Abuhabaya, Abdullah , Fieldhouse, John D. and Brown, D.R.

Variation of Engineering Performance and Emissions using Biodiesel Fuels

Original Citation

Abuhabaya, Abdullah, Fieldhouse, John D. and Brown, D.R. (2010) Variation of Engineering Performance and Emissions using Biodiesel Fuels. In: 2nd International Conference on Nuclear and Renewable Energy Sources, 4th-7th July 2010, Ankara, Turkey.

VARIATION OF ENGINE PERFORMANCE AND EMISSIONS USING BIODIESEL FUELS

Abdullah Abuhabaya[1*], John Fieldhouse[1], David Rob Brown[1]

[1] University of Huddersield, Queensgate, Huddersfield HD1 3DH, UK

Abstract

There is considerable concern over the increasing demand on our limited supply fossil fuel and as a result initiatives are being considered to extend the use of such fossil fuels. In addition there is international concern regarding the associated pollution levels and it is these collective concerns that have increased the demand for alternative fuels to be used in internal combustion engines. This study investigates the engine performance and exhaust emissions of a compression ignition CI engine over its full speed and engine load range when running on differing type of biodiesel. Engine performance, measured as torque, power and specific fuel consumption are recorded at each engine parameter setting along with the exhaust emissions of carbon monoxide (CO), unburned hydrocarbons (HC), oxides of nitrogen (NOx) and carbon dioxide (CO_2). It is seen that the benefits are not very clear and that reduced emissions may in fact be balanced by reduced performance or that increased performance is offset by higher emissions. Overall conclusion is that the sustainability of biodiesel as a green fuel is in question, with reports that deforestation is taking place to grow fuel stock. The paper will present the empirical results and look towards the peripheral effects of using arable land to satisfy the increasing need for fuel, and question the sustainability of such an approach. The increased demands on engine servicing are also considered within the paper, so presenting a balanced holistic approach to the uses of biofuels. The biodiesel processor was developed for the production of biodiesel from vegetable oils such as rapeseed, soybean, sunflower, corn and waste vegetable oil. The vegetable oils and its biodiesel samples were characterized and their rheological behavior was analyzer.

Keywords: Fossil fuel, Alternative fuels, Biodiesel, Engine performance, Exhaust emissions

1. Introduction

The European Commission Green Paper ‘‘Towards an European strategy for the security of energy supply”, sets the objective of 20% substitution of conventional fuels by alternative fuels in the road transport sector by the year 2020 [1]. An extensive worldwide search is underway for alternative fuels to replace conventional oil based fuels. The main reason is the increased prices, the very limited resources for such fossil fuels and increasing stringent environmental regulations. Growing concerns about greenhouse gas emissions will lead to an increase in biofuels and oxygenated fuels production [2] .The application of biofuels [3, 4] and oxygenated fuels [5, 6] plays an important role in the alternative fuel for the internal combustion engines. There have been great efforts to use alternative fuels in diesel engines for substitution of diesel fuel. Different vegetable oils such as soybean oil, castor oil, rapeseed oil, jatropha curcas oil have been considered as alternative base fuels for diesel engines [7–9]. Advantages of vegetable oils as fuel sources are that they are renewable, can be produced locally, cheap and less pollutant for environment compared to diesel fuel. The emissions and engine performance of diesel engines fuelled with biodiesels have been examined by many investigators [7, 10–15]. The biodiesels used in the experiments performed by these investigators were produced from different vegetable oils such as palm, waste cooking, soybean, Karana, rubber seed, etc. Vegetable oils have an ignition quality equivalent to diesel fuel and their combustion characteristics are much the same, but their viscosity is too high for the modern fuel pumps. Researchers have indicated that higher viscosity resulted in incomplete atomisation of neat vegetable oil fuel which in turn prevents complete combustion of large fuel droplets resulting in carbon deposits. Knocking,

