Production and Performance of Biodiesel from Palm Fatty Acid Distillate

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Abstract. Nowadays exhaustion of fossil fuel, increasing fuel price and the scarcity of petroleum products exist. It promotes the interest in the growth of alternative sources for petroleum-based fuel. Biodiesel is renewable fuel obtained from vegetable oil, animal fats and algae. The biodiesel from palm oil has been considered as the most merging alternate fuel used for transportation. The esterification and transesterification process is employed to extract biodiesel from PFAD due to high FFA content. In the esterification process, 2% of H2SO4 as an acidic catalyst with 12:1 molar ratio at 60°C temperature for 60 min was used as process parameters. In the transesterification process 0.5% KOH, 8:1 molar ratio is mixed at 60°C for 60 min. The properties of oil such as density, viscosity, flash point, fire point, etc., have been analysed. The biodiesel is blended with standard diesel and tested in DI diesel engine for its performance and emissions. The performance of test fuel is plotted for the various blends of biodiesel at the different loading conditions. The performance attributes such as brake thermal efficiency, specific fuel consumption, have been calculated and compared with the diesel. Brake Thermal Efficiency comparatively low for biodiesel and it blends due to lower calorific value. The emission attributes such as carbon monoxide, hydrocarbon and smoke are found to decrease with an increase in the blending ratio of biodiesel. The NOx is found to increase for biodiesel and its blends compared to diesel due to better combustion.

Keywords: Palm fatty acid distillate, biodiesel, transesterification, performance, emission

1. Introduction

Nowadays Exhaustion of fossil fuel and increasing population, the scarcity of petroleum products exists. Also, the demerit of using diesel such as air pollution and global warming issues [1]. Due to that many researchers started studying and analysing the alternative fuel which overcomes this scarcity and also the demerits of diesel. They conclude that the alternative fuel is the best substitute for the emerging problem. The search resulted in alternative fuels such as alcohol, natural gas, hydrogen, biodiesel, biomass, etc. Biodiesel is one of the suitable replacements for the conventional diesel and is gaining more importance. Excluding all this, it is biodegradable, non-toxic and it is a renewable source of energy which helps in reducing greenhouse emission. Biodiesel from the vegetable oil has properties such as kinematic viscosity, density, calorific value and cetane number are close to diesel which makes it more suitable for compression ignition engines [2]. In such vegetable oil, palm oil is the particular non-edible oil, which is available more in Malaysia and India. In the world’s biofuel category, biodiesel is the second-largest producer, approximately 22.6% of biofuel has produced in 2013 (i.e) 6.5 billion gallons [3]. Pertinent challenges arising from producing biodiesel have been mostly about the high-priced nature of the process which may lead to a hike in biodiesel price when differentiated from that of conventional diesel.

Efforts are consequently taken to produce a bit cheap and profitable biodiesel economically. Many researchers have proved that the emission characteristics such as particulate matter, hydrocarbon, carbon monoxide, Sulphur level are less in biodiesel fuel. The methods used for producing biodiesel are transesterification, pyrolysis, emulsification, blending, de-polymerization. The process which is commonly used for biodiesel production is transesterification. Dennis et al. discussed the process of
catalysed Transesterification [4], 92% yield of biodiesel obtained from the process. The biodiesel from various oils has better properties than diesel but the viscosity is higher than diesel which makes the spray characteristics poor during the injection. Although biodiesel has better properties to be used in engines there is an important difference in properties like the viscosity of the oil which lead to the poor spray of fuel during injection and it resulted in incomplete combustion. Fatty acid content decides the process whether direct transesterification or undergoes the esterification process before the transesterification. Shatesh kumar et al. discussed the effectiveness of biodiesel using a carbon-based solid catalyst in palm fatty acid distillate [5]. He obtained 96% yield from his methodology. Rajesh et al. used coconut fatty acid distillate to produce biodiesel and tested the blends of biodiesel in diesel engine. The method resulted in a yield of 92%. Biodiesel showed better performance and emission characteristics in comparison to conventional diesel [6].

