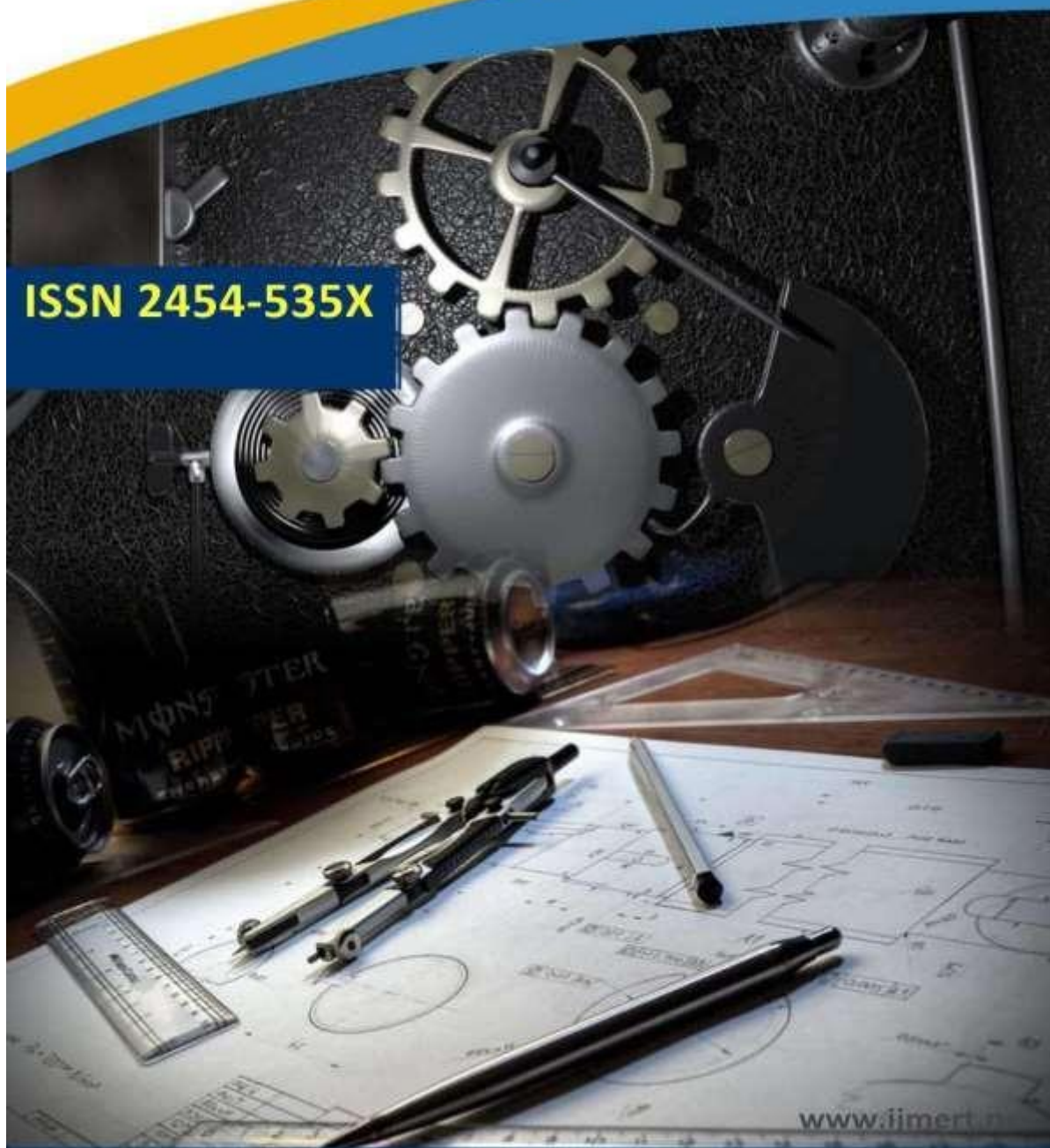




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Attempting to Use 20% Biodiesel in Internal Combustion Engines: An Investigation Using Increased Intake Pressure and Varying Injector Nozzle Setups

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ABSTRACT: The study investigates if increasing the intake pressure and utilizing a different injector nozzle configuration can result in increased efficiency while using 20% biodiesel in internal combustion engines. Under both normal induction and enhanced intake pressure conditions, the performance, combustion, and emission characteristics of a four-stroke compression ignition engine using a blend of pongamia methyl ester and diesel as fuel were investigated. The engine was equipped with three distinct fuel injectors, each with a different number and size of nozzle holes. This work has addressed the performance and combustion factors, including peak cylinder pressure, exhaust gas temperature, air fuel ratio, ignition delay, braking thermal efficiency, and emission parameters, including NO_x and smoke opacity. The data generated indicates an improvement in both performance and smoke emission.

