

# Effect of Mix waste cooking-oil biodiesel on performance and exhaust emissions of a CRDI engine

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**Abstract:** In fast-moving world, energy crisis and waste disposal are increasing day by day. To overcome the energy crisis, it is crucial that we consume less energy. The world contains potential resources to meet the demand of energy apart from electricity, highest demand among all sources. Hence to gear up the use of alternative methods from the wastes into an alternate fuel. The transportation is playing a major role in economic growth and globalization, but cause air pollution in all medium. In regard to crisis, biodiesel production from locally available mix waste cooking oil, which can be an major alternative to production of biodiesel apart from food resources. The aim of this paper is to extract the biodiesel from mix waste cooking oil using conventional methods and study the performance of B20 biodiesel blends with respect to best fuel injection time (IT), Injection opening pressure (IOP) and number opening holes in injector using common rail direct injection engine (CRDI). The experimental studies showed that waste cooking oil methyl ester (WCOME) at 27 deg before top dead centre and IOP 240 bar, B20 blend gives better results and 5 holes 0.3 mm injector nozzle give 31.7% Brake thermal efficiency, 37 HSU smoke, 37 ppm Hydrocarbon, 0.115% carbon monoxide of volume and reduce in 2% of nitrogen dioxide without any modification of engine.

## 1.0 Introduction

India's primary energy consumption is increased by 7.9% in recent year and it is highest growth rate per annum reached from since past 10 years. The emission of carbon is also increased by 7% [1]. However convectional or fossil fuels resources are limited and polluting, therefore, need to use sagacious methods. The alternative methods for non polluting, indigenous and virtually inexhaustible resources is Non convectional resources. India is the fourth largest generator of renewable energy i.e., grew up to 27% from last 11 years [1]. The biofuels as renewable source is more demanding fuel in the society due to climate change and increase energy independence to many nations in the world. Biofuels are envisaged as an effective way of reducing the emissions of the greenhouse gases and an alternate to fossils fuels that are very limited in availability. The developing countries like India, which imports 75% of its crude oil and petroleum products, is highly influencing to global warming and high variation in oil prices in international market[2]. For serenity, it is challenging to generation biofuels for development of nations to solve the problem of global warming and engender new opportunities to remove unemployment and demand of fossil fuels[3]. Biofuels are environment friendly fuels and their utilization in support of fossil fuels would reduce global concerns about containment of carbon emissions. Urbanization and industrialization demands of alternative to fossil fuels, which is leading to deforestation, global warming[4]. Bio fuel will account 4 to 7 % of the total energy consumption in the world by 2030[5][6].



The plant edible and non edible oil fuels having higher ignition delay with less burning rate, hence an alternate fuel is requires injection advance relevant to its delay period. At 2400 rpm engine will show increase in the brake thermal efficiency when rapeseed oil fuel is used in standard injection timing. For the same setup, it shows the reduction in the carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) emission. An experimental result shows longer combustion duration with moderate rate of pressure rise [13]. Delay period will influence the diesel engine in greater extent on both design and performance. Biodiesel with higher cetane number shows the shorter ignition delay compared with diesel. Change in the injection timing and start of combustion lead to advance start of injection. The star to injection plays a key role in affects of combustion characteristics, exhaust gas temperature and exhaust emissions of the engine. The lower compressibility and density of the biodiesel cause the shorter ignition delay (ID) that leads to higher combustion temperature, hence reduction in premixed combustion period due to shorter ID. For used cooking methyl ester (UCME) , ID is lower than the diesel and decrease with the increase in the percentage of blend, because of the oleic and linoleic fatty acid methyl ester will split into smaller compounds in combustion chamber resulting in the higher spray angle and hence lead to earlier ignition. With increase in the load, ID increases, combustion temperature and exhaust gas dilute. [14] For waste palm oil methyl ester and canola oil methyl ester, start of combustion is earlier of 1.2<sup>o</sup> Crank angle and 0.4<sup>o</sup> crank angle respectively as compared with diesel. [15] Biodiesel are having slightly lesser centane number so, it exhibits longer delay periods and reduce burning rate hence resulting combustion delay, higher exhaust and higher lubricate oil temperature. [13]. Ignition timing delay gradually increases with the biodiesel blends. The combustion duration is shorten for all biodiesel blends, results increase in brake thermal efficiency(BTE) for different load condition, which impute to the percentage of oxygen increases in the blends.

