Soot reduction from the combustion of 30% rapeseed oil blend in a HSDI diesel engine

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The use of rapeseed oil (RSO) in diesel engine results in a significant reduction of NO_x emissions but the soot that is emitted from the combustion of RSO are several orders of magnitude higher compared to that of diesel. In this study an attempt has been made to reduce the soot that is emitted from the combustion of RSO in diesel engine to take advantage of their lower NO_x emissions. This was achieved by using blends of RSO, and the soot emission from the blend of 30% RSO was reduced to diesel equivalent levels of soot by varying the fuel injection parameters. By operating RSO blend under diesel equivalent levels of soot a further reduction in NO_x emission was achieved.

Introduction

The internal combustion engines fueled by fossil fuels are one of the main sources of CO_2 and other hazardous pollutants. Generally the fuels from renewable resources are beneficial from the environmental point of view. As they are very effective in reducing some of the harmful emissions, which eventually reduces the concentration of CO_2 in the atmosphere and the global climate change. In case of diesel engines, pure plant oils (PPO)/ straight vegetable oil (SVO) and biodiesel are used as renewable sources of alternative fuels. PPO/SVO and biodiesels are non-toxic, biodegradable, non-explosive and are safe during transport and storage due to their high self ignition temperatures. Generally PPO/SVO contains triglycerides, where one molecule of glycerol has three molecules of long chain fatty acids connected to each of OH glycerol group and the fatty acids of PPO are mainly mono-saturated 60-70% and di-saturated 10-20% [1-2]. These glycerol's can be removed through transesterification process to form methyl-esters, which are commonly known as biodiesel [1-3]. The properties of biodiesel are very close to that of diesel, however PPO/SVO have lower calorific value, lower cetane number and viscosity about 10 to 12 times higher than that of diesel, which leads to problems associated with cold flow, cold start, deposit formation in nozzle, injector and into the combustion chamber. High viscosity of SVO/PPO can be reduced through transesterification, blending and fuel preheating. The transesterification process described above offers reduction of viscosity thus the biodiesel can be used directly in diesel engines with very little modifications. Blending of PPO/SVO with diesel fuel also reduces the viscosity, however effective reduction in viscosity is possible only for low concentration of PPO/SVO in diesel. It has been shown by Rakopoulos *et al.* [4] that only a small fraction (up to 20%) of SVO/PPO can be effectively used without any engine modifications. Preheating of PPO/SVO also lowers the viscosity of the plant oils. The viscosity characteristics of PPO/SVO are given in [5-8], and it has been shown that by heating the fuel to temperatures between 70 - 80 °C results in a reduction of about 3 to 4 times of its viscosity.

In this work RSO and its blend of 30% in diesel have been used as a fuel in a direct injection diesel engine. The viscosity was lowered by blending and preheating the fuel by allowing it to pass through a heat exchanger fitted in the fuel system.

From our previous work [9] it has been shown that NO_x emissions can be effectively reduced up to 30% by using RSO and its blends compare to that of diesel fuel. The attempt has been taken to reduce soot emissions to take an advantage of lower NO_x emissions from RSO. In order to exploit the advantage of lower NO_x emissions of RSO, experiments were carried out to reduce the soot emissions by varying the fuel injection parameters such as injection pressure and injection timing. The fuel injection pressure and the fuel injection timings were swept from 800 to 1200 bar and from 0 to 12 deg bTDC respectively to reduce the soot from RSO to obtain diesel equivalent soot and to simultaneously maintain lower NO_x emissions.

Experimental setup

In this investigation a 4 cylinder, 16 valve high speed direct injection diesel engine was used. The engine is fully instrumented with sensors and devices which enables us to control the engine torque, speed, injection parameters, in cylinder pressure, emissions and fuel consumption. Detailed schematic of the experimental setup is shown in figure 1. The engine control software allows to control and change engine parameters such as injection pressure, injection timing and EGR rate on a real time basis. The in-cylinder pressures were measured using a Kistler pressure transducer and the LabView software. The gaseous emissions (CO, THC, NO_x) were measured using a Horiba-Mexa gas analyzer. The smoke number was measured using an AVL smoke meter and the fuel consumption of diesel fuel was measured using an AVL fuel consumption meter, however the fuel

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consumption of RSO was measured using a burette metering management.