KEYWORDS: Biodiesel; Increase intake pressure; Compression ignition engine; Fuel injector, Injector nozzle hole

INTRODUCTION

Energy security is a major barrier to the survival and growth of modern economies, especially growing nations like India. As per the 2011 Census, 68.84% of Indians live in rural areas and depend on agriculture as their primary source of income. This means that farmers' energy needs, especially for irrigation, must be prioritized in addition to increasingly mechanized cultivation, harvesting, and processing of agricultural goods. Petroleum

diesel is the most commonly utilized fuel in the farm sector and is always in demand. Furthermore, petro diesel is the most sought-after fuel for the transportation sector. India's production of crude oil fell 2.3% in 2016 to 856 thousand barrels per day (tbpd). However, the country uses different feedstock, and most experts have found that lower mixes

EXPERIMENTAL SETUP

The specification of the engine in which the experiments were conducted is given in Table 1. It is TV-1 model engine manufactured by Kirloskar Oil Engine Ltd., India, and is widely used in rural India for agricultural and related applications. The engine is coupled with an eddy current dynamometer (ECD) for loading the engine. The cylinder gas pressure and fuel line pressure are measured using piezo sensors (Make: PCB Piezotronics, Model HSM111A22). The exhaust gas temperature is measured with the help of K-type Chromel-Alumel thermocouple with a range and resolution of 0-1000°C and 0.01°C respectively. The flow rate of air is measured using an orifice meter, connected to water manometer and the fuel flow is measured using a manometer and DP transmitter. A data acquisition system is connected to the engine for recording and processing of experimental data. The data sampling and recording are done using

ICEngineSoft software. For the experiments under supercharged condition, two reciprocating compressors (C1 and C2) are used, specifications of which are shown in Table 2. The output from the two compressors is fed to an air tank of 35 litre capacity, which is equipped with a pressure regulator to control intake pressure. The NO_x emission is measured using a multi gas analyzer of Netel make (Model: NPM-MGA-1)

with a range of 0-5000ppm and resolution of 1ppm. The smoke opacity is measured using smoke meter of light absorption type of Netel make (Model: NPM-SM-111B) with range of 0-100% and resolution of 0.01%. The uncertainty in the measurement of independent variables and calculated parameters are shown in Table 3. The schematic diagram of engine and testing equipments used is shown in Fig.1.

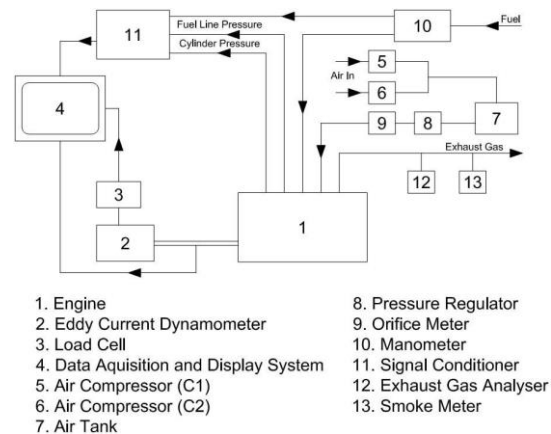


Figure 1. Block diagram of experimental set up, instrumentation and data acquisition system

Table 1. Specifications of the test engine and accessories

Engine	Kirloskar TV1
No of cylinders	1
Rated speed	1500 rpm
Rated power	5.2 kW
Compression ratio	17.5
Cylinder Bore	87.5 mm
Stroke Length	110 mm
Swept volume	661.45 cm ³
Clearance volume	41.09 cm ³
Connecting Rod length	234.00 mm

	Compressor 1 (C1)	Compressor 2 (C2)
Make	ELGI	CEC
Power (HP)	2	3
Displacement Volume (lpm)	249	310
Number of cylinders	1	2
Speed (rpm)	2880	950
Tank Capacity (Litre)	100	200
Max. Working Pressure (kgf/cm ²)	10	12

Normal injection pressur

Table 2. Specifications of the compressors used**Table 3.** Uncertainty of measurements

Parameter	Uncertainty
Speed	± 0.64%

Normal injection timing

23⁰ bTDC

Type of cooling

Water cooled, forced circulation

Combustion chamber type

Hemispherical bowl in piston

Combustion chamber dimension

52 mm diameter (concentric)

Fuel Injection pump

Jerk pump with rack and pinion

Valve timings:

Inlet valve open

10⁰ bTDC

Inlet valve close

39⁰ aBDC

Exhaust valve open

31⁰ bBDC

Exhaust valve close

12⁰ aTDC**Table 2.** Specifications of the compressors used

Specification	Compressor 1 (C1)	Compressor 2 (C2)
Make	ELGI	CEC
Power (HP)	2	3
Displacement Volume (lpm)	249	310
Number of cylinders	1	2
Speed (rpm)	2880	950
Tank Capacity (Litre)	100	200
Max. Working Pressure (kgf/cm ²)	10	12

Table 3. Uncertainty of measurements

Parameter	Uncertainty	Parameter	Uncertainty
Speed	± 0.64%	BTE	± 1.47%
Load	± 0.74%	AFR	± 1.97%
Airflow	± 1.63%	NOx	± 2.64%
Fuel flow	± 1.10%	Smoke	± 2.55%
BP	± 0.98%		

MATERIALS AND METHODS

The biodiesel considered for the experimentation is the derivative of inedible Pongamia oil. The transesterified biodiesel, the Pongamia Methyl Ester (PME) is obtained from the local biodiesel centre. The biodiesel is mixed with diesel in 20:80 proportion by volume and stirred well to obtain the B20 fuel blend. Different properties of the PME and B20 are tested and are listed in Table 4. The density is measured using Hydrometer, kinematic viscosity using viscometer (Cannon-Fenske), calorific value using Bomb calorimeter (Make: Aditya) and flash point using Cleveland open cup tester (Make: Aditya).

