Effects of Varying Injector Opening Pressure on the Performance of a B20 JOME Biodiesel Fueled Diesel Engine

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ABSTRACT

The present work examines the influence of Injector Opening Pressure (IOP) on Jatropha oil fueled Compression Ignition (CI) engine. A Direct Injection (DI) type diesel engine was tested with a blend of 20% Jatropha Oil Methyl Ester (JOME) with 80% diesel (B20) on volume basis. The engine was run on four different injector opening pressures viz. 190, 210, 220 and 230 bar along with standard IOP of 200 bar. For all IOPs, performance considerations like brake thermal efficiency (BTE), brake specific fuel consumption (BSFC), combustion factors such as cylinder pressure and ignition delay and emission issues such as CO, UBHC, smoke opacity and oxides of nitrogen (NO_x) were investigated. From the experimental examinations it was observed that IOP of 220 bar showed improvement in terms of BTE and BSFC by about 2.3% and 4.4%. Considerable enhancement in reduction of emission levels particularly for CO, UBHC and smoke were also observed for increased IOP of 220bar by about 26.4%, 12.96% and 3.4% respectively, compared to the engine operated at standard IOP of 200 bar. However, NO_x emission level was deteriorated compared to normal IOP. It was also found that increasing the IOP, lowered ignition delay and increased the in-cylinder pressure.

Keywords: *Biodiesel; Diesel engine; Injection pressure; Performance; Combustion; Emissions.*

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Nomenclature

JOME	Jatropha Oil Methyl Ester	CI	Compression Ignition
B20	blend of 20% JOME with diesel fuel by volume	BSFC	Brake Specific Fuel Consumption
B100	100% JOME	DI	Direct Injection
BTE	Brake Thermal Efficiency	HRR	Heat Release Rate
CO	Carbon Monoxide	UBHC	Unburned Hydrocarbons
NO_x	Oxides of Nitrogen	bTDC	Before Top Dead Center
CA	Crank Angle	deg	Degree
IOP	Injector Opening Pressure	TBOs	Tree Borne Oil seeds

Introduction

Direct injection (DI) type diesel engines have demonstrated as the most excellent option in applications like transportation and generating power, but rapid depletion of crude oil, their rising prices and rising pollution problems are the major concerns [1, 2]. Alternative energies, particularly biofuels are getting increased interest in the past few years [3-5]. Vegetable oils are easily available, renewable, have higher cetane number. They can be used in diesel engines with minor modifications and can be readily blended with diesel. Jatropha oil [6], Karanja oil [7], Palm [8], Sunflower [9], Rapeseed [10] and Soybean [11] oils are few vegetable oils that have been attempted as fuel in diesel engines earlier.

In the research of biodiesel operated diesel engine, thermal efficiency improvement, fuel consumption enhancement and pollutant reductions are considered as the main factors. To attain these, quick and improved fuel-air mixing is an important requirement [12]. Nevertheless, the usage of biodiesel as a neat fuel in diesel engine affects engine operation and performance characteristics as a result of differences in chemical and physical properties of biodiesel [13-15]. This affects the fuel injection parameters, fuel-air mixing and combustion [16-18]. Vegetable oils high viscosity and surface tension influence the atomization as these parameters increase the fuel drop size. This in turn enhances the spray penetration [19, 20]. The biodiesel-air mixing characteristic can be largely enhanced by choosing the suitable injection factors and improved combustion chamber design.

In a DI diesel engine, the injection system has to accomplish a high intensity of atomization so as to improve evaporation in short time and to realize adequate penetration of spray in order to use the maximum air charge. Performance and emission traits of CI engines are mainly controlled by fuel atomization and spray processes. When injector opening pressure is low, atomization i.e. fuel particle size will increase and the period of first phase of combustion process i.e. ignition delay will increase. This condition results in decline in engine performance, as a result of poor combustion process due to poor mixture formation.

When the injector opening pressure is increased the fuel is well atomized and the fuel droplet size will turn into small. Effective atomization enhances the surface area of the fuel, as a result improved fuel-air mixing and high rate of evaporation can be attained [19, 20]. Since the mixing of fuel with air enhances during ignition delay period, performance of engine will be increased [21, 22]. If the injector opening pressure is very high, that will result in finer atomization. Lesser momentum of small droplets will affect dispersion of fuel in the air. As a result, the combustion efficiency will drop down due to poor homogeneous mixing [23]. Hence in order to improve the performance of a biodiesel operated engine a detailed investigation is required on the injection parameters particularly by varying the injector opening pressure. Operating the engine with higher IOP is a valuable approach to improve biodiesel powered DI diesel engines performance and to decrease emission levels due to disintegration of fuel into finer droplets and enhanced mixing.

