www.rericjournal.ait.ac.th

Dual Biodiesel for Diesel Engine – Property, Performance and Emission Analysis

K. Srithar*[1] and K. Arun Balasubramanian[+]

Abstract *– Numerous works on the consumption of biodiesel and its blends in diesel engines have been performed. This paper enlightens the physical–chemical properties, performance and emission analysis of the mixed fuels of pongamia pinnata biodiesel, jatropha biodiesel and diesel fuel blends. Physical and chemical properties of diesel fuel, pongamia pinnata biodiesel, jatropha biodiesel and the combination of diesel-pongamia pinnata – jatropha (DPJ) blends are determined according to requirements and test methods. The key fuel properties such as calorific value, kinematic viscosity, specific gravity, volatility characteristics, cetane number, surface tension and corrosiveness of the blends were measured using the International Standard methods. The results indicate that the calorific value of the blends decrease with an increase in concentration of dual biodiesel in the blends. The kinematic viscosity, specific gravity, surface tension, cetane number, flash and fire point temperatures of the dual biodiesel blends are augmented with an increase in concentration of dual biodiesel in the blends. The viscosity of dual blends decreases with an increase in temperature and also nears the viscosity of diesel at higher temperatures. The specific fuel consumption values of dual biodiesel blends were comparable to diesel. The dual biodiesel blends provided less HC and CO than diesel.*

Keywords **–** Biodiesel, diesel engine, dual biodiesel, performance and pollutant emissions

1. INTRODUCTION

The scarcity of fossil fuel resources in the world enlightens the importance of new and renewable energy resources. Renewable energy has become a vital element of global energy policy to decrease greenhouse gas emissions caused by fossil fuels. Alternative transport fuels such as hydrogen, natural gas and biofuels are the options for the transport sector at the prospect of lack of oil availability and its environmental impact. Biodiesel has received ample consideration as a substitute for diesel fuel since it is biodegradable, nontoxic and can considerably decrease exhaust emissions and overall life cycle emission of carbon oxides from the diesel engine when utilized as a fuel.

Wang *et al.* [1] reported that, the vegetable oils possess almost the same heat values as that of diesel fuel. The engine power output and the fuel consumption of the engine are also closest compared with that of pure diesel. Vegetable oils can directly be used in diesel engines, as they have calorific value very close to diesel. The high viscosity and low volatility of vegetable oils, however, leads to difficulty in atomizing the fuel. This can be reduced by means of preheating the oil or blending it with diesel or transesterification etc.

Lin *et al.* [2] revealed that transesterification seems to be a simple and an efficient method for fuel production. In the studies conducted, it was seen that biodiesel is renewable alternative fuel for diesel engines. They can be used instead of diesel fuel or mixed to the diesel fuels to be used as fuels and lubricators in diesel engines.

Ali *et al.* [3] performed the biodiesel production from neem oil and found the properties of the biodiesel. The authors revealed that the kinematic viscosity of neem biodiesel was 18.1 centistokes lower than that of raw neem oil due to the tansesterification process. After the tansesterification process, the density of neem oil was reduced and the calorific value was improved.

Agarwal *et al.* [4] described the process of transesterification and found an effective method of reducing vegetable oil viscosity. Economic analysis revealed that, vegetable oil and its derivative as diesel fuel substitutes have almost similar cost as that of diesel. Fuel injection characteristics depend on both the type of injection system and the fuel properties. Researchers have shown that physical and chemical properties of biofuels may vary significantly depending on their chemical composition, leading to affect the engine performance and exhaust emissions. Therefore, when considering a specific biofuel, a measurement of its properties is required [5].

Bhale *et al.* [6] investigated the cold flow properties of 100% biodiesel fuel obtained from Mahua. The low temperature flow properties of Mahua biodiesel are less favorable than petroleum diesel fuel. However, blending with ethanol and kerosene has improved the cold flow performance.

Anand *et al.* [7] revealed that, among the various alternative fuels, biodiesel is emerging as a promising choice for compression ignition engines due to its renewable nature and superior emission characteristics. The experimental investigations conducted by various researchers on variety of biodiesel fuels show a wide variation in engine performance and emission characteristics. The lack of correlations predicting various physical properties of biodiesel fuels derived

*Mechanical Engineering Department, Thiagarajar College of Engineering, Madurai, Tamil Nadu-625015, India.

[+]Mechanical Engineering Department, Sethu Institute of Technology, Kariapatti, Virudhunagar, Tamil Nadu-626115, India.

[1]Corresponding author: Tel: + 91 9842185302, Fax: + 914522483427
E-mail: ponsathya@hotmail.com.

from different feed stocks is posing a serious limitation to the combustion modelers. The authors attempted to evolve a comprehensive methodology for estimating the properties of biodiesel fuels based on their composition and chemical structure.

Albuquerque *et al.* [8] reported that transesterification of vegetable oils decreases the viscosity, density and flash point of the raw material. The authors evaluated the properties of biodiesel oils obtained from different biomass sources (castor, soybean, cotton, and canola) and their binary blends prepared in concentration ranges between 20 and 80%vol. Each sample was analyzed for viscosity, specific gravity and iodine index.

Laza and Bereczky [9] studied the basic properties of the pure rape seed oil-higher alcohols fuel blends according to the appropriate international standards. The viscosity, lower heating value and cetane number of the blend decreases with the increase of alcohol concentration in the blend.

Moser *et al.* [10] analyzed the fuel properties and emission characteristics of blends (20 vol.%) of soybean oil methyl esters (SME) and partially hydrogenated SME (PHSME) in ultra low sulfur diesel fuel (ULSD) were determined and compared with neat ULSD. The following changes were observed for B20 blends of SME and PHSME versus neat ULSD: improved lubricity, higher kinematic viscosity and cetane number, lower sulfur content, and inferior low-temperature properties and oxidative stability.

Li *et al.* [11] studied the effects of different ethanol–diesel blended fuels on the performance and emissions of diesel engines. The presence of ethanol generates different physico-chemical modifications of the diesel fuel, notably reductions of cetane number, low heat content, viscosity, flashpoint, and pour point, etc. These modifications change the spray characteristics, combustion performance, and engine emissions.

Pramanik [12] investigated the properties of jatropha oil and the oil found suitable as fuel for diesel engines. The author concluded that the heating value of the vegetable oil is comparable to the diesel oil and the cetane number is slightly lower than the diesel fuel. However, the kinematic viscosity and the flash point of jatropha curcas oil are several times higher than the diesel oil.

