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Experimental Investigation of Multiple Fry Waste Soya Bean Oil in an Agricultural CI Engine

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Abstract: Meeting the growing energy demand for sustainability and environmental friendly fuels is a continuous process. Several oxygenated fuels were tried and tested according to the availability depending upon the geographical locations to find a solution against rapidly depleting fossil fuels (gasoline and diesel). In the present investigation, the viability of waste fry cooking oil converted into biodiesel fuel and its various physiocochemical properties was evaluated. In this regard, the performance and emission of a CI engine was compared using biodiesel fuel and mineral diesel fuel. Experimental research was performed on a single-cylinder agricultural CI engine with indirect injection, and biodiesel fuel was used with three different types of fry oils. The fry oil was classified as one-time fry, two-time fry, and three-time fry. Engine efficiency and tail pipe emission attributes were evaluated for the three different fuels. The different fuel blends used for the experiment were B60 and B80 and were tested at full load, at different engine speed (rpm). It was found that brake specific fuel consumption (BSFC) increased with increasing speed, whereas brake thermal efficiency reduced with increasing engine speed. Brake thermal efficiency (BTE) reduces with increase in the engine speed because of a poor air–fuel ratio at high speed. CO_2 emission is higher because of the higher density and heating value of the biodiesel fuel, which depends on the blending ratio and the frying time of the fuel. It was also encountered that NO_x emission was higher for maximum test fuels except one-time fry waste cooking oil biodiesel at 60% blend, which showed lower NO_x than diesel fuel. Smoke opacity in both the blends have a decreasing trend with increasing speed and are lower than pure diesel. The 1FWCOB (fry waste cooking oil biodiesel), 2FWCOB, and 3FWCOB fuel exhaust gas temperature (EGT) is reduced because of higher cetane number and lower heating value. Based on the result obtained, it was concluded that by increasing the frying time of the soya bean waste cooking biodiesel, the emission characteristics and engine performance were affected. The need for sustainable fuel is important, thus the use of waste fry cooking oil is a potential replacement for diesel.

Keywords: waste fry oil; soya bean; biodiesel; NO_x; CI engine; emission

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1. Introduction

Transformation of the automotive industry has resulted in rising energy demand [1,2]. Diesel engines are in demand in many sectors due to their better fuel economy, higher efficiency, more reliability, lower fuel cost, and long-lasting capacity. Currently, there is much interest among researchers in alternative fuels and renewable energy because of the strict environmental emission policies, depleting fossil fuels, and enhanced global energy demand [3–5]. Direct-ignition compression-ignition engines (CI engine) capture a prominent share in the transportation sector [6] and other energy needs. The cost of the primary energy consumption fuels is increasing daily and due to increase in the population the need of energy is also increasing [7,8]. Thus, there is a strong need to shift to alternative sources of energy, which are renewable in nature, environmental friendly, and cost effective [9,10]. Small and medium capacity energy needs can be easily meet by the direct-ignition compression-ignition engines. Many experimentation and simulation studies have been conducted on diesel engines by adopting biodiesel fuel, processed from different vegetable and organic fat oil. Soya has been favored because of its renewable, reasonable, and low-grade oil factors [11,12].

Although the cost of soya cooking oil is higher than the conventional diesel oil in the present scenario, this will be a wrong decision against the increase cost of food and will strengthen the controversy of food vs. fuel. After cooking, however, a huge amount of fried soya cooking oil becomes waste and generally remains unused and unattended. Thus, by converting this fried soya cooking oil into biodiesel fuel can be a good alternative to the energy requirement up to medium scale, without modification in the existing diesel engine. The cost of biodiesel fuel comprises 75–90% of the raw edible cooking oil [13,14]. Therefore, it is important to use waste cooking oil to produce biodiesel to make it economical and sustainable, and in many restaurants/homes the waste cooking oils are disposed of in the drainage system, causing bad odor, blockage, and degrading groundwater [15–17]. Therefore, in many countries, pollution taxes have been implemented for disposing oils in the environment. In Turkey, the Ministry of Environment and Urban Planning has implemented law number 2872 to curb the waste of vegetable oil [10].

Because of the availability of different waste fry cooking oils and biodiesel fuels from different sources, it is difficult to maintain globally the biodiesel standards as per ASTM and EU norms. Combustion and fuel injection are affected by the physical and chemical attributes of biodiesel oil. Ignition delays are shortened by adopting biodiesel fuel because of higher cetane numbers related to diesel fuel. At the same time, biodiesel has a higher viscosity and boiling point; these properties affects the atomization, evaporation, and spray of the fuel advancing toward protracted combustion duration and slow burning [13]. Taking into account these explanations, biodiesel research should be focused on sustainable and inexhaustible sources, keeping in mind its effect on performance and combustion aspects of the engine as well as the exhaust emission. Thus, researchers have accomplished numerous surveys on WCO biodiesel and its blend with petro-diesel.