Table 4. Characteristics of petrodiesel and tranesterified Pongamia

Item	Petrodiesel	PME (B100)	B20	ASTM D6751 specification for B100
Density in kg/m ³	827	885	839	870 - 890

Kinematic Viscosity@40°C in cst	2.74	5.58	3.31	1.9 - 6.0
Calorific value in kJ/kg	42,000	38,350	41,230	--
Flash point in °C	71	164	90	130 - 170
Oxygen content (%mass)	0	10.8 ^[9]	--	--

Three different fuel injectors of Bosch make with 3, 4 and 5 FINHs of hole sizes 0.25mm, 0.31mm and 0.26 mm respectively have been used for the experiments. The total area of fuel flow or the total injector nozzle orifice area with the 3, 4 and 5 hole fuel injectors are 0.1473 mm², 0.3019 mm² and 0.2655 mm² respectively. The test trials were carried out at 190 bar fuel pressure with the fuel injection timings of 23° CA before Top Dead Centre (bTDC). All these experiments were conducted at the natural aspiration as well as Enhanced intake pressure condition at 20%, 40%, 60%, 80% and full (100%) load on the engine. An air inlet pressure of 100 kPa (gauge pressure) was maintained for intake pressure condition. Fuel consumption, air flow rate and Gas Temperature at the exhaust (EGT), NOx emission and Smoke Opacity (SO) were determined at different load conditions.

RESULTS AND DISCUSSIONS

The paper intends to shed light on the improvement accrued by using enhanced intake pressure and various injection configurations while using tranesterified pongamia and it blends with petrodiesel. The data collected through experimentation have been analysed and discussed in this section.

PERFORMANCE CHARACTERISTICS

Comparison of Brake Thermal Efficiency (BTE)

The variation of BTE at different loads on the engine under different operating conditions is shown in Figure 2-5. Here D and B20 represent diesel and B20 fuel respectively with prefix 3H, 4H and 5H representing the number of nozzle holes in the fuel injector. The suffixes N and S refer to natural aspiration and Enhanced intake pressure respectively. The legend 3HB20N represents 3 hole injector with B20 fuel under natural aspiration. It is observed from Figure 2 that with 3 hole injector the BTE increased with load up to 80% load and slightly decreased at full load for both the fuels. This decrease in BTE is as a result of larger quantity of fuel injected at full load with lesser

Air Fuel Ratio (AFR) resulting in incomplete mixture formation. At full load under natural aspiration, BTE of 26.66% and 28.3% are obtained for B20 and diesel fuels in that order. This difference is due to the dominating effect of higher viscousness and density of biodiesel blend that leads to larger fuel droplets that contribute to reduce the BTE at higher loads, as the combustion at higher loads is dominated by diffusion combustion [9]. Also, higher bulk density of

biodiesel causes more fuel delivered into the injector, thereby resulting in lesser BTE [10]. Figure 3 shows the variation of BTE with load under Enhanced intake pressure at 100kPa gauge pressure, while Figure 4 and 5 compare the variation of BTE at different loads with and without increased intake pressure for 3 hole and 4 hole injectors respectively. It is observed that the best BTE is obtained with 3 hole injector and least BTE is obtained for 4 hole injector for both the fuels at all load conditions, under natural aspiration as well as Increased intake pressure. This least BTE is due to the fact that the total nozzle orifice area of 4 hole injector is more than twice that of 3 hole injector leading to excessive quantity of fuel injection that resulted in low AFR (Table 5) and thus incomplete combustion. A notable experimental observation is that with 4 hole injector under natural aspiration, the engine could not run at full load. This may be due to the excessive quantity of fuel injected at full load, resulting in too rich mixture for effective combustion. However, the engine ran successfully at full load with this injector under supercharged condition. Under natural aspiration, the best BTE of 29.98% was obtained for 3 hole injector at 80%

load for diesel fuel with corresponding AFR of 20.7. But under Increased intake pressure, the best BTE of 34.64% is obtained for 3 hole injector with B20 fuel at full load with corresponding AFR of 22.5, while with 4 hole injector at the same load condition BTE of 16.98% is obtained

has gradually increased with load and best BTE is obtained at full load, compared to the same occurred at 80% load under natural aspiration. This is due to the increased oxygen availability causing better combustion due to increased intake pressure. It can be observed from Table 5 that due to increased intake pressure, for B20 fuel the AFR has increased from 16.1 to 22.5 for 3 hole injector and 11.8 to 18.7 for 5 hole injector respectively, at full load. However for 4 hole injector, the BTE has increased up to 80% load and then decreased at 100% load. This is attributed to the insufficient oxygen availability even under increased intake pressure as AFR is only 11.4 for B20 fuel (Table 5). This indicates the need to further increase the boost pressure for achieving complete combustion. Since the 4 hole and 5 hole injectors supply larger quantity of fuel per cycle due to their higher total orifice area, further increase in boost pressure may result in higher BTE. Also, subjected to mechanical strength considerations the engine can be run at overload conditions yielding higher BTE. In other words, suitably redesigned, downsized engine with larger quantity of fuel injection by means of 4 hole or 5 hole injector with higher boost pressure by means of a

with an AFR of 11.4.