Prabhakar *et al.* [13] conducted experiments with pongamia pinnata biodiesel in a single cylinder diesel engine. The authors reported that the brake thermal efficiency was decreased about 1.7% for B20 (20% biodiesel and 80% diesel) blends compared with that of diesel fuel. The brake specific fuel consumptions were increased for biodiesel blends due to low calorific value of biodiesel.

Mohammed and Medhat [14] operated the diesel engine with jatropha biodiesel. The specific fuel consumption of jatropha biodiesel was 8.62%, 6.6%, 5.57%, and 16.82% higher on B10 (90% diesel:10% biodiesel), B20 (80% diesel:20% biodiesel), B30 (70% diesel:30% biodiesel), and B50 (50% diesel:50% biodiesel) than that of diesel fuel at 2000 rpm respectively. This was due to the higher relative density and lower energy density of jatropha biodiesel.

Pi-qiang Tan *et al.* [15] conducted experiments with jatropha biodiesel on four cylinder diesel engine. The authors revealed that, NOx emission of jatropha biodiesel was higher than that of diesel. This was due to higher oxygen levels in the combustion chamber helps to promote NOx formation reactions.

Raheman and Kumari [16] tested a diesel engine with jatropha biodiesel and emulsified jatropha biodiesel. The authors revealed that the brake thermal efficiency of JB10 (10% jatropha biodiesel: 90% diesel) was 10% less than that of diesel due to its lower calorific value. The JB10S10W (emulsion of JB 10 with 10% water) exhibited 3% to 4% higher brake thermal efficiency than jatropha biodiesel at higher loads. This was because the micro explosion phenomenon due to volatility difference between water and fuels that enhanced air fuel mixing during higher engine load and hence the improvement in combustion efficiency.

Kumar and Kumar [17] performed the experimental investigation on C.I. engine with biodiesel blends of cotton seed methyl esters and neem oil methyl esters. It was observed that the smoke and emissions for the blends of cottonseed and neem are less, as compared to pure diesel. The authors reported that 20% cottonseed blend was produced better performance and emission values than diesel.

From the literatures, several works on the consumption of biodiesel and its blends in diesel engines have been performed. From previous studies, it is evident that single biodiesel offer acceptable engine performance and emissions for diesel engine operation. Very few works have been conducted with the combination of diesel and two different biodiesel as a fuel. But the unrevealed concept of two biodiesels [18-22] really applies to diesel engines instead of the single biodiesel and producer gas/ ethanol.

Various researchers focused on single biodiesel like soybean oil, rapeseed oil, pongamia pinnata oil, cotton seed oil, neem oil, mahua oil, jatropha oil, honne oil, rice bran oil etc., and its blends with diesel. The researchers have left a gap for the combination of dual biodiesels (mixtures of two different biodiesel).

Most of the literatures suggested that pongamia pinnata oil (also called as karanja oil) and jatropha oil are suitable substitute of diesel. In this paper, two biodiesels namely pongamia pinnata oil (PPB), jatropha oil (JB) has been blended with diesel fuel. The most important physical and chemical properties of pongamia pinnata biodiesel–jatropha biodiesel-diesel fuel blends are analyzed and compared to those of diesel fuel. Fuel properties like calorific value, specific gravity, viscosity, flash point, fire point, corrosiveness, surface tension and cetane number are tested.

The potential of dual biodiesels and its blends with diesel fuel as alternative substitute for diesel fuel is investigated. Experimental tests have been carried out, to evaluate the performance and exhaust emission characteristics of a diesel engine.

2. MATERIALS AND METHODS

The oils and blends (pongamia pinnata biodiesel and jatropha biodiesel) were selected on the basis of its physical and chemical properties described in the past literatures. Most of the researchers used the pongamia pinnata oil (karanja oil) and jatropha oil as a single biodiesel fuel for conducting the experiments. The above said oils are available in India. The raw non edible vegetable oils were purchased from nearby oil plants.

The biodiesels were produced separately in the laboratory environment by transesterification method. The combinations of two biodiesels, diesel:pongamia pinnata biodiesel: jatropha biodiesel (DPJ) was prepared from the two different biodiesels. (pongamia pinnata biodiesel and jatropha biodiesel). DPJ dual biodiesels were tested with six different blending ratio's (DPJ 1 is 90:5:5, DPJ 2 is 80:10:10, DPJ 3 is 70:15:15, DPJ 4 is 60:20:20, DPJ 5 is 50:25:25 and DPJ 6 is 0:50:50).

The test fuels were used in a four-stroke, single cylinder, direct injection, water cooled diesel engine under constant engine speed and varying load conditions and their performances were compared.

The experiments were conducted on a computerized single cylinder, four stroke, water cooled diesel engine and the performance and emission characteristics were compared with baseline data of diesel fuel. Tests were conducted at constant speed and at varying loads for all dual biodiesel blends. Three experiments for each load were carried out for accuracy. Experimental analysis was conducted at 0, 20, 40, 60, 80 and 100% of rated load using six different dual biodiesel mixtures (DPJ 1, DPJ 2, DPJ 3, DPJ 4, DPJ 5 and DPJ 6). Each experiment was carried out thrice at different climatic conditions of a complete year for repeatability and accuracy.

2.1 Biodiesel Production

The biodiesel preparation flow chart is shown in Figure 1. The biodiesel can be extracted by the following process namely pretreatment of vegetable oil, transesterification of oils, washing and heating and biodiesel extraction.

The vegetable seeds are dried and the vegetable oil is extracted in oil mills. The vegetable oil is pretreated to remove the impurities from the extracted vegetable oil through primary filtration and secondary filtration. The primary filtration is done by mesh and then the secondary filtration is done by filter paper for removal of micro impurities. The filtered vegetable oil has small amount of moisture content which is removed by heating the oil to 110^{o}C by an electrical heater.

The process of removal of all the glycerol and the fatty acids from the vegetable oil in the presence of a catalyst is called transesterification. In this method triglyceride reacts with ethyl alcohol in the presence of a catalyst (NaOH) producing a mixture of fatty acids, vegetable oil ester and glycerol. The vegetable oil ester is called biodiesel.