For a diesel engine, intensity of atomization in improved by increase with injection system to achieve effective evaporation in short time and good air fuel mixture. The performance and emission are controlled by the atomization and spray process. With low atomization, fuel particle size increase inturn increase the ignition delay and vice versa. By these poor combustion process and emission will increases and durability of engine declines. With the increase in the injection opening pressure, atomization increases following effective combustion enhances inturn emission will reduce. With higher increase of pressure, momentum of small droplets will reduce dispersion of fuel into the air hence combustion efficiency will drop down. Henceforth the diesel engine for good performance, disintegration of fuel into air should br enhance. For B20 Jatropaha biodiesel, engine running with different IOP shows that at 220bar there will be increase in brake thermal efficiency and brake specific consumption by 2.3% and 4.4% and carbonmooxide (CO), unburnt hydrocarbon (UHC) , smoke emission levels were decreased and nitrogen dioxide (NOx) level marginal increased with increase in IOP. [20] For cottonseed oil biodiesel with difference injector opening pressure range from 220 bar to 240 bar with increase in the injector opening shows in improvement of performance in the CI engine. With the same setup, emission levels are lower compared with neat diesel but NOx emission had increased slightly. [21] With increase in the blend percentage, peak pressure will gradually decrease. Comparing with different level of blend, B20 blends will attains lesser combustion pressure with respect to injection pressure and injection timing. [16]

For the biodiesel blend mix, combustion behaviour is controlled by the compression rate of the engine cylinder. [14] In a single cylinder diesel engine test rig at constant speed of 1500 rpm is fuelled with waste cooking oil blends with different blends ratios B10, B20 and B30with respect to different engine loads gives less thermal efficiencies, higher specific fuel consumptions, high exhaust gas temperature , low air fuel ratio, lower carbon monoxide , hydrocarbon emissions but higher in nitrogen dioxide & cabondioxide emissions. Comparing with all the results B20 blends show the better result comparing with neat diesel. [17] Experimental test were conducted on the direct injection diesel engine using different percentage of biodiesel blends with corresponding to 2,4,6,8% by oxygen mass was prepared from waste cooking oil by transesterification process. The results showed with increase in specific fuel comsumptions and decrease in the thermal efficiencies for different load conditions.

Biodiesel having an excellent reputation of very low emission compared to ethanol. Biodiesel is a by-product of biomass, restaurant grease and only fuel extracted from fats in plants and animals[9].Biodiesel produce 93% more energy than any other alternative fuel extracted. Biodiesel or

fatty acid methyl ester (FAME) and long chain of alkyl esters reduces harmful emission by an average of 40 to 50% over a regular diesel [3][7][8][9]. The extraction of biodiesel is having numerous feedstocks include edible oil, non edible oil, Animals fats, municipal waste, and plastic and so on. The best quality of biodiesel is depends on unsaturated and saturated esters present in it. The saturated methyl ester shows higher freezing point and high oxidation stability and in unsaturated has lower freezing point and poor oxidation stability. [19] The most common methods used for producing the biodiesel in transesterification because of its intelligibility.

From the literature review, for the optimisation of combustion characteristics, in turn emissions can be obtained by advancing of injection timing, improved injection opening pressure and modification in injector geometry for edible and non edible oil is essential. Some work as been carried with cooking oil with different blends ratio with neat diesel. The results concluded that B20 ie. 20% biodiesel give better emissions characteristics. The aim of the current study is to collect used mix cooking oils collected from local restaurants, hotels and street side vendors. The waste mix cooking oil methyl ester is extracted and blended with neat diesel in 1:5 ratio and determine the properties as per the ASTM standard. Conducted an experimentation to get optimization result of biodiesel blends for different injection timing, Injector opening pressure and change in injector geometry to improve the BTE and to get low emissions.

## 2. Fuel Used and Experimental Setup

### 2.1 Fuel Used

The selection of feedstock is major factor for extraction of biodiesel production. Biodiesel contain higher unsaturated fatty acids yields the biodiesel has less viscous and have higher cloud point and pour point. [7] Biodiesel extracted from higher unsaturated fatty acids have high oxidation stability. From the local survey, waste cooking oil is mixture all kind of cooking oil and collected nearly 100 lits per week. Biodiesel is produced from cooking oil by using transesterification method. The collected cooking oil is filtered to saperate from the solid materials. Extraction is conducted using a conical flask with the reflux condenser and the thermometer with magnetic stirrer. The cooking oil is pre heated to 65°C and treated with 1% sodium hydroxide (NaOH) by volume. The properties of B20 and B100 blends waste mix cooking oil biodiesel (WMCO) with neat local diesel are determined from SLN test laboratory, Bangalore, INDIA. The properties of fuels are listed in the table 1.

