Study of Performance, Emission and Combustion Parametersof a Direct InjectionDiesel Engine using Eucalyptus and Nerium biodiesels as fuel

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Abstract

Self-reliance in energy is vital for the overall economic development of any country. Fossil fuels have given us utility and continued their role in a variety of areas, but the faster depletion of fossil fuels, rapid increase in the number of automobiles and the ever increasing cost of petroleum products triggered the interests of many researchers across the world to arrive at an alternative fuel which is most suitable for use in diesel engines. This paper presents an experimental investigation on the performance, emission and combustion characteristics of two different biodiesels – Nerium and Eucalyptus biodiesel, in a single cylinder direct injection diesel engine. Both Nerium and Eucalyptus biodiesels are blended separately with diesel fuel 30% by volume [N30 and E30] and the various characteristics were studied. Studies showed that the use of biodiesel blends resulted in a significant reduction in Hydrocarbon and Carbon monoxide emissions with a slight reduction in the Brake thermal efficiency of the engine. However, a significant increase in the NOx emissions was noted while using the blends of biodiesel.

Keywords: biodiesel, combustion, eucalyptus, emission, Nerium, performance.

I. INTRODUCTION

Energy consumption is inevitable for the existence of human beings. Fuels derived from petroleum products have been the most important source of world's energy and mostly the transportation sector. It is estimated that towards the end of this century, crude oil and petroleum products will become very scarce and costly. Even though the fuel economy of modern engines are improving day by day, the enormous increase in the number of automobiles have started dictating the demand for fuel. It is believed that gasoline and diesel, which are the most widely used fuels these days, will be facing extinction towards the end of this century. So, it is the need of the hour to find other sources of eco-friendly, renewable fuels which can be used as an alternative to the conventional fossil fuels. With increased use and depletion of fossil fuels, alternative fuel technology will become much more common in the years to come.

Biodiesels, produced from vegetable oils, has been under research as an alternative fuel for the past few years. Biodiesel can either be used as a sole fuel, known as neat biodiesel or can be blended with petroleum diesel in various proportions for use in diesel engines. Recent researches in this field show that biodiesels can be blended with diesel up to 30 % by volume without any modifications to the engine. Further increasing the biodiesel content in the fuel blend requires minor modifications like varying the injection pressure, injection timing, compression ratio etc. In a few foreign countries, B20 (20% biodiesel + 80% diesel) fuel blend has been used widely in compression ignition engines as a partial alternative to petroleum diesel.

Biodiesel could be produced from a wide variety of vegetable oils such as Palm oil, Rice bran oil, Neem oil, coconut oil, Soyabean oil, Sunflower oil, Jatropha, Pongamia etc. but most of the above are edible oils. As far as a developing country like India is concerned, the use of an edible oil for biodiesel production leads to an imbalance between the food and the fuel sector. So the main criterion to be followed in this case is that the alternative fuel (biodiesel) should be produced from a non-edible vegetable oil. Some of the main non-edible vegetable oils are Jatropha, Pongamia, Mahua, Nerium, Eucalyptus, Castor oil etc.

The vegetable oil source from which the biodiesel is derived is selected depending upon their availability in that region of the country [1]. It is estimated that if the farm lands available in the country are properly utilized, India could be a leading producer of biodiesel in the world [2-3]. Therefore, the use of biodiesel as an alternative fuel would contribute to the overall

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development ofagriculture, economy and environmental sector of the nation.

In the present work, biodiesels are produced from two different sources of vegetable oils namely Nerium Oil and Eucalyptus oil. The basic criterion for the selection of the above two oils are that they are non – edible oils. Biodiesel produced from Nerium oil is known as Adelfa biodiesel and has experienced a few researches as an alternative fuel in the recent years. However, biodiesel production from Eucalyptus oil is a new area and has faced very few researches as an alternative fuel. In this investigation, Nerium and Eucalyptus biodiesels were produced and blended with petrodiesel 30% by volume [N30, E30] and the various performance, emission and combustion characteristics were analyzed and tested on a single cylinder direct injection diesel engine.

High viscosity and low volatility are the two main problems of vegetable oils which limits their use as a fuel in diesel engines. These drawbacks of vegetable oils are overcome by the process of 'Transesterification'. Transesterification process removes the fatty acid content present in the vegetable oils in the form of glycerol and thereby reduces its viscosity [4-5].