Under Increased intake pressure it is also observed that for 3 hole and 5 hole injectors for both the fuels, the BTE

turbocharger may increase the power density, simultaneously achieving higher BTE. The larger injector hole size may also mitigate the problem of injector coking, which is a common problem when biodiesel is used for extended period of operation in unmodified diesel engines [27, 28].

On Increasing intake pressure significant increase in BTE is observed for both the fuels with all the three fuel injectors used in the study at all loads. As seen in Figure. 4, with 3 hole injector at full load for B20 fuel, BTE has increased from 26.66% to 34.64%, an increase of 30% (relative) due to increased intake pressure. But for diesel at the same load, BTE has increased by 20% (relative) from 28.3% to 34.11s%. With 4 hole injector, as seen in Figure. 5, at 80% load BTE has increased by 93% (relative) from 10.59% to 20.5% for B20 and by 67% (relative) from 11.48% to 19.24% for diesel. Similar trend was observed with 5 hole injector. Thus Increased intake pressure is more effective for biodiesel blend compared to diesel. This may be due to improved mixing and evaporation of biodiesel at higher cylinder pressure and enhanced AFR under Increased intake pressure, further assisted by the fuel bound oxygen [29-32].

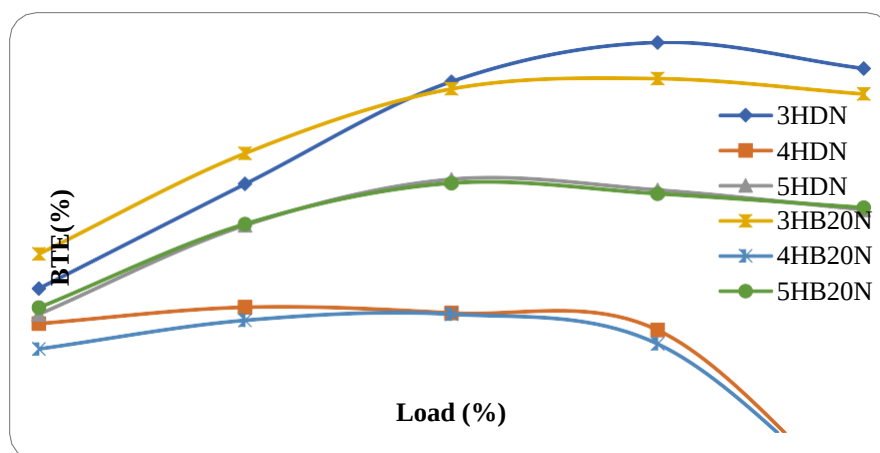


Figure 2. Variation of BTE with load under natural aspiration

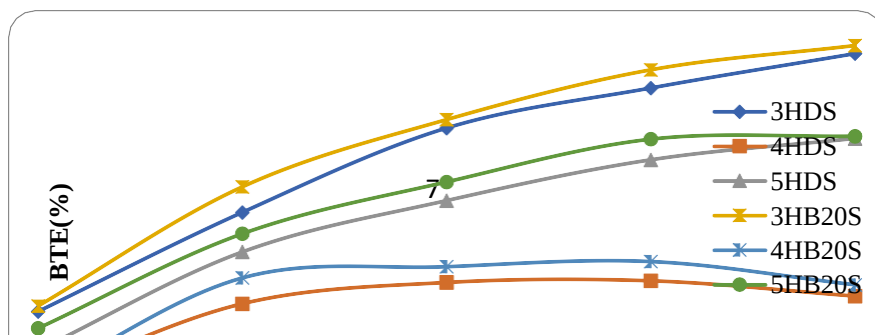
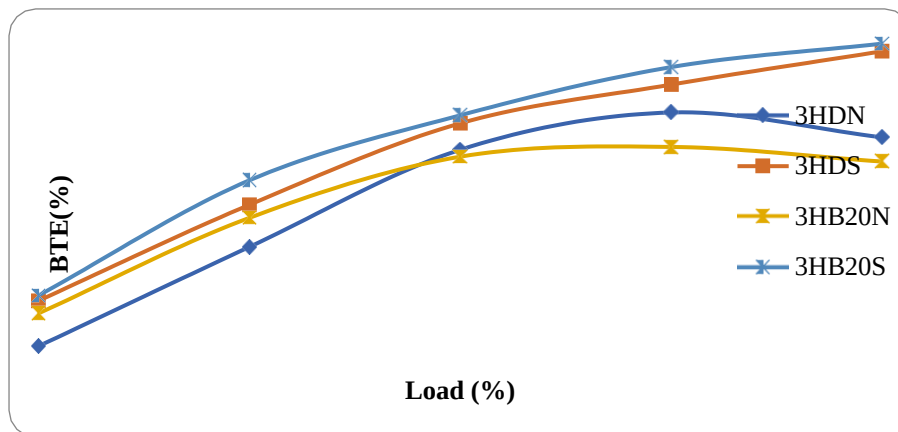
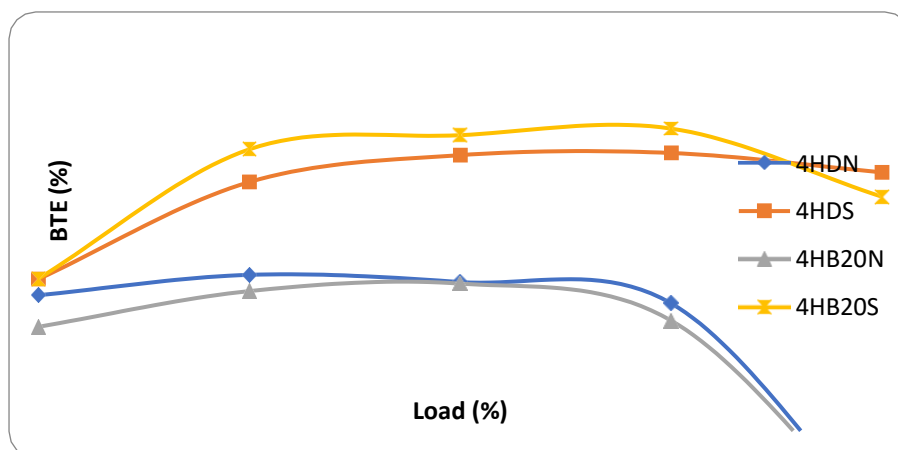


