

Experimenting the various behavior of pumpkin seed oil methyl ester with varied injection pressure

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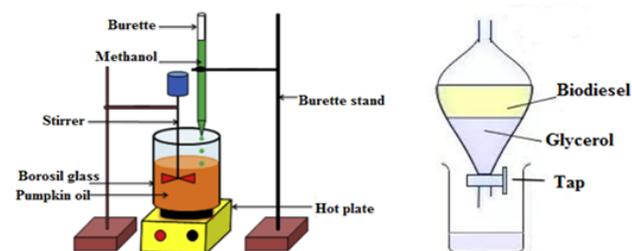
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Graphical abstract



Abstract

Biofuel is a viable substitute source of energy for diesel vehicles due to its greater physio-chemical properties. The biofuels used in this study is synthesized from pumpkin seed oil using the esterification reaction technique. The biodiesel was synthesized under ideal conditions and was employed to evaluate the impact of injection pressure varying from 200 to 275 bar in 25 bar increments and was tested for its effectiveness, combustions and the emission performance of 1 cylinder, 4 stroke DI diesel engine at a regular momentum of 1500 rpm using 25% Pumpkin seed biodiesel (PSBD25). The outcomes demonstrated that the BTE of PSBD25 be raised by 1.68 %, with decrease by 6.5% BSFC, the release of CO, HC, and smoke were diminished by 57%, 33% and 36% respectively, but NO emissions were boosted at higher IP of 250 bar by 18.5% compared to the standard IP of 200bar. Pressure in the cylinder and heat release rate for PSBD25 were increased, but ignition

delay was shortened when compared to PSBD25 at standard IP of 200 bar. It is concluded that, there is a greater progress in performance and ignition features, as well as a reduction in exhaust gas release for PSBD25 with the exception of NO emissions at 250 bar IP at maximum load conditions.

Keywords: Pumpkin seed biodiesel, performance, heat release rate, ignition delay, diesel engine, injection pressure, emission

Abbreviations

CI Engine	Compression Ignition Engine	DI	Direct Injection
PSBD	Pumpkin Seed Biodiesel	NOx	Oxides of Nitrogen
PSBD 25	25% Pumpkin Seed Biodiesel +75% Diesel	HC	Unburned Hydrocarbon
NO	Nitrogen Oxide	BP	Brake power
BSFC	Brake specific fuel consumption	HRR	Heat release rate
BTE	Brake thermal efficiency	ID	Ignition delay
CO	Carbon monoxide	IP	Injection pressure
ppm	Parts per million	NOP	Nozzle opening pressure
CO ₂	Carbon dioxide	IT	Injection timing

IP	Injection pressure	kWh	kilo Watt hour
BTDC	Before Top Dead Center	EGR	Exhaust gas recirculation
MROPR	Maximum rate of pressure rise	CA	Crank angle
EGT	Exhaust gas temperature	PM	Particulate matter

1. Introduction

Petroleum is a chief resource of fuel for automotive vehicles. Toxic gases are released into the atmosphere during the burning of fossil fuels. As a result of growing environmental deterioration and decrease of fossil fuels reserves, researchers are working on substitute energy sources such as biomass and biofuels (Aydın and İlkılıç, 2017; Samuel *et al.*, 2020). Vegetable oils and their methyl esters are currently increasing in popularity as sustainable energy sources (Soudagar *et al.*, 2020; Samuela *et al.*, 2020). However, vegetable oils are a feasible replacement for diesel and have poor combustion characteristics due to its reduced flowability and volatility. The main drawbacks of vegetable oils utilized in diesel engines are carbon buildup, injector fouling, piston ring stickiness, fuel line obstruction, poor fuel atomization, and lubricating oil condensation. As a result, it is now important to restore the physio-chemical properties of vegetable oils (Anbarasu and Karthikeyan, 2015). Biodiesel was regarded as the most potential replacement to diesel since it is renewable, had lower carbon content, and produces less emissions. Vegetable oil, waste cooking oil and animal fat are some of the oils used for the manufacture of biodiesel. The benefits of the biodiesel is reduction in CO, HC and smoke emission due to the excess oxygen in the molecular structure of the biodiesel which promotes oxidation of the fuels leads to better combustion compared to diesel.

Recent novel biodiesels were derived from non-edible oils (Rajan *et al.*, 2022), Yellow oleander biodiesel (Rajan *et al.*, 2021), rubber seed oil biodiesel (Gimbun *et al.*, 2013), Orange biodiesel (Karthikeyan *et al.*, 2019), Rapeseed biodiesel (Labecki *et al.*, 2014), Chicha oil biodiesel (Tamilselvan *et al.*, 2017), Lemon peel biodiesel (Ashok *et al.*, 2017), Lemongrass biodiesel (Sathiyamoorthi and Sankaranarayanan, 2016), Moringa *olifera* oil biodiesel (Pradeepraj and Rajan, 2019) and so on. These biodiesels were manufactured using transesterification technique, and their performance and emissions in diesel engines were studied. These oils were blended with diesel on volume basis. Neem oil and pumpkin biodiesels were included among the viable biodiesel alternatives. Many studies have explored the engine behaviours of various biodiesels and their blends, reporting reductions in all effluents excluding NO_x similar to diesel (Maheshwari *et al.*, 2022; Rajan and Kumar, 2009). Some investigators found that cleaner combustion using biodiesel and its blends is possible, resulting in fewer emissions when oxygenate chemicals are employed (Mathew *et al.*, 2021; Ali *et al.*, 2020; Fattah *et al.*, 2014; Shehata *et al.*, 2015; Fattah *et al.*, 2021).