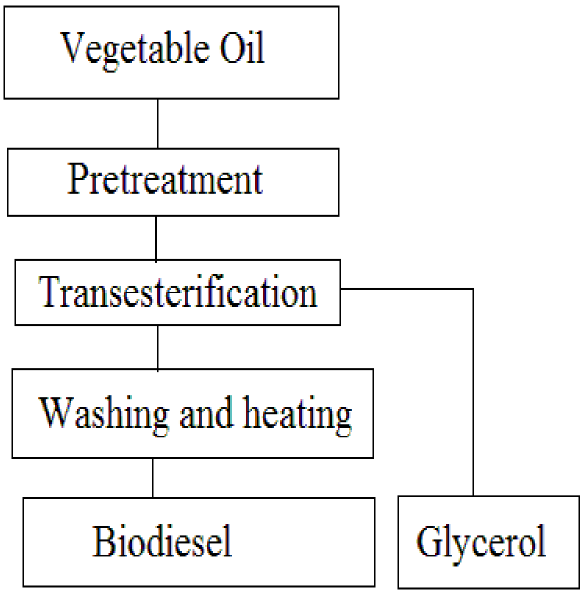

Fig. 1. Flow chart for biodiesel preparation.

The manufacturing process of biodiesel can be carried out in two ways, either batch or continuous flow process. The maximum ester yield of 98% is possible using 20% methanol and 1% of NaOH at 60^{o}C reaction temperature after 90 min. The main product of transesterification is biodiesel and the by-products produced are glycerol, which can be refined and used in cosmetic industries, and oil cake that can be used as fertilizer.

The esterified vegetable oil is then transferred to separating funnel and left for settling of 8 hours. The setup is not to be disturbed during settling process, because more time taken for settling the byproducts. The glycerol formed in the separating funnel is removed and the vegetable oil ester (biodiesel) is collected from the funnel.

The vegetable oil ester is then washed by distilled water to remove the impurities. The distilled water is added to the separating funnel and this water settles all the impurities at the bottom of the funnel. Water with impurities is then removed and then the vegetable oil ester is collected from funnel and further heated to 110^{o}C to remove water poured during washing. Thus after finishing the water washing and heating pure biodiesel is extracted [23].

2.2 Biodiesel Properties

2.2.1 Calorific Value

The calorific values of raw oils, biodiesel and dual biodiesel are determined in the laboratory by bomb calorimeter. The calorimeter has a cylindrical bomb in which combustion occurs. The bomb has two valves at the top. One supplies oxygen to the bomb and other releases the exhaust gases. A crucible in which a weighted quantity of fuel sample is burnt is arranged between the two electrodes. The calorimeter is fitted with water jacket which surrounds the bomb.

Fuel sample is weighed and placed into the crucible. A fuse wire (whose weight is known) is stretched between the electrodes and close contact with the test fuel. Pure oxygen supplied to the bomb through the valve. The bomb is then placed in the calorimeter. The thermometer indicates a steady temperature after the fuel is fired and temperature readings are recorded in 30 seconds interval until maximum temperature is attained. The constant temperature from the reading is taken for the calorific value calculations.

$$\text{Calorific value} = W\, t / M$$

Where, W – weight of the water in the calorimeter
t - time taken in seconds
M - mass of the test fuel

2.2.2 Kinematic Viscosity

Viscosity is the internal resistance offered by the fluid to the movement of one layer of fluid over an adjacent layer. It is due to the cohesion between the molecules of the fluid. The kinematic viscosity of the raw oil, biodiesel, and dual biodiesel are determined using Redwood Viscometer.

The orifice with ball valve in the redwood viscometer is closed and then the test fuel is filled in the cylindrical oil cup up to the mark in the cup. Required amount of water is filled in the water bath. The water is heated to a particular temperature. Stirred the water bath and maintain the uniform temperature. At a particular temperature, lift the ball valve and collect the oil in the 50 ml flask and note the time taken in seconds for the collecting 50 ml of oil. A stop watch is used to measure the time taken.

$$\text{Kinematic viscosity} = A\, t + B/t \quad \text{in Centistokes}$$

where, t is time taken for collection of 50 ml of oil in sec A and B are constants. Here A = 0.26 and B =171.5.

2.2.3 Density

Density is a basic physical property of a homogeneous substance. It is an intensive property and it is the mass of a substance contained in a unit of volume.

Initially weigh a dry 25 mL graduated cylinder using digital weight balance. Then remove it from weight balance and add 10 mL of test fuel in the cylinder. Again weigh the graduated cylinder containing test fuel. Record the weight of oil then calculate the density of the test fuel using the formula (Density = mass / Volume).

2.2.4 Flash Point Temperature

Flash point temperature of raw oils, biodiesel and dual biodiesel are determined using Pensky Marten's apparatus. Flash point temperature is the lowest temperature at which the lubricating oil gives off enough vapors that ignite for a moment when tiny flame is brought near it. Flash point temperature is used to indicate the fire hazard of fuel and evaporation losses under high temperature.

The test fuel is filled in a cup up to the mark. Fix the lids on the top through which a thermometer and a stirrer are inserted. Heat the fuel by 5°C per minute. The stirrer is continuously rotated. At every 1°C rise of temperature, introduce a test flame into the oil vapor. When a test flame causes a distinct flame in interior cup, the temperature is observed and recorded which represents the flash point temperature.

2.2.5 Cetane Number

The cetane number is the most important fuel property for compression ignition engines which affects the engine performance and exhaust emissions. The formula for the cetane number is = $[\,0.72 \times \text{diesel index} + 10\,]$

where Diesel index = [(Aniline point (^{o}F) x API gravity at 60^{o}F)/100]

Aniline point is the lowest temperature at which the oil is completely miscible with an equal volume of aniline. API (American Petroleum Institute) gravity is given by $\text{API} = \left(\frac{141.5}{\text{Specific gravity at } 60^{o}\text{F}}\right) - 131.5$

2.2.6 Surface Tension

The surface tension of the test fuels are determined by drop counting method in a stalagmometer. The stalagmometer is a glass tube which is widened in middle part. The test fuel is filled inside the stalagmometer and the fuel is flowing out from the bottom side of the stalagmometer and forms the drop due to smaller diameter of the bottom side. The fuel drops are counted and collected in the bottle. Similarly water is filled inside the stalagmometer and the water drops are counted.

Surface tension = (surface tension of water x density of fuel x number of water drops) / (density of water x number of fuel drops).

2.2.7 Corrosion Test

The copper corrosion test measures the corrosion tendency of fuel when used with copper, brass, or bronze parts. Corrosion is a chemical action that destroys the surface of a metal by oxidation alone or in combination with a chemical process. It should be tested in fuels, especially for transportation and storage conditions.

In the present study corrosion level is measured according to the ISO -2160 standard test method. In this method, a polished copper strip is immersed in a specific volume of sample test fuel and heated at 50°C for 3 hours. At the end of the heating period, the strip is removed, washed and the colour assessed against corrosion standards. The copper strip colour indicates the test fuel classification according to ISO -2160.