[*] E-mail: a.abuhabaya@hud.ac.uk

encountered during the test at low load and low cylinder temperature, was due to the low cetane number of vegetable oil [7]. The use of vegetable oils [17], such as palm, soya bean, sunflower, peanut, and olive oil, as alternative fuels for diesel engines dates back almost nine decades, but due to the rapid decline in crude oil reserves, it is again being promoted in many countries. Depending upon the climate and soil conditions, different countries are looking for different types of vegetable oils as substitutes for diesel fuels. For example, soya bean oil in the United State, rapeseed and sunflower oils in Europe, palm oil in South-east Asia (Malaysia and Indonesia) and coconut oil in the Philippines are being considered.
In addition, some species of plants yielding non-edible oils, e.g. jatropha, karanji and pongamia may play a significant role in providing resources. From previous studies, it is evident that there are various problems associated with vegetable oils being used as fuel in compression ignition CI engines, mainly caused by their high viscosity. The high viscosity is due to the large molecular mass and chemical structure of vegetable oils which in turn leads to problems in pumping, combustion and atomization in the injector systems of a diesel engine. Therefore, a reduction in viscosity is of prime importance to make vegetable oils a suitable alternative fuel for diesel engines. The problem of high viscosity of vegetable oils has been approached in several ways, such as preheating the oils, blending or dilution with other fuels, transesterification process and thermal cracking/pyrolysis [8]. Therefore, the main objective of the present study was to decrease the viscosity of vegetable oils such as rapeseed oil, sunflower oil, corn oil, soybean oil and waste vegetable oil which are transformed into fatty acid methyl esters (FAME) by transesterification process, to see the effect of using the prepared of biodiesel as fuel on the engine performance and exhaust emissions.
Biodiesel, as defined by the American Society for Testing and Materials (ASTM), is a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats. Due to the great molecular similarities between biodiesel and petroleum-based diesel, this alternative fuel has a chance of fulfilling the demands that the diesel engine makes of its fuel [16]. Biodiesel has been reported as a possible substitute or extender for conventional diesel and is comprised of fatty acid methyl/ethyl esters, obtained from triglycerides by transesterification with methanol or ethanol. Transesterification of vegetable oils with simple alcohol has long been the preferred method for producing biodiesel. Through transesterification, high viscosity is reduced to a value closer to that of diesel fuel while cetane number and heating value are saved [18]. As seen in Figure1, three moles of alcohol are used per mole of triglyceride for the stoichiometric transesterification reaction. This reaction results in three moles of fatty acid alkyl monoester (biodiesel) and a mole of glycerol that is the by-product of this reaction.

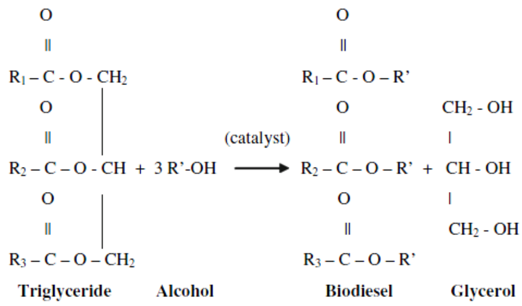

Figure 1. Stoichiometric transesterification reaction [18]

2. Experimental setup
2.1. Biodiesel production process

Biodiesel processor "Fuelpod" was used for the production of biodiesel from rapeseed, sunflower, soybean, corn and waste vegetable oil. The vegetable oils were collected from the local area. Fifty liters of each type of vegetable oils were taken batch wise in the transesterfication vessel. For the transesterification process shown in Figure 2, 50L of vegetable oil was taken in a single tank section and heated at 65^{o}C for 2-3 hours; a separately prepared mixture of 200 gm of sodium hydroxide NaOH (amount of NaOH was increased if the oil contained a measurable amount of free fatty acid, since free fatty acid consumes NaOH, converting it to the sodium salt). The NaOH required for the transesterification was dissolved in 8L of methanol and added to the tank. Ester forms the upper layer in the separating funnel and glycerol forms the lower layer. As seen in Figure 3, that a machine processor as used to converted vegetable oil to biodiesel in this study. It is complete system and corresponding methodology for makeing biodiesel at University of Huddersfield laboratory.