Rosca et al. [18] experimented with waste biodiesel fuel and conventional diesel in a DI-CI engine. An injection pump test bench supported the findings of fuel injection features. As the injection duration and cyclic delivery increased because of biodiesel properties, pressure wave propagation decreased. Because of low pressure wave propagation, maximum HRR was lowered, resulting in early combustion for biodiesel fuel. Hemanandh et al. [19] explored the use of waste fish fried oil in a one-cylinder, four-stroke CI engine. Waste fish fried oil biodiesel was blended with conventional diesel in a 10%, 20%, and 30% ratio. At 100% load, it was detected that CO emission was inversely proportional to the waste fish fried oil blending; HC emission at full load was lowered for biodiesel, but at lower load the HC emission was higher for biodiesel blend. NO_x emission was higher for waste fry fish oil blend in contrast to diesel, but at full load, 10% biodiesel blend showed lower NO_x emission. BSFC (brake specific fuel consumption) decreased with a 10% blending ratio, which was because of the lower calorific value and density of the biodiesel fuel. BTE was marginally higher with increasing biodiesel blend. Nour et al. [20] utilized various alcohols (n-octanol, n-heptanol, and n-butanol) with biodiesel (used fry oil) to enhance the performance and tail-pipe emission characteristics of a diesel engine. Ultrasonic-enhanced transesterification was employed to produce used frying oil biodiesel, achieving low production time, low viscosity, and high yield. Three ternary fuels were prepared using 80 vol% diesel, 10 vol% used fry oil biodiesel, and 10 vol% (n-octanol, n-heptanol, and n-butanol) in a diesel engine with 1/4, 1/2, and 3/4 loading. Thermogravimetric analysis concluded the improvement of vaporization characteristics of biodiesel fuel. During the use of n-butanol alcohol, specific fuel consumption increased by 6% and thermal efficiency was reduced, whereas for other fuel blends (n-butanol and n-heptanol) the results were similar to conventional diesel. Fuel blends displayed diminishing smoke opacity, NO_x, CO, and CO_2 were comparable with diesel.

Subramani et al. [21] analyzed the exhaust emission, performance, and combustion characteristics of 20% waste cooking oil biofuel blend with nanoadditives in a variable compression ratio CI engine. Cerium oxide nanoparticles were mixed with B20 biofuel by magnetic stirrer and then by ultrasonication at 15, 30, 45, 60 and 75 ppm ratio. The engine speed was kept constant at 100% load. It was observed that B20+cerium 45 ppm showed improvement in brake thermal efficiency by 3.62%, and SFC was downscaled by 3.3% in contrast to diesel. Nanoparticles improved the atomization of the fuel, leading to complete burning during combustion. CO, NO_x, and HC emission dropped by addition of cerium nanoparticles. Cerium acts as an oxygen buffer and reduces the NO_x emission by further increasing the cerium dosage. Dhinesh et al. [22] investigated WCO biofuel in different blend ratios of 20, 40, 60, and 100. Transesterification technique was used to produce biofuel and then analyzed by gas chromatography mass spectroscopy; properties were in accordance with ASTM standards. Fuel modeling was implemented by ANSYS for diesel fuel, WCO biodiesel, and its blend. Experimental and simulation showed. NO_x emission was enhanced by 16.46%; therefore, to curtail NO_x exhaust gas, recirculation was carried out at 5%, 10%, and 15%. The use of EGR reduced NO_x emission but at the same time increased other emissions, such as CO, HC, CO_2, and smoke; thus, 10% EGR was the optimal balance between NO_x and other emissions.

Hemanandh et al. [23] researched the performance and emission features of used cooking oil transesterified biodiesel and hydrotreated waste cooking oil, using a four-stroke, one-cylinder CI engine of 4.3 kW and run at fixed speed of 1500 rpm. Waste cooking oil was hydrotreated by aluminum oxide/nickel–molybdenum catalyst at a temperature of 633 K and pressure of 6 MPa, whereas transesterification was carried out using sodium hydroxide and methanol. Blends of 100% FMWCO, 100% HTWCO, 25% FMWCO, and 75% diesel and 25% HTWCO, and 75% diesel were studied on the basis of emission and performance at different loading conditions. NO_x, CO, CO_2, HC, smoke, and BSFC were reduced, but at the same time, BTE increased for hydrotreated waste cooking oil in contrast to diesel fuel. Upendra et al. [24] implemented the emission parameters of numerous edible, nonedible, alcohol, waste, and waste animal fat biodiesel. The experiment was carried out on a DI one-cylinder CI engine at fixed speed and fixed injection timing. It was observed through numerical analysis that emission was highest with soya bean edible biodiesel by 21.79%, whereas for waste oil it was 15.8%. Particulate matter was reduced by 45% for soya bean and 23.83% for frying oil. Smoke was reduced by 89.14% and 93.8% for fry oil and sunflower oil, respectively. Mustafa et al. [25] explored the use of frying palm oil biodiesel in a four-stroke, four-cylinder II engine. During the experiment, it was observed that thermal efficiency was reduced by increasing the blending ratio of frying palm oil biodiesel. NO_x emission increased; B60 at 3000 rpm had the highest NO_x, whereas smoke was lowest for B100 at 3000 rpm. Lertsathapornsuk et al. [26] experimented on the use of waste frying palm oil in a six cylinder, 127 kW diesel generator with three fuels (diesel, 100% waste fry palm oil biodiesel, and 50% waste palm oil biodiesel). At different engine load, its NO_x, HC, SFC, and engine efficiency were investigated. Furthermore, as the load of the engine NO_x emission increased, B100 showed highest NO_x emission, whereas for HC emission B100 was lowest. Engine efficiency was low at lower loads, but at 75% load, the B100 showed better efficiency than other fuels. Waste fry palm oil biodiesel blend showed increased SFC in contrast to diesel at different loads.

