RESEARCH ARTICLE OPEN ACCESS

Experimental Investigation of Performance and Emission Characteristics of Blends of Jatropha Oil Methyl Ester and Ethanol in Light Duty Diesel Vehicle

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ABSTRACT
Diesel engine are most versatile engine which are mostly use as main prime movers in transportation , decentralized electric generation and agricultures sector. The current growth in environmental degradation and limited availability of fossil fuels has been a matter of concern throughout the world. In view of this fact it has become necessary to explore renewable alternative fuel from resources available locally, such as vegetable oils alcohol, animal fats etc. whose properties are comparable with mineral diesel and it can be used in the existing C.I. engine without any major hardware modification. The fuel should also meet the present energy needs for vast rural population, stimulating rural development and creating employment opportunities. Apart from this, it should address global concerns about net reduction of carbon emissions. The present energy scenario has motivated the world scientist to explore non petroleum, renewable and clean fuel which helps in sustainable development. The bio origin fuel can provide a feasible solution. Biodiesel is the one of the bio-origin fuels, it can derive from vegetable oil (edible or non-edible), and animal fats .However in India it is not viable to produce biodiesel using edible oil due to food security issues. Non-edible oils are more preferred oil as a feedstock to produce bio-diesel. Vegetable oils are the mixture of organic compound which contain straight chain compound to complex structure of proteins and fat which called triglycerides. Triglyceride made of one mole of glycerol and three moles of fatty acids. The vegetable oil has high viscosity than mineral diesel due to high molecular weight and complex molecular structure. Neat vegetable oil due to its poor volatility and high viscosity is not suitable for diesel engine application.
In the present investigation, 5%, 10%, 15% and 20% (v/v %) blends of Jatropha oil methyl ester (JOME)and ethanol were prepared and further compared with neat diesel and 100 %JOME in terms of performance and emission characteristics. Transesterification process is used to produce methyl ester from oil. Physico-chemical properties of blends are insignificant to that of baseline diesel fuel. From the experimental trial it has been found that Brake thermal efficiency of the engine is higher for all the blends compare to baseline diesel fuel. At full load condition BTE of 20 % blends of JOME and ethanol is 12.1% higher than that of neat diesel fuel. At 100 % loading condition neat JOME showed BTE of 23.91%.Brake Specific energy Consumption (BSEC) was highest for 100% JOME and lowest for 20 % blend. The hydrocarbon emission (HC) was highest for diesel and lowest for 100% JOME due to presence of enriched oxygen at full load condition. At part load condition CO emission for all the test fuels were insignificant but at full load condition CO emission for diesel is 0.2 % while for 20 % blend it is 0.11%. NO_x emission was found to be higher for biodiesel blends at full load condition neat diesel showed 26.5 % less emission than 20 % blend which showed highest NO_x emission.
Keywords – Jatropha ethanol blend, Transesterification, Emission

I. INTRODUCTION

Energy is a key factor for economic growth and social development. With increasing trend of industrialization, the world energy demand is growing by leaps and bounds. Since their exploration, the petroleum based fuels continue to remain as major conventional energy source. However, they are limited and also result in environment degradation. Perturbations in petroleum prices and air pollution are necessitating exploration of alternate to these conventional fuels. [1-2].

India is one of the fastest growing economies in the world and surge in industrialization has resulted in exponential energy consumption. India is rich in coal and blessed with renewable energy in the form of solar, wind, hydro and bio-energy, however, its hydrocarbon reserves represent only 0.3% of the global reserves. [3] India does not have enough oil reserves and is heavily dependent on imports. India's per capita consumption is very low at 560 kilogram of oil equivalent (KGOE) as compared to the world average of 1790 KGOE in 2009. [4]. In 2010-11, India spent 129 billion US $ towards import of crude oil. [5]. The diesel engines are extensively used in India due to low fuel consumption and high efficiencies as they operate at higher compression ratio. These engines are extensively used in transportation, commercial, domestic, electric power generation, farming, construction and in many industrial activities for the generation of power/mechanical energy. [6]. Pollutants from diesel engines include carbon monoxide (CO), carbon dioxide (CO_2), Hydro carbon (HC), nitrogen oxides (NOx), particulate matter and smoke. These emissions have hazardous effects on air, water, soil and human health as well they also cause climatic change. [6-8]. In order to protect the global environment and leasing a new life to millions of diesel engine, it has become necessary to explore alternative fuels that give engine performance at par with diesel. [9]. Renewable resources which include biomass, biofuels such as alcohols, biodiesel, ethers, and other renewable resources are widely explored [10].

