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An experimental study on the thermal efficacy, combustion and exhaust characteristics of a CRDI CI engine fueled with a novel pedicel biodiesel

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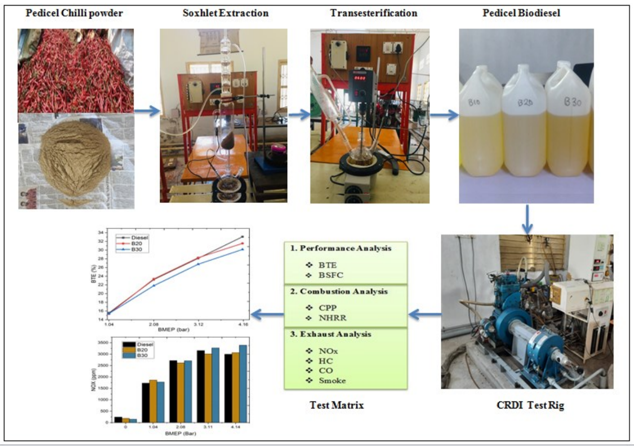
Graphical abstract



Abstract

In contemporary industrialization, the prevalent occurrence of energy crises and emissions poses significant challenges, necessitating the exploration of alternative fuel sources and the implementation of measures to minimise hazardous emissions. These efforts are crucial for attaining the sustainable development goals set forth by the United Nations. The current study is to empirically examine the effects of a newly developed biofuel on the operational characters of a CRDI engine with this investigation will involve the utilisation of different mixtures of pedicel oil at various brake mean effective pressures. The generation of oil from bio-waste collected from industry in Guntur Mirchi-yard, pedicel of dried hot peprica or chilli using Soxhlet extraction method. After the synthesis, the characterization of Pedicel bio-oil (PBO) is done using gas chromatography-mass spectrometry (GCMS) and results are estimated using standard ASTM methods. After characterization, bio-oil is converted to pedicel bio-diesel (PBD) using a transesterification process. When the engine was operated using a combination of 80% diesel and 20% pedicel oil (referred to as the D80B20 blend), it resulted in a notable improvement in brake thermal efficiency by 1.6%. Additionally, this blend led to a reduction in emissions of oxides of nitrogen by 6.7%. However, it is worth noting that smoke levels marginally increased under full-load conditions with a 500 bar fuel injection pressure (FIP). The D80B20 fuel mixture exhibited a 7% reduction in hydrocarbon emissions compared to pure diesel fuel when the engine was operating at maximum load with an ignition timing of 23° before top dead centre. This numerical analysis clearly shows that D80B20 at IT 23° bTDC and FIP 500 bar give better results. Although it doesn't need any engine adaptations, the biodiesel made from leftover chili pedicel is a viable diesel replacement fuel.

Keywords: waste pedicel biodiesel, GC-MS, CRDI engine and emission control.

Nomenclature

ASTM	American Society for Test Materials	EGT	Exhaust Gas Temperature
PB20	20% Pedicel Biodiesel + 80% Diesel	HSD	High Speed Diesel
PB30	30% Pedicel Biodiesel + 70% Diesel	CA	Crank Angle in degree
BTE	Brake Thermal Efficiency	NOx	Oxide of Nitrogen (ppm)
bTDC	Before Top Dead Center	HC	Hydrocarbon (ppm)
CR	Compression Ratio	CO	Carbonmonooxide (%)
IT	Injection Timing	SO	Smoke Opacity (%)

1. Introduction

One of the greatest worldwide challenges over the past decade has been the usage of fossil fuels for power production. One of the greatest vital assets for humankind

A. N Phani Deepthi, J. Prabakaran, A. P Sathiyagnanam and Srinivasa Prasad Sanaka (2024), An experimental study on the thermal efficacy, combustion and exhaust characteristics of a CRDI CI engine fueled with a novel pedicel biodiesel, *Global NEST Journal*, **26**(7), 05479.

