

## Experimental Study on Effect of Injection Pressure to Spray Characteristics, Performance and Emissions of Diesel Engine DI 20 C Using Biodiesel Fuel

Alham A. K. Mahanggi<sup>1</sup>, Bambang Sudarmanta<sup>2</sup>, Hary Soebagyo<sup>3</sup>

<sup>1,2</sup>Combustion and Energy System Laboratory, Department of Mechanical Engineering, ITS, Sukolilo Surabaya 60111, Indonesia

<sup>3</sup> Balai Besar Teknologi Kekuatan Struktur (B2TKS), Badan Pengkajian dan Penerapan Teknologi (BPPT), Indonesia

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### Abstract

Biodiesel as an alternative fuel can replace fossil fuels. However, biodiesel has a higher value of viscosity, density and surface tension to fossil fuels. Increasing the injection pressure on the injector is one solution to overcome the problem of high viscosity, density, and surface tension in biodiesel. This study aims to determine the effect of increasing injection pressure and injection timing variations on spray characteristics, performance and exhaust emissions diesel engine. Injection pressure namely 200, 210, 220, 230 kg/cm<sup>2</sup> by setting the rotation of adjusting screw the injector. The results of this study were obtained by increasing the pressure injection of biodiesel fuel by 230 kg/cm<sup>2</sup> resulting in fuel spray characteristics better than the standard 200 kg/cm<sup>2</sup> and resulting improvements in the penetration length, spray angle, the average diameter size of each 30%, 28%, and 9.78%. And performance improvements and exhaust emissions also occur, namely Thermal Efficiency, Specific Fuel Consumption, and Smoke Opacity with values of 16.99%, 14.15%, and 46.39% improved respectively.

**Keywords:** Biodiesel, Injector, Injection Pressure, Spray characteristic, Performance, Emission

### 1. Introduction

Indonesia still relies on the use of fossil fuels. Fossil fuels are non-sustainable energy sources, which are commonly used in industrial and transportation fields. For example in diesel engines, Solar, Dexlite, and Pertadex are the result of distillation of fractions from petroleum (fossil fuels), which the availability is limited. The use of fossil fuels also has a negative impact on the environment. Exhaust emissions from combustion of fuel are one of the main causes of the greenhouse effect (such as CO, CO<sub>2</sub>, HC, etc.). With the adverse effects of the depletion of fossil fuels, alternative fuels are needed to reduce dependence on fossil fuels engine near or equal to using fossil fuels. This can be done by increasing injection pressure to improve biodiesel properties, namely viscosity, density, and surface tension.

Biodiesel is a fuel that is very potential to be used as a substitute for fossil fuels. This is because the raw materials derived from vegetable oils, can be renewed, can be produced periodically and easily obtained. However, fuel spray characteristics are influenced by the physical properties of fuel kind of density, viscosity and surface tension [1] where biodiesel is a fuel that has a higher value of viscosity, density, and surface tension but low at the heating value compared to fossil fuels. The higher value

of viscosity, density, and surface tension on the biodiesel fuel causes the atomization of the fuel is not good and more difficult to mix with air which results in incomplete combustion. Therefore certain treatments are needed so that biodiesel fuel can be used and produce a performance on the engine near or equal to using fossil fuels. This can be done by increasing injection pressure to improve biodiesel properties, namely viscosity, density, and surface tension.

Sudarmanta [1] conducted a study on the transesterification of crude palm oil and spray characteristic tests using a diesel motor injector. It was produced that the properties of transesterification biodiesel, in this case, the viscosity, density, and surface tension were still slightly higher than the properties of diesel fuel. Experimental and computer simulations of spray characteristics showed that higher viscosity resulted in poor atomization characteristics, namely in the form of poorer evaporation. Whereas higher density and surface tension produce slightly more liquid forms, penetration, and droplet so that the gas phase distribution becomes narrower.

