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Performance and Emission Characteristics of Waste Frying Oil Biodiesel Stored Under Optimized Condition

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Abstract

Diesel engines are the most ideal prime-movers for automobiles, railways, and marine transport to generate power. A hasty switch to alternative fuels is crucial to meet the diesel fuel demand as well as to safeguard the environment from the pollution caused by the diesel fuel combustion. In recent periods, biodiesel becomes an established possible substitute fuel for Compression Ignition (CI) engines as it offers numerous important advantages like bio-degradability and renewability. It also produces comparable engine performance and relatively lowers toxic emissions. A single cylinder, 4.4 kW rated power CI engine was operated with biodiesel with Pyrogallol (PY) stored at optimized storage conditions (B100 (PY)), biodiesel stored at 4.5 months at ambient condition (B100) and diesel fuel. The engine performance results indicate that the brake specific fuel consumption by B100 (PY) was lower with 9.62% than that of B100 and 15.09% higher than the base line diesel fuel. The thermal efficiency of the engine fuelled with B100 (PY) was comparable with diesel. The engine thermal efficiency with diesel and B100 (PY) is 31.79% and 29.53% respectively. Further, there was no significant changes in combustion characteristics, viz. heat release rate and gas pressure available in cylinder between B100 (PY) and diesel fuel. The Nitrogen Oxides (NO_x) with B100 (PY) was 15.04% higher than diesel. This is because of 10 - 11% oxygen substance present in biodiesel. However, the NO_x concentration by B100 (PY) was 8.43% lower than B100. Similarly, the smoke density with B100 (PY) was 9.83% and 25.72% lower than B100 and diesel fuel respectively. The engine performance results thus showed that waste frying oil (WFO) biodiesel has to be stored under optimum conditions to obtain equivalent engine performance and lower emissions.

Keywords: Biodiesel, waste frying oil, antioxidant, pyrogallol, storage stability, diesel engine;

1. Introduction

The declining of world fossil fuel supply needs a source of replacement. The resources of an alternative fuel resource will play a critical role to uproot the scarcity. The demand for fossil fuel raises due to the increasing transportation, mechanization and industrialization. Thus, limited sources and environmental pressure have necessitated the seek for alternative fuels [1], which partially solves the problems of environmental degradation, economy stability, energy security, constraints on fuel import and agricultural economy. Generally, diesel engines were operated by using fossil fuels blended with different biodiesel and their blends, which are approved as a power source with high efficiency of energy generation in the field of automobile. Biodiesel is a renewable fuel that is obtained from vegetable oils, such as sunflower, sesame, groundnut, cotton seed, soybean, canola, waste cooking oils, or animal fats. These oils and fats undergo a chemical reaction with an alcohol, such as ethanol or methanol in the presence of a catalyst to form fatty acid methyl ester called as biodiesel. Biodiesel contains no aromatics, and has higher cetane number than diesel fuel, and with trifling oxygen and sulphur content [2]. Among these, biodiesel from waste cooking oil is considered as an important source. Waste frying oil (WFO) has dual benefits (i) waste oil disposal strategy for government saves environmental pollution, and (ii) lowering of gas emission, which in turn guards human health. The biodiesel can be utilised as a potential alternative fuel in conventional CI engines without any alteration in engine parts [3, 4]. In addition, biodiesel cost is twice the rate of conventional diesel due to the high cost of biodiesel feedstock [5]. The cost of biodiesel fuel can be trimmed down by using the waste animal fats, waste frying oils, for the biodiesel production[6].

Zhang et al. and Supple et al. has stated that the use of WFO as a replacement for raw vegetable oil to produce

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biodiesel is a recommended approach to crash down the feedstock cost[7, 8]. Therefore, a search on cheaper feedstocks (inedible or waste feedstocks) for biodiesel production by the researchers is carried out to cut down the production costs. Low priced feedstocks as biodiesel source have been scrutinized, and few of them are described below. Lin and Li evaluated the engine performance and emissions with waste cooking oil and marine fish-oil biodiesel as the fuel. As a result they observed that the commercial biodiesel obtained from WFO, fish-oil biodiesel has higher NO_xemissions and black smoke opacity and a lower Carbon monoxide (CO) and Carbon dioxide emission (CO_2) and brake-specific fuel consumption rate (BSFC)[9]. The methyl ester produced from WFO used in a direct injection diesel engine was assessed by Utlu et al. They observed that the levels of emission, such as CO, CO_2, NO_x, and smoke darkness of WFO biodiesel are less than the conventional diesel fuel [10].