and its continued growth is energy [Uyumaz 2020]. The energy issue is a major worldwide issue. Because they provide a considerable quantity of energy, fuels are essential. Petroleum and natural gas are examples of fossil fuels, which are the primary energy sources. Eighty percent of the planet's energy comes from fossil fuels due to extensive usage of diesel machinery [Perumal and Ilangkumaran 2017]. An experimental investigation is done on CRDI Diesel Engine, B20 and B30 as the fuel for 0 to 100% Load conditions at IT 23°bTDC, 1500 rpm, and combustion as well and discharge parameters are found compared with the neat diesel (D100). Several investigators carried out research to determine the influence of different variants on combustion, engine efficiency, and emissions parameters. The study's findings suggested that using a biodiesel blend could aid in lowering CO, NOx, and PM discharges when sustaining engine performance within safe ranges [Can *et al.* 2017]. In comparison to diesel fuel, we found that using Pongamia biodiesel reduced emissions of smoke and CO. Higher O2 content and reduced S content are blamed for the decrease in emissions. Pongamia biodiesel exhibited no visible effect on various performance parameters indicating that the fuel might be used as an acceptable substitute for diesel sans negatively impacting engine effectiveness [Abu-Hamdeh and Alnefaie 2015]. Researchers analyzed the combustible characteristics of canola biodiesel combinations. The study discovered that while sustaining comparable engine performance, the variants led to reduced emissions of CO, HC, and PM [Nantha Gopal and Thundil Karupparaj 2015]. The research also revealed that increasing the amount of canola biodiesel might reduce NOx emissions. Some investigations assessed the functionality of 2 fuels which were almond oil and palm oil. The almond oil emits less greenhouse gases compared to the palm oil [Prabu *et al.* 2018]. When compared to diesel, the blends led to fewer discharges. On engine performance metrics including fuel usage for brakes, the fuel blends had no appreciable impact [Dhar *et al.* 2014]. According to the study, higher Pongamia biodiesel compositions could represent an acceptable substitute for diesel, but additional investigation is needed to enhance engine operation and minimize emissions. The study outlined in this journal article looked at the usage of n-butanol as a supplement. The investigators examined the efficiency and discharges of biodiesel with and without n-butanol as an addition. The addition of n-butanol to biodiesel elevated engine efficiency by raising BTE and decreasing FC [Lei Zhu *et al.* 2011]. The researchers tested biodiesel blends to determine how fuel injection pressures, timings, and compression ratios affect diesel engine performance. The testing findings show that a 20% biodiesel blend performs best at CR 20, 25 bTDC injection time, and 200 bar injection pressure. Biodiesel and its mixtures were studied for performance, emission, and combustion. [Jagadish 2016]. Researchers have discovered that waste fatty molecules can produce high-quality gasoline. Modern common rail direct injection (CRDI) engines favour bio-constituent blends with 75% biofuel, although diesel engines may lose efficiency. Animal fat-based biodiesel blends had 13% higher brake-specific fuel consumption than the baseline. The biochemical stability of rapeseed oil-diesel mixtures has improved. All of the biodiesels examined reduce brake fuel conversion efficiency by 2%. Biodiesel and diesel lower emissions significantly. Rapeseed oil biodiesel/diesel blends reduced HC emissions by 12%, CO emissions by 19%, and CO2 emissions by 5.3%. [Duda *et al.* 2018]. The researchers tested Calophyllum inophyllum biodiesel and diesel in a CRDI diesel engine. The study found that raising the pilot injection rate from 5% to 15% might reach 36.85% BTE. Pilot injection of 15% reduced HC and CO emissions by 53.60% and 44.70%, respectively, compared to diesel fuel. Thus, the EGR 10% rate with 15% pilot injection reduced NOx emissions by 10.5%. Pilot injection should be 15% and EGR 10% for best engine performance [Susanth Kishna *et al.* 2019]. The use of n-butanol led to lower discharges of CO, NOx, and PM. Some researchers studied the functionality, ignition, and discharge parameters of Karanja biodiesel combinations were analyzed. The implementation of blends resulted in a drop in BTE and a rise in BSFC. In Karanja biodiesel blends, however, SO, CO, and HC levels reduced but NOX rose. In general, the research emphasizes biodiesel as a viable substitute fuel supply. It also emphasizes the need to address the associated drawbacks, such as lower efficiency and increased NOx emissions [Rajesh *et al.* 2020]. In this journal, we studied the DI CI engine operated with ethanol–biodiesel combinations. Ethanol, when used as a biodiesel, can offer several benefits over Euro V diesel [Musthafa *et al.* 2018]. Ethanol has a higher octane rating than diesel, which means it is more resistant to knocking and can allow for more advanced in this journal investigation of anisole as a supplement in WCO. It is determined that WCO methyl ester containing 10% by volume anisole may be used efficiently in low-emission CI engine operations. Anisole has been shown to effectively reduce the acid value. 