PRELIMINARY APPROACH TOWARDS A CDI SYSTEM MODIFICATION OPERATING ON NEAT RAPESEED OIL

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Abstract

A Common-rail Diesel Injection (CDI) Bosch system was modified to operate on neat rapeseed oil (RSO) in a single tank mode. The performed modifications were derived from the fundamental and comparative injection studies. Laser droplet sizing, high-speed imaging and the Acoustic Emission (AE) tests combined with the basic bench scale experiments were employed to define the main direction of modifications. The RSO pre-heating was found as the most feasible direction of the modification. Some technical constrains were taken into account prior to the modification. The paper indicates on the main direction of the modification and evaluates the preliminary results of the CDI engine tests. Cold start, deposit formation, engine oil deterioration and drivability of a Mercedes Benz 220 C-class car had been investigated to assess the modification. The injection system did not exhibit the same magnitude of undesired effects as previously recorded in similar test with DI Diesel engines. A long-term drive tests provided very promising results on which further modification could be based. The engine test and inspection revealed that RSO pre-heating of successfully alters its properties enabling its successful use in a CDI system.

1. Introduction

Unstable situation on the crude oil market resulting in an unpredictable price rise, as well as an increasing effort to seek for Diesel substitutes led to an interest in using neat vegetable oils. With the recent popularity of the cultivation of oilseed rape in the European Union (in UK it is currently the third most-widely grown crop), rapeseed oil (RSO) is the most obvious candidate for evaluation as a Diesel fuel substitute. Particularly, cold pressed RSO is emerging as a potentially viable alternative to diesel fuel. Whilst longer-term engine tests confirmed the satisfactorily operation of larger-cylinder IDI (indirect injection) engines when fuelled with rapeseed oil [7] a number of problems associated with the use of rape-seed oil in DI (direct injection) engines and small-cylinder IDI engines were identified in [7, 26, 30, 21, 9]. The difference in viscosity, surface tension and density between RSO and Diesel is anticipated to have an adverse effect on the combustion of RSO in most of existing Diesel engines. Additionally poor fuel flow, filter clogging [1, 31] and engine oil deterioration [28] would complete the list. There have been a number of literature suggestions how to reduce the viscosity of rapeseed oil and thus to alleviate these problems [12, 24, 27, 32].

Broader research work on performance of Diesel engines running on rapeseed oil were presented by Hemmerlein et al. [10], Peterson [28] who evaluated winter rapeseed oil as a Diesel fuel and by others investigators [2, 22, 27]. The results revealed very satisfactory short-term emission results concerning CO, HC, NO_x and soot. As in previous investigations [2, 22, 27], lower maximum temperature in the combustion chamber, lower emission of nitrogen oxides and soot were reported. Despite the successful tests when Diesel engines were working on plant oils for a short time, the actual real assessment of such success needs to be measured in long-term operational periods. Recent studies and engine tests showed difficulties in direct fuelling Diesel engines caused mainly by higher viscosity of RSO, which leads to a decrease of engine performance [21, 29, 1, 20, 9]. Despite the successful use of RSO and its derivatives in the IDI Diesel engines presented by Hemmerlein [10] and in [14], similar application in the DI engines is still highly problematic manifesting in so-called “short-” and “long-term” problems [1, 25]. However, the number of successful modifications of IDI engines as well as some attempts on DI showed that RSO could help create a sustainable and cheap source of mechanical energy. Theoretical work of modelling of plant oil atomisation in DI engines has already been performed [23] to provide the fundamental information required for the modification. The latest development of CDI engines indicates a high performance and efficiency together with deep emission reduction. Considering all promising results of other DI engines operating on RSO it can be expected that modifications of the CDI system would enable it to operate on RSO and hence create a very efficient and sustainable Diesel powered energy source. Nevertheless recent operation of the CDI engines on RSO has been problematic due to different physical properties of the oil, which badly influence fuel delivery, spray development and therefore reduction of the air/fuel mixture. The long-term problems manifest in coking tendencies, carbon deposit formation, start-up and engine oil deterioration [1].

The CR injection process finely controlled by an electronic control unit does not overcome spray obstruction and therefore needs to be redesigned. To improve atomisation the injection system requires modification derived from fundamental spray pattern characteristics, droplet sizing tests and broad engine tests. In order to improve atomisation of RSO parameters like penetration, spray cone angle and drop size distribution under different injection fuel pressure and temperature need to be assessed similarly to studies performed for diesel in [13, 17, 3, 19] or its alternative [18]. Such studies could provide the necessary basic experimental data to characterise the mechanism responsible for deficiency during RSO combustion in CR engines and this has been defined as the aim of the present paper.