Materials and Methods

Biodiesel production and properties

Raw Jatropha oil is a Tree Borne Oil (TBOs) obtained from jatropha, a large perennial shrub or small tree which is regarded as the raw material for the biodiesel production. In India larger capability exists for making thousands of thousand hectares of badlands for the plantation of jatropha to produce oil [24]. Jatropha seeds contain 37% oil [25, 26].

Biodiesel from raw Jatropha oil was produced by alkali catalyzed transesterification process. Transesterification is a chemical reaction which converts large triglycerides into small straight chain esters. The raw Jatropha oil is heated in a reactor. Then the quantity of base catalyst KOH required is weighed and dissolved in Methanol which is called lye. The prepared lye is transferred to the reaction vessel. The mechanized stirrer is started to ensure agitation. A two-hour period has been found by experience to be safe for the reactions to cease [27]. The reacted products were drawn off from the bottom through a valve and collected in a container, known as the settling and separating tank. The products collected were allowed to settle in the settling tank for at least eight hours. The remaining liquid in the settling tank is crystal clear and drawn off and collected in a clean, separate container. 20% of so prepared Jatropha Oil Methyl Ester was then blended with 80% diesel on volume basis. The properties of raw jatropha oil, JOME and its 20% blend were determined and are compared with the diesel in Table 1. Even though properties of JOME can be compared with diesel the viscosity of JOME was observed to be higher by about 44.1% and calorific value was lower by about 2.9%, when compared to diesel.

Table 1: Properties of biodiesel from jatropha, its blend and diesel.

Properties	**B100**	**B20**	**Diesel**	**IS: 15607 specification**	**Test methods IS1448 / ASTM**
Density (Kg/m^3)	873	852	850	860-890	P16
Kinematic Viscosity (cSt)	4.18	3.02	2.9	2.5-6.0	P 25/ D 445
Calorific Value (MJ/kg)	42.73	43.75	44.12		D5865
Flash Pt (°C)	148	88	76	120	P 21 / D93
Cloud Pt (°C)	10.2	6.9	6.5	-	D2500
Pour Pt (°C)	4.2	3.3	3.1	-	D2500

Experimental setup

Kirloskar made engine was used for investigation. The engine is a four stroke, single cylinder, water cooled DI diesel engine. It develops an output of 5.2 kW. It is a constant speed engine which operates at 1500 rpm. Figure 1 shows the schematic diagram of the experimental setup. Table 2 specifies the important engine specifications. An eddy current dynamometer was connected to the engine with a data acquisition system for its testing. A piezoelectric transducer was installed in the cylinder head to measure the cylinder pressure and on the flywheel a crank angle encoder was fixed to measure the crank angle. The signals from crank angle encoder and pressure transducer were supplied to the charge amplifier for combustion analysis. For analysis of combustion, SeS combustion analyzer was used. CRYPTON 5 gas analyzer was used for the measurement of UBHC, CO and NO_X emissions. AVL 437C was used for the measurement of smoke intensity.

Engine modifications

To examine the influences of varying the injector opening pressure the injection pressure of the MICO made injection pump was varied. The injection pressure of the pump was altered by adjusting the spring tension of the injector. The spring stiffness of the injector was modified by adjusting the screw equipped on the top of the injector. Hand operated fuel injection test bench was used for the measurement of injector opening pressure. To carry out the investigation injector opening pressures were varied to 190, 200, 210, 220, and 230 bar.