Some researchers carried out the experimental study on the effect of injection pressure variations using biodiesel fuel. Ahmad [2] conducted a study of the effect of injection pressure on performance on dual fuel diesel engines. Variations are made by changing the thick-

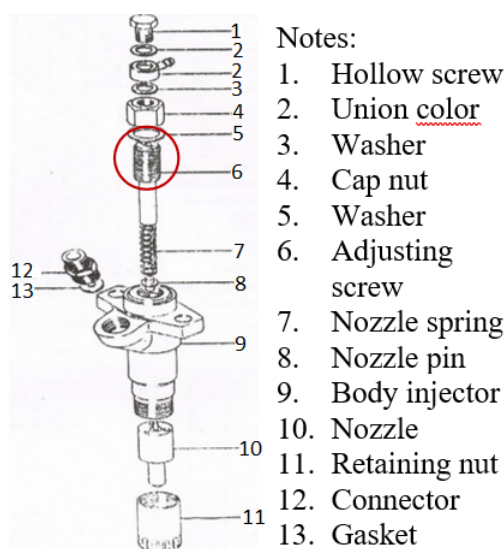
ness of the shim or adjusting the washer according to the variation, namely 190 bar, 210 bar, 230 and 250 kg/cm<sup>2</sup> with a constant engine speed of 2000 rpm and loading from 200 W to 2000 W at intervals of 200 W, dual fuel system between biodiesel fuels with syn-gas. The best performance results obtained at a pressure of 250 kg/cm<sup>2</sup> with an increase in the percentage of thermal efficiency of 40,766% and spray angle ( $\emptyset$ ) of 29.41%, and a decrease in the percentage of SFC biodiesel, SFC on dual fuel systems and spray length (L) of 30,766%, 13,24% and 19.23%.

Mutyalu et al. [3] investigated the effect of fuel injection pressure on the performance and emissions characteristics of a diesel engine with Shea Olein Biodiesel

fuel. The experiment was carried out on stationary water cooled naturally aspirated single cylinder 4-stroke and direct injection Kirloskar engine at a constant rated speed of 1500 rpm and load at 2,79 kW. The test was conducted at different injection pressures (190, 200, 210, 220, 230 bar). The best performance and emissions are produced at a pressure of 210 bar. Where the results of chart trends such as BSFC have decreased at a pressure of 210 bar. While at higher injection pressures, BSFC has increased because of higher momentum of fuel got impinges on cylinder walls leads to wastage of fuel and improper combustion. And HC and CO emissions also decrease at a pressure of 210 bar.

**Table 1.** Properties of Fuels

Properties	Diesel Fossil	Bio Diesel
Lower Caloric Value (LHV) (kJ/kg)	46218.09	42542.54
Densityat 15 °C (kg/m <sup>3</sup> )	857	875
Densityat 40 °C (kg/m <sup>3</sup> )	844	857
KinematicsViscosityat 40 °C (mm <sup>2</sup> /s)	4.2	4.5
Surface Tension (dyne/cm)	66	68
Cetane number	53	58



**Figure 1.** Injector Geometry

## 2. Material and Method

### 2.1. Fuel Properties

The biodiesel used in this test is B100 biodiesel from palm oil (CPO) obtained from PT. Wilmar Nabati Indonesia, where biodiesel in Indonesia uses more raw materials from palm oil because it is easily obtained [4]. But when compared to diesel fuel, the properties of biodiesel fuel have a higher value of viscosity, density, surface tension,

and cetane number but low at the heating value. Table 1 shows differences in properties of diesel fuel and biodiesel.

### 2.2. Spray Characteristic Test

To find out the results of fuel atomization, spray characteristic tests were carried out using a Bosch pump tester with biodiesel fuel. Figure 1 shows the injector used in Diamond DI 20 C diesel engines. Then the injection pressure variation is performed by setting the rotation in