2. Problem definition

Reviews of the available resources on Diesel engines modifications, the preliminary tests in which an unmodified CDI engine was run [1] and the analysis of the bench scale experimental results [11] directed the authors to form the following conclusions. These were grouped as a recognised problem together with its expected solution and a mean to meet it:

1. Quantities of injected fuel limit performance of CDI system and result in overall engine effectiveness. Due to differences in viscosity, density and surface tension, injected volumes of RSO are expected to be different from Diesel. Injection process requires more thoroughly studies considering fuel metering under the rail pressure oscillations. Investigation of the oil metering is expected to provide information about the alternation of injected quantities by applying higher injection pressure or RSO temperature.
2. The use of RSO in CDI poses a few challenges to injection system operation due to higher density and viscosity. The filter clogging is one of the common problems. Hence, several experiments should be performed to investigate the influence of RSO flow across a fuel filter at different fuel temperatures. RSO and the fuel filter pre-heating and alternative filter replacement should overcome the clogging problem.
3. Spray characteristic of RSO is expected to be significantly different in terms of spray penetration, cone angle and drop size distribution. The poorer spray atomisation is expected to be the main reason of incomplete combustion. Studies of these parameters should pro-vide information if there is any feasible way to improve the spray characteristic without modifying the injector.

4. Fuel flow inside the injector is expected to be sensitive to different fuel properties as originally designed for Diesel. Especially, higher viscosity and surface tension would reduce the fuel flow in the injector and therefore lead to the injection delay (hesitation) and shortening of the effective duration of injection. The acoustic emission experiments are expected to verify this phenomenon. Measurements at varying fuel temperature and pres-sure should provide information if the injection delay could be overcome by the increased fuel temperature of the injection pressure.

The defined problems were looked in series of various experiments utilising different techniques. The aim was to provide enough information to determine a set of technical changes required for modification of a CDI.

3. Experimental details

Studies of RSO characteristics in a CDI system in comparison to Diesel were performed. The tests involved investigation of RSO flow and injection sampling, spray characterisation, droplets sizing and acoustic emission probing. The experiments were carried out using a Bosch CDI. The injection port was designed to accommodate a commercial, seat-hole Mercedes (A6110700587) common-rail injector (0.18 mm bore-diameter). A schematic presentation of the experimental system is illustrated in Figure 1.

Samples of cold pressed RSO and calibration oil (exhibits the same physical properties as Diesel) named here as standard oil (SO) were used in experiments at different oil temperatures.

