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Production of Palm fatty acid distillate biodiesel and effects of its blends on performance of single cylinder diesel engine

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Abstract

Fossil fuels are commonly used fuel for automobiles. The reserve stock and exhaust gas emission of fossil fuel cause a serious problem. So there is a need of an alternative ecofriendly fuel. Biodiesel is a renewable fuel produced from plant and animal material by esterification. Esterification is an acid catalyzed reaction that converts free fatty acid (FFA) of oil into triglycerides. Transesterification is base catalyzed reaction they converts triglycerides into mono alkyl esters. The main problem of biodiesel is its high cost which could be reduced by use of less expensive feed stock. Palm fatty acid distillate (PFAD) is a waste from extraction of palm oil. PFAD is used for production of biodiesel. The calorific value of PFAD biodiesel is 38600 MJ/kg while density is 879 kg/m^3, flash point is 147°C, viscosity is 3.96 mm^2/s and cetane number is 49. A single cylinder, 4 stroke, water cooled diesel engine of Kirlosker Oil Engine is used for evaluating performance of PFAD biodiesel blends and diesel. The engine performance for various PFAD biodiesel blends at various loads are comparatively equal to that of diesel fuel. Brake power of various blends is comparatively equal to brake power of diesel. Brake Thermal Efficiency increases comparatively for 50% PFAD blends. Specific Fuel Consumption for PFAD blends is slightly higher than diesel. Indicated power of PFAD blends is less than indicated power of diesel.

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Keywords: Production, Biodiesel, Engine performance, Esterification, Transesterification, NaOH, H_2SO_4.

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1. Introduction

The vegetable oil was used as a fuel around 100 years ago by the inventor of diesel engine Rudolph Diesel. Rudolph Diesel used peanut oil in his CI engine. After exploration of fossil fuels they were continued to be major conventional energy source. With the increasing trend of industrialization and modernization the world energy demand are also increasing at a faster rate. Most of the countries import crude oil to fulfil their energy demands. Also these fossil fuels are dominant sources of carbon monoxide (CO), carbon dioxide (CO_2), sulphur oxides (SOx) [1].

Hence due to exhausting sources of fossil fuels and emissions caused by them there is a need of alternative ecofriendly fuel [2-5]. Biomass is a potential source for alternative ecofriendly fuel. Biomass is a general term for energy derived from plant and animal material through variety of conversion. There are plants that produce oil and hydrocarbon substance as part of natural metabolism.

The use of vegetable oils directly in an engine is considered impractical because these oils contain free fatty acids (FFA), phospholipids, sterols and other impurities. This vegetable oil is converted into biodiesel by the process of esterification. Esterification is a reaction involving FFA and alcohol which yields fatty acid alkyl ester and water [6-8].

At present main drawback of use of biodiesel is its higher cost than petroleum based diesel [9-10]. The high cost of biodiesel is mainly due to its being produced from high quality virgin oil with low content of free fatty acid. A way of reducing biodiesel cost is to use less expensive feedstock containing high FFA, recycled or waste oil and products of refining vegetable oils [11-13]. With feedstock having high FFA content biodiesel is produced in two steps. The first is to reduce the FFA content of oil by esterification. The second is transesterification which converts esterified oil to mono alkyl ester and glycerol.

This paper investigates the production and properties of palm fatty acid distillate biodiesel and their comparison with diesel fuel. The use of palm fatty acid distillate as a engine fuel has a potential to reduce exhaust emission since palm oil has less than half (38 grams in comparison to 86 grams per MJ of energy) of carbon dioxide emission than customary diesel. Experimental tests are conducted on the single cylinder four stroke compression ignition engine. The performance of the engine using blends of palm fatty acid distillate biodiesel were evaluated and compared with the performance obtained with diesel. The blends for testing were used as PFAD 10%, PFAD 15%, PFAD 20%, PFAD 25%, PFAD 30%, PFAD 50%. And performance of engine was recorded at 0%, 20%, 40% 60%, 80%, 100% and overload conditions. The significant performance parameters of C.I. engine were selected as Specific fuel consumption, brake power, brake thermal efficiency, mechanical efficiency, indicated power and torque.

Abbreviations

PFAD	Palm fatty acid distillate
FFA	Free fatty acid

2. Production Process

Palm is an ornamental tree. In extraction of palm oil from palm oilseeds we get 95% edible oil and 5% non edible waste oil. The non edible oil obtained from distillation process is called as palm fatty acid distillate (PFAD). PFAD is brownish in color and solid at room temperature. PFAD is non edible due to high FFA content up to 60%.

