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Performance Evaluation of Four-Stroke C.I. Engine with Methyl Ester of Sunflower Oil

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ABSTRACT
Compression ignition engines play an indispensable role in agriculture and transport sector and such consumption of petroleum diesel has been increasing. However, the concerns about long term availability of conventional diesel and environmental degradation caused by burning of diesel fuel have mandated that the renewable alternative to diesel fuel should be explored to overcome these twin problems. In this paper various blends FAMEs of sunflower and petroleum diesel were tested on engine test rig and found the comparison of performance of C.I. engine using biodiesel, its blends with petroleum diesel on the basis of mechanical efficiency, brake thermal efficiency, brake specific fuel consumption and exhaust gas temperature.

Keywords
Biodiesel, FAMEs, Esterification, Transesterification.

1. INTRODUCTION
With the increasing threat of depletion of fossil fuels, the world is facing an economic set back along with environmental degradation. To overcome this haphazard situation, biofuels were introduced to run the engines. Compressed ignition engines are preferred over Spark ignition engines as they have high thermal efficiency and torque with less fuel consumption than the later. C.I. Engines uses diesel as fuel which is the backbone of the progress of mankind. Diesel consumption in India as in 2005 has increased considerably in 2013-14. This shows that the fossil fuels are depleting at a higher rate thus demanding an alternate renewable source of energy.

Biodiesel is a mono – alkyl ester of fatty acid. These fatty acids are derivatives of carboxylic acids i.e. vegetable oil or animal fats. Vegetable oil is a triglyceride which consists of 3 fatty acids and 1 glycerol molecule. Under transesterification process, vegetable oil reacts with alcohol molecule to give Fatty Acid Methyl Ester (FAME) i.e. Biodiesel.

Worldwide biodiesel production is mainly from soybean, sunflower and canola oil. In India, total consumption of edible oil in 2012-2013 is 17.9 million ton and out of which 10.2 million ton was imported. Looking at the population of India to be 1.44 billion by year 2030, we need to achieve a grain production of 267 million ton per year. Without any increase in our agricultural area, grain production will be 222 million ton per year leaving a gap of 45 million ton. Thus, there is no agricultural land available for cultivation of vegetable oil for biodiesel. Therefore, National policy on biodiesel [1, 2] was launched in December, 2009 with the aim to achieve a target of 20% blending of petroleum diesel and biodiesel by 2017. The policy will bring about accelerated development and promotion of the cultivation, production and use of biodiesel to increasingly substitute petrol and diesel for transport and be used in stationary and other applications, while contributing to energy security, climate change mitigation, apart from creating new employment opportunities and leading to environmentally sustainable development.
The potential feed stocks of non – edible oil in India are ratanjyot, karanja, neem, kusum, pilu, bikal, sal, undi, tumba etc. Some other important feed stocks found in different parts of the world are Sunflower, Coconut, Cottonseed and Soybean. The selection of the most efficient biodiesel is done on the basis of its fatty acid composition and other properties like density, viscosity etc.

Fatty acids can be saturated (palmitic, stearic, arachidic), monosaturated (palmitoleic, oleic, erucic) and polysaturated (linoleic, linolenic). Ideally, vegetable oil that contains high monosaturated fatty acids and low saturated and polysaturated fatty acids is considered to be a suitable fuel for C.I. Engines. The fatty acid composition of a vegetable oil can be determined by Gas Chromatography. It is a technique which seperates mixtures into individual components. Gas chromatography is more convenient and precise method for qualitative and quantitative analysis of fatty acid methyl esters.