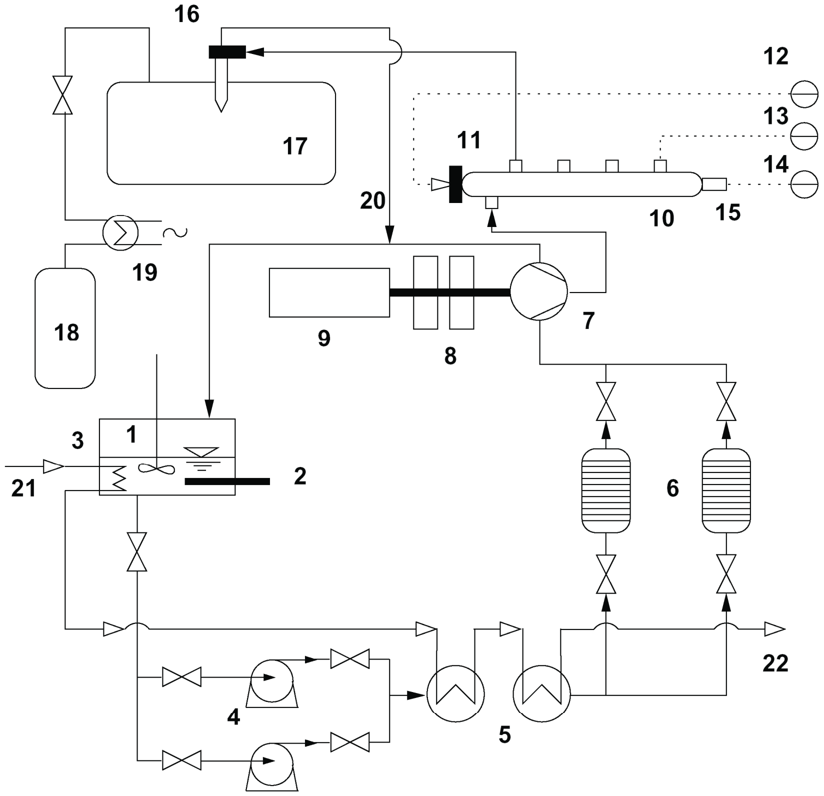


Figure 1. Schematic presentation of the experimental rig (the injection stand and the spray chamber), 1-fuel tank, 2-fuel electric heater, 3-fuel water cooler, 4-low pressure fuel pumps, 5- heat exchangers, 6-fuel filters, 7-high pressure pump, 8-transmission, 9-electric motor, 10-rail, 11-rail pressure control valve, 12-pressure valve controller, 13-rail fuel temperature indicator, 14-rail pressure indicator, 15-rail-pressure sensor, 16-nozzle port, 17-spray chamber, 18-gas cylinder, 19-in-flow gas heater, 20-fuel return, 21-cooling water inlet, 22-cooling water outlet

Table 1 lists full injection conditions and experimental parameters and some properties of used oils.

Two different gases were used in the experiments, which produced in-engine air compression conditions (N_2 , SF_6) up to maximum pressure equivalent to 4.9 MPa of air.

3.1. Flow and injection tests

The series of tests in which the SO and RSO flow and their injected volume were measured had been performed. The aim of these experiments was to investigate differences in the oils flows through the fuel filter and the injection metering between SO and RSO. The first part of the experiments RSO was preheated up to 30, 40 or 60°C and then pumped through the filter. The flowrate as well as oil temperature were measured after the fuel filter. The readings were taken every 10 minutes. Two brand new Bosch NG172 (1St) fuel filter were used separately for each oil. Results were compared with the SO flow at 30°C. The injection stand was adopted to measure fuel amounts delivered through the CR nozzle. The experimental setup comprised of the automatic system to collect fuel for a required number of injection or the motor revolutions and the glass burettes wherein fuel was collected. The system allowed producing the appropriate injection pressure and temperature of the tested oil. The measurements were performed at different frequency and duration of injection for SO and RSO accordingly. The ambient pressure was atmospheric and the ambient temperature was 22°C. The measurements were performed at the injection frequency of 5 Hz. The frequency was chosen as a compromise between the experimental variables and the accuracy of the measurements.

The Table 1 presents in details the experimental parameters investigated in this part of the research.

Table 1. Fuel properties and the experimental condition

Fuel type/Parameter	Standard oil	Rapeseed oil
Density at 20°C, [kg/m^3]	823.2	921.1
Viscosity at 20°C, [mm^2/s]	3.81	73.78
Oil tank temperature, [°C]	20, 30, 25, 40, 50, 60	
Injection pressure[1)], [MPa]	56.3, 131.3	
Injection pressure[2)], [MPa]	30, 50, 60, 80, 100	
Fuel pre-pressure, [bar]	4.1	
In-cylinder temperature, [°C]	20	
In-cylinder densities, [kg/m^3]	3, 6, 15, 30, 45, 60	
Injection frequency, [Hz]	1.0[1)], 3.0, 5.0, 7.0, 10.0	

1)Spray characteristics experiments. 2)Injection tests

3.2. Spray penetration and sizing

All the measurements were made in a high-pressure injection chamber which enabled the study of spray behaviour at different injection conditions. Spray penetration lengths and spray cone angle were measured for a wide range of injection pressures and three different fuel injection temperatures: 25, 40 and 60°C, and chamber densities in the range from 3 to 60 kg/m^3 (Table 1). The results of measurements of RSO were compared with the SO spray at

25°C. A Kodak high-speed image analyser (HSC) - model 4540hx was used to capture images of spray. Gamma correction of the images prior to the technique of a threshold value was applied to determine the spray penetration and cone angle. Similar sets of experiments were performed using a Phase Doppler Anemometry instrument to obtain drop size distribution. Also, measurements of arithmetic, Sauter and De Broukere mean diameters were performed for both RSO and SO. The light source was an Argon-Ion Dantec laser providing beams at two wavelengths, green (λ=514.5 nm) and blue (λ=488.0nm). The beams were transmitted to the PDA probe through an optical fibre and then focused at the measurement volume at a focal length of 600 mm from the PDA transmitter and 30 mm downstream from the nozzle tip. All the sizing test were performed using two dimensional PDA setup, whereas the raw data processing was carried out with 1D configuration only due to better validation and proper statistical presentation of the drop populations. Details on the experimental setup and the procedure can be found in [5, 6].