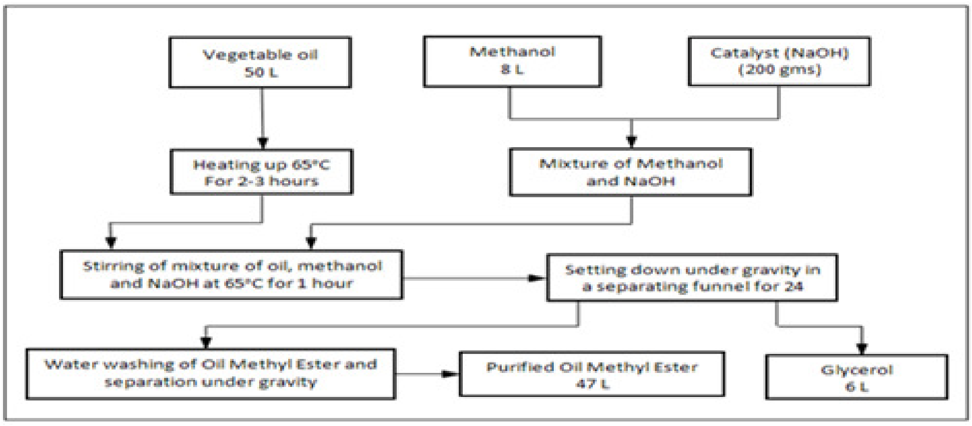

Figure 2. Flow chart for Transesterification process [17]

Figure 3. "Fuelpod" Equipment for transesterifying oils

2.2. Biodiesel as a fuel for CI engine

Biodiesel produced by using biodiesel processor and its specified was used to run diesel engine, Figure 4. The engine test runs were carried out on a steady state engine test bed with a 2009 2.2L Ford puma engine from the Ford Transit van. Emissions were measured using a Horiba EXSA 1500 system. The specifications of the four-stroke, direct injection diesel engine, turbocharged diesel test engine are given in the following: Bore = 89.9 mm, stroke = 94.6 mm, engine capacity = 2402 cc, compression ratio = 17.5:1, fuel injection release pressure = 135 bar, max power = 130 kW @ 3500 rpm, max torque = 375.0 Nm @ 2000-2250.

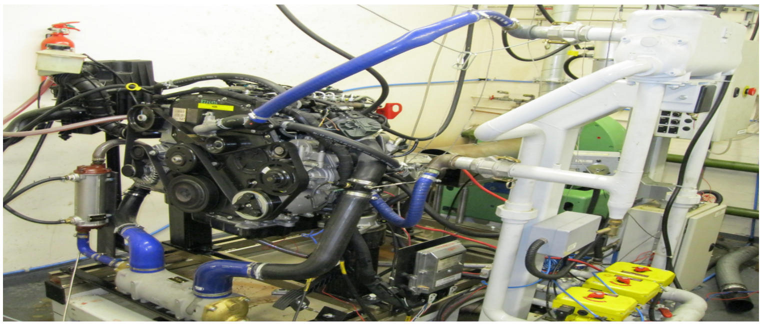

Figure 4. Typical view of Ford Puma Engine as used in testing

The engine was run at a series of steady state engine operating conditions. These operating conditions were across an engine speed range of 1500, 2200, 2600, 3000 and 3300 rpm and different engine loads of 25%, 50%, 75% and 100%. At each of these positions the engine was allowed to settle for about fifteen minutes and the results averaged at a rate of fifteen per second with the values averaged over the last ten minutes of operation.

3. Results and discussion

3.1. Biodiesel production

The experiment of biodiesel production was repeated for each batch of oils to determine the yield of biodiesel and glycerin in "Fuelpod" machine. The average yield of vegetable oils biodiesel were found to be 47 L. thus, the average yield of biodiesel obtained after transesterification process was about 94% by volume from the oils. The average amount of glycerol obtained as a by-product from 50 L of vegetable oils was 6 L, as shown in Figure 2.

