Experimental Investigation of Using Eucalyptus Oil and Diesel Fuel Blends in Kirloskar TV1 Direct Injection Diesel Engine

K. Anandavelu[1,*], N. Alagumurthi[2], and C.G. Saravannan[3]

[1]Department of Mechanical Engineering, MRK Institute of Technology, India
[2]Department of Mechanical Engineering, Pondicherry Engineering College, Pondicherry
[3]Department of Mechanical Engineering, Annamalai University, Chidambaram, India
*Corressponding author: anandavel01@ yahoo.com, Mobile: 9443397738 Fax: 04144-260270

Abstract: The aim of this study is to partial replacement of diesel fuel with eucalyptus oil and experimentally determines their effects on the engine performance, combustion and exhaust emissions such as brake specific energy consumption (BSEC), brake thermal efficiency (BTE), heat release rate, cylinder pressure and emissions such as smoke density, carbonmonoxide (CO), unburned hydrocarbon (UBHC) and oxides of nitrogen (NO_x). For this purpose, five different blends containing 10, 20, 30, 40 & 50% of eucalyptus oil with diesel fuel were prepared in volume basis and tested in naturally aspirated direct injection kirloskar TV1 diesel engine with constant speed of 1500 rpm at varying load conditions. Results indicated that the brake thermal efficiency is increased about 6.2% for 60:40 DF/EOF blend (blend has 60% of diesel and 40% of eucalyptus oil) as compared to standard diesel fuel (DF) operations. Further the results showed that at full load condition, 60:40 DF/ EOF blend have 16.7%, 25% and 15.15% reduction of smoke, CO and UBHC respectively as compared to standard DF. NO_x emission is slightly reduced about 0.97% for 60:40 DF/ EOF blend as compared to DF. The heat release rate and cylinder pressures are increased positively.

Keywords: Biofuel, Eucalyptus, Performance, Emission, Diesel engine.

1. Introduction

The most important element which affects the world economy is the sustainability of petroleum resources. The world energy demand is increases rapidly because of increase in the use of petroleum based fuels and also due to the limited resources, instabilities of petroleum based fuel supplier countries. Nowadays, many countries are replacing their conventional energy sources with renewable energy. With the increase of environment constraints and the prices of the oil leads to search of alternative for the existing petroleum based fuels. The alternative fuels have to be not only sustainable, but also friendly in respect to environment and techno – economically competitive. Biofuel are alternative one which is new and renewable fuel will answer the energy issues faced by the countries. This new potential sources of energy can help to reduce the dependence on petroleum based fuels. Biofuels are normally produced from edible and non-edible crops such as cottonseed, palm nut, groundnut, jatropha curcas, animal fats, algae etc. [1-2]. The usage of the biofuels leads to reduce the import of petroleum based fuels and it will create jobs for the rural areas where agriculture is the main activity. Biofuels are used directly in internal combustion engines (or) some fuels required modifications to bring the relevant properties closer to petroleum based fuels.

Compression ignition (C.I.) engines are the most fuel-efficient engines ever developed for transportation purposes due, largely to their relatively high compression ratio and lack of throttling losses. C.I. engines have lower emissions of carbon monoxide and unburned hydrocarbon as compared with gasoline engines [3-4]. Dr. Rudolf Diesel first developed the diesel engine in 1895 and run with the variety of oils including vegetable oil. He said "the diesel engine could be run with vegetable oils as engine fuels may seen insignificant today, however these oils become in the course of time as important as petroleum and coal for production at present" [5]. In 1970's the petroleum crisis came out and vegetable oil - based alternative fuels became more attractive because of its environmental benefits and better quality exhaust emission [6].The cost of vegetable oils is the main reasons which makes it handicap to commercialization of the product [7]. The vegetable oils are as 10% lesser calorific value than the diesel fuel. The main drawback (or) problems of using the vegetable oils is its chemical properties, it has high viscosity and low volatility as compared to petroleum based fuels [8]. Due to these properties of vegetable oil, it leads to severe engine deposits, injector choking and piston ring sticking [9]. In order to overcome these problems, the vegetable oil can be used in four ways such as (a) direct use and blending, (b) micro emulsion, (c) Pyrolysis and (d) tranesterification [10]. In this study, the direct use and blending method is adopted. Biomass derived Eucalyptus oil is chosen and directly blending with the diesel fuel without any modification to the oil. Eucalyptus oil is extracted from the leaves of the eucalyptus tree. Eucalyptus oil has a clear, sharp, fresh and very distinctive smell. And it is pale yellow in color and watery in viscosity. Eucalyptus oil production is perennial and not seasonal, as the eucalyptus leaves were available abundantly throughout the year. From the results, Poola et al, 1994 it is noted that Orange oil and Eucalyptus oil can be the potential candidate for the internal combustion engines [11].