Table1. Fatty acid composition of Sunflower oil

S no.	Fatty acid	%age composition in oil
1	Palmitic acid (C16:0)	5.35
2	Stearic acid (C18:0)	3.41
3	Oleic acid(C18:1)	19.58
4	Linoleic acid(C18:2)	46.87
5	Arachidonic acid	0.70

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6	Eicosadienoic acid	0.06

The cetane number is a prime indicator of the fuel quality. Higher the cetane number lesser is the fuel ignition delay and hence better will be the fuel. Yamane et al. [3] investigated the effect of varying amounts of oleic i.e. monosaturated fatty acid and linoleic i.e. polysaturated fatty acid containing methyl ester in fuel on the ignition delay and concluded that the oleic methyl ester has shorter ignition delay. Gopinath et al [4] concluded that the overall percentage of unsaturation or saturation may not be the sole factor to decide the cetane number of biodiesel. According to Knothe [5] and Refaat [6], the properties such as heating value, melting point, cetane number, viscosity and oxidation stability decrease with increase in the degree of unsaturation of the given vegetable oil. In contrast, density, bulk modulus, lubricity and iodine value increase.

The iodine value of a biodiesel is indicative of the presence of unsaturated fatty acids in it. If a fuel with higher iodine value is burnt in an engine, it results in polymerization of glycerides which in turn leads to deposition of thick sludge on the walls of combustor and hence engine performance decreases [7].

Viscosity is defined as the property of moving fluid in which shear stresses are produced between two adjacent fluid layers or between fluid layer and solid surface (in this case the solid surface is combustion chamber). This property increases with increase in molecular weight and decreases with increase in temperature and degree of unsaturation. A high value of viscosity causes operational problems in the engine such as carbon deposits, oil ring sticking and gelling of lubricating oil. This characteristic of oil can be lowered by methods of blending, preheating and trans-esterification etc. [8, 9]. Masjuki et al. [10] used preheatedpalm oil to run a CI engine. Better spray and atomizationcharacteristics were obtained due to reduction in the viscosity of fuel while preheating it. Torque, brake-power, specific fuel consumption,exhausts emissions and brake thermal efficiency werefound to be comparable to those of mineral diesel. Abbas et al. [11] experimented with pure sunflower oil and reported a higheremission of CO, NOx, HC and PM as compared to that of mineraldiesel due to a shorter ignition delay and higher diffusive burning.

Another characteristic of fuel is density which is mass per unit volume. The density of oil decreases with its molecular weight but increases with increasing unsaturated fatty acid composition in the fuel. High density fuel has low volatility and hence cannot be ignited easily.

Other properties like cloud point, pour point, flash point and cold filter plugging point have also played important role in selection of appropriate feed stock for the C.I. Engine. Aninidita et al [12] reported that these characteristics increase with increasing concentration of saturated fatty acids in a given ester and indicate their potential usefulness for cold climate conditions. They also describe the flammability of the fuel.

1.1 Sunflower and its properties:

Sunflower is native to North America and is grown in many areas of the US, Egypt, Afghanistan, India, China, Russia and throughout Europe. The oil seeds are generally dark in colour and have a thin hull that covers the kernel. The oil content varies from 38 to 50% and is a major source of vegetable oil in the world. Sunflower oil contains high proportions of monounsaturated (oleic C18:1) and polyunsaturated (linoleic C18:2) fatty acids.

Sunflower oil methyl ester (SNOME) has a cetane index value of 58.5 and a heating value of 40.02 MJ/kg. Karaosmanoglu et al. [13] have tested SNOME in a diesel engine. The tests show no change in lubrication characteristics, brake power and BSFC. Kaufman et al. [14] conducted a durability test for SNOME and detected starting problems, but no deterioration was found in the injection system. A lower energy delivery, of the order of 5.3%, was observed, which resulted in a lower power output and exhaust temperature. Hasimoglu et al. [15] reported that in low heat rejection engines, the SFC and BTE were found to improve with SNOME.