10% by volume of the selected variant may be used efficiently in low-emission CI engine operations [Asokan *et al.* 2019]. This study found that a 20% (B20) to 40% (B40) blend of that tamanu oil and diesel fuel was used to fuel the coated engine. The results showed reduced emissions and improved performance. The Taguchi with grey relational analysis (GRA) optimization method was used to examine how load and fuel affect the emission level of a copper-chromium-zirconium alloy-coated diesel engine. Fuel significantly reduces CO and HC exhaust gas emissions in coated-type diesel engines, according to experiments [Sureshbabu *et al.* 2023]. In this journal, we studied an insightful comparison of different characteristics of CI engines running on variants possessing or not possessing an additive. DTBP is employed in biodiesel at a concentration of around 1% to enhance the accessibility of oxygen throughout the burning phase and enhance the CN. This leads to efficient combustion and can reduce the formation of NOX emissions [Radheshyam *et al.* 2019]. Therefore by comparing the addition of 1% DTBP in biodiesel with normal biodiesel concluded that blending with DTBP shows better results in engine performance and emissions. From this journal, we noted that the main reason for choosing juliflora as a biodiesel will be for high oil content; the oil can be extracted from the seeds which are easy to cultivate. In terms of efficiency, as the load grows, the BSFC progressively drops. Due to the small quantity of diesel and its HCV, BSFC is believed to correspond with calorific levels and also with the volume of administered fuel. For Emissions, a slight decrease in CO, and HC occurred. Increasing % the composition of juliflora oil leads to more NOx emissions cause of has high O2 content which leads to incomplete combustion [Atmanli *et al.* 2018]. Increased fuel injection pressure (FIP) reduces fuel droplet size, improving atomization and evaporation. A more complete fuel burn will increase thermal efficiency and power production. Increased FIP also shortens combustion delay. This accelerates mixture reduction and significantly reduces inflammatory NOx [Arunprasad and Balusamy 2018]. This journal says that When added to bio-oil,1-pentanol can improve the fuel's viscosity, density, heating value, stability, and performance. Its chemical structure makes it an effective solvent and emulsifier. At lower loads, the addition of 1-pentanol can improve engine performance by increasing the BTE and reducing FC. This is because 1-pentanol has an enhanced O2 level, which results in increased absolute combustion and minimization of unburned HC. However, at higher loads, the inclusion of 1-pentanol may have a negative influence on engine effectiveness as a result of reduced energy density compared to diesel fuel. This can result in reduced power output and potentially lower fuel efficiency [Rajesh kumar and Saravanan 2015]. WCO can be a renewable fuel option for CI engines. The findings indicate that WCO has qualities comparable to diesel and may be utilized as an alternative resource [Damodharan *et al.* 2018].The study also found that diesel engines fueled by a mixture of diesel and WCO performed comparably to those fueled by diesel alone. The investigators examined n-pentanol/diesel combinations and investigated the application of a higher pentanol/diesel combination to optimize the fuel’s sustainable portion. They utilized 3 EGR levels to reduce NOx emissions. At moderate and elevated loads, boosting EGR levels reduced NOx levels [Ashok *et al.* 2019]. Nevertheless, the SO grew for all combinations over a particular EGR level. The utilization of WPO generated from MSW as a fuel for CI engines was examined. The research discovered that introducing n-pentanol enhanced the engine's combustion features, leading to lower CO, HC, and PM levels. The use of cold EGR and optimized IT further improved the engine's emissions and reduced the formation of NOx [Ashok *et al.* 2020]. This research investigates the usage of PLME derived from leftover hog fat. Various IP and IT configurations are used to examine PLME20-fueled diesel engines. Increasing IP increases efficiency by 3% while reducing the BSEC by 1.88 MJ/kWh for the identical combination [Manimaran *et al.* 2020]. For increased IP, HC and CO emissions are lowered but NOx emissions rise. In this manuscript, the researchers investigated the engine performance by utilizing 100% CIME as a fuel, paired with a 21 IT and 10% EGR rate. This combination of factors can result in lower emissions of NOx and PM, as well as better engine efficiency [Pan *et al.* 2018]. The study focuses on the extraction of bio-oil utilizing solvent segregation, as well as the impact of different parameters on the yield and properties of the produced variant [Rajesh Kumar 2016]. The non-polar hexane solvent produced the highest percentage of oil yield and the resulting bio-oil had a high percentage of neutral fatty acids, Bio-oil amalgamation, comprising solvent selection, extraction conditions, and determination of bio-oil characteristics utilising FTIR and GC-MS analysis.