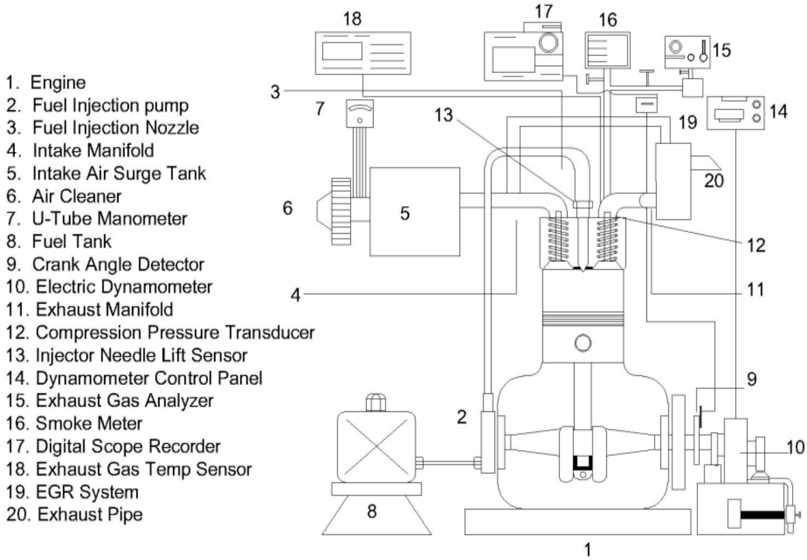

Figure1: Schematic of the experimental setup

Table 2: Engine specifications

Make	Kirloskar TV1
Type	Vertical diesel engine, 4stroke, water cooled, single cylinder
Capacity	661 cc
Bore & Stroke	87.5 mm & 110 mm
Compression ratio	17.5:1
Fuel	Diesel
Rated brake power	5.2 kW @ 1500 rpm
Ignition system	Compression ignition
Combustion chamber	Hemispherical combustion chamber

Test method

To carry out the experimental investigation, diesel and B20 were used as fuel. Initially investigation was done using diesel at various engine loads for engine operated at basic injector opening pressure of 200 bar. Then it was performed using B20 as fuel at the same basic injector opening pressure of 200 bar. The engine tests were then executed at various injector opening pressures of 190, 210, 220, and 230 bar and at different loads. These results were then determined, evaluated and analysed with basic injector opening pressure of 200 bar.

Results and Discussion

Performance analysis

BSFC is a parameter that indicates how effectively an engine is transforming fuel energy into useful work. The BSFC changes for engine with diesel and B20 at various injector opening pressures is shown in Figure 2. It was found that the BSFC reduced with increasing the injector opening pressures. It was observed that the BSFC decreased marginally with increasing injector opening pressures from the basic injector opening pressure of 200 bar (0.295 kg/ kW-hr) to 210 bar (0.29 kg/ kW-hr) and 220 bar (0.282 kg/ kW-hr) for B20. This can be reasoned to better combustion caused by enhanced mixing. However, it was found that with increase in injector opening pressure beyond 220 bar the BSFC increased which agrees with the findings of other researchers [21, 28, 29]. Further, it was found that the BSFC increased with lowering the injector opening pressure to 190 bar (0.312 kg/ kW-hr) from 200 bar. These can be reasoned to inferior combustion of B20 due to inadequate atomization.

Figure 3 shows the comparison of BTE at various injector opening pressures. BTE of B20 was higher at high injector opening pressures due to superior mixture formation and complete combustion. It was noticed that for B20 the BTE increased with increasing injector opening pressures from the basic injector opening pressure of 200 bar (28.65% at full load) to 210 bar (28.75% at full load) and 220 bar (29.31% at full load). It was also noted that increase in injector opening pressure above 220 bar, lessened the BTE. This was reasoned to drop in droplet size. Lower momentum of smaller droplet will affect the fuel dispersion in air. The drop in the relative velocity of fuel in relation to the air will result in partial choking of fuel by its own products of combustion leading to incomplete combustion. Further, it was found that the BTE reduced with decreasing the injector opening pressures to 190 bar (27.5% at full load) from 200 bar. This was owed to inadequate combustion of B20 as a result of poor atomization and air fuel mixing. A similar result was obtained by other indications researchers such as Hountalas *et al*., [21] and Venkanna *et al*., [29].

