EXPERIMENTAL INVESTIGATION IN DIESEL FUEL, RAPESEED OIL AND ITS BLEND COMBUSTION IN OFF-ROAD DIESEL ENGINES

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Abstract. The paper presents comparative analysis of the combustion and emission characteristics of rapeseed oil (RO) and blends of 25 %, 50 % and 75 % of rapeseed oil in diesel fuel for different engine load and speed conditions. The stand tests were performed on a four-stroke, four-cylinder, direct injection, naturally aspirated diesel engine D-243. The in-cylinder pressure data were analysed to extract the heat release rate, ignition delay, in-cylinder pressure peak and maximum in-cylinder pressure rate. The influence of rapeseed oil amount in the fuel on the exhaust emission and brake specific fuel consumption were also investigated. The bench testing results show that when the engine was running at 1400 min^{-1} at low and full loads auto-ignition delay was longer by 4.2 % and 2.1 % respectively compared to the auto-ignition delay while running on diesel fuel. The in-cylinder pressure peak and pressure rise rate while operating at full and moderate load increases with the increase of the amount of rapeseed oil in fuel. While the engine was operating at low the load in-cylinder pressure peak and pressure rise rate decreases when increasing the amount of rapeseed oil in fuel. The brake specific fuel consumption of the fully loaded engine running on 100 % RSO increased by 17 % and 22 % at 1400 min^{-1} and 2200 min^{-1} speeds respectively when compared to that of diesel fuel. The brake thermal efficiency decreased at the same operating conditions only by 1.6 % and 5.5 % respectively. When the engine was running on rapeseed oil NO_x, unburned HC emissions and the exhaust opacity decreased, CO emissions increased.

Keywords: diesel engine, diesel fuel, rapeseed oil, auto-ignition delay, emissions, exhaust opacity.

Introduction

Diesel engines play an important role in transport, industry and agriculture. Because of limited fossil reserves, the increasing price of mineral fuel and ecology aspect, we are forced to search for and apply new alternative and renewable energy resources. At present, biodiesel, i.e., vegetable-oil-based methyl or ethyl esters, is the most widely used biofuel for diesel engines. However, along with this widely produced biofuel, straight vegetable oils (SVOs) are used in small quantities, too. The advantages of using SVOs are related to the reduction of chemicals employed in fuel production, decrease of transportation expenses and independence from the fuel suppliers.

Though the physical and chemical properties of rapeseed oil are similar to those of diesel fuel, several of their differences impact the preparation of the combustible mixture and the combustion processes in the engine cylinder [1]. One of the problems encountered when using pure rapeseed oil in diesel engines is related to viscosity which tends to be over ten times higher than that of diesel fuel. The oil with higher viscosity is injected more poorly, has a tendency to evaporate slower and problems related to its flow throughout the pipelines and filtering arise. The preparation of the combustible fuel-air mixture in an engine is also affected by the surface tension of the fuel. The surface tension of rapeseed oil is higher than that of diesel fuel by approximately 20 % [2]. When the surface tension is higher, more energy input is needed to increase the droplets surface area and to reduce the droplets diameter.

The experimental tests show that the differences of physical properties between diesel and rapeseed oil have a high influence on the fuel injection parameters such as injection pressure, timing and duration of the injection and also the injected fuel spray penetration [3]. Due to the higher rapeseed oil viscosity, the fuel injection rate thought the injector nozzle is decreased, which in turn extends the injection duration even though the pressure at the injector grows. Higher rapeseed oil density and viscosity affects the pressure wave velocity and therefore the start of injection.

According to the results of many studies the brake specific fuel consumption is higher when the engine runs on vegetable oil rather than on mineral diesel [4; 5]. This is related to the lower calorific value of the oil. The emission of nitrogen oxides (NO_x) is usually lower because the peak of the combustion temperature is lower due to the decreased efficiency of the combustion processes. Although not at all engine operating modes, usually the emission of carbon monoxide (CO) and unburned hydrocarbons (HC) is higher.