Biodiesel has higher boiling point, high specific gravity and higher cetane number than diesel fuel and contains 10% oxygen. It is a low smoke emissions fuel and environmentally friendly.The ignition delay gets shorten due to its higher cetane number, which results in reduction of NO_x emissions in the initial phase of combustion process. Exhaust gas emissions such as CO, Hydro Carbons (HC), Particulate matters (PM), Sulphur Oxides (SO_x), polycyclic aromatic hydrocarbons, and smoke are also exhausted lower with biodiesel than with diesel [11-15]. On combustion biodiesel provides considerable reductions in CO emissions [16], PM emissions [17], and total HC emissions when compared to the conventional fossil fuels [18- 20].

Agarwal and Das reported that better performance in terms of brake-specific energy consumption, thermal efficiency, exhaust emissions, components wear and smoke opacity was observed in the engine fuelled by biodiesel than that of diesel engines during the complete combustion [21]. Similar results were observed by many researchers with different biodiesel and its blends from various sources [22-25].

Gopal et al.have identified a remarkable reduction in smoke emission, CO and unburned HC, but NO_x seems to be slightly higher for biodiesel and its blends compared to diesel fuel [26]. Numerous studies on CI performance using WFO derived biodiesel are available in the literature. Biodiesel was obtained from waste palm oil [27, 28], waste peanut oil [29], waste coconut oil [30] etc., Many researches have been carried on the use of substitute input products like soybean and rapeseed waste oil in the production of biodiesel for use in CI engines [22, 31-37]. Engine performance parameters, such as ignition delay, thermal efficiency, specific fuel consumption (SFC), cylinder pressure, heat release rate, exhaust gas temperature (EGT), concentration of NO_x, HC and smoke were analyzed while running the CI engine using waste frying oil biodiesel [38-44].

Cetinkaya and Karaosmanoglu made a performance in an engine operating on waste frying oil biodiesel and showed that the smoke reduction was around ,60 % for B100 (100% biodiesel) when compared to conventional diesel fuel [23].A 34 kW, direct injection, four stoke ,three cylinder engine fuelled with biodiesel from waste fried olive oil shows the result with a reduction of CO (58%), CO_2 (8.6%), and SO_x emissions (57.7%).Any have, an increase in SFC with 8.5% and 32% of NO_x emissions, were observed respectively[45].

The performance and emissions of an engine with soybean biodiesel by toting up by various antioxidants, such as Butylated hydroxyanisole (BHA)and tert-Butylhydroquinone (TBHQ) and found effectively on governing the NO_x discharge for soybean biodiesel, but the other additives have no effect on dropping the NO_x release [46]. Ryu, observed the efficacy of five different additives, such as Propyl Gallate (PG), Butylated hydroxytoluene (BHT), BHA, TBHQ, and α-tocopherol respectively. The BSFC of biodiesel fuel with additives was found to be shrunken compared to biodiesel fuel without antioxidant additive [47].

Ileri and Koçar, have determined that the 2-Ethyl Hexyl Nitrate (EHN) could be a potential additive for dropping NOx emission at the increasing rate of the CO emission. EHN followed by BHA and BHT was found to be a best NO_x reducer [48]. Rizwanul et al. performed an experiment with BHA and BHT antioxidant at 1000 ppm concentration to palm biodiesel and observed the engine performance and emission characteristics [49]. Roy et al. reported that HC and CO emissions reduction were possible with the increase of blending ratio between biodiesel and diesel [50].Balaji et al., reported that SFC and Brake thermal efficiency (BTE) are approximately similar with increase in ratio of PY as an additive for Neem oil biodiesel. And also found that HC emission lowered by 31% at full load compared with diesel, and a rise inCO_2, CO and smoke emissions were noticed [51]. Varatharajan et al. examined diesel engine fuelled with soybean biodiesel added with P-Phenylenediamine (PPD) derived aromatic amine antioxidants and noted that a remarkable reduction in NO_x level [52].

