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Experimental Investigation of Diesel-WCOB Engine Performance with A Small Proportion of Ethanol/Isobutanol as A Fuel Additive

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Abstract: The globe is beginning to face fast-expanding global warming concerns that require immediate treatment. Biodiesel can be considered the most widely used and versatile sustainable fuel for a variety of uses. Because it is biodegradable, environmentally friendly, and renewable, it offers a viable solution to the looming energy crisis. Waste cooking oil is among the locally available sources that might be utilized as an extra source in different countries at a reasonable cost. Combining used cooking oil and diesel is a viable option for diesel engines because it has been certified for use at blending ratios as low as 20% as a commercial fuel. However, when it comes to fuel additives, the best alternative is to use waste cooking oil at high mixing ratios with diesel to power diesel engines. The goal of this research is to examine the various performance parameters of a diesel engine and the characteristics of biodiesel blended fuels by measuring the specific fuel consumption of the brakes and the thermal efficiency of the brakes and to investigate the impact of isobutane and ethanol additions at rates of 5% and 10% on the properties of the fuel and engine efficiency to enhance the specifications of the blended fuel in high proportions B40. Mixed fuel B40 with 10% ethanol (B40E10) can be used as a highly mixed fuel to enhance diesel engine performance. The density, kinematic viscosity, and flash point of diesel fuel were the lowest and rise with the amount of WCOB in the mixture, while the blended fuel B40 had the greatest value and improved with the percentage of additives. Increases in the proportion of additives also result in a visible rise in the braking force and fuel consumption.

Keywords: Biodiesel, diesel, WCO, iso-butanol, ethanol, fuel blending

1. Introduction

Fossil fuels are one of the world's oldest sources of energy, and despite their long-term reliance, fossil fuels continue to be a significant and necessary source of energy generation in large industrialized countries [1]. Scientists in the fields of environment and climate have begun to realize that the continuing use of traditional energy sources creates environmental concerns such as global warming [2]. Furthermore, in the coming years, oil production will be expensive, requiring energy that is often equal to or greater than the energy produced. [3], [4]. As a result, oil corporations and oil-producing countries have made significant scientific efforts to reduce their environmental impact through smart technology and the use of highly effective materials such as composite materials and porous media to rationalize usage

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[5]. Even in non-environmental areas, shifting from reliance on traditional energy sources to renewable energy sources wherever possible is critical. Using limitless renewable energy saves enormous amounts of fossil fuels and preserves their strategic store for use in other industrial projects; the world is no longer able to dispense with its products [6], [7].

Many countries are beginning to explore alternative energy sources to mitigate the environmental harm caused by the use of fossil fuel sources. Despite the variety of suggested renewable energy sources, their usage is currently restricted to a few applications. These sustainable energy sources account for a modest portion of worldwide energy use. Energy is utilized efficiently in some places based on the appropriateness of climatic circumstances that vary from region to region, but high-cost technology is often required for conversion and usage [3].

Internal combustion engines are still widely used in transportation and industry due to their efficiency and durability [8], [9]. The internal combustion engine IC is built to operate on liquid fuels, limiting the use of renewable energy sources. Because of the increasing need for more energy in the future [10], it is important to develop acceptable replacements that can operate these types of engines without requiring substantial changes to their design.

Biodiesel is the most appropriate and feasible replacement fuel for diesel that has piqued the curiosity of academics due to its comparable characteristics to diesel [11]. Biodiesel is a green, sustainable fuel that may be made from animal fat and non-edible vegetable oil through the transesterification process [12]. Unlike diesel, biodiesel has no sulfur, is non-toxic, biodegradable, and may be considered a renewable energy source [13], [14], and can also be used as a fuel combined with mineral diesel in specific quantities [15]. However, this method can lead to some operating problems such as coking coal in the injector nozzle, contamination, and crystallization of lubricating oil, fuel filter blocking, piston rings clinging to cylinder walls, acidity-induced corrosion, and increasing wear on engines [16], [17].