Table 1. Details of Crude fat oil generated from Chilli Pedicel wastage

Wetback (ml)	Chamois wash water (ml)	Degreasing (ml)	Temperature°C	Heating duration (min)	Fat oil yield (ml)
100	200	200	>100	40-45	50-55
200	200	100	>100	40-45	65-75
100	200	200	>100	40-45	45-50
200	200	-	>100	70-95	170-185
200	250	50	>100	60-75	160-170
250	250	-	>100	80-90	220-230

2. Materials

2.1. Feedstock accumulation and recovery of crude fat oil

The synthesis is done using many agricultural resources. There are many crops such as edible and non-edible plants for the making of biodiesel. Linseed, Sorghum, Corn, Soybean, etc are some of the edible sources used for biofuels. Several non-edible plant sources are used as feedstock **[**Tian *et al.* 2017**]**. Now in this, we are selecting an edible source named “CAPSICUM ANNUUM”. It is one of the most cultivated crops in India. India is the largest producer with 1.98 million tonnes and contributes 43% of world capsicum annuum production, followed by China, Ethiopia, Thailand, Pakistan, and Bangladesh. It has most of its production from the state named Andhra Pradesh Up to 700 metric tons is produced in the year 2022 and shares 57% in total production. The Guntur Mirchi Yard in Andhra Pradesh accounts for more than 40% of India's chilli production. The capsicum annuum contains a stem that has 10% moisture content and can form bacteria so this stem is removed from it and thrown away from this waste we collected it into packets and used it as feedstock for our experiment.

Especially compared with alternative solvents like acetone and ethanol, hexane removes more oil. Except in severe climes, it can maintain its liquid form under all environmental circumstances. Its minimal reactivity allows for easy elimination from solids and oil while utilizing little energy.

Figure 1. Collection of Red Chilli by Workers

2.2. Soxhlet extraction

Soxhlet extraction is a process of extracting chemicals from solid materials. It is additionally referred to as ongoing separation. Soxhlet recovery is used to determine the unrefined lipid level. Most plants' kernels and fruits contain a lot of lipids. The assessment of lipid level could be utilized to determine its excellence. The extracting process is now extensively employed both at residence and across the globe [Yilmaz and A. Atmanli 2017]. The Soxhlet extracting approach is a well-known traditional technique that is the suggested benchmark methodology in China for grain and oil evaluation. This process is expensive and is usually done in a research facility through a lipid remover. Table 1 shows the raw pedicel oil extracted from waste feedstocks.

2.3. Transesterification

Trans-esterification is defined as the process in which triacyl glycerides from a variety of feedstock such as non-edible oil seeds, vegetable oils, animal fats or tallow, waste cooking oil, and microbial lipids or single cell oil (from algae, oleaginous yeast, filamentous fungi and bacteria) are converted into fatty acid methyl esters (bio-diesel) in the presence of alcohol (methanol or ethanol). Transesterification is an eco-friendly process carried out under mild conditions. This process can be used to produce bio-diesel from a variety of feedstocks. Vegetable or animal oils-based triglycerides consist of three fatty acids linked to one glycerol moiety [Patel Shivani 2011]. In this reaction, triglycerides are reacted with an alcohol and produce esters and glycerol through three stepwise reactions. Trans-esterification can be classified as catalytic and non-catalytic processes catalyzed trans-esterification process can be classified into acid and base catalyzed processes. Depending on the nature of the catalyst phase, the acid or base catalyst can be divided into three subclasses such as homogeneous, heterogeneous, and enzymatic catalyst. The conversion efficiency of homogeneous catalyzed trans-esterification is better when the FFA is less than 1 mg of KOH/g of oil [Li *et al.* 2015]. A two-step trans-esterification process is needed when the free fatty acid (FFA) value is greater than 1 mg of KOH/g of oil. The main limitations of homogeneous catalysts are soap formation during the transesterification process and expensive separation of the catalyst after the process. As a result of such problems, feedstocks which are having high FFA can be easily converted by the heterogeneous catalyst. The evaporated vapors of solvent (n-hexane) travel through the feed flask and get condensed by the condenser into liquid by chilling and cooling the vapor. The condensed solvent collects in the received flask. The experimental work is performed for three different solvents to Chili pedicel powder ratio. Transesterification is done after the rotary evaporation of the pedicel bio-oil is prepared. It is ready to blend with the neat diesel.

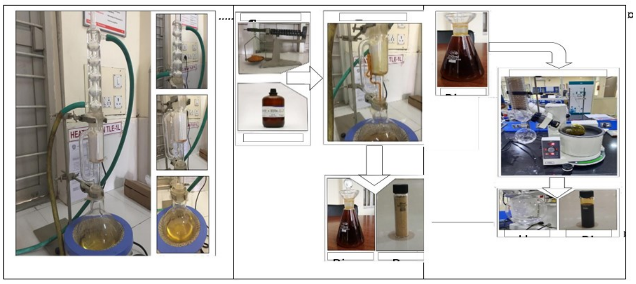


Figure 2. Extraction of Bio-Oil Process

Table 2. Fuel properties

Parameter	Diesel	D80B20	D70B30
Density(kg/m^3)	836	877	870
Kinematic Viscosity(cst)	2.71	7.57	7.27
Cetane Index	52	58.75	58.07
Flash Point(°C)	75	14	14
Net CV (Kcal/kg)	10355	10187	9458