2.1Pretreatment

The palm fatty acid distillate used for production of biodiesel contains triglycerides, free fatty acids, water and other contaminants in various proportions. Pretreatment involves removal of impurities of PFAD for processing of biodiesel. Impurities present in PFAD can cause less production output.

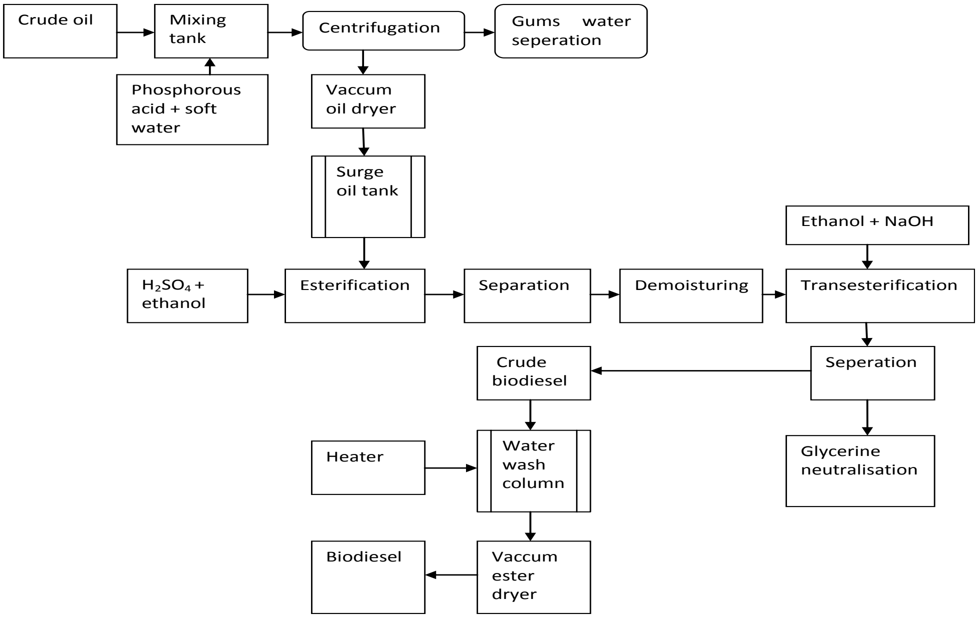


Fig. 1 Production process

2.1.1 Filtration

The PFAD is fed through filter paper in filter press. This removes solid impurities from crude PFAD oil.

2.1.2 Centrifugation

Centrifugation is carried out for removal of solid impurities and gums. The palm fatty acid distillate is fed to centrifuge. These causes the solid impurities to settle down and are removed from palm fatty acid distillate.

2.1.3 P_H balancing

Palm fatty acid distillate is highly acidic. Water washing is used to maintain normal P_H. PFAD is mixed with water and process is continued till P_H of water becomes neutral.

2.1.4 Demoisturing

After P_H balancing palm fatty acid distillate contains water. PFAD is heated in oven at 90^0C for 15 min for removal of moisture.

2.2 Esterification

Esterification is an acid catalyzed chemical reaction involving free fatty acid of oil and alcohol which yields triglycerides and water [14-15]. In esterification PFAD is added to a mixture of H_2SO_4 and ethanol.

PFAD is heated upto 60^0C for removal of moisture. A mixture of 1 liter PFAD, 250 ml of ethanol and 5 ml of H_2SO_4 are added to closed reaction vessel. The system is closed to prevent loss of ethanol. The reaction temperature is kept 65^0C just above boiling point of ethanol to boost rate of reaction. The reaction time is 60 minutes. Excess alcohol is usually used to ensure total conversion of oil into esters. After 60 min check the FFA content it should be less than 2%. If it is more than 2% continue the reaction. When FFA content becomes less than 2% continue for transesterification.

2.3 Separation

Once esterification is complete we get two products glycerine and esterified oil. Each has substantial amount of ethanol. The reacted mixture is neutralized if necessary. Glycerine is dense and gets separated from bottom of settling tank. Centrifuge could also be used to separate material faster.

2.4 Demoisturisation

The esterified oil is heated in an oven at100^0C for 15 min to remove moisture.