2.3 Performance Analysis

Engine performance is an indication of the degree of success. The performance of dual biodiesel blends are evaluated with diesel. The diesel engine is operated with different dual biodiesel combinations.

The performances of test fuels are analyzed in a Kirloskar make single cylinder, four-stroke, direct injection diesel engine coupled with eddy current loading device. Experiments are conducted with varying loads while engine speed is kept constant at rated speed of 1500 rpm. Tests are conducted at 0, 20, 40, 60, 80 and 100% of rated load for all fuels.

Fuel flow rates are obtained with calibrated burette. The exhaust gas temperatures are measured using Chromel Alumel (K-Type) thermocouple. The engine is coupled with eddy current loading device and the parameters like brake specific fuel consumption and brake thermal efficiency and brake specific energy consumption are evaluated for different load conditions. Before switched off the engine, the engine is run by diesel fuel in order to flush out the vegetable oil from the fuel line and fuel filter. By doing this, cold starting problems of the engine can be avoided to a large extent. Flow control valves, fuel measurement devices and thermocouples are provided at different places to make operation possible.

The engine analyses are conducted to find out its performance and emission values in the diesel engine using DPJ dual biodiesels. The emission analysis is discussed in the Section 2.3.1.

2.3.1 Emission Analysis

The emission characteristics of dual biodiesel blends are measured with the help of AVL make smoke meter and Crypton make exhaust gas analyzer at the engine steady state condition.

The smoke meter is utilized to find the smoke opacity of exhaust gas. The opacity of smoke is measured by light obscuration method. In this method, the intensity of a light beam is reduced by smoke, which is a measure of smoke intensity.

The Crypton make exhaust analyzer is used to measure the carbon monoxide (CO), carbon dioxide (CO_2), hydro carbon emission (HC) and nitrogen oxides (NOx). The NOx emissions are measured by chemical cell method. The carbon monoxide, carbon dioxide emissions and hydrocarbons are measured by Non dispersive infra red method (NDIR).

The experimental set up is shown in Figure 2 and the detailed engine specifications are given in Table 1. The detailed specification of the Crypton five gas analyser used is given in Table 2, and detailed specification of the AVL smoke meter used is given in Table 3.

2.4 Error Analysis

The percentage error of various instruments that are utilized for this experiment is calculated. Percentage error = Minimum Scale / Minimum Value Measured. The Table 4 listed the percentage of error for various instruments.

Table 1. Test engine specifications.

Items	Specifications
Model	AV1
Made	Kirloskar
Type	Single cylinder, Four stroke
Bore x Stroke	87.5 x 110 mm
Rated Output	5.2 (kW / 1500 rpm)
Compression ratio	17.5 : 1
Injection Pressure	13.5 MPa
Type of Cooling	Water Cooling

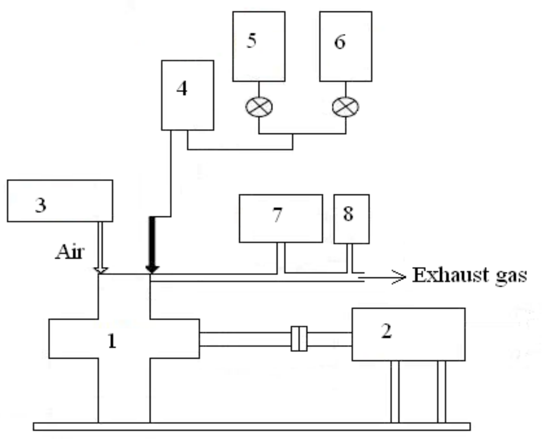

Fig. 2. Experimental setup.

Table 2. Specification of gas analyzer.

Ranges	CO - 0 to 10%, HC - 0 to 10000 ppm, CO_2 - 0 to 20%, O_2 - 0 to 25%, RPM – 0 to 10,000 rpm
Accuracy/ Performance	CO - 0.06% CO, HC – 12ppm HC, CO_2 – 0.50% CO_2, O_2 – 0.10% O_2
Resolution	CO – 0.01% vol, HC – 1ppm vol, CO_2 – 0.1% vol, O_2 – 0.01% vol

Table 3. Specification of smoke meter.

Specification	Measurement (range)	Resolution
Opacity	0 - 100%	0.1%
Absorption (k value)	0 - 99.99m^{-1}	0.01m^{-1}
Speed	400 – 6000m^{-1}	1 rpm
Oil Temp.	0- 150^{o}C	1^{o}C
Linearity check	50 % of Measurement range	

Table 4. Error analysis.

Sl. No	Instruments	Error, %
1	Stop watch	1.25
2	Burette for fuel measurement	1.0
3	Digital bomb calorimeter	1.0
4	Thermometer	1.0
5	Weight balance	1.0
6	Manometer	1.0
7	Smoke meter	0.6
8	Exhaust Temperature Gauge	5.0

3. RESULTS AND DISCUSSION

This section discussed in detail about the various properties of the dual biodiesel, the performances and emission characteristics of various DPJ blend in a computerized diesel engine. The property analysis of calorific value, specific gravity, kinematic viscosity, flash point temperature, cetane number, surface tension and corrosion test are discussed in 3.1-3.7. The Table 5 shows the values of different properties. The performance analysis on brake thermal efficiency, specific fuel consumption and exhaust gas temperature are described in the section 3.8. The exhaust gas emission analysis on hydro carbon, carbon monoxide, carbon dioxide, nitrogen oxides and smoke are revealed in the Section 3.9.

Table 5. Fuel properties of the dual biodiesel.

Fuel	Density (kg/m^3)	Calorific Value (MJ/kg)	Kinematic viscosity at 40ºC (cSt)	Flash Point (º C)	Cetane Number
ASTM Method	D1298	D420	D 0445	D 0093	D976
PPB	871	40.13	5.9	160	48
JB	835	42.97	4.8	125	51
DPJ 1	832	46.10	4.1	67	46
DPJ 2	835	45.50	4.3	75	47
DPJ 3	838	45.10	4.4	85	48
DPJ 4	839	44.60	4.6	96	49
DPJ 5	841	44.10	4.7	102	50
DPJ 6	853	41.60	5.4	140	51
Diesel	830	46.58	4.0	58	47

3.1 Calorific Value of Fuels

Calorific value of a fuel measures the energy content in a fuel. This is an important property of the biodiesel that determines the suitability of the material as alternative to diesel fuel. Digital bomb calorimeter was used to find out the calorific value of fuels. The calorific values of any fuel need to be high for complete combustion or for burning process.The calorific value of diesel - pongamia pinnata biodiesel-jatropha oil biodiesel blend DPJ 1 and DPJ 2 is found to be close to that diesel fuel.