1.2 Transesterification

Transesterification is defined as the phenomenon of chemical reaction between triglyceride and alcohol molecule in the presence of an acid or base catalyst. In this process, triglyceride is broken down into diglyceride and then diglyceride into monoglyceride along with a glycerol molecule. It was [16] reported that the transesterification process has been proven worldwide as an effective means of biodiesel production and viscosity reduction of vegetable oils. Transesterification is a reversible process in which the yield of biodiesel will be directly influenced by the amount and types of alcohol (CH_3OH, C_2H_5OH) and catalyst (bases or acids) along with reaction time and temperature. The acid or basic catalyst selection is done on the basis of number of free fatty acids present in the vegetable oil. If the free fatty acid is less than one, basic catalyst is used else acid catalyst is used. Fangrui et al [17] suggested that base catalyst is successfully used only when free fatty acid is less than one. Crabbe [18] concluded from his experiments that base catalyst can also be used in case of free fatty acids more than one but comparatively their amount increases.

2. EXPERIMENTAL PROCEDURE

2.1 Formation of biodiesel

The acid value of the oil should be less than one. If it is more than one, the oil is neutralised by adding an alkaline catalyst to ensure that the acid value remains below an acid value of one. This process is called esterification.

Optimum acid- catalyzed esterification is achieved using 1% sulfated zirconia as solid acid catalyst with a methanol to oil ratio of 9:1 at a temperature of 60°C and reaction time of 2 hours. During this process, free fatty acids were converted into fatty acid methyl esters. The acid value of sunflower oil is less than one as it is an edible oil. Consequently, this pre-treatment process of esterification is not required the and thus reduces the cost of producing the biodiesel fuel.

Transesterification of sunflower oil is done using biodiesel reactor. The biodiesel reactor as shown in figure1 consists of a steel vessel that is hemispherical in shape at the top and conical at the bottom which is fitted with a regulating valve. Twelve litres of Sunflower oil was filled in the steel vessel. The oil was heated to 100°C using an electric heater which is installed inside the reactor to provide the temperature required for the process. To keep a constant temperature inside the reactor, a thermostat is mounted along with the electric heater. The values of all of the important parameters are displayed in digits on the display board. The temperature of the oil was kept constant for 30 minutes to remove moisture contents and then allowed to drop to 60°C. In parallel, methoxide (methanol + sodium hydroxide) was prepared by adding 6:1 molar ratio of methanol to oil (by volume) and 1% sodium hydroxide (NaOH by weight %) to the sunflower oil. The

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mixture (methoxide) was poured into the reactor that already contained the heated sunflower oil at 60°C. While maintaining the reaction temperature at 60°C throughout the oil pool, the mixture was continuously stirred for one hour using a mechanical stirrer[3] (powered by a 65-watt electric motor) which is mounted on the steel vessel. A variable speed drive and a reversing switch mechanism are used to rotate the stirrer in clockwise and anticlockwise directions and to regulate the RPM of the motor. A magnetic pickup type sensor is used to measure the speed of the stirrer. Simultaneously, the methanol was recovered using the tube in a tube type (counter flow) heat exchanger. In this heat exchanger, cold water is drawn from a water reservoir by a 40 W capacity water pump and hot water flows back to the reservoir by the action of gravity. The heat exchanger is kept inclined to maintain the natural flow of water. In the inner tube, methanol vapours enter from the reactor and are condensed upon contact with a cold surface. These are then collected in a beaker. The methanol recovery process took approximately 40 minutes. After one hour, the stirrer and the electric heater were put off and the solution was allowed to settle for a minimum of eight hours. Due to the difference in their densities, the glycerol settled to the bottom of the reactor and the esters of the sunflower oil (biodiesel) rose to the top. Later on the glycerol is drained out using the regulating valve and is collected in a beaker of suitable capacity. Three litres of luke warm (40°C) water was added to the methyl ester and stirred for 2 to 3 minutes to remove any traces of glycerol, methanol and NaOH that remained after the transesterification process in the biodiesel. The solution was then allowed to settle for half an hour. The water (milky white) was drained through the regulating valve, and the process was repeated for four times until the turbidity of the drained water came out at par with the original water. After removing the glycerol, methanol and NaOH from the ester, the oil was heated again at 100°C to remove all traces of water. The result was a pure biodiesel that was suitable for use.