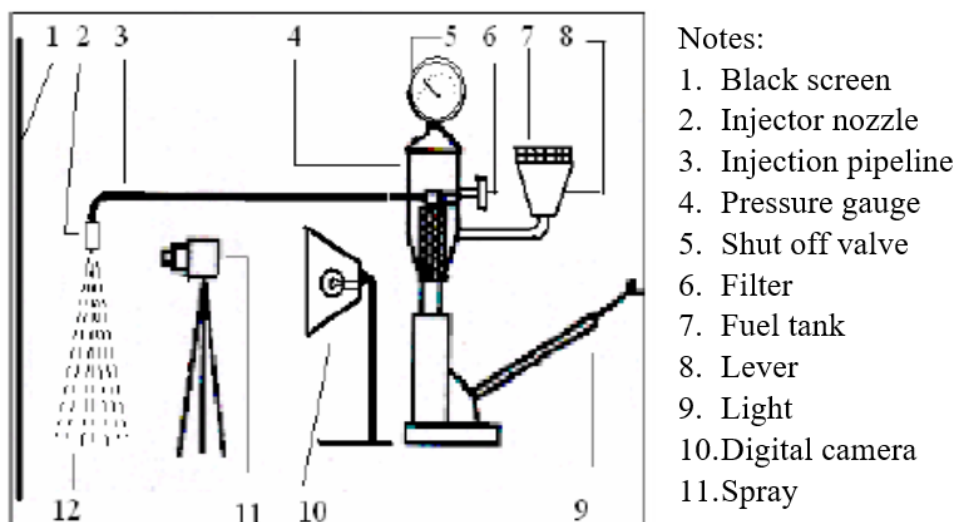


Figure 2. Schematic of spray characteristic testing

adjusting screw on the injector until the injection pressure will be tested, where injection pressure will be seen in the pressure gauge. The pressure variations in this study were 200, 210, 220 and 230 kg/cm<sup>2</sup>. This test was carried out at the motor fuel laboratory of the mechanical engineering department, ITS Surabaya.

Figure 2 shows the fuel spray characteristic test series. After testing, the length of penetration and spray angle of the fuel will be measured, and the calculation of the average droplet size (SMD) with the formula approach from Jasuja [5] is as follows:

$$SMD = 2,25\sigma^{0,25}\mu_L^{0,25}\dot{m}_L^{0,25}\Delta P_L^{-0,5}\rho_A^{-0,25} \quad (1)$$

### 2.3. Experimental Setup

The study was carried out experimentally on a diesel engine with a constant speed of 2000 rpm. This test is carried out on a Diamond diesel engine DI 20 C with the main shaft that has been coupled directly with the electrical generator as an electrical dynamometer. Data retrieval was carried out on each variation of load tested, which is 1000 Watts to 7000 Watts with the increment of 1000 Watts. This testing was carried out at the Workshop on Laboratory of Combustion and Energy Systems, Department of Mechanical Engineering, FTI-ITS Surabaya. Figure 2 shows the experimental method carried out in this test and the engine specifications shown in Table 2.

Table 2. Engine specifications

No.	Specification	Description
1.	Make	Diamond
2.	Model	DI 20 C
3.	Engine type	Four stroke, horizontal, water cooled
4.	Fuel injection	Direct injection
5.	Number of cylinders	Single cylinder
6.	Start of injection (BTDC)	20°
7.	Compression ratio	16 : 1
8.	Bore	105 mm
9.	Stroke	115 mm
10.	Cylinder volume	1000 cc

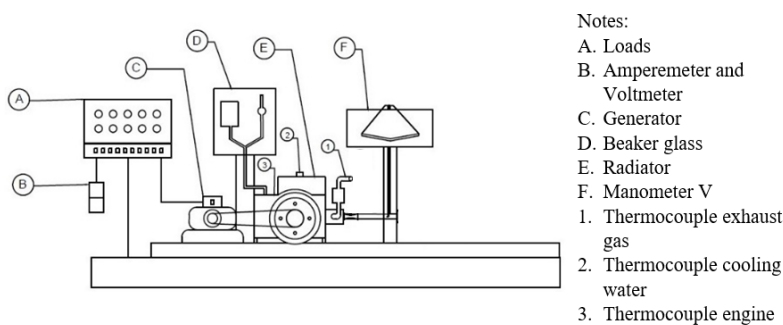


Figure 3. Schematic of engine performance test

### 3. Results and Discussion

The analysis of this study was carried out by compiling the results of the spray characteristics and experimental results of performance test and exhaust emission test.

#### 3.1. Result of Spray Injection Characteristic Test.

Based on the properties of biodiesel that we have acknowledge, in the previous paragraph. Higher viscosity causes higher flow momentum so that the spray penetration length becomes longer, while higher surface tension makes it difficult for droplets of fuel to become smaller granules (secondary break up) which will then spread in all directions. This spread causes the contact surface of droplet fuel with less air, so the evaporation that occurs will be longer than the fuel which has a higher surface tension value.