Among these fuels, Biodiesel is a biofuel made from transesterification of vegetable oils which can be used in diesel engines either as an additive or extender of diesel with satisfactory performance [11-18].

Alcohol is one of the biofuel which gained the importance as a fuel for internal combustion engines since their invention. Historically, the level of interest in using alcohol as a motor fuel has followed cycles of fuel shortages and/or low feed-grain prices. The properties of methyl, ethyl, propyl and butyl alcohol are compared with octane (high quality gasoline) and hexadecane (high quality diesel fuel) and it was found these alcohols can be used for blending in fuel in internal combustion engine showing promising results. Octane and hexadecane (petroleum fuels) have higher boiling points, lower latent heats and are insoluble in water. The alcohols become more like petroleum fuels as their chemical weights increase. [19]. Due to their higher octane number and high oxygen content, use of alcohol in gasoline engine shows promising results as compared to gasoline. [20].

In context to compression ignition (CI) engine, some difficulties were faced by the researchers with the use of alcohols mainly due to their low cetane number, high latent heat of vaporization and long ignition delay. However, there is significant amount of improvement seen in exhaust emissions particularly oxides of nitrogen (NO_x). [21].

II. Jatropha as a Feedstock

Jatropha plant (Jatropha Curcas) or physic nut is a shrub or a small tree belonging to the genus Euphorbiaceous. The Jatropha plant originated from South America, but now the plant can be found worldwide everywhere in arid and semiarid tropical and sub-tropical countries. The Jatropha plant can be grown in almost all types of soils. It can even be grown in very poor soil and still produce a high average yield of seeds. However, light sandy soil is the most favorable. The Jatropha plant is a multiple use plant. Jatropha can be found from sea level to high altitudes. The tree grows to a maximum height of nearly 8m. The Jatropha fruit maturation takes 45 – 50 days. The plant starts producing yield 4 – 5 months after planting. The Jatropha trees produce a round fruit with a soft brownish skin, which have 1.5 – 3 cm in diameter and weigh 1.5 – 3 g. The seeds contain about 30-35% oil.

III. Ethanol as a C.I. Engine Fuel

Ethanol is suitably used in gasoline engines for many decades. Raw material used for producing ethanol varies from sugar in Brazil, cereals in USA, sugar beet in Europe to molasses in India. Brazil uses ethanol as 100 % fuel in about 20% of vehicles and 25% blend with gasoline in the rest of the vehicles. USA uses 10% ethanol-gasoline blends while India use 5-20% blend with gasoline.

Ethanol is one of the possible fuels for diesel replacement in compression ignition (CI) engines also. The application of ethanol as a supplementary CI engine fuel may reduce environmental pollution, decentralized the production, results reduce the transportation cost, strengthen agricultural economy, create job opportunities, reduce diesel fuel requirements, save foreign exchange and thus contribute in conserving a major commercial energy resource. Ethanol was first suggested as an automotive fuel in USA in the 1930s, but was widely used only after 1970 [22].

Despite the fact that transesterification reduces the viscosity and increases the volatility of esters derived from vegetable oils but when compared to diesel, it is still having quite higher viscosity and lower volatility. To overcome these problems, addition of some oxygenated compounds like alcohols in biodiesel fuel is found to be helpful.
So addition of ethanol will solve the above problems by giving some other advantages of reduction in emissions and balance between different crops.

A wide range of work have been carried out for evaluating the potential of biodiesel-alcohol blend for IC engine application and a comprehensive review of some of the research findings are summarized below.

Prommes et.al. studied the phase diagram of diesel-biodiesel-ethanol blends at different purities of ethanol (95%, 99.5% and 99.9%) at different temperature and also find out the physical chemical properties of selected blend and examined the emission performance in a diesel engine and compared with base diesel. Diesel and ethanol with 95% purity were Insoluble. In case of 99.5% ethanol, the inter solubility of three components was not limited. It could be mixed into a homogeneous solution at any ratio. It observed that the blend of 90% diesel,5% ethanol and 5% biodiesel had very closed fuel properties compared to diesel. Emission of the blends CO and HC reduce significantly at high engine load, where NOx increased when compare with diesel [23].