**Table 1: Shows the properties of Biodiesel**

SI No	Parameters	Diesel	B20	B100	ASTM
1	Kinematic viscosity, mm <sup>2</sup> /s	2.5	3.7	2.1	ASTM D445
2	Flash Point, °C	55	73	91	ASTM D93
3	Calorific Value, kcal/kg	10392	10240	9410	ASTM D5865
4	Density, kg/m <sup>3</sup>	830	839	844	ASTM D4052
5	Cetane Number	50	49	52	ASTM D613
6	Pouring Point, °C	-11.4	-22	-5	ASTM D5949
7	Cloud point, °C	-9.3	-7	-1	ASTM D5773
8	Saponification value, mg KOH/g	244.74	176.2	232.4	ASTM D5558

### 2.2 Experimental Procedure:

First step, experimental tests were conducted on compression ignition (CI) engine with constant engine speed of 1500 rpm at different loading conditions. After attaining the stable condition for same condition optimum brake thermal efficiency (BTE) is determined. The specification of the engine test rig is shown in table 2. Second step at 100% and 80% load condition CI engine is runned using diesel, WMCO biodiesel fuels with 3, 4 and 5 holes Injectors. Water is circulated through the engine, engine head for the cooling. The cylinder pressure is recorded using the piezoelectric transducer mounted on the cylinder head. By recording the cylinder pressure and cylinder temperature the heat release rate (HRR) of the fuel is recorded. The ID is calculated between the start of injection

and start of ignition. The exhaust gas constituents are determined during the steady state operation using Hartidge smoke meter and five gas analysers.

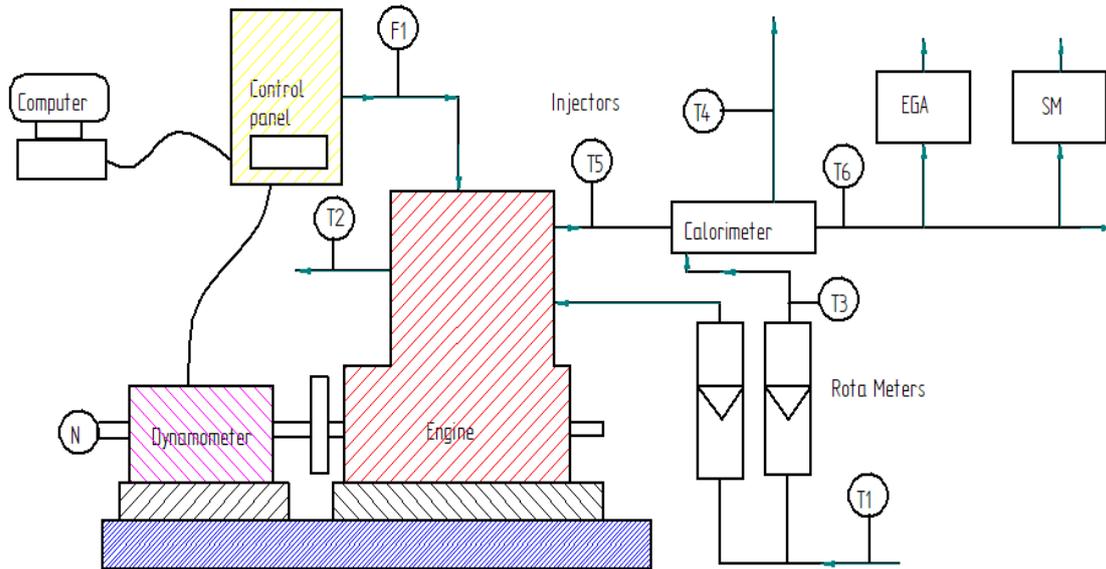


Figure 1: CI engine test rig used for the current experimental study.