Many researchers have implemented research with waste cooking oil and cooking fry oil biodiesel and its blend with diesel to examine its effect on engine performance and emission characteristics. However, there is a research gap for the use of one-time, two-time, and three-time used fried soya biodiesel oil in the diesel engine with its performance and emission characteristics. The main objective of this study is to evaluate the physiochemical properties of one-time, two-time, and three-time used fried soya biodiesel oil and to find its compatibility with the existing diesel engine. This study examined the performance and emission features under the influence of diesel and waste fry cooking oil (one-time, two-time, and three-time) used together under different blending conditions at varying engine speed and 100% load. The blends were prepared in the ratio of fry waste cooking oil biodiesel 60% and diesel 40%, and fry waste cooking oil biodiesel 80% and diesel 20%. Engine speed was varied from 1200 to 1800 rpm with a 200 rpm increment at constant load of 100%. Various performance and emission parameters were analyzed for the test fuel and compared with the baseline data of conventional diesel fuel.

2. Biodiesel Production and Fuel Properties

Soya bean oil is readily available in USA, Brazil, India, Argentina, China, and other countries as major edible oil for cooking. Fresh soya bean cooking oil was procured from the open market and used for frying in the kitchen. The method of preparing the sample of different fry oil, fry time and fry food, was kept constant. The waste and used cooking oil was filtered and categorized as first fry waste cooking oil, second fry waste cooking oil, and third fry waste cooking oil. Biodiesel was prepared using the transesterification process in the university lab. Methanol alcohol (99.9% purity) and potassium hydroxide catalyst (reagent grade 90%, flakes) were used for preparation of biodiesel, which were procured from Sigma Aldrich, South Korea. Biodiesel was produced by the method of one-stage alkaline transesterification using fry waste cooking oil (soya bean). A liquid solution of methanol (135 mL) and potassium hydroxide (2.5 gm) was mixed with 500 mL of fry waste cooking oil in a 10:1 molar ratio and heated to 55 °C for 2 h [27]. Three types of fry oil were categorized into three different biodiesel fuels, namely, first fry waste cooking oil biodiesel (1FWCOB), second fry waste cooking oil biodiesel (2FWCOB), and third fry waste cooking oil biodiesel (3FWCOB).

The biodiesel standard was assured by comparing the properties of biodiesel and diesel with ASTM D6751. All the fuels were within the standard limits. Different physicochemical properties of the biodiesel were evaluated as per ASTM standards given in Table 1. The various physicochemical properties evaluated are given in Table 2. The experiments were carried out with pure diesel and a blend of biodiesel. Blends of 1FWCOB, 2FWCOB, and 3FWCOB were prepared in a ratio 60% biodiesel and 40% diesel (B60), and 80% biodiesel and 20% diesel (B80), compared with each other and pure diesel.

Table 1. Fuel properties test and limits [28].

Test	ASTM Test	ASTM Limits
Kinematic viscosity, mm^2/s	D 445	1.9–4.1
Cloud point, °C	D 2500	–
Pour point, °C	D 97	4.4–5.5 °C
Flash point, °C	D 93	52 °C min
Sulfur by weight, %	D 129	0.5% max
Cetane number	D 613	40 min
Density	D 5002	15–35 °C

Table 2. Fuel physicochemical properties.

Property	Unit	Standard (ASTM)	Diesel	1FWCOB	2FWCOB	3FWCOB
Density	$kg\ m^3$	900	833	841	858	871
Viscosity	mm^2/s	1.9–6	2.72	4.41	4.66	4.79
Calorific value	$kJ\ kg^1$	>33,000	43,400	39,435	38,915	38,121
Cloud Point	°C	−2 to 12	−8	−6	−6	−5
Flash Point	°C	>130	78	67	73	77
Pour Point	°C	−15 to 10	−6	−11	−9	−8
Cetane Number	CN		55.32	58	61	65
Sulfur Content	%		0.048	0.014	0.012	0.012

3. Experimental Setup

A single cylinder, water-cooled agriculture diesel engine, with a rated power output of 7.4 kW was utilized for this study and its experimental setup is shown in Figure 1. The diesel engine was fueled with indirect injection, manufactured by Daedong Korea Ltd. (Daegu Gwangyeoksi, Korea). Experimentation was accomplished at a constant load and variable speed of 1200, 1400, 1600, and 1800 rpm. Various engine specifications and its details are given in Table 3. An eddy-current dynamometer was utilized for measuring the power output of the engine. BTE and BSFC were analyzed for measuring the variation in engine performance parameters. Engine emission parameters were analyzed by using a Hephzibah (HG-550RT), South Korea, gas analyzer. A probe was placed in the exhaust pipe to obtain the digital readings of the emission. Smoke of the engine was measured using a smoke meter. Exhaust gas temperature was measured using a k-type thermocouple. To reduce the parapraxis in the data, uncertainty has been calculated. When obtaining accurate data during experimentation, it is important to calibrate the equipment. To obtain an accurate data during the experiment, readings were collected more than twice and then the arithmetic mean was computed. Range and resolution of the smoke meter and gas analyzer are listed in Table 4.

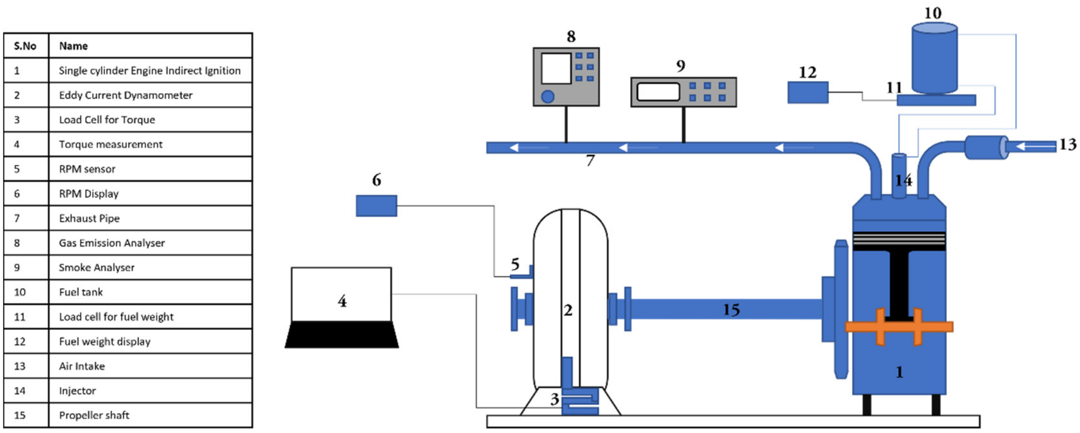

Figure 1. Experimental setup.