Temperature, molar ratio, catalyst, reaction time are some of the factors which affects the process. Prabakar et al studied optimized parameters to extract bio-diesel from the skin of the sheep and a compatibility test was done in diesel engines. The transesterification process resulted in 92% yield with the esterification process parameters H₂SO₄ methanol to oil ratio 18:1 and reaction time 4h and transesterification parameters NaOH 0.5 wt %, methanol to oil ratio 6:1 and reaction time 1h at 65°C. Study on the engine showed B20 performance is better than diesel at maximum load [7]. Route and Parida studied the Argemone oil which had a high acid value. Maximum yield of 86% was obtained by the use of esterification and transesterification. The obtained biodiesel is tested in an engine and biodiesel blend of 20% resulted in better emission characteristics and performance than diesel [8]. Kavitha et al. extracted biodiesel with 90.2% of yield by using sterculia oil with the design of Box-Behnken to optimize the transesterification process. 1.5% of catalyst,1:4 of methanol to oil ratio 55°C at 900 rpm agitation speed is found to be optimized parameters. The authors reported that the B10 and B20 blends performance and emission was better than the diesel [9]. In the current study, biodiesel extraction, properties of the oil and biodiesel and its characteristics in a DI diesel engine were discussed.

2. Materials and Methods

2.1 Materials

The feedstock palm fatty acid distillate was purchased from a oil dealer and it is a light-yellow colour semi solid. In this, palmitic acid higher than other acids. Due to the high FFA content, PFAD is subjected to the esterification and Transesterification process. Here H₂SO₄ and KOH are used as acid and base catalyst. Laboratory grade methanol, phenolphthalein indicator, ethanol is purchased from local chemical shop. The experimental setup employed for biodiesel extraction consists of 500ml glass beaker, hot plate with temperature and speed controller, digital thermometer and a separation flask.

2.2 Properties of Raw PFAD

The properties of oil such as kinematic viscosity at 40oc, pour point, Flashpoint, density, Gross calorific value, acid number, iodine value, saponification value of palm fatty acid distillate are found with standard testing method. The property of raw palm fatty acid distillate oil is given in Table 1. The FFA% determines whether the oil requires one step or two step transesterification process. Here the FFA% is greater than 2.5 hence two step transesterification was carried out to extract biodiesel.
### Table 1. Property of raw PFAD

| S.No | Parameter                              | Unit       | Results   |
|------|----------------------------------------|------------|-----------|
| 1    | Kinematic viscosity @ 40°C              | CST        | 34.6      |
| 3    | Total acid Number                      | Mg of KOH/g | 8.55      |
| 4    | Pour point                             | °C         | < -10     |
| 5    | Flash point                            | °C         | 240       |
| 7    | Total sulphur                          | g/100g     | 0.878     |
| 8    | Carbon content                         | g/100g     | 3.54      |
| 9    | Iodine value                           | -          | 51.1      |
| 10   | Saponification value                   | -          | 152.6     |
| 11   | FFA as palmitic acid                   | %          | 82        |

#### 2.3 Biodiesel Production Process

![Diagram of biodiesel production process](image)

**Fig.1 Process of biodiesel production**

**2.3.1 Esterification process:**

In PFAD palmitic acid is present at a higher amount and the free fatty acid is greater than 2.5% [2]. The Fig.1 shows the process of palm fatty acid distillate biodiesel production. Generally, esterification is carried by heating the oil with alcohol which results in the formation of ester. Here, 2% of H₂SO₄ is used as catalyst in this process. The reaction takes place with 12:1 molar ratio at 60°C for 60 mins. The presence of any water should be removed to avoid formation of soap during the reaction. For this purpose, the ester is heated at a temperature between 100 to 110°C. Fig.2 shows the experimental setup used for producing biodiesel. The Fig.3 shows the reactant mixture after esterification process.
2.3.2 Transesterification Reaction:
The FFA content decides the process of Transesterification. Once the ester FFA% comes below 2.5, the transesterification process is carried out to get PFAD biodiesel. The alkali catalyst i.e KOH is used in the transesterification process. The process parameters values of 0.5% alkali catalyst, 8:1 molar ratio, at 60°C for 60 min was the conditions used for transesterification. The methanol and the alkali catalyst were added to oil when it reaches 60°C. After the rated time the reactant mixture is transferred to the separating funnel. The mixture separates in two different layers after 2 hours. The Fig. 4 shows the solution after transesterification process. The bottom layer consisted of glycerine and the top layer is PFAD biodiesel. The biodiesel obtained is washed with distilled water to remove impurities. The biodiesel after washing with water is heated above 100°C in order to eliminate any water content present in it [10]. The properties of the PFAD biodiesel is given in the Table 2.