Since biodiesel has different physical properties than mineral diesel, engine combustion characteristics such as delay period, amount of fuel mass burned, and so on might change. As a result, several researchers tried very hard to examine the impacts of modifying key features such as injection pressure (IP) and timing (IT). Some research investigations have been conducted in order to maximize the IT and the IP while utilizing biodiesel and its different mixtures with diesel, either separately or in combination. With technological improvements, combustion is predicted to occur sooner, resulting in additional fuel being blistered before TDC and peak pressure occurring closer to TDC (Saravanan *et al.*, 2014; Ganapathy *et al.*, 2011). Retarding the IT within certain limits can reduce NO_x emissions without having a major impact on engine efficiency (Agarwal *et al.*, 2015; Sayin C and Gumus, 2011; Vinayagam *et al.*, 2021). Increase in injection pressure may boost biodiesel atomization however NO_x may rise as a result of improved combustion (Ergenc *et al.*, 2012).

This investigation (Kannan *et al.*, 2012) examined the effect of IP and IT and observed that 280 bar IP with IT of 25.5° BTDC were appropriate for biodiesel operation, leading in increased BTE and decreased NO_x and smoke. They (Deep *et al.*, 2017) studied the implications of different Injection Pressure Time operating with castor biodiesel mixture (B20). It is evident that delaying the IT diminishes the pressure of the cylinder and BTE. But the emissions of CO and HC were decreased when the IP augmented to 300 bar, while NO_x release seems to be favorable at 21 BTDC injection timing at the expense of considerable drop in BTE and smoke opacity at 25° BTDC. Arunprasad and Balusamy (Arunprasad and Balusamy, 2018) investigated the effect of IP and IT features operating on biodiesel mixes. At maximum load, the BTE improved by 2.4 % with an increment in IP and 1.5 % with a rise in IT, and it was less significant than diesel. At 230 bar IP and 27° BTDC IT all the releases were diminished except NO_x and CO₂ were improved substantially as IP and IT increases.

Most of the researchers reported that CO, HC and smoke be diminished with rise in NO_x release (Jindal *et al.*, 2010; Abed *et al.*, 2019; Harish *et al.*, 2020). This research (Donepudi, 2017) findings revealed that as IPs raised, BTE also raised, but BSFC was dropped, and NO_x was enhanced as IPs continued to increase. They (Jiaqiang *et al.*, 2018) utilised fish oil to study the influence of FIP. They determined that increasing the proportion of biodiesel in diesel declines thermal effectiveness whilst also increasing HC, NO_x, and CO release.

They (Banapurmath *et al.*, 2009) disclosed the effect of IP variation on a C.I engine through Honge oil methyl ester. The raise in BTE at elevated IP of 260 bar was owing to enhanced air assimilation rate and fuel evaporation. This work (Agarwal *et al.*, 2014) explored the impact of various IP (500 and 1000 bar) experimentally. The results showed that with lower IP, the heat release rate (HRR) and cylinder pressure are increased. The researchers (Rajan *et al.*, 2021) reviewed the performance of diesel engine via

yellow oleander biodiesel at different FIPs and disclosed inferior levels of emissions excluding NO_x emissions at higher FIPs. Pankaj Shrivastava and Tikendra Nath Verma (Shrivastava and Verma, 2020) studied the upshot of various IP with varied blends of Roselle biodiesel on CI engine and it is clear that at 220 bar IP Co₂ release is augmented by 1.6%, while No_x and smoke release diminished by 3.18 and 2.20 percentage for RB20 blend than that of unblended. Consequence of IP with waste cooking oil (5-30%) blends under six dissimilar IP ranging from 170 to 220 bar (Yesilyurt *et al.*, 2019). The results showed that biodiesel fuels established enhanced IP resulted in increased rotational torque, BP and BTE up to 210 bar Furthermore, higher IP decreased smoke opacity despite boosting NO_x and Pollutant emissions.

Thiruvenkatachari *et al.* (2022) studied the CRDI engine using 20% Azolla biodiesel mix with different fuel injection pressure of 300 bar and 900 bar. The results revealed that, as the injection pressure increases, BTE for B20 at 900 bar injection pressure is 3% higher than the diesel fuel at 300 bar injection pressure under full load conditions. The HC, CO, and smoke emission for B20 at 900 bar injection pressure were diminished by 13.3%, 28.5%, and 12.3%, respectively, in contrast to diesel. Mukund Kumar *et al.* (2022) examined the influence of FIPs and FITs of Jatropha biodiesel with hydrogen as dual fuel with different flow rates of hydrogen with three different fuel injection pressures. Results revealed that the UHC and soot emissions were found to be diminished and for hydrogen dual fuel operation with 9 lit/min flow rate at a FIP of 1500, bar and a FIT of 11°bTDC. However, it is also observed that the NO_x emissions were increased with 9lit/min hydrogen flow rate at a FIP of 1500, bar and a FIT of 17°bTDC. Yogesh *et al* (2022) examined the effects of varying injection pressures (200 & 300 bar) in a CI engine with mango seed biodiesel mixtures. Results showed that BSFC was found to be greater for the blends, while CO, smoke, and HC were diminished but the NO_x emissions were greater for the blends.