Fig.1 Biofuel Reactor

2.2 Engine Test Rig

Engine selected for this study is widely used in agriculture sector of India is a single cylinder, four stroke, diesel engine connected to eddy current dynamometer for loading, as shown in Fig 2. Test rig has standalone panel box consisting of air box, fuel tank, manometer, fuel measuring unit. Rotameters are provided for cooling water and calorimeter water flow measurement. Pizeo-electric transducer is mounted in the cylinder head and signals obtained are interfaced to computer through engine indicator for obtaining P-Θ diagrams. Windows based engine performance analysis software package "engine soft" was used for online performance evaluation of an engine.

2.2.1 Engine Specifications

Capacity: 5.2 kW
No. Cylinder: Single
Cylinder Bore; 87.5 mm
Stroke Length: 110 mm
Compression Ratio: 17.5
Stroke Type: Four

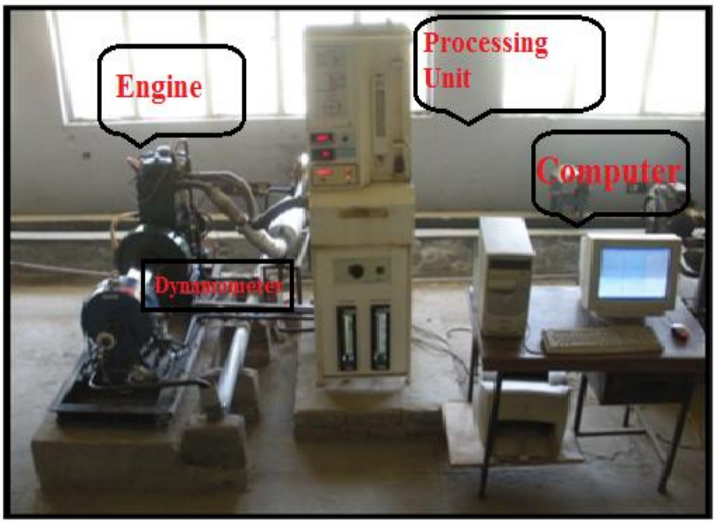

Fig.2 Engine Test Rig

3. RESULTS AND DISCUSSIONS

The biodiesel formed was then blended with diesel to make SB10, SB20 and SB50. Pure diesel and pure biodiesel (Figure3) were also tested.

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Fig.3 Sunflower Biodiesel

Fig. 4(a) shows the plots of BSFC Vs BMEP for pure biodiesel (SB100) and its various blends SB10, SB20 and SB50 in comparison to petroleum diesel. For all range of fuels consideration the plots of BSFC shows similar trends i.e. at lower values of BMEP, up to 4.1 bars, BSFC decreases and later on curves level off for higher value of B.M.E.P. Further, plot of petroleum diesel shows lowest value of BSFC for all ranges of B.M.E.P. in comparison to pure biodiesel and its blends. However, it is observed that SB20 shows promising behavior by reflecting second lowest values for BSFC at all range of BMEP. As far as other blends (SB10, SB50 and SB100) are concerned, they reflect erratic behavior. From above, it can be concluded that SB20 gives minimum value for BSFC.

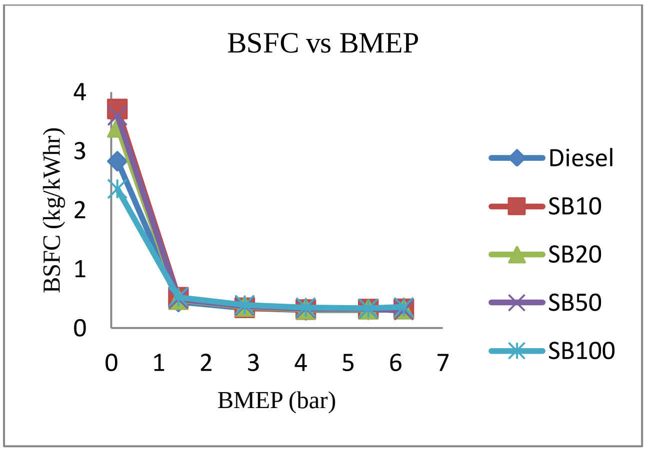

Fig. 4(a) shows the plots of B.S.F.C. Vs B.M.E.P.