Nevertheless, most of the researches are carried out using standard engines which are optimized for running on mineral diesel. If the fuel injection parameters of an engine, i.e., pressure and injection timing, are optimized for rapeseed oil, the performance of an engine running on rapeseed oil can be improved [6; 7]. The tests of a 2.0L 4 cylinder direct injection diesel engine show [7] that when the fuel injection pressure is increased, the auto ignition delay is reduced, the combustion process is started earlier, the in-cylinder pressure and the heat release rate are increased. Due to this the emissions of CO and HC are decreased; however, the NO_x emission is increased. Retarded fuel injection shifts the combustion process towards the expansion stroke. Therefore, the maximum pressure in the cylinder is lower. Due to the retarded injection, the nitrogen oxide emission was decreased; however, the CO and HC emission and exhaust opacity were increased.

The aim of this research was to investigate the combustion process peculiarity when the engine operates on rapeseed oil and its blends with diesel fuel.

Objects, apparatus and methodology of the research

The stand tests were performed on a four-stroke, four-cylinder, direct injection, naturally aspirated diesel engine D-243. The fuel was injected by an in line fuel injection pump thorough five holes injection nozzles with the initial fuel delivery starting at 25º before the top dead centre (BTDC). The needle valve lifting pressure for all injectors was set to 19.0 ± 0.5 MPa.

The load characteristics of the engine were taken at 1400 min^{-1} (maximum torque) and 2200 min^{-1} (rated) speed when operating alternately on diesel fuel (DF), pure rapeseed oil (RSO), 25 % RSO and 75 % DF (RSO25), 50 % RSO and 50 % DF (RSO50), 75 % RO and 25 % DF (RSO75) blends.

The torque of the engine was measured with an electrical AC stand dynamometer. The fuel mass consumption was measured with the AVL fuel balance with an accuracy of ± 0.12 % and the air mass consumption was measured by using the AVL air metering equipment with an accuracy of ± 0.25 %.

In-cylinder gas pressure diagrams versus the crank angle were recorded at every 0.1 crank angle degree (CAD) by using the AVL indication and data acquisition system. A piezoelectric uncooled transducer GU24D mounted into the first cylinder and connected to the MICROIFEM piezoelectric amplifier-signal conditioning along with the AVL crank angle encoder 365C (± 0.1º) have been used to record gas pressure for every load-speed setting point with an accuracy of ± 0.1 bar.

To determine the start of injection the history of the nozzle-needle-valve lifting was used which was recorded by using the Hall effects position sensor ASMB 470004-1. The needle-valve lifting signals have been transmitted to the Kistler type 5247 amplifier module mounted on the signal conditioning platform Compact 2854 A. The AVL IndiModul 622 was introduced as a multi-channel indicating system for the acquisition and processing of fast crank-angle based cylinder pressure and nozzle-needle-valve lift signals. For the analysis and calculation of the heat release rate the average in-cylinder gas pressure of 100 engine cycles was used.

The auto ignition delay was determined as the period in degrees (CAD) between the start of fuel injection and the start of combustion. As the start of injection the point at which the needle-valve lifts about 5 % of its total stroke was taken. As the start of combustion the point at which the heat release differential curve crosses the zero line and changes its value from minus to plus was taken. These points were determined with an accuracy ± 0.1^o of the crank angle degrees.

The amounts of nitric oxide NO (ppm), nitrogen dioxide NO_2 (ppm), carbon monoxide CO (ppm) and total unburned hydrocarbons HC (ppm) in the exhausts were measured with the Testo 350 XL gas analyser. Total emissions of nitrogen oxides NO_x were determined as a sum of both NO and NO_2 gases. The exhaust opacity (%) was measured with a Bosch RTT 100/RTT 110 opacity-meter with an accuracy of ± 0.1º.

