

Full Length Research Paper

Performance test of palm fatty acid biodiesel on compression ignition engine

Praveen K. S. Yadav^{1*}, Onkar Singh² and R. P. Singh¹

¹Department of Oil and Paint Technology, Harcourt Butler Technological Institute, Kanpur, India.

²Department of Mechanical Engineering, Harcourt Butler Technological Institute, Kanpur, India.

Accepted 15 September, 2016

Vegetable oil causes problem when used as fuel in compression ignition engines. This problem is due to high viscosity and low volatility of vegetable oils, which can be minimized by the process of trans-esterification. The relatively high cost of refined vegetable oils render the resulting fuels unable to compete with petroleum derived fuel. To reduce the cost of biodiesel a relatively low cost palm fatty acid which is the by-product of palm oil refinery was chosen as feed stock. A two step acid catalyzed methanolysis process is employed for efficient conversion of palm fatty acid into palm fatty acid methyl esters (FAME). The conversion of palm fatty acid into palm FAME was done on pilot plant. This paper presents the results of performance of compression ignition engine fueled with different blends of high speed diesel with biodiesel obtained from conversion of palm fatty acid. Parameters like torque, brake specific fuel consumption and brake thermal efficiency were calculated at different loads for pure diesel and different combinations of dual fuel. The results indicate that, in case of palm fatty acid biodiesel, the dual fuel combination of B40 can be used in the diesel engines without making any engine modifications.

Key words: Trans-esterification, methanolysis, palm fatty acid, fatty acid methyl esters (FAME), compression ignition engine, triglyceride (TG).

INTRODUCTION

Energy is an essential factor for economic growth. Building a strong base of energy resources is necessary for sustainable economic and social development of any country. In view of limited fossil fuel reserves and environmental concerns the efforts are made to search a potential alternate. Moreover, the exhaust of petroleum diesel is the main reason for environmental pollution. Under these circumstances it becomes necessary to look for some self sustainable, biodegradable and environment friendly alternate fuels. Biodiesel, which is fatty acid methyl ester (FAME) is biodegradable and substantially reduces the exhaust emissions, when used in different blend ratios with petroleum diesel. Biodiesel does not increase the level of carbon dioxide in the atmosphere and therefore helps in minimizing green house effect. There is a growing interest in biodiesel because of its similarities in properties with fossil fuel

(Prafulla et al., 2009; Ramadhas et al., 2004). Biodiesel will mitigate the vulnerability and the adverse effects of use of fossil fuels. Several countries have introduced policies encouraging the use of biodiesel to replace part of their fossil fuel use and also prevent environmental degradation. However, production cost of biodiesel is not economically competitive with fossil fuel due to higher cost of lipid feedstock. The production of biodiesel can be made economical by using low grade lipid feedstocks containing high amount of free fatty acids (FFA). Waste cooking oil and non conventional oil seed oils viz. Tobacco seed oil with high free fatty acid content can be used as substitute of conventional diesel (Wang et al., 2006; Zlatica and Predojevic, 2008; Veljkovic et al., 2006). Lipid feedstock which are non edible in nature like karanja oil and Mahua oil can also be used for production of biodiesel (Stalin and Prabhu, 2007; Ramadhas et al., 2004; Shashikant and Raheman, 2005). However, the limitation with non edible feedstock is its low availability. In this study palm fatty acid (PFA) which is the by-product of refining of palm oil is used as feedstock for producing biodiesel. Here the study has been carried out on PFA

*Corresponding author. E-mail: pkyhbt@yahoo.co.in. Tel: 91-9415485447. Fax: 91-512-2533812.

feedstock with 93 wt% FFA content. The use of PFA as feedstock for production of biodiesel has the following advantages:

- i.) It does not compete with edible grade oil bearing seeds of food market as it is the by-product of refining of palm oil and is non-edible.
- ii.) It is easily available.
- iii.) Generally, the high cost of biodiesel is the major obstacle for its commercialization, as the biodiesel produced from vegetable oil or animal fat is usually more expensive than the petroleum diesel. In view of low cost of PFA, the biodiesel produced will be economically competitive.

A two step process is used for the conversion of PFA into FAME. The first step of the process is to reduce FFA content by esterification with methanol in presence of acid catalyst. In the second step, triglyceride (TG) portion of the lipid reacts with methanol in presence of base catalyst to form methyl ester and glycerol (Meher et al., 2006; Siti Zullaikah et al., 2005; Fangrui et al., 1999; Vicente et al., 2004). The acid catalyst is generally sulfuric acid and base catalyst is usually sodium or potassium hydroxide (Vicente et al., 2004; Zheng et al., 2006; Di Serio et al., 2005; Pramanik, 2003). Product from the reaction is separated into two phases under gravity. The FAME portion is washed with water and dried to meet the biodiesel fuel standards. The biodiesel produced from low grade lipid feedstock and its blends with fossil fuel can be used in diesel engines without any modifications of the engine. The use of biodiesel reduces the gas emissions, improves lubricity and thus increases the life of engine ((Pramanik, 2003; Ramadhas et al., 2005; Mustafa Canakei et al., 2006).