3.3. Acoustic emission test

An injector signal with different temporal characteristic was measured using the data acquisition system consisting of a Lead Zirconium Titanate sensor, the signal conditioning circuit, the data acquisition board and the computer equipped with the appropriate software. The data acquisition system was build and tested at Heriot-Watt University and allowed to use four AE channels. The sensor was placed on the injector side on its body and connected to the preamplifier filtering a bandwidth of 0.1 to 1.2 MHz. The signal conditioning circuit utilised the analogue processing unit to produce raw AE signal with variable gain.

4. Results and discussion

The following section presents only the selected results of the performed experiments. It is believed that chosen examples are typical and represent a wider set of results.

4.1. Injection metering and fuel filter clogging

Figure 2(a) illustrates results of a test where RSO was subjected to different temperatures simultaneously flowing through a fuel filter. At each case, the oil was preheated in the fuel tank, pumped through the filter and diverted to a discharge tank. The figure compares rapeseed oil results with the flow of standard oil at three different tank temperatures i.e. 30,40 and 60°C.

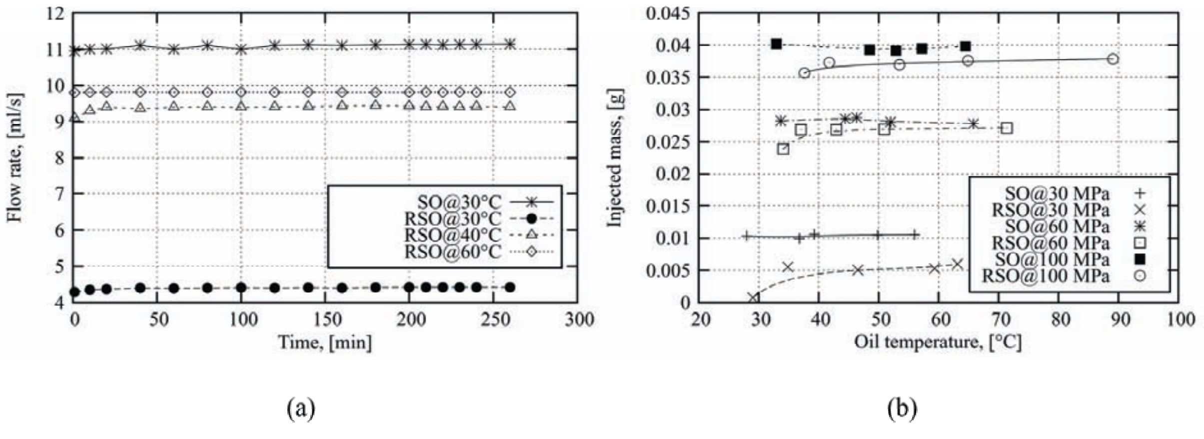


Figure 2. (a) Flow rate of SO and RSO through the filter at different constant fuel temperatures. (b) Effect of the oil temperature on injected mass for SO and RSO at different injection pressures and oil temperature. (Injection duration - 1 ms, injection frequency 5 Hz)

The figure shows that pre-heating RSO increases the flowrate across the filter. The RSO flow at 30°C is much lower than in case of SO. The flow is nearly 3 times lower as result of noticeably high viscosity i.e. 35 cP. At 60°C, RSO is close to the SO flow at 30°C. In this case the vegetable oil viscosity was approximately 12 cP in comparison to 4 cP of standard oil. After certain time the oil and system reached a stable temperature and subsequently the flowrate became constant. The experiments were finished after 250 minutes and the fuel filter was inspected. A similar results but for waste cooking oil were presented by Bari et al. [4].

The author investigated oil flows at different temperatures through a filter and compared with Diesel. A difference in flow rates was about 240 %, i.e. waste cooking oil flow as lower than the conventional Diesel. The results indicate serious flow deterioration of RSO at temperatures lower than 40°C. Oil pre-heating improves radically the flow but the similar flow cannot be reached. RSO subjected to the constant heating and recirculating in the system gets heated slower than SO. This can be due to higher flow properties and poorer heat transfer. Generally, rapeseed oil requires longer pre-heating period to reach desired temperature and this may indicate an extra pre-heating system must be fitted to provide fast and efficient oil heating. It can be concluded that a separate filter heater should be considered to ensure enhanced oil flow through filter.