From this extensive literature review, it is demonstrated that the use of a higher IP is beneficial, in particular to bio fueled engines. There is several notable work has been done on different biodiesel with varying injection pressures. Only a very basic research is available with the exploit of pumpkin seed oil blended biodiesel in a diesel engines as it is a noval biodiesel. However, the study of diesel engine using noval Pumpkin seed oil biodiesel with high injection pressure (IPs) is not investigated and not published so far. By keeping this in mind, the author aims to study the influence of elevated IPs like 200, 225, 250

Table 1. Physicochemical charactersitics extracted fuels following ASTM D6751

Properties	Diesel	Pumpkin seed oil	Pumpkin seed biodiesel	PSBD25
Density (kg/m ³)	830	921	883	843
Kinematic Viscosity @ 40oC (cSt)	3.2	35.6	4.41	3.5
Calorific value (MJ/kg)	43	35.1	36.5	39.0
Flash point (oC)	48	230	120	112
Fire point (oC)	60	240	130	118
Cetane Number	48	42	56	52
Oxygen content (%) by weight	-	10.4	10-12	10-12

and 275 bar, utilizing biodiesel in a CI engine. Thus our goal is to study the impact of different IPs on performance and emissions and combustion behaviors of 1 Cylinder, 4 Stroke Kirloskar diesel engine using a 25% concentration of biodiesel (PSBD25) made from pumpkin seed biodiesel and diesel and the values are assessed and matched to the standard operating conditions using diesel and biodiesel blend.

2. Experimentation

2.1. Oil Extraction and biofuel production

Seed oil is made by crushing pumpkin seeds at a low temperature, and the oil yield ranges around 40 to 60%. The transesterification technique is used to create biofuels. To prepare a sodium methoxide mix, 1 litre of pure pumpkin oil in a round bottom conical flask is taken and dissolve 10g of sodium Hydroxide catalyst (which speed up the reaction) in a glassware using 200ml of methanol. The mixture is then poured with pure seed oil in a three-necked flask, and warmed to 65 degree celcius, and swirled constantly at 500rpm for one hour. The mixture is then shifted to a separating flask and let to rest 8 hours for settling (Samuel *et al.*, 2020; Mujtab *et al.*, 2021). Figure 1 depicts the biodiesel manufacturing process. Figure 2 represents the schematic view of preparation of biodiesel process (Kumar *et al.*, 2009). To eradicate and refine contaminants from biofuels, a distilled water processing technique was used by mixing and shaking with 1/3 of its quantity of warm distilled water with biodiesel for around 3 times. The processed biofuel was entirely free of residual water and methanol after drying. In the filtering procedure, filter paper was employed for obtaining pure biodiesel. Additionally, Pumpkin Seed BioDiesel (PSBD) fuel PSBD25 fuel was created by mixing with 25% diesel volume ratio. Table 1 lists out the properties of extracted fuel.

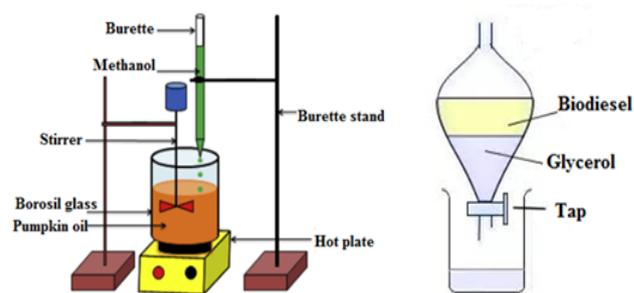


Figure 1. Biodiesel preparation set up

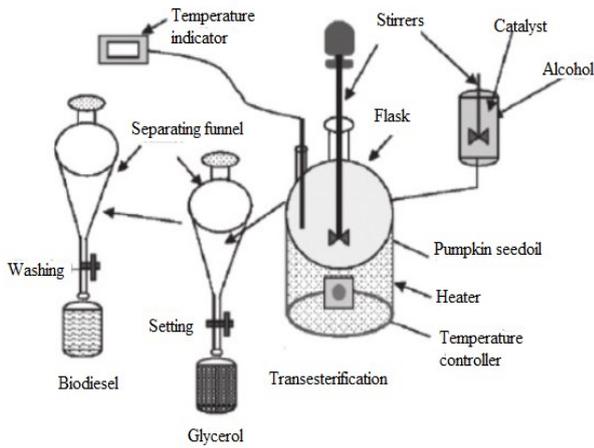


Figure 2. Schematic view of preparation of biodiesel process

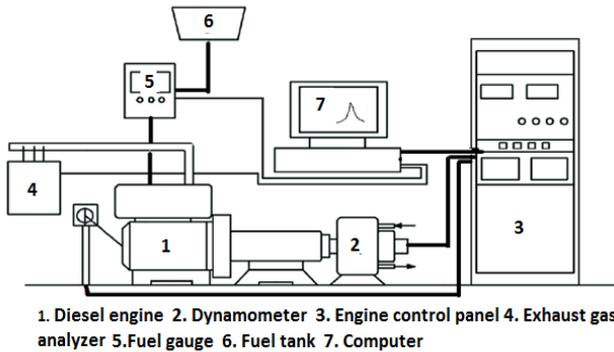


Figure 3. Test engine setup

2.2. Test engine and procedure

A mono-cylinder Diesel Kirloskar engine coupled with dynamometer (swinging field electrical, 5 KVA AC, 220Volt, 1500rpm) is taken for experimentation. Figure 3 shows the diagrammatic illustration of test engine setup. Two distinct tanks are utilised.. The volumetric fuel flow air flow rate was deliberated using burette and U-tube manometer. The manufacturers recommendation of IP is around 200 bar and engine speed is restricted by centrifugal governor. Figure 4 depicts flow diagram of the test engine specifications. An AVL-444 gas analyzer is used to evaluate various emission concentrations and AVL-437 smoke meter is indulged to quantify smoke opacity through the use of probe at the tail side.