Table 3. Engine specification.

Parameters	Description
Manufacturer	Daedong
Engine Type	Horizontal, 4-stroke
Rated Power Output (kW)	7.4
Engine Cooling	Water Cooled
Number of Cylinder	1
Stroke Length (mm)	95
Bore (mm)	95
Compression Ratio	21
Displacement (cc)	673
Injection Pressure (kg cm^{-2})	200

Table 4. Range and resolution of the smoke meter and gas analyzer.

Exhaust Emission	Range	Resolution
HC	0–10,000 ppm	1 ppm
CO	0–9.999%	0.001%
NO_x	0–5000 ppm	1 ppm
Smoke	0–100%	0.05%

4. Result and Discussion

4.1. Performance Characteristics

4.1.1. Effect on Brake Specific Fuel Consumption

Brake specific fuel consumption is an important factor to analyze the efficiency of the fuel being consumed. The fuel used in the engine was fry waste cooking oil with different frying times, namely, samples 1FWCOB, 2FWCOB, and 3FWCOB. The variation in BSFC for diesel fuel, 1FWCOB, 2FWCOB, and 3FWCOB is given in Figures 2 and 3, with respect to speed for the B60 and B80 blends, respectively.

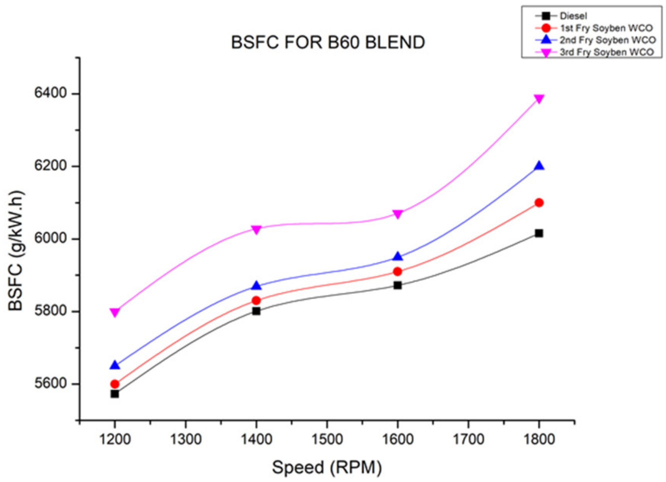

Figure 2. BSFC of different fry oils (B60 blend) at different rpm.

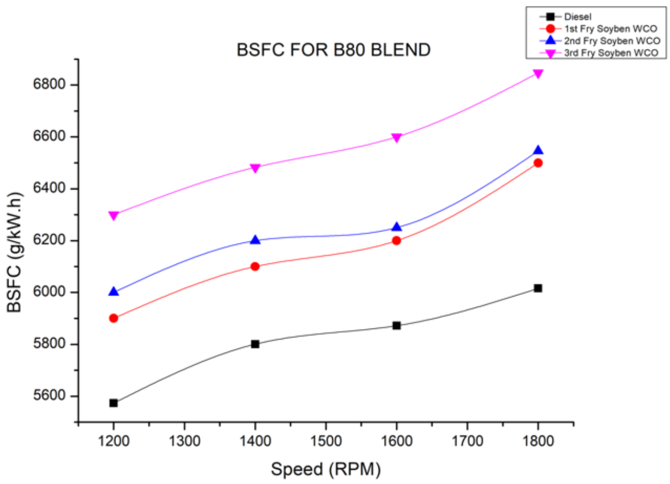

Figure 3. BSFC of different fry oils (B80 blend) at different rpm.

From the results, it can be clearly observed that the BSFC rises with increase in the speed of the engine at constant load. 3FWCOB was the highest BSFC compared to the other test fuels. BSFC is low at 1200 rpm (low speed) because of low fuel consumption, whereas at higher speed the BSFC increases due to the higher fuel consumption to develop high power. As biodiesel has the character of high viscosity and low heating, to develop the same power, more fuel is required. BSFC was highest for 3FWCOB B80 blend, which is because of the higher density of the biodiesel blends resulting in higher viscosity. Thus, to produce same power, more fuel is burned in the combustion stage. The high density of B80 blend as compared to B60 blend gives rise to more discharge of fuel with the same displacement of the plunger in the fuel injection pump, thereby resulting in the increase in higher BSFC [28,29].