2.4. Fuel Characterization by GC-MS analysis:

The chemical ingredients of Chilli Pedicel bio-oil (B100) are studied using gas chromatography spectroscopy. Figure 3 illustrates the chromatographic spectrum of pedicel bio-oil. The chromatogram exhibits a variety of chemical compounds characterized by distinct retention durations. The GC-MS analysis indicates the subsistence of various substances and principal fatty acids. The negligible constituents encompass oleic, caprylic, caproic, and capric acids. This observation indicates that the methyl ester derived from Prosopis julifera predominantly consists of saturated fatty acids.

The C–H shows the alkane presence. The C=C linkage indicates the existence of the aromatic compounds. The presence of O–H, C-O, and C=O represents the elevated O$_2$ levels.

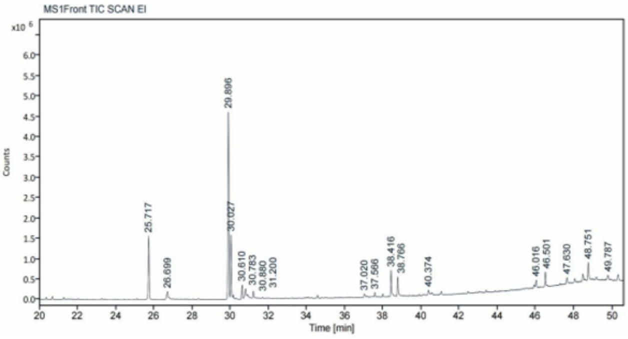


Figure 3. Chromatograph of Pedicel Bio-oil

2.5. Test Engine

The investigation is conducted using an individual-cylinder CRDI VCR engine manufactured by Kirloskar. Figure 8 depicts the actual research arrangement used to evaluate the effectiveness and exhaust attributes of pedicel biodiesel combinations. The engine is interlinked to an ECU along with a solenoid injector driver, compression pressure sensor (PCB piezotronics, USA), and Kubler Crank angle sensor (100 resolution). The speed capacity is 5500rpm with a TDC pulse. A Yokogawa fuel flow transmitter (0-500mm), Pressure transmitter (250WC), and a high-speed data acquisition device of 16bit, 250KS/s are also present. Apex Innovations Pvt. Ltd. engines are used to conduct information evaluation, coverage, entering, and processing. As a loading system, a water-cooled Techno Mech-10 Eddy current dynamometer was utilized. Stainless steel water-cooled EGR system with vacuum pump & pneumatic regulator that is also connected to the ECU to manage the exhaust gas discharge speed. Throughout the responsive duration, the AVL DI GAS 444N (five gas analyzer) was used to determine the exhaust discharge level from the engine emissions.

Figure 4. CRDI diesel engine Test Rig

Table 3. Engine specifications

Make and Model	Kirloskar, TV1
Number of cylinders	One
Stroke	Four
Bore	87.5mm
Stroke length	110mm
Swept volume	661cc
Compression ratio	17.5
Rated output	3.5 kW at 1500rpm
Cooling system	Water cooled
Injection timing, CA bTDC	23°C
Injection pressure	600bar

2.6. Experimental Procedure

The initial tests were conducted using diesel fuel without any alterations to the engine under ambient circumstances to assure the dependability of the results. Before each recording, the engine underwent a 5-minute operation period to attain steady-state function. The tests encompassed a range of loads, spanning from the smallest to the greatest. These loads were quantified as BMEP values of 1.06, 2.07, 3.11, and 4.16 bar. The beginning of combustion is measured by calculating the crank inclination at the moment when 10% of the mass fraction was exploited. The current investigation examines the influence of elevated levels in biodiesel and diesel mixes on various parameters. This investigation was conducted using a stationary CI engine equipped with a CRDi arrangement. Three different combinations of diesel and waste petroleum biodiesel were deliberately produced, and these combinations were labeled as D100, D80B20, and D70B30, indicating the respective blend percentages. The test mixes were subjected to a period of observation to verify the uniformity of the mixture. The consistency of the combinations was established using a UV-visible spectrometer, whereas the distribution of WLBD was investigated using the gravity method. The mixtures exhibited stability and did not display any discernible separation of phases. During the testing, the significant parameters, including fuel injection time, FIP, and CR, were retained at the same values: 23°CA bTDC, 17.5:1, and 500 bar, correspondingly. The investigations were done instantaneously under virtually comparable conditions.