The characteristics of combustion were examined through sensor, encoders and data acquisition system. Cylinder

Table 2. Instruments range, accuracy and uncertainties (Kumar *et al.*, 2017)

Instrument	Measurement	Range	Accuracy	Uncertainty
AVL DI Gas 444 Five gas analyzer	CO	0-10%Vol	±0.03%	±0.2%
	CO ₂	0-10%Vol	±0.1%	±0.15%
	HC	0-20000ppm	±10ppm	±0.2%
	O ₂	0-22%Vol	±0.1%	±0.5
	NO _x	0-5000ppm	±50ppm	±1
AVL 437 Smoke meter	Opacity (%) Absorption (m-1)	0-100 HSU	0.1	±1%
		0-99.9	0.01	±1%
Encoder		720o	±1%	±0.2%
Transducer		0-250bar	±1%	±0.2%

pressure is measured using AVL pressure transducer. Crank angle encoder was used to convert the analog value of angle into digital. The range, accuracy and uncertainties are depicted in Table 2. To obtain the baseline measurement, the machine was operated with pure diesel and PSBD25 blend. Then the engine is operated with PSBD25 at different injections pressures of 225, 250 and 275bar with different operating conditions by using the injector pressure tester after the essential adjustment and shown in Figure 5.

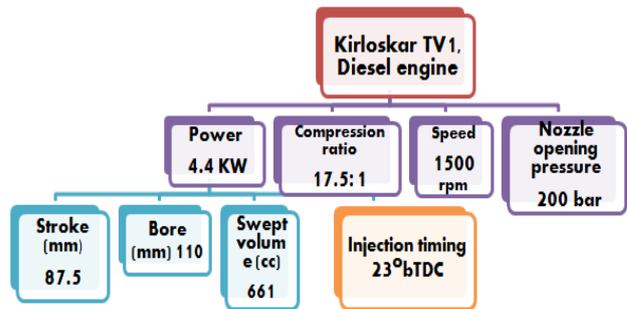


Figure 4. Flow diagram of the test engine specifications

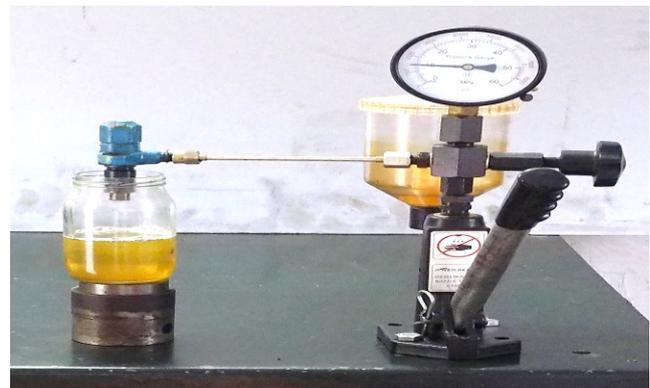


Figure 5. Fuel injector pressure tester

To obtain a consistent speed, the engine was initially started and heated up under idling circumstances before being operated at no-load to fully loaded conditions at a uniform rate of 1500, rpm. The engine was tested using PSBD25 mix at various IPs, and the results were tracked. Each experimentation was executed three times to get measurements, and the average value of each measurement is utilised for calculations. All the datas was examined and differentiated to diesel at 200 bar standard IP.

2.3. Uncertainty analysis

Accuracy of an experiment conducted using conventional instruments varies depending on the manufacturer (Kumar *et al.*, 2017; Balu *et al.*, 2020; Rajeshwaran *et al.*, 2018). This analysis was accomplished with measured parameters and computed values to make certain average accuracy of the results acquired from the instruments. Errors and uncertainty in an instrument are affected by environmental circumstances based on the observation, instrument calibration, operating condition, and accuracy of the instrument employed. Measurement uncertainty could be attributed to multiple sources of measurement errors (Teja *et al.*, 2022; Sureshababu *et al.*, 2023). Every specific measurement error connects with other errors to influence measurement of uncertainty, which is known as uncertainty dissemination, and each specific error is referred to as a fundamental error.

Experimentation is performed 3 times, and mean values were used to determine the uncertainty. In this research work an uncertainty analysis was performed utilizing the square root approach, which was highly liked by the scientists and researchers. Figure 6 shows the uncertainties in the observed and computed values. The experiments uncertainty was computed using the values of BP, BTE, BSFC, HC, CO, NO_x, and smoke specified in the equation below. Total percentage of experiments uncertainty was obtained by using the formula

$$\begin{aligned} \text{Overall uncertainty} &= \text{Square root of} \\ &[\text{uncertainty of } \{(BP)^2 + (BTE)^2 + (BSFC)^2 \\ &+ (HC)^2 + (CO)^2 + (NO_x)^2 + (Smoke)^2\}] \\ &= \text{Square root of } (0.3)^2 + (0.5)^2 + (0.5)^2 \\ &+ (1)^2 + (0.5)^2 + (2)^2 + (1)^2 = \pm 2.3\% \end{aligned}$$

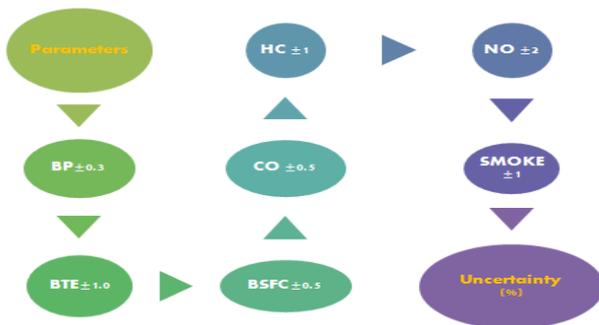


Figure 6. Shows uncertainties of measured parameters

3. Results and discussion

Diesel engine test was performed with unblended diesel and PSBD25 at various injection pressures with different loads for about 10cc consumption of fuel was noted and the emission measurements were noted for each test.