4.1.2. Effect on Brake Thermal Efficiency

Brake thermal efficiency (BTE) is the ratio of brake power to the energy of fuel consumed [30]. BTE defines the efficiency of the fuel's chemical energy conversion to useful work. Combustion quality in the engine is also expressed through BTE. The variation in brake thermal efficiency with respect to the speed in rpm is shown by the Figures 4 and 5. Form the experimental results it was observed that BTE of diesel fuel is high at all rpm, with respect to the test fuel and lower for 1FWCOB, 2FWCOB and 3FWCOB. The possible reason for the reduction in the lower BTE trend is because of the lower calorific value and increase in fuel consumption [4]. BTE is decreasing with increase in the engine speed (rpm), due to the poor air–fuel ratio at higher speed, which results in the lower combustion rate for the test fuel. The BTE value for diesel at 1200, 1400, 1600, and 1800 rpm was 15.07%, 14.48%, 14.30%, and 13.96%, respectively. BTE values for B60 test fuels 1FWCOB, 2FWCOB, and 3FWCOB at 1200 rpm were 14.34%, 13.92%, and 13.48%, respectively. At 1800 rpm, fuels 1FWCOB, 2FWCOB, and 3FWCOB indicated 13.15%, 12.8%, and 13.38%, respectively. BTE values for B80 test fuels 1FWCOB, 2FWCOB, and 3FWCOB at 1200 rpm were 14.77%, 14.60%, and 14.4%, respectively, and at 1800 rpm were 13.6%, 13.50%, and 12.94% for 1FWCOB, 2FWCOB, and 3FWCOB, respectively.

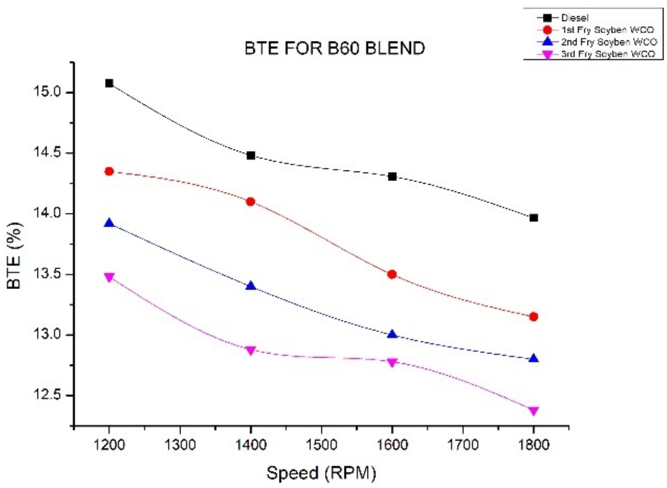

Figure 4. BTE of different fry oils (B60 blend) at different rpm.

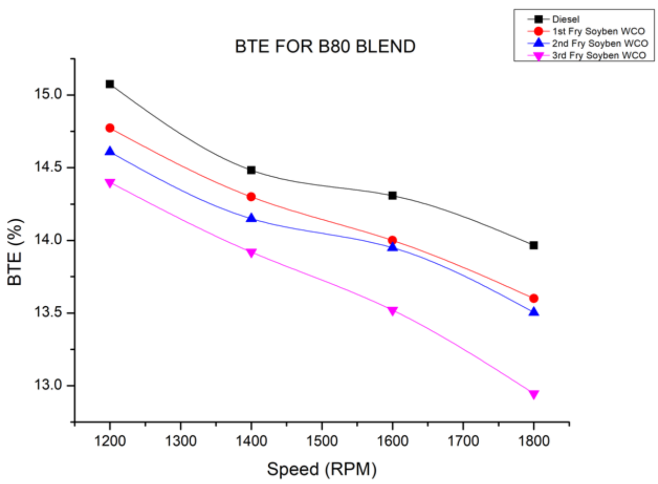

Figure 5. BTE of different fry oils (B80 blend) at different rpm.

BTE decreases with increase in the biodiesel blend due to the high density and viscosity of the fuel [31,32]. The 1FWCOB fuel showed an average drop of 5.3% and 2.2% in efficiency for B60 and B80 blend, respectively, compared to diesel fuel. 2FWCOB indicated a drop of

7.95% and 3.2% in efficiency for B60 and B80 blend, respectively, whereas 3FWCOB showed a reduction of 7.47% and 5.82%, respectively, for B60 and B80 blend. The analysis was carried out for the steady state condition of the engine after warming for one-half hour. Different sets of readings were taken; the results were the same and reproducible.

4.2. Emission Characteristics

4.2.1. Variation in CO_2 with Speed

The variation in CO_2 emission with respect to the engine speed (rpm) is given in Figures 6 and 7 for the B60 and B80 blend test fuels and diesel fuel.

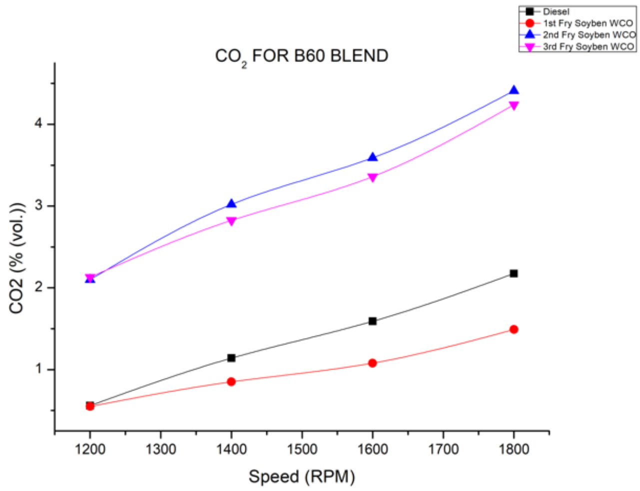

Figure 6. CO_2 emission of different fry oils (B60 blend) at different rpm.