The injected quantities of standard and rapeseed oil are compared in Figure 2(b) for the selected injection pressures and in a range of oil temperatures. Three pairs of curves exhibit a general overlook at these two types of oil and changes in injected quantities. The figure shows the rise of injected oil quantities with fuel temperature and injection pressure, but illustrates a combined effect of these two parameters on injection. As the injection pressure and temperature increase the points are getting closer and the pressure effect seems be dominant over the temperature effect. This is manifested in the closed oil curves for each pressure set.

4.2. Spray characterization

Figure 3 illustrates a sample of experimental data in a comparative study. Processing of the spray development images showed discrepancy between the solenoid valve activation and injection rate.

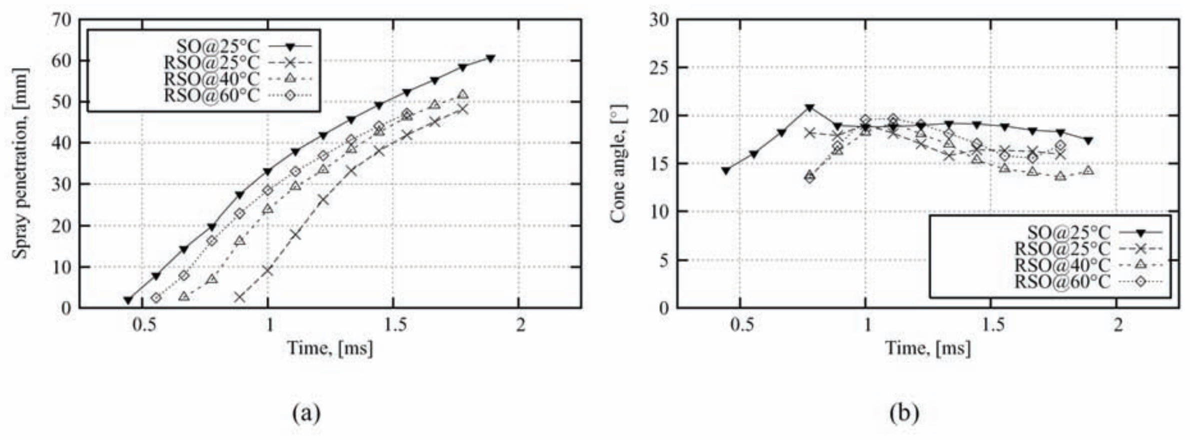


Figure 3. Spray characterisation at the injection pressures of 93.75 MPa at ρ_{amb}=15.0 kg/m^3 of ambient density, for three RSO temperatures: 25, 40 and 60°C and compared with SO at 25°C. (a) Spray penetration and (b) Spray cone angle

This phenomenon was noted for all the injection rates of tested fuels however the delay phenomenon was longer for RSO. Higher viscosity of RSO results in slower flow within feed passages and therefore higher "hesitation". In case of low injection pressure (< 30 MPa) and fuel temperature injection did not result in atomisation at all. The SO values indicate shorter injection delay and in all cases the first detected spray was recorded before

5 10^{-4} s. The same trend cannot be observed clearly for RSO. Increased injection pressure slightly reduces injection delay as it was concluded before this does affect the fuel flow inside the nozzle. It can be concluded that in this case the pressure drop across the nozzle is less affected by changes of RSO viscosities and more by momentum forces resulting in penetration values less dependent on temperature.

For all investigated cases penetration of RSO spray was less developed in comparison to SO. Spray processing revealed differences in the shape and rate of development of RSO sprays. The temperature increase has some effect on spray development resulting in an increase of penetration due to a reduction of RSO viscosity. Although, the RSO oil spray penetration at 60 °C was observed to be lower than that of SO at 25 °C for all the pressure conditions investigated. It was observed from spray images that increased ambient pressure results in significant reduction of penetration and “richer” and denser fuel spray. It indicates the higher degree of air entrainment and the presence of small vortexes at the edge of the sprays. Shear forces between the stagnant gas and liquid sprays result in such a phenomenon which would contribute to an increase in the mixing and evaporation of RSO droplets as concluded previously by Laguitton et al. [17]. It can be concluded from the data presented in these figures that lower ambient pressure, higher injection pressure and higher fuel temperature render RSO spray characteristics similar to that of SO. The injection pressure effect is more significant and similar to the one reported in [13] performed in the similar range of the injection conditions.

