This expression shows that the spray tip penetration is affected by the density of the fuel.

Fig. 4 shows the spray tip penetration for mineral diesel fuel and rapeseed oil at two speeds of the injection pump and maximum fuel delivery. As it is seen, at 1100 min^{-1} speed at the beginning of the injection process the spray tip penetration for rapeseed oil is higher than that of mineral diesel fuel. However, approximately 0.5 ms after start of the injection the diesel fuel spray overtakes the rapeseed oil spray. The cause of such event might be linked with a higher initial speed of the spray due to higher RO injection pressure. At this operation mode the maximum rapeseed injection pressure was by 7.3 % higher than of diesel fuel. At 750 min^{-1} speed the spray tip penetration for RO was shorter at the same time intervals than that of diesel fuel. Although in this case, rapeseed oil injection pressure was 7.9 % higher than diesel fuel injection pressure, but it was still lower by 17.5 % comparing with its value at the rated speed. After 1 ms of injection beginning, rapeseed oil spray tip penetration was 52.63 mm, while in case of diesel fuel it was 63.64 mm.

Conclusions

1. The experimental investigation results indicate that differences in the physical properties of diesel fuel and rapeseed oil significantly influenced the injection characteristics, including the injection pressure, injection timing and its duration as well fuel sprays tip penetration.
2. Because of increasing the RO content in the blend the sound velocity in fuel (pressure wave propagation speed from the pump to the injector) increased, that resulted into advanced injection timing.
3. Both the injection duration and maximum injection pressure increased due to increasing the content of RO in the fuel.
4. The comparison of RO and mineral diesel fuel sprays development showed that the spray for diesel fuel was longer than that of RO when injecting adequate fuel quantities.

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