Tests were carried out with pressure variations

namely 200, 210, 220 and 230 kg/cm<sup>2</sup> using biodiesel fuel. The aim is to test the spray characteristics in order to find out the results of the atomization of biodiesel fuel at each injection pressure to approach the results of the atomization of diesel fuel. Atomization is converting liquid fuels injected by engine injectors into droplet shapes with certain patterns and directions [4]. Good atomization will also produce good engine performance and emissions, this is because fuel droplets are injected to form small particles which will collide with high-pressure air to mix and produce more complete combustion. Figure 4 shows the effect of increasing injection pressure on spray atomization and Table 3 shows the calculation results of the Sauter mean diameter (SMD) with the increasing electrical load for B100 biodiesel fuel. As seen in Figure 4 and Table 3, the penetration length and size of the Sauter mean diameter (SMD) decrease and the spraying angle increases with increasing fuel injection pressure.

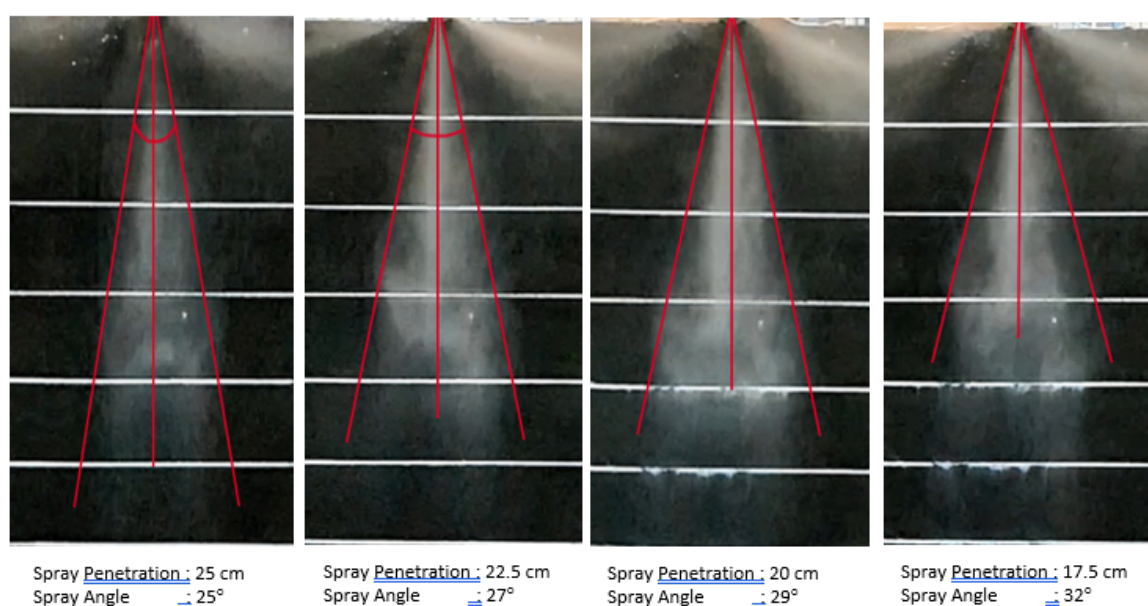


Figure 4. Atomization result of biodiesel fuel; (a) 200 kg/cm<sup>2</sup>; (b) 210 kg/cm<sup>2</sup>; (c) 220 kg/cm<sup>2</sup>; (d) 230 kg/cm<sup>2</sup>