Figure 3. Variation of BTE with load under increased intake pressure**Figure 4.** Variation of BTE with load for 3Hole injector**Figure 5.** Variation of BTE with load for 4Hole injector

Comparison of Exhaust Gas Temperature (EGT)

Figure s. 6-8 depict the variation of EGT with load for diesel and B20 fuels with the different fuel injectors. It is seen from the Figure ures that EGT increases with load for all injectors and both the fuels. The larger quantity of fuel burnt at higher loads is the possible explanation. In Figure s. 6 and 7 it can be seen that both under natural aspiration as well as Increased intake pressure, the EGT is minimum for 3 hole injector and is maximum for 4 hole injector at all loads. This may be due to smaller injector nozzle orifice of 3 hole injector, resulting in smaller fuel droplet size leading to faster evaporation and combustion taking place early. Lesser oxygen availability coupled with larger fuel droplet size tend to delay the combustion with 4 and 5 hole injector leading to higher EGT.

Figure .8 compares the variation of BTE for 3 hole injector at different loads under natural aspiration and increased

intake pressure. It can be seen that EGT has reduced due to increased intake pressure, especially at more than 60% load, for both the fuels. For B20 at full load, EGT reduced on increased intake pressure by nearly 20% from 453°C to 364°C. Better distribution and mixing of fuel with air and faster combustion owing to higher AFR available, which is also reflected in higher BTE and partly due to dilution of combustion products, resulted from increased intake pressure. However, no significant variation in EGT is observed between the two fuels with three hole injector. But with 4 hole injector it is observed in Figure .9 that, for B20 EGT is higher than diesel under natural aspiration and is lesser under Increased intake pressure. The biodiesel is found to have shorter delay period. Shorter delay period for B20 with higher AFR under Increased intake pressure and larger delay period compared to diesel under natural aspiration with very rich mixture (AFR is 8.42 at full load) is the reason for the above observation.