Results and discussion

Some of the most important parameters of the diesel combustion process are the auto-ignition delay, peak in-cylinder gas pressure, in-cylinder pressure gradients and heat release rate. The auto-ignition delay depends on the atomisation of the liquid fuel, vaporisation of fuel droplets and mixing of fuel vapours with the cylinder hot air charge as well as by the fuel properties determined prehistory of combustion reactions of the fuel, cylinder compressed air and residual gas mixture conditions (pressure, temperature, swirl intensity), which lead to auto-ignition.

Fig. 1 shows that the auto-ignition delay was longer throughout the whole speed and load range, when the engine was running on pure rapeseed oil. At low load (BMEP = 0.1 MPa) and 1400 min^{-1} speed, the auto-ignition delay increased by 4.2º (33.5 %) compared to diesel fuel. When the engine load was rising, the difference in the auto-ignition delay decreased. At the maximum load the difference decreased to 2.1º (26.8 %), i.e., decreased two times. The auto-ignition delay changes remained the same when the engine ran at the rated 2200 min^{-1} speed. As the amount of RSO in the fuel blend increased, the combustion started later.

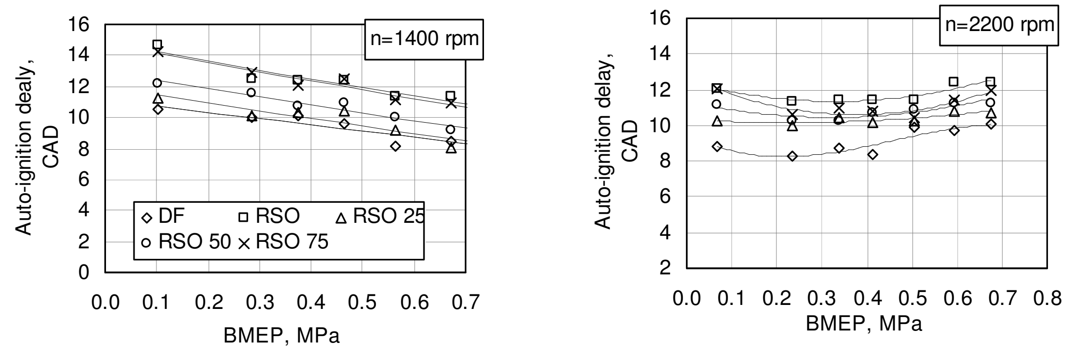

Fig. 1. **Dependency of auto-ignition delay on engine load and rapeseed oil amount in the fuel**

The peak of the in-cylinder pressure was about 6 bars higher for pure RSO compared to diesel fuel when running under full and moderate loads (Fig. 2), but under lower loads the maximum pressure was about 2 bars lower for pure rapeseed oil. A higher maximum gas pressure was obtained because of the faster pressure rise rate. Because of a longer auto-ignition delay a larger amount of combustible mixture was prepared; therefore the heat release rate after ignition was higher (Fig. 3).

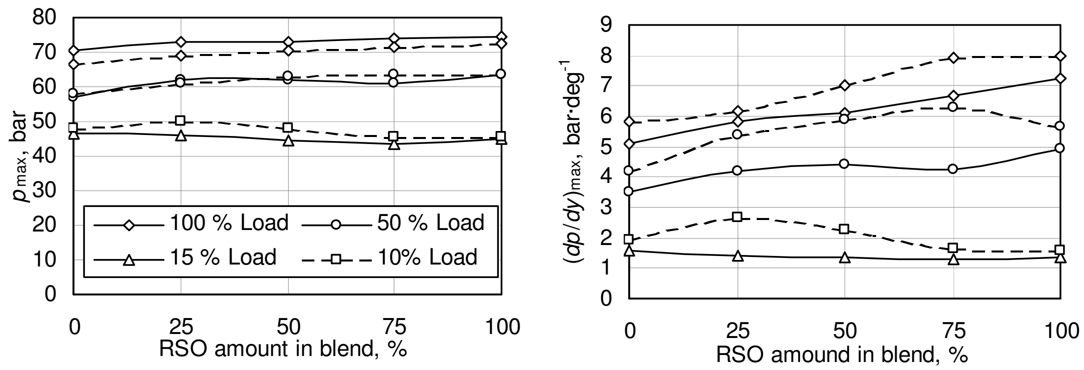

Fig. 2. **In-cylinder pressure peak (p_{max}) and maximum cylinder pressure gradient ($(dp/d\varphi)_{max}$) as functions of RSO amount in fuel:** — n = 1400 min^{-1}; --- n = 2200 min^{-1}