Han et. al. investigated the injection and atomization characteristics of biodiesel-ethanol blend and found that ethanol will affect the decrease of peak injection rate and shortening of the injection delay due to decrease of fuel properties such as: density and dynamic viscosity in addition to that, the ethanol improves the atomization performance of biodiesel fuel because the ethanol blended fuel have a low kinematic viscosity and surface tension, then that has more active interaction with the ambient gas, compared to biodiesel [24].

Di et. al. conducted experiment on four cylinder direct injection diesel engine using ultra low sulphar diesel blended with biodiesel and ethanol at maximum torque speed of 1800 rpm at varies load and investigate regulated and unregulated gaseous emission and found that the Brake specific HC and CO emission decrease while NO_x and NO_2 emission increases in case of diesel –biodiesel fuel. The emission of formaldehyde, 1, 3 but aldehyde, toluene, and overall BTX (benzene, toluene, xylene) in general decreases, however acetaldehyde and benzene emissions increases. In case of diesel-ethanol fuel Brake specific HC and CO emission increases significantly and NOx emission decreases at low engine load. The emission of benzene and BTX vary with engine load and ethanol contents. Similar to the biodiesel-diesel fuel the formaldehyde, 1,3 butadiene, toluene, xylene emission decreases while the acetaldehyde and NOx emission increase. It was observed that there are significant difference in the gaseous emission between the biodiesel-diesel blend and the ethanol-diesel blend. [25].

Fang et.al. Investigated the effect of ethanol on combustion and emission in premixed low temperature combustion (LTC) in a four cylinder heavy duty diesel engine. In this investigation biodiesel was used as additive to prevent the stratification of ethanol and diesel blends. The premixed low temperature combustion was achieved by the medium level of exhaust gas recirculation and the prolonged ignition delay. The lower combustion temperature, lead to higher HC and CO emissions. It was found that ethanol-diesel-biodiesel is effective in reducing NOx emissions and smoke simultaneously in premixed LTC. The EBD blends fuels were also good to extend the load range of premixed LTC [26].

Botero et. al. examined free-falling droplets of ethanol, diesel, biodiesel(castor oil) and their mixture in a high temperature combustion chamber and studied combustion characteristics including the burning rate, micro explosion ,shooting propensity. It was found that biodiesel to diesel significantly reduce the extent of shoots formation and slightly reduce the burning rate in addition to higher soot formation of methyl stearate than castor oil biodiesel. By adding of ethanol to diesel and biodiesel, micro explosion is observed, .The biodiesel/ethanol mixture exhibiting stronger propensity, leading to significantly reduce gasification time and extend of soot formation [27].

Yilmaz et.al. analyzed operation of a diesel engine on biodiesel-ethanol and biodiesel-methanol blends and compare with diesel and biodiesel. The fuel D100, B100, B85M15 and B85E15 were used on a two cylinder, 4 strokes direct injected water cool diesel engine at 5 loads between low load to full load at 3000 rpm and found that biodiesel alcohol blends as compared to diesel reduce NO emission while increasing CO and HC emission at below 70% load. It was also found that biodiesel ethanol blends is more effective than biodiesel methanol for reduction emissions and overall engine performance [28].

Lin et.al. studied the profit and policy implications of producing biodiesels-ethanol-diesel fuels blends to specification and developed a non-linear optimization model to analyze biodiesel, ethanol & diesel (BED).This model establish optimum blends to improve the system profitability given production cost, market demand and fuel price while meeting multiple property criteria such as kinematic viscosity, density, lower heating value, cloud point, cetane number. The proposed optimization model in this study integrated with pertinent mixing rules of fuel properties enables stabilizing the optimum recipes to improve the system profitability by meeting multi objectives and promoting opportunity to develop potential additives to improve blend fuel quality [29].
On the basis of the exhaustive literature review, it has been observed that biodiesel and ethanol can easily miscible. Blending of ethanol and biodiesel shall result in decrease in viscosity of biodiesel, improvement in atomization combustion quality and

the emission characteristics. So it can be used as a potential substitute of mineral diesel without any modification in the existing engine. Also, Using of biodiesel and ethanol is beneficial for the balance of carbon.