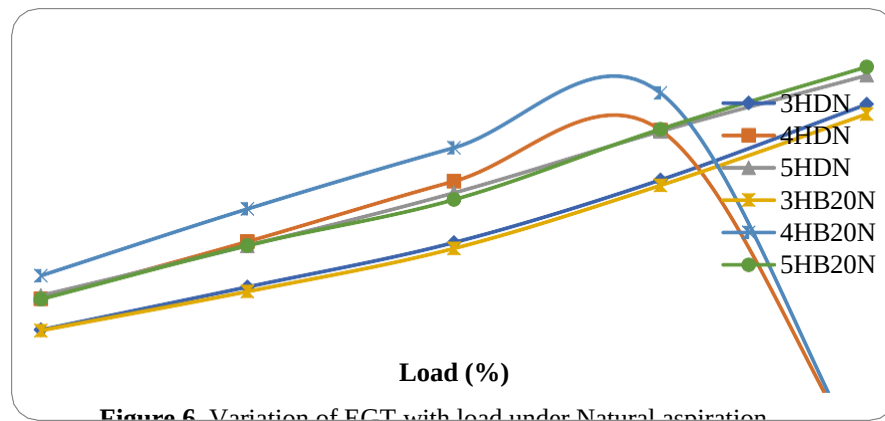


Figure 6. Variation of EGT with load under Natural aspiration

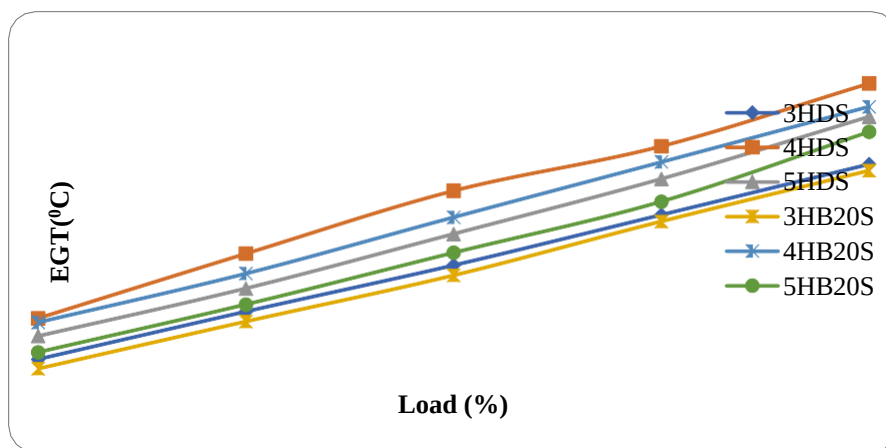
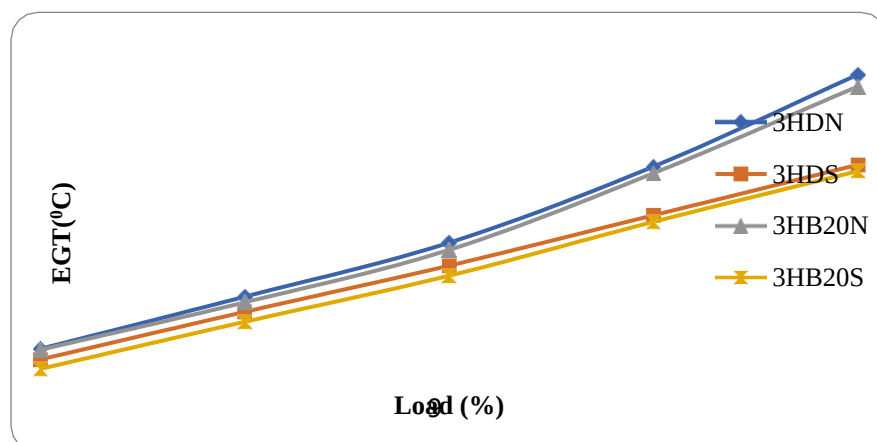
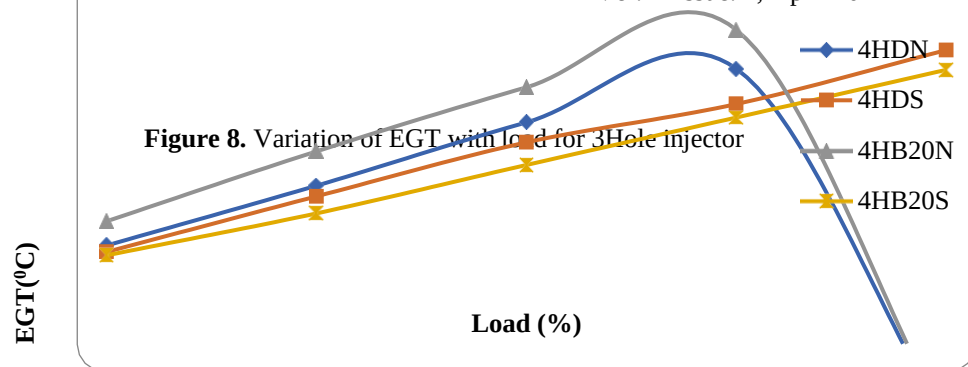


Figure 7. Variation of EGT with load under increased intake pressure



**Figure 9.** Variation of EGT with load for 4Hole injector Comparison of Air Fuel

Ratio (AFR)

AFR is the ratio of mass of air inducted to mass of fuel injected into the combustion chamber. Table 5 shows the values of AFR for the three different fuel injectors at different loads for diesel and B20, under natural aspiration as well as increased intake pressure. The AFR decreases with increase in load for all the cases, as the quantity of fuel injected increases with load. Also AFR increases under increased intake pressure compared to natural aspiration as more air is inducted at higher pressure in the former case. It is seen in Table 5 that the AFR is the maximum with 3 hole injector and the minimum with 4 hole injector at both the natural aspiration and supercharged conditions. This is because, the AFR is inversely proportional to the flow area in the fuel injector nozzle hole or the quantity of fuel injected. Further it is seen that the AFR is lesser for B20 compared to diesel as fuel in all the cases. This is due to the increase in the mass of fuel injected with B20 as fuel, owing to its higher density.

Table 5. AFR at different loads for different fuel injectors

Load (%)	3Hole Injector				4Hole Injector				5Hole Injector			
	DN	DS	B20N	B20S	DN	DS	B20N	B20S	DN	DS	B20N	B20S
20	46.6	60.3	44.5	58.8	37.9	44.0	35.43	43.1	40.3	51.0	39.7	49.9
40	33.5	41.0	32.0	39.4	20.2	31.1	19.44	30.2	28.7	36.8	27.5	34.9
60	27.9	34.2	26.1	32.1	13.2	23.0	12.19	22.7	22.1	28.4	21.7	27.9
80	20.7	28.0	19.5	26.9	9.1	16.9	8.42	17.7	15.9	23.9	15.7	22.9
100	17.4	23.4	16.1	22.5		12.6		11.4	11.9	19.9	11.8	18.7