2.5 Transesterification

Transesterrification is a base catalyzed reaction involving triglycerides and ethanol which yields mono alkyl esters and glycerine [16]. A mixture of 5 gm NaOH and 250 ml ethanol is added to esterified oil. The mixture is charged to a closed reaction vessel. The temperature is kept 65^0C for 60 min. Excess alcohol is usually used for complete conversion of fat into esters. FFA content of mixture is checked after 60 min and it should be less than 0.5%. Also P_H should be neutral.

2.6 Separation

Once transesterification is complete there exist two products biodiesel and glycerine. The esterified oil is kept for 8-10 hours in a settling tank for separation of ethyl ester and glycerine. Glycerine settles down due to its high density at bottom and can be separated out. This gives a palm ethyl ester.

2.7 Alcohol removal

Once glycerine and palm ethyl ester are separated the excess alcohol phase is removed by flash evaporation process or distillation. The oil is heated upto 65^0C for removal of ethanol. Care must be taken to ensure no water resides in recovered ethanol. The amount of ethanol recovered is 200 ml.

2.8 Glycerine neutralization

The byproduct glycerine contains unused catalyst and soap. Hence refining of glycerine is important due to its numerous application [17-18]. The glycerine is neutralized with acid and sent to storage as crude glycerine [19].

2.9 Washing

Once separated from glycerine the biodiesel contains water, alcohol etc. It is purified by washing with warm water [20-21]. For 1 lit of palm ethyl ester 3 lit of water are used for washing. Washing is done till P_H of water becomes neutral.

2.10 Demoisturisation

Palm ethyl ester is heated in oven at 90^0C for 20 min for removal of moisture. Moisture should be less than 0.5%. This gives a pure palm ethyl biodiesel.

2.11 Product Quality

Prior to use as a commercial fuel biodiesel must be analyzed using sophisticated equipments to meet ASTM standards. The most important aspect of biodiesel production to ensure trouble free operation in diesel engine are complete reaction, removal of glycerine, removal of catalyst, removal of alcohol and absence of FFA [22-23].

3. Properties of Biodiesel

Table 1. Properties of Biodiesel

Properties	Unit	PFAD	PFAD biodiesel	Diesel	Chicken fat biodiesel	Jatropa Biodiesel	Biodiesel standards
Density	kg/m^3	920	879	850	870	970	870-900
Viscosity	m^2/s	36.57×10^{-5}	3.96×10^{-6}	2.6×10^{-6}	5.4×10^{-6}	5.7×10^{-6}	1.9×10^{-6}-6.0×10^{-6}
Sp. Gravity	kg/L	0.980	0.962	-	-	0.93	0.88
Moisture	vol. %	5	0.05	0.02	0.02	-	≤0.03
Acid value	mg KOH/gm	8.55	0.800	0.35	0.8	2.20	0.80
Flash point	K	-	420	341	447	447	≥403
Calorific value	MJ/kg	-	38600	42000	39340	39170	-
Cetane number	-	-	49	46	58.4	53	48-60

4. Production cost analysis

Table 2. Production cost analysis for 1liter of PFAD biodiesel

Components	Unit	Quantity taken	Unit price (Rs)	Total (Rs)
Raw material				
PFAD	kg	1.2	20	24
Ethanol	Lit	0.500	200	100
H_2SO_4	Lit	0.005	40	0.20
NaOH	kg	0.005	60	0.30
Production				
Electricity	Rs			4
Other	Rs			2
Process water	Lit			2
Recovery				
Ethanol	Lit	0.200	200	20
Total	Rs			112.5

5. Blending

Straight vegetable oils (SVO) even though projected as an engine friendly fuel by many researchers have recently lost its attraction. Being highly viscous and less volatile, SVO's will result in poor spray atomization, vaporization, and pose serious threat to the engine [24]. More over many SVO's are edible oils whose continuous supply cannot be ensured in our country. Measures like blending, microemulsification, transesterification have turned out to be effective methods of viscosity reduction in vegetable oils, thus making their usage in DI diesel engines feasible [25].

Biodiesel also has high density and viscosity than diesel. Hence it is blended with diesel. Blending refers to the mixing of vegetable oil with other low viscosity fuels like diesel and alcohol. It results in reducing the viscosity of the blends. The blends can be directly used in diesel engines for better results.

A blend of 10 % raw PFAD biodiesel and 90 % diesel fuel by volume is designated as PFAD10. The various blends made for testing performance of diesel engine are PFAD10, PFAD15, PFAD20, PFAD25, PFAD30, PFAD50.