No significant variation was found in BSFC and BTE for Neem oil biodiesel with A-tocopherol acetate as an additive and also HC, CO and smoke emissions were increased with antioxidant concentration [53]. Sharma and Murugan, studied the effect of long term storage by its IP of biodiesel with and without antioxidant and made a performance study on CIengine. In this study Jatropha biodiesel with waste tyre pyrolytic oil and its blends were added with four different antioxidants like TBHQ, PG and PY. The results showed that the totalling of antioxidant to the biodiesel make better the fuel performance. A decrease in BSFC was found to be with the fuel containing 20% blend and PY with a highest reduction on NO_x and HC emission. As a result it was concluded that biodiesel with PY shows good response towards long term storage while performance on diesel engine [54].

Palash et al. evaluated the engine performance and smoke emission of biodiesel blends obtained from Jatropha oil with and without the addition of antioxidant N,N'-diphenyl-p-phenylenediamine (DPPD). By adding the additive of 0.15% (m) DPPD in various proportions of blends, the reduction in NOx emissions were observed under the full throttle condition compared to biodiesel blends without the additive [55]. Hess et al reported that the biodiesel with BHA / BHT shows a drastic reduction of NOx emissions in diesel engines. As a summary, the antioxidants serve an additional purpose as well [46]. It is observed that the biodiesel oxidize more swiftly than petro diesel and storage stability is a concern. To improve its storage stability, biodiesel blends are likely to be added with antioxidants. Addition of additives makes a potential impact on the emission of biodiesel combustion[56].

In this study, the performance of a single cylinder, four stroke, 4.4 kW rated CI engine with 100% WFO biodiesel, WFO biodiesel stored at an optimum condition with pyrogallol as an additives and with diesel were carried out. The engine's operational factors, such as BSFC, BTE, brake power, heat release rate, total fuel consumption, cylinder gas pressure, and emissions were compared for three fuels namely 100% biodiesel, biodiesel with additive and diesel.

2. Materials and methods

2.1. Test fuel

Biodiesel obtained from waste frying oil collected from Indian fast food in which various food items, such as fish, chicken, beef were fried. The conversion of WFO to biodiesel was carried out by standard transesterification process. The engine testing and performance were carried out with the following three sources (i) 100% biodiesel maintained at optimum storage condition (B100 (PY)) i.e. stored at 45°C for 4 months with 435 ppm of pyrogallol as an antioxidant, the optimum condition of biodiesel was obtained by experimenting the biodiesel by treating with various composition of storage condition under response surface methodology (Box Behnken method), (ii) 100% biodiesel stored at atmospheric conditions for 4 months without the addition of antioxidant (B100) and (iii) Diesel. Table 1 shows the specification of test fuels. The fuel stored under optimum condition temperature is maintained in a electrical food warmer (Make: FW 554). The chemicals for the preparation of biodiesel, such as methanol, NaOH and antioxidant pyrogallol (Supplier:Merck) were procured from local chemical dealer. The engine operating performance and smoke emission tests were conducted at standard engine testing laboratory at Chennai, India.

2.2. Experimental setup

The engine experiments were conducted in an IC engine laboratory. A single cylinder, 4 strokes, air cooled, direct injection CI engine was used. The engine specification is given in Table 2. An electrical dynamometer coupled with the engine with a rheostat with loading arrangement to supply the load and the setup is shown in Figure 1. The engine test laboratory equipped with a complete measuring facilities relating to diesel engine performance parameters and analysis of exhaust gas emissions. The engine was equipped with pressure sensor (make: Kistler, model: 6961A250), crank angle encoder (make: Kistler) and data acquisition system. Two separate tanks were used for biodiesel and diesel fuels. The consumption of fuel was measured by accounting the time taken for a preset quantity of fuel to flow into the engine. An exhaust gas analyser (make: AVL. 444, model: DI GAS) to quantify the CO, HC, and NOx concentrations in the exhaust gas. The smoke density was recorded using a Smoke meter (make: AVL, model: 415).