There are several ways to enhance the characteristics of biodiesel to fulfill the required standards for the fuel. Some studies have proposed modifying the fuel injection procedures, which would include engine modifications and the usage of accessory components to allow for the injection of high viscosity fuels [18], [19]. However, this approach is not recommended because of the large number of actuators that must be changed, resulting in considerable cost increases [20]. One possible option is to combine biodiesel and petrodiesel to power diesel engines, which have been authorized as fuel for internal combustion engines at mixing percentages as low as 20%.[21]. The direct integration of refineries in the combined processing of petroleum fractions with biodiesel (waste cooking oil, WCO) is among the most advanced approaches [22]. Another technique is biodiesel pyrolysis, which generates more biogasoline than biodiesel [23]. Chemical processing of waste cooking oil (WCO) and the use of the resulting fatty acid esters as an engine fuel is yet another alternative, but it's also the most complex [24]. At the chemical level, it's an acronym for long-chain fatty acids with low alkyl esters [25]. While the diesel ether/glycerol combination had only a minor effect on engine combustion quality or efficiency, Blasio et al [26] discovered that the oxygen content of the additives had a significant advantage over other factors. As a result, the most practical solution is to use fuel additives to enable the use of biodiesel and high blending ratios in regular engine operation [27].

The goal of this research was to compare performance parameters in the characteristics of waste cooking oil mixed with petrodiesel at various mixing ratios of up to 40%. The research was also expanded to see how additives such as isobutanol and ethanol, at 5% and 10%, are effective on density, viscosity, and heating value. Finally, fuel tests and engine performance evaluations, as well as specific brake fuel consumption and brake thermal efficiency, were carried out. To compare the results, the same engine settings were employed to test these samples, which was critical for evaluating the engine performance trend and determining the proper mixture for engine operation.

Table 1 - Fuel blending composition

Diesel (% vol.)	Biodiesel (% vol.)	Iso-butanol (% vol.)	Ethanol (% vol.)	Abbreviation
100	0	0	0	B0
90	10	0	0	B10
80	20	0	0	B20
70	30	0	0	B30
60	40	0	0	B40
55	40	5	0	B40IB5
50	40	10	0	B40IB10
55	40	0	5	B40E5
50	40	0	10	B40E10

2. Materials and Experimental Setup

2.1 Fuels Production

Biodiesel was produced in a specialist chemical facility using waste cooking oil (WCO) gathered from local eateries, while diesel was supplied from a gas station. At a slow stirring rate, biodiesel (WCOB) was added to the diesel. To obtain a homogenous fuel blend, the liquid was spun for 30 minutes at a constant temperature of 50–55 °C. WCOB was added in volume percentages of 10 %, 20 %, 30 %, and 40 % to samples of mixed diesel biodiesel fuel formulated as B10, B20, B30, and B40, respectively. (Where 10% WCOB and 90% diesel are used for B10).

The specialized chemical firm supplied iso-butanol and ethanol additives, which were stored according to the instructions. The same procedure was used to produce B40IB5 (55% diesel + 40% WCOB + 5% iso-butanol), B40IB10 (50% diesel + 40% WCOB + 10% iso-butanol), B40E5 (55% diesel + 40% WCOB + 5% ethanol), and B40E10 (50% diesel + 40% WCOB + 10% ethanol) by combining iso-butanol and ethanol with mixed biodiesel diesel fuel (B40) at 5% and 10% additive ratios, respectively. The completed fuel mixture was stored in the lab for roughly 24 hours before any experiments were performed. The nine fuel mixes that were being produced are shown in Table 1. Table 2 summarizes the ASTM-measured properties of these nine types of fuel. The density of the fuel was determined using a density meter under the ASTM D1298 standard procedure, while the viscosity of the fluid was tested using the ASTM D445 standard procedure, the calorific value was measured using ASTM D 5865, and the flashpoint and the fire point were measured using ASTM D 93.

Table 2 - Specifications of different fuels

Properties	B0	B10	B20	B30	B40	B40IB5	B40IB10	B40E5	B40E10
Flash point (°C)	62	67	72	77	81	79	78	77	75
Fire point (°C)	85	89	94	97	102	100	99	99	97
Kinematic Viscosity (mm2/s) @ 40 °C	2.44	2.63	2.72	3.36	3.74	3.45	3.22	3.32	3.07
Density (kg/m3) @ 15 °C	836	840.7	842.4	846.1	851.2	847.7	843.3	844.2	841.3
Heating Value (MJ/kg)	43.65	43.1	42.61	41.96	41.4	40.79	40.18	40.82	40.23

2.2 Test Engine and Procedure

On a water-cooled four-stroke diesel engine with a high-pressure fuel pump, the test was conducted. There was a 1996 cm3 swept volume, a compression ratio of 21.2 to 1, and a bore to stroke ratio of 0.86 for this engine. To adjust the engine's torque and speed, an eddy current dynamometer is linked to it and controlled by a dynamic controller. Table 3 lists the engine parameters, and Figure 1 depicts the diesel engine's schematic diagram. The test engine was started about 10 mins before each experiment to guarantee steady engine functioning and to clear the fuel line of any leftover fuel from the previous experiment, which was sufficient to ensure reliable findings. Engine testing was conducted 2 - 3 times for every fuel type, with the values averaged recorded under similar conditions.