3.2. Fuel properties

The fuel properties of standard diesel and vegetable oils biodiesel are presented in Table 1. The calorific values of vegetable oils biodiesel were found to be about 37 MJ/ kg. However, calorific value of diesel fuel was 42.5 MJ/kg, and it is more than biodiesel. The presence of chemically bound oxygen in vegetable oils lowers their calorific values by about 12 % as shown in the table. Also shown from the Table 1, that kinematic viscosity of vegetable oils was found to be changed from 40 to 5 mm^2/s at 40^oC temperature. The high viscosity of these oils is due to their large molecular mass in the range of 600-900, which is about 20 times higher than that of diesel fuel [17]. The reduction in viscosity during transeserification process reduces the problem associated with using vegetable oil in the engine. Density of biodiesel and diesel were determined and found to be about 885 and 845 kg/m^3, respectively. The flash point of vegetable oils biodiesel was found between 167 and 179^{o}C. Cloud and pour point were also determined and found between -39.7 and 2^{o}C.

Table 1. Properties of vegetable oils and its biodiesel

Fuels	Kinematic Viscosity At 40^{o}C (mm^2/s)	Calorific Value (MJ/kg)	Cloud Point (^{o}C)	Pour Point (^{o}C)	Flash Point (^{o}C)	Density (kg/m^3) At 15^{o}C
Corn oil	39.3	37.37	-1.1	-40.0	277	920
Rapeseed oil	37.98	37.37	-3.9	-6.7	246	910
Soybean oil	35.28	36.75	-3.9	-12.2	254	915
Sunflower oil	33.72	37.26	7.2	-15.0	274	920
Waste oil	41.7	37.16	0	-39.7	279	910
Corn Biodiesel	4.78	37.45	0	-10	167	880
Rapeseed Biodiesel	4.47	37.70	-1	-11	163	880
Soybean Biodiesel	5.23	37.34	1	-7	178	885
Sunflower Biodiesel	4.53	37.00	1	-6	173	885
Waste oil Biodiesel	5.58	37.90	2	-7	179	885
Diesel	2.4	42.54	-5	-17	76	845

3.3 Engine performance and exhaust emissions
3.3.1 Effect biodiesel on engine performance

Figure 5 shows the variation in the brake power with the engine speed of the test engine operated at full load condition of standard diesel and different type of biodiesel. The brake power reached its peak value at the speed of about 2600 rpm for all fuels. The brake power of the engine with standard diesel was higher than that biodiesel for all types. At higher speeds of 2600 and 3000 rpm, standard diesel produced 5.5% and 5.8% higher power compare with rapeseed biodiesel. Due to the fact that the lower calorific value of biodiesel was about 12% lower than that of standard diesel, both torque and brake power reduces. However, difference in the brake power between standard diesel and biodiesel were very small in most cases. Figure 6 shows the variation in the torque of the engine fuelled with standard diesel and different type of biodiesel versus engine speed. It was observed that the engine yields the maximum torque for all fuels in the speed range of 1500 to 2000 rpm, while the minimum torque was obtained in the range of 3000 to 3300 rpm. The torque of the engine fuelled with standard diesel was higher than that biodiesel. The reason for the reduction of torque with biodiesel can also be attributed to the lower calorific value of the biodiesel. The mean increase in the torque between standard diesel and biodiesel was determined as 8.2%. Figure 7 shows the variations in the BSFC of both standard diesel and biodiesel with respect to the engine speed. The BSFC is the ratio of the fuel consumption to the engine brake power. The BSFC for biodiesel operation was on an average 11.6% higher than that for standard diesel operation. This increase may be attributed to the collective outcomes of the higher fuel density, higher fuel consumption and lower brake power due to lower calorific value of the biodiesel. The higher BSFC was obtained at biodiesel from waste vegetable oil compared with other type of biodiesel. Compared to biodiesel from waste vegetable oil, the BSFC was averagely 13.2% and 2.8% lower for standard diesel and rapeseed biodiesel, respectively.