Table. 1. Test fuel Specifications

Properties	B100	B100 (PY)	Diesel
Density at 15°C, (g/m^3)	0.857	0.871	0.860
Kinematic viscosity at 40°C, (cSt)	3.671	3.691	4.24
Flash point, °C	203	211	52
Heating value, (MJ/kg)	39.85	40.14	43.35
Cetane number	56.61	57.4	49
Iodine value (gI_2/100 g of oil)	71.33	73.42	80-135
Acid value (mg KOH/g of oil)	0.204	0.213	-

Table 2. Engine specifications

Make	Kirloskar
Rated power	4.4 kW
Bore diameter	87.5 mm
Compression ratio	17.5:1
Dynamometer	Electrical
Number of cylinder	One
Rated speed	1500 rpm
Stroke	110 mm
Cranking	Hand Cracking
Injection timing	23° bTDC

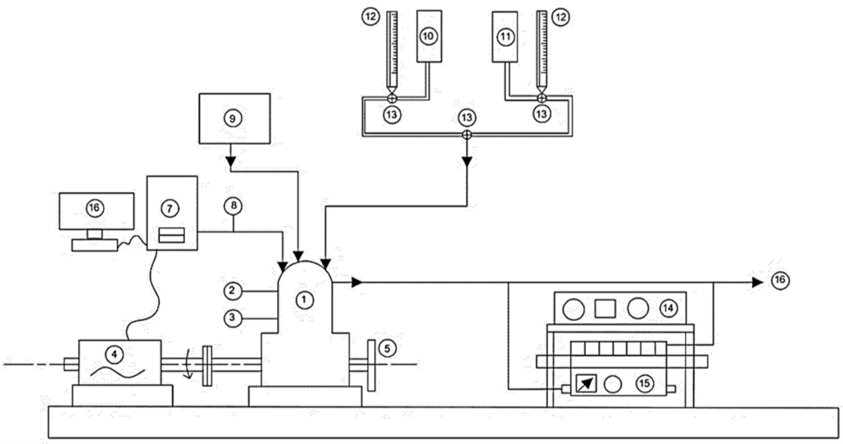

Figure 1 . Schematic layout of experimental system

1. Engine, 2. Electrical dynamometer, 3. Electrical load bank,
4. Diesel fuel tank, 5. Biodiesel fuel tank, 6. Burette,
7. Two way control valve, 8. Pressure sensor, 9. Personnel computer,
10. Data acquisition system, 11. Crank angle encoder, 12.Exhaustgas thermocouple,
13. Di gas analyzer, 14. Smoke meter (FSN), 15. Exhaust gas to air.

2.3. Test methods

The engine was operated for a start-up period till the circulation water and oil attains a firm temperatures. The engine takes half an hour to attain its stable running condition. After warming up, the test procedures were set and the engine was permitted to attain a steady state prior to note of data. Regulatory test procedures were followed to verify and ensure conformity with the mandatory standards to measure the emissions.

The engine was started with required fuel and made to run for 15 – 20 mins. The engine was operated at various load conditions of 0, 25, 50, 75 and 100% of full load and at 1500 rpm. At each loading condition, the constant engine speed was maintained at 1500 rpm and the heat release data, crank angle vs. cylinder gas pressure, fuel consumption (time taken for 10 cc), exhaust gas temperature and gas emissions were taken. The parameters such as BSFC, TFC, BTE and brake power output were calculated based on the data collected. Emissions from exhaust gas were generally measured for every loading condition on a volumetric basis. The exhaust emissions measurements were calculated as a weighted average.

3. Results and discussion

The performance of a single-cylinder diesel engine was studied with the fuels listed below:(i) B100 (PY) - 100% waste frying oil biodiesel stored under optimum storage condition (waste frying oil biodiesel treated with 435 ppm PY and stored at 45°C for a period of 4 months), (ii) B100 – 100% waste frying oil biodiesel stored for 4.5 months at ambient condition without the addition of antioxidant, (iii) Base line diesel fuel.