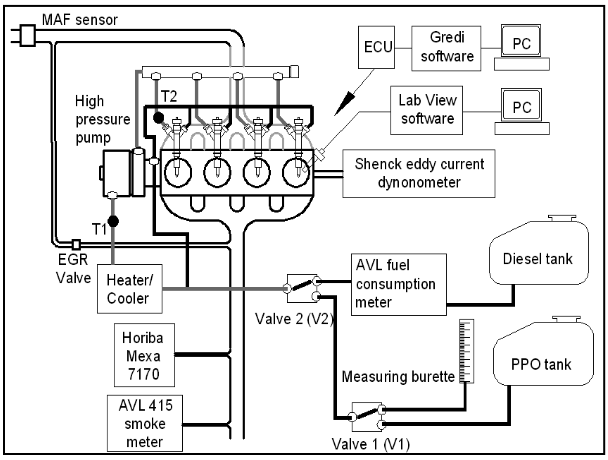

Fig. 1: The schematic of experimental setup.

As can be seen in figure 1 the engine fuel system is modified to use RSO. Modifications include additional tank, couple of 2-way valves and in-line heater/cooler. A temperature controller is used to regulate the temperature of the heater/cooler to maintain uniform temperature of the fuel. The temperature of the RSO was measured at two points in the fuel pipe line. The temperature T_2 was measured at the upstream of the injector and it was maintained at 70 °C during all runs for RSO. To avoid problems with cold flow and cold start, the engine was started with diesel and then switched to RSO and similarly before shutting down, the engine was switched back to diesel fuel.

Results and discussions

The results of soot and NO_x emissions for pure RSO and their blends in diesel fuel are described in [9] and summarized in figure 2.

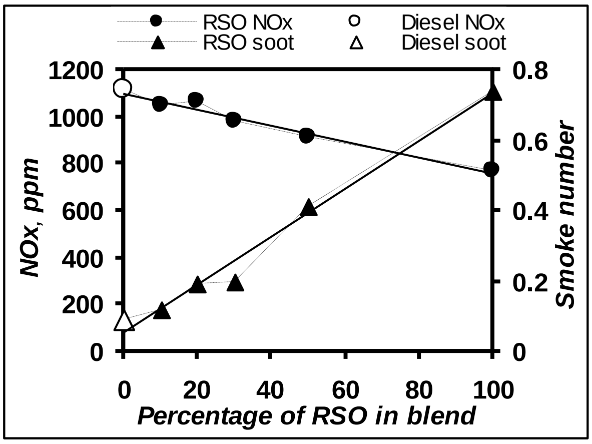

Fig. 2: The soot and NO_x emissions for RSO, their blends and diesel (summarized from [9])

It can be seen that the emissions of NO_x decreases with increasing concentration of RSO in the blend and on the contrary the smoke number increase with higher concentration of RSO in the blend. By using a blend of 50% RSO in diesel the NO_x emissions are lowered by 18% and the soot emissions increases by 355% compared to that of diesel. Similarly by using a blend of 30% RSO in diesel the NO_x emissions are lowered by 12% and the soot emissions increases by 122% compared to that of diesel.

In order to utilize the advantage of lower NO_x emissions of 50% and 30% blends of RSO, different fuel injection strategies were tried to reduce their soot levels to that of diesel equivalent soot when the engine is operated under standard engine conditions (injection pressure of 800bar, injection timing of 9deg bTDC, 0% of EGR, engine speed of 2000 rpm and engine load of 2.7 bar BMEP).

Due to the limitations of the experimental operating conditions diesel equivalent soot was not achieved for 50% RSO but it was possible to reduce the soot from the blend of 30% RSO to diesel equivalent soot as shown in figure 3.

