Performance and emission characteristics of dual fuel engine using biodiesels

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Abstract. The introduction of the strict emissions norms is diverting the research for the development of new technologies which leads to the reduction of engine exhaust emissions. The usage of biodiesel in CI engine can enhance air quality index and protects the environment. Biodiesel can do an increment in the life of CI engines because it is clean-burning and a stable fuel when compared to diesel. Moreover, biogas has the potential to decrease both nitrogen oxides and smoke emissions simultaneously. Operating the engine in dual-fuel mode can provide lower emissions and a proper substitute for diesel. In this research, a modified CI Engine with single cylinder is used. Biogas is used as primary fuel and diesel, Mahua oil-diesel blend and Fish oil-diesel blend are used as secondary fuel. The effect of various secondary fuel blends on performance and emission characteristics in dual fuel engine are compared. In light of the performance and emission qualities it is reasoned that, utilization of the dual fuel mode in engine signifies the durability and lessens the harmful emissions from the engine with the exception of hydrocarbon and CO emissions. The excessive viscosity of fish oil and mahua oil prompts inconvenience in siphoning and spray attributes. The incompetent mixing of raw fish oil and raw mahua oil with diesel and biogas including air leads to incomplete combustion.

Keywords: Dual fuel; Performance; Emission; Mahua oil; Fish oil

1. Introduction
The Energy is a necessity in our day-to-day existence as a method of improvisation human livelihood prompting financial growth and efficiency. The re-visititation of renewables will help alleviate environmental change in an astounding way however should be maintainable to guarantee a manageable future for ages to meet their energy needs. Information with respect to the interrelations between feasible turn of events and environmentally friendly power is as yet restricted. Monetary and cultural advancement of any country relies particularly upon the accessibility of fuel sources. Fuel sources are fundamental contribution to the territories of any creation, yet sadly the fuel sources accessible are restricted in quality as well as things that is accessible are quickly drained, putting away is vital for humankind to create non-traditional wellsprings of energy that satisfies the interest as well as simultaneously keeps the climate perfect. Biodiesel has its position as the most prominent elective fuel as a result of its inexhaustibility and supportability. Biodiesel is produced using battery-powered a characteristic asset that doesn't deliver destructive side-effects. It can be obtained from different by-products like vegetable oils, reused cooking-oil, creature fat and green growth, which are feasible and simple to prepare and
utilize. Biodiesel got from eatable, non-palatable oil and creature fat can be utilized in fuel motors that has no adjustments. Alternative fuels have different advantages than conventional fuels because they have nano-scopic carbon-emissions contrasted with diesel and gasoline, moreover they likewise have more prominent maintainability to provide long term benefits, easy of production is also another factor of using alternative fuel in the modern world and also in contrast with solid fuels comprising of coal, wood, charcoal elective fuels consume quicker and abandon no build-up. And one of the main merits of alternative fuels in the modern world is their low greenhouse gas emissions. The dual fuel compression-ignition engine is a solution that makes it conceivable to execute the idea of utilizing biogas (without the need to refine it to bio-methane quality) as fuel for vehicles.