The engine performance result with the three fuels is described in terms of brake specific fuel consumption, thermal efficiency, exhaust gas temperature, heat release data, cylinder pressure data, smoke, NO_x, and unburnt hydrocarbon in the exhaust gas.

3.1. Brake specific fuel consumption

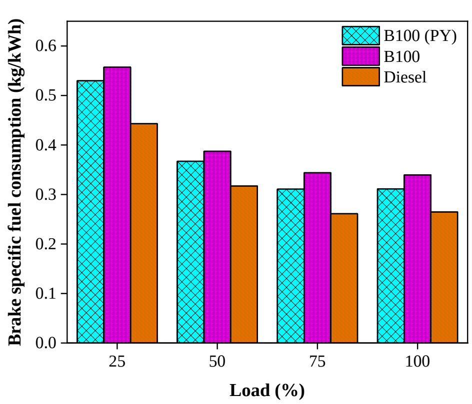

Figure 2. Brake specific fuel consumption vs load.

The engine's brake-specific fuel consumption (bsfc) at different loads while using B100 (PY), B100 and diesel fuel were shown in Fig 2. It is perceived that, for all the three test fuels, the bsfc decreased up to 75% of its full load condition. And further, the bsfc was minimum with all three fuels at 75% full load and it was 0.312, 0.343 and 0.260 kg/kWh for B100 (PY), B100 and diesel respectively. Compared to diesel fuel operation, the bsfc was 15.08% and 24.04%higher respectively with B100 (PY) and B100 fuel operation. This may be due to the poor energy content of biodiesel.

Compared to B100, the bsfc with B100 (PY) was 9.62% and 9.06% lower at 75% and 100% full load respectively. As B100 (PY) was stored under optimum storage conditions, it would have undergone reduced oxidative degradation and its quality would have been maintained. Identical results were obtained by using B100 and B100 treated with antioxidants as fuels [47, 48, 51, 57-59]. At 100% full load, there was marginal increase in bsfc for all fuels because at this load, relatively more fuel would have been injected to produce the rated power output and the engine would have operated with an air fuel ratio closer to stoichiometric.

3.2. Brake thermal efficiency:

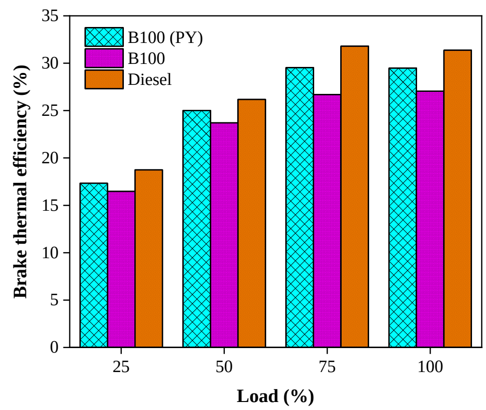

Figure 3. Brake thermal efficiency vs load.

The dissimilarity of thermal efficiency pertaining to engine load for the three fuels B100 (PY), B100 and diesel is given in Fig 3. For all the tested fuels, the thermal efficiency was seen to upsurge with load up to 75% load. And also it is seen that maximum BTE was obtained at 75% of full load. At 75% load, the thermal efficiency with diesel, B100 (PY) and B100 were found to be 31.79%,29.53% and 26.69% respectively. However, with B100 (PY), the engine thermal efficiency is nearer to the diesel fuel operation.

The BTE with B100 (PY) and B100 were lower compared to conventional diesel fuel due to their low energy content. At full load, more fuel is injected and the engine runs with very little excess air and there is possibility for incomplete combustion of fuel which leads to a drop in thermal efficiency. The optimum storage condition of B100 with the presence of antioxidant in biodiesel reduces oxidation and promotes more complete combustion thereby improves the brake thermal efficiency. Venkatasubbaiah showed similar kind of result with rice bran oil biodieseltreated with N,N′-diphenyl-p-phenylenediamine antioxidant [60]. Kivevele et al., also showed this kind of trend while using *croton megalocarpus* biodiesel treated with pyrogallol [59]. Balaji and Cheralathan reported similar trend in thermal efficiency for Neem oil biodiesel treated with L-ascorbic acid as antioxidant [61]. Varatharajan et al., obtained similar result for jatropha biodiesel added with antioxidant like BHTand α-tocopherol [62].