3.2 Specific Gravity of Fuels

Specific gravity of different dual blends was measured using a precision hydrometer. The diesel is having low specific gravity while comparing with pongamia pinnata biodiesel, jatropha biodiesel and its blends with diesel. The specific gravity of biodiesel is associated to combustion process, which is greatly reliant on the excellence of atomization. Fuel atomization is also related to viscosity and surface tension of the fuel. Higher specific gravity and viscosity of dual biodiesel leads to lesser volatility which causes the deprived atomization of dual biodiesel during fuel injection in combustion chamber. Dual biodiesel DPJ 6 gives higher specific gravity and DPJ 1 gives lower specific gravity. In this view DPJ 1 should give better performance as an alternative fuel.

3.3 Kinematic Viscosity

Kinematic viscosity was measured using Redwood viscometer. Kinematic viscosity is one of the main properties of any fuel to fulfill the smooth engine operation. Lower the viscosity results high volatility, better atomization and complete combustion of fuel during injection in diesel engine.

The kinematic viscosities of dual biodiesel blends vary in the range of 4.1– 5.4 cSt and are higher than those of diesel fuels used in this study. The kinematic viscosity of the raw oil is very high compared to diesel. The use of neat vegetable oils generates some problems, when subjected to prolonged usage in CI engines. These problems are attributed to high viscosity and low volatility. After the transesterification process, the viscosity of the oil decreases. The kinematic viscosity of blend DPJ 1 is nearer to diesel.

3.4 Flash Point Temperature

The temperature at which the vapours of oil flash when subjected to a naked flame is known as flash point temperature of a fuel. The flash point temperature was measured using Pensky Marten’s closed cup apparatus. Flash point temperature of dual biodiesel is not affected the engine performance parameters but it gives the combustible properties of dual biodiesel. Flash point temperature is good indication of relative flammability of the oil. The flash point temperature of biodiesel is important for transporting and protection policy involved in the handling and storage of dual biodiesel. The flash point temperature of DPJ 1, DPJ 2, DPJ 3, DPJ 4, DPJ 5 and blend DPJ 6 is 67^o C, 75^o C, 85^o C, 96^o C, 102^o C, 140^o C where as the diesel is 58^o C. These results show that the selected biodiesels could be safely stored due to its higher flash point temperatures.

3.5 Cetane Number

The cetane number is the most important fuel property for compression ignition engines which affects the exhaust emissions, noise and startability of a diesel engine. In general, lower the cetane numbers higher are the noise levels. Low cetane fuels increase ignition delay so that start of combustion is nearer to top dead centre. This is similar to retarding of injection timing which is also known to result in higher emission level. The higher cetane number of biodiesel is still considered positive. Studies have shown that as levels of unsaturation increase, cetane number decreases, and as the chain length increases the cetane number increases. The cetane number of blend DPJ 1 is nearer to diesel.

3.6 Surface Tension

Surface tension affects the spray characteristics and atomization of fuel droplets; these lead to significant effect on combustion efficiency. The surface tension is determined by the drop counting method in a Stalagmometer. From the results, the dual biodiesel blend DPJ 1 has closer surface tension value with the diesel; other blends are higher than diesel. This property is important to the fuel spray process in the diesel engine combustion chamber. DPJ 6 has higher surface tension which creates larger dual biodiesel droplets. Hence, the fuel spray process is hard in combustion chamber and gives poor engine performances.

3.7 Corrosion test

The corrosion test is conducted to compute the corrosion tendency of fuel. Corrosion is electro chemical reactions that devastate the exterior of a metal with an oxidant. The dual biodiesel is maintained at a constant heat and a copper strip is inserted in it. The change of colour in copper strip is examined and analyzed. The corrosion test of dual biodiesel is important to know the feasibility of dual biodiesel in transporting, handling and storage purpose. In this current analysis, corrosion level was measured according to the ISO-2160 standard test method. The result shows that all samples tested are classified as 1a, which is a suitable classification from the point of view of corrosion.

3.8 Performance Characteristics

Figure 3 shows the variations of load on brake thermal efficiency for different dual biodiesel blends. It can be also observed that, DPJ 1 gives the maximum thermal efficiency of 26%, DPJ 2 gives 25.2% where as the diesel gives 26.3% at the same load. DPJ 1 gives the maximum thermal efficiency than other DPJ blends. This is due to the higher calorific value of DPJ 1 than that of other dual biodiesel. At low load conditions, the thermal efficiency of the diesel engine has enhanced with escalating concentration of the dual biodiesels in the fuel. This is due to the additional volatility provided by the dual biodiesels. The dual biodiesels have a quantity of oxygen, which is used for the complete combustion in the disesel engine.

The effect of load on specific fuel consumption is shown in Figure 4. As load increases the SFC reduces for all the dual biodiesel blends. For the maximum load, the value of SFC of DPJ 1 is 0.355 kg/kw h, Blend DPJ 2 is 0.36 kg/kw h, DPJ 3 is 0.362 kg/kw h whereas diesel fuels have 0.36 kg/ kw h. The SFC is high for the increased value of dual biodiesel blends, due to the lower calorific value of it.

The changes in load with respect to exhaust gas temperature variation are shown in Figure 5. Exhaust temperature increases with increase in load in all cases. For the maximum load, the value of exhaust temperarture of DPJ 1 is 212°C, Blend DPJ 2 is 231°C, DPJ 3 is 245°C whereas diesel fuels have 186°C. The increase in exhaust gas temperature with engine load is clear from the simple fact that, more amount of fuel is required by the engine to produce the extra power needed to take up the additional loading.

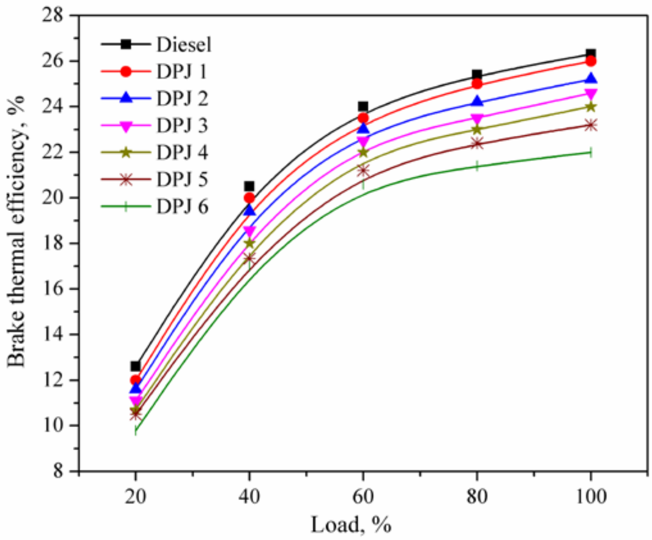

Fig. 3. Variations of load on brake thermal efficiency.