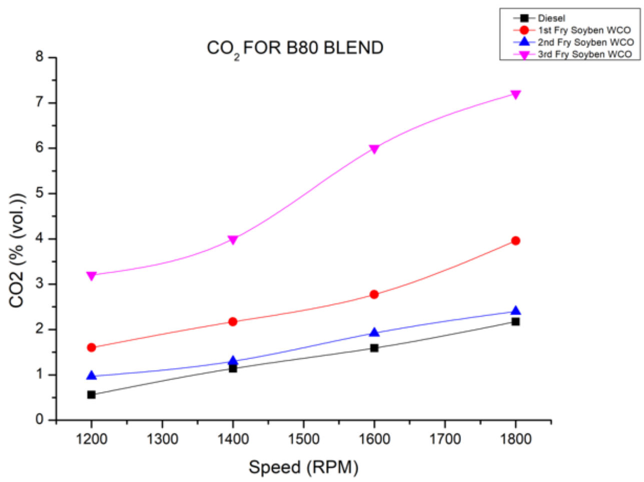

Figure 7. CO_2 emission of different fry oils (B80 blend) at different rpm.

From the Figures 6 and 7, it is clear that CO_2 emissions of diesel fuel were lower than that of the biodiesel blends (1FWCOB, 2FWCOB, and 3FWCOB). Diesel fuel at 1200 rpm and 1800 rpm showed 0.6 vol%. and 2.2 vol%. CO_2 emission. In the B60 blend, shown in Figure 6, it can be observed that 2FWCOB has a higher CO_2 emission than other biodiesel fuels and diesel. At 1200 rpm, 2FWCOB showed 2.1 vol%. CO_2 and 4.4 vol%. CO_2, recorded for 1800 rpm.

In the B80 blend shown in Figure 7, it can be observed that all the biodiesel fuels have CO_2 emission greater than diesel fuel. 3FWCOB has the highest CO_2 emission compared to other fuels. 3FWCOB recorded 3.3 vol%. CO_2 at 1200 rpm and 7.2 vol%. CO_2 at 1800 rpm. The association of higher CO_2 with the biodiesel fuel can be justified as biodiesel has higher oxygen content. It reacts with the unburned carbon atoms at the time of combustion, which leads to the formation of CO_2. CO_2 emission is higher because of the higher density and heating value of the biodiesel fuel, which depends on the blending ratio and the frying time of the fuel. The higher amount of CO_2 results from the incomplete combustion of the fuel at higher rpm [33].

4.2.2. Variation in NO_x with Speed

Nitrogen oxides are formed because of the reaction between nitrogen and oxygen particles under high temperature conditions in the engine combustion chamber. Zeldovich explained NO_x formation by using the following chemical formula [34]:

$$N_2 + [O] \rightarrow NO + [N]\ [N] + [O_2] \rightarrow NO + [O]\ [N] + [OH] \rightarrow NO + [H]$$

Figures 8 and 9 show the NO_x emissions with the variation in the speed, which varies from 1200 to 1800 rpm. Variation in NO_x for diesel fuel was 150, 168, 187, and 205 ppm for engine speed 1200, 1400, 1600, and 1800 rpm, respectively. At 1200 rpm, B60 blend fuels displayed 162, 181, and 198 ppm of NO_x for 1FWCOB, 2FWCOB, and 3FWCOB, respectively, whereas at 1800 rpm the NO_x was 235, 263, and 271 ppm for 1FWCOB, 2FWCOB, and 3FWCOB, respectively. B80 blend fuels, i.e., 1FWCOB, 2FWCOB, and 3FWCOB, showed 158.5, 170.5, and 249 ppm, respectively, at 1200 rpm. However, at 1800 rpm, NO_X increased to 223, 227, and 329 ppm for 1FWCOB, 2FWCOB, and 3FWCOB, respectively. Biodiesel blends showed higher NO_x emission because of the high combustion temperature of biodiesel. Oxygen and nitrogen atoms react with each other rapidly because of the higher temperature of combustion. 1FWCOB had the lowest NO_x emission at the same time changing the fuel to 3FWCOB, NO_x increased. The shorter ignition delay and increased amount of biodiesel undergoing premix combustion results in higher cylinder pressure and temperature due to the high density of the biodiesel fuel. This results in a higher amount of fuel consumption for the same injection conditions and greater oxygen present in the combustion chamber leading to NO_x emission [31,32]. Another aspect for the trend of increasing NO_x with increasing density (degree of unsaturation) is that as the density of the biodiesel feedstock increases, its bulk modulus increases and leads to advanced injection timing [35,36]. Fatty acids having double bond structure are promoted by the formation of hydrocarbons during combustion, which give rise to the formation of NO_x emissions [37,38].

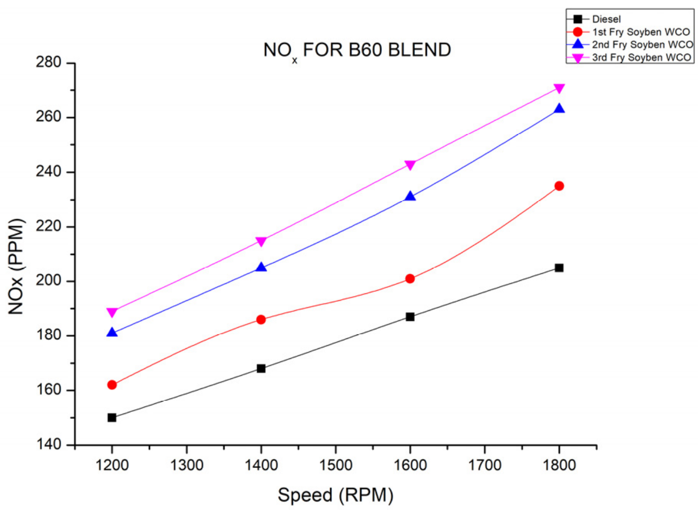

Figure 8. NOx emission of different fry oils (B60 blend) at different rpm.