Fig. 4(b) shows the plots between BTE Vs BMEP for diesel and various blends of sunflower oil. Contrary to Fig. 4 (a) the plot shows rising trends with increase in BMEP up to 4.2 bar and later on curves level off. Engine shows highest value of BTE with petroleum diesel at all ranges of BMEP whereas SB100 shows lowest value of BTE for all values of BMEP. At low value of BMEP engine give high BTE and with increase BMEP the value of BTE narrow down to negligible value at 6.2 bars. Similar to BSFC trends the diesel fuel gives maximum brake thermal efficiency for all ranges of BMEP followed by SB20.

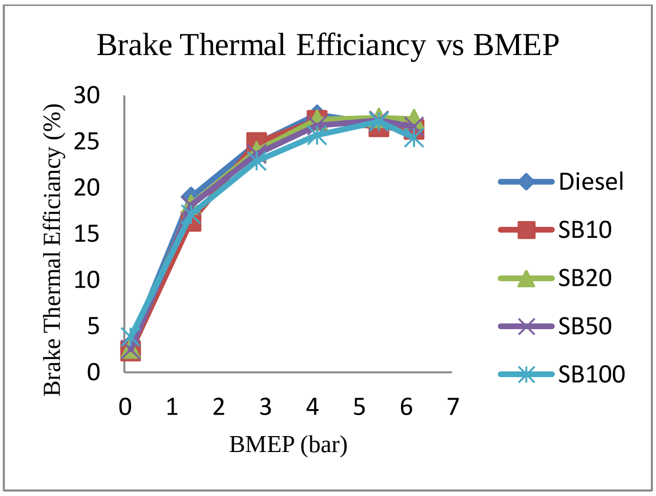

Fig. 4(b) shows the plots of B.T.E. Vs B.M.E.P.

Fig. 4(c) shows the plots between M.E. Vs BMEP for diesel and various blends of sunflower oil. The plot shows rising trends with increase in BMEP. Engine shows highest value of M.E with petroleum diesel at all ranges of BMEP whereas SB100 shows second highest value of M.E for all values of BMEP. At low value of BMEP engine give high M.E and with increase BMEP the value of M.E narrow down to negligible value at 6.1 bars. Similar to BSFC trends the diesel fuel gives maximum mechanical efficiency for all ranges of BMEP followed by SB100.

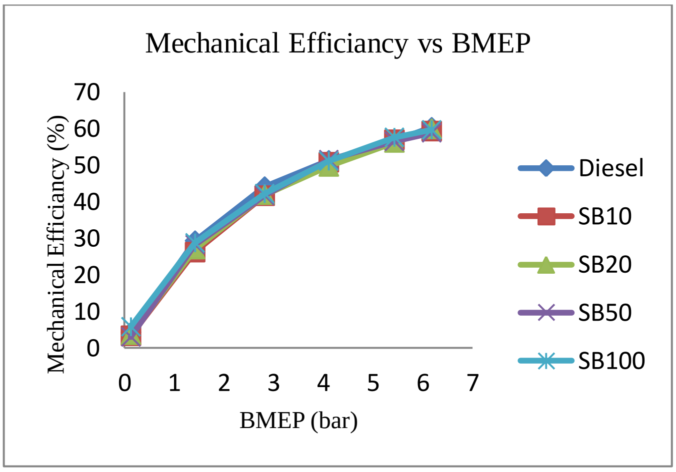

Fig. 4(c) shows the plots of M.E. Vs B.M.E.P

Fig. 4 (d) shows the plots of Exhaust gas temperature Vs BMEP for sunflower biodiesel, its various blends (SB10, SB20, SB50) and petroleum diesel. It is evident from the plots that in case of SB20 the exhaust gas temperature is recorded maximum. Whereas for BMEP 4.1 onward SB10 show similar trends to that of SB20. The possible reason of high temperature for exhaust gases for SB20 is incomplete combustion inside the cylinder and it remaining fuel particles continue to burn in the exhaust.