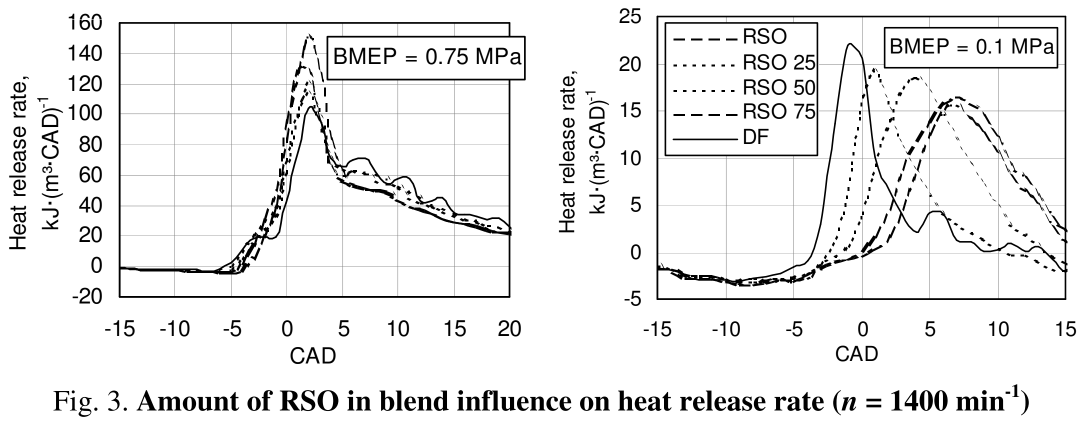

Fig. 3. **Amount of RSO in blend influence on heat release rate (n = 1400 min^{-1})**

While the engine was operating at low load and the amount of rapeseed oil in fuel blend was rising, the heat release rate decreased, therefore the in-cylinder pressure increased slower.

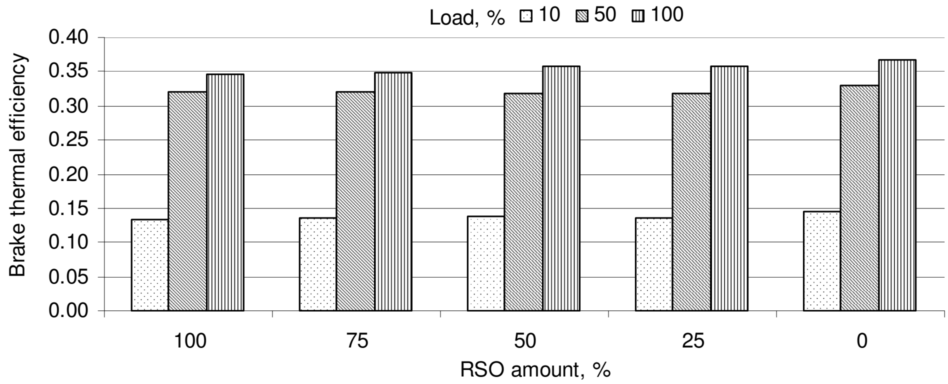

Fig. 4. **Influence of the amount of RSO in fuel and engine running mode on the brake thermal efficiency**

The changes in the combustion process have influence on the engine fuel consumption. Under the same engine operating conditions the brake specific fuel consumption (bsfc) for RSO and its blends was higher than those of diesel fuel. This was due to the fact that increasing amount of RSO in the blend lowers the heating value of the fuel. The bsfc for 100 % RSO increased by 17 % at maximum torque mode and by 22 % at rated mode. However, the brake thermal efficiency decreased at the same operating conditions only by 1.6 % and 5.5 % respectively. It is noticeable that this decrease of the brake thermal efficiency was obtained while the engine was operating on the blend RSO25 (Fig. 4). When the concentration of RSO the in blend was further increased the brake thermal efficiency changed negligibly.