6. Experimental test setup and procedure

The PFAD biodiesel and diesel blends were used as alternative fuel to operate diesel engine in the Automotive Power Plant Laboratory of Department of Automobile Engineering, in Rajarambapu Institute of Technology Sakhrale. The Performance test are conducted on a computerized single cylinder, four stroke, direct injection, water cooled diesel engine test rig. The engine is coupled to eddy current dynamometer for variable loading. The engine specification is shown in table 3 and schematic diagram of experimental test setup is as shown in figure 2.

The engine has been run using biodiesel and required data are collected to calculate the engine performance parameters. The performance of PFAD biodiesel-diesel blends at different loading conditions namely 0%, 20%, 40%, 60%, 80%, 100% and overload were evaluated.

Table 3. Engine test setup specification

Description	Value
Manufacturer	Kirlosker Oil Engine Ltd Pune
Engine Type	Single Cylinder, 4 Stroke, water cooled, Diesel engine.
Cylinder	Single
Stroke	110 mm
Cubic capacity	661 cc (0.661 liter.)
Bore	87.5 mm
Net Power	5.2 kW @ 1500 rpm
Compression Ratio	17.5 :1

Table 4 and Table 5 below shows the performance parameters of engine using PFAD biodiesel and diesel blend at 0% and 100% load condition respectively.

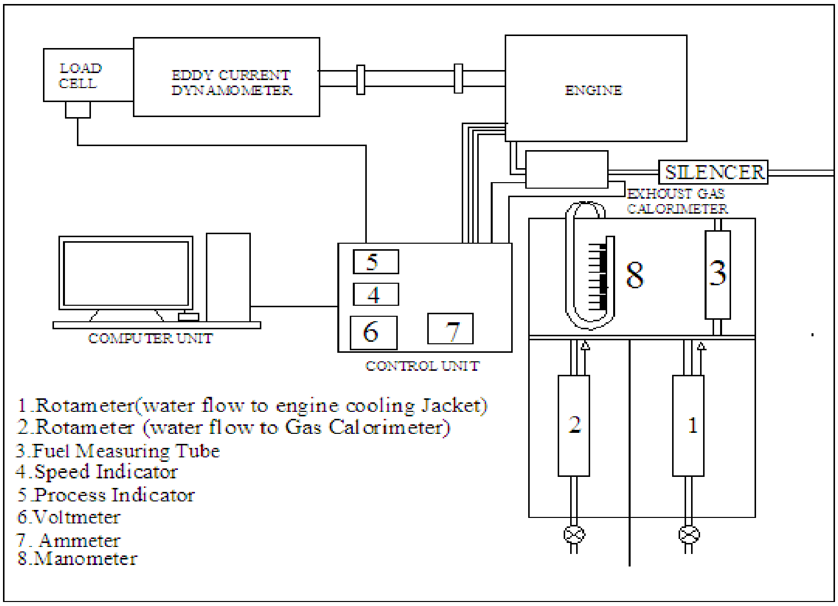


Figure 2. Computerized Single Cylinder Diesel Engine setup for testing PFAD biodiesel blends and diesel fuel.

Table 4. The observed engine performance using PFAD biodiesel and diesel at zero load

Performance	Diesel	PFAD10	PFAD15	PFAD20	PFAD25	PFAD30	PFAD50
Brake power (kW)	0.45	0.45	0.43	0.48	0.46	0.48	0.45
Specific fuel consumption (kg/kW-hr)	0.804	0.915	0.88	0.74	0.81	0.76	1.21
Torque (N m)	0.29	0.29	0.28	0.31	0.3	0.31	0.29
Brake thermal Efficiency (%)	10.66	9.9	10.49	12.8	11.84	12.85	8.99
Indicated power (kW)	4.84	1.82	1.72	1.82	2.04	1.47	1.91
Mechanical efficiency (%)	9.40	24.89	24.99	26.56	22.55	32.76	23.46