2. Literature Review

The higher availability of oxygen in the B20 fuel results in less CO emission [1]. Due to the large availability of oxygen in biodiesel, it aids to the complete combustion of the fuel but also results in increased emissions of CO$_2$ [2]. Schumacher et al. [3] detailed that running a TA DDC heavy-duty diesel engine on biodiesel-diesel blends reduced CO, PM and THC but resulted in higher emissions of NOx. Preto et al. [4] hypothesized that N$_2$ from the environment will be quickly transformed into NOx if the fuel has a high rating of cetane and contains elevated oxygen content. Biogas–diesel gave predominant execution in the decrement of soot emissions because of the shortfall of aromatics and the low Sulphur [5]. Sundar et al. [6] examined the various working modes of diesel engine and discovered that when running the engine in diesel mode, the utilization of fuel was lesser when compared to running the engine in dual fuel mode. Comparative BSFC results were found for the biodiesel blends which showed an increase in BSFC with the increase in engine speeds, and at 2000 rpm, lower BSFC values were seen for all blends. All things considered, the Brake Specific Fuel Consumption appeared to diminish because of progress in calorific properties. Santhosh et al. [7] hypothesized that one of the central point when operating ordinary engines on elective fuel are the emission qualities because it’s normal from an elective fuel to deliver minimum emissions possible. Bari et al. [8] noticed that the NOx emissions quickly increments at 2800 rpm when operating the engine on palm biodiesel whereas it was significantly lesser at 2000 rpm, and this was the most minimal emission that was seen with diesel at 2000 rpm; likewise, palm biodiesel showed less HC emissions at 48 ppm when compared to the 108 ppm of crude oil. This was mainly due to the higher availability of oxygen in the biodiesel. Moreover, it was additionally stated that the CO emissions were much lower for palm oil biodiesel when compared to diesel with a colossal difference of 55% when the engine was operated around 2000-2500 rpm. Deep et al. [9] obtained 1.5%, 0.7% and 1.4% lower in smoke, CO and NOx emissions exclusively when diesel was doped with 10-40% by volume of 1-octanol and run on CI engine. Zhang et al. [10] discovered that the NOx, smoke and CO emissions got reduced by 1.9%, 2.2% and 3.1% when diesel was doped with 30% by volume as compared to diesel run on a heavy-duty CI engine. CI engines are recommended to be fueled by biogas which helps in achieving high diesel substitution, especially when the torque is more. Feroskhan et al. [11] researched the outcomes of preheating the charge in dual fuel mode. The main fuel is biogas which is passed through flowmeter and gets heated before injection and introduced into the engine after which it is mixed with air in the intake. This mixture is ignited by means of pilot diesel injection within the cylinder after it undergoes compression. According to the authors’ observation, the brake thermal efficiency is enhanced by preheating of charge, decreased biogas flow rates and at high rate of engine operation.

Majority of the above research work involve studies on several biodiesel blends but research on mahua oil and fish oil biodiesel blends with biogas can be rarely seen. Past studies published in several journals fueled the current work which gauges both the biodiesel blends’ (mahua oil and fish oil) ability to be a better alternative fuel in terms of performance and emission characteristics in dual fuel mode.
3. Blend Preparation
It is necessary to lower the viscosity of the biodiesel as usage of pure biodiesel will result in gum formation and engine choking. Hence, pure diesel is mixed with biodiesel in which Mahua and Fish Oil is taken as 20% (Refer Table 1). Thus, three blends were taken into consideration along with pure diesel to determine the performance (BTE) and emission (HC, NOx, CO) characteristics. Diesel-only is mentioned as D in Table 1.

Table 1. Blend preparation.

| Diesel quantity/% volume | Mahua oil/% volume | Fish oil/% volume | Result |
|--------------------------|-------------------|------------------|--------|
| 100                      | 0                 | 0                | D      |
| 80                       | 20                | 0                | M20    |
| 80                       | 0                 | 20               | F20    |

4. Experimental Setup
The diagram of the engine setup, and all instruments used in the experiment are shown in Figure 1. The CI Engine is adjusted in the way to run in dual-fuel mode. The specification of the engine used is mentioned in Table 2. Eddy Current Dynamometer was used to provide loads. The pilot fuels used in this mixture are Diesel, Diesel with Biogas (Diesel-Dual), Mahua Oil Biodiesel with Biogas, Fish Oil Biodiesel with Biogas supplied through direct injection.

Figure 1. Block diagram of the experimental setup.
5. Methodology

In this research, the applied load, biogas flow-rate (which is determined by the engine) and different fuels taken into consideration with biogas are the main variables. The method involves running the Kirloskar AV1-XL Engine on Diesel to heat up the engine. Additionally, diesel blend was allowed to flow for 40 mins so the temperature becomes constant. For each of the 4 blends the Performance and Emission characteristics were recorded. Method of the experimentation and properties of various blends are provided in Table 3 and Table 4 respectively.

