Study On Performance and Emission Characteristics of VCR Diesel Engine Fuelled with Palm Fatty Acid Distillate Biodiesel

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Abstract. This work consider the use of PFAD oil for the production of renewable and environment friendly biodiesel fuel as an alternative to conventional diesel. Test quantities of PFAD oil biodiesel were produced through transesterification reaction, 20% methanol (vol% PFAD oil), 0.8% (wt%) potassium hydroxide catalyst at 60°C reaction temperature and 90 min reaction time. The PFAD oil biodiesel produced was subsequently blended with petroleum diesel and characterized as alternative diesel fuel through ASTM standard fuel test. Variable Compression Ratio (VCR) engine test rig was used to determine the effect of compression Ratio (CR) on the performance and emission characteristics of the test fuel. Test were carried out at compression ratios of 16:1, 17:1, and 18:1 at different load. The performance parameters like Brake Thermal Efficiency (BTE), Brake Specific Fuel Consumption (BSFC) and Exhaust gas temperature (EGT) were studied. At higher compression ratio the increase in BTE is observed for PFAD20 blend when compared to diesel. BSFC of biodiesel blend is higher at all compression ratios due to lower heating value of the fuel. However the biodiesel exhibited lower emission at CR 18 compared to neat diesel except NOx. The NOx is increased due to higher compression and better combustion characteristics of the biodiesel blend. Thus B20 blend at CR18 can be effectively used in diesel engine with better performance and reduced emissions.

Keywords: Palm fatty acid distillate, Performance, Emission, Variable compression ratio, Diesel engine

1. Introduction

The growth of a nation can be seen by the energy usage for its progress in various sectors. The energy is an essential one which involves in every part of life and day to day activities. Hence it is important to focus on the energy and the problems associated with it. The major sectors which depend on the energy are industries, transportation and domestic requirement. Due to rapid development and increased population, the non-renewable source of energy is depleting in recent decade. Especially, the transportation sector relies on conventional fuels like petrol and diesel which are obtained from fossil fuels. Due to the rapid depletion of fossil resources, it is predicted that the reserves may vanish in the near future. In this regard, more people are working to find a best feasible solution to overcome the energy demand. More focus is given on the transportation sector and efforts are made to find an alternative source of fuel to replace diesel. The factors which are considered for selecting a fuel are cost, demand and environmental issues. Also, the combustion of the fuels emits harmful emission which affect the humans and the environment [1]. Hence efforts are made to find a suitable alternative in the
place of diesel which should be easily available, environmentally friendly, renewable and lower emissions. Another important point should be considered is the engines which are used in recent automobiles. The fuel should be used readily in the existing engines without more modifications. In this point of view, the biodiesel is one of the better sources of energy for the diesel engines. The biodiesel are derived from various edible and non-edible vegetable oils which are renewable in nature. But the raw oil when used in diesel engines directly has many drawbacks like incomplete combustion, higher viscosity leading to spray characteristics, carbon deposits, etc. In order to overcome the problem the oils are transformed into methyl esters through the process called transesterification. The biodiesel thus obtained will have superior properties compared to neat diesel and most suitable to be used in diesel engines. These properties of the biodiesel helps in using it in engines with any change in the design, operating conditions or modifications.

Many works on experimental investigation in diesel engine using biodiesel from various feedstocks were carried out by researchers all over the world to study the performance. The most of the final conclusions are same in nature with little variation in the performance for different biodiesel. To use biodiesel in diesel engines with better performance than diesel, minor modification should be made on the engine. In current work the biodiesel derived from PFAD and tested in a compression ignition diesel engine at various compression ratios. The performance and emission of biodiesel at various CRs is compared with diesel fuel. Different techniques were employed to improve the performance of biodiesel than diesel. Although biodiesel is having better combustion and emission characteristics when used as fuel in diesel engine, the performance is lower compared to diesel. The reason for the reduced performance are due to its physicochemical properties like, calorific value, viscosity, density, surface tension, etc. Also the biodiesel is mostly tested in an unmodified diesel engine irrespective of its change in the physicochemical properties of biodiesel. In the present work the biodiesel blend and diesel are tested using VCR direct injection diesel engine. Compression ratios 16:1, 17:1 and 18:1 was selected for the study and the biodiesel blend were tested under the three CRs. Based on the literature survey, modifications on the engine tend to improve the performance of the engine, when the compression ratio is higher, the biodiesel performance found to increase.