| S.No | Parameter                        | Unit       | Results |
|------|----------------------------------|------------|---------|
| 1    | Kinematic viscosity @ 40°C       | CST        | 4.5     |
| 3    | Total acid Number                | Mg of KOH/g| 0.800   |
| 4    | Pour point                       | °C         | 13      |
| 5    | Cloud point                      | °C         | 16      |
| 6    | Flashpoint                       | °C         | 178     |
| 7    | Gross calorific value            | Cals/g     | 8005    |
| 8    | Density @ 15°C                   | Kg/m³      | 880     |
| 9    | Ash content                      | Wt %       | 0.0075  |
2.4 Engine Specification

The testing of the fuel was carried out using a single cylinder four stroke direct injection water cooled diesel engine. The aim is to study the performance and emission characteristics of PFAD biodiesel and its blends and to compare it with diesel. The engine was tested with diesel, 80% diesel+20% biodiesel, 60% diesel+40% biodiesel and 100% biodiesel at varying loads. Table 3. gives the detailed specification and the Fig.5 shows the layout of the test engine which is used in this study. For bringing the stable condition, the engine is first operated with diesel for about 30 min [11]. The diesel fuel is first tested followed by the blends of biodiesel.

| Description       | Specification                                      |
|-------------------|----------------------------------------------------|
| Manufacturer      | Kirloskar                                          |
| Engine type       | Single cylinder, four-stroke, Diesel engine        |
| Injection pressure| 220 bar                                             |
| Dynamometer       | Eddy current                                       |
| Engine cooling    | Water cooled                                       |
| Stroke            | 110mm                                              |
| Cubic capacity    | 661cc                                              |
| Bore              | 87.5mm                                             |
| Net power         | 5.2kW @ 1500rpm                                   |
| Compression ratio | 17.5: 1                                            |
| Injection timing  | 23° bTDC                                           |

![Fig.5 Schematic layout of the experimental engine setup.](image)

3. Result and Discussion:

3.1 Brake thermal efficiency (BTE)

The BTE is an important parameter of an engine and the Fig. 6 shows the comparison of diesel and PFAD biodiesel blends. It is seen from the graph that the BTE of diesel and biodiesel blends show an increasing trend with respect to load. This is due to more fuel injection at higher loads to compensate the power requirement [12]. The biodiesel and its blends have lower BTE when compared to diesel which is clear from the Fig 5. The reason for this trend might be caused by the reduced calorific value, higher kinematic viscosity and density of biodiesel [13]. Better performance is noted for B20 blend than...
B100 and B40 blend. The oxygen content in the biodiesel and the higher calorific value of biodiesel led to improved performance for B20 blend. This results in enhanced combustion thereby increasing the brake thermal efficiency [14].

![B100 and B40 blend](image1)

**Fig.6 Load vs BTE**

3.2 Brake Specific fuel consumption

![B100 and B40 blend](image2)

**Fig.7 Load vs BSFC**

BSFC values of diesel and biodiesel blends are shown in the Fig.7. The biodiesel and its blends show higher BSFC than that of neat diesel. Calorific value is the important parameter in BSFC. BSFC varies with calorific value i.e higher calorific value tend to reduce the BSFC and vice versa. In PFAD biodiesel, the calorific value is low hence more fuel is required to be supplied to the engine at increasing loading condition. It decreases sharply with the increases of load for diesel, biodiesel and its blends. The increased combustion chamber temperature which favours better evaporation resulting in better combustion caused the BSFC reduction at higher load [15]. The BSFC is higher for B100 and is the lowest for diesel fuel. Higher mass of fuel is injected for PFAD methyl ester blends at same volume and injection pressure due to its greater density and viscosity for improved performance. Calorific value of biodiesel is the main reason for increase in BSFC compared to diesel [6].
3.3 Carbon monoxide