**Table 3.** Sauter Mean Diameter Calculation Results

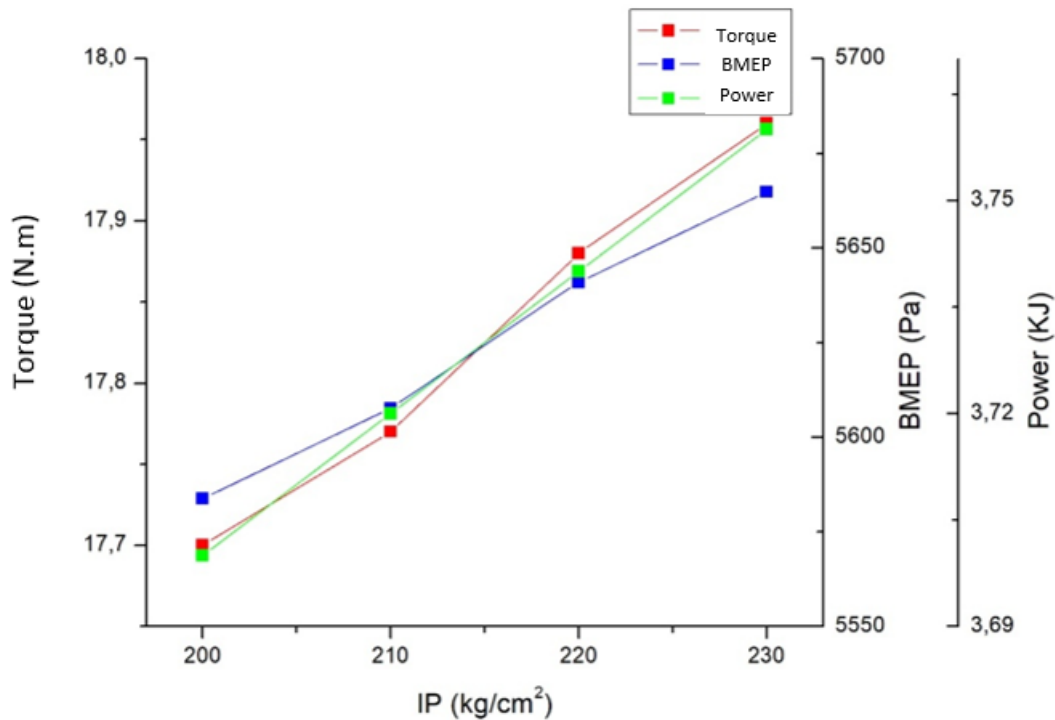
No.	Load	Injection Pressure			
		200 kg/cm <sup>2</sup>	210 kg/cm <sup>2</sup>	220 kg/cm <sup>2</sup>	230 kg/cm <sup>2</sup>
1	1000	0,0135	0,0131	0,0128	0,0123
2	2000	0,0140	0,0134	0,0131	0,0127
3	3000	0,0144	0,0139	0,0134	0,0129
4	4000	0,0148	0,0144	0,0139	0,0134
5	5000	0,0153	0,0149	0,0144	0,0138
6	6000	0,0158	0,0154	0,0149	0,0142
7	7000	0,0163	0,0158	0,0151	0,0146
Mean		0,0149	0,0144	0,01398	0,01346

After testing the fuel spray characteristics with variations in the increase in injection pressure using biodiesel fuel, better atomization results were obtained at an injection pressure of 230 kg/cm<sup>2</sup>. Due to the injection pressure of 230 kg/cm<sup>2</sup>, it produces a spray angle of 32° higher than other pressures which cause the sprayed fuel to spread more in all directions and accelerate the droplets of fuel into smaller granules. The shorter penetration length of 17.5 cm causes smaller flow momentum [1] and the average SMD value is 0.01346 making evaporation increase [6]. Sudarmanta also reported that the increasing pressure of injection tends to increase quality of spray atomization, where it is occurred for all blend fuels. This

result of atomization process tends to decreaseduration of ignition delay, duration of premixed combustion and diffusion combustion and total heat release [7].

### 3.2. Result and Analysis of Performance Test and Exhaust Emission, Biodiesel Fuel with Injection Pressure Variations.

This test was carried out to determine the performance and exhaust emissions with injection pressure variations of 200, 210, 220, 230 kg/cm<sup>2</sup> using B100 biodiesel fuel. The final results of this study are performance and exhaust emissions including brake thermal efficiency, brake specific fuel consumption, air-fuel ratio, and smoke opacity.