3. Results and Discussions

3.1. Combustion

3.1.1. Cylinder pressure (vs) Crank Angle:

The Incylinder pressure corresponding to CA at various BMEP for the blends D100, D80B20, D70B30, and D100 at 23° BTDC is shown in Figure 5. For all of the evaluated fuels, cylinder pressure rises with progressive load from 0% to 100%. The maximum pressure from 0 to 100% load obtained for D100 is 78.976 bar, for D80B20 is 74.915 bar and for D70B30 is 77.58 bar respectively. There is a noticeable change in peak pressures at 100% load and no significant change at lower loads. A similar trend is observed with all evaluation fuels and corresponds with the trends [Rajesh kumar and Saravanan 2015**]**. This may be due to the lower cetane of D70B30 than D80B20 which tries to prolong the ignition delay. A surge in the volume of the combustion chamber delay leads to a reduced cylinder pressure. However, D70B30 shows better cylinder pressure at all engine lads compared to D80B20 in addition to this high oxygen concentration of chilli Pedicel Biodiesel (PBD) enhances combustion rate this is the reason behind attaining higher pressures. The blend D80B20 shows low peak pressure compared with D70B30 at 0% which is 51.92 bar and at 100% which is 77.58 bar which is quite nearer to D100 at 100% 78.976 bar. All of the investigated fuels had identical in-cylinder gas pressure profiles. Natural diesel operation produced greater in-cylinder values, which may be attributed to the higher calorific level, culminating in a greater PCP [Zhou *et al.* 2013].

3.1.2. HRR (vs) CA:

Figure 6 depicts the overall HRR as a function of CA at varied BMEP for all experimental sources. The plots show that as the load elevates, the NHRR for both combinations, especially diesel, rises. At lower loads, NHRR decreases as the level of the blend rises; at intermediate and excessive loads, NHRR grows as the intensity of the combine expands. The reason is due to the elevated burning latency. The IDP is completely dependent on the CN of the fuel **[**Emiro *et al.* 2018**]**. At 100% load, the highest NHRR for diesel is 80.33 J/deg, 77.55 J/deg for D80B20, and 71.82 J/deg for D70B30J/deg. The greater the LHE of the PBD, the more heat it takes from the chamber to dissipate, resulting in cooling of the combustion zone. The explanation for this tendency might be attributed to improved oxygenation circumstances in the mix as a result of biodiesel inclusion, which enables consistent fuel burning **[**Nanthagopal *et al.* 2019**]**.