II. PREPARATION OF BIODIESEL BY TRANSESTERIFICATION

The best method for the production of biodiesels is the transesterification of vegetable oils with an alcohol. Vegetable oils are converted into biodiesels by the process of transesterification so as to overcome the properties of pure vegetable oils such as high viscosity and low volatility. The reaction is based on one mole of triglyceride (vegetable oil) reacting with three moles of methanol or ethanol to produce three moles methyl or ethyl esters (biodiesel) and one mole glycerol [10].

The transesterification of Nerium biodiesel was performed as follows; Nerium oil was first taken in a three way flask. NaOH pellets, which are used as the catalyst, are mixed with methanol in a beaker. The resultant solution was known as Methoxide solution. This Methoxide solution was then added to the Nerium oil in the three way flask and stirred well. Again this mixture was heated up to 70^{o}C with continued stirring for one hour. The solution obtained was then poured in a beaker and allowed to settle down for nearly 24 hours. The glycerol was settled down at the bottom and methyl esters (biodiesel) were formed at the top. Methyl esters of Nerium oil were separated and heated above 100^{o}C to remove any untreated methanol. The cleaned biodiesel obtained was the methyl esters of Nerium oil, simply called as Nerium biodiesel.

Ethyl transesterification was adopted in the production of Eucalyptus biodiesel. i.e., Ethanol was used in the transesterification of eucalyptus. Eucalyptus biodiesel was produced using 500 ml of pure eucalyptus oil and 100ml of ethanol with 5g of NaOH as catalyst. Eucalyptus oil was taken in a three way flask. The pellets of NaOH catalyst were dissolved in ethanol in a beaker. The resulting solution was called Ethoxide solution. This solution was then added to the Eucalyptus oil in the three way flask and then mixed well and is agitated thoroughly for 1 hour at 60^{0}C. During the stirring process, the color of the mixture changed from clear yellow to reddish yellow. The solution obtained was then poured in a flask and allowed to settle down for nearly 24 hours. Then glycerol was settled as a dark brown colored liquid at the bottom of the flask and ethyl esters (coarse biodiesel) were formed at the top. Then the glycerol was removed and the coarse biodiesel was heated above 100^{0}C to remove any untreated ethanol. The NaOH impurities are removed by washing with water. The cleaned biodiesel thus obtained was the ethyl ester of Eucalyptus oil, simply known as Eucalyptus biodiesel.

The properties of the two biodiesels used for this experimental investigation is shown in the table 1. The various physico–chemical properties of Nerium and Eucalyptus biodiesel show its suitability for use in a diesel engine.

Table 1. Properties of the tested fuels

Property	Petrodiesel	Eucalyptus biodiesel	Nerium biodiesel
Calorific Value (MJ/Kg)	43.2	42.5	42
Specific gravity (15^{0} C)	830	850	890
Viscosity (40^{0} C) cSt	1.57	1.85	3.7
Flash point (^{0}C)	56	45	70
Cetane No.	50	48 - 50	45

III. EXPERIMENTAL SETUP

A Kirloskar AV1 engine, naturally aspirated, single cylinder direct injection diesel engine with a maximum power output of 3.7KW was used for the experimental investigation. The layout of the experimental setup is shown in figure 1 and the detailed engine specifications are shown in Table 2.

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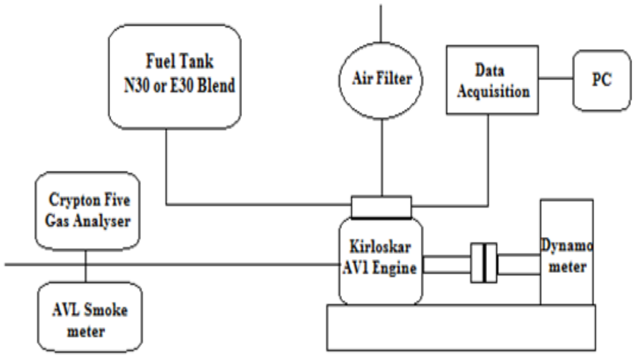

Figure 1. Schematic Representation of Engine Setup

The engine was coupled to a rheostat load bank with electrical loading. A DC generator with electrical load bank was used for loading purposes. The rheostat connected in series to the circuit controls the load on the engine by controlling the voltage. An Orifice meter attached to the inlet manifold was used to measure the flow rate of air and a Coriolis flow meter was used to measure the fuel flow to the engine. Thermocouple sensors are used to measure the exhaust gas temperature. The cylinder pressure was measured by means of the pressure transducer located on the cylinder head of the engine. A precision crank angle encoder was provided with the main shaft of the engine. Carbon monoxide, Unburned Hydrocarbons and Nitrogen oxide emissions in the engine exhaust were measured by using a Crypton Five gas analyzer and the smoke density was measured using the AVL smoke meter.

