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Compression Ratio and Injection Angle Effect on Performance and Emissions of a Diesel Engine Fuelled With Rapeseed Biodiesel and Diesel Fuel

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Abstract. Diesel fuel is largely utilized in the transport, agriculture, commercial, domestic and industrial sectors for the generation of power energy. Vegetable oils present a very hopeful alternative fuel to diesel oil, since they are renewable, biodegradable and clean burning, having properties analogous to that of diesel. In this theoretical study, effects of different injection angles, compression ratios and different piston bowls on the engine performance and emissions were investigated by using two different fuels which are standard diesel (D2) and RME (Rapeseed Oil Methyl Ester). Simulations were carried out with DIESEL-RK software that calculates the parameters of engine power, torque, specific fuel consumption and the emissions of NO_x, with an engine speed of 1500 rpm. It was shown that the increase of compression ratio and injector angle increased power and reduced specific fuel consumption while having higher NO_x emission negatively in all engine and fuel conditions. Additionally, the best optimization parameter having ZMZ-514 piston bowl with at 55^o injection angle is considered as optimized parameters despite of high NOx emission value.

Keywords: Injection angle, compression ratio, piston bowl, DIESEL-RK, rapeseed biodiesel, performance, emissions.

1. Introduction

The worldwide shortage of fossil fuels has caused a rising interest in diesel engines with high thermal efficiency and superior fuel economy characteristics to those of spark ignition gasoline engines [1]. Liquid fuels like alcohols and vegetable oils, gaseous fuels such as natural gas, Liquefied Petroleum Gas (LPG), hydrogen, biogas, and producer gas, are promising alternative fuels. The search for alternative fuels, which promise a harmonious correlation with sustainable development, energy conservation, efficiency and environmental preservation, has become very important today [2]. One of them is biodiesel which is alternative fuel for diesel engine. Biodiesel is typically produced through the reaction of a vegetable oil or animal fat with methanol or ethanol in the presence of a catalyst to yield methyl or ethyl esters (biodiesel) and glycerine. This reaction is called “transesterification”. The advantages of biodiesel are renewability, higher combustion efficiency, lower sulphur and aromatic content, higher flash point and higher biodegradability, and higher oxygen content [3]. Biodiesel fuel also has low soot emissions due to its high cetane number and high combustion temperature in the cylinder [1]. Moreover, use of biodiesel in the diesel engines decreased net atmospheric CO_2 levels, because it is made from oils and alcohols which are produced via photosynthetic carbon fixation. Although, important disadvantages of biodiesel are lower energy content, higher viscosity, higher cloud point and pour point, higher nitrogen oxide (NO_x) emissions and high price [3]. Biodiesel produced from different vegetable oils (soybean, rapeseed and sunflower) have been used in internal combustion engines without major modifications, with only slightly decreased performance. Physical and chemical properties of soybean oil and rape oil methyl esters are close to diesel fuel. Therefore, those blends are used an alternative fuels recently. Exhaust emissions of diesel engines operating on neat biodiesel and its

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blends with diesel fuel have been reported in numerous studies [4]-[6]. In many investigations, reductions in carbon monoxide (CO), total hydrocarbons (THC), and particulate matter (PM) emissions and smoke, along with increases in oxides of nitrogen (NO), have been determined in the exhausts. The fluid motion inside the engine cylinder is inherently unsteady, turbulent and three dimensional. The gas motion is unstable during the intake and compression processes and breaks down into three dimensional turbulent motions. Therefore, proper understanding of in-cylinder air motion and also the effect of bowl shape are required to improve performance and reduce emissions without compromising fuel economy [7].