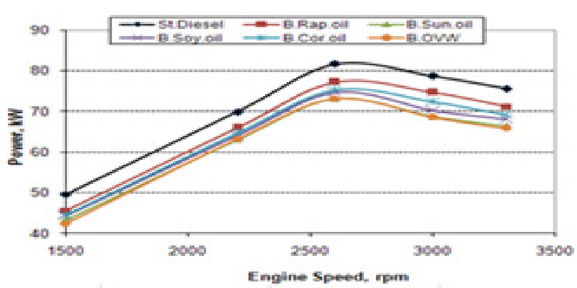

Figure 5. Brake power versus engine speed for fuels tested at full load

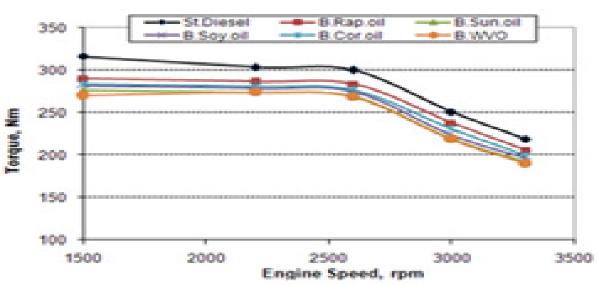

Figure 6. Brake torque versus engine speed for fuels tested at full load

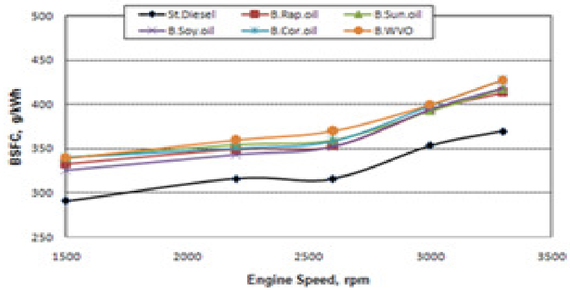

Figure 7. BSFC versus engine speed for fuels tested at full load

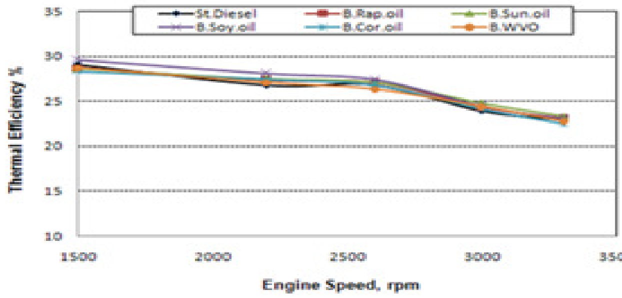

Figure 8. Thermal efficiency versus engine speed for fuels tested at full load

Brake thermal efficiency for standard diesel and biodiesel as a function of engine speed are shown in figure 8. The maximum thermal efficiency values were observed in the range 1500 to 2200 rpm for the standard diesel and biodiesel. It was seen that biodiesel has higher thermal efficiency than standard diesel and the mean difference between them was about 1.5%. The improvement of thermal efficiency with biodiesel can be attributed to the oxygen content and higher cetane number of biodiesel. These properties lead to favourite effects on the combustion process and improve thermal efficiency slightly in biodiesel operation in spite of lower calorific value of biodiesel.