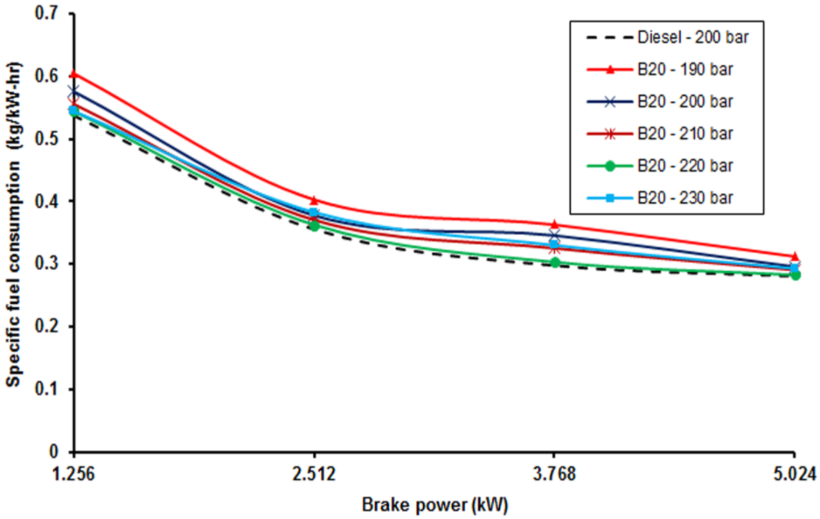

Figure 2: Variations of BSFC at different injector opening pressures

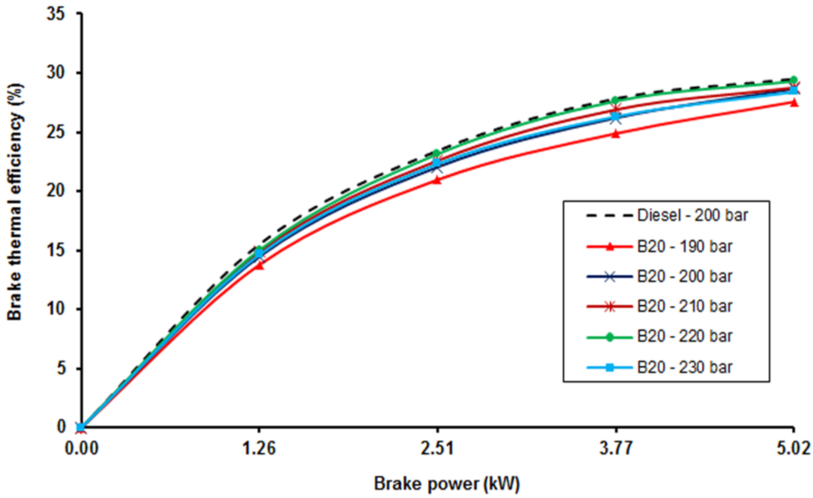

Figure 3: Comparisons of BTE at different injector opening pressures

Emission analysis

The variations of unburnt hydrocarbon emissions for diesel and B20 blend at various injector opening pressures is shown in Figure 4. It was noticed that the UBHC emissions for B20, decreased with increasing injector opening pressures from the basic injector opening pressure of 200 bar (27 ppm) to 210 bar (25.48 ppm) and 220 bar (23.5 ppm). This can be endorsed to improved combustion due to improved atomization. It was also observed that increasing the injector opening pressures above 220 bar marginally increased UBHC emissions. Further it was found that the UBHC emissions substantially increased with lowering the injector opening pressures to 190 bar (28.3 ppm) from 200 bar. This was caused by poor combustion of B20 due to poor atomization.