T1,T3: intake water temperature, T2: Outlet Engine Jacket water temp, T4: Outer Calorimeter water temperature, T5 Exhaust gas temperature before calorimeter, T6: Exhaust gas temperature after calorimeter, F1: Fuel flow Differential pressure unit, N:rpm encoder, EGA exhaust gas analyser, SM : Smoker meter

Table 2: Specification of engine

Parameters	Specifications
Type	TV1 ( Kirloskar Make )
Software used	Engine soft
Nozzle opening pressure	200 to 225 bar
Governor type	Mechanical centrifugal type
Number of cylinders	Single cylinder
Number of strokes	Four stroke
Fuel	H. S. Diesel
Rated power	5.2 KW ( 7 HP at 1500 RPM )
Cylinder diameter ( Bore )	0.0875 m
Stroke length	0.11m
Compression ratio	17.5 : 1

Table 3: shows the Uncertainty analysis

Measured variable	Accuracy ( ± )
Load, N	0.1
Engine speed, rpm	3
Temperature, °C	1
Fuel Consumption, g	0.08
Measured Variable	<b>Uncertainty ( % )</b>
HC	±3.4
CO	±2.1
NOx	±2.6
Smoke	±1.6
Calculated Parameters	<b>Uncertainty ( % )</b>
BTE, %	±1.1
HRR, J/°CA	±1.2

### 2.3 Uncertainty analysis

Table 3 shows the uncertainty of measurements, give the best estimate of the measurement and consider the results when you add or subtract the measurements for uncertainty. This step of collecting data will give the true value that falls within the range of the measurements obtained during the experiments.

### 3.0 Results and discussion

The results shows the effect of the injection timing (IT) , Injection opening pressure(IOP), Number of Holes in injector on the performance of common rail direction injection (CRDI) diesel engine with the WMCO and Diesel.

#### 3.1 Optimization of IT

The engine at rated speed of 1500 rpm and constant injection opening pressure, the effect of injection timing on brake thermal efficiency at four different injection timing 19<sup>0</sup>, 27<sup>0</sup>, 23<sup>0</sup> and 31<sup>0</sup> BTDC is determined at variable load is shown in the fig 1. The results show the effect of IT on BTE with diesel and B20 WMCO biodiesel. The decrease of BTE is due the lower calorific value compared the diesel and high fuel consumption for the same power. Due to high viscosity of WMCO biodiesel, the mixture of air and fuel is poor. For advanced injection timing, ignition delay period will increase and heat release rate decreases during the pre mixed combustion phase. The highest BTE is recorded at the 27<sup>0</sup> BTDC compared with other ITs values and at 4.16 kW, 27<sup>0</sup> BTDC is showing the best optimum result compared to other combination results