**Figure 5.** Power, Torque and BMEP with variation injection pressure at average of loads

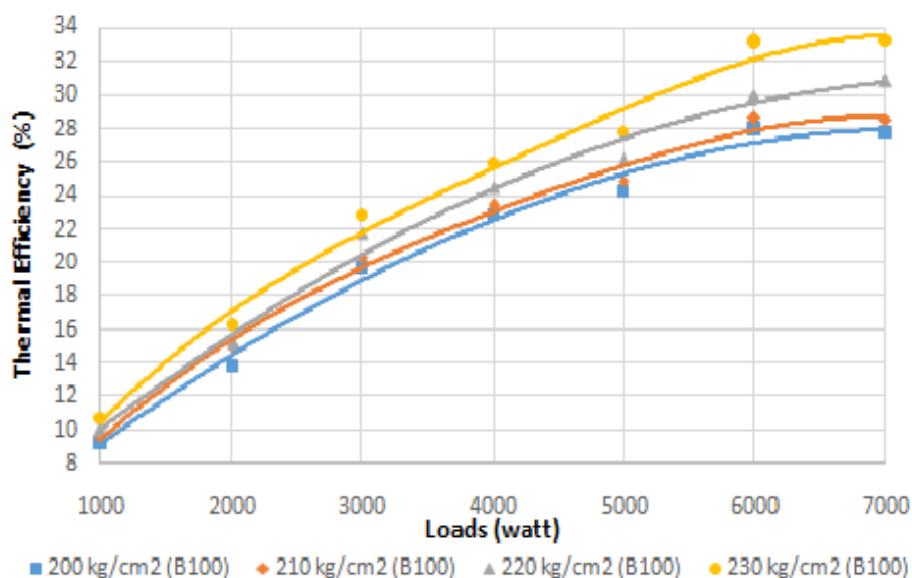


Figure 6. Thermal efficiency on variation of injection pressure versus engine loads

Figure 5 for performance parameters such as power, torque, and BMEP are relatively the same, this is because the load given to the engine rpm are similar. Figure 6 shows a graph of thermal efficiency with the increasing of loads with variations in injection pressure using biodiesel fuel. In Figure 6, it can be seen that the increasing fuel injection pressure results in higher thermal efficiency of 16.77% at a pressure of 230 kg/cm<sup>2</sup> compared to the standard pressure of 200 kg/cm<sup>2</sup>. This is because the power generated by the engine increases with increasing load. Increased injection pressure results in better atomization as produced in testing spray characteristics. This results in more complete combustion. Agarwal et al reported that BTE increases with increasing fuel injection pressure at full load because higher injection pressures make it more effective in improving fuel spray characteristics and the resulting performance is better [8].

Figure 7 shows a graph of brake specific fuel consumption for the increasing of loads with variations in injection pressure using biodiesel fuel. In Figure 7, it can be seen that the increasing fuel injection pressure results in lower brake specific fuel consumption of 14.01% at a pressure of 230 kg/cm<sup>2</sup> compared to the standard pressure of 200 kg/cm<sup>2</sup>. This is because the power produced by the engine increases along with the increasing of the load and also the amount of biodiesel injected into the combustion chamber will also be more. In accordance with the results of the spray characteristics test, fuel atomization is better with increased injection pressure which results in more complete combustion and causes less fuel needed. Channapattana et al reported that BSFC reduces with the increase in IP for all the fuels tested. This is due to better atomization at higher IP which exposes larger surface area of fuel droplet to the high temperature air leading to complete combustion of fuel [9].

Figure 8 shows the air-fuel ratio graph for the addition of loads with variations in fuel injection pressure using biodiesel fuel. In Figure 8, it can be seen that the increased fuel injection pressure produces AFR which is higher by 13.31% at the injection pressure of 230 kg/cm<sup>2</sup> compared to the standard pressure of 200 kg/cm<sup>2</sup>. This is because the use of biodiesel fuels with properties such as higher viscosity, density, and surface tension causes more fuel needed on the engine but produces incomplete combustion. With increasing fuel injection pressure, it produces better fuel atomization according to the more perfect spray characteristics and combustion test results.

Figure 9 shows a graph of Smoke Opacity for the addition of the load obtained from the exhaust gas generated from combustion of fuel and air with variations in fuel injection pressure. In Figure 9, from all variations in injection pressure, it serves to increase with increasing load. This is because the high temperature of the engine temperature increases. With the increasing amount of fuel entering the combustion chamber, the mixture of fuel and fuel becomes rich. Then it can be seen that the increase in fuel injection pressure results in a lower smoke opacity of 46.39% at the fuel injection pressure of 230 kg/cm<sup>2</sup> compared to the standard pressure of 200 kg/cm<sup>2</sup>. This is because of better fuel atomization according to the spray characteristics test results in more complete combustion. Song J.T. This is because biodiesel is free of sulphur and aromatic. Smoke is produced from the dehydrogenation of polycyclic from aromatic processes. In addition, the unsaturated fatty acids in biodiesel also affect the combustion process. Because unsaturated fatty acids have a saturated vapour temperature that is smaller than diesel fuel. So biodiesel is more volatile and combustion can be more perfect [10].