4.3. Droplet sizing

Some selected distribution results of the SO and RSO sizing are shown in Figure 4. Two general effects on spray were investigated in comparative studies: the injection pressure and oil temperature. Figure 4(a) presents the temperature effect on RSO Sauter mean diameter (D32) with ambient density of 15 kg/m^3. The RSO curves have been compared with the SO D32 ranges (depicted by a grey band in the chart) corresponding to the lowest (37.50 MPa) and highest (131.25 MPa) injection pressure. The chart represents a typical trend recorded for RSO for the whole range of studied ambient pressures (only a selected example is shown here). Results indicated that the aerodynamic resistance of the ambient gas has important role in breaking-up the RSO drops, because of high surface tension and viscosity. It can be seen that the temperature effect leads to reduced D32 values of RSO but still higher than SO by 50 % on average. Further reduction of D32 values was recorded for higher ambient pressures i.e. 45 and 60 kg/m^3.

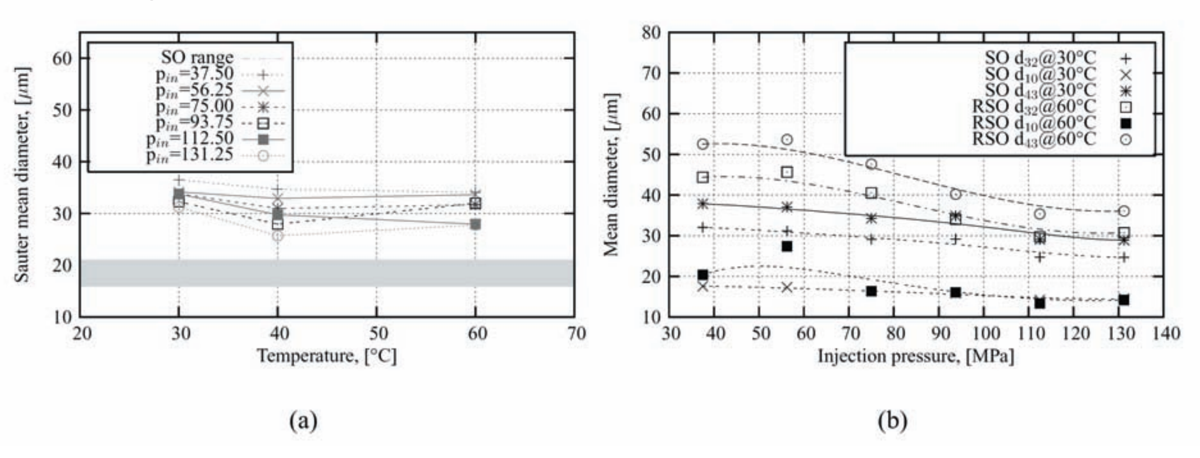
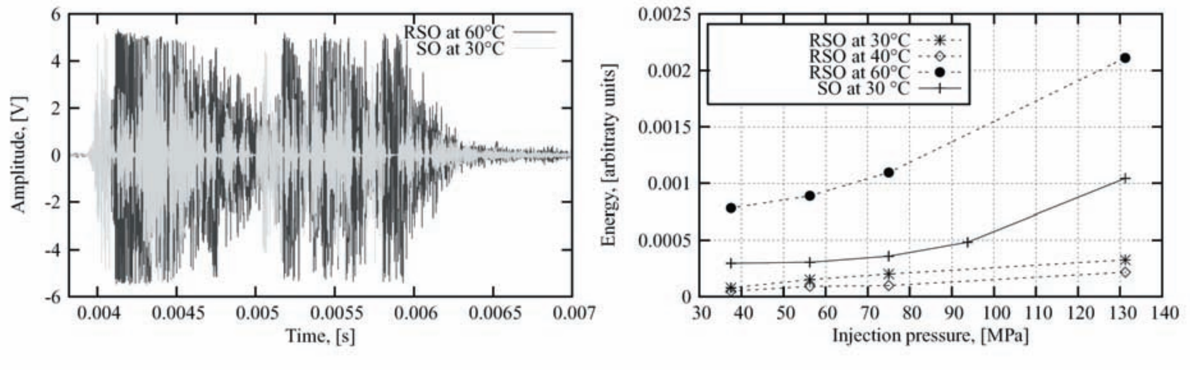