MATERIALS AND METHODS

PFA was procured from M/s Kanpur Edibles Pvt. Ltd. Kanpur, India. The composition of the palm fatty acid was determined with the help of gas liquid chromatography (Figure 1). The palm fatty acid contains 0.2% Lauric acid, 1.2% Myristic acid, 42.7% Palmitic acid, 0.1 % Palmitoleic acid, 4.5% Stearic acid, 38.9% Oleic acid, 11.5% Linoleic acid, 0.7% Linolenic acid, 0.1% Arachdic acid and 0.1 % traces. All chemicals including methanol, sulfuric acid and sodium hydroxide were of analytical grade. The acid value, saponification value and iodine value of PFA were 184, 198 and 52, respectively.

EXPERIMENT

The process of transesterification was used to reduce the high viscosity of triglycerides. The transesterification reaction is represented by the general equation in Figure 2. A two step process was used for conversion of PFA into palm FAME. The first step of the process was to convert PFA into FAME by esterification with methanol (MeOH) in presence of acid catalyst. In the second step the PFA content was further reduced by reaction with MeOH in presence of base catalyst (Stalin and Prabhu, 2007).

Production of biodiesel

The operating conditions for production of biodiesel were first optimized at laboratory scale by studying the effect of variation of molar ratio of PFA to MeOH from 1:1 to 1:12 keeping the wt% of catalyst and temperature constant. The amount of catalyst was decided by varying the wt% of H₂SO₄ catalyst from 0.2 to 1.2% for first step and wt% of NaOH catalyst from 0.5 to 2.5% for second step keeping the molar ratio of PFA to MeOH and temperature constant. The effect of temperature was studied by varying the temperature from 40 to 65 °C keeping other parameters constant. The production of biodiesel in bulk was done at the optimized conditions of molar ratio 1:10 (PFA: MeOH), 1 wt% of H₂SO₄ and 2 wt% of NaOH at 65°C using the pilot plant in the Oil and Paint Technology Department, Harcourt Butler Technological Institute, Kanpur, India. The plant mainly consists of three continuous stirred tank reactor, a dosing unit, a condenser, a boiler, storage tanks for raw material and finished product and pumps. A schematic flow diagram and pilot plant used for biodiesel production are shown in Figure 3a and b respectively. Preheated PFA and catalyst (H₂SO₄) in methyl alcohol solution were fed in continuous stirred tank reactor. After the completion of the reaction the reaction product was transferred to separator for the separation of methyl esters under gravity. The top phase containing FAME also contained excess methanol and water formed during the reaction. Excess methanol was separated and purified and reused as starting material. The FAME phase was taken off at the bottom and passed into evaporator to remove and collect the traces of methanol. The FAME still had residual PFA requiring further purification. The PFA was neutralized with sodium hydroxide in methanol (NaOH–MeOH) solution. Both neutralization and transesterification reactions took place at the same time. The product obtained from the purification step was settled in a separator. The FAME phase was separated and washed with hot water to remove impurities. The final product obtained was characterized and its comparison with petroleum diesel is given in Table 1.

Analysis of palm fatty acid methyl ester

The composition of biodiesel was confirmed by FT-IR spectrum (Figure 4) . Sharp band in the range of 2925.13 cm⁻¹ is due to C-H stretching vibrations of methyl and methylene groups. A sharp band at 1743.67 cm⁻¹ is attributed to C=O stretching frequency. Absorption at 1437 and 1463.25 cm⁻¹ is assigned to asymmetric -CH₃ or -CH₂ bending vibrations. Bands at 1246.56, 1196.93 and 1171.19 cm⁻¹ are due to C- O stretching of ester. The bands obtained at 1117.90, 1017.31 and 880.31 cm⁻¹ are due to C-C stretching.

Calorific value of biodiesel

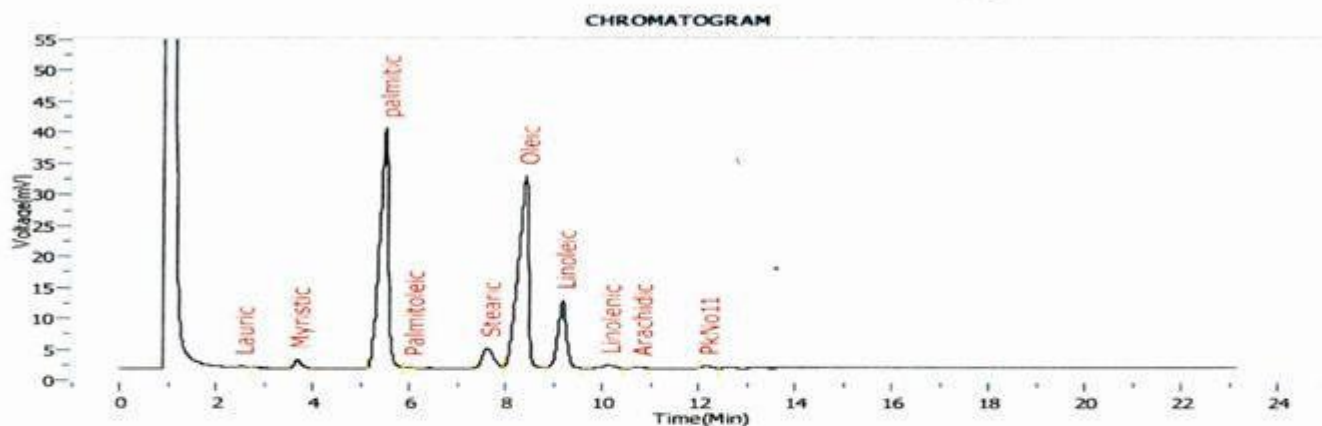
Different blends of biodiesel and conventional diesel were prepared and the calorific value of each sample was determined with the help of Bomb Calorimeter and the values are given in Table 2. The blending of FAME with petroleum diesel was done by intense mixing of both with help of electric stirrer at room temperature on v/v basis. For example, for making a sample B20, first 20% by volume of FAME was taken in the beaker and further 80% by volume of petroleum diesel was added and then it was vigorously mixed with help of electric stirrer at room temperature.