2. Experimental

2.1 Property Analysis

The physico – chemical properties of eucalyptus oil with those of diesel fuel is given in the Table 1. The density, viscosity, boiling point and flash point of eucalyptus oil are comparable with that of diesel fuel. Table 2 shows the variation of calorific value, viscosity and density of eucalyptus and diesel fuel blends.

Table 1. Physico–chemical properties of eucalyptus oil with diesel fuel.

Properties	Eucalyptus	Diesel	Indian requirements as per IS 1460-1974
Density @ 40°C in gm/cc	0.8955	0.827	Nil
Kinematic viscosity @ 40°C in CST	1.68	-	2.0 – 7.5
Conrad son carbon residue	1.9	-	0.20
Flash point in °C	54	74	38
Pour point in °C	-5	-23	6 max.
Heating value in kJ/kg	43270	42700	-
Calculated cetane number	-	40-55	42

Table 2. Variation of viscosity, calorific value and density of EOF blends.

Sl. No.	Fuels	Fuels blended (% volume)	Viscosity (cst)	Calorific value (kJ/kg)	Density
1.	DF	100% diesel fuel	3	42700	0.827
2.	90:10 DF/EOF	90% diesel fuel+10% Eucalyptus oil fuel	2.9	42757	0.8338
3.	80:20 DF/EOF	80% diesel fuel+20%Eucalyptus oil fuel	2.8	42814	0.8407
4.	70:30 DF/EOF	70% diesel fuel+30% Eucalyptus oil fuel	2.7	42871	0.8475
5.	60:40 DF/EOF	60% diesel fuel+40% Eucalyptus oil fuel	2.6	42928	0.8544
6.	50:50 DF/EOF	50% diesel fuel+50% Eucalyptus oil fuel	2.5	42985	0.8613

2.2 Experimental Setup

A 5.2 KW four stroke single cylinder, direct injection, water cooled, constant speed (1500 rpm), vertical cylinder direct injection Kirloskar TV-1 diesel engine was used in the test. The compression ratio, injection pressure and timing of the engine were 17.5:1, 220 bar and 23 bTDC and the experimental set up is shown in Figure 1. The AVL make transducer with the sensitivity 16:11 pc/bar water cooled piezo-electric pressure transducer inserted into the cylinder head which is used to measure the combustion chamber pressure. A personal computer (PC) interfaced with an AVL 619 indimeter hardware and medium – software version 2.2 data acquisition system to collect combustion parameter data such as heat release rate, in cylinder pressure and cyclic variations. Engine speed was measured by inbuilt magnetic pick-up sensor connected to a frequency meter. An AVL 444 Di gas analyzer was used to measure the oxides of Nitrogen (NO_x), Carbon dioxide (CO_2), Carbon monoxide (CO) and unburned hydrocarbon (UBHC) emissions. The smoke intensity was measured by an AVL 413 smoke meter. The exhaust gas temperature was measured with k-type thermocouple. The engine was run for 30 min with diesel fuel to attain a normal working temperature. In first phase the test was conducted with diesel fuel (DF) and the results were obtained. In second phase of work the tests were repeated under the same conditions with different blends of eucalyptus oil and diesel fuel. The engine was maintained at constant speed and all the measurement were repeated at least three times. Finally the average value of three readings was taken for the calculation.