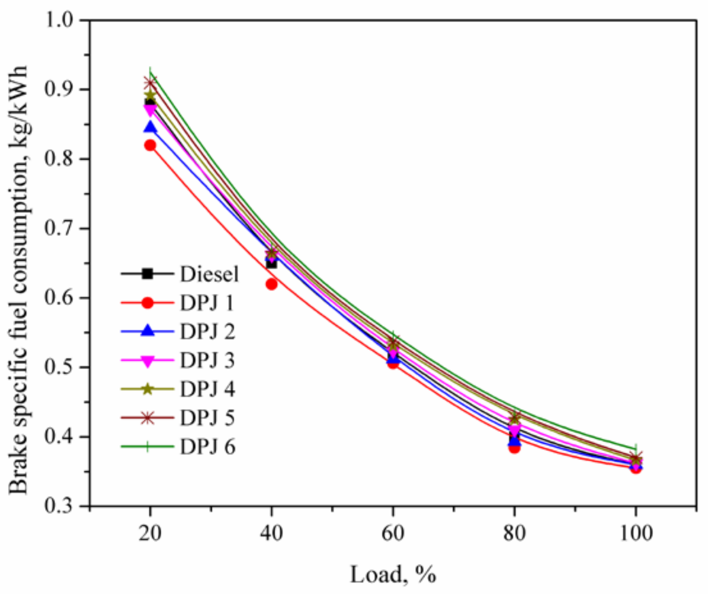

Fig. 4. Effect of load on brake specific fuel consumption.

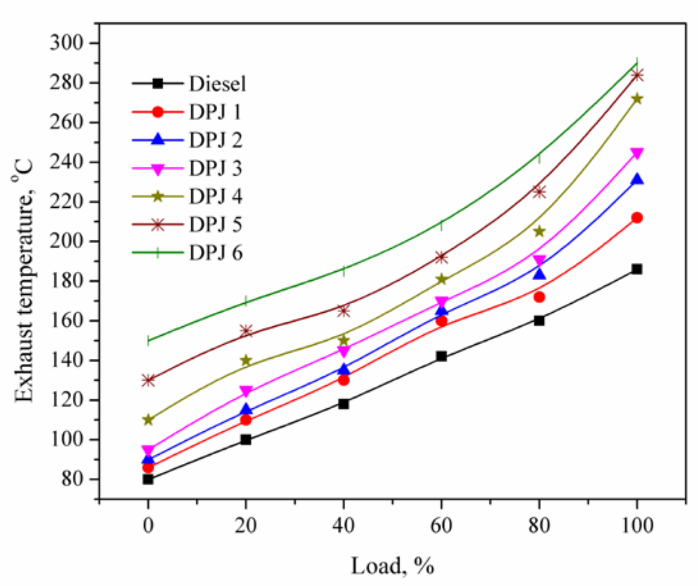

Fig. 5. Variations of load on exhaust gas temperature.

3.9 Emission characteristics

Figure 6 shows that, the relation between load and Hydro Carbon (HC) increased by increasing the load for each blend. All the Blends give lower HC than diesel. From the results, Blend DPJ 1 gives lesser HC than other blends. It gives 50% lower HC than diesel at the maximum load.

At lower combinations of dual biodiesel blend, the oxygen present in the biodiesel assist for complete combustion. But, as the dual biodiesel combination increases, the negative result attained due to high viscosity and density which reduces the complete combustion and increases the hydro carbon emission.

The dual biodiesels and blends generally exhibit lower HC emission at lower engine loads and higher HC emission at higher engine loads. This is because of relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at high engine load.

The variations of carbon monoxide on load are shown in Figure 7. Carbon monoxide (CO) content is also increasing with increase in load. The dual biodiesel blends give lower CO than diesel exept DPJ 6. This is due to the oxygen contents in the biodiesel which makes easy burning at higher temperature in the cylinder. DPJ 6 blends is deviated from all other dual biodiesel blends. This is due to the high viscosity; the air-fuel mixing process is affected by the difficulty in atomization and vaporization of dual biodiesels. Higher the engine load, richer fuel-air mixture is burned and thus more CO is produced.

The variations of carbon dioxide (CO_2) emission with different dual biodiesel blends is shown in Figure 8. The dual biodiesel blends give higher CO_2 than diesel. DPJ 1 gives the CO_2 value of 4.75 % vol whereas diesel gives 4.7% vol. It is an indication of efficient combustion. It is desirable in combustion process, to have higher CO_2 production and less HC and CO emissions since it is a measure of combustion efficiency [24].

The effect of load on nitrogen oxides is shown in Figure 9. The nitrogen oxides (NOx) increased by increasing the load for each blend. From the results, NOx emission is higher for dual biodiesel blends than diesel. However, Blend DPJ 1 gives lesser NOx than other dual biodiesel blends. The vegetable oil based biodiesel contains a small amount of nitrogen. This contributes towards NOx production. The higher average gas temperature, the presence of fuel oxygen and residence time at higher load conditions with the blend combustion caused higher NOx emissions.

It is observed from Figure 10, that the load increases with increase in the smoke percentage. For the maximum load, the smoke for diesel was 33%, where as the DPJ 1 gives 31% and DPJ 2 gives 32% with the same maximum load. In other blends, the smoke percentage is more than the diesel with the same brake power. The higher density and viscosity may be the reason for more smoke emissions as compared to neat diesel. The high viscosity of pure biodiesel deteriorates the fuel atomization, and increases exhaust smoke.