Engine test

The performance of the prepared palm FAME was studied and compared with the conventional diesel fuel. The tests were performed at Mechanical Engineering Department, Harcourt Butler

PEAK REPORT (ANRF)

Method Name : Default
 Sample Name : PFA Methyl Ester
 Run No : 20
 Analysis Time : 9/6/09 4:05:41 PM



Peak No	RT (Min:Sec)	Area (mV-Sec)	Height (mVolt)	RF	Amount (Ml)	Amount%	Component Name
1	2:32	1.8299	0.2837	1	1.8299	0.178	Lauric
2	3:41	12.3957	1.2991	1	12.3957	1.169	Myristic
3	5:30	491.4392	38.6281	1	491.4392	42.664	palmitic
4	6:01	0.819	0.0733	1	0.819	0.102	Palmitoleic
5	7:37	50.7973	3.1879	1	50.7973	4.493	Stearic
6	8:24	457.3748	30.9331	1	457.3748	38.997	Oleic
7	9:10	133.9003	10.9324	1	133.9003	11.443	Linoleic
8	10:08	7.8221	0.4835	1	7.8221	0.704	Linolenic
9	10:46	1.128	0.1066	1	1.128	0.129	Arachidic
10	12:10	3.795	0.3384	1	3.795	0.053	PKNo11

Number of Peaks : 10
 Total Peak Area : 1161.301 mV-Sec



Figure 1. Chromatogram of palm fatty acid methyl ester.

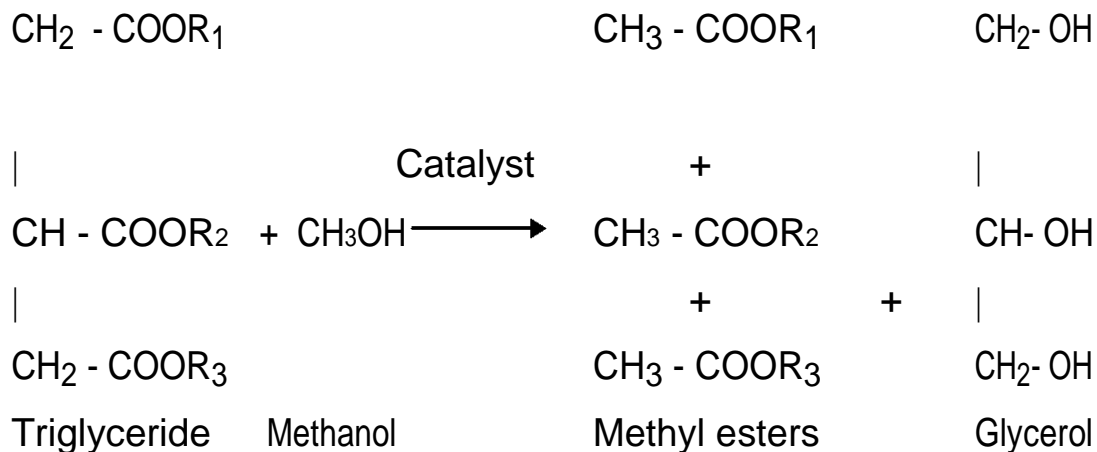


Figure 2. General equation of transesterification.