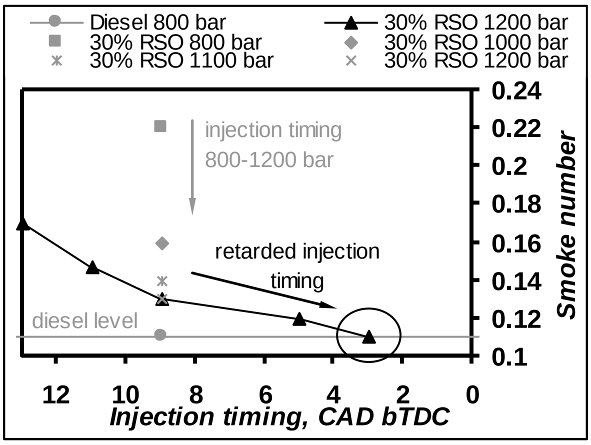

Fig. 3: Strategies adopted for achieving diesel equivalent level of soot from 30% RSO in diesel.

Diesel equivalent level of soot emissions for 30% RSO was achieved by increasing the injection pressure from 800 bar to 1200 bar and by retarding injection timing from 9 deg bTDC to 3 deg bTDC. As could be seen in figure 4, column A corresponds to standard engine operating conditions and column B corresponds to operating conditions for diesel equivalent soot for 30% RSO (at 1200 bar and 3 deg bTDC, 0% EGR, 2000rpm, 2.7 bar BMEP). Higher injection pressure causes better atomization and formation of smaller fuel droplets and at the same time higher entrainment of warm air on to the liquid core enhances vaporization of fuel droplets, which effectively lowers soot emissions.

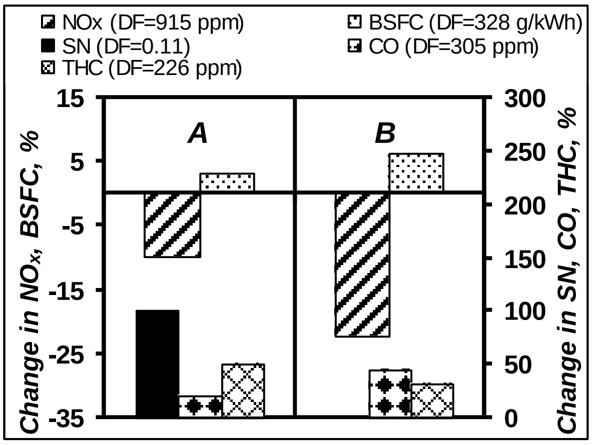

Fig. 4: Percentage change in exhaust emissions for 30% RSO: Column A (with respect to diesel fuel under standard engine operating conditions) and Column B (with respect to operating conditions at diesel equivalent soot levels).

By retarding the injection timing the combustion is shifted towards the expansion stroke and the peak cylinder pressures are lower, which eventually reduce the global in-cylinder temperature and thereby by lowering the soot formation rates. Under the conditions of diesel equivalent soot the NO_x emissions are further reduced by an order of 22 % compared to diesel fuel under standard engine operating conditions. Generally NO_x emissions decrease with retarded injection timing (lower in cylinder pressure and temperature) on the contrary an increase in the injection pressure leads to better atomization, better entrainment, higher in-cylinder pressure, higher in-cylinder temperature and higher NO_x. In this case the effect of retarded injection timing overrides the contributions from increased injection pressure which eventually results in an efficient reduction of NO_x emissions. The other gaseous emissions such as CO and THC measured under diesel equivalent soot conditions are still higher compared to that of diesel under standard engine operating conditions, however these emissions can be easily oxidized by using an oxidizing catalyst.

Other interesting combustion characteristics such as ignition delay, heat release, combustion duration, premixed and diffusion phase combustion under the standard and diesel equivalent soot levels, and their contributions to NO_x and soot emissions will be presented.

Conclusions

In this work the advantage of lower NO_x emissions for 30% blend of RSO in diesel was further explored to reduce their soot emissions to diesel equivalent levels through different fuel injection strategies. The main findings are summarized as:

- by using pure RSO and their blends the NO_x emissions are lowered compared to that of diesel fuel.
- diesel equivalent level of soot emissions for 30% blend of RSO were achieved by simultaneously retardation the injection timing and by increase the injection pressure.
- reduction of NO_x emissions by about 22% was achieved for 30% blend of RSO under the operating conditions of diesel equivalent soot.
- 30% RSO blend can be successfully used in DI diesel engine with low levels of NO_x emissions the same and even lower soot emissions compared to that of diesel.

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