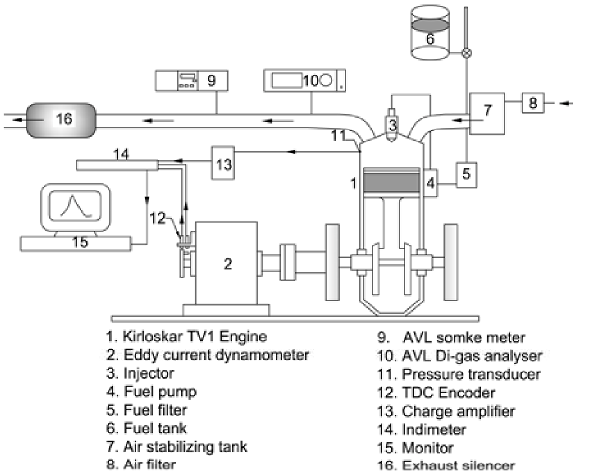

Figure 1. Experimental setup.

2.3 Error Analysis

The Errors and uncertainties in the experiments can arise normally from selection of the instruments, condition, calibration, environment, observation, reading and test planning. The uncertainty analysis is needed to show the accuracy of the experiments. The various parameters like total fuel consumption, brake power; specific fuel consumption and brake thermal efficiency were calculated using the percentage uncertainties of various instruments.

Total percentage uncertainty of this experiment is

= Square root of [(Uncertainty of TFC)^2 + (Uncertainty of brake power)^2 + (Uncertainty of specific fuel consumption)^2 + (Uncertainty of brake thermal efficiency)^2 + (Uncertainty of HC)^2 + (Uncertainty of NO_x)^2 + (Uncertainty of EGT indicator)^2 + (Uncertainty of hartidge smoke meter)^2 + (Uncertainty of pressure pickup)^2]

= Square root of [$(1)^2 + (0.2)^2 + (1)^2 + (1)^2 + (1.03)^2 + (0.014)^2 + (0.15)^2 + (1.0)^2 + (0.1)^2$]

= 2.26 %.

Using the above calculation procedure the total uncertainty of the whole experiment is obtained and it is $\pm$ 2.26%.

3. Results and Discussion

3.1 Performance

3.1.1 Brake specific energy consumption

The variation in brake specific energy consumption (BSEC) with test fuels against the brake power is shown in Figure 2. The BSEC measures the amount of energy given as input to develop one kilowatt power [13]. The BSEC is an important parameter rather than brake specific fuel consumption because it takes care of both mass flow rate and calorific value of the fuel [14]. In the using of blends 90:10 DF/EOF, 80:20 DF/EOF and 70:30 DF/EOF, the BSEC was 4.03–6.2% lower than standard DF at full load condition. It is found that the BSEC increases for the higher proportions of eucalyptus oil and diesel fuel blends as compared to the standard DF in the entire load range. This is happened due to the combined effect of heating value and higher density of EOF blend, so lager amount of EOF is supplied to the engine to maintain constant brake power. Agarwal and Rajamanoharan have reported that higher density of fuel leads to more fuel flow rate for the same displacement of plunger in the fuel injection pump, thereby increasing BSEC [12].

3.1.2 Brake thermal efficiency (BTE)

The variation in the BTE of the engine with EOF blends as reference to standard diesel fuel (DF) is shown in Figure 3. In the test operations with EOF blends, the engine yields relatively high BTE values up to 60:40 DF/EOF blends. There is very slight decrease in the BTE with the use of 50:50 DF/EOF as compared to standard DF. The improvement in BTE is more significant at higher brake outputs. At full load condition the blend 90:10 DF/EOF, 80:20 DF/EOF, 70:30 DF/EOF and 60:40 DF/EOF results higher BTE about 3.14-4.04% as compared to standard DF. This is because of better vaporization and mixture preparation of eucalyptus oil resulting in rapid heat release rate [15].

3.2 Emission Parameters

3.2.1 Smoke density

Smoke which normally forms at fuel-rich zone at higher temperature and pressure [16-18].The variation in the smoke density of the engine for EOF blends and standard diesel fuel is depicted in Figure 4. At full load condition, it is about 1.27% to 16.17% reduction in smoke density recorded for the EOF blends. This is due to the complete combustion and the presence of oxygen in the eucalyptus oil. The possible reason for lower smoke formation is also due to the efficient mixing of eucalyptus oil blends with air which reduces primary smoke formation.