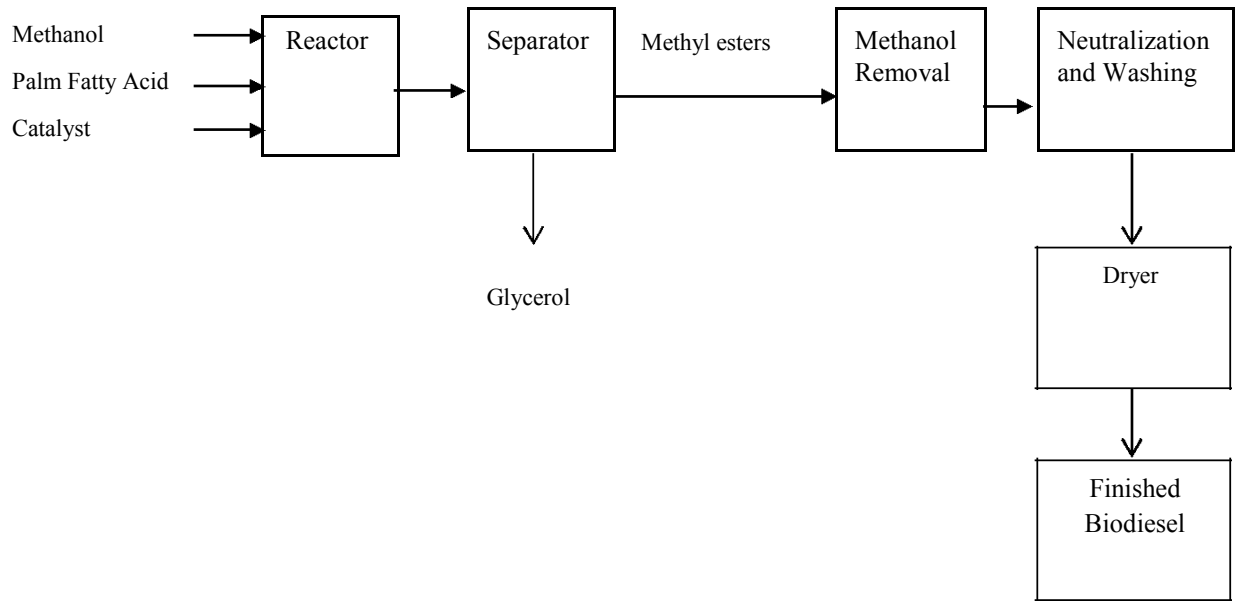


Figure 3a. Schematic diagram for biodiesel production.



Figure 3b. Photograph of Pilot Plant used for Biodiesel production.

Table 1. Chemical and physical properties of petroleum diesel and PFA methyl ester.

Properties	Petroleum diesel	PFA methyl ester
Density gm/cc	0.831	0.897
Kinematic Viscosity cSt (40°C)	4.223	4.951
Calorific value MJ/Kg	43.79	38.05
Flash Point (°C)	67	165
Acid Value mg of KOH/g	-	0.42

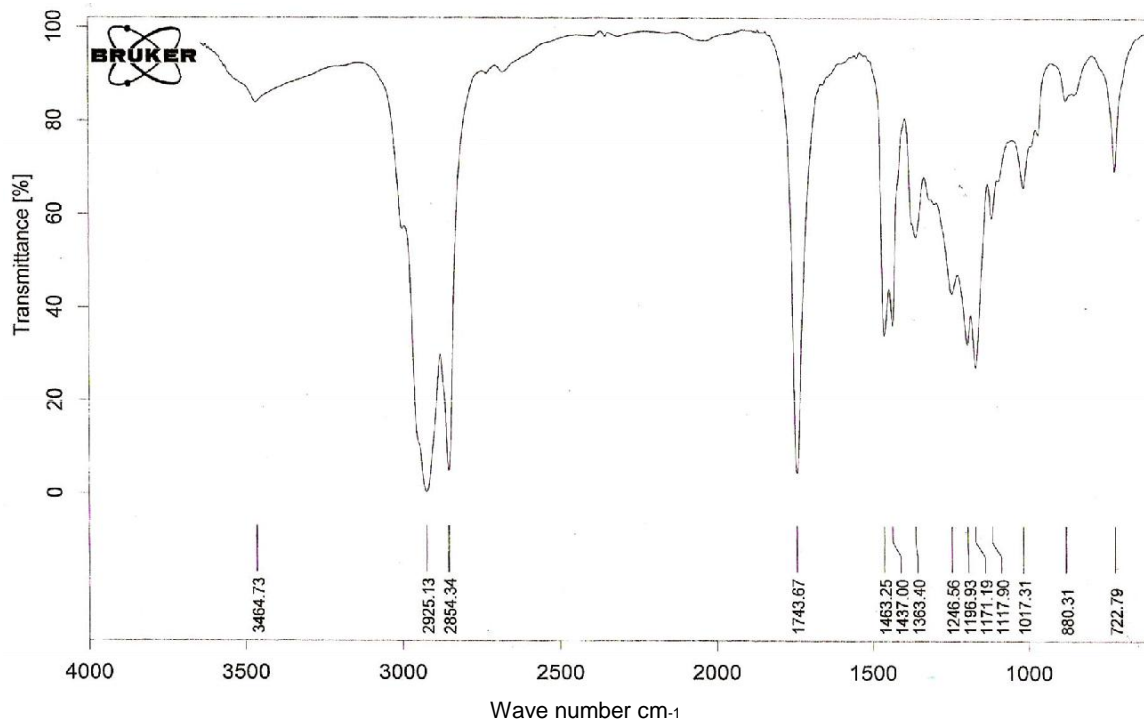


Figure 4. FT-IR spectrum of produced biodiesel.

Table 2. Calorific value of different blends of biodiesel and conventional diesel.