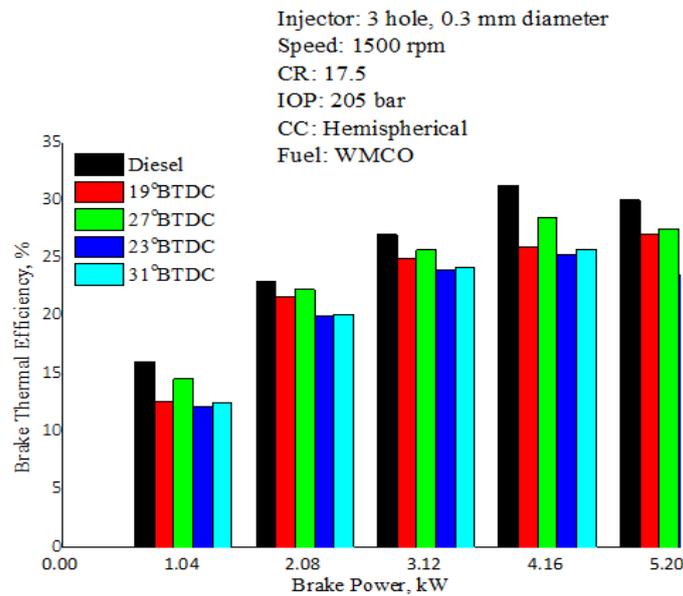


Figure 2: Shows the injection timing v/s Brake thermal Efficiency

#### 3.2 Effect of IT on Emissions

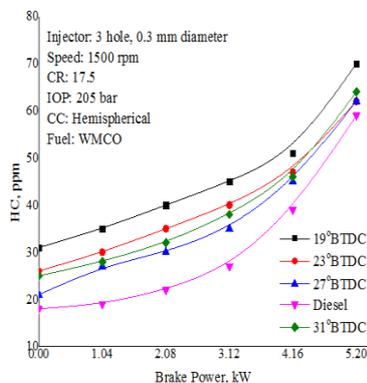


Figure 3: Shows the effect of IT on HC

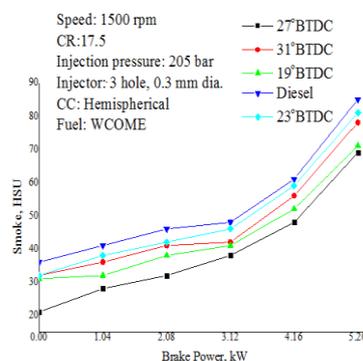


Figure 4 : Shows the effect of IT on Smoke

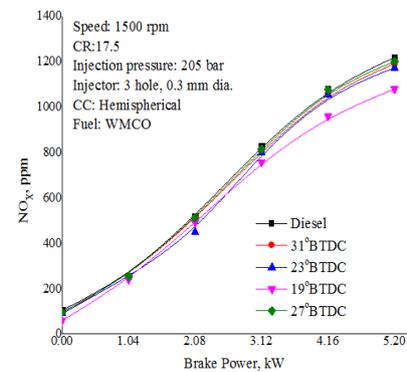
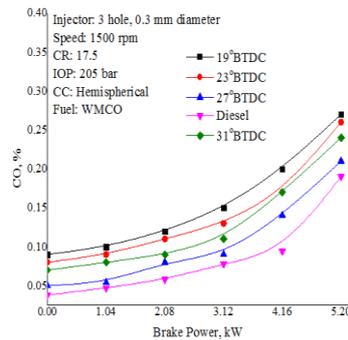


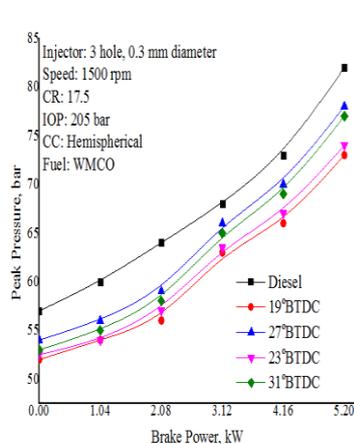
Figure 5 : Shows the effect of IT on Smoke



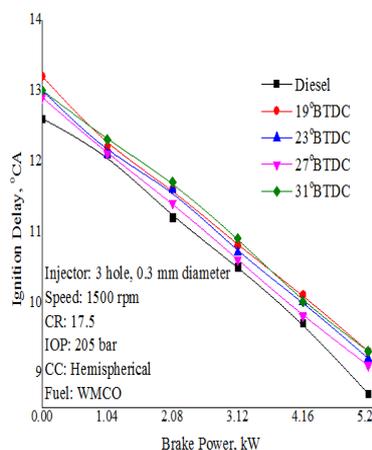
**Figure 6:** Shows the effect of IT on Cox

The performance of single cylinder diesel engine working under a rated speed 1500 rpm, variable load test were conducted for different ITs keeping the injection pressure constant. For each parameter, emission like CO<sub>x</sub>, NO<sub>x</sub>, HC and smoke were recorded. From the results of five reading at each condition, optimum IT is determined. The effect of IT on emissions with diesel and biodiesel is shown in fig 2-6. Due the higher molecules of HC and particulate associate smoke opacity are increases with respect to power output. With higher viscosity and density could also a part for increase in emission. Due to the incomplete combustion, emission of CO, HC also increase with the power is observed. From the obtain the result, at IT 27° BTDC, WMCO B20 biodiesel gives good performance compared to other IT's. Emission like CO, HC, NO<sub>x</sub> and smoke are liberated at the exhaust is less compared with other IT's.

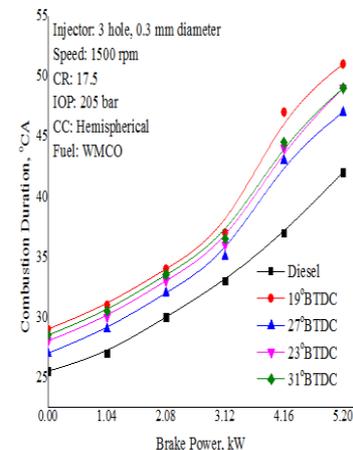
### 3.3 Effect of Injection timing on combustion parameters



**Figure 7:** Shows the Peak pressure



**Figure 8:** Shows the Ignition Delay



**Figure 9:** shows the combustion Duration

The effect of IT on peak pressure (PP), Ignition delay (ID) and combustion duration (CD) with brake power is shown in fig 7-9. It is observed that peak pressure is lower for biodiesel but ID and CD is increases. This is due to lower adiabatic flame temperature, longer ID and higher combustion duration for the WMCO biodiesel. As the IT is advanced the peak pressure gradually increases with power output. From the result it is observed that, at 27° BTDC the biodiesel liberates higher peak pressure, lower the ID and also have lower combustion duration compared to other IT advance.