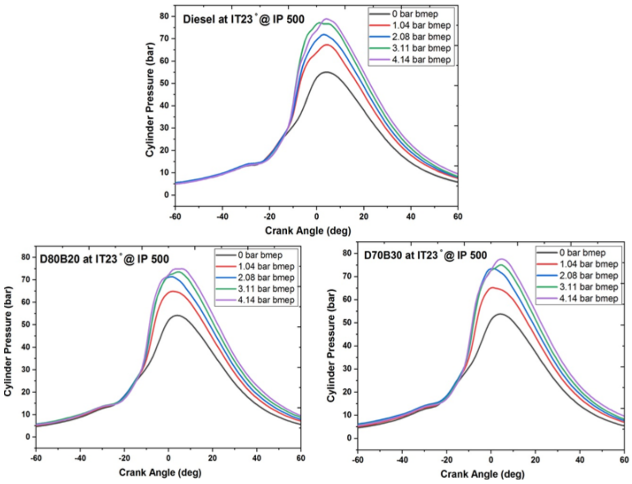


Figure 5. Crank Angle vs. Incylnder Pressure at different BMEP

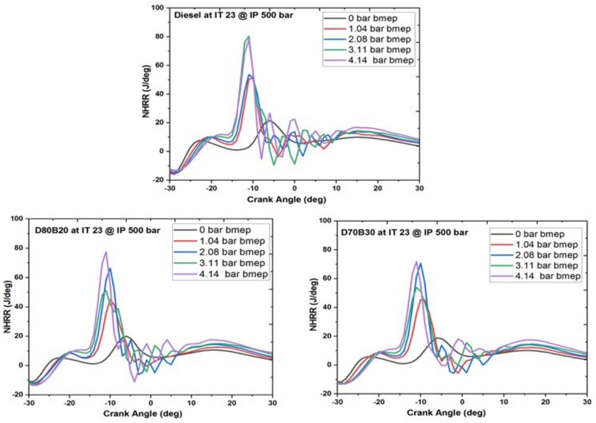


Figure 6. Crank Angle vs Net Heat Release Rate at different BMEP

3.2. Performance investigation:

3.2.1. BTE (vs) BMEP

Figure 7 reveals how the brake thermal efficiency (BTE) changed between four different test specimens that were each tested at various engine brake mean effective pressures (BMEPs). The brake thermal efficiency (BTE) has a range of 17.06% to 34.3% for usual diesel fuel, 16.27% to 33.78% for D80B20, and 15.66% to 32.12% for D70B30 fuels. As anticipated, the BTE values demonstrate a positive correlation with engine load. This can be because of the combined impact of an augmentation in power production and a reduction in thermal dissipation **[**Ashok *et al.* 2017**]**. Additionally, it has been observed that increased engine temperatures under greater loads contribute to improved fuel vaporization. This, in turn, enhances the combination of air and fuel, thereby reducing the ignition delay. Consequently, higher brake thermal efficiency (BTE) has been documented under these conditions of elevated engine loads **[**Ashok *et al.* 2019**]**.

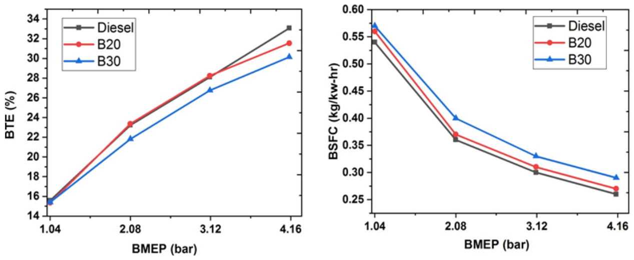


Figure 7. Differences of (a) BTE and (b) BSFC at different BMEP

3.2.2. BSFC (vs) BMEP

Figure 7 illustrates the impact of raising the proportion of waste pedicel biodiesel in conjunction with diesel on the BSFC. Regarding engine load, the brake-specific fuel consumption numbers exhibit a range of 0.54 to 0.26 kg/kW-hr for diesel, 0.56 to 0.27 kg/kW-hr for D80B20 fuel, and 0.57 to 0.29 kg/kW-hr for D70B30 fuel. In constant-speed engines, it is observed that the BSFC of various fuels tends to drop as the BMEP of the engine climbs. This might be caused by the circumstance that the % increase in fuel usage is less than the % increase in braking power, leading to a reduced BSFC rating [De Poures *et al.* 2017]. At all BMEPs, the BSFC of diesel-pedicel biodiesel combinations is larger than that of diesel alone. This conclusion is backed by the reality that the reduced average calorific worth of pedicel biodiesel necessitates a larger capacity of fuel to deliver an identical quantity of power [Dillikannan *et al.* 2020].

3.3. Emissions

3.3.1. NOx and Smoke

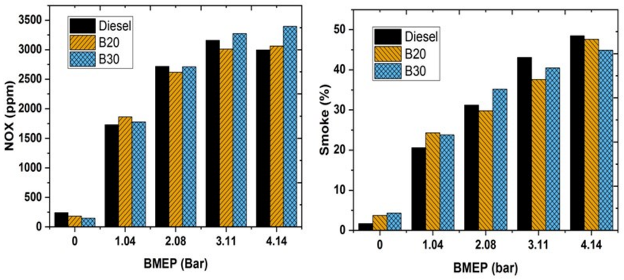


Figure 8. Dissimilarities of (a) NOx and (b) Smoke at different BMEP

The volume of NOx released by the engine is related to the retention duration and temperature of the mixture in the combustion region [Sithivinayagam and Anandavelu 2023]. At higher temperatures the formation is high. Figure 8 shows the NOx emissions at various BMEP for D100, D80B20 (B20 in the graph), and D70B30 (B30 in the graph). NOx levels rise as load rises, and a comparable sequence was found for both combinations, especially diesel. The larger reductions are recorded from low to medium loads as the concentration of PBD NOx increases. Because of the lean air-fuel proportion, the reduced BMEP emits less NOx. Nevertheless, NOx emission elevated with higher engine loads, which might be attributed to the formation of multiple fuel-rich areas of concern as a result of increased fuel burning at higher engine loads, which raised cylinder temperature and resulted in higher NOx [Emiroğlu and Şen 2018]. The maximum NOx obtained with B20 is 3064ppm and for B30 is 3394ppm and for D100 it is 3158ppm. As the load grows from moderate to greater numbers, so does the ignition interruption, resulting in premixed combustion. Enhanced charge duration results in a significant decrease in NOx levels [Yilmaz and Atmanli 2017].