3.3. Exhaust gas temperature

Fig. 4. Shows the disparity of exhaust gas temperature at varied loads. It is found that the exhaust gas temperature increases with rise in increase in load, which may be because of the power output increase with respect to load. Due to this increased output, more fuel would have been injected, resulting in greater heat release rate and increase in EGT at high loads. All the tested fuels show a similar trend. At 75% full load, the maximum EGT attained while operating the engine with B100 (PY) was 252°C which is 5.55% higher than diesel and 6.34% lower than B100. Similar trend was documented by Balaji and Cheralathan, Kivevele et al., Zafer Aydin and Aykut Safa , and Ajay V. Kolhe et al., [58, 59, 70, 71]

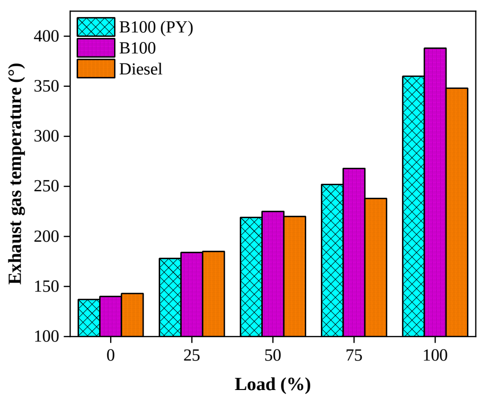

Figure 4. Exhaust gas temperature vs. Load

3.4. Cylinder gas pressure:

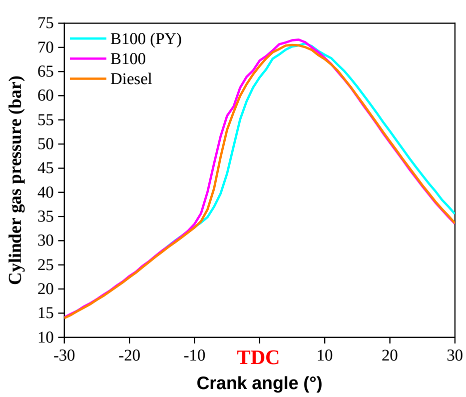

Figure 5. Cylinder gas pressure vs crank angle.

Fig.5.Shows the profiles of cylinder gas pressure with B100 (PY), B100and diesel fuels at 75% load condition. There is no significant difference in cylinder gas pressure profiles among the biodiesel fuels and diesel fuel. The presence of oxygen in biodiesel would have helped for the better combustion of biodiesel fuels[63-65]. The maximum pressure was found to be 71.822 bar, 70.826 bar and 70.494 bar respectively, for B100,B100 (PY) and diesel respectively.

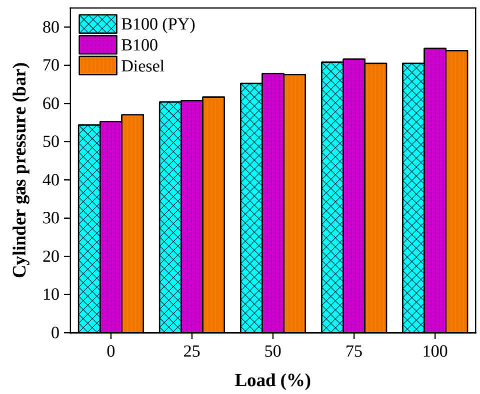

Figure 6. Cylinder gas pressure vs load.

Fig.6.Shows the maximum gas pressure in the cylinder at different engine loads. It is observed that the gas pressure in the cylinder increases with the respective engine load, which is due to more fuel injection at higher loads to produce more power output.