### Table 2. Specification of baseline engine.

| Item                      | Specification            |
|---------------------------|--------------------------|
| Engine                    | Kirloskar AV1-XL model   |
| Engine speed              | 1800 rpm                 |
| Bore                      | 87.5 mm                  |
| Stroke                    | 80 mm                    |
| Engine capacity           | 0.481 L                  |
| Maximum pressure          | 74 bar                   |
| Working cycle             | 4-stroke diesel          |
| Combustion mode           | Dual fuel                |
| Compression ratio         | 17                       |
| Maximum power & torque    | 5.97 kW & 25 Nm          |

### Table 3. Method of the experimentation.

| Limit          | Fuels                    | Name | Parameters Investigated                     |
|----------------|--------------------------|------|---------------------------------------------|
| Load (0-20 Nm) | Mahua oil+Diesel+Biogas  | M20  | BTE, HC, CO, NOx, smoke                     |
| Load (0-20 Nm) | Fish oil+Diesel+Biogas   | F20  | BTE, HC, CO, NOx, smoke                     |
| Load (0-20 Nm) | Diesel+Biogas            | DD   | BTE, HC, CO, NOx, smoke                     |

### Table 4. Properties of various fuel blends.

| Properties                  | Diesel         | Mahua oil     | Fish oil      |
|-----------------------------|----------------|---------------|---------------|
| Density                     | 837 kg/m³      | 838.12 kg/m³ | 838.88 kg/m³ |
| Kinematic viscosity at 40°C | 4.45 mm²/s     | 3.20 mm²/s   | 3.17 mm²/s   |
| Calorific value             | 45.5 MJ/kg     | 38.86 MJ/kg  | 40.67 MJ/kg  |

6. Results and Discussions

The performance and emission characteristics of the dual fuel engine with the various blends of biodiesel are discussed here. D refers to diesel-only mode. All other three (DD, M20 and F20) are dual fuel mode.

6.1 Brake thermal efficiency

BTE of diesel and diesel dual blend are higher than mahua and fish oil blends at lower loads (below 15Nm). Above 15Nm, BTE of diesel and diesel dual blend decreased whereas mahua and fish oil blends showed an increase in BTE (Refer Figure 2). Comparing all the prepared blends, the fish oil
blend shows a consistency with BTE at both lower and higher loads. Overall, the trend of BTE first increases then decreases this could be the effect of lesser oxygen available in the combustion-chamber. Whereas, mahua oil biodiesel with biogas blend (M20) and fish oil biodiesel with biogas blend (F20) have high amounts of oxygen which results in the steady increase of BTE at higher loads. The BTE is high for the blends with higher calorific value as less energy is produced. Diesel has more calorific value compared to Biodiesels. Hence, the BTE is slightly less for F20 and M20 blends. While the efficiency of M20 is lesser than F20 due to its lower calorific value.

Figure 2. Brake Thermal Efficiency (%) v/s Load (Nm) for different fuel blends

6.2 NOx emissions
With the increment in load, the combustion-chamber gets heated up and the temperature increases resulting in NOx formation. All the biogas blends have resulted in lower NOx emissions in comparison with D (pure diesel) as shown in Figure 3 and also available in literatures [12, 13]. Among the biogas blends, mahua oil blend has the lowest NOx emission overall. Diesel has the highest NOx emissions at all loads. This is because the development of the Nitrogen Oxides pivot on the temperature inside the combustion chamber. Furthermore, when compared with diesel the combustion-chamber temperature is much higher for biodiesel blends. Among the three blends, diesel with biogas has higher calorific value than both F20 and M20, whereas M20 has the least calorific value. Therefore, M20 has the lowest NOx emission.
6.3 \textit{HC emissions}

The biogas blends have higher HC emissions because diesel consumption will get reduced by the amount of methane present in Biogas (Refer Figure 4). With the increase in load, the biogas blends have shown a decreasing trend in HC emissions. The hydrocarbon emissions are high for biogas blends because of the presence of biogas which replaces air from the combustion chamber. The combustion process works more effectively at maximum engine speed and loads, thus we see a decline in the HC emissions of all the biogas blends at high loads. Comparing the biogas blends, M20 has the lowest emission because of the high oxygen content present in its molecular structure which helps in better combustion. Similarly, F20 has lower HC emission than diesel with biogas due to the same reason. Hence, we see the above trend. Whereas, with the increase in load for diesel there was a notable increase in HC emission.