3.1. Cylinder pressure

Figure 7 depicts the modifications in Cylinder pressure with crank angle for diesel and PSBD25 with different injection pressures. Generally, the in-cylinder pressure of a CI engine is influenced by viscosity, disintegration and

vaporization, air fuel combination rate of reaction, ignition delay time, and fuel burned up during the premixed combustion stage of the fuel (Abed *et al.*, 2019). At maximum power, cylinder pressure obtained for PSBD25 with 225, 250 and 275 bars of injection pressure is 69, 71 and 65 bars respectively, and for unblended diesel and blended PDBD25, it is 68.3 and 67 bars respectively at 200 bar IP. Peak pressure might have increased owing to greater atomization of fuel particles at higher injection pressure resulting in improved combustion. The cylinder pressure was found lower at 275 bar IP owing to lesser momentum of fuel particle unable to reach the other end of the combustion resulting in more gathering of fuel, leads to poor combustion. It is found that for PSBD25 at 250bar IP, the cylinder pressure was increased by the 4 and 2bars compared to 200 and 225bars pressure respectively at maximum load.

3.2. Heat release rate (HRR)

HRR is the quantity of heat liberated by burning of fuel inside the engine cylinder during combustion. Figure 8 displays the change in HRR as a function of crank angle for blended and unblended fuels at full load. The diesel fuel was considered to have a greater HRR during the premixed combustion phase than PSBD25. This was due to biodiesel's elevated viscosity which inhibited fuel atomization tending to lower HRR and delayed burning. Because PSBD25 fuel has a shorter ID time, it burns less fuel in the premixed combustion, resulting in a lower heat release rate. The fuel with the highest volatility (unblended diesel) will generate more vapour quickly and has a greater possibility of releasing more heat during the combustion stage. At maximum load, HRR obtained for PSBD25 with 225, 250 and 275 bars, it is 71.3 J/oCA, 73.4 J/oCA and 63J/oCA respectively at full load and for unblended diesel and blended PSBD25, it is 68 J/oCA and 65 J/oCA respectively at 200bar IP. The premixed combustion stage for PSBD25 at higher injection pressures is greater than the normal injection pressure. This might be due to improved atomization of fuel which allows them to easily penetrate the air, leading to an increase in the premixed combustion phase (Harish *et al.*, 2020)

3.3. Maximum rate of pressure rise

The pace of pressure increase was affected by the quantity of heat accumulated during the first stage of the burning process, and amount of fuel used. It is a critical metric for determining the production of knocking propensity within the combustion chamber because of the shorter and longer ignition delay of the feed fuel. The higher ignition delay time led to a greater buildup of feed inside the combustion chamber and a rapid combustion, elevates the rise in HRR and pressure rate (Ganapathy *et al.*, 2011). Figure 9 illustrates the effect of increasing IPs on MROPR with BP for diesel and PSBD25 with various injection pressures. The MROPR enhanced by all NOP increments for PSBD25 at all loads. Additionally, the MROPR of PSBD25 rises at all IPs leading to better fuel disintegration and evaporation, during which the fuel rapidly emits heat energy at a greater rate, thus boosting

the pressure rise. The MROPR for the unblended diesel and PSBD25 at standard NOP is 4.4 and 4.6 bar/oCA respectively, whereas for PSBD25 with 225, 250 and 275 bars IPs are 4.9, 5.0 and 4.7 bar/oCA. Ashok *et al.* (2017) observed a similar pattern of rate of pressure rise for biodiesel. The similar trends of curve were achieved by the researchers Rajan *et al.*, 2017 with Yellow Oleander biodiesel mixture.