Table 2. Engine Specifications

Particulars	Specifications
Make	Kirloskar Oil Engines
Model	AV 1
Type	Single Cylinder, Four Stroke, Direct Injection
Bore	80 mm
Stroke	110 mm
Cubic Capacity	0.553 litres
Compression Ratio	16.5 : 1
Rated Power	3.7 KW (5 Hp)
Sfc at rated power	245 g/KWhr at 1500 rpm
Injection Pressure	180 bar
Injection Timing	23^0 bTDC

IV. EXPERIMENTAL PROCEDURE

Before taking all the readings, the engine was allowed to warm up for few minutes. The engine was started with Diesel until it is in warmed up condition and then the performance, emission and combustion characteristics of the engine under various loading conditions were noted. Then the fuel was switched to Nerium biodiesel blends and the characteristics of the engine were noted for various loading conditions of the engine. The same procedure was repeated for Eucalyptus biodiesel blends. The engine was tested under B30 blend [30% biodiesel + 70% petrodiesel] and the values were obtained. Before stopping the engine, the fuel was again switched to pure diesel so as to avoid future startup problems. Different performance, emission and combustion characteristics were obtained and analyzed in this manner.

V. RESULTS AND DISCUSSIONS

The various combustion, performance and emission parameters of the direct injection compression ignition engine with biodiesel blends as the fuel have been discussed in this section.

A) Combustion parameters

Pressure – Crank angle diagram

The different pressure profiles at various power outputs of the engine for diesel fuel, Nerium biodiesel blend (N30) and eucalyptus biodiesel blend (E30) is shown in the figure. The figure 2(a) and (b) shows that the peak cylinder pressure is higher for eucalyptus biodiesel (E30 blend) at all tested loads. The combustion characteristics are determined based on the variation of cylinder pressure with respect to the crank angle. For an engine power output of 0.9 kW, the peak pressures are found to be 70 bar, 72.6 bar and 74 bar, respectively, for diesel, N30 and E30. Similarly, for an engine power output of 3.6 KW, the peak cylinder pressures are found to be 86 bar, 87.4 bar and 90 bar respectively for pure diesel, N30 and E30 fuel blends respectively. As the biodiesel content in the fuel blend increases, the peak cylinder pressure also increases. The better combustion of biodiesel at the premixed combustion period is responsible for this phenomenon. The same trend can be observed at other engine loads also. The lowest peak pressure corresponds to pure diesel fuel, at all engine loads.

B)Performance parameters

Specific Fuel Consumption

The SFC of an engine is defined as the ratio of the total fuel consumption to the brake power output of the engine. The figure 3 shows the variation of SFC with respect to the power output of the engine at a

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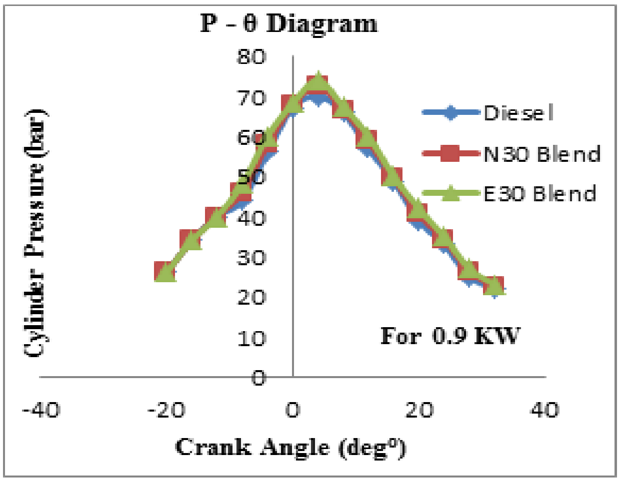
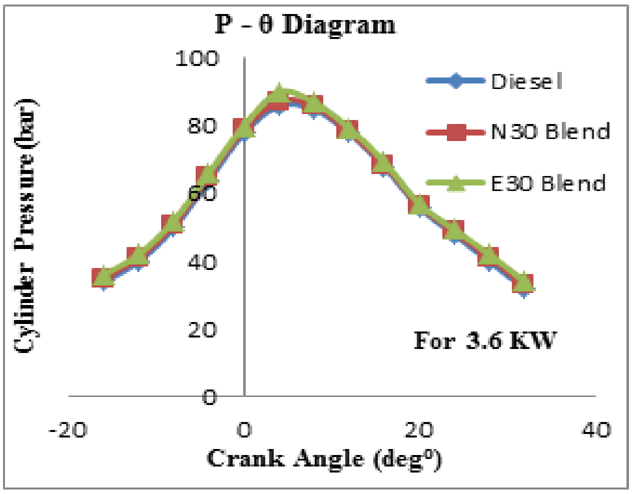
constantspeed of 1500 rpm for diesel fuel, N30 fuel blend and E30 blend.