Spray characteristics such as injector-hole diameter, injection pressure, spray angle and injection time and different piston bowls have a significant effect to control combustion in diesel engine [8]. Especially, the relative position of the axes of the piston bowl and the injector angle with respect to the cylinder axis also plays a role in in-cylinder mixture motion and combustion. Koci *et al.* [9] explained that split injections are effective in the reduction of unburned hydrocarbon (UHC) and carbon monoxide (CO). In addition, the compression ratio has a vital effect on engine performance. The torque and power increase as the compression ratio increase this is due to higher pressure inside the combustion chamber. In general, the maximum torque is obtained with diesel operation at all compression ratios. The observed maximum torque values of the biodiesel fuel blends operations were less than the diesel fuel value for each fuel due to lower heating values of biodiesel [2]. From the literature survey, it is clear that the in-cylinder fluid flow is very much dependent on the shape of the combustion chamber [7]. However, there is a very limited study on the effect of piston bowl configuration on the in-cylinder flow characteristics. The effect of compression ratio on engine parameters, emission and combustion characteristics have not been considered extensively [10]. In this direction, diesel engines have also developed their technologies with parallel of improvements of these alternative and renewable fuels. The advancement of these technologies has increased the importance of simulation during manufacturing which becomes an obligation. Today, the widespread use of computer-aided simulations during the manufacturing minimized the challenges and irreversible errors.

In this study, effects of different injection angles, compression ratio and different piston bowls (ZMZ-514 and 10D100) on the engine performance and emissions were investigated by using two different fuels which are standard diesel (D2) and RME (Rapeseed Oil Methyl Ester).Simulations were carried out with DIESEL-RK software that calculates the engine power, torque, specific fuel consumption and the emissions of NO_x at injector4-hole nozzle.

2. Material and Method

2.1. Material

2.1.1. Properties of various fuel and engine parameters

The performance and emission values were investigated for different piston bowls and compression ratios using different fuels which are injected at different injection angles. For this purpose, two different fuels have been chosen for the experiment. The fuel properties of these fuels are illustrated in Table 1 [11]. Additionally, the specifications of engine are shown in Table 2.

Table 1: Properties of diesel fuel and RME B100

Property	**Diesel No:2**	**RME B100**
Mass composition of fuel		
C	0.870	0.773
H	0.126	0.118
O	0.004	0.108
Low heating value (MJ/kg)	42,5	39.45
Cetane number	48	54.4
Fuel density (kg/m^3)	830	874
Dynamic viscosity (Pa.s)	0.003	0.00692

Table 2: Specification of Diesel Engine

Engine Type	**Four Stroke Diesel Engine**
Number of Cylinders / Valves	4 Cylinders / 4 Valves
Bore x Stroke	150mm x 180mm
Compression Ratio	16:1, 18:1, 20:1 and 22:1
Nominal Engine Speed	1500 rpm
Engine Design	In Line
Cooling System	Liquid Cooling

2.1.2 Biodiesel production

Vegetable oils can be edible such as cottonseed, groundnut, corn, rapeseed, soybean, palm oil, sunflower, peanut, coconut, etc. and non-edible such as jatropha, pongamia, neem, rubber seed, mahua, silk cotton tree, jojoba, and castor oil. Of the vegetable oils, rapeseed oil, has been successfully demonstrated as potential oils for biodiesel production. The most commonly used method of biodiesel production is the transesterification (alcoholysis) of oil (triglycerides) with methanol in the presence of a catalyst, which gives biodiesel and glycerol (by-product).The basic flow chart of RME biodiesel production is illustrated in Figure 1.