Figure 4. (a) Temperature effect on the Sauter mean diameter of RSO and comparison with SO (The ambient density of 15 kg/m^3). (b) Effect of fuel injection pressure (at various oil temperatures) on values of the arithmetic, Sauter and De Broukere mean diameter of RSO and SO (The ambient density of 60 kg/m^3)

As it can be expected the higher oil temperature and ambient pressure (gas density) results in the deeper reduction of mean diameter. The similar observation was reported in [8] and it can be explained as the result of a reduction of the relative velocity and hence the tendency for drops to break. Figure 4(b) presents the variation of arithmetic, Sauter and De Broukere mean diameter of RSO at 60°C in the comparison to SO injected at 30°C for the higher oil temperature and ambient pressure. The figure clearly shows the effect of injection pressure on droplet mean diameter, which decreased at higher injection pressures. The trend observed is consistent with other measurements reported in the literature [15]. It can be concluded that such observation is caused by an effect of surface tension and viscosity reducing with temperature and the aerodynamic resistance of the ambient gas enhancing the break-up of drops. It needs to be highlighted that the RSO measurements was effected by number of "satellite" drops present close to the measuring point. This might lead to the higher number of large drops present in nearly each drop population. The distributions of droplet size revealed the presence of one pick well representing Gaussian droplet size distribution. It is interesting to notice that RSO distribution showed higher number of small drops but also the larger ones comparing to SO distribution and this effect could be explained using the Lefebvre correlation. Furthermore, close analysis of the injection pictures in relation to the PDA test showed the presence of circulating drops inside vortexes appearing especially at the edge of sprays which may contribute in the higher number of tiny drops. It has been noticed that RSO drop population consists of a significant number of larger drops within a range of 60-120 μm. Contribution of these large drops in values of D_{32} and D_{10} is significant, thus the increased number of small drops does not result in reduced values of mean drop diameters since the noticeable number of large drops is present in the population. An earlier study [16] indicates droplet diameters of Diesel fuel up to 500 μm for much lower injection pressures. In summary, it can be seen that the effect of temperature is pronounced and shows more rapid decrease together with the highest ambient pressure however oil temperature has slightly less effect on distribution than injection pressure. By increasing the ambient gas pressure and oil temperature the RSO distribution curve shifts more towards lower drop ranges. The mean drop size values closely follow or even exceed data of SO.

4.4. Acoustic emission results

AE tests were performed in the comparative studies to analyse closely the injector performance operating on RSO. As concluded from the spray characterisation results, the RSO spray development exhibits a certain level of hesitation which was associated with the obstruction of oil flow inside the injector channels. Thus, the AE tests were expected to provide information about the internal flow (during the actual injection) of RSO in comparison to SO for various injection and ambient conditions. A summary of the AE results is presented in Figure 5. The Figure 5(a) presents the AE signal recorded for SO and RSO at 30°C and 60°C accordingly. The signals were recorded at the ambient density of 60 kg/m^3 and the injection pressure of 131.25 MPa. The chart confirms a delay shift features the RSO signal but also shows the higher overall energy of the signal. The energy is directly proportional to the "strength" of events taking place inside the injector. The corresponding energy values for the signals were 0.00285255 and 0.00930928 (of arbitrary units) accordingly. The effect of oil temperature on the internal flow is presented in the Figure 5(b) for various infection pressures. As expected, the AE energy on the internal flow rapidly increases with oil temperature exceeding values recorded for SO. The effect does not confirm the results of measurements of injected quantities of RSO. It can be concluded that the energy describes an event which can be associated with the internal flow which one of the components is the effective flow and hence the oil release. Nevertheless, the results confirm that the injection enhancement due to increased oil temperature.