Fuel	M2 (g)	M2-M1 (g)	T (°C)	Cv(MJ/kg)	% Decrease
B0	0.4944	0.3996	1.868	43.79	-
B5	0.4959	0.4011	1.854	43.26	1.2
B10	0.4964	0.4016	1.838	42.8	2.3
B20	0.4967	0.4019	1.820	42.27	3.5
B30	0.5012	0.4064	1.811	41.57	5.1
B40	0.5028	0.4080	1.796	41.01	6.3
B50	0.5048	0.4100	1.772	40.19	8.2
B60	0.5066	0.4118	1.755	39.58	9.6
B70	0.5085	0.4137	1.748	39.22	10.4
B80	0.5102	0.4155	1.736	38.74	11.5
B90	0.5116	0.4168	1.728	38.42	12.3
B100	0.5122	0.4174	1.716	38.05	13.1

Table 3. Engine specifications.

Make: Kirloskar India Limited
Number of cylinder: 1
Number of strokes: 4
Rated power: 3.7 KW at 1500 rpm
Loading device: Eddy Current
Fuel oil : High Speed Diesel, Biodiesel
Bore and stroke: 80 x 110 mm

Technological Institute, Kanpur, India. The engine used for this study is a single cylinder, four strokes, water cooled vertical diesel engine manufactured by Kirloskar India Limited. The technical details of the engine are given in the Table 3. Engine tests were performed at the estimated speed of 1500 rpm at varying load. The tests were performed with pure diesel and different blends of dual fuel for the study of Torque, brake specific Fuel efficiency, brake power and brake thermal efficiency. All the observations were performed thrice to obtain the average value of each observation so as to minimize the influence of measurement and observation errors. A three way hand operated control valve and two fuel

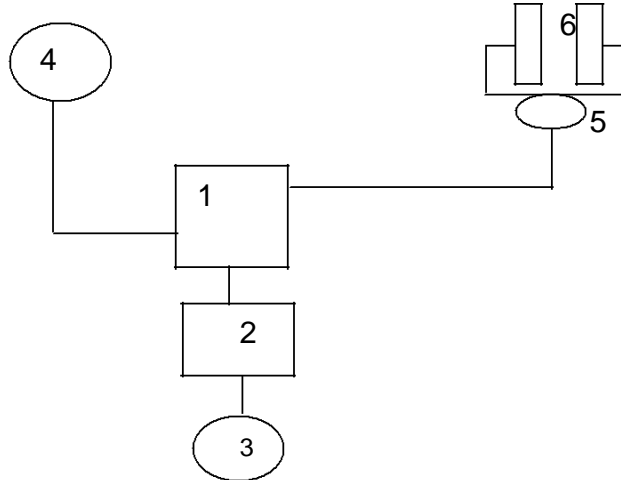


Figure 5. Schematic diagram of engine test set up. (1) Engine (2) Dynamometer (3) Control unit (4) Cooling system (5) Three way valve (6) Fuel meters.

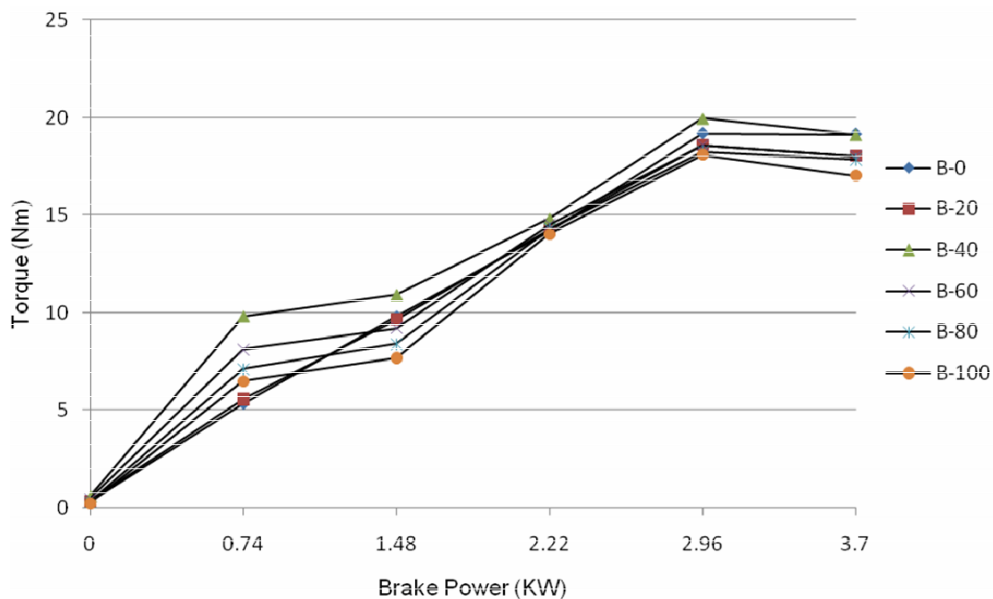


Figure 6. Comparison of torque Vs brake power for different proportions of biodiesel in petroleum diesel fuel.

meters were added to modify the engine fuel system as per the requirement. The schematic diagram of the experimental set up is shown in Figure 5.