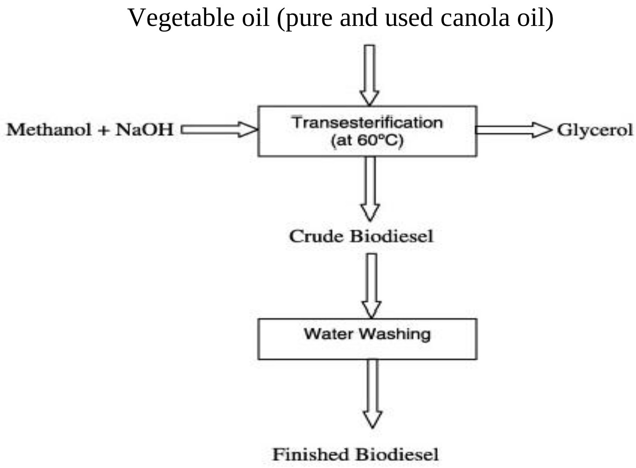

Fig. 1: The basic flow chart of biodiesel production

2.2. Method

2.2.1. Diesel RK

Diesel-RK is full cycle thermodynamic engine simulation software. One is designed for simulating and optimizing working processes of two and four-stroke internal combustion engines with all types of boosting. The program can be used for engine performances prediction such as specific fuel consumption, engine power, torque values, and also combustion and emission analysis. The RK-model has a capability to optimize the piston bowl shape and fuel injection system parameters (spray direction, diameter and number of nozzle) as well as to develop multiple injection strategy and the Common Rail controlling algorithm over the whole operating range [11]. The DIESEL-RK combustion model supports the library of different fuels including different blends of biofuels with diesel oil. Physical properties of biofuel blends are used in the spray evolution simulations and in modelling the evaporation and combustion processes. In this simulation study, Diesel-RK was used to calculate the performance and emission values for two different piston bowls by Diesel 2 and RME B100 fuels which are injected at different injection angles. The schematic appearance of piston bowls used in simulation program is given in Figure 2.

Fig. 2: Piston bowl design with Diesel RK**a)** ZMZ-514**b)** 10D100

3. Results and Discussion

The parameters, which were calculated to obtain the engine performance are; brake power, engine torque, specific fuel consumption and NO_x emissions. These parameters were calculated by varying various parameters such as different piston bowls (ZMZ-514 and 10D100), fuels (Diesel No:2 and Biofuel RME B100), different injections angles (15^o, 25^o, 35^o, 45^o, 55^o) and compression ratio (16:1, 18:1, 20:1 and 22:1) at injector 4-hole nozzle. Figure 3 shows the variation of power versus injector angles at compression ratio 22:1. The power increased with the increment of injector angle and the highest power values were obtained by 55^o injector angle in ZMZ-514 piston bowl and standard diesel fuel (D2). It was observed that the power values obtained from rapeseed oil methyl ester were much smaller value than standard diesel fuel in 15°, 25°, and 35° injector angle. However, the power values approached to values calculated from the standard diesel fuel in 45° and 55° injector angles. This situation was observed in all simulated compression ratio. But, the power values calculated from 10D100 piston bowl increased gradually with the increasing injector angle for both RME and standard diesel fuel. Variation of specific fuel consumption versus injector angle at 22:1compression ratio is shown in Figure 4. The specific fuel consumption of RME and standard diesel showed a significant reduction with the increment of injector angle (especially, 45°, 55°). The specific fuel consumption of RME was 0,25707 kg/kWh and 0,27061 kg/kWh for ZMZ-514 and 10D100 piston bowls at 55° injector angle and 22:1compression ratio, respectively. Whereas, it was 0,23122 kg/kWh and 0,23678 kg/kWh for diesel, respectively. It was shown in Figure 5 that NO_x emission for rapeseed biodiesel increased with the increasing compression ratio for two different piston bowls compared to standard diesel (D2). The minimum level of NO_x emission was calculated at RME injected at 10D100 piston bowl. The reason that 10D100 piston bowl has less NO_x emission against ZMZ-514 piston bowl may be due to the swirl effect of ZMZ-514 piston bowl which makes a better combustion. So, the peak combustion temperature of ZMZ-514 became higher than that of 10D100 piston bowl. The variation of specific fuel consumption versus compression ratio at 55° injector angle is shown in Figure 6. The specific fuel consumption values achieved from ZMZ-514 piston bowl is less than that of 10D100 piston bowl for all compression ratio used in simulation.