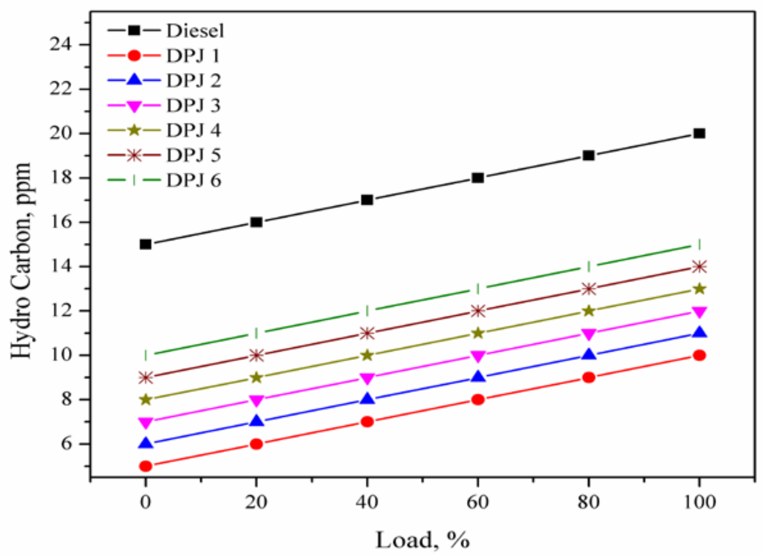

Fig. 6. Effect of brake power on hydro carbon emission.

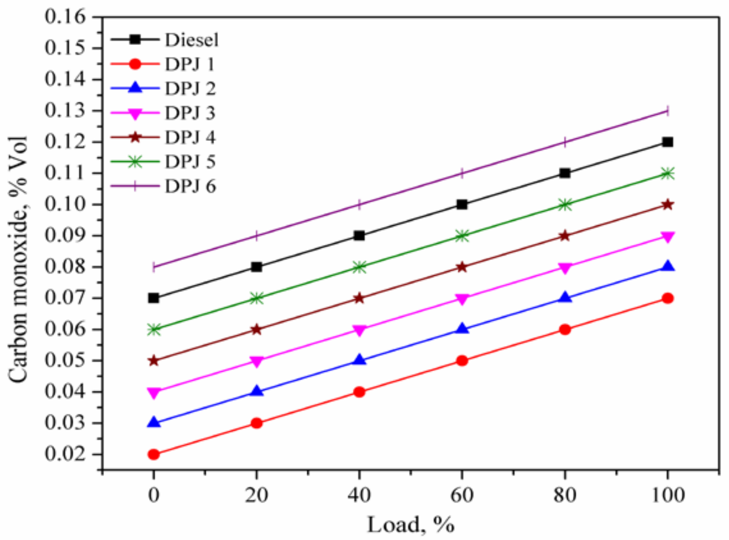

Fig. 7. Carbon monoxide variations with different dual biodiesel blends.

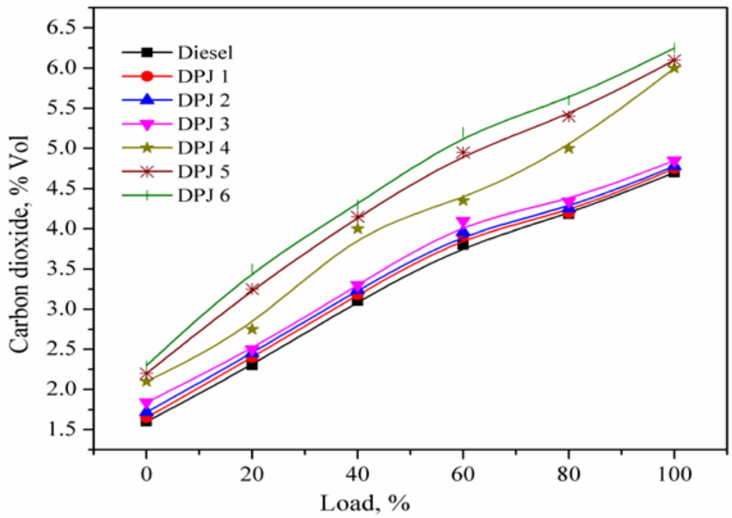

Fig. 8. Carbon dioxide variations with different dual biodiesel blends.

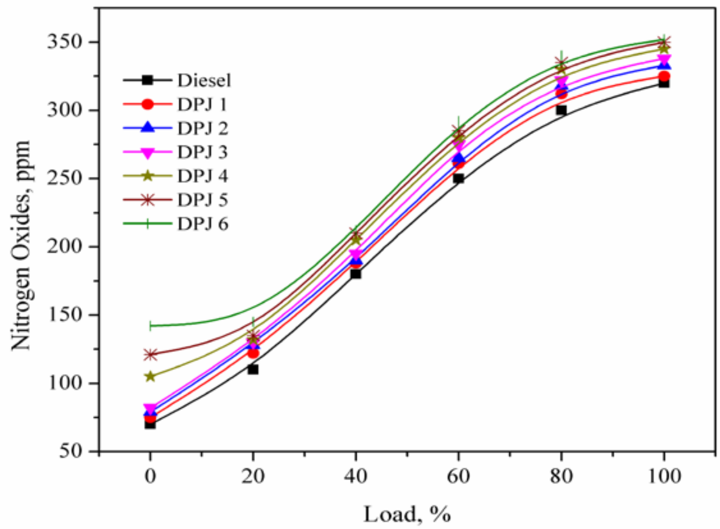

Fig. 9. Nitrogen Oxides variations with different dual biodiesel blends.

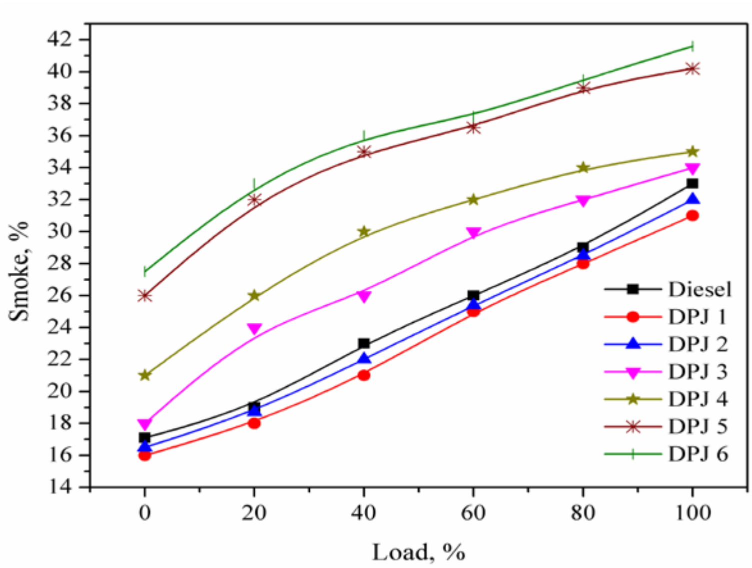

Fig. 10. Effect of load on smoke.