2. Materials and Methods

2.1 PFAD properties

The properties of the palm fatty acid distillate such as kinematic viscosity, acid number, pour point, flash point, total sulphur, iodine value etc. are determined as per the ASTM standards. The property of raw PFAD is given in Table 1.

| 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      |
2.2 Biodiesel Production from PFAD

In PFAD palmitic acid is present at a higher amount and the acid value is greater than 2.5% [2]. The property of the palm fatty acid distillate oil is given in Table 1. 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 [2]. Ester formed is heated to 100°C to remove any water content present in it. The FFA content decides the process of Transmesterification. Once the ester FFA% comes below 2.5, the transesterification process is carried out to get PFAD biodiesel through transesterification process. Potassium hydroxide was used as catalyst to speed up the transesterification process. The process parameters values of 0.5% KOH, 8:1 molar ratio at 60°C for 60 min was selected for transesterification. The oil is heated to 60°C, the methanol and catalyst is added once the temperature is stabilized. The reactant mixture is then allowed to remain at 60°C for 60 min. After the rated time the reactant mixture is transferred to the separating funnel. The mixture separates in two different layers after 2 hours due to the density difference between the biodiesel and glycerine formed. The bottom layer consisted of glycerine and the top layer is PFAD biodiesel. The biodiesel is collected through gravity separation from the separating funnel. The biodiesel obtained is rinsed with distilled water to remove impurities. The biodiesel undergoes seven washing to eliminate all the impurities. The washed biodiesel is heated to about 100°C to eliminate water and neat biodiesel is obtained. The various physicochemical properties of the palm fatty acid distillate biodiesel is presented in Table 2.

Table 2. Properties of Biodiesel of PFAD

| S.No | Parameter                              | Unit     | Results  |
|------|----------------------------------------|----------|----------|
| 1    | Kinematic viscosity @ 40°C             | CST      | 3.5      |
| 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   |

Table 3. Test Engine Specification

| Description            | Specification                                |
|------------------------|----------------------------------------------|
| Model                  | Kirloskar TV1                                |
| Engine type            | Single cylinder, four-stroke, VCR Diesel engine |
| Stroke                 | 110mm                                        |
| Cubic capacity         | 661cc                                        |
| Bore                   | 87.5mm                                       |
| Net power              | 5.2kW @ 1500rpm                              |
| Compression ratio      | 12:1 to 18:1                                 |
| Dynamometer            | Eddy current, water-cooled                   |
| Injection pressure     | 200 bar                                      |
| Injection timing       | 23° before TDC                               |

The testing of the fuel was carried out using a single cylinder, water cooled, four stroke, direct injection diesel engine. The main objective is to study the effect of compression ratio on the performance
and emission of PFAD biodiesel and to compare it with diesel. The biodiesel blend selected for the study is B20 which shows close performance to diesel. The various compression ratio selected are 16:1, 17:1 and 18:1 and the B20 blend was tested under these CRs. The engine specification is given in the Table 3 and the photographic view of the VCR diesel engine is shown in Fig 1. The engine is operated with diesel for 30 min to attain the stable condition [11]. The experiment was started when the temperature of the cooling water becomes steady. Initially the engine is tested with diesel fuel followed by biodiesel blends.

3. Result and Discussion:

The blend in the proportion of 80% diesel and 20% biodiesel (B20) was tested in the engine. A single cylinder VCR engine is used to test the fuel blends. The results such as BTE, BSFC, EGT, CO, UHC, NOx and smoke opacity of the diesel and biodiesel were discussed under this section. The observations of the above said parameters were discussed in result and discussions.

3.1 Brake thermal efficiency

![Figure 2. Load vs BTE](image-url)
Brake thermal efficiency PFAD 20 and diesel at various CRs were compared and depicted in the Fig. 2. With respect to the load increase there is gradual increase of brake thermal efficiency. Almost the graph looks alike for both the fuels and at all compression ratios. The BTE of PFAD 20 increases with respect to rising compression ratio of the engine. The BTE of PFAD 20 at CR 16:1 is 21.77% and at CR 18 is 26.55%. Thus, the PFAD 20 blend at CR 18:1 is higher compared to diesel fuel at CR 17.5:1. The increase in BTE for higher compression ratio can lead to better fuel atomization, evaporation and combustion due to enriched oxygen content in it [4]. Also high temperature and pressure in the cylinder promotes better combustion compared to diesel resulting in higher BTE for PFAD20 at CR 18 [5].

3.2 Brake Specific fuel consumption

![Figure 3: Load vs BSFC](image)

The Fig. 3, shows that the changes of specific fuel consumption and Load at various CRs. The BSFC is quite opposite to Brake thermal efficiency. Brake specific fuel consumption keeps on decreasing with increase in load. Calorific value is the important parameter in BSFC. BSFC varies with calorific value i.e higher the calorific value of the fuel then lower the SFC and vice versa [6]. Calorific value of PFAD biodiesel is less compared to diesel. Due to blending of 20% of biodiesel with diesel reduces the calorific value of PFAD20. Thus the PFAD 20 at CR16:1 and CR17:1 show higher BSFC than diesel. But at increased compression ratio the better combustible nature of the PFAD20 enhances the performance in turn reducing the BSFC [7].