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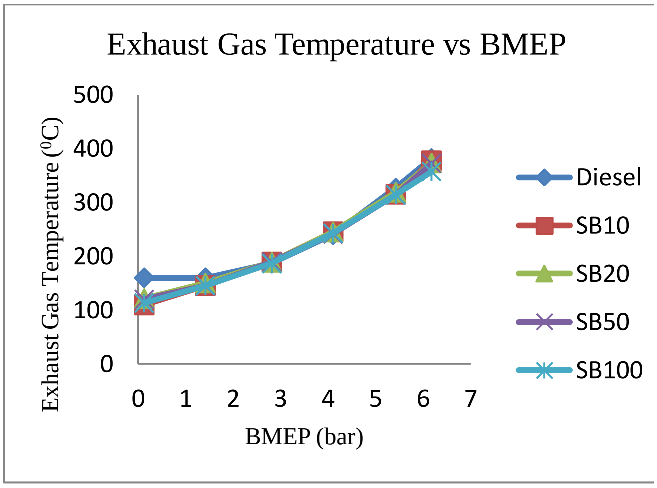

Fig. 4(d) shows the plots of E.G.T. Vs B.M.E.P.

4. CONCLUSIONS

From the ongoing study following conclusion were drawn:

- Sunflower oil has lower acidic value and hence esterification is not necessary to reduce its acidic value before going for transesterification. Thus, reducing its cost of production.
- The plots for BSFC Vs BMEP indicate for all range of BMEP. The BSFC with diesel is minimum value. SB20 proves to be best alternative, to unmodified C.I. engine as it gives minimum value for BSFC after diesel.
- For brake thermal efficiency, similar trends were obtained as that of BSFC. SB20 gives second best value for BTE after diesel fuel.
- For Mechanical efficiency, SB100 is the best fuel after diesel.
- Exhaust gas temperature is indicative of after combustion during expulsion of charge through exhaust. Here, SB20 shows maximum exhaust gas temperature. It depicts that for better results combustion inside the combustion chamber should be improved either by using additives or by changing engine parameter, (injection pressure, and compression ratio) which effects combustion.

Table2. Advantages of the substitute fuel

S No.	Property of fuel	Advantages of sunflower biodiesel
1	Source of energy	Renewable source of energy
2	Sulphur content	No sulphur content is present as it is a vegetable oil and hence no particulate matter is present in the exhaust
3	Carbon content	On the basis of life cycle of the carbon dioxide, the CO_2 emissions reduces to 70% comparative to petroleum diesel
4	Brake Specific Fuel Consumption (BSFC)	SB20 is the best alternative to diesel as it's consumption is minimum
5	Brake thermal efficiency	SB20 gives the second best value of brake thermal efficiency after petroleum diesel
6	Mechanical efficiency	SB100 has best mechanical efficiency and can replace diesel

Table3. Disadvantages of the substitute fuel

S No.	Disadvantages of sunflower biodiesel
1	Presently, it is costlier than the petroleum diesel.
2	It's outlets are not available
3	Edible crop production is adversely affected by its production as land is utilized in growing non-edible crop for production of biodiesel

4.1 Cost comparison among the tested fuels:

The sunflower biodiesel costs more than diesel in the current scenario where we have higher costs of refining the biodiesel before it can be used as a fuel in the engine. The transesterification and esterification processes require large scale machines for refining at low costs, and large scale machines have not yet been employed. Thus, presently the biodiesel costs are much higher, almost double per litre of that of petroleum diesel. But as we put more diesel into the blends, the cost per litre of the fuel decreases.