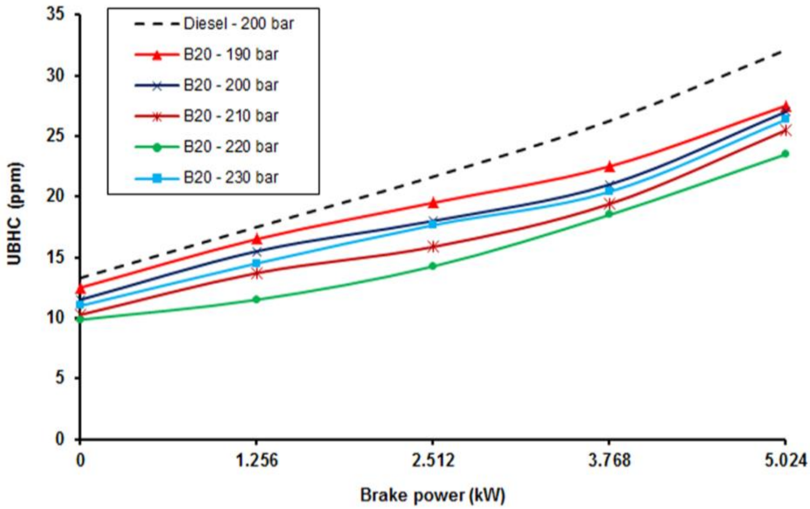

Figure 4: Variations of UBHC emissions at different injector opening pressures

Figure 5 shows the comparison of CO emissions for diesel and B20 at various injector opening pressures. It was observed that CO emission was reduced with increased injector opening pressure operation primarily due to superior atomization and complete combustion. It was observed that the CO emissions decreased with increased injector opening pressure. Compared to basic injector opening pressure, the CO emissions for increased injector opening pressures of 210 bar and 220 bar were lower by 8.9% and 26.35% respectively at full load. However further increase in injector opening pressures was found not so advantageous; furthermore, a decrease in injector opening pressures was also observed as not desirable as it led to increase in

CO emissions from the engine. This result is comparable to the reported values [21, 28].

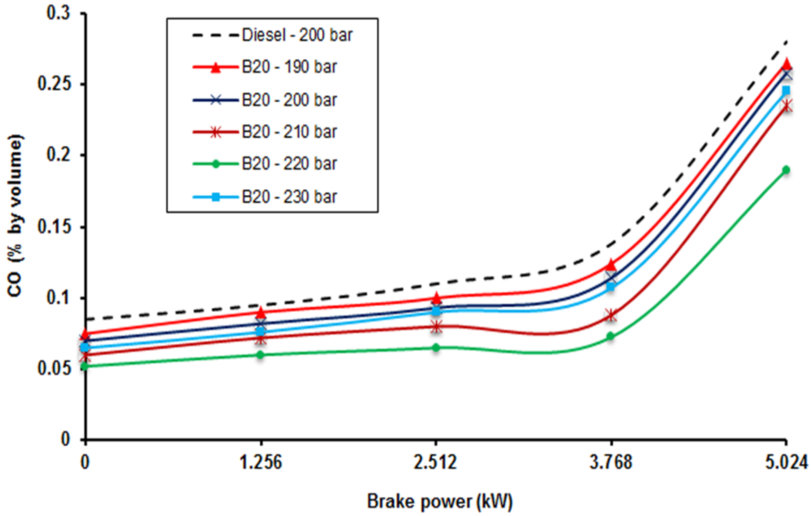

Figure 5: Comparisons of CO emissions at different injector opening pressures

Figure 6 displays the variation of NO_x emissions for diesel and B20 at various injector opening pressure. It was observed that at high injector opening pressures s, NO_x emissions were increased. With B20 as fuel, the NO_x emissions at full load increased from 670 ppm to 689 ppm and 728 ppm on increasing the injector opening pressures by 10 bar and 20 bar from the basic injector opening pressures of 200 bar respectively. This was attributable to higher combustion temperatures as a result of improved combustion due to better mixture formation owing to improved atomization. However, on lowering the injector opening pressure to 190 bar, the NO_x emissions were dropped to 652 ppm, in the same way on increasing the injector opening pressures to 230 bar, the NO_x emissions were declined to 679 ppm, which agrees with the findings of other researchers [28, 29]. With B20 as fuel and at 220 bar, the NO_x emissions were higher by about 12.86%, compared to diesel (645 ppm) at full load.

The smoke opacity comparison for Diesel and B20 at different injector opening pressures is shown in Figure 7. It was noticed that at lower injector opening pressure more smoke emissions were emitted compared to high injector opening pressures. At lower injector opening pressure, the atomization process was inadequate. This resulted in bigger droplets size and