4. CONCLUSION

The calorific value, specific gravity, kinematic viscosity, flash point temperatures, cetane number, surface tension and corrosion test for diesel-pongamia pinnata biodiesel–jatropha biodiesel (DPJ) were evaluated in this study. From this analysis, the calorific value and kinematic viscosity of DPJ 1 was closer to diesel values. The cetane number of DPJ blends was higher than those of diesel. The flashpoint temperature of DPJ blends was higher than that of diesel fuel, facilitating safe transport and storage. The dual biodiesel blend DPJ 1 has closer surface tension value with the diesel; other blends were higher than that of diesel.

From the performance analysis, the thermal efficiency of blend DPJ 1 and DPJ 2 were very closer to the diesel values. The specific fuel consumption values of dual biodiesel blends were comparable to that of diesel.

From the emission analysis, the DPJ blends were produced lower HC and CO than those of diesel. This was a considerable advantage over diesel while using the DPJ dual biodiesel blends. The DPJ blends gave higher NOx than those of diesel. Based on these results, DPJ 1 and DPJ 2 were closer to diesel. Hence they can be recommended as fuel for stationary agricultural purpose diesel engines.

ACKNOWLEDGEMENT

The authors would like to thank the Union Grant Commission (UGC), India for providing the financial assistance to carry out this work at I.C. Engines Laboratory, Thiagarajar College of Engineering, Madurai, Tamil Nadu.

REFERENCES

[1] Wang Y.D., Al-Shemmeri T., Eames P., McMullan J., Hewitt N., Huang Y. and Rezvan S., 2006. An experimental investigation of the performance and gaseous exhaust emissions of a diesel engine using blends of a vegetable oil. *Applied Thermal Engineering* 26: 1684–1691.

[2] Lin L., Ying D., Chaitep S., and Vittayapadung S., 2009. Biodiesel production from crude rice bran oil and properties as fuel. *Applied Energy* 86: 681–688.

[3] Ali M.H., Mashud M., Rubel M.R., and Ahmad R.H., 2013. Biodiesel from Neem oil as an alternative fuel for Diesel engine. *Procedia Engineering* 56: 625 – 630.

[4] Agarwal D., Kumar L. and Agarwal A.K., 2008. Performance evaluation of a vegetable oil fuelled compression ignition engine. *Renewable Energy*, 33:1147–1156.

[5] Torres-Jimenez E., Jerman M.S., Gregorcb A., Lisec I., Dorado M.P. and Kegl B., 2011. Physical and chemical properties of ethanol–diesel fuel blends. *Fuel* 90: 795–802.

[6] Bhale P.V., Deshpande N.V. and Thombre S.B., 2009. Improving the low temperature properties of biodiesel fuel. *Renewable Energy* 34: 794–800.

[7] Anand K., Sharma R.P. and Mehta P.S., 2011. A comprehensive approach for estimating thermo-physical properties of biodiesel fuels. *Applied Thermal Engineering* 31: 235-242.

[8] Albuquerque M.C.G., Machado Y.L., Torres A.E.B., Azevedo D.C.S., Cavalcante Jr. C.L., Firmiano L.R. and Parente Jr., E.J.S., 2009. Properties of biodiesel oils formulated using different biomass sources and their blends. *Renewable Energy* 34: 857–859.

[9] Laza T. and A. Bereczky. 2011. Basic fuel properties of rapeseed oil-higher alcohols blends. *Fuel* 90: 803–810.

[10] Moser B.R., Williams A., Haas M.J. and McCormick R.L., 2009. Exhaust emissions and fuel properties of partially hydrogenated soybean oil methyl esters blended with ultra low sulfur diesel fuel. *Fuel Processing Technology* 90: 1122–1128.

[11] Li D.-G., Zhen H., Xingcai L., Wu-gao Z. and Jian-guang Y., 2005. Physico-chemical properties of ethanol–diesel blend fuel and its effect on performance and emissions of diesel engines. *Renewable Energy* 30: 967–976.

[12] Pramanik K., 2003. Properties and use of jatropha curcas oil and diesel fuel blends in compression ignition engine. *Renewable Energy* 28: 239–248.

[13] Arun Balasubramanian K., 2012. Dual Biodiesel Blends in Diesel Engine - Performance and Emission Analysis. *European Journal of Scientific Research* 75: 400-408.

[14] Prabhahar M., Muralimanohar R. and Sendilvelan S. 2012. Performance, emission and combustion characteristics of a direct injection diesel engine with pongamia methyl ester and diesel blends. *European Journal of Scientific Research* 73: 504-511.

[15] EL-Kasaby M. and M.A. Nemit-allah. 2013. Experimental investigations of ignition delay period and performance of a diesel engine operated with Jatropha oil biodiesel. *Alexandria Engineering Journal* 52: 141–149.

[16] Tan P.-Q., Hu Z.-Y., Lou D.-M., Li Z.-J. 2012. Exhaust emissions from a light-duty diesel engine with Jatropha biodiesel fuel. *Energy* 39: 356-362.

[17] Raheman H. and S. Kumari. 2014. Combustion characteristics and emissions of a compression ignition engine using emulsified jatropha biodiesel blend. *Biosystems Engineering* 123: 29-39.

[18] Dilip Kumar K. and P. Ravindra Kumar 2012. Experimental investigation of cotton seed oil and neem methyl esters as biodiesel on CI engine. *International Journal of Modern Engineering Research* 2: 1741-1746.

[19] Arun Balasubramanian K., Guruprasath A., Vivar M., Skryabin I. and Srithar K., 2013. Performance and emission characteristics of double biodiesel blends with diesel. *Thermal Science* 17: 255-262.

[20] Arun Balasubramanian K. and K. Srithar. 2014. Multiple biodiesel mixtures in diesel engine - performance and emission analysis. *Energy Education Science and Technology Part A: Energy Science and Research* 32(1): 13-24.

[21] Arun Balasubramanian K., Vigneswaran S. and Srithar K., 2014. Energy and exergy analysis of CI engine using dual biodiesel blends with diesel. *Australian Journal of Basic and Applied Sciences* 8(2): 78-86.

[22] Srithar K., Arun Balasubramanian K., Vivar M. and Skryabin I., 2013. An experimental investigation on diesel and low heat rejection engines with dual biodiesel blends. *International Journal of Green Energy* 10: 1041–1055.

[23] Leduc S., Natarajan K., Dotzauer E., McCallum I. and Obersteiner M., 2009. Optimizing biodiesel production in India. *Applied Energy* 86 supplement 1: S125-S131.

[24] Nwafor O.M.I., 2004. Emission characteristics of diesel engine operating on rapeseed methyl ester. *Renewable Energy* 29: 119–129.