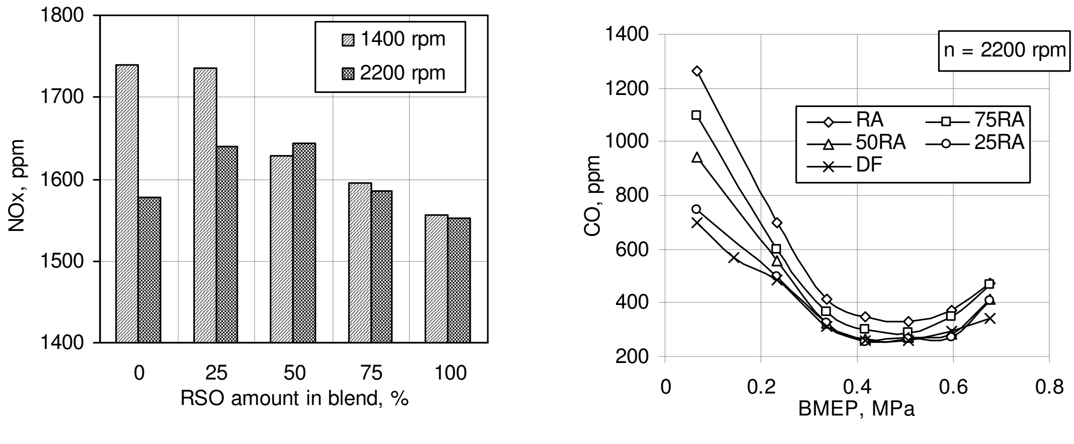

Fig. 5. **Influence of the amount of RSO in fuel on NOx and CO emissions**

Fig. 5a shows the variation of the maximum nitrogen oxides emissions (NO_x) for all fuels used in the study under full load conditions. As we can see, while the engine was running at 1400 min^{-1} speed the NO_X emission decreased while the amount of RSO in the fuel blend was increased. At the rated speed of 2200 min^{-1} the NO_X emissions increased while the RSO amount in the fuel blend was increased up to 50 %. Further increase of RSO in the blend resulted in lower NO_X emissions. When the engine was running on pure RSO at 1400 min^{-1} speed and at the rated 2200 min^{-1} speed, the NO_X emission was 10.6 % and 1.7 % lower respectively, compared to diesel fuel.

As it can be seen in Fig.5b when operating on RSO and its blends the carbon monoxide (CO) emissions were higher when compared to diesel fuel. Moreover, CO emissions increased with increasing amount of RSO in the fuel. At 2200 min^{-1} engine speed and full load CO emissions while running on pure RSO were about 39 % higher than when using diesel fuel. At low load (BMEP = 0.068 MPa) CO emissions increase reached 81 %. The rise of carbon monoxide emissions may be related to the lower cetane number and the longer auto-ignition delay.