(a)



(b)

Figure 2(a), (b). Cylinder pressure profiles for various power outputs

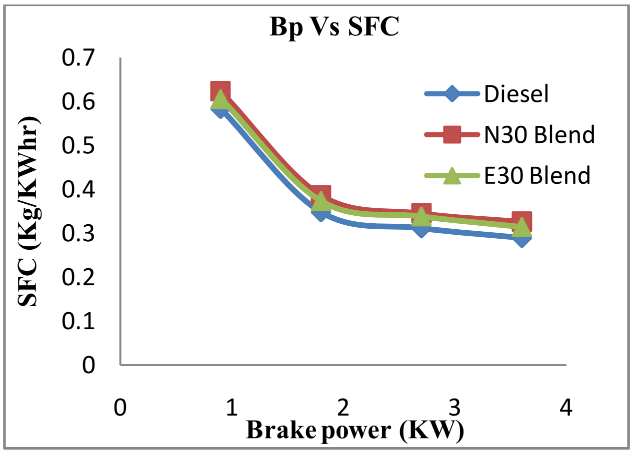


Figure 3. Variation of SFC with power output

The various factors like the fuel specific gravity, viscosity, calorific value etc. influences the SFC of a diesel engine. When the biodiesel content present in the fuel blend increases, the calorific value of the blend decreases and so as to maintain the same speed and power output of the engine, the flow rate of the fuel blends increases. Therefore, with increase in biodiesel quantity in the fuel blend, the SFC of the engine increases. However, when the power output of the engine increases, the SFC decreases for all the tested fuel blends. At lower power outputs (0.9KW), the SFC of pure diesel and the lower blends is found to be much lower than that of N30 and E30.

Brake Thermal Efficiency

The Brake Thermal Efficiency (BTE) of an engine represents how efficiently the input fuel energy is converted into thermal energy. The BTE is inversely proportional to the specific fuel consumption (SFC) of the fuel. The relationship between BTE and brake power for diesel, N30 blend and E30 fuel blend is shown in figure 4. The overall characteristics of BTE follow a general trend for both diesel and biodiesel blends. It can be seen that, for all the cases, the BTE increases with an increase in the load on the engine. As expected, the BTE of diesel fuel is found to be higher than biodiesel blends at almost all loads. The maximum BTE of the engine using diesel was observed to be around 28.6 %. There was a marginal decrease in the BTE of nearly 6.9% while using E30 blend as the fuel. The BTE of the engine for N30 fuel blend was found to be further lower than that of both diesel and E30 blends. The reason for the decrease in BTE for biodiesel blends when compared to diesel may be the lower calorific value, higher viscosity and higher density of the biodiesels when compared to diesel.