### 3.4 Effect of Injector opening pressure for the Biodiesel

In the next process of optimization, performance of Biodiesel at 27° BTDC advanced IT is studied for different injection opening pressure (IOP) using CRDI engine. At each trail engine is operated at constant rated speed 1500 rpm, 17.5 compression ratio and 0.3 mm diameter injector

opening. At 27° BTDC, engine is operated at 210bar, 220 bar, 230 bar, 240 bar and 260 bar at different injector opening such as 3, 4 and 5 holes is studied and presented in below graphs.

3.4.1 Effect of injector opening pressure on Brake thermal Efficiency (BTE) for different nozzle geometry

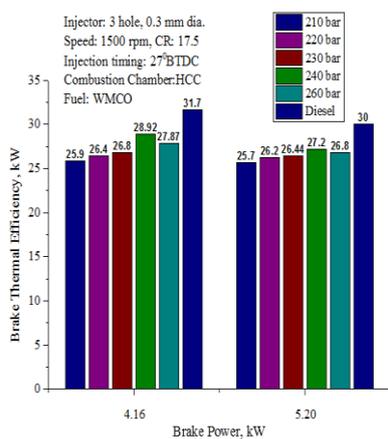


Figure 10: Shows the effect of 3 holes

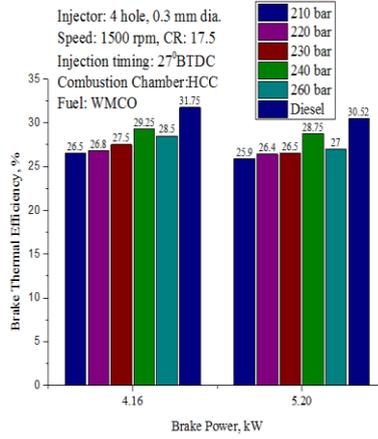


Figure 11: Shows the effect of 4 holes

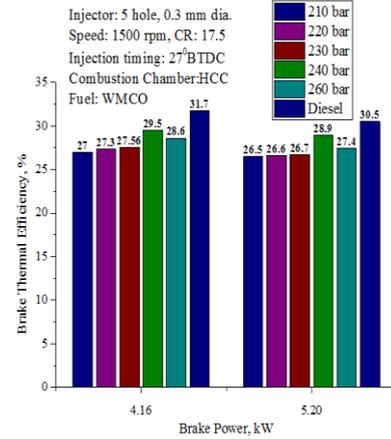


Figure 12: shows the effect of 5 holes

The Fig 10-12, shows the variations of BTE at different IOP and different nozzle geometry. From results it is observed that at 240 bar highest BTE efficiency is obtained compared with other trails. This is because, at 240 bar air fuel mixture, atomization and spray characteristics are better. AS increase in the IOP at 260 bar will leads to delay injection, hence BTE is decreasing. BTE was 29.25 % at 80% load with 4 holes nozzle and at 240 bar pressure. However BTE is 28.92% and 28.1% at 4 & 5 hole injector at 240 bar. Engine operating at 240 bar (24Mpa) with 4 hole nozzle injectors give better BTE compared to 3 & 5 holes nozzle. It is seem as number of holes increases, fuel –air mixing rate also increases.

3.4.2 Effect of Injector opening pressure and Nozzle geometry on Emissions

The fig 13-24, shows the effect of IOP on emission such as Smoke Capacity, CO, NOx and HC at different loads. By the results it is observed that the emission will reduces with the increase in the IOP. Lowest emission is recorded at 4 holes and 5 holes at 240 Bar IOP. Due to better air–fuel mixture in–turn complete combustion at this parameter, emission is reduced at 80% load. At 24MPa , Smoke level