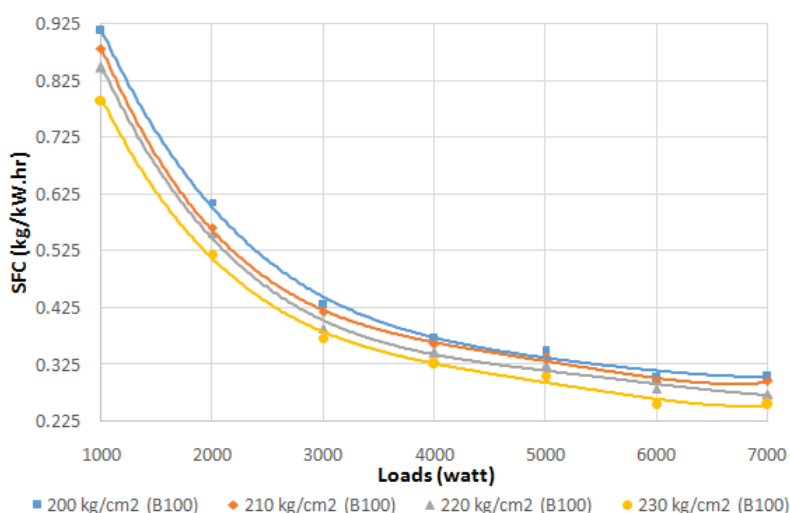


Figure 7. Specific fuel consumption versus engine loadon variation of injection pressure

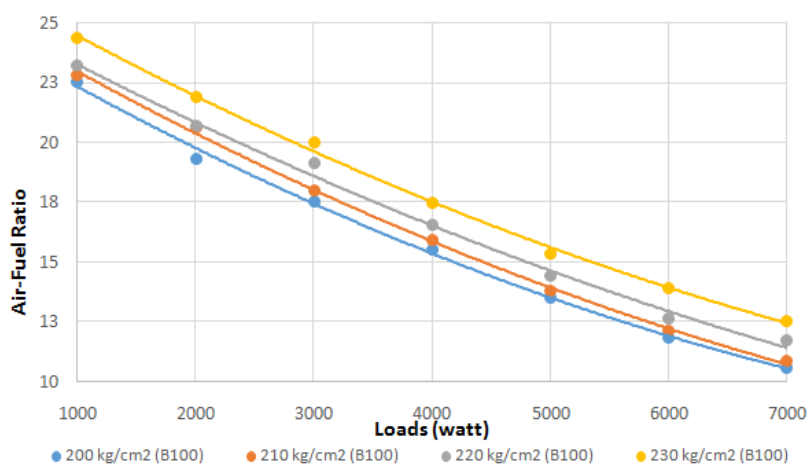


Figure 8. Air-fuel ratio versus engine loadson variations of injection pressure

#### 4. Conclusions

From the experimental study on effect of injection pressure on performance and emission diesengine DI 20 Cusing biodieselfuel, it can be drawn several conclusions.

1. Increased injection pressure results in better spray characteristics which include penetration length, spray angle, and SMD. The length of penetration and SMD decreased by 30%, 9.78% and the spray angle increased by 28% at injection pressure 230 kg/cm<sup>2</sup> compared to the standard injection pressure of 200 kg/cm<sup>2</sup>.
2. Increased injection pressure results in better performance which includes BTE, BSFC, and AFR. BTE and AFR increased by 16.77%, 13.31% and BSFC decreased by 14.01% at injection pressure of 230 kg/cm<sup>2</sup> compared to the standard injection pressure

of 200 kg/cm<sup>2</sup>.

3. Increased injection pressure results in better exhaust emission which include Smoke opacity. Smoke opacity decreased by 46.39% at injection pressure of 230 kg/cm<sup>2</sup> compared to the standard injection pressure of 200 kg/cm<sup>2</sup>.

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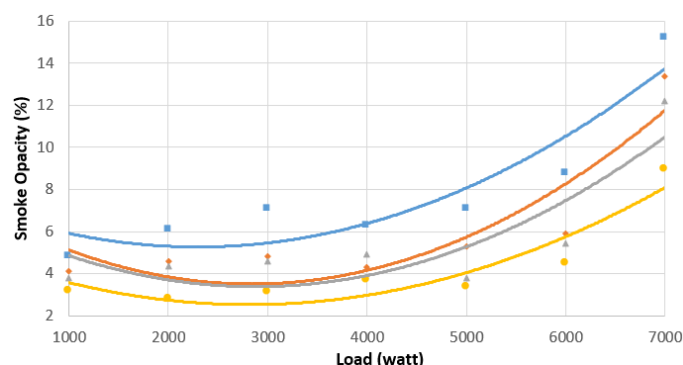


Figure 9. Smoke opacity versus engine loads on variation of injection pressure

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