Table 3 - Specifications for diesel engines

Configuration	In line 4
Combustion type	Direct Injection
Displacement	1996 cc
Bore/Stroke ratio	0.86
Rated output	68 kW @ 3200 rpm
Torque output (max)	275 Nm @ 1700 rpm
Ratio of compression	22.4

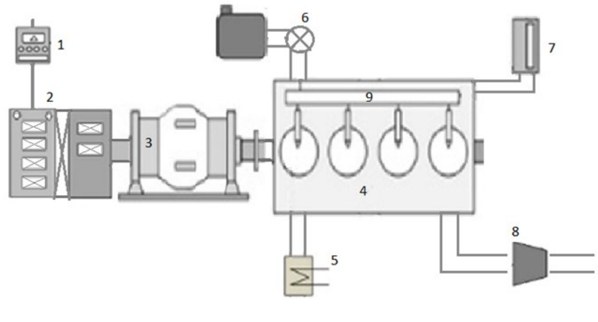

Fig. 1 - Schematic diagram of the system configuration (1- power supply 2- control panel 3- dynamometer 4- diesel engine 5-coolant system 6- fuel tank 7-air intake 8-exhaust system 9- direct injection system)

3. Results and Discussion

The amount of waste cooking oil in the mixed diesel and biodiesel fuel formulations was raised from 10% to 40% with diesel fuel, and characteristics like density, kinematic viscosity, heating value, and flashpoint of the blends were investigated. Table 2 shows the physical characteristics of mixed biodiesel fuels. It can be observed that the concentration of biodiesel and additives in the blended fuels has a significant impact on the characteristics of the fuels. The density of the fuel influences its spray characteristics as well as the power of diesel engines during combustion and fuel injection. The greatest density was B40 (851.2 kg/m^3), while the lowest density was B0 (836 kg/m^3). Pure diesel fuel has a lower density than any other mixed fuel due to the higher density of WCOB. while viscosity is a temperature-dependent measure of inner particle friction during fluid flow. The viscosity of an engine is an important factor in its performance. It regulates the spray characteristics of fuel as it enters the combustion chamber, causing engine deposits to form as a byproduct. Table 2 depicts the increasing trends in the kinematic viscosity of blended fuel as the amount of WCOB or the proportion of additives increases. On the other hand, the flashpoint of biodiesel should preferably be greater than the minimum of 52°C stipulated by ASTM regulations for petroleum fuel. The connection between the flashpoint and the quantity of WCOB in the mixed fuel is shown in Table 2. When compared to other fuels, B40 has the maximum flashpoint of 81 °C, making it safer and more stable in usage. A 40% increase in WCOB in the fuel mixture might raise the flashpoint about 9°C.

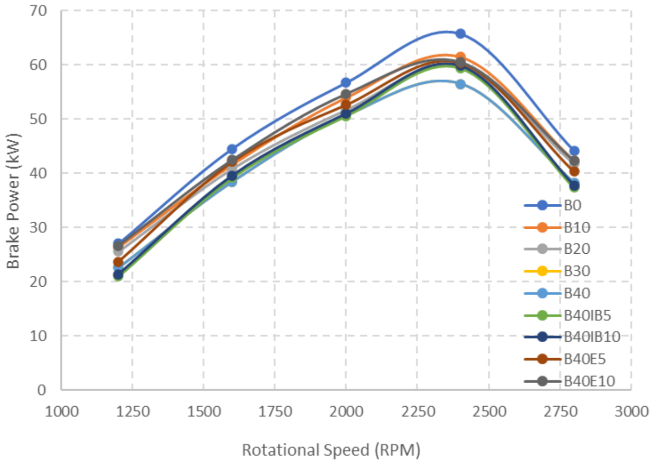

Fig. 2 - Braking power (BP) for a range of mixed fuels with iso-butanol and ethanol additives with various speeds of the engine