3.3.2 Effect biodiesel on exhaust emissions

Figure 9 shows the variation of HC emission with load for standard diesel and six different type of vegetable oil biodiesel. It was observed from the Figure 9 that biodiesel produces relatively lower HC emission, compared to that of standard diesel at all cases. This may be attributed to the availability of oxygen in biodiesel, which facilitates better combustion. Also it was seen that HC emission of biodiesel was almost identical. There was a reduction of 25.3% in hydrocarbon emission for waste oil biodiesel, whereas it was 39.5% for sunflower oil biodiesel. The variation of carbon dioxide emission at different loads for standard diesel and biodiesel is shown in Figure 10. At 25% and 50% loads, CO_2 emissions of the diesel were not much different from those of biodiesel. However, at full load, CO_2 emissions of the standard diesel decrease significantly when compared with those of biodiesel. CO_2 emissions of biodiesel operation were averagely 7% lower than those of standard diesel operation. Biodiesel has higher cetane number compared standard diesel, which causes lower ignition delay period and autoignition capability. High oxygen content of biodiesel associated with lower ignition delay period provides an important reduction in CO_2 emission by improving combustion. Figure 11 shows variation in the oxide of nitrogen emission plotted against engine load for standard diesel and biodiesel. It is known that formation of NOx emissions are strongly dependent upon the equivalence ratio, oxygen concentration and burned gas temperature. The oxygen content of biodiesel is the main reason for higher NOx emissions. The oxygen in the biodiesel can react easily with nitrogen during the of combustion process, thus causing higher emissions of NOx. Many researchers reported that oxygenate biodiesel can cause an increase in NOx emissions. Normally, complete combustion causes higher combustion temperature, which results in higher NOx formation. The NOx emission with biodiesel was higher than that with standard diesel in most of engine loads. In biodiesel operation, an average of 14.4% increase in the NOx emission was measured compared to standard diesel operation. A noticeable increase in the NOx emission was observed with the use of standard diesel and biodiesel.

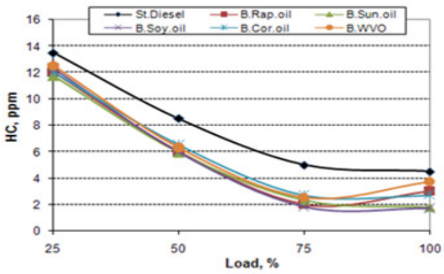

Figure 9. Variation of hydrocarbon emissions with load for fuels tested

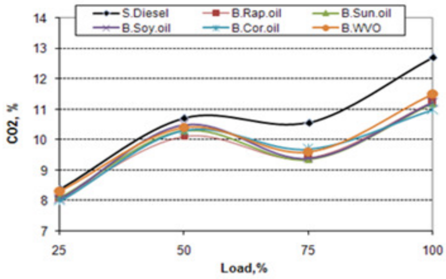

Figure 10. Variation of carbon dioxide emissions with load for fuels tested

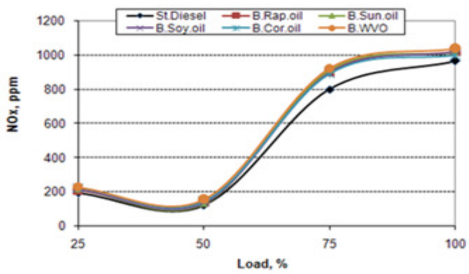

Figure 11. Variation of oxide of nitrogen emissions with load for fuels tested

4. Conclusions

Base on the results of this study, the following specific conclusions were drawn.

Biodiesel processor "Fulpod" was developed for the production of biodiesel from vegetable oils by using alkali-catalyzed transesterification process. The maximum ester yield was obtained by using 16% methanol and 8% NaOH at 65^oC reaction temperature. The fuel properties, such as kinematic viscosity, density, calorific value and cloud, pour and flash point, were measured and found as shown in properties table results. After esterification of vegetable oils, the kinematic viscosity was reduced to 5 mm^2/s from 40 mm^2/s. For the analyzed samples, the properties were similar in some cases and diverge in other. The brake power and torque of the engine with standard diesel were higher than those with biodiesel at all engine speed operation. Due to the fact that the lower calorific value of biodiesel was lower than that of diesel fuel, both torque and brake power reduce. Because of higher fuel density and lower calorific value, biodiesel showed slightly higher BSFC in comparison with standard diesel. The NOx emission with biodiesel was higher than that with diesel fuel, while CO_2 and HC emissions were lower, when compared to those of standard diesel. The results showed a 33 % reduction in HC emissions and a 8% reduction in CO_2 emissions for biodiesel with a 8.7% increase in NOx emission. Thus, any types of vegetable oils biodiesel can be used as an alternate and nonconventional fuel to run all types of CI engine.

References

[1] Directive 2003/30/EC on the promotion of the use of biofuels or other renewable fuels for transport (2003), "8 May 2003, on the promotion of the use of biofuels or other renewable fuels for transport", Official Journal of the European Union, L 123/43.