COMBUSTION CHARACTERISTICS

Ignition delay in degrees of crank angle for the two different fuels with different fuel injectors under natural aspiration as well as increased intake pressure at 80% load is shown in **Figure . 10**. No significant variation is observed in ignition delay with change in injector. However, on increased intake pressure it decreased by one degree crank angle for all injector configurations. This is attributed to the higher charge temperature and pressure that reduced the delay period. Further it is seen that ignition delay has decreased by one degree crank angle for B20 compared to diesel. This may be due to the higher cetane number of the biodiesel compared to diesel. **Figure . 11** shows the variation in peak combustion chamber temperature and pressure respectively at 80% load for different fuel injectors. It is observed that increased intake pressure resulted in about 25% increase in peak combustion chamber temperature for all the three fuel injectors. This may be partly due to the higher pressure of the inducted air and partly due to the better and more complete combustion of the fuel droplets with higher AFR

at the higher ambient pressure. Maximum peak temperature is obtained with three hole injector where combustion is more complete that resulted in highest BTE and minimum peak temperature is obtained with 4 hole injector on account of incomplete combustion due to lack of oxygen, both under natural aspiration as well as Increased intake pressure. Similar trend can be seen regarding peak combustion chamber pressure, which is depicted in **Figure . 12**. No significant variation in peak pressure and peak temperature is observed between diesel and B20 fuels.