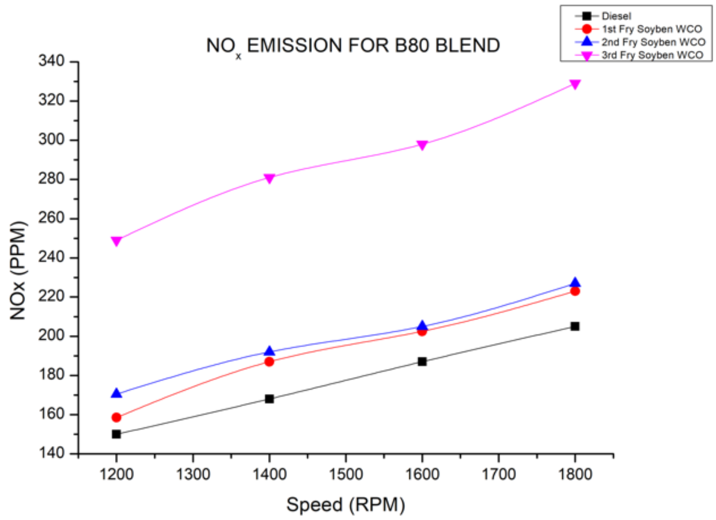

Figure 9. NO_X emission of different fry oils (B80 blend) at different rpm.

4.2.3. Effect on Smoke with Engine Load

Smoke is generated because of incomplete combustion of the fuel in the combustion chamber. Figures 10 and 11 show the variation in smoke opacity from the engine at 100% load for B60-FWCOB and B80-FWCOB blend at different rpm. It can be observed that the smoke opacity in both the blending fuels decreases with increase in engine speed, which are lower than pure diesel oil. Reduced smoke implies that the exhaust gases constitute fewer hydrocarbons. High cetane index and approximately 10% higher oxygen content help in the combustion of biodiesel fuel, which reduce the smoke opacity. More oxygen in the fuel results in complete combustion of the fuel. Biodiesel showed lower smoke than diesel, owing to the rich oxygen content in the biodiesel-blended fuel [39]. Therefore, the smoke emission is lower for biodiesel blends compared to pure diesel. For B60 blend, 2FWCOB shows more smoke opacity compared to the other waste oils. The smoke opacity value for diesel, 1FWCOB, 2FWCOB, and 3FWCOB at 1200 rpm is 65%, 60%, 62%, and 52%, respectively, whereas at 1800 rpm it is 36%, 27%, 35%, and 23% for diesel, 1FWCOB, 2FWCOB, and 3FWCOB, respectively. B80 fuel blends at 1200 rpm indicated 63%, 45%, and 65% smoke opacity for 1FWCOB, 2FWCOB, and 3FWCOB, respectively. At 1800 rpm, 1FWCOB, 2FWCOB, and 3FWCOB fuels indicated 30.2%, 22%, and 28.4% smoke opacity, respectively. 2FWCOB shows the lowest smoke opacity in B80 blend. More smoke is generated when more fuel is injected into the combustion chamber, resulting in partial combustion. 2FWCOB in B60 blend showed higher smoke, which can be inferred as more fuel being injected into the combustion chamber.

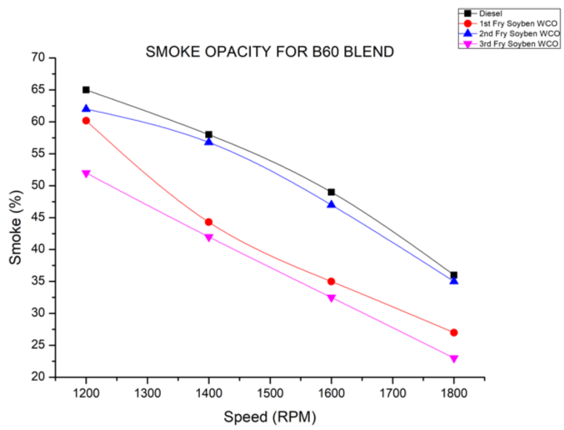

Figure 10. Smoke emission of different fry oils (B60 blend) at different rpm.

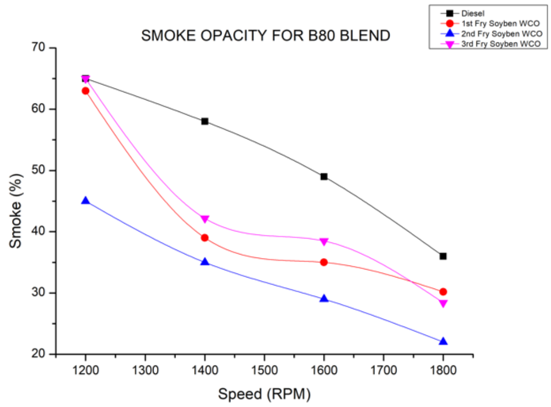

Figure 11. Smoke emission of different fry oils (B80 blend) at different rpm.

4.2.4. Influence of Speed on Exhaust Temperature

Figures 12 and 13 present the variation in exhaust temperature with speed at 100% load for B60 blend and B80 blend, respectively, for the different biodiesel fuels. It can be observed from the results obtained that with rise in engine speed, the exhaust gas temperature increases for all the test fuels. Exhaust temperature for diesel fuel at 1200 rpm and 1800 rpm was 481 and 544 °C, respectively. Maximum brake power was also obtained at 1800 rpm. EGT at 1800 rpm for 1FWCOB, 2FWCOB, and 3FWCOB are 527, 540, and 540 °C, respectively. Overall, 1FWCOB showed the lowest EGT trend in B60 biodiesel blend.