3.5. Heat release rate:

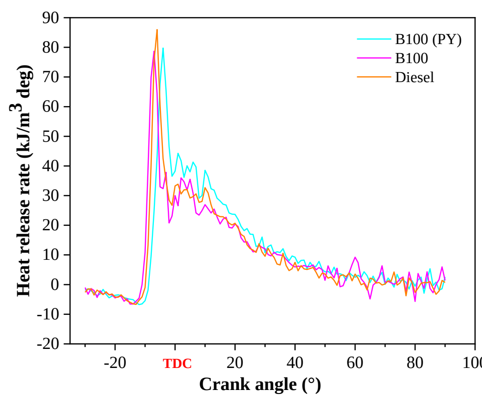

Figure 7. Heat release rate vs crank angle.

Fig 7. shows the variation of HRR with B100 (PY), B100 and diesel at 75% full load. Different stages of combustion like ignition delay period, rapid combustion, controlled combustion and after burning could be seen in the HRR diagram. It is found that the maximum HRR for B100 (PY),B100 and diesel are 79.79, 78.65 and 85.97 kJ/m3 deg respectively. The slight decrease in maximum heat release rate with biodiesel fuels may be owing to their lower content of energy and higher viscosity. Furthermore, no significant difference in maximum HRR between B100 and B100 (PY) is observed.

The data from HRRC graph was utilized to find the combustion factors such as start of fuel injection (SoI), start of combustion (SoC), ignition delay (ID) and maximum HRR.

The ignition delay was calculated by taking the difference in crank angle among SoI and SoC. Table 3. shows these parameters for diesel, B100 (PY), and B100 at 75% full load. In this work, start of injection was 23° bTDC as recommended by the supplier. Further, it is noticed that, the delay in ignition for B100 was the lowest followed by diesel and B100 (PY). The ignition delay slightly decreases with the use of B100 compared to diesel.

Table 3. Combustion parameters at 75% load

Fuel	SoI (° bTDC)	SoC (° bTDC)	ID (°CA)	Maximum gas pressure in cylinder (bar)	Maximum HRR (kg/m^{3}deg)
B100 (PY)	23	8	15	70.824	79.772
B100	23	10	13	71.600	78.660
Diesel	23	9	14	70.496	85.981

Similar results were documented by Ryu et al., with soybean oil biodiesel mixed with antioxidants [47].Sharma and Murugan, also pointed out similar trend for the diesel engine operated with Jatropha biodiesel treated with antioxidants [54].

3.6. NOx concentration:

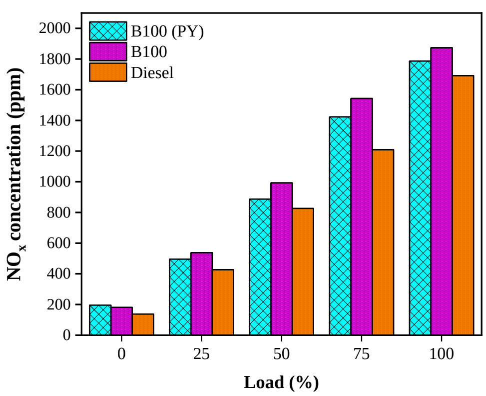

Figure 8. NO_x concentration vs load.

The variation of NOx concentration with increase in load for B100 (PY),B100 and diesel is shown in Fig 8. It is well known that the major factors that affect the formation of NOx are temperature and availability of oxygen [66]. It is seen that at all low loads (No load and 25% full load) the NOx concentration is very less. This mightbe due to the lower combustion gas temperature. It is seen that the increase in exhaust gas with increase in engine loads for all the fuels tested. This could be due to the higher quantity of fuel undergoing combustion at higher loads to produce more power output which in-turn release a high combustion gas temperature.

The higher NOx concentration from biodiesel fuels is observed than the diesel, because of the availability of oxygen in biodiesel, which promotes complete combustion resulting in higher gas temperature. It is reported that biodiesel contains 10 – 10% oxygen when compared to B100, B100 (PY) produces lower NOx. This may be due to the presence of antioxidant in the biodiesel stored under optimum conditions. At 75% full load, B100 (PY) showed 8.42 % lower and 15.04% higher NOx concentration with B100 and diesel respectively. Similar results were documented by many researchers [48, 67, 68, 72, 73].