(a) (b)

Figure 5. (a) Comparison of the RSO and SO acoustic emission signals. (b) Flow energy con-tents inside the injector at different oil temperatures

4.5. System modification

Considering the summary of the presented results it can be concluded that the RSO temperature rise would positively contribute in injection and lead to enhanced spray development. Also, the injection improvement could be reached by increasing the injection pressure especially at the low engine load where the low injection pressures are utilised. Despite understanding of the modification steps need to be taken the CR system does not offer a high level of flexibility to apply suggested changes unless the suitable tools are available. Modification of the system becomes especially difficult due to a lack of information of the Engine Control Unit (ECU) and its accessibility. The ECU box incorporates a program which governs the operation of the injection system by collecting and processing incoming signals as well as accordingly responding to them. The ECU code is incorporated in a microprocessor chip and can by accessed only through a specialised tool and altered through a specific interface. It becomes clear then, that any modifications changing the injection regime or conditions must be performed in combination of re-programming the ECU or replacing the existing electronic components. An alternative way is to change mechanical components being used to produce fuel spray. Although, following such way only limited number of changes can be performed. Therefore, a full set of suggested modifications could not be fully implemented and had to be partly applied. Some of the injection parameters like the rate of injection and the injection timing were automatically adjusted by the ECU itself due to its adaptive feature. It has been recognised that the control unit flexibly responded to new properties of the fuel and corrected the injection timing accordingly advancing or delaying ignition. This was performed only in the thermodynamical state of RSO remains unchanged. The most problematic issue the injection pressure alternation. It has expected that suggested modifications would have been more successful if the injection pressure could have been further increased. Considering feasibility of the suggested solutions a set of modifications was made at Elsbett Company. The modification involved the following major changes to the injection system and the engine:

1. The fuel delivery loop was equipped with a new fuel filter with a filtrating cartridge mesh around 3 μm. The system comprises an additional backup fuel filter allowing a flexible interchange in case of fuel delivery through the master one. Conjointly, the filter was pre-heated and an additional hand-pump was build in between the filter and the fuel delivery pump. Filter replacement intervals were set to 10000-15000 km.

2. The fuel delivery system was re-designed and changed to ensure free RSO flow even at low oil temperatures. The low-pressure loop of the system was equipped with the pre-heating unit employing an external Diesel heater. The heater was turned on prior to the start-up and kept running to ensure desired engine block temperature being reached. Since the engine reached appropriate temperature the pre-heating system was switched over and utilised the heat generated during the engine operation. These two heating modes were integrated and controlled automatically according to the ambient temperature.
3. A separate pre-heating system was constructed to ensure additional injectors heating along the injector body. The system utilised the battery power and was controlled by an automatic relay. Injectors heating were integrated with heating inside of the fuel delivery system. Additionally, glow plugs were replaced with the more efficient ones.
4. The lube oil was replaced by the enhanced engine oil (PLANTMOT) suitable for Diesel engines working on plant oils. The selection on the oil was based on periodical examination of oil samples withdrawn from the engine. The parameters like density, viscosity and epsilon value were measured and compared with a corresponding mineral oil sample.

The output of the modification was studied in a short - and long-term tests and a summary of the results is presented:

1. The car has been successfully operating on RSO for 265,000 km without major problems. Engine inspection did not revealed the deposit build up and a typical lacquer formation on the nozzle tip was not found.
2. The driving test revealed the power loss of approximately 10 % and the fuel consumption increase was around 2 up to 4 %. A significant noise reduction was found due to less "knocking" coming out of the engine.
3. The engine oil tests have not revealed significant volume increase (due to unburned RSO) nor higher concentration of copper.
4. The minimum RSO pre-heating temperature at which successful ignition took place was 20°C. It has been recorded that 45°C ensured fully successful engine ignition.

5. Conclusions

A commercial common-rail injection system had been modified based on various fundamental studies of rapeseed oil. The influence of oil properties has been experimentally tested in different injection and ambient conditions using various experimental techniques. The conclusions are summarised as follows:

1. Using rapeseed oil in CD engines leads to shot- and long-term problem which can be overcome by applying a set of modifications of fuel delivery and injection system. The bench scale spray and injection studies provide sufficient information to elaborate type of modification which needs to be performed.
2. Oil pre-heating up to 60°C enables safe engine operation and does not require major engine modifications. To amend the rapeseed oil delivery, the replacement of existing fuel lines as well as filter is required. Increasing rapeseed oil injection pressure or its temperature improves atomisation and therefore enhances combustion. A new type of engine oil was applied and the
3. Close investigation of the injector performance showed that rapeseed oil at 60°C provides a similar injector performance, however featured but a noticeable injection delay.
4. A modification of a Mercedes Benz 220 C-class had been performed and the engine test did not revealed significant faults for 265,000 km of the car's driving. The long-driving test revealed the power loss about 10 % and the fuel consumption increase within 2-4 %.

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