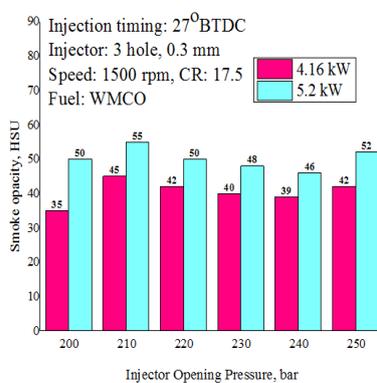


Figure 13: Shows the effect of 3 holes

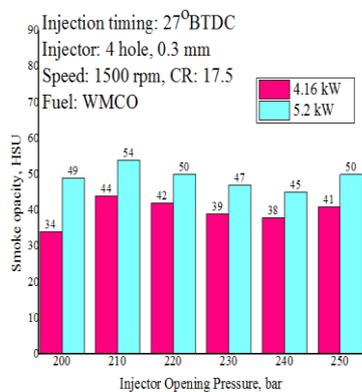


Figure 14: Shows the effect of 4 holes

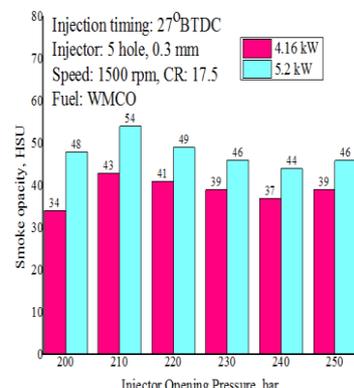


Figure 15: Shows the effect of 5

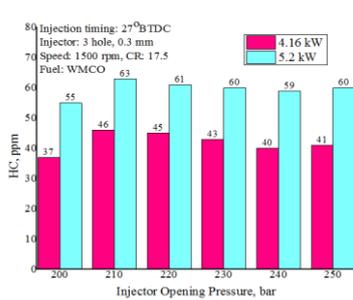


Figure 16: Effect of 3 holes on HC

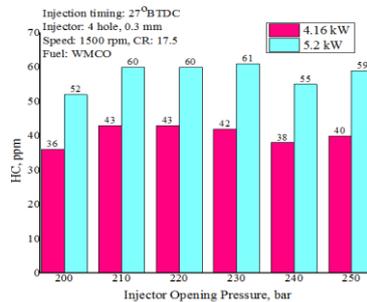


Figure 17: Effect of 4 holes on HC

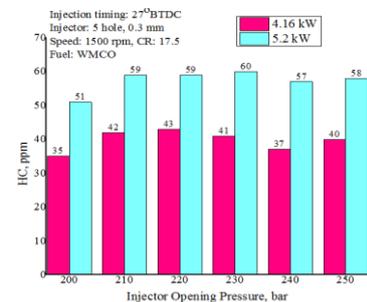


Figure 18: Effect of 5 holes on HC

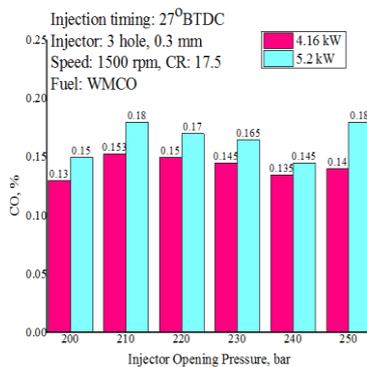


Figure 19: Effect of 3 holes on CO

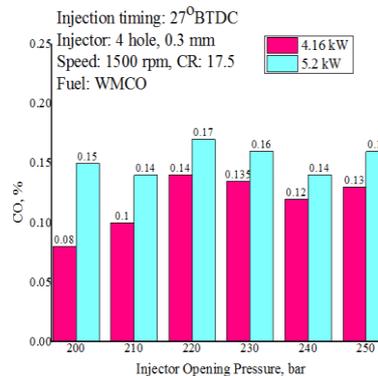


Figure 20: Effect of 4 holes on CO

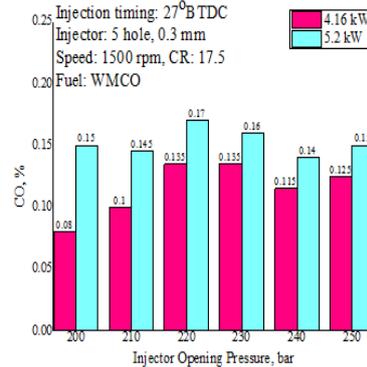


Figure 21: Effect of 5 holes on CO

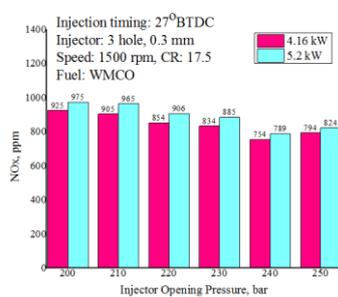


Figure 22: Effect of 3 holes on NOx

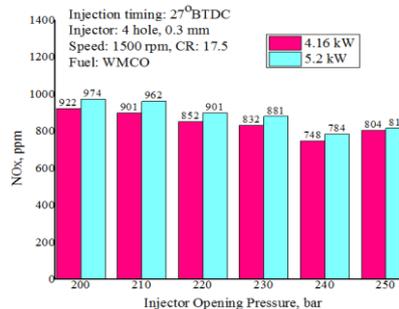


Figure 23: Effect of 4 holes on NOx

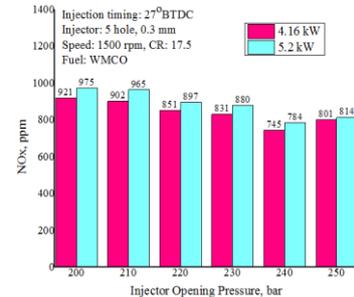


Figure 24: Effect of 5 holes on NOx

Hydrocarbon, CO, & NOx level for 4 & 5 holes are 38 HSU & 37 HSU, 38 ppm & 37 ppm, 0.12 % Volume & 0.125 % of volume and 748 ppm & 745 ppm. Enhancement of atomization in-turn leads to better performance with reduction of ID. It is observed that NOx emission is slightly increasing due to BTE for better air-fuel mixture releases higher pressure and temperature, hence operating temperature increases. As injector opening increases the diffusion of fuel into the charge will increase, hence better optimization is obtained.

### 3.4.3 Effect injector opening on performance characteristics

Fig 25, show the effect of injector opening pressure (IOP) on peak pressure, ignition delay and combustion durations operating with 5 holes injector at 27° BTDC IT. The results show the pressure decrease in WCMO compared with the fossil fuel due to lower energy content. It is observed that the peak pressure increase with load, further increase