5. REFERENCES

[1] Report of the committee on Development of Bio fuel Planning Commission. Government of India 2003 http://planningcommission.nic.in/reports/genrep/cmtt bio.pdf

[2] National Policy on Bio fuels, Ministry of New & Renewable Energy, Government India Estate, New Delhi.Dec.2009

[3] Yamane, K., Ueta, A., Shimamoto, Y. Influence of Physical and Chemical Properties on Biodiesel Fuels on Injection, Combustion and Exhaust Emission Characteristics in a Direct Injection Compression Ignition Engine. International Journal of Engine Research, 2001, Volume 2, No.4, 1-13.

[4] A. Gopinath, Sukumar Puhan, G. Nagarajan. Effect of biodiesel structural configuration on its ignition quality. International Journal of Energy and Environment Volume 1, Issue 2, 2010 pp. 295-306.

[5] Gerhad Knothe. Dependence of bio-diesel fuel properties on the structure of fatty acid alkyl esters. Fuel Processing Technology 86 (2005): 1059-1070.

ISSN (O): 2393-8609

International Journal of Aerospace and Mechanical Engineering
Volume 1 – No.2, November 2014

[6] Refaat, A. Correlation between the chemical structure of biodiesel and its physical properties. Int. J. Environ. Sci. Technol. 2009, 6, 677- 694.

[7] Gunstone, F.D. 2004. Rapeseed and Canola Oil: Production, Processing, Properties and uses. London: Blackwell Publishing Ltd.

[8] Pramanik, K. 2003. Properties and use of jatrophacurcas oil and diesel fuel blends in compression ignition engine. Renewable Energy 28: 239-248.

[9] Ramos, M.J., Fernandez, C.M., Casas Abraham, Rodriguez Lourdes Perez Angel. 2008. Influence of fatty acid composition of raw materials on biodiesel properties. Bioresource Technology doi: 10.1016/j.biortech.2008.06.039

[10] Masjuki HH, Kalam MA, Maleque MA, Kubo A, Nonaka T. Performance,emissions and wear characteristics of an I.D.I diesel engine using coconutblended oil. J Automobile Eng 2001; 3:393–404.

[11] Abbas MK, Davis IL. The composition of organic fraction of particulate emissionof a diesel engine operated on vegetable oil. SAE 901563; 1990.

[12] Aninidita Karmakar, SubrataKarmakar, Souti Mukherjee. Properties of various plants and animals feed stocks for biodiesel production. Bioresource Technology 101 (2010) 7201-7210

[13] Karaosmanoglu F, Kurt G, Ozaktas T. Long term CI engine test of sunflower oil. Renewable Energy 2000; 19:219–21.

[14] Kaufman KR, Ziejewski M. Sunflower methyl esters for direct injected diesel engines.American Society of Agricultural Engineers 1984; 27(6):1626–1633.

[15] Hasimoglu C, Ciniviz M, Ozsert I, Icingur Y, Parlak A, Salman MS. Performance characteristics of a low heat rejection diesel engine operating with biodiesel. Renewable Energy 2008; 33(7):1709–15.

[16] Peterson CL, Reece DL, Hammond DL, Cruz R, Thompson J. A comparison of ethyland methyl esters of vegetable oils as diesel fuel substitute. In: Proceedings ofalternate energy conference, ASAE; 1992. p. 99–110.

[17] Fangrui M, Hanna MA. Biodiesel production: a review. Bioresour Technol 1999; 70:1–15.

[18] Crabbe E, Hipolito CN, Kobayashi G, Sonomoto K, Ishizaki A. Biodiesel productionfrom crude palm oil and evaluation of butanol extraction and fuelproperties. Process Biochem 2001; 37:65–71.