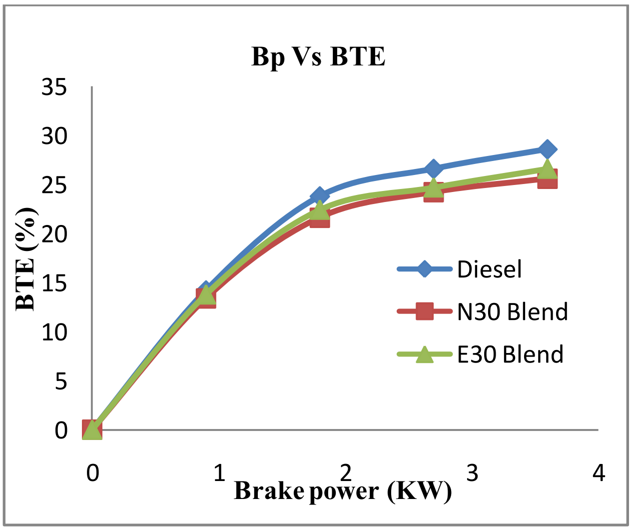


Figure 4. Variation of BTE with power output

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C) Emission parameters

Hydrocarbon emission

Unburned Hydrocarbons (HC) is an important parameter in finding the emission characteristics of a diesel engine. Unburned hydrocarbon emission occurs when the fuel molecules in the engine fails to burn completely. The figure 5 compares the HC emission for diesel fuel, N30 and E30 fuel blends. It can be clearly seen that the HC emissions of biodiesel blends is much lower than that of diesel. HC emissions are found to be significantly reduced when the biodiesel content in the fuel blend is increased. This is because when the biodiesel content is increased, more Oxygen content will be available for combustion and as a result, the quality of combustion process increases, thereby leading to effective and more complete combustion and reduced HC emissions. The HC emission for Eucalyptus biodiesel (E30) is found to be nearly 27% lower than diesel fuel at higher power outputs [3.6 KW]. Similarly, the use of Nerium blend (N30) also recorded a reduced HC emission of nearly 16% lower than that of diesel.

Carbon monoxide emission

Carbon monoxide (CO) is another important emission occurring in an engine due to incomplete combustion of the fuel, mainly due to lack of oxygen atoms for effective combustion. CO emission also takes place if enough time is not available for effective combustion to occur. The variation in CO emission for diesel, N30 and E30 blends are shown in figure 6. It can be observed that CO emissions of biodiesel blends are found to be significantly lower than that of diesel fuel. The reason is that more effective and complete combustion takes place due to the increased number of oxygen atoms in the biodiesel. Since sufficient oxygen content is available for combustion, most of the CO is oxidized and converted to CO_2.

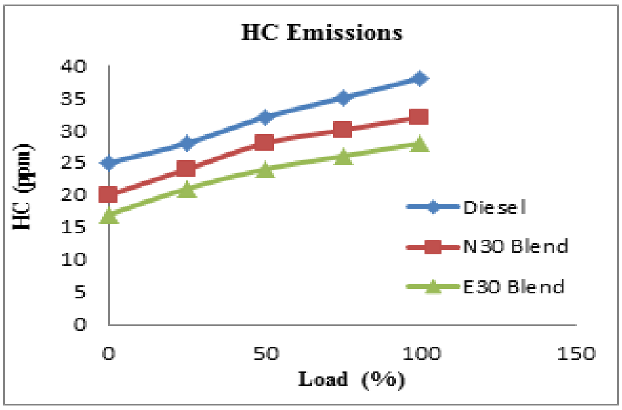

Figure 5. HC emissions at various engine loads

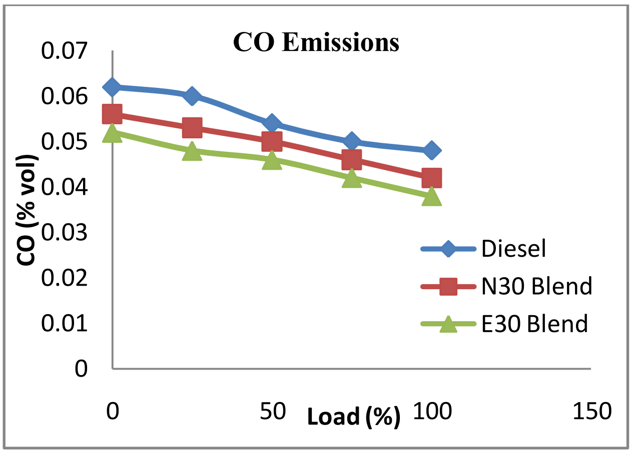

Figure 6. CO emissions at various engine loads

Oxides of Nitrogen emission

The variation of NOx emissions for diesel, biodiesel and the various fuel blends is shown in the figure 7. In general, the NOx emission from an engine increases with increase in power output of the engine. There are three main factors on which the NOx emissions of a diesel engine depends – oxygen concentration, maximum combustion temperature and the residence time. Since the combustion temperature is higher and the oxygen concentration is greater for biodiesel, it can be seen that at all engine loads, the NOx emissions of biodiesel blends (N30 and E30) are higher than that of diesel. For all the tested fuels, the maximum NOx emissions were observed at a power output of 3.60KW. Previous researches in this field suggest that an oxygenated additive named 'Di Ethyl Ether [DEE]' can be added to the diesel or biodiesel fuel blends to reduce the NOx emissions. NOx emissions can also be effectively reduced by adjusting the injection timing and by adopting Exhaust Gas Recirculation [EGR] [6].