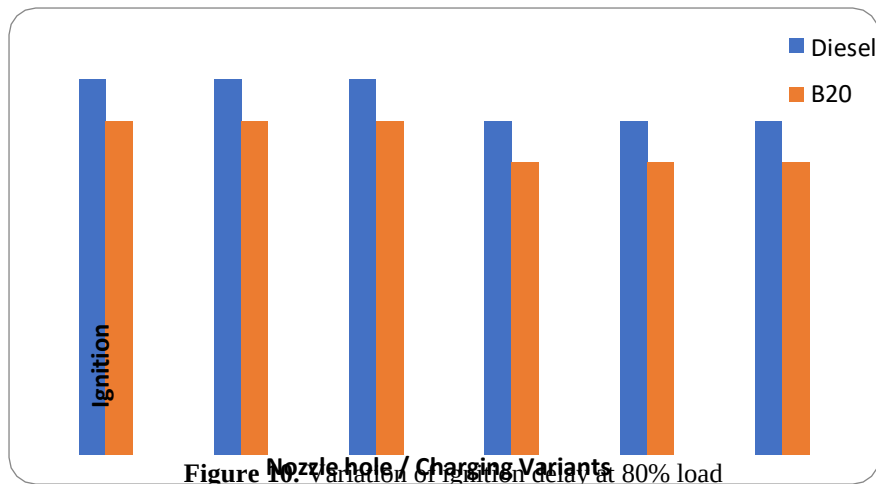


Figure 10. Variation of Ignition delay at 80% load

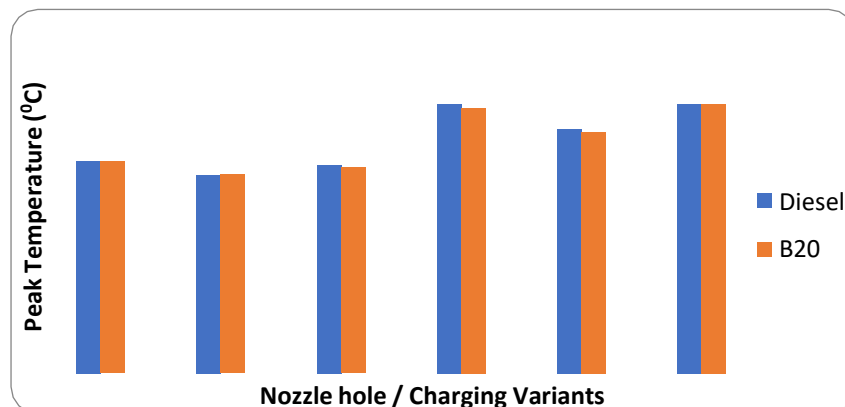


Figure 11. Variation of peak combustion chamber temperature at 80% load

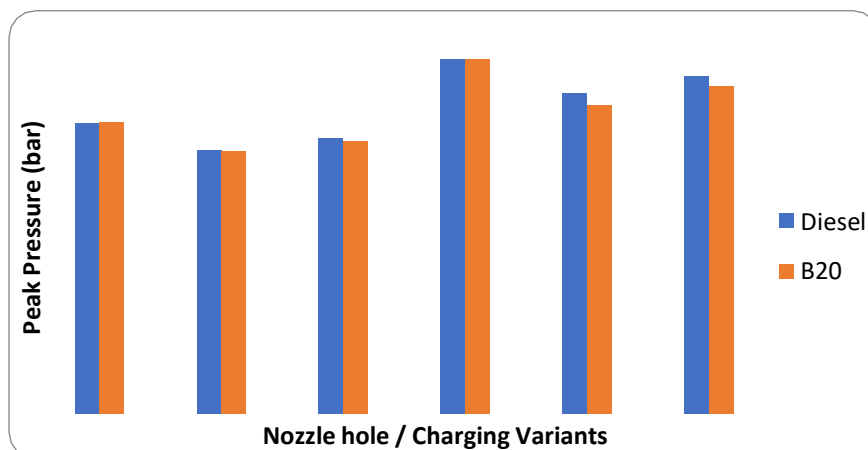


Figure 12. Variation of peak cylinder pressure at 80% load

Comparison of Nitrogen Oxides (NO_x) emissions

The formation of NO_x in engines is governed by the peak combustion temperature and the availability of oxygen. Figure. 13 shows the variation of NO_x emission for diesel and B20 fuels with different injectors under natural aspiration and increased intake pressure at 80% load. NO_x emission has increased on increasing intake pressure for both diesel and B20 with all the three injector nozzles. This may be due to multiple reasons including the higher oxygen availability due to increased intake pressure, increased combustion chamber temperature due to higher charge temperature and pressure and better combustion of the fuel that also resulted in higher BTE. Higher NO_x emission is observed for B20 fuel compared to diesel for all the injector nozzles, which may be due to the presence of fuel bound oxygen in B20. With 4 hole and 5 hole injectors NO_x emission is found to be lesser compared to 3 hole injector. This may be due to the increased quantity of fuel injected that resulted in lower AFR, incomplete combustion and lesser peak temperature.

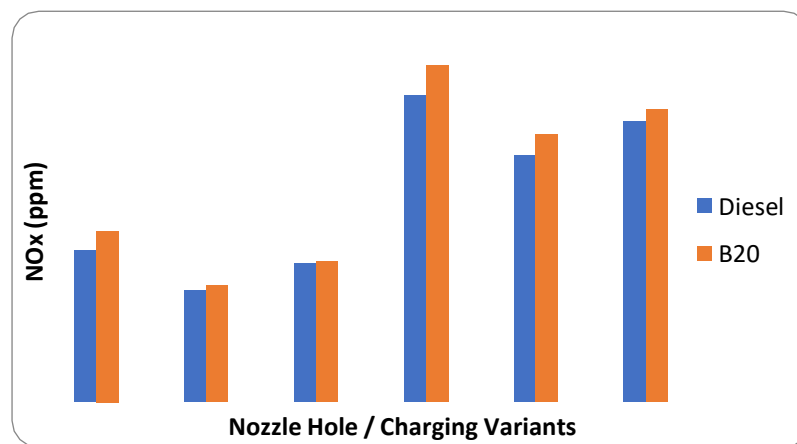


Figure 13. Variation of NO_x emission at 80% load

Comparison of Smoke Opacity (SO)

Figure 14 shows the smoke opacity (in %) observed with different fuel injectors, for two fuel variants at 80% load, under natural aspiration as well as Increased intake pressure conditions. It is seen that SO has slightly decreased on increased intake pressure compared to natural aspiration for all the injectors, for both the fuels. This is due to the higher AFR on Increased intake pressure resulting in better mixture formation and thus better combustion. Also, SO is the minimum with 3 hole injector and maximum with 4 hole injector for all the fuel variants, the 5 hole injector exhibiting intermediate values of smoke opacity. This is attributed to the better combustion of fuels with 3 hole injector with higher AFR as well as smaller fuel droplet size due to smaller injector orifice diameter resulting in better mixture formation compared to 4 hole and 5 hole injectors. Among the two different fuels used, B20 has given slightly lesser SO compared to diesel. This may be due to the fuel bound oxygen present in B20.

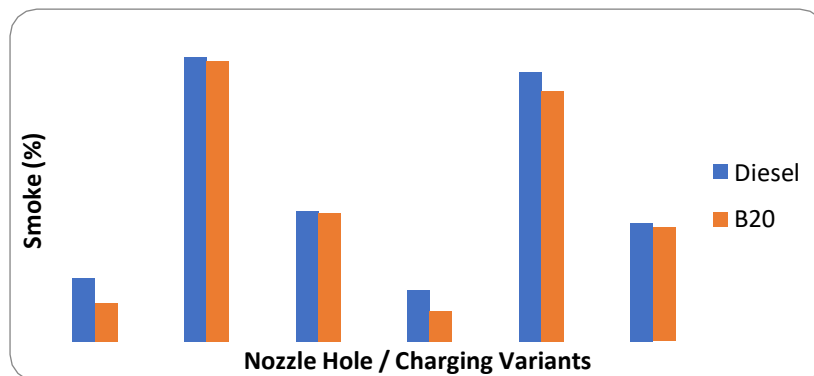


Figure 14. Variation of Smoke Opacity at 80% load

CONCLUSIONS

The objective of the this work was to analyse the effect of use of fuel injectors having increased number of nozzle holes with different nozzle orifice diameters, along with inducting air at higher pressure. The based on the analysis carried out following conclusions are drawn:

- Increasing the number of fuel injector nozzle holes and increasing the nozzle hole diameter under natural aspiration condition reduces BTE, NO_x emission, increases EGT and smoke opacity due to low air fuel ratio.
- Increased intake pressure increases BTE, NO_x emission, but decreases smoke opacity for both diesel and biodiesel

blend.

- 3 hole fuel injector gives best BTE and smoke opacity under natural aspiration and increased intake pressure at 100kPa gauge pressure.
- Due to Increased intake pressure the occurrence of best BTE got shifted from 80% load to 100% load for 3 hole and 5 hole injectors with both diesel as well as biodiesel blend.
- Increase in BTE due to increased intake pressure is larger for biodiesel blend compared to diesel for all fuel injector variants used.

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