IV. EXPERIMENTAL TEST RIG

In the present investigation, the trials were conducted on a Kirloskar make, single cylinder, four stroke, vertical, constant speed, air cooled, direct injection, CAF 8 model diesel engine which is used in India in agriculture sector, for decentralized power generation and in small scale industrial applications. An electrical dynamometer coupled to the engine was used as a loading device. The load can be increased or decreased on the dynamometer and there by engine by switching on or off the load resistances. Fuel consumption was measured with the help of a digital stopwatch and burette. Detailed technical specification of the engine and dynamometer is summarized in Table 1. Engine emission parameters like HC, NO_x, CO etc. were recorded using AVL Di gas analyzer. Measurement of engine smoke was carried out using AVL smoke meter.

All the instruments used in the test rig were of standard quality and the error within the permissible range. The details of test rig instrumentation are shown in Table 2.The engine trial was conducted as specified in IS: 10,000 and engine operated at no load, 20,40, 60 and 100% load condition. The engine was started using neat diesel and allowed to attain stability for at least 30 minutes before taking observations. After engine conditions stabilized and reached to steady state, the base line data were taken. In the subsequent stages, diesel line was swapped with Jatropha biodiesel and ethanol blends and respective parameters were noted. The detailed layout of the engine test set up is shown in Fig. 1.

Table 1.Technical specification of the engine and the alternator

Engine Specification	
Make	Kirloskar oil Engine Ltd., India
Model	DAF 8
Rated Brake Power (bhp/kW)	8 / 5.9
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	95 x 110
Compression Ratio	17.5:1
Cooling System	Air Cooled (Radial Cooled)
Lubrication System	Forced Feed
Cubic Capacity	0.78 L
Starting	Hand Start with cranking handle
Dynamometer Specification	
Manufacturer	Kirloskar Electric Co. Ltd., India
Dynamometer Type	Single phase, 50 Hz, AC alternator
Rated Output	5KVA@1500rpm
Rated Voltage	230V
Rated Current	32.6 A

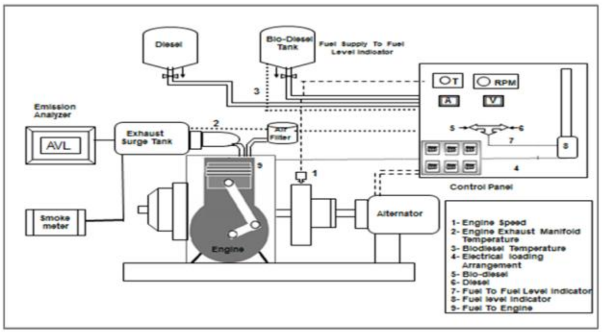

Figure 1. Schematic diagram of experimental test rig setup

Table 2. Test rig specification

S. N	Instrument Name	Measurement Range	Resolution	Measurement Technique	% uncertainty
	AVL DI GAS ANALYSER				
1	Carbon Monoxide	0 – 10 % Volume	0.01 %volume	Non dispersive infra-red sensor	0.2 %
2	Hydrocarbons	0 – 20.000 ppm Volume.	1ppm	Flame ionization detector-FID	0.2 %
3	Oxides of Nitrogen	0-5,000 ppm volume	1 ppm	Chemi-luminescence principle, electro chemical sensor	0.2 %
	AVL SMOKE METER	**0 - 100%**	**±1 % volume**	**Hatridge principle**	**0.1 %**

V. RESULTS AND DISCUSSIONS

Biodiesel could reduce significantly CO, HC and smoke emissions while increasing NO_x emissions slightly in comparison to diesel fuels. For a blend of biodiesel and diesel (20% volume), CO, HC and PM decreased by 11%, 21.1% and 10.1% respectively whereas NO_x emission increased by 2% [30]. The increase in NO_x emission is the main hurdle to implement the use of biodiesel. This problem may be overcome by adding of alcohol in biodiesel. Alcohol has the potential for reducing NO_x and PM because it has high latent heat of evaporation (840 KJ/kg) and higher oxygen contents (34.8%). It is worth relevant to mention that the use of alcohol diesel blends has some disadvantages such as reduced lubricity, viscosity, cetane number and ignitability. However, in case of biodiesel alcohol blends, these difficulties are over come as biodiesel has higher viscosity and better lubricity**.**

VI. COMPARISION OF PHYSICO CHEMICAL PROPERTY

The Physico-Chemical property i.e. density, specific gravity, kinematic viscosity, calorific value and cold filter plugging point of diesel, neat Jatropha biodiesel (JB), ethanol (E) and blend of ethanol and Jatropha biodiesel in different proportion (5%,10%,15%,20%) by volume (Table 3) was evaluated and summarized in the Table 4. It has observed that by increasing the amount of ethanol blend in biodiesel reduced the specific gravity, calorific value and kinematic viscosity. The viscosity of neat Jatropha biodiesel is more than the diesel fuel, however, with blending of ethanol it gradually decreases. The reduction of viscosity results in improved volatility, proper atomization and proper mixing of fuel with air whereas reduction in calorific value and high heat of evaporation of ethanol helps in reduction of NO_x.