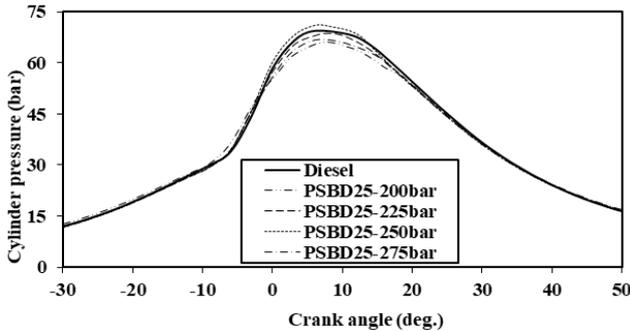


Figure 7. Cylinder pressure versus crank angle

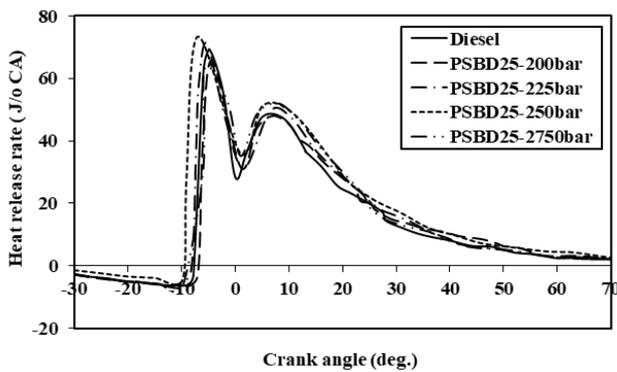


Figure 8. HRR versus CA

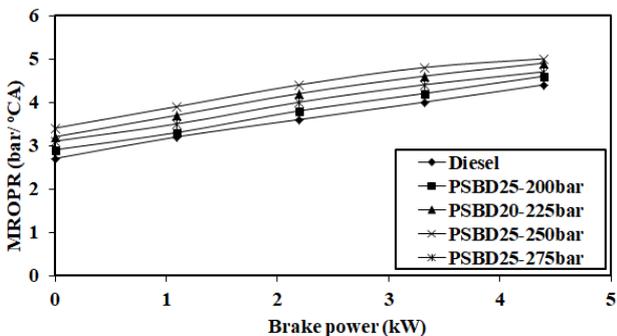


Figure 9. MROPR versus BP

3.4. Ignition delay

Figure 10 illustrates ignition delay between unblended diesel and blended diesel at different injection pressures. The ignition delay diminishes as engine load increases due to higher combustion chamber wall temperature at injection and decreased exhaust gas dilution. The ignition delay for PSBD25 and its diesel mixture is less than that of diesel and reduces as injection pressures increase. This could be because of PSBD25 mix have a larger cetane number than diesel (Harish *et al.*, 2020). The biodiesel had a minor amount of diglycerides with a higher boiling point than diesel. One probable explanation for the reduction in ignition delay in the PSBD25 mix was the higher oxygen content in the biodiesel fuel, which resulted in quicker burning than diesel. At full load, the ignition delay

of diesel and PSBD25 at 200bar pressure is 11°CA, 10°CA, and for 225,250 and 275 bar pressure are 9°CA, 8°CA and 9.5°CA respectively at maximum power. The delay period lowers with increasing injection pressures owing to increased atomization of biodiesel particles and higher oxygen content in the biodiesel, which promotes quicker evaporation and therefore minimises the delay period. The similar trends of curves were achieved by the researchers Rajan *et al.*, 2017 with Yellow Oleander biodiesel mixture.

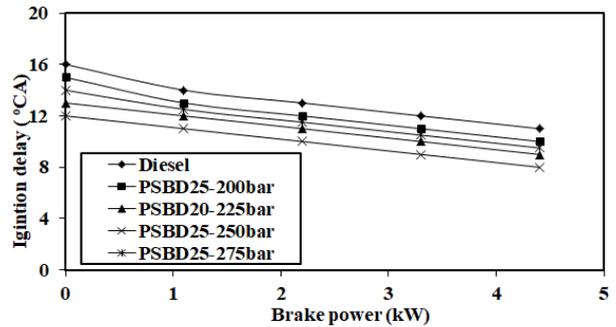


Figure 10. Ignition delay versus BP

3.5. BTE

BTE measures an engine's ability to convert thermal energy from fuel into mechanical energy. Figure 11 illustrates the change in thermal efficiency for diesel and PSBD25 with BP at different IPs. It is observed that BTE increases as increase in IPs and loads. PSBD25 has a lower BTE than diesel because of its energy content and greater viscosity (Agarwal *et al.*, 1015). Additionally, as the IP rises to 250bar, the BTE rises as well. This is attributed to greater fuel atomization and vaporization at higher IPs, resulting in better burning of PSBD25-air combination. BTE was dropped at 275 bar pressure because more fuel was injected under maximum power circumstances, resulting in slower combustion and a lesser BTE. At maximum load, the BTE of PSBD25 at IPs 225, 250, and 275bar is 30.1%, 31.9%, and 29.2 %, respectively, and for diesel and PSBD25 at 200bar IP is 31.4% and 28.6%, respectively. When compared to 250 bar IP, the BTE of PSBD25 at 275bar IP dropped by 1.5% at maximum load. PSOME25's BTE at 250bar IP is 2.1% greater than PSBD25 at normal IP of 200 bar. A similar pattern of BTE curve obtained for biodiesel mix by the researchers Pradeepraj *et al.*, 2019

3.6. BSFC

BSFC is defined as the amount of fuel burned by the engine to produce one kilowatt of power at the crankshaft. Hence, a lower BSFC value is always favorable for the engine that is efficient. Figure 12 depicts the variations of BP versus BSFC for blended and unblended diesel. The actual fuel consumed by the test engine was determined by taking frequent measurements of the fuel weight or volume under varied load conditions. When compared to diesel, the BSFC of the PSBD25 is enhanced with 200bar IP. Because of its low energy content and high viscosity, PSBD had a higher BSFC at normal IP 200 bar at peak load. As IP increases, the atomization of fuel particles decreases which increases the air-fuel combining rates and thus continuing to increase the HRR. At regular

IP, the BSFC for diesel and PSBD25 is 0.28 and 0.31 kg/kWh, respectively, while at peak load, it is 0.30, 0.29, and 0.33 kg/kWh for IPs 225, 250, and 275 bar, respectively. Because of increased homogenization and vaporization of the fuel–air mixture at higher IPs, the BSFC of PSBD25 at IP250 bar was reduced by 6.5 % and by 3.2 % at 225 bar when contrasted to PSBD25 at 200 bar. The BSFC has increased at 275 bar due to less momentum of fuel leading to poor combustion and hence higher BSFC at peak load. A similar pattern of BTE curve obtained for biodiesel mix by the researchers Pradeepraj *et al.* (2019).