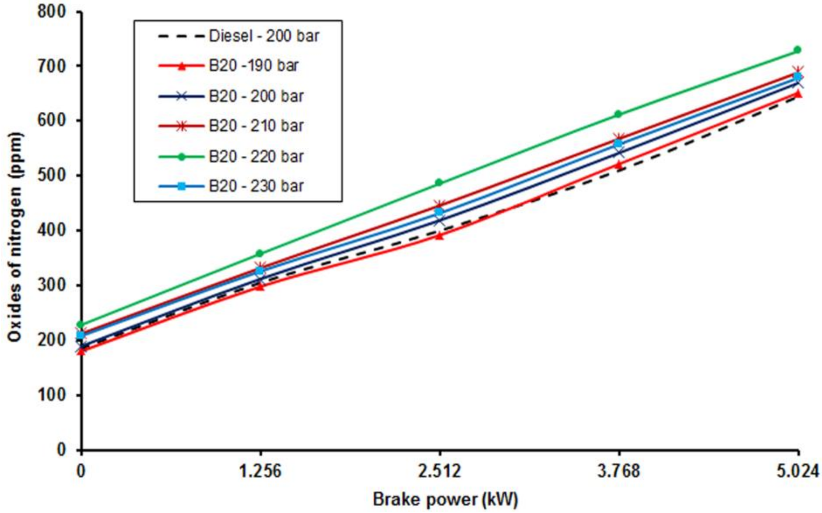

Figure 6: Variations of NO_x emissions at different injector opening pressures

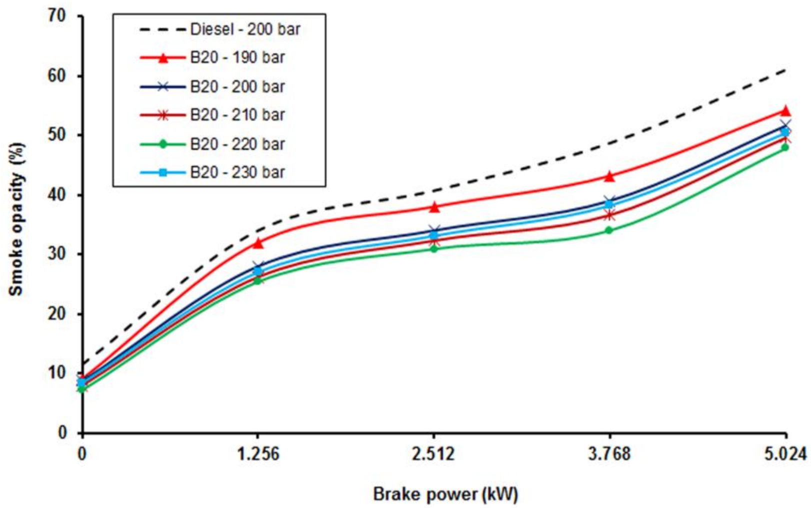

Figure 7: Comparisons of smoke emissions at different injector opening pressures

hence bigger core. Smoke emissions generally form in the core region [30]. For this reason, at a lower injector opening pressure of 190 bar (54.2%) more smoke emissions was formed due to bigger size droplet. However, at higher injector opening pressures i.e. at 210 bar (49.6%) and 220 bar (47.8%), it was found that lower smoke emissions were formed compared to standard injector opening pressures of 200 bar (51.6%) as a result of small fuel droplets size, superior fuel- air mixing and complete combustion. This result is comparable to the reported values [28, 29].

Combustion analysis

Figure 8 illustrates the change in ignition delay period for diesel and B20 operated engine at various injector opening pressures. The ignition delay period decreased at high injector opening pressures because of very high temperature in the cylinder due to improved air-fuel mixing and enhanced pre-combustion reactions. The ignition delay period decreased with increasing injector opening pressures from the standard injector opening pressure of 200 bar (7.6^o CA) to 210 bar (6.9^o CA) and 220 bar (6.3^o CA) at full load operation. This was mainly due to improved atomization and fuel-air mixing. However, increasing the injector opening pressures above 220 bar increased the delay period to 7.2^o CA. Further, it was found that the ignition delay substantially increased by lowering the injector opening pressures to 190 bar (8^o CA) from 200 bar. This was caused by poor atomization, vaporization and air fuel mixing of B20.