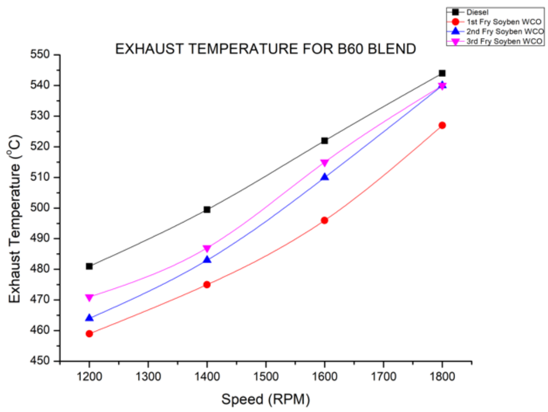

Figure 12. Exhaust temperature of different fry oils (B60 blend) at different rpm.

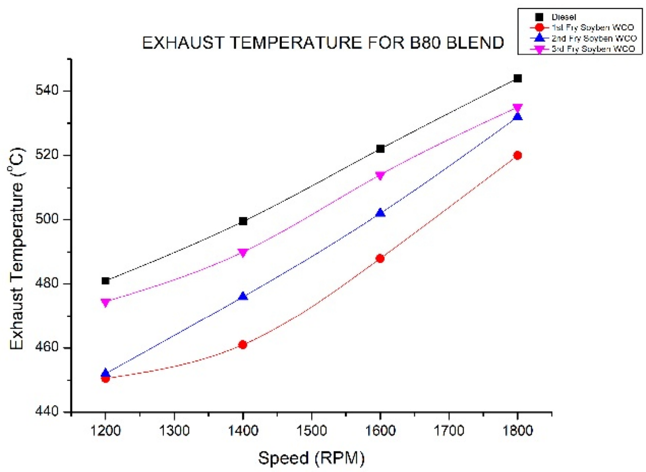

Figure 13. Exhaust temperature of different fry oils (B80 blend) at different rpm.

EGT is influenced by ignition delay. EGT increases because of delayed combustion, which is a result of longer ignition delay. As the cetane number decreases, ignition delay is sustained [40]. However, in the case of B60 and B80 blends of 1FWCOB, 2FWCOB, and 3FWCOB fuel, EGT is reduced because of higher cetane number and lower heating value. Furthermore, increased cetane number results in ignition delay. [41,42]. B80 has lower EGT than B60 because of higher cetane number of the latter blend. Therefore, increase in ignition delay is because of the lower cetane number, which is the main cause for rise in exhaust gas temperature. This resulted in a sustained power period in the combustion chamber.

5. Conclusions

In the present investigation, an experimental study was conducted on an unmodified single cylinder, water-cooled agricultural CI engine. Biodiesel produced from FWCOB (soya bean oil) was used for the investigation. The fry oil was classified into three types, namely, first fry waste cooking oil biodiesel (1FWCOB), second fry waste cooking oil biodiesel (2FWCOB), and third fry waste cooking oil biodiesel (3FWCOB) There was a measurable change in the physiochemical properties (viscosity and density) with change in the type of the oil. The test was designed to carry out the study with pure diesel and blends of biodiesel. Blends of 1FWCOB, 2FWCOB, and 3FWCOB were prepared in the ratio 60% biodiesel and 40% diesel (B60), and 80% biodiesel and 20% diesel (B80), compared with each other and pure diesel. Engine attributes were compared for emission and performance for all the test fuels by varying the engine speed (1200, 1400, 1600, and 1800 rpm) at 100% load condition. BSFC, BTE, CO_2, NO_x, smoke opacity, and EGT were correlated with diesel fuel. Results showed that BSFC increases with increasing speed from 1200 rpm to 1800 rpm. BSFC was low at low engine speed because of low fuel consumption, whereas at higher speed, BSFC increased because of higher fuel consumption because of the higher viscosity and low heating value of the biodiesel blend fuel. BTE was reduced with increase in the engine speed because of poor air fuel ratio at high speed. Biodiesel blends have reduced BTE compared to diesel fuel because of higher density and viscosity of the biodiesel fuel blends along with the lower calorific value, compared to diesel. Minimum drop of BTE was 5.3% and 2.2% for B60 and B80 blends, respectively, for 1FWCOB fuel.

CO_2 emission is higher because of the higher density and heating value of the biodiesel fuel, which depends on the blending ratio and the frying time of the fuel. Biodiesel blends showed higher NO_x emission because of the high combustion temperature of biodiesel. 1FWCOB had the lowest NO_x emission, with increasing 3FWCOB the NO_x increased. Smoke opacity in both the blends have a decreasing trend with increasing speed and are lower than pure diesel. For B60 and B80 blends of 1FWCOB, 2FWCOB, and 3FWCOB fuel, EGT is reduced because of higher cetane number and lower heating value. 1FWCOB showed the lowest exhaust gas temperature trend in B60 biodiesel blend. Based on the results obtained, it was concluded that by increasing the frying time of the soya bean waste cooking biodiesel, the emission characteristics and engine performance were affected. Among the three fry fuels (i.e., 1FWCOB, 2FWCOB, and 3FWCOB), 1FWCOB performed the best and showed better engine performance and emission characteristics.

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Nomenclature

BSEC	Brake Specific Energy Consumption
BTE	Brake Thermal Efficiency
CI	Compression Ignition
CO	Carbon Monoxide
FWCOB	Fry Waste Cooking Oil Biodiesel
HC	Hydrocarbon
HRR	Heat Release Rate
IC	Internal Combustion
NO_x	Nitrogen Oxide
WCO	Waste cooking Oil

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