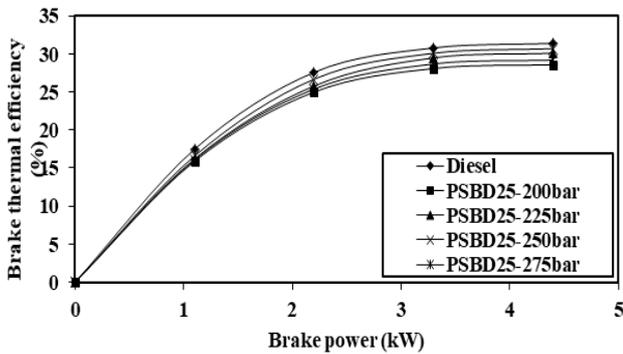


Figure 11. Change of BTE with BP

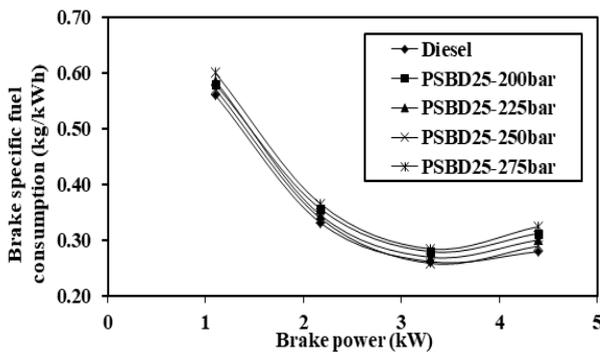


Figure 12. Changes of BSFC with BP

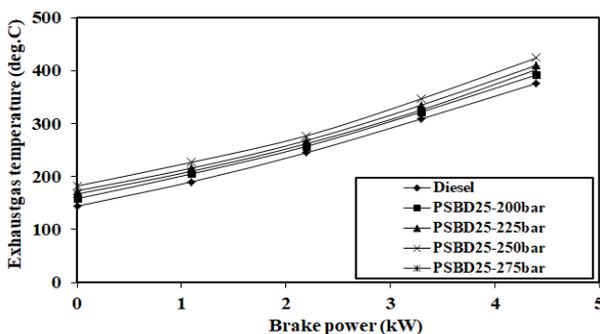


Figure 13. Change of EGT with BP

3.7. Exhaust gas temperature (EGT)

Figure 13 portrays the changes in EGT caused by different IPs for PSBD25 and diesel. Exhaust gas temperature for the tested fuel augmented as the load increased since the engine needed additional fuel to flame to produce the required power. The blended and unblended diesel viscosity may impacted injection and spray configuration, as well as succeeding evaporation and burning conditions (Ganapathy *et al.*, 2011; Agarwal. *et al.*, 2015). It is known, EGT increases with an increase in load due to greater

energy released from the fuel. Furthermore, the combustion process is enhanced to boost the IPs through improved atomization and combining of fuel and air, which leads to better burning of fuel, as a consequence, higher EGT. The higher EGT for PSBD25 was achieved because of PSBD25 burned slower than diesel. At peak load, the EGT of diesel and PSBD25 is 376°C and 392°C and for 225, 250, and 275 bar it is 410°C, 424°C, and 402°C respectively.

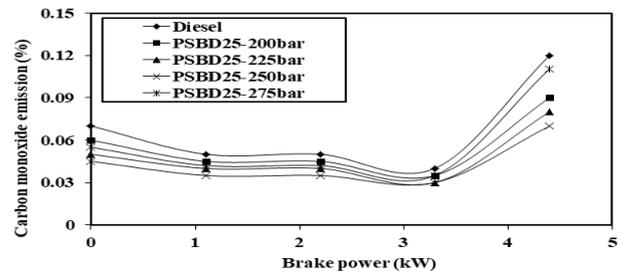


Figure 14. Changes of CO with BP

3.8. Carbon monoxide

Figure 14 depicts the change in CO emanations for both diesel and PSBD25 with different IPs with brake power. CO emissions formation in CI engines is normally correlated with diesel qualities and combustion features. CO emission of PSBD25 at normal IP 200 bar is lowered due to excess O₂ molecules, which assist the oxidation of the fuel–air combination, leading to an improvement in biodiesel combustion. Additionally, increasing IPs enhances spray penetration in compressed air, which enhances fuel and air mingling and enhanced burning process, leading to improved biodiesel combustion [23, 24]. CO emissions for diesel and PSBD25 are 0.12% and 0.09% respectively at regular IP of 200 bar, while IPs 225, 250, and 275 bar emissions are 0.08%, 0.07% and 0.11% respectively at maximum power. CO emissions for PSBD25 at 225 and 250 bar IP were diminished by 33% and 42%, respectively, as compared to diesel, and by 11% and 22% decreased when compared to PSBD25 at 200 bar CO emission improved by 57% for PSBD25 at 250 bar as contrast to diesel at normal IP 200 bar at maximum load. A similar pattern of BTE curve obtained for biodiesel mix by the researchers Pradeepraj *et al.* (2019).

3.9. Hydrocarbon

Figure 15 displays change of HC with BP for diesel and PSBD25 at various IPs. At a normal IP of 200 bar, PSBD25 had such a higher HC than diesel at peak power conditions. The change in IP of PSBD25 has a significant influence on HC emissions. As according Senthil Kumar *et al.* [28] PSBD25 exhibited lesser HC at 225 and 250 bar IP as compared to diesel at normal IP of 200 bar. This is responsible for higher injection pressure since the fuel is more atomized as well as the droplets of diesel fuel acquire more velocity and penetration, lead to complete burning. A further rise in IP, above 250 bar, enhances HC emissions due to lack of proper fuel interaction and a shortage of oxygen for combustion. At a standard IP of 200 bar, diesel and PSOME25 emit 48 and 43 ppm, respectively, while PSBD25 emits 36, 32, and 39 ppm,

respectively, at 225, 250, and 275 bar IPs. The HC emissions for PSBD25 at 225, 250, and 275 bar IPs were declined by 16%, 33%, and 9%, as compared to PSBD25 at normal IP of 200 bar at peak power. A similar pattern of BTE curve obtained for biodiesel mix by the researchers Pradeepraj *et al.* (2019).