Smoke Intensity

Smoke is produced in an engine exhaust mainly during acceleration, overloading or even during full load operation of the engine. Under these conditions more fuel is burned in the engine and the prevailing temperatures inside the combustion chamber become very high. Thermal cracking of molecules due to the high temperature, leads to soot formation. Figure 8 indicates the smoke intensity of the tested fuels with respect to various loads on the engine. It can be seen that E30 fuel blend resulted in an increase in smoke intensity when compared to diesel while the use of N30 fuel blend resulted in a slight decrease in the smoke especially at high engine loads. The increase in smoke intensity of

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E30fuel can be attributed to the higher viscosity of the fuel blend resulting in a poor atomization.

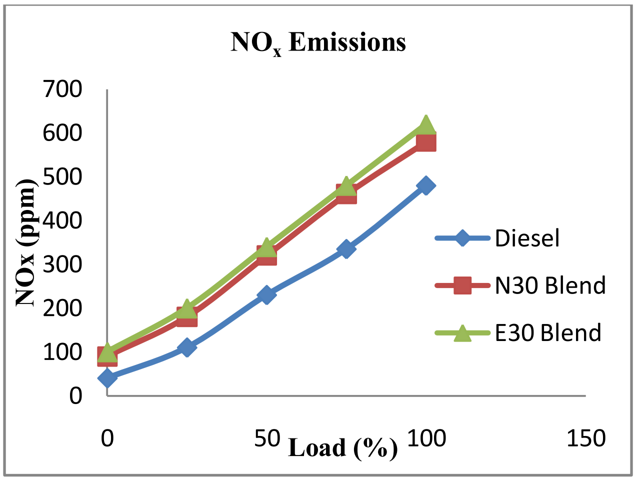

Figure 7. NOx emissions at various engine loads

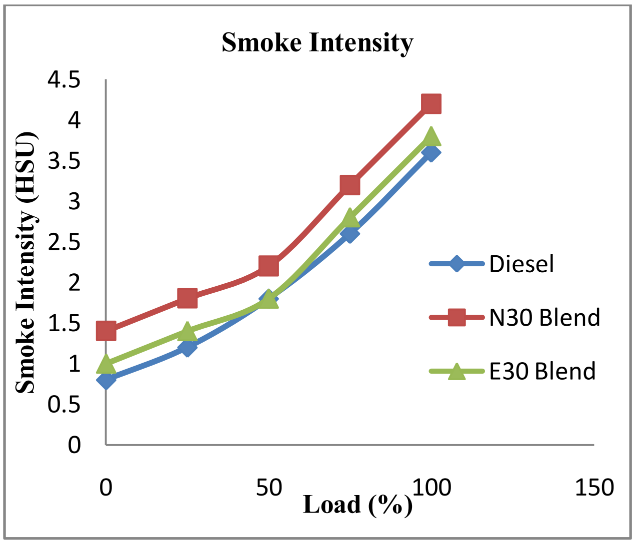

Figure 8. Smoke Intensity at various engine loads

VI. CONCLUSION

This research aimed at determining the suitability of Nerium biodiesel and Eucalyptus biodiesel as an alternative fuel for diesel engines. In this work, the effect of blending Nerium and Eucalyptus biodiesels with diesel on the performance, emission and combustion characteristics of a direct injection diesel engine were tested. In order to overcome the problems created by the high viscosity and lower heating value of the pure oils, transesterification process was employed. The similarities of various physico – chemical properties of Nerium and eucalyptus biodiesel with diesel show its suitability for use as an alternative fuel. Following are the main conclusions drawn from this work.

- The combustion characteristics of Nerium and Eucalyptus biodiesel blends are found to be similar to that of diesel fuel. As the biodiesel content in the blend increases, the peak cylinder pressure increases. The combustion starts earlier due to the reduction in ignition delay and the combustion duration increases when the biodiesel content in the blend increases.
- The SFC increases with increase of biodiesel content in the blend due to decrease in heating value of the fuel blend.
- The BTE of biodiesel blends are found to be lower than that of diesel at all loads and power outputs of the engine.
- A significant reduction in the HC and CO emissions was noted whereas NO_x emissions and Smoke intensity recorded an increase while using biodiesel fuel blend as the fuel (B30).