Effect of blending on torque

The variation of brake power output and the torque for different fuel combination is depicted in Figure 6. It is observed that for all fuels as the brake power increases, torque increases to the maximum at 80% load and then decreases for all the fuel samples. The graphical representation reveals that the torque increases for B-0 to B-40 fuel samples and then decreases. A dual fuel B-40 means

40% of biodiesel is blended with conventional diesel. This could be because of higher cetane number of biodiesel and complete burning of fuel. In the case of dual fuel mixtures with higher proportions of biodiesel, the torque produced is less due to lesser energy released. This is attributed to the low calorific value of the palm FAME.

Effect of blending on brake specific fuel consumption

Figure 7 shows the effect of blending on brake specific fuel consumption for various fuel combinations. The brake specific fuel consumption is observed to decrease sharply for all fuels at higher

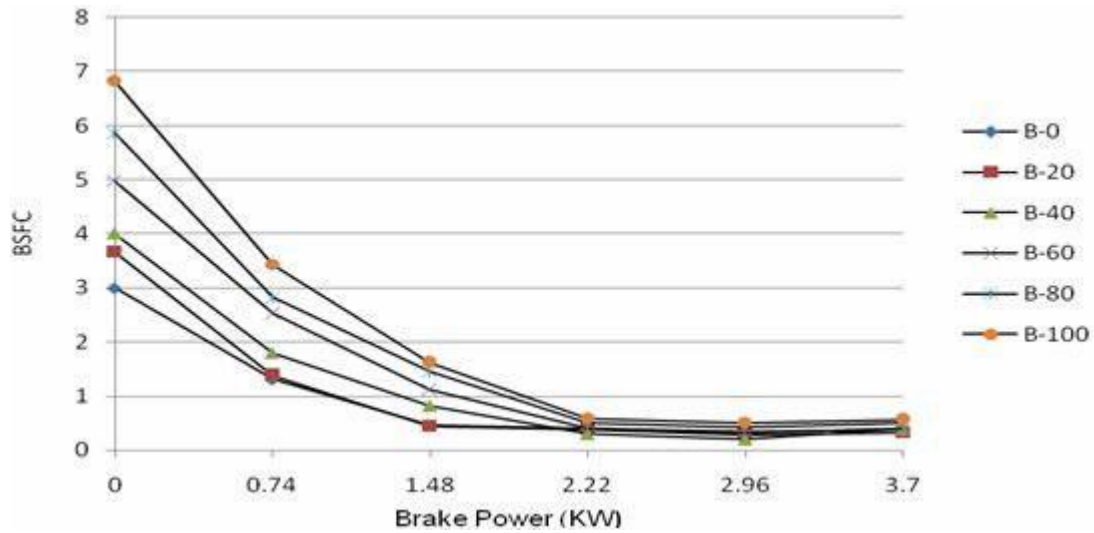


Figure 7. Comparison of Brake specific fuel consumption Vs Brake power for different proportions of biodiesel in petroleum diesel fuel.

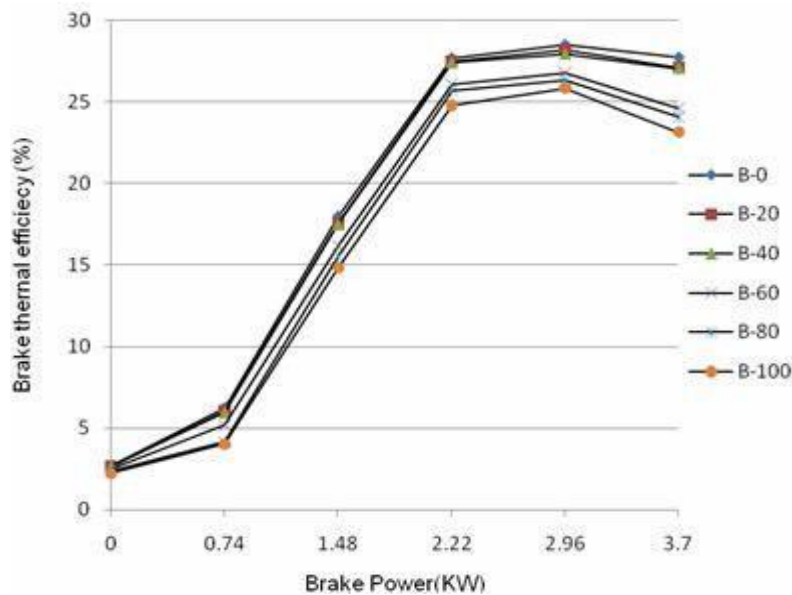


Figure 8. Comparison of Brake thermal efficiency Vs Brake power for different proportions of biodiesel in petroleum diesel fuel.

load. The main reason for this could be that percent increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher load. This indicates that the compression ignition engines run efficiently at higher load than at part load. Graphical representation shows that for certain brake power the specific fuel consumption is found to be lowest in case of pure diesel (B-0) and it increases as blending is increased from B-0 to B-100. However, at higher load the specific fuel consumption for B-40 is lowest. The lower fuel consumption of B-40 as compared to B-0 could be because of possible synergistic effect of biodiesel with diesel as the oxygen present in biodiesel might have helped in improved combustion of the blend. However, on increasing the biodiesel

proportion in the blend further this effect was negated due to the reduced calorific value of these blends.