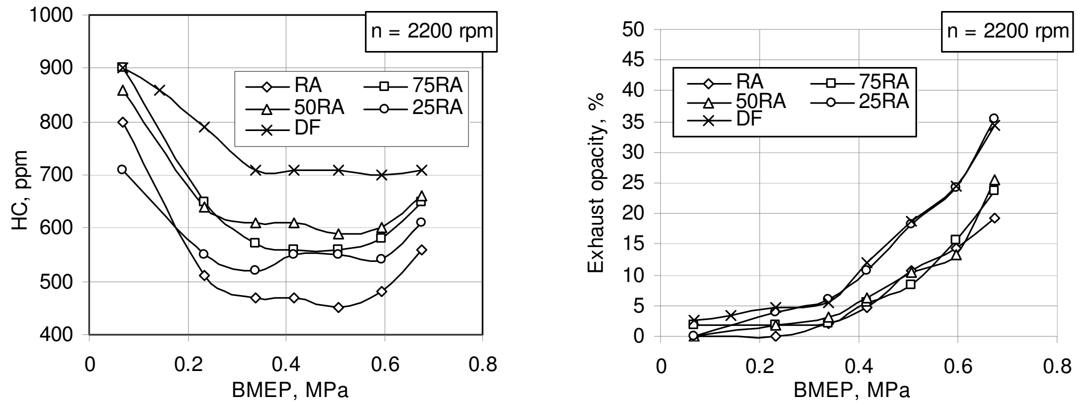

Fig. 6. **Influence of the amount of RSO in fuel on HC emissions and exhaust opacity**

The analysis of Fig. 6 shows that unburned hydrocarbon (HC) emissions were lower while the engine was running on RSO and its blends. At rated mode HC emissions decreased by 21 %. When the engine operated on diesel fuel and RSO25 blend the exhaust opacity remained similar. As the RSO amount in the fuel blend increased the exhaust opacity decreased. The exhaust opacity for pure RSO was about 44 % lower compared to that of diesel fuel.

Conclusions

1. When the engine was running at 1400 min^{-1} at low load and at full load the auto-ignition delay was longer by 4.2 % and 2.1 % respectively compared to the auto-ignition delay while running on diesel fuel.
2. The in-cylinder pressure peak and pressure rise rate while operating at full and moderate load increases with the increase of the amount of RSO in fuel. While operating at low load the in-cylinder pressure peak and pressure rise rate decrease when increasing the amount of rapeseed oil in fuel.
3. The brake specific fuel consumption of the fully loaded engine running on 100 % RSO increased by 17 % and 22 % at 1400 min^{-1} and at 2200 min^{-1} speeds respectively when compared to that of diesel fuel. The brake thermal efficiency decreased at the same operating conditions only by 1.6 % and 5.5 % respectively.
4. When the engine was operating on rapeseed oil NOx, unburned HC emissions and the exhaust opacity decreased while CO emissions increased.

References

1. Rakopoulos C.D., Antonopoulos K.A., Rakopoulos D.C. etc. Comparative performance and emissions study of a direct injection diesel engine using blends of diesel fuel with vegetable oils or bio-diesels of various origins. Energy Conversion & Management, 2006, vol.47, pp.3272-3287.
2. Spicher U., Lüft M. Optimierung der Kraftstoffstrahlausbreitung für Pflanzenöl, insbesondere natürliches Rapsöl, bei der Verwendung moderner Diesel-Einspritzsysteme // Forschungsbericht / Universität Karlsruhe Institut für Kolbenmaschinen. – 2007,- p. 59.
3. Slavinskas S., Skukauskaitė B. Experimental investigation on injection characteristics of rapeseed oil as fuel for diesel engine. Engineering for rural development. 2011,- pp.234-238.
4. McDonnell K.P., Ward S.M., Menuty P.B., Howard-Hildige R. Results of Engine and Vehicle Testing of Semirefined Rapeseed Oil. Transactions of the ASAE, Vol. 43(6) 2000, pp. 1309-1316.
5. Labeckas G., Slavinskas S. Performance of direct-injection off-road diesel engine on rapeseed oil. Renewable energy, 2006, vol. 31, pp.849-863.
6. Nwafor OMI, Rice G, Ogbonna AI. Effect of advanced injection timing on the performance of rapeseed oil in diesel engines. Renewable Energy, 2000, vol. 21, pp.433-444.
7. Labecki L., Ganippa L.C. Effects of injection parameters and EGR on combustion and emission characteristics of rapeseed oil and its blends in diesel engines. Fuel, 2012, vol.98, pp.15-28.