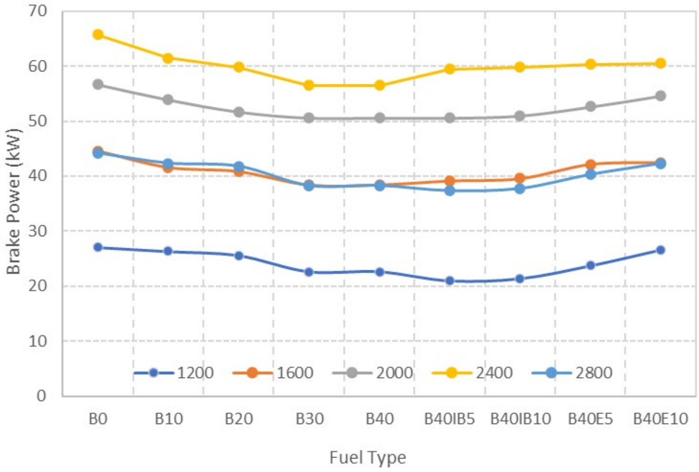

Fig. 3 - Braking power (BP) at various speeds of the engine for a variety of mixed fuels

Engine testing is critical in determining the quality and fitness of fuel for use in diesel engines under various circumstances. In this research, a variable-speed engine with an increment in 400 rpm from 1200 to 2800 rpm was examined. Mineral diesel fuel was used as a comparison threshold for reliable results with other fuel samples. For comparison and to assess the effect and amount of the additives, a mixed ratio of 40 percent WCOB and 60 percent diesel (B40) was also employed. The engine tests data are collected after the proper time after start-up, to achieve a stable operation and to achieve reliable results. Because of the torque at a specified engine speed, the engine braking power is defined by the net power of the engine. Figures 2 and 3 illustrate the brake power generated from the rotational speed engine. Overall, it can be seen that the brake power at all ranges of fuels is high at increased rotational speeds, except for the high-speed 2.8k. However, at the same engine speeds, the measured braking power of the fuel models differ substantially. Mineral diesel fuel B0 was supplied with maximum braking power through the engine speeds and followed by the mixed fuel B10, B20, B30, and B40, and the highest value about 66kW at the rotational speed of 2.4k. On the other side, the lowest brake power is obtained at all rotational speeds using a high mixing ratio of biodiesel B40. Variable braking force reduction has been achieved at all rotational engine speeds by increasing the amount of WCOB in the fuel mix relative to pure diesel. The relatively low heating value of WCOB than pure diesel [28], [29] explains this decrease in brake force. However, as shown in Table 2, this decrease is not equivalent to a decrease in heating value, implying a second reason where the fuel combustion efficiency increases as a result of the existence of oxygen in biodiesel [30]. Overall, the B40 engine may not be the ideal option for engine applications. The addition of iso-butanol additives to the mixture at a 5% ratio, on the other hand, in comparison to the B40 blended fuel, results in a considerable rise in braking force. However, increasing the iso-butanol ratio to 10% does not result in the same rise as previously obtained. This is supported by two opposing properties: a drop in heating value and an increase in fuel viscosity, which is enhanced by increasing the proportion of additives [31]. Furthermore, when compared to the B40, the addition of ethanol boosted the braking force even more than the other additions, with the B40E5 and B40E10 having the largest braking power for all rotary engine speeds.

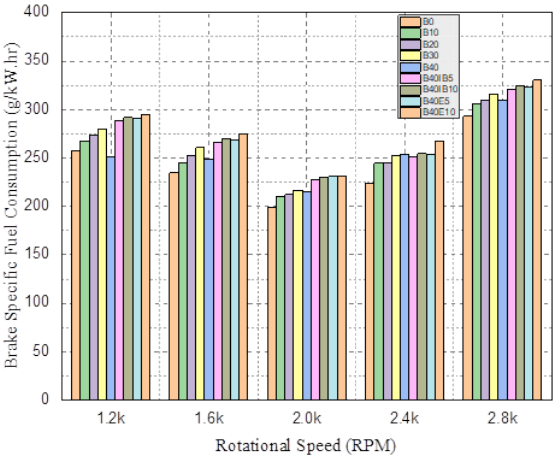

Fig. 4 - Braking-specific fuel consumption (BSFC) for a variety of mixed fuels at various engine speeds

The quantity of fuel burned by the engine is referred to as the Engine Brake Fuel Consumption (BSFC). This quantity is derived from the fuel flow rate over a given period and the expected braking force at a given engine rpm. Because the fuel injector provides fuel to the engine cylinders depending on the volume of fuel, fuel density plays a significant role in determining the BSFC when utilizing blended fuels. Figure 4 displays the quantity of fuel that was consumed in the engine at various rotational speeds. In all tested fuel models with an increase in engine speed, similar patterns were seen in the change. There are also considerable BSFC variations across fuel samples at the same engine rpm. Generally, the brake consumes less fuel at 2k RPM than other speeds. Then the consumption of the fuel increases gradually. The fuel consumption of the minimum achievable at all rotational speeds with mineral diesel fuel B0 follows the blended fuel. Higher results on the other hand, when the mixing ratio is raised. This increase can be attributable to the greater density and heat value of WCOB in comparison to pure diesel, which needed increased fuel consumption to produce the same power braking. [30]. Moreover, the blended fuel (B40) demonstrates a good level of operating fuel especially at 2k RPM when the brake consumes about 220 g/kW hr. The blended fuel B40 also shows low consumption comparing to B40IB5, B40IB10, B40E5 and B40E10, at all speeds. The brake consumed roughly the same amount of B40IB5, B40IB10, and B40E5. However, B40E10 was consumed a little more than the other fuels at all RPMs. In general, the addition of additives to the fuel mixture results in varying increases depending on the amount of additions in BSFC vs blended fuel B40. This tendency can be explained by the fact that the heating value decreases as the additive ratio increases [30]