Effect of blending on brake thermal efficiency

The effect of blending on brake thermal efficiency for various fuel combinations is depicted in Figure 8. The brake thermal efficiency of engine was low at part load as compared to the engine running at higher load. This is due to relatively less portion of the power being lost with increasing load. The variations in brake thermal efficiency between various blends of fuel at higher load was less than that at part load and is in accordance with the trend observed

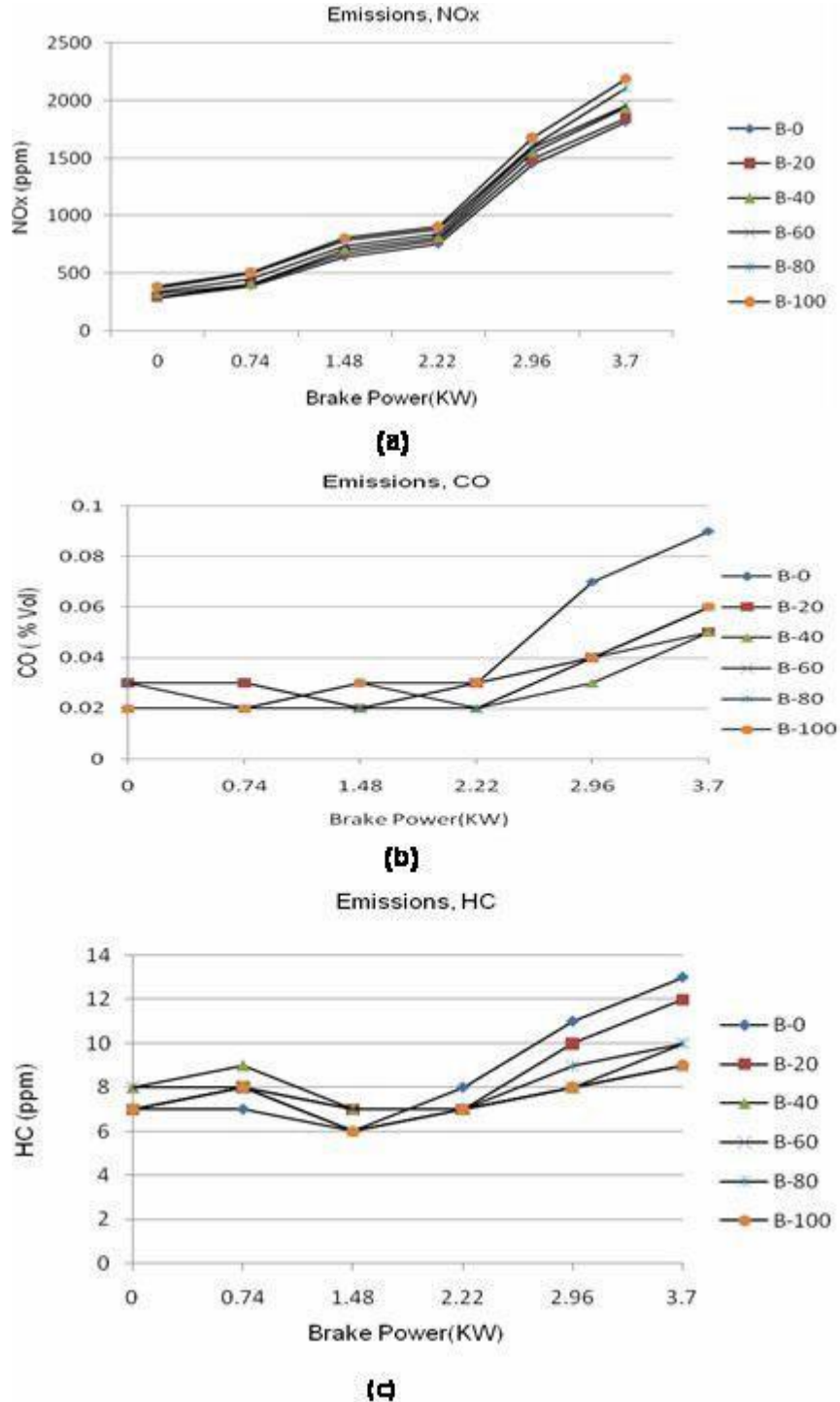


Figure 9. (a) Comparison of nitrogen oxides Vs brake power (b) Comparison of carbon monoxide Vs brake power. (c) Comparison of hydrocarbon Vs brake power.

for brake specific fuel consumption. At higher load the brake thermal efficiency for B-40 was nearly the same as that of B-0. It is because of increased temperature inside the cylinder due to more amount of fuel burning at higher load, resulting in proper atomization and ease of vaporization, which in turn forms a better oil-air mixture in the combustion chamber and yields better combustion.