In general, Nerium and Eucalyptus biodiesels are found to be very good alternatives to be used in direct injection diesel engines. NOx emissions could further be reduced by adding Di Ethyl Ether [DEE] additives.

REFERENCES

[1] S.P Singh, D. Singh, Biodiesel production through the use of different sources and characterization of oils and their esters as the substitute of diesel: A review, *Renewable and Sustainable Energy Reviews*, 14 (2010) 200–216.

[2] S. Prabhakar, K. Annamalai, Biodiesels: An alternative renewable energy for the next century, *Journal of Scientific and Industrial Research*, 70 (2011) 875-878.

[3] Refaat A. A., Attia N. K., Sibak H. A., El Sheltawy S. T. and El Diwani G. I., Production optimization and quality assessment of biodiesel from waste vegetable oil, *International Journal of Environmental Science and Technology*, 1 (2008), 75-82.

[4] Pradeep Kumar A.R, K. Annamalai, Premkartikkumar. SR, Experimental Investigation On Emission Parameters Of Transesterified Adelfa Oil (Methyl Ester Of Nerium Oil), *International Journal of ChemTech Research*, Vol.5, No.4 (2013), 1664-1670.

[5] M. Prabahar, R. Murali Manohar, S. Sendilvelan, Performance and emissions characteristics of a diesel engine with various injection pressures using Biodiesel, *Indian Journal of Science and Technology*, Vol. 5 No. 6 (2012), 2880-2884.

[6] Lyes Tarabet, Khaled Loubar, Mohand Said Lounici, Samir Hanchi, Mohand Tazerout, Eucalyptus Biodiesel as an Alternative to Diesel Fuel: Preparation and Tests on DI

ISSN:2278 – 7798

Diesel Engine, *Journal of Biomedicine and Biotechnology*, (2012), Article ID 235485.

[7] Jinlin Xue, Tony E. Grift, Alan C. Hansen, Effect of Biodiesel on Engine performance & Emissions‖, *Renewable & Sustainable Energy Reviews*, (2011), 1098–1116.

[8] S. Prabhakar and K. Annamalai, Non-edible vegetable oils: A critical evaluation of oil extraction, fatty acid compositions, biodiesel production, characteristics, engine performance and emissions production, *Biomass and Bio Energy*, *ARPN Journal of Engineering and Applied Sciences*, Vol. 24 (2010).

[9] Balusamy, K. Marappan, Comparative study of Performance and Emission Characteristics of a Diesel Engine Fueled by Emulsified Biodiesel/Diethyl Ether Blended Biodiesel, *International Conference on Emerging trends in Engineering and Technology*, Vol. 35 (2010), 678–685.

[10] Ayhan Demirbas, Progress and recent trends in biodiesel fuels‖, *Energy Conversion and Management 50* (2009), 14–34.

[11] Pradeep Kumar. A. R, Annamalai. K, Premkartikkumar. R, Influence of Injection Timing on Emission Parameters Of Adelfa Biodiesel (Nerium Oil Methyl Ester – Nome) Fuelled DI CI Engine, *International Journal Of Innovative Technology And Research*, Volume No. 1, Issue No. 1 (2013), 099-102.

[12]. Alireza Shirneshan, Morteza Almassi, Barat Ghobadian, Ali Mohammad Borghei Gholam Hassan Najaf, Effects of Biodiesel and Engine Load on Some Emission Characteristics of A Direct Injection Diesel Engine, *Current World Environment*, Vol. 7(2) (2012), 207-212.

[13]. Ashish Jawalkar, Kalyan Mahantesh, Performance and Emission Characteristics of Mahua and Linseed Biodiesel Operated at Varying Injection Pressures on CI Engine, *International Journal of Modern Engineering Research (IJMER)*, Vol.2, Issue.3 (2012), 1142-1149.

[14]Amar Pandhare and Atul Padalkar, Investigations on Performance and Emission Characteristics of Diesel Engine with Biodiesel (Jatropha Oil) and Its Blends, *Journal of Renewable Energy*, Volume 2013, Article ID 163829, 11 pages.

[15] Joshi M Mishra, Jha B, Jatropha; an alternate substitute to Fossil fuel, *Journal of Applied Energy*, Vol. 10 (2011), 512 – 520.

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