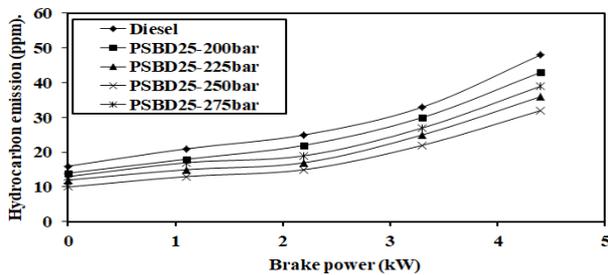


Figure 15. Changes of HC with BP

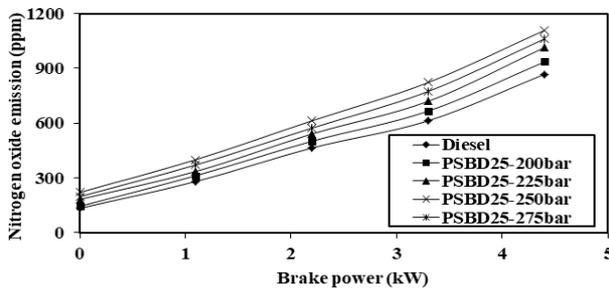


Figure 16. Change of NO with BP

3.10. Nitrogen oxide

Figure 16 explores the change in NOx emission with BP for unblended diesel and blended PSBD25 at varied IPs. When PSBD25 was compared to diesel at 200 bar IP, there was a rise in NOx emissions. NO emissions rose at full load when IPs enhanced from 200 to 250 bar due to an increase in peak temperature. This could be owing to biodiesel having greater oxygen content in its structure and greater atomization and evaporation of fuel at greater IPs, leading to high NOx emissions as contrast to diesel, as stated by Agarwal *et al.*, 2015 NOx emissions for diesel and PSBD25 are 868 and 936 ppm, respectively, while NO emissions for IPs 225, 250, and 275 bar are 1015, 1109, and 1062 ppm, respectively. NOx emissions were increased by 8.4%, 18.5%, and 13.5% for 225 bar, 250 bar and 275 bar IPs as compared to PSBD25 at original IP 200 bar respectively at peakload. Senthil Kumar *et al.* (2017) presented a similar pattern in NO emissions curves for biodiesel blend.

3.11. Smoke

Figure 17 indicates change of smoke with BP for diesel and PSBD25 at different IPs. Smoke emission increased with increasing engine load for all tested fuels, as shown. The diesel fuel produced the most smoke of all of the fuels tested, followed by the biodiesel mixture PSBD25. Smoke was reduced for PSBD25 with a normal IP of 200 bar as compared to diesel because PSBD25 has a greater O₂ concentration and creates a cleaner combustion than diesel. Furthermore, with increased injection pressures, smoke emission for PSBD25 was reduced due to greater atomization of biodiesel particles and additional oxygen available in the fuel, resulting in

better combustion of biodiesel mix (Kannan *et al.*, 2012). At standard IP, smoke from diesel and PSBD25 is 32% and 28%, respectively, while at 225, 250, and 275 bar IP, it is 23%, 20%, and 26%, respectively. Smoke emissions were declined by 22%, 36% and 11% for PSBD25 at 225, 250 and 275 bar, respectively, compared to PSBD25 at standard IP of 200 bar, due to improved fuel atomization and mixing with air, resulting in lower smoke emission for PSBD25 at higher IPs. Chauhan *et al.* (2009) reported a similar pattern of results on smoke emissions with biodiesel mixtures.

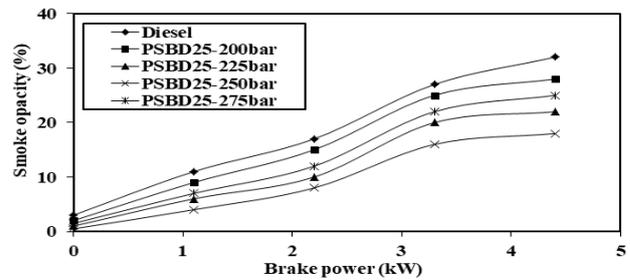


Figure 17. Change of smoke with BP

4. Conclusion

The varying combustion characteristics of a CI Diesel engine using a PSBD25 with dissimilar IP were examined in this research and the outcomes of the investigations lead to the following conclusions:

- Increased IPs improves the engine's performance characteristics in terms of BSFC and BTE by using PSBD25. When compared to PSBD25 at standard injection pressure of 200 bar, the BTE was augmented by 1.68% and BSFC was declined by 6.5% at 250 bar and the EGT of the PSBD25 decreased at increase in injection pressures.
- In terms of emissions, increasing the IPs for PSBD25 diminishes CO, HC, and smoke were diminished by 57%, 33% and 36% respectively, but NO emissions were boosted at higher IP of 250 bar by 18.5% compared to the standard IP of 200 bar at peak load.
- Subsequently, when compared to PSBD25 at 200 bar pressure, the PSBD25 blends at 250 bar IP offers adequate performance and lower exhaust gas emissions at peak power.
- At maximum power, raising the injection pressures for biodiesel reduces the ignition delay while rising the pressure in cylinder and heat release rate.
- Furthermore, raising the IP reduces the combustion duration and elevates temperature ensuing enhanced combustion. Overall, the biodiesel mix with augmented IP improves combustion and performance characteristics while decreasing the engine's SFC, CO, HC, and smoke emissions.

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