Emission characteristics

Figure 9a shows the comparison of nitrogen oxide (NOx) emissions of different fuel combinations with brake power. Graphical representation shows that there is an increase in NOx emission with blends of biodiesel fuel as compared to petroleum diesel. This occurs due to high temperature generated because of fairly

complete combustion process on account of adequate availability of oxygen in fuel and hence, the fuel NO_x is also found along with thermal NO_x.

Figure 9b shows the variation of carbon monoxide (CO) emissions of different fuel combinations with respect to brake power. The graphical representation shows that with the increase of biodiesel content in the fuel the CO emissions decrease. At low load the difference between the CO emission on pure diesel and B-40 fuel are low, which significantly increases at high load. This is due to the fact that fuel B-40 containing oxygen atoms leads to almost complete combustion and therefore, results in lower CO emission.

The variation of hydrocarbon (HC) emission of different fuel combinations with brake power is shown in Figure 9c. It is observed from the graphical representation that the HC emission is reduced with the increase of biodiesel content in the fuel at higher load. This could be due to almost complete combustion of fuel because of presence of oxygen atom.

Conclusion

In the present study, biodiesel is produced from low cost PFA with high FFA using two step trans-esterification process. Various parameters viz. molar ratio, catalyst concentration and temperature were optimized and then fuel quality biodiesel was produced from PFA at pilot scale using the optimized process conditions of molar ratio 1:10 (PFA: MeOH), 1 wt% of H₂ SO₄ and 2 wt% of NaOH at 65°C. The final product is a light yellowish material meeting the ASTM standards for biodiesel. A high quality product is produced in continuous stirred tank reactor with low residence time, and at lower temperature which is considered to be a more economic solution. It is concluded that the biodiesel produced from low used in diesel engines. The results obtained in the study of torque output, brake specific fuel consumption and brake thermal efficiency indicate that dual fuel combination of B-40 can be used in diesel engines without any modifications in the engines.

ACKNOWLEDGEMENT

Authors are thankful to all India Council for Technical Education, New Delhi, India, for providing the financial support for pursuing this research work at H.B.T.I. Kanpur, U. P., India.

REFERENCES

- Prafulla D, Patil, Shuguang Deng (2009). Optimization of biodiesel production from edible and non edible vegetable oils. *Fuel*, 88: 1302-1306.
- Ramadhas AS, Jayaraj S, Muraleedharan C (2004). Use of vegetable oils as I.C. engine fuel - a review. *Renewable Energy*, 29: 727-742.
- Stalin N, Prabhu HJ (2007). Performance test of IC engine using karanja biodiesel blending with diesel. *ARPN J. Eng. Appl. Sci.*, 2: 32-34.
- Ramadhas AS, Jayaraj S, Muraleedharan C (2004). Biodiesel production from high FFA rubber seed oil. *Fuel*, 84: 335-340.
- Shashikant VG, Raheman H (2005). Biodiesel production from mahua oil having high free fatty acids. *Biomass and Bioenergy*, 28(6): 601-605.
- Wang Y, Ou S, Liu P, Xue F, Tang S (2006). Comparison of two different processes to synthesis biodiesel by waste cooking oil. *J. Mol. Catalysis A: Chemical*; 252: 107-112.
- Zlatica PJ (2008). The production of biodiesel from waste frying oils: A comparison of different purification steps. *Fuel*, 87: 3522-3528.
- Veljkovic VB, Lakicevic SH, Stamenkovic OS, Todorovi ZB, Lazic ML (2006). Biodiesel production from tobacco seed oil with a high content of free fatty acids. *Fuel*, 85: 2671-2675.
- Meher LC, Vidyasagar D, Naik SN (2006). Technical aspects of biodiesel production by transesterification - a review. *Renewable Sustain. Energy Rev.*, 10: 248-268.
- Siti Zullaikah, Chao- Chin Lai, Shaik Ramjan Vali, Yi- Hsu Ju (2005). A two- step acid - catalyzed process for the production of biodiesel from rice bran oil. *Biores. Technol.*, 96; 1889-1896.
- Fangrui Ma, Milford A, Hanna (1999). Biodiesel production: A review. *Biores. Technol.*, 70: 1-15.
- Vicente G, Martinez M, Aracil J (2004). Integrated biodiesel production: a comparison of different homogeneous catalysts systems. *Biores. Technol.*, 92; 297-305.
- Zheng S, Kates M, Dube MA, McLean DD (2006). Acid-catalyzed production of biodiesel from waste frying oil. *Biomass Bioenergy*, 30: 267-272.
- DiSerio M, Tesser R, Dimiccoli M, Cammarota F, Nastasi M, Santacesaria E (2005). Synthesis of biodiesel via homogeneous Lewis acid catalyst. *J. Mol. Catal. A: Chem.*, 239 (102): 111-115.
- Pramanik K (2003). Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. *Renewable Energy*, 28: 239-248.
- Ramadhas AS, Jayaraj S, Muraleedharan C (2005). Performance and emission evaluation of a diesel engine fueled with methyl esters of rubber seed oil. *Renewable Energy*, 30:1789-1800.
- Mustafa Canakei, Ahmet Erdil, Erol Arcaklioglu (2006). Performance and exhaust emissions of a biodiesel engine. *J. Appl. Energy*, 83: 594-605.