3.2.2 NO_x Emission

From the reports of several researches it is found that NO_x emissions are higher for biofuels [19-21]. The formation of NO_x is highly dependent on the in-cylinder temperature, oxygen concentration and residence time for the reaction to take place [22]. Figure 5 shows the variation of NO_x emission with brake power for diesel fuel and various EOF blends. It is found that about 4.12% reductions in the NO_x emission upto 70:30 DF/EOF blends. At full load condition, NO_x emission for 60:40 DF/EOF blend is almost same as that of standard DF. Due to the presence of oxygen in the EOF is the reason for increase in the NO_x emission [23].

3.2.3 Carbon Monoxide (CO) Emissions

CO emission is generally formed by the presence of oxygen during combustion is insufficient to form CO_2 [24-25]. Incomplete combustion of carbon leads to CO formation. The variation of CO emission for different EOF blends is depicted in Figure 6. At full load condition, it is found that about 12.5-25% reduction in the CO emission is recorded for EOF blends as compared to standard DF. This is because of lower viscosity of eucalyptus oil blends. Another reason for lesser CO emission is enrichment of oxygen in the EOF blends leads to complete combustion.

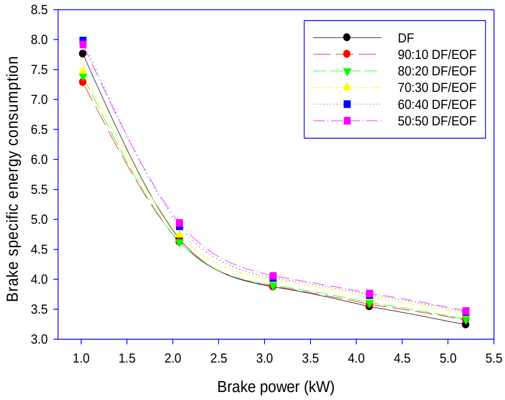

Figure 2. Variation of brake specific energy consumption with different blends of EOF.

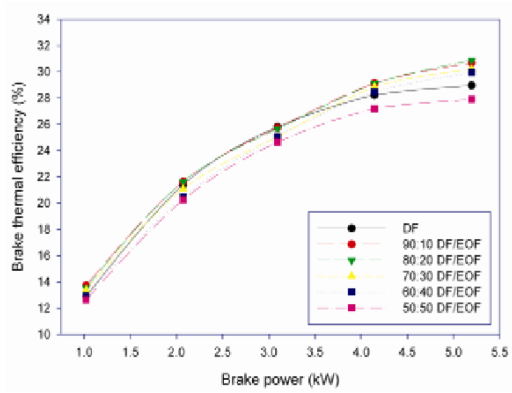

Figure 3. Variation of brake thermal efficiency with different blends of EOF.

3.2.4 Unburned Hydrocarbon (UBHC) Emissions

The influence of UBHC emissions for different EOF blends with respect to brake power are shown in Figure 7. At full load condition, the UBHC emission is higher for standard DF than EOF blends. In the using of 90:10 DF/EOF, 80:20 DF/EOF, 70:30 DF/EOF and 60:40 DF/EOF, the UBHC emissions is 3.03-15.16% lower than standard DF respectively. This reduction occurred because of the lower viscosity of the eucalyptus oil in the blends. In addition the eucalyptus molecules are polar, which cannot be absorbed easily by non-polar molecule lubrication oil layer and hence the UBHC emission production for EOF blends is lower [26-27].

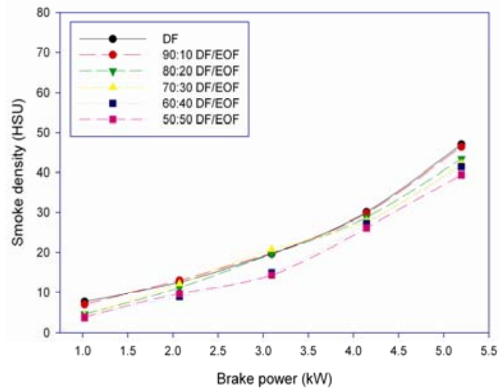

Figure 4. Variation of smoke density with different blends of EOF.