3.7. Smoke density

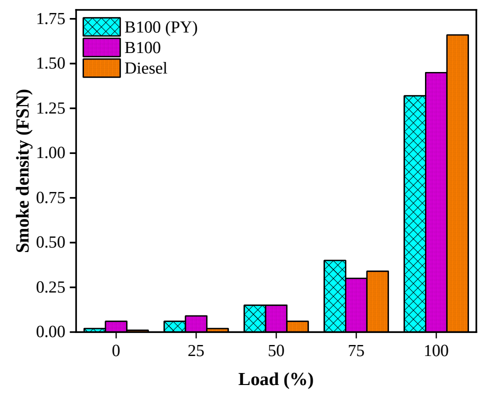

Figure 9. Smoke density vs load.

Fig.9. shows the difference in smoke density in terms of increase in engine load. An increase in smoke density is noted with a rise in engine load. At low and medium loads (no load to 50% load), the smoke density is less than 0.25FSN, because at these loads, the engine runs with larger quantities of excess air. Maximum smoke density was recorded at 100% full load for all the test fuels. At 75% and 100% loads, both biodiesel fuels showed lower smoke density. The smoke density of biodiesel was lower than diesel due to its oxygen content [69]. The use of B100 (PY) as fuel resulted in 9.83% and25.72% lower smoke density compared to B100 and diesel respectively at100% load. The presence of antioxidant in B100 (PY) would have resulted in more complete combustion resulting in lower smoke density. Similar results were obtained by many researchers [48, 58, 68].

3.8. HC emission

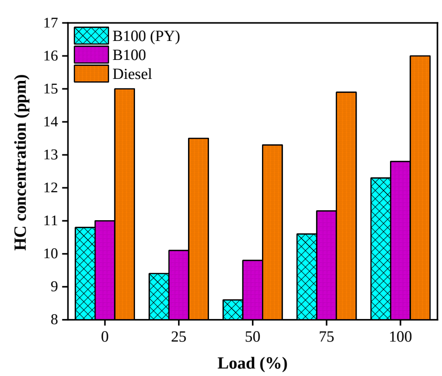

Figure 10. HC concentration vs load.

The variation of HC emission by B100 (PY), B100 and diesel are presented in Fig 10. The HC concentrations of the all fuels are found to be the maximum at full load. The oxygen content in biodiesel fuels namely resulted in lower HC concentration compared to diesel. The biodiesel stored under optimum condition showed lower HC compared to B100 and diesel. At 75% load, B100 (PY) has 33.31% lower HC concentration than diesel. Similar result was recorded in many research works [53, 67, 68, 72, 73].

Conclusion:

The Performance and emission parameters of a CI engine fuel by waste frying oil biodiesel stored under optimized condition (B100 (PY)) have been evaluated and likened with base line diesel fuel and B100. The storage conditions were optimized using response surface methodology. The optimized storage condition for waste frying oil biodiesel was found as antioxidant concentration 435 ppm, storage temperature 45°C and storage period 4 months. The engine performance results were summarised as follows:

- The brake specific fuel consumption with B100 (PY) was lesser than that of B100 because of oxidative degradation and operation by diesel fuel shows a higher rate, and causes the low content of energy in biodiesel.
- The BTE of B100 (PY) and B100 were lower compared to diesel due to their lower energy content. It is observed that at 100% load, more fuel is injected with very little excess air which leads to efficiency drop due to partial fuel combustion.
- Further, there was no significant difference in combustion characteristics, viz. cylinder gas pressure and heat release rate between B100 (PY) and diesel fuel.
- It is found that, the B100 has lowest ignition delay followed by diesel and B100 (PY).
- B100 (PY) shows high exhaust gas temperature than that of B100 and diesel fuel.
- The NO_x concentration was found to be higher for biodiesel fuels compared to diesel. This is due to the availability of oxygen in biodiesel.
- Biodiesel has lower smoke density than diesel due to its oxygen content. In addition to that, biodiesel with antioxidant have resulted low smoke density due to complete combustion .
- The biodiesel stored under optimum condition showed lower HC compared to B100 and diesel.
- The engine performance results indicate that biodiesel produced from waste frying oil has to be stored under optimum conditions to obtain comparable engine performance and lower emissions.

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