in the load BTE efficiency decrease Fig 1 due to negation effect. In fig 26 result are calculated based on the static fuel IT. ID reduces with increase in the load. Compared with diesel fuel, WMCO shows reduction in ID because of increase temperature and proper mixing of charge. Henceforth IOP increase with reduction in ID leads to increased BTE operating using WMCO biodiesel. Fig 27, shows the increase in the pressure combustion duration increase due the volatile nature of the biodiesel, density, diffusion of the fuel is reduced.

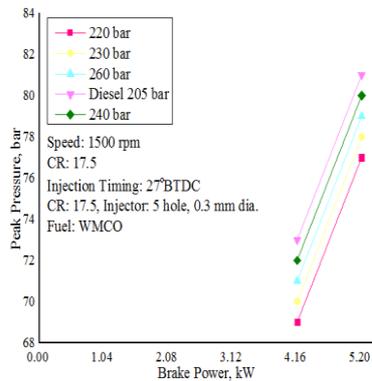


Figure 25: Effect of IOP on peak pressure

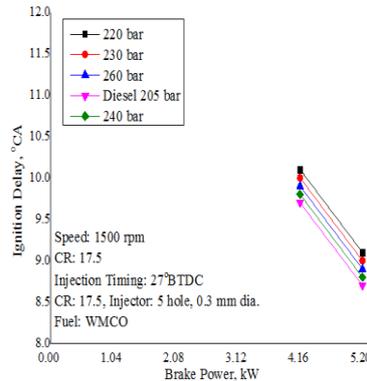


Figure 26: Effect IOP on ID

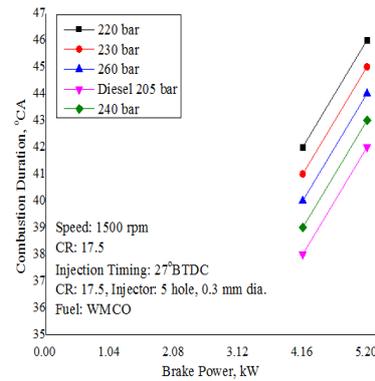


Figure 27 Effect of IOP on CD

#### 4.0 Conclusion

From the characteristic results the following the observations that is concluded when WMCO biodiesel blend with diesel, operated using CRDI engine at constant engine speed 1500 rpm and compression ratio (CR) of 17.5

1. With WMCO biodiesel at B20 blend, BTE yields better results at IT of 27° BTDC, 205 bar.
2. At 27° BTDC, Biodiesel gives maximum BTE of 28.2% as compared with fossil fuel 31.25% with 3 holes injector.
3. BTE for 5 holes injector is found be increased to 31.7 at 24Mpa ,80% load.
4. Smoke, HC and CO for 5 hole at 24MPa, 80% load is 37 HSU, 37 PPM and 0.115 % of volume and it is reduced compared to diesel.
5. NOx is 745 PPM, observed that it is increased by 2% with respective diesel.
6. For 5 holes injector, 24MPa and 80% load, peak pressure is 72 bar, 9.8 °CA ignition delay and 39° CA of combustion duration.

From overall experimental characteristic results, CRDI engine with 5 holes injector of 0.3 mm dia at 240 bar, 27° BTDC and 80% load condition the WMCO biodiesel give optimising results without any modification.

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