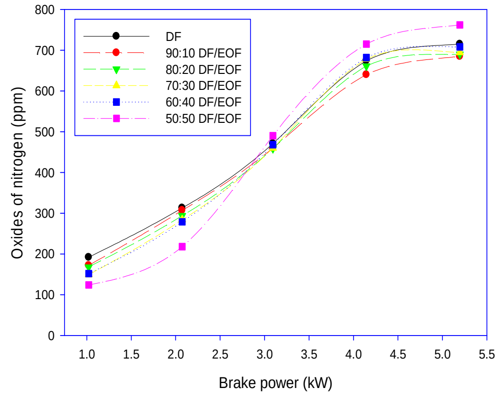

Figure 5. Variation of oxides of nitrogen with different blends of EOF.

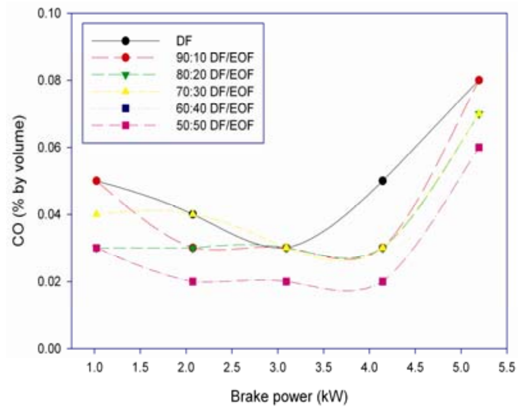

Figure 6. Variation of carbonmonoxide emission with different blends of EOF.

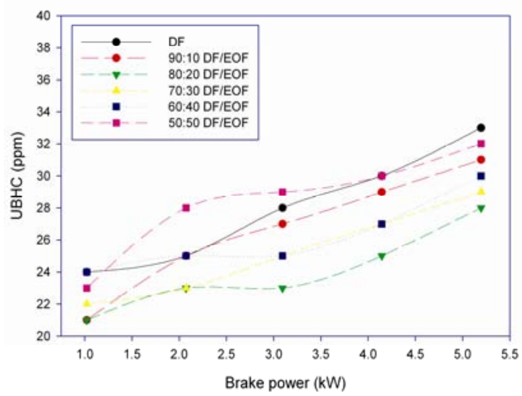

Figure 7. Variation of unburned hydrocarbon emission with different blends of EOF.

3.3 Combustion Analysis

3.3.1 Cylinder pressure

Figure 8 shows the variation of cylinder pressure with crank angle for various blends of EOF and diesel fuel. It is found that higher proportions of EOF blends produces higher cylinder pressure compared to that of DF. This trend may be attributed due to the low cetane number and viscosity of the eucalyptus oil. From the figure it is recorded that the ignition delay is higher for the EOF blends as compared to standard DF. Because of increase in ignition delay more amount of fuel is accumulated in the combustion chamber during the initial stage of combustion and thus higher cylinder pressure is occurred from no load to full load condition.

3.3.2 Heat release rate

The Heat release rate (HRR) at full load condition is shown in Figure 9 for different blends of EOF and DF at varying angles -30° to 90°. The heat release rate for the 90:10DF/EOF blend is similar to standard DF. For other EOF blends, the HRR are higher than that of standard DF. This may be attributed due to the low viscosity and cetane number of the blended fuel. Due to the low viscosity of the eucalyptus oil, it improves its volatility property thereby mixture preparation with the air is improved during the ignition delay period. As the proportion of eucalyptus oil is increased in the blend, the ignition delay period increases and hence higher heat release rate is obtained.

3.3.3 Peak cylinder pressure

Figure 10 shows the plot of peak pressure for different EOF blends and standard DF for 100 cycles against maximum brake power. The in-cylinder pressure is an indicator of the cyclic variations. In-cylinder traces for 100 cycles are taken for analysis as single cycle variations is too tedious and not in practice. Air-fuel ratio and maximum flame speed are the two most important parameters which affect the peak cylinder pressure. From the figure, it is observed that there will be both wide and narrow variations of air fuel ratio for measured cycles. The variation of cycle is normally rely on fuel droplet size, droplet penetration, droplet momentum, penetration rate, maximum penetration, degree of mixing it with air, evaporation rate and radiant heat transfer rate [18,28]. If any one of the property is varied then there is cyclic variation. For 60:40 DF/EOF and 50:50 DF/EOF blends deviate more as compared to DF. This occurred because of low cetane number of the blend, leads to longer ignition delay as the volatility of the fuel is improved. From the traces of the cyclic variations up to 70:30 DF/EOF blend confirmed that the lean-fuel combustion existed in the test. The cylinder peak pressure is slightly increased with increase of eucalyptus oil in the blends.