[2] Yoon, S. H., Ha, S. Y., Roh, H. G. and Lee C. S. (2009), "Effect of bioethanol as an alternative fuel on the emissions reduction characteristics and combustion stability in a spark ignition engine'', Journal of Automobile Engineering, Vol. 223, pp. 941-951.

[3] Poulopoulos, S. G. and Philippopoulos, C. J. (2003), ''The effect of adding oxygenated compounds to gasoline on automotive exhaust emissions'', Trans. ASME, J. Engng Gas Turbines Power, Vol. 125, pp. 344-350.

[4] Marriott, C. D., Wiles, M. A., Gwidt, J. M., and Parrish, S. E. (2008), ''Development of a naturally aspirated spark ignition direct-injection flex-fuel engine'', SAE technical paper 20008-01-0319.

[5] Zhang, J., Qiao, X., Guan, B., Wang, Z., Xiao, G., and Huang, Z. (2008), "Search for the optimizing control method of compound charge compression ignition (CCCI) combustion in an engine fueled with dimethyl ether", Energy Fuels, Vol. 22, pp 1581-1588.

[6] Cataluna, R., Silva, R., Menezes, E. W., and Ivanov, R. B. (2008), "Specific consumption of liquid biofuels in gasoline fuelled engines", Fuel, Vol. 87, pp 3362-3368.

[7] Nwafor, OMI, Rice, G., Ogbonna, AI. (2000), "Effect of advanced injection timing on the performance of rapeseed oil in diesel engines", Renewable Energy, 21:433–44.

[8] Pramanik, K. (2003), "Properties and use of jatropha curcas oil and diesel fuel blends incompression ignition engine", Renewable Energy, 28:239–48.

[9] Enoki, K., Hayashi, S., Sawa, N. (1994), "Effective utilization of blended plant fuels for precombustion chamber compression ignition engines". SAE 940330.

[10] Karabektas, Murat (2009), "The effects of turbocharger on the performance and exhaust emissions of a diesel engine fuelled with biodiesel", Renewable Energy, Vol. 34, pp 989-993.

[11] Devan[a], P.K. and Mahalakshmi[b], N.V. (2008), "A study of the performance, emission and combustion characteristics of a compression ignition engine using methyl ester of paradise oil–eucalyptus oil blends", Applied Energy, Vol. 86, pp 675-680.

[12] Azoumah[a], Y., Blin[a], J. and Daho,[b] T. (2009), "Exergy efficiency applied for the performance optimization of a direct injection compression ignition (CI) engine using biofuels", Renewable Energy, Vol. 34, pp 1494-1500.

[13] Ghobadian[a], B., Rahmini[a], H., Nikbakht[a], A.M., Najafi[a], G. and Yuaf[b], T.F. (2009), "Diesel engine performance and exhaust emission analysis using waste cooking biodiesel fuel with an artificial neural network", Renewable Energy, Vol.34, pp 976-982.

[14] Banapurmath, N.R. and Tewari, P.G. (2009), "Comparative performance studies of a 4-stroke CI engine operate on du fuel mode with producer gas and Honge oil and its methyl ester (HOME) with and without carburettor", Renewable Energy, Vol. 34, pp 1009-1015.

[15] Benjumea[a], P., Agudelo[b], J., Agudelo[b], A. (2009), ''Effect of altitude and palm oil biodiesel fuelling on the performance and combustion characteristics of a HSDI diesel engine'', Fuel, Vol. 88, pp 725-731.

[16] Saka, S., Kusdiana, D. (2001), "Biodiesel Fuel from Rapeseed Oil as Prepared in Supercritical Methanol", Fuel, Vol.80, pp 225-231.

[17] Barnwal*, B.K. and Sharma, M.P. (2005), "Prospects of biodiesel production from vegetable oils in India", Renewable and Sustainable Energy Reviews, Vol. 9, pp 363-378.

[18] Canakci, M. and Sanli, H. (2008), "Biodiesel production from various feedstocks and their effects the fuel properties", Vol. 35, pp 431-441.