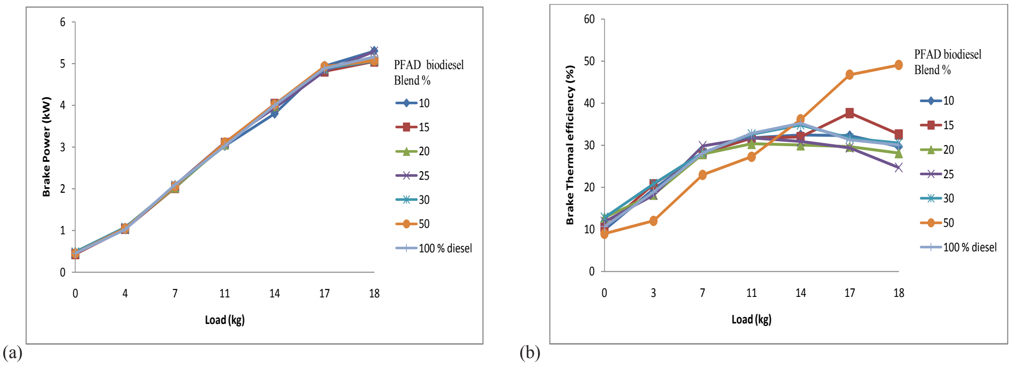
Table 5. The observed engine performance using PFAD biodiesel and diesel at full load

Performance	Diesel	PFAD10	PFAD15	PFAD20	PFAD25	PFAD30	PFAD50
Brake power (kW)	4.88	4.94	4.81	4.86	4.81	4.88	4.93
Specific fuel consumption (kg/kW-hr)	0.274	0.281	0.248	0.322	0.329	0.315	0.235
Torque (N m)	3.33	3.38	3.30	3.36	3.31	3.34	3.37
Brake thermal Efficiency (%)	31.26	32.28	37.64	29.68	29.42	31.67	46.77
Indicated power (kW)	5.49	5.82	5.81	6.02	5.84	5.19	5.83
Mechanical efficiency (%)	88.84	84.87	82.83	81.1	82.3	93.96	84.57

7. Results and discussions

7.1 Brake Power

Figure 3 (a) shows varitation of brake power of PFAD blends and diesel with load. The results show there is no noticeable difference in brake power of PFAD blends and diesel. At different load brake power of PFAD blends increases with increase in load because of the higher density of blends containing a higher percentage of PFAD biodiesel and has led to more discharge of fuel for the same displacement of the plunger in the fuel injection pump, thereby increasing the brake power. Maximum brake power is 4.88 N m for diesel at full load.



(a) (b)

Figure 3 (a) Effect of load on brake power (b) Effect of load on Brake Thermal Efficiency

7.2 Effect of load on brake thermal efficiency

The variation of brake thermal efficiency of the engine for different PFAD biodiesel and diesel blends is shown in Figure 3 (b) and compared with the brake thermal efficiency obtained with diesel. From the test results it was observed that initially with increasing load the brake thermal efficiencies of the PFAD biodiesel blends and the diesel increases and the maximum thermal efficiencies were obtained and then tended to decrease with further increase in load. The brake thermal efficiency of PFAD 50 biodiesel has an increasing trend with increase in load and brake thermal efficiency of other PFAD blends is close to brake thermal efficiency of diesel upto 80% load.

Maximum brake thermal efficiency is 49.08% at overload condition for PFAD50 and minimum of 9.9% for PFAD10 at no load.

7.3 Effect of load on specific fuel consumption

Figure 4 (a) compares the specific fuel consumption of diesel and various PFAD blends. It was observed that the specific fuel consumptions of the diesel as well as the blends were decreased with increasing load. It is also found that fuel consumption of PFAD blends is slightly higher than diesel. The fuel consumptions were also found to increase drastically with PFAD50 biodiesel diesel blends. This is mainly due to the combined effects of the relative fuel density, viscosity and heating value of the blends. Maximum specific fuel consumption is 1.22 kg/kW hr for PFAD50 at no load and minimum is 0.244 kg/kW hr for diesel at 80% load.