CO emissions resulting from the combustion of engine is mainly as a result of incomplete combustion. Apart from that, the air-fuel ratio is also a main concern for CO emission. If the air fuel ratio decrease, CO emission increases. In biodiesel, the CO emission is observed to decrease as a result of higher oxygen concentration which helps to improve the quality of combustion. The comparison of biodiesel blend and diesel for various loading conditions are given in the Fig 8. CO is emitted from the engine when there is insufficient air supply for combustion. CO emission percentage is found to decrease by the increasing percentage of biodiesel with diesel. Insufficient time at higher engine speeds leads to incomplete combustion and hence all the quantity of fuel injected is not completely burnt. The higher oxygen content and cetane number of biodiesel fuel is the reason for the reduced CO emission [16]. Higher CO emission is observed for diesel fuel due to incomplete combustion at increased loading conditions. More fuel is injected to maintain the conditional loading at higher loads. The insufficient oxygen for combustion of diesel fuel leads to higher CO emission [17].

![Fig.8 Load vs CO](image1)

3.4 Unburnt Hydrocarbon (UHC)

![Fig.9 Load vs UHC](image2)
Fuel characteristics, operating conditions, fuel injection characteristics are reasons for Hydrocarbon emission. The unburnt hydrocarbon emission for various test fuels at various loads are given in Fig. 9. When comparing to diesel fuel, biodiesel showed lower hydrocarbon emission than diesel fuel due to better combustion. In general, biodiesel possess higher cetane number and higher in cylinder temperature than diesel [6]. It is also the reason for the reduction of HC emission. B20 and B100 produced may results in reductions of HC emission by 30.3% and 38.8% when compared to diesel. The reduction of Carbon monoxide and Hydrocarbon emission are mainly due to the oxygen rich nature of biodiesel. This helps the fuel to undergo more complete combustion. Due to high cetane value of biodiesel, the ignition delay period is reduced which helps in better combustion leading to reduced HC emission [18].

3.5 Nitrogen oxides

NOx emission with respect to load for diesel and biodiesel blends is given in Fig.10. NOx emission does not depend on the single fuel property it depends on the coupled mechanism of various fuel properties and the operating condition. NOx of all the fuels increases with corresponding increase in load and the same is shown in the Fig. 10. NOx emission increases with raise in load as a result of higher combustion temperature and high adiabatic temperature [13]. Nitrogen oxide emission for biodiesel and its blends is greater than diesel due to elevated cetane number and high oxygen concentration. PFAD biodiesel has higher NOx emission than the other biodiesel blends and diesel. The unsaturation of Fatty Acid Methyl Ester is correlated with the rise of nitrogen oxide emission. The ignition delay is reduced as a result of high saturated fatty acids which can have higher cetane number [19].

3.6 Smoke opacity

Generally, smoke emissions occur due to incomplete combustion of the engine. Fig. 11. gives the trend of smoke at various loads for diesel and biodiesel fuels. It is clear from the graph that with increase in load, the percentage of smoke increases for all the fuels tested. Smoke emission directly depends on load, when load increases smoke emission increases. Higher smoke is observed with increase in load because of the the air-fuel mixture increase in the combustion chamber and due to improper combustion [6]. It is observed that the diesel has higher smoke emission than biodiesel and its blends. The rich mixture formed at higher load conditions are oxidized for biodiesel and its blends. This is due to the availability of rich oxygen content in the biodiesel. Also high temperature prevails in the combustion chamber when biodiesel fuel is burned when compared to diesel. This helps to vaporize the fuel droplets thereby better mixing and better combustion resulting reduced smoke.
4. Conclusion

In this current work, biodiesel extraction from palm fatty acid distillate and its performance and emission characteristics were analyzed.

- In esterification 2\% of H$_2$SO$_4$ with a molar ratio of 12:1 under 60°C for 60 min.
- In transesterification 0.5 wt\% KOH with a 8:1 molar ratio at 60°C for 60 min and attained a yield of 93\% from Palm fatty acid distillate oil.
- The brake thermal efficiency of palm fatty acid distillate biodiesel and its blends are comparatively lower than diesel. The performance of B20 blend is close to diesel fuel.
- The BSFC increases for PFAD biodiesel and its blends owing to high viscosity, density and lower calorific.
- PFAD biodiesel has lower CO, HC emission and smoke emission than diesel due to better combustion.
- High values of NO$_x$ was noted for all the biodiesel blends as a result of increased temperature in the combustion chamber resulted from better combustion.

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