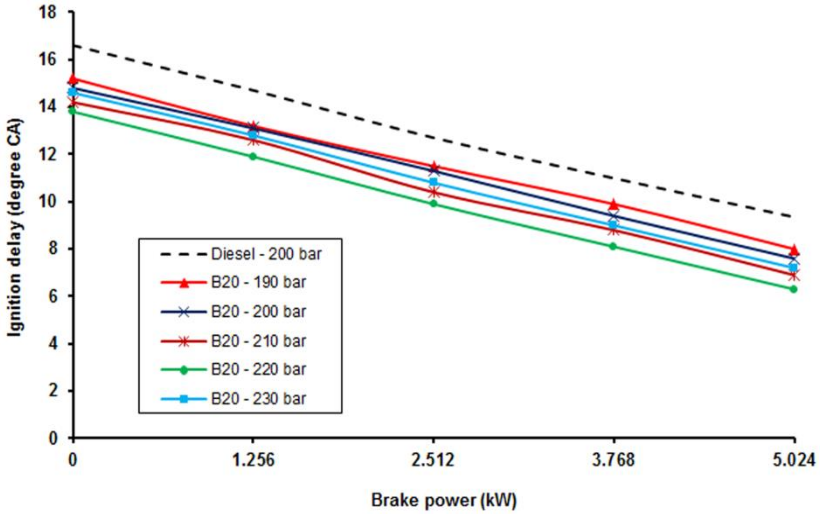

Figure 8: Changes of ignition delay at different injector opening pressures

The variation of in-cylinder pressure in a cycle is important parameter which indicates the efficiency of combustion process. Cylinder pressure changes with respect to crank angle for engine operated with B20 and diesel at various injector opening pressures is presented in Figure 9. The results had shown that cylinder pressure increased when injector opening pressure was increased from 200 bar to 220 bar, however, further increase in IOP to 230 bar resulted in decrease in in-cylinder pressure. It was noticed that the effective results were obtained for injector opening pressure of 220 bar with B20. Better combustion due to better atomization and air-fuel mixing can be reasoned to this. Lowering the injector opening pressures to 190 bar resulted in decrease of cylinder pressure. This was due to poor combustion of B20.

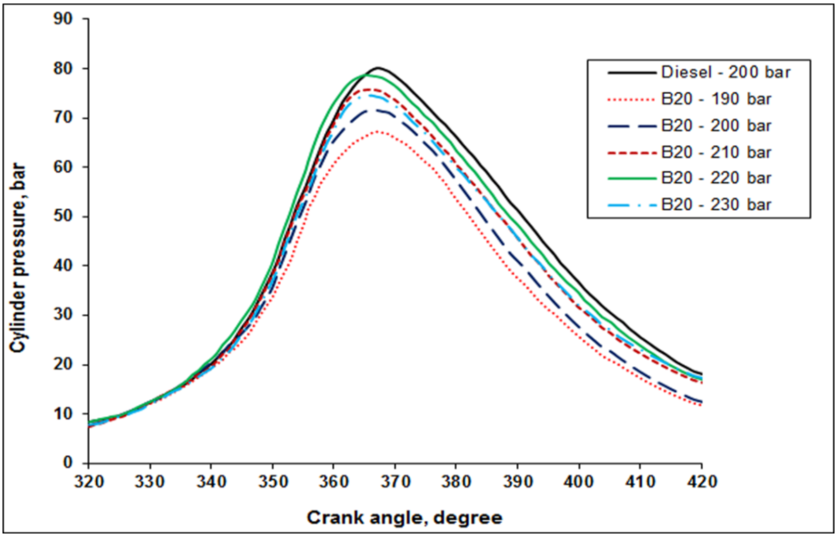

Figure 9: Variations of cylinder pressure at different injector opening pressures

Conclusions

The present work deals with the investigation on effects of injector opening pressure on the performance of a biodiesel operated DI diesel engine. The experimental results of this study show that

1. Performance parameters of the engine initially improved and then decreased with increasing injector opening pressure i.e. BTE increased marginally and BSFC slightly decreased with increasing injector

opening pressure from 200 bar to 220 bar due to better atomization and air fuel mixing and complete combustion. In addition, increase in injector opening pressure to 230 bar or decrease in injection opening pressure to 190 bar were found not desirable as it led to drop in BTE and increase in BSFC of the engine due to poor disintegration of fuel into fine droplets and mixing.

2. For the same reasons CO, UBHC and smoke emission levels were decreased with increasing injector opening pressure from 200 bar to 220 bar. However, NO_x levels were increased.

3. For the same reasons peak in-cylinder pressure increased and ignition delay decreased with increasing injector opening pressure from 200 bar to 220 bar.

The present analysis reveals that for this engine with 20% blend of jatropha biodiesel, increased injection opening pressure of 220 bar was observed to be better in terms of performance, combustion and exhaust emissions due to improved atomization of the fuel and air-fuel mixing. The present phase of investigation showed that the performance, combustion and emission characteristics of biodiesel fueled engine can be further improved by suitably adjusting the injector opening pressure.

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