3.3 Exhaust Gas Temperature

The Fig 4, is plotted between Exhaust gas temperature and Load. As the load increases, Exhaust gas temperature also increases respectively. From the graph, it is noted that the temperature of the exhaust gas is more for biodiesel. It is generally said that Exhaust gas temperature decreases at increased compression ratio as a result of ignition delay period reduction and better combustion. The exhaust temperature of PFAD20 at CR16:1 (250°C) is recorded higher and at CR18:1 has the lowest EGT (212°C). At lower compression ratio, due to high kinematic viscosity and surface tension of the biodiesel it is not properly atomized for easy mixing with the compressed air [8]. But at high compression ratio the temperature and pressure in the cylinder helps the fuel particles to evaporate at a faster rate which helps in easy mixing with air. Thus the late burning larger fuel particles are reduced at the expansion resulting in reduced exhaust gas temperature [9].
3.4 Unburnt hydrocarbon emission

The Fig 5, is plotted between unburnt hydrocarbon and load at varying compression ratios. Hydrocarbon is denoted in ppm. The unburnt hydrocarbon tend to increase for both the fuel with an increase in load. The supply of more fuel to the engine at higher loading condition to preserve the output of the engine at the same level. This results in rich mixture zone leading to higher unburnt hydrocarbon emissions [10]. As a result of increase in compression ratio of the engine, the UHC emission decreases. At lower compression ratio improper air fuel mixture may lead to higher emission. Proper air fuel mixture formation is resulted as a result of high temperature and pressure inside the cylinder due to higher compression ratio. This results in lowering the unburnt hydrocarbon at CR18:1.

3.5 Carbon Monoxide

The change in carbon monoxide emission versus the engine load at different compression ratios is shown in the Fig. 6. In general, the carbon monoxide emission tend to increase with respect to the load acting on the engine. At higher loads in order to meet the energy demand more fuel is supplied [11]. This causes incomplete combustion to take place resulting in higher CO. Also biodiesel has inbuilt
oxygen resulting in reduced CO compared to diesel at all compression ratios. On the other hand, when CO of higher and lower compression ratio compared, the CR18:1 shows lower CO. Better combustion might be the possible for reduced CO emissions at higher compression ratio.

![Figure 6: Load vs CO](image)

3.6 Nitrogen oxides

Figure 7 shows the variation of Nitrogen oxide emission with load for the ratios 16:1, 17:1 and 18:1. It is well known that the NOx emission is in direct relationship with the combustion chamber temperature and pressure [12]. More valence electrons are formed due to higher temperature and pressure and splitting of nitrogen atom from the incoming air. This causes increase in NOx emission in the exhaust. Thus at higher compression ratio i.e at CR18:1 results in increased NOx when compared to diesel and PFAD 20 at CR16:1 and 17:1. At lower CRs the temperature inside the cylinder is not high due to poor atomization and burning of the fuel resulting in reduced NOx. PFAD20 at CR 18:1 has highest value of 340 ppm followed by diesel of 320 ppm. Since the diesel combustion is better when compared to PFAD20 at CR16:1 and 17:1.

![Figure 7: Load vs NOx](image)
3.7 Smoke Opacity

The fig. 8 shows the smoke opacity of the engine when tested by diesel and PFAD20 at three different compression ratios. The term opacity refers to the quality of lacking transparency or translucence. As the load increases, Smoke opacity also gradually increases. This is due to more fuel supplied and the unburnt fuel particles coming out of the engine due to incomplete combustion [13]. It is well known that the formation of smoke starts at the fuel rich areas inside the cylinder [14]. The smoke emission of diesel is found to increase than PFAD 20 at CR16:1, 17:1 and 18:1. This is due to absence of enriched oxygen in diesel which lack oxidation during combustion. With increase in compression ration the air temperature is increased which help the fuel to easily vaporize for better combustion. The smoke opacity is very much reduced at higher compression ratio due to improved oxidation, higher temperature and pressure prevailing inside the combustion chamber [15].

![Figure 8: Load vs Smoke Opacity](image)

4. Conclusion

This paper discusses the use of PFAD20 blend and its performance and emission characteristics under the variable compression ratio. For B20 blend test were carried out at CR of 16:1, 17:1 and 18:1 at different load. The various performance and emission parameters of engine like BTE, BSFC, EGT, UHC, CO, NOx and smoke opacity were also discussed.

- The BTE of PFAD20 at CR16:1 and 17:1 is lower compared to diesel. But at CR18:1 BTE of PFAD20 is higher than diesel
- The BSFC of diesel and B20 decreased at high load condition. PFAD20 at CR18:1 recorded lower BSFC among all test conditions
- The EGT for diesel is 215.6°C and for PFAD20 at CR16:1, 17:1 and 18:1 are found to be 250°C, 233°C and 212°C.
- The UHC emission is reduced by 43.15%, CO emission reduced by 33.1% with corresponding change in CRs between 16:1 and 18:1
- Highest NOx emission is observed for PFAD20 at CR18:1 due to better combustion whereas PFAD20 at CR16:1 recorded the lowest NOx
- Smoke opacity of PFAD20 at three different compression ratios recorded low compared to neat diesel.
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