Table:- 3 Test fuel blend nomenclature

S.No.	Nomenclature	%Ethanol (vol.)	% Jatropha biodiesel (vol.)	% Diesel
1.	D100	0	0	100
2.	JB100	0	100	0
3.	E5JB95	5	95	0
4.	E10JB90	10	90	0
5.	E15JB85	15	85	0
6.	E20JB80	20	80	0

Table 4 Physico-Chemical Properties of Diesel, Ethanol, and Biodiesel (J) blend oil (BJ&E)

Property	Density (kg/m³), 40°C	Sp. gravity	Viscosity (mm²/s)	Calorific Value (MJ/kg)	Cold flow property (°C)
Diesel	823.02	0.823	2.7	45.66	-5
Ethanol	805.46	0.8062	0.875	26.82	≤ -35
JB-100	880.02	0.8808	5.936	40.26	-8
JB95E5	879.01	0.8798	5.0359	38.87	-8
JB90E10	875.46	0.8762	4.4269	38.207	-6
JB85E15	873.72	0.8745	4.0385	37.866	-6
JB80E20	867.62	0.8684	3.6916	36.747	-7

VII. ENGINE PERFORMANCE AND EMISSIONS BRAKE THERMAL EFFICIENCY (BTE)

Fig.2 shows the variation of brake thermal efficiency (BTE) with respect to brake mean effective pressure (BMEP) for various test fuels. From the experimental investigation it has been found that BTE for all the test blends was higher in comparison to baseline diesel fuel and JB100. At full load condition the BTE for JB95E5, JB90E10, JB85E15, JB80E20, D100 and JB100 is 24.02%, 24.93%, 25.53%, 26.10%, 22.65% and 21.69 % respectively. This is due to the fact that biodiesel ethanol blend contains around 20-25% enriched oxygen and higher cetane number than neat diesel fuels. Due to this, better combustion and atomization takes place hence there is improvement in the break thermal efficiency in case of biodiesel ethanol blends. It can also been seen that the increase in ethanol concentration in blends increases the BTE due to reduction in viscosity and density. These results are in agreement with the result obtained by Agrawal et al [31].

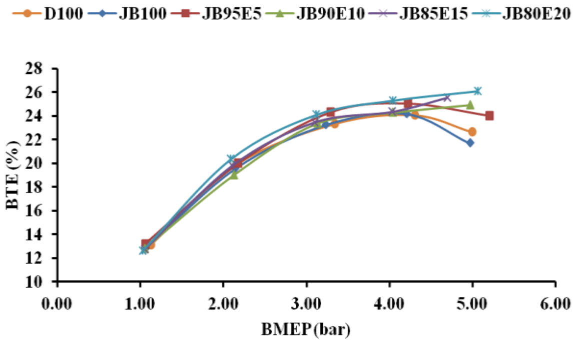

Fig.2 BTE Vs BMEP

VIII. BRAKE SPECIFIC ENERGY CONSUMPTION (BSEC)

Basic specific energy consumption is an essential and ideal parameter for comparing engine performance of the fuels having different calorific value and density.Fig.3. shows the variation of brake specific energy consumption (BSEC) with respect to brake mean effective pressure (BMEP) for various test fuels. From the experiment it has been observed that BSEC for various biodiesel-ethanol blends are lower in comparison to baseline diesel fuel and JB100. At full load condition BSEC for D100 is 15.90 MJ/KWh while for JB 100 it is 16.60MJ/KWh. BSEC for JB80E20 shows lowest BSEC value (13.79MJ/KWh) in comparison to other test fuels. The results are in similar to the result obtained by Qi et.al. [32].