Figure 3. NO\textsubscript{x} Emission (ppm) v/s Load (Nm) for different fuel blends

Figure 4. HC Emission (ppm) v/s Load (Nm) for different fuel blends
6.4 CO emissions
Diesel, diesel dual and fish oil blends have shown a decreasing trend below 15Nm load. Above 15Nm load, CO emissions of diesel and diesel dual blend massively increased. Whereas, mahua oil and fish oil blends’ CO emissions showed no change. Dual Fuel mode engine has higher CO Emission than Diesel mode (refer Figure 5). The effect done by engine speed and load is negligible. The main reason behind this is the scarcity of oxygen in the chamber. Therefore, the CO emission for diesel-dual is higher in comparison with pure diesel. Considering Mahua Oil from the figure it shows that at the injection opening the CO emission is lower. This can be explained by better and complete combustion of fuel. The CO Emission observed for M20 is higher due to knocking caused by scarcity of oxygen. The CO concentration shows a decreasing trend in fish oil blend this may be due to higher amount of viscosity and a slight increment in specific gravity suppresses the combustion process.

![Figure 5. CO Emission (%) v/s Load (Nm) for different fuel blends](image)

6.5 Smoke emissions
As the load increases more fuel is injected and decrease in oxidation takes place this leads to higher smoke as shown in Figure 6. Mahua oil biodiesel blend has the highest smoke density due to its higher viscosity and heavy molecular structure. The values for diesel, mahua oil and fish oil blends spiked up at higher load with mahua oil blend being the highest. However, diesel dual blend showed no change in the value above 15Nm. With increase in load fish oil shows higher smoke density than diesel this can be due to the process of combustion remains incomplete in the chamber and F20’s higher viscosity and improper air mixing. As we can see an increase in Brake Power the Smoke Density is also increased for all fuels. However, at lower loads diesel produced more smoke as compared to higher loads this can be due to the advanced combustion. The effect of higher smoke density is mainly due to poor volatility, higher viscosity and improper mixing of biogas compared to diesel and diesel-dual.
Figure 6. Smoke emission (%) v/s Load (Nm) for different fuel blends

7. Conclusions
In this research, Diesel, Diesel-Dual (Diesel with Biogas), M20 and F20 (Biodiesel with Biogas) were tested keeping the ratio of Mahua or Fish (20%) with Diesel (80%) and Biogas. The aim of this thesis is to find the best performing biodiesel-blend. After the study, it was investigated that:

- Diesel-Dual and Fish Oil blends resulted in better BTE at higher loads.
- The value for NOx is lower for biodiesels at high loads in comparison with diesel and diesel–dual, and M20 also resulted into the lowest HC Emission.
- The highest CO Emission was observed for Diesel-Dual and M20.
- Higher Smoke emissions were observed in biodiesel blends compared to diesel and diesel-dual.

The obtained results in the discussed experimentation can also be further performed with intermixing of various concentrations of biodiesel blends that can lead to more sustained performance and emission characteristics. Demerits were also observed while using M20 and F20 as they contain high density and viscosity which in turn cannot be completely replaced by diesel. Furthermore, storage problems of biodiesel can be taken into consideration first and if the biodiesels are maintained and stored properly they can be used as sustainable fuels.

Abbreviations

| Symbol | Full Form |
|--------|-----------|
| BTE    | Brake Thermal Efficiency |
| NOx    | Nitrogen Oxides |
| HC     | Hydrocarbon |
| CO     | Carbon Monoxide |
| D      | Diesel 100% |
| DD     | Diesel + Biogas (CH₄ + CO₂) |
| M20    | Mahua oil (20%) + Diesel (80%) + Biogas |
| F20    | Fish oil (20%) + Diesel (80%) + Biogas |
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