4. Conclusion

A single cylinder compression ignition engine is operated successfully using eucalyptus oil blend as fuel and compared the performance, emission and combustion characteristics with diesel fuel. The test results are given below:

1) EOF blends exhibits longer ignition delay and higher combustion duration compared to diesel fuel. The heat release rate is higher for higher proportions of eucalyptus oil in blend. The HRR for 60:40 DF/EOF blend is 147.865 kJ/m^{3}deg and standard DF is 99.109 kJ/m^{3}deg.

2) Brake thermal efficiency is increased up to 60:40 DF/EOF blends as compared to diesel fuel. The BTE at full load is 29.954% for 60:40 DF/EOF blend and 28.969% for standard DF.

3) Reduced viscosity and increased volatility are the benefits of these blends.

4) The Smoke, CO and UBHC emission is reduced significantly. It is found that 16.7% reduction in smoke, 25% reduction in CO and 15.16% reduction in UBHC for 60:40 DF/EOF blend at full load condition.

5) NO_x emission is 0.97% less for 60:40 DF/EOF blend as compared to DF.

6) The combustion analysis shows that performance of 60:40 DF/EOF blend is good as that of diesel fuel.

7) There is no significant carbon deposit is found in the injector nozzle tips for all the blends of EOF and DF.

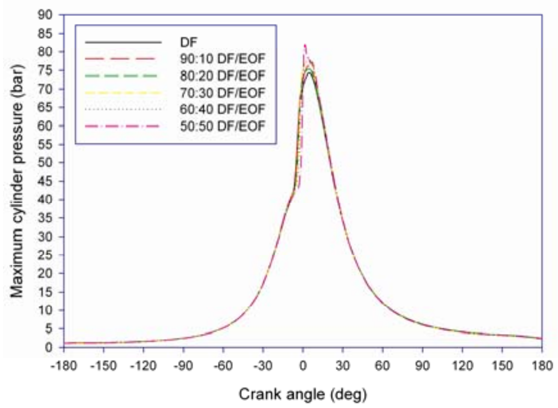

Figure 8. P-θ diagram of different blends of EOF at maximum brake power.

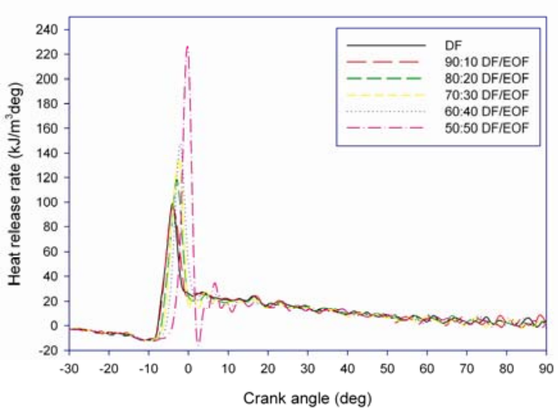

Figure 9. Heat release rate of different blends of EOF at maximum brake power.

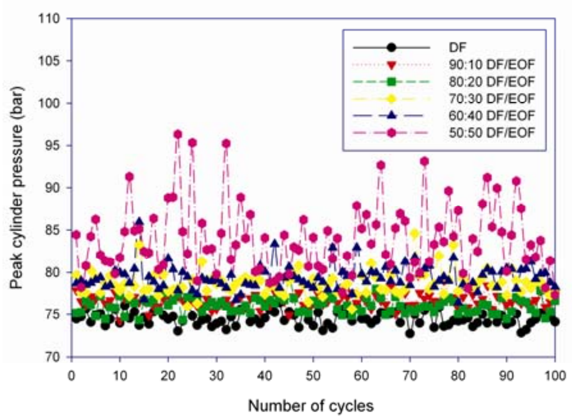

Figure 10. Peak pressures of different blends of TPOF at maximum brake power.

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