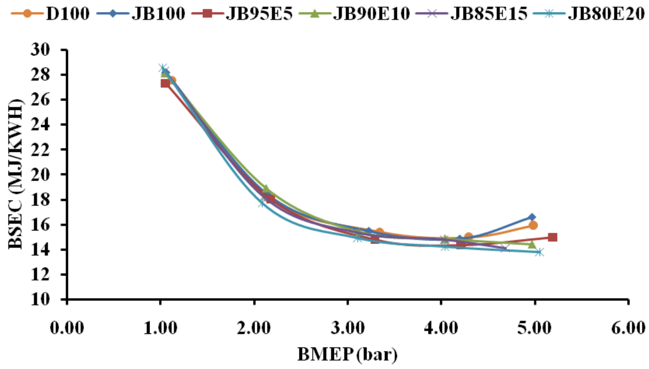

Fig:-3 BSEC Vs BMEP

IX. EXHAUST TEMPERATURE

Fig. 4 shows the variation of exhaust temperature with brake mean effective pressure of diesel fuel and biodiesel-ethanol blend. It shows that the exhaust gas temperature increased with increase in load in all cases. The highest value of exhaust gas temperature of 430ºC was observed with the JB100, whereas the corresponding value with diesel was found to be 370º C. This is due to the lower heating value of the biodiesel-ethanol blends and also due to higher viscosity.

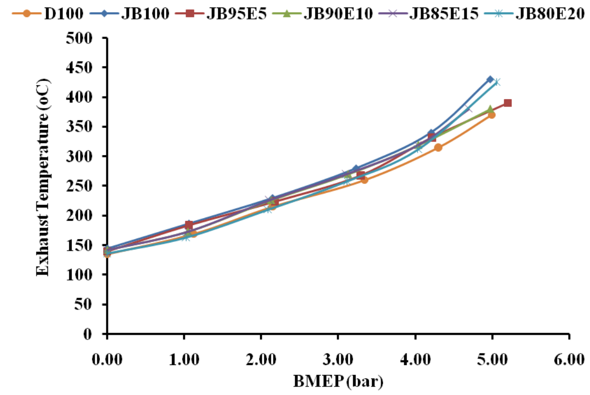

Fig:-4 Exhaust Temperature Vs BMEP

X. CO EMISSIONS

CI engine operate on lean mixture and at high stoichiometric fuel air ratio. Therefore CO emission is insignificant than Gasoline engine but they are further reduced by use of biofuels. Fig.5 shows the variation of carbon monoxide (CO) with respect to BMEP for various test fuels. CO emission for all the test fuels is found lower in comparison to baseline diesel fuel. The CO emissions are found to be increasing with increase in load since the air-fuel ratio decreases with increase in load such in internal combustion engines. The engine emits less CO using biodiesel ethanol blends as compared to that of diesel fuel under all loading conditions. With increasing ethanol percentage in biodiesel, CO emission level decreases as amount of oxygen content in biodiesel helps in complete combustion and proper oxidation. The higher cetane number of blend as compared to that of mineral diesel is also one of the reasons of better combustion. At part load condition the variation in the emission level of different blends are insignificant but at full load condition baseline diesel fuel shows highest CO emission level (0.2% v/v). However, for JB100 and JB80E20 CO emission level are 0.18% and 0.11 % respectively. The results obtained are accordance with Zhu et.al. [33].

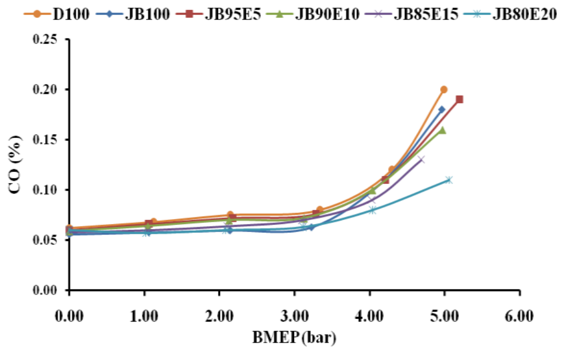

Fig:-5 CO (%) Vs BMEP

XI. UNBURNT HYDROCARBON

Unburnt Hydrocarbons (UBHC) known as organic emissions are the result of incomplete combustion of HC fuel and is a useful measure of combustion inefficiency.

Fig.6 shows the variation of UBHC emission in exhaust gas (ppm) with respect to BMEP for various test fuels. It is observed that HC emissions gradually increase with increase of engine load. Moreover, the HC emissions of the biodiesel and ethanol biodiesel blends are lower than baseline data of diesel. This may be due to the fact that low cetane rating of the test fuels deteriorates combustion process. Another reason for HC emission is quenching effect due to higher value of latent heat of evaporation. At part load condition the variation in HC emission is insignificant to that of mineral diesel but at full HC emission for D100 is 58 ppm while JB 100 shoes lowest HC emission of the level of 42 ppm. These results are in agreement with the result obtained by Agrawal et al [31].