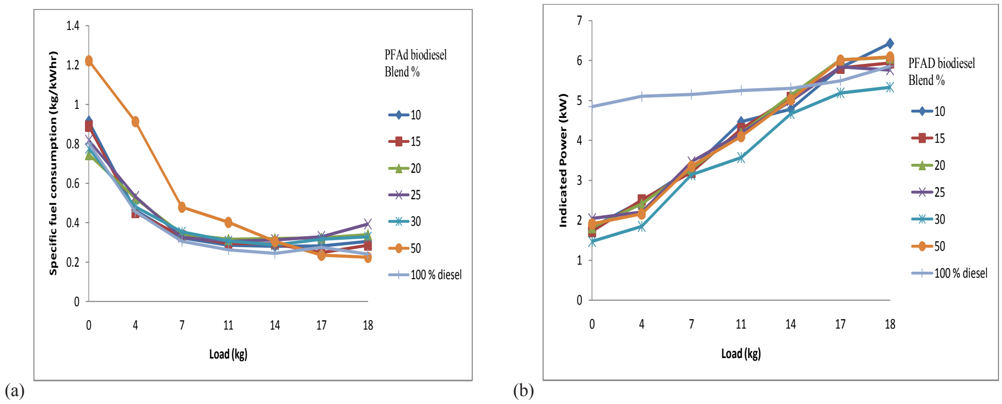


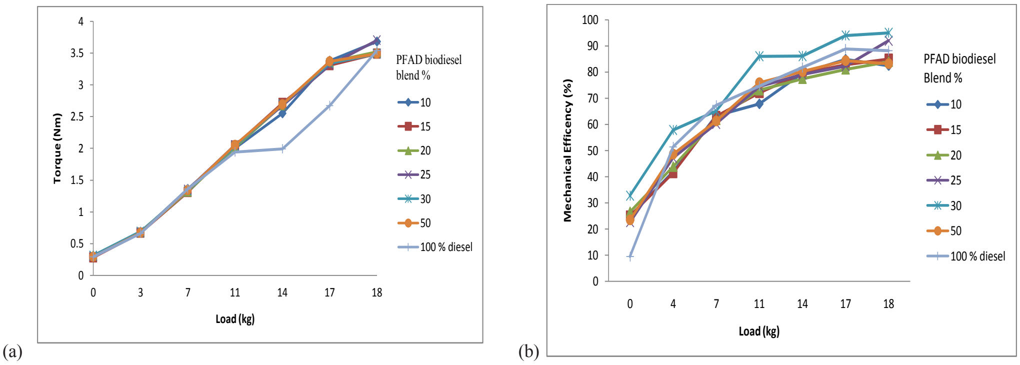
Figure 4 (a) Effect of load on S.F.C (b) Effect of load on Indicated power

7.4 Effect of load on indicated power

Figure 4 (b) shows indicated power of various PFAD blends and diesel at different loads. The indicated power of PFAD blends increases with increase in load. Indicated power of PFAD blends is quite less than indicated power of diesel. This could be due to lower heating value and higher density of PFAD blends than diesel. Maximum value of indicated power is 5.82 kW for PFAD10 at full load and minimum is 1.82 kW for PFAD10 at zero load.

7.5 Effect of load on torque

The variation of engine torque with load is shown in Figure 5 (a). Torque for PFAD blends increases with increase in load. Torque for various PFAD blends is equal to torque of diesel. Maximum torque is 3.38 N m at full load for PFAD10 and minimum is 0.28 N m at zero load for PFAD15.



(a) (b)

Figure 5 (a) Effect of load on torque (b) Effect of load on mechanical efficiency

7.6 Effect of load on Mechanical efficiency

The variations of mechanical efficiency of PFAD blends with load are shown in Figure 5 (b). As brake power increases with increase in load the mechanical efficiency of PFAD blends increases. Minimum mechanical efficiency is 9.4% for diesel at zero load and maximum is 93% for PFAD30 at full load.

8. Conclusion

The Palm fatty acid distillate biodiesel could be easily used as an alternative fuel to diesel engine. Esterification and transesterification using H_2SO_4 as acid catalyst and NaOH as base catalyst can reduce FFA about 60% to less than 0.5%. Also the reaction time of 60 min and temperature about 65°C make a simplified production system. The purification process gives a high quality palm ethyl ester biodiesel with properties close to ASTM standards.

The brake power obtained through out is same for all blending and diesel fuel. 50% blending of PFAD biodiesel increases thermal efficiency as compared to other blending of fuel. As blending increases with respect to load S.F.C. decreases and is same as diesel fuel. But S.F.C for 50% blending increases as compared to diesel fuel. The acceptable brake thermal efficiencies and S.F.C were achieved upto 30% blending. Indicated power of PFAD blends is less compared to diesel fuel. But indicated power increases with increase in load. Torque of engine for various blends and load is same as torque of engine obtained from diesel fuel. Brake power of engine for various blends increases with increase in load and are equal to brake power for diesel fuel. Hence mechanical efficiency for various blends is close to that of diesel fuel. Mechanical efficiency of PFAD10 is slightly greater than diesel.

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