The most important metric for measuring engine fuel conversion efficiency is brake thermal efficiency (BTE). This is based on the used fuel during a particular period, as well as the heating value of the tested fuel, projected braking power at a specific engine speed. Figure 5 displays the thermal efficiency of the brake for several fuel samples at various rotational engine rpm. The thermal efficiency of all fuels increases up to 2k RPM. Above 2k, in contrast, the efficiency decreases in all cases. The highest thermal efficiency was (42%) that recorded at 2k RPM with the B0. Then the percentage goes down by increasing the RPM. Mineral diesel has the highest BTE across the entire engine speed range, followed by blended fuel, except at 1.2k RPM, where B40 has the highest thermal efficiency up to 35%. B40 shows also good thermal efficiency at 1.6k which is roughly similar to that of B0. Two crucial elements may explain this behavior; the heating value and fuel's oxygen concentration [32]. The major criterion for pure diesel is a large heating value, whereas oxygen content is in blended fuel. Due to the opposing effects of these characteristics, BTE improves with B40 mixed fuels over pure diesel because of improvements in the fuel combustion process. This enhancement is due to the oxygen concentration of the mixed fuel, which has a greater impact than the decrease in heating value [21]. Generally, all additives, B40IB5, B40IB10, B40E5, and B40E10 show a slight decrease in values of the efficiency at all RPMs. The latent vaporization heat and the heating value of the additions lead to a lower cylinder temperature, which has the potential to diminish the fuel mixture's combustion efficiency [33].

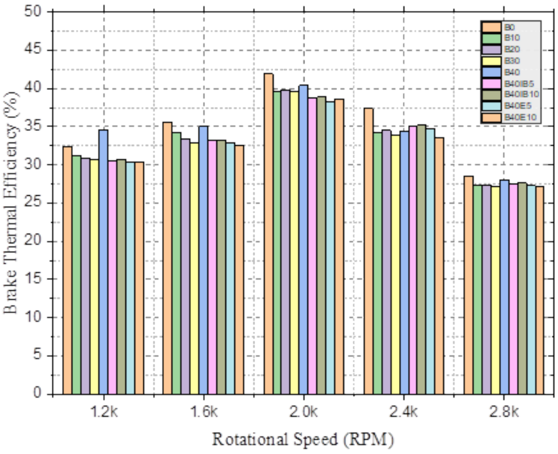

Fig. 5 - Variations in brake thermal efficiency versus engine speed for various mixed fuels

4. Conclusions

Biodiesel was prepared from waste cooking oil and then blended in various quantities up to 40% with mineral diesel, which was used as a comparison point with other kinds. A series of experiments were carried out to assess the characteristics of blended fuels with and without isobutane and ethanol additions at 5% and 10% addition rates. The engine performance tests were conducted at varying engine revs, from 1200 to 2800 rpm in increments of 400 rpm. The density, kinematic viscosity, and flashpoint of the mixed fuels were observed to be rather excellent. According to the findings, the B40 blended fuel has the highest viscosity, density, and flashpoint of the fuels mixed with lower mixing ratios, and these properties improve significantly as the amount of additives increases. On the other hand, with the rise of the mixing ratio, the heating value decreased, and with the growth of the percent of the additives decreased further. Engine performance testing is a critical indicator for determining the quality of fuel and its appropriateness for turning diesel engines. The results of the engine tests at all speeds demonstrate that the use of fuel with high mixing ratios B40 produces the least braking power, and it reduces as these ratios drop. Furthermore, as the proportion of additions grows, so does the braking performance at all rotational speeds. With the addition of 10% ethanol, the best gains were achieved. But, the additions to blended fuel enhanced fuel consumption rates. However, it is recommended that 10% ethanol be used with blended fuel (B40E10) to increase engine performance while maintaining excellent thermal efficiency.

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