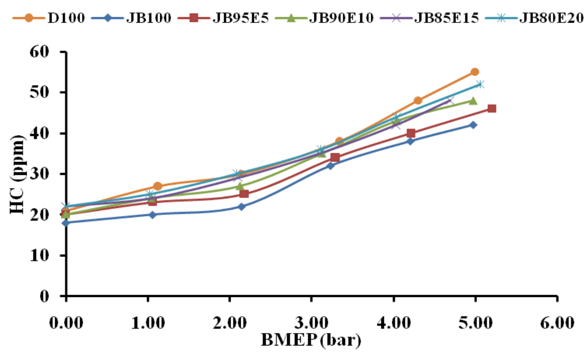

Fig:-6 HC (ppm) Vs BMEP

XII. NOx EMISSIONS

The nitric oxide (NO) and nitrogen dioxide (NO_2) are grouped together as NO_x emission, nitric oxide is the predominant oxide of nitrogen produced in side in the cylinder .At lower temperature the nitrogen is inert but at temperature higher than 1100°C nitrogen reacts with oxygen and form NOx. Fig.7 shows the variation of Nitrogen oxide (NO_x) ppm with respect to BMEP for various test fuels. It has observed that NOx emission increases with increase in engine load. Compared with diesel, NO_x emission increase when fuelled with biodiesel. The higher value of latent heat of evaporation and lower calorific value of ethanol decrease the combustion temperature. The cooling effect of the alcohol should be dominant factor on NOx emission at low load but at high engine load the cooling effect of the alcohol is less influential leading to small difference in the NOx emissions between the fuels. The results obtained are in accordance with Sahoo et. al. [34]

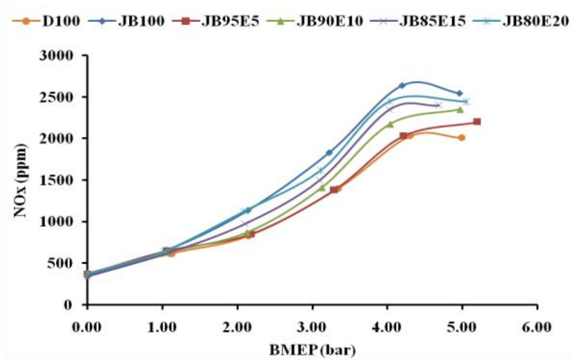

Fig:-7 NOx (ppm) Vs BMEP

XIII. SMOKE OPACITY/PM EMISSIONS

Fig.8 shows the variation of % of smoke variation with respect to BMEP for various test fuels. It has observed that smoke opacity increases with engine load because of fuel consumption gradually increase with increase of load. At high load more fuel is burnt in diffusion mode. This leads to increase in the smoke opacity. The PM decreases when the engine is fuelled with biodiesel and blend of Jatropha oil and ethanol compared with diesel. By increasing the percentage of ethanol in biodiesel blend, have resulted in reduction in smoke at all load condition. The blended fuel contains more oxygen than biodiesel which leads to improve the combustion process and reduce PM emissions. Blending biodiesel with ethanol could reduce the viscosity and density of the blend which leads to better atomization and hence lower PM emissions. But higher percentage of ethanol in blend to produce the cooling effect due to high latent heat of evaporation causing an increase in PM emissions. The results obtained are accordance with Zhu et.al. [33]

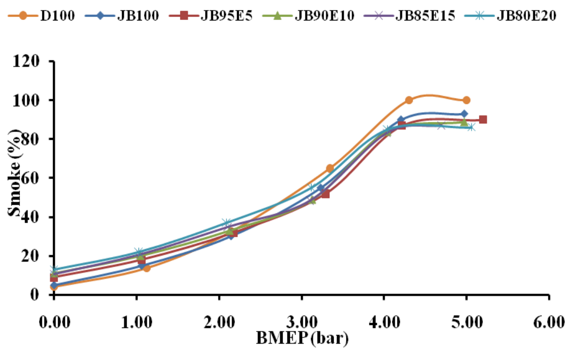

Fig:-8 Smoke Vs BMEP

XIV. CONCLUSION

In the present study, the experiments were conducted using blends of Jatropha oil methyl ester and ethanol. Subsequently performance, and emission studies were carried out and compression has been made taking neat diesel and neat Jatropha biodiesel.
Based on the experimental results, the following major conclusions have been drawn:

1. Full load brake thermal efficiency was found to increase with increase in ethanol percentage in the biodiesel as a result of higher cetane rating of biodiesel. Full load BTE of all the ethanol blended fuels were found higher than diesel baseline, However, JB80E20 exhibited an impressive 20% increase over baseline data of diesel.
2. BSEC for JB80E20 was lower followed by JB85E15, JB90E10, JB95E5, D100, and JB100. The main reason for lower BSEC for biodiesel ethanol blend is amount of oxygen present in the fuel as well as proper atomization of the test fuels.
3. Due to lower heating value of biodiesel JB100 shows highest exhaust temperature compare to baseline diesel fuel, rest of the blends are having exhaust temperature range between D100 and JB100.
4. Emission of carbon-monoxide was found to reduce with increase in the biodiesel-ethanol percentage. At part load condition the variations insignificant but after 60 % loading condition significant increase in CO emission was observed for all the test fuels. JB80E20 exhibit lowest CO emission whereas, for baseline diesel fuel CO emission was highest.
6. It was observed that HC emissions increase gradually with increase in load. HC emissions of the biodiesel-ethanol blends were lower than baseline data of diesel. This may be due to the lower self ignition temperature as well as lower cetane rating of the test fuels which leads to the quenching effect.
7. NO_x emission was highest for JB100 while for mineral diesel it was lowest. This is due to the enriched oxygen present in the biodiesel- ethanol blends. At full load condition NOx for JB 100 was 26% higher than that of neat diesel followed by JB80E20, JB85E15, JB90E10 and JB95E5.
8. Variation in smoke opacity was comparable for all the test fuels in comparison to baseline diesel fuel at lower loding condition. However, at peak load baseline diesel fuel shows highest smoke followed by JB100, JB95E5, JB90E10, JB85E15 and JB80E20.

As an outcome of the exhaustive engine trials, it may be recommended that 20% (v/v) of Jatropha biodiesel and ethanol blends can be used as a feedstock for IC engine application.

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ABBREVIATION

%	Percentage.
η_{th}	thermal efficiency
A	ampere
Bhp	Brake Horse Power
BMEP	Brake Mean Effective Pressure
BP	brake power
BSEC	Brake Specific fuel Consumption
BTE	Brake Thermal Efficiency.
CO	Carbon Monoxide
CO_2	Carbon Dioxide.
cSt	Centi Stroke
D100	Neat Diesel
h	hour
HC	Hydrocarbon
JB-100	100 % Jatropha biodiesel
JB95 E5	95% Jatropha Biodiesel+ 5% ethanol
JB90 E10	90% Jatropha Biodiesel+ 10% ethanol
JB85 E15	85% Jatropha Biodiesel+ 15% ethanol
JB80 E5	80% Jatropha Biodiesel+ 20% ethanol
kW	Kilo Watt
kWh	Kilo Watt Hour
L	Liter
mm	Millimetre
MT	Million Tonne
NOx	Nitrogen Oxides
Ppm	Parts Per Million
PM	Particulate matter
Q_{lcv}	calorific value of kilogram fuel
rpm	Revolution Per Minute

APPENDIX

Formula for calculation of Brake Thermal Efficiency and Brake Energy Fuel Consumption

Brake Thermal Efficiency (η_{th}):

$$\eta_{th} = \frac{brake\ power}{fuel\ power}$$

$$\eta_{th} = \frac{3600 \times BP}{FC \times Q_{lcv}}$$

Where:

η_{th} = thermal efficiency;

BP = brake power [kW];

FC = fuel consumption [kg/h = (fuel consumption in L/h) x (ρ in kg/L)];

Q_{lcv} = calorific value of kilogram fuel [kJ/kg];

ρ = relative density of fuel [kg/L].

Brake Fuel Energy Consumption:

$$\mathbf{BSEC} = \frac{m_f \times Q_{lcv}}{1000 \times BP} \times 3600 \text{[MJ/kWh]}$$

Where:

m_f= mass flow rate [Kg/sec];

Q_{lcv} = calorific value of kilogram fuel [kJ/kg];

BP = brake power [kW].