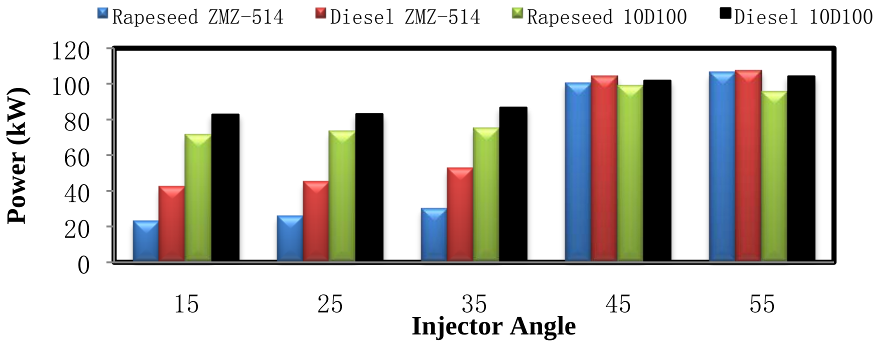

Fig. 3: Variation of power versus injector angles at 22:1 compression ratio

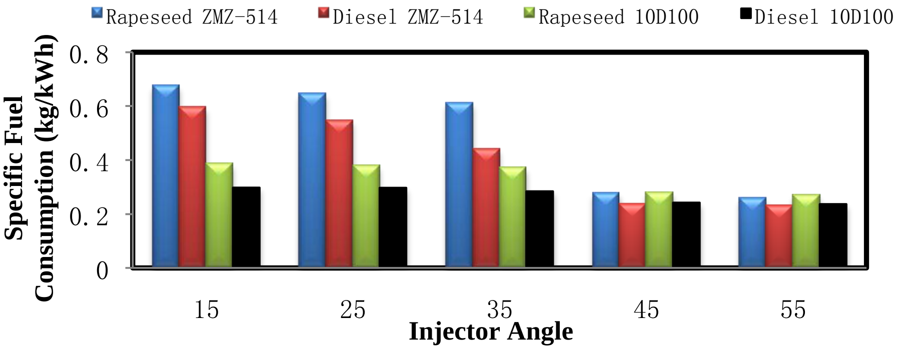

Fig. 4: Variation of specific fuel consumption versus injector angle at 22:1compression ratio

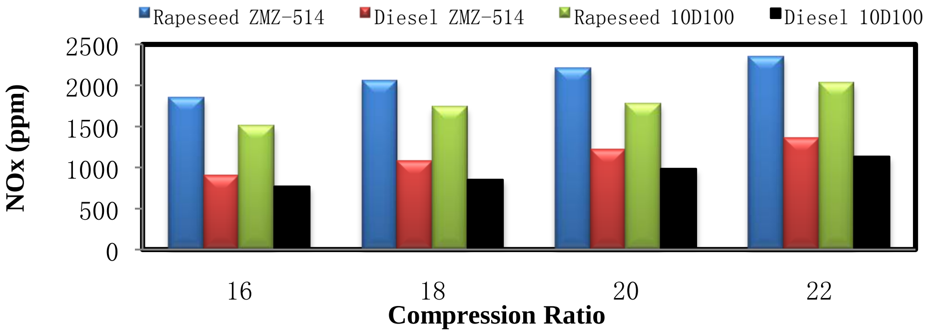

Fig. 5: Variation of NO_x versus compression ratio at 55° injector angle

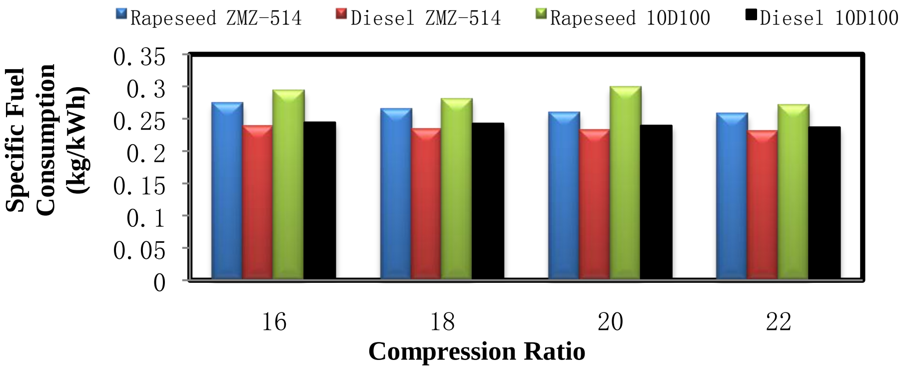

Fig. 6: Variation of specific fuel consumption versus compression ratio at 55^o injector angle

4. Conclusions

The purpose of this work was to determine the effect of injection angles, piston bowls and compression ratio on the performance and emission of diesel engine using RME biodiesel and standard diesel fuel by simulating the Diesel RK software. It was found that the increase of compression ratio and injector angle increased power and reduced specific fuel consumption while having higher NO_x emission negatively in all engine and fuel conditions. It was shown that piston position played also a predominant role in the air pattern inside the cylinder. As a result, the best optimization parameter having ZMZ-514 piston bowl with at 55^o injection angle is considered as optimized parameters despite of high NO_x emission value.

5. Acknowledgements

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