Figure 8 depicts the smoke opacity of all experimental fuels. Smoke opacity rises as the BMEP grows. All of the experimental fuels exhibit the same trend. Even though the findings are highly equivalent to D100 discharges, the SO climbs somewhat as the amount of PBD rises. This is due to the fundamental fact that when engine loads increase, more fuel is injected into the combustion space to generate the desired power output, resulting in extra fuel-rich areas and increased exhaust smoke generation [Dillikannan *et al.* 2020]. The maximum Smoke at 4.14 bar BMEP is noted as 48.5HSU for D100; for B30 is 47.6HSU and for B20 it is 44.9HSU. This tendency is induced by the diffusion combustion stage, which is driven by a decrease in fuel-air blending speed owing to subsequent introduction [Zhou *et al.* 2013].

3.3.2. HC and CO

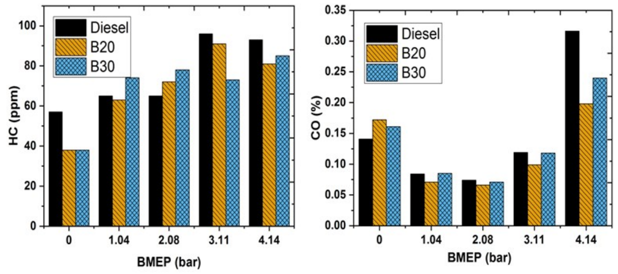


Figure 9. Variations of (a) HC and (b) CO at different BMEP

The major source of HC is partial combustion of the charge within the cylinder. Figure 9 depicts the engine emissions at various BMEPs for the B20, B30, and D100. It has been noticed that when BMEP increases, the HC emissions decrease. HC rises as the blend's concentration increases. This propensity is induced by the CN, leading to a thin exterior flame region, which raises the HC **[**De Poures *et al.* 2017**]**. Because the temperatures are low, the increased LHV of PBD results in lean combustion and quenching, resulting in post-oxidation. Its contributions to diesel supply extra oxygen during combustion, and a smaller percentage of PBD does not impact the spray properties of the combination, allowing for an enhanced combination [Ashok *et al.* 2019].

Figure 9 shows CO emissions from CRDI fueled with B20, B30, and D100. CO emissions decrease with rising BMEP at reduced BMEP and rise with increasing BMEP at greater BMEP. Identical patterns were seen for all experimental fuels, owing mostly to the reduced combustion temperature. Increased BMEP, on the contrary, improved CO, which may be due to the greater combustion speed at greater engine loads, which facilitates CO oxidation [Li *et al.* 2015]. This is primarily because when PBD levels rise, the engine's cylinder temperature decreases. At lower loads, lean charge absorbs heat from the products of combustion whereas at higher loads combustion gradually increases as a result of accumulation of fuel droplets. Lower viscosity increase sprays penetration and leads to wall deposits [Radheshyam *et al.* 2019]

4. Conclusions

The concentration of PBD on combustion and emission parameters was analyzed in this paper without any modifications in the CRDI Diesel engine test rig with blends B20 and B30 and compared with D100.

- The increase in load ICP, and net HRR decrease and at elevated loads increase as a result of premixed combustion. The heat release rate (HRR) of the diesel, B20, and B30 blends exhibited a reduction of 0.95%, 0.92%, and 0.87%, respectively.
- The brake thermal efficiency (BTE) has a range of 17.06% to 34.3% for usual diesel fuel, 16.27% to 33.78% for D80B20, and 15.66% to 32.12% for D70B30 fuels. BTE range from Diesel > B20 > B30, respectively.
- The NOx obtained with B20 is 3064ppm and for B30 is 3394ppm and for D100 it is 3158ppm. NOx emissions were noted to be lower for test fuel D80B20 at 100% load and are quite nearer to D100 at similar engine conditions.
- The emissions of HC exhibit a decreasing pattern as the loads increase. Furthermore, the HC increases in direct proportion to the combination. The Diesel and B30 exhibited an increase of 5.8% and 4.71, respectively, in comparison to the B20.
- CO emissions are significantly elevated at 100% load and reduced at 50% load. The CO emission reductions for B20 and pure diesel, as well as the B30 mix, were 15.19% and 10.45% respectively. Nevertheless, the mix D70B20 exhibits reduced emissions compared to all other fuels tested.
- Smoke is found to be high from low to medium loads and low from medium to higher loads for the blend D80B20. The maximum Smoke at 4.14 bar BMEP is noted as 48.5HSU for D100; for B30 is 47.6HSU and for B20 it is 44.9HSU.

As a result of the findings, it is possible to infer that the Pedicel Bio-diesel may be a regionally based prospective alternative.

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