IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
ISO 3297:2007 Certified
Vol. 3, Issue 12, December 2016

Experimental Investigation of Single Cylinder Diesel Engine Using Biodiesel Ethanol Blended Fuels

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Abstract: Alternate fuels are promising substitute for current exhaustive uses of petrol and diesel. Biodiesel is derived from renewable resources that can be produced by a simple chemical process using edible, non-edible, waste vegetable oils and animal fats. Jatropha has cetane number near to diesel hence selected as blend in diesel. From research 20% blend of biodiesel was selected as optimum blend. Hence in this research we used Jatropha blends 10%, 25% and 30%. Experiments performed on 240PE Research engine Kirloskar Make 3.5 kW rated power. Ethanol acts as NO_x (Oxides of nitrogen) reducing medium so used blend of ethanol in diesel of 5% concentration as higher blends are not stable at room temperature (phase separation problem). Jatropha blends and ethanol blends have shown increase in Brake Specific Fuel Consumption (BSFC). Jatropha 25% blend (J25) and Ethanol 5% blend (E5) shown nearby performance values of mineral diesel hence selected as optimum blends. Jatropha blends increased NO_x emissions sufficiently by 40% (J25 blend) and ethanol blends reduced NO_x emissions by 24% (E5 blend). From optimum blend, a research blend is created using both Jatropha and Ethanol JDE (J25E5D70) and tested for performance and emissions.

Keywords: Jatropha, Ethanol, Oxides of Nitrogen (NO_x), Brake Specific Fuel Consumption (BSFC).

I. INTRODUCTION

Continuously increasing number of vehicles, the depletion of conventional automotive fuels and increasing air pollution levels from vehicles are challenges in front of the world. Researchers all over the world are trying to find an alternative to fossil fuels. Biodiesel in one of the attractive alternative to petroleum diesel. It is produced by the transesterification of a triglyceride and alcohol in presence of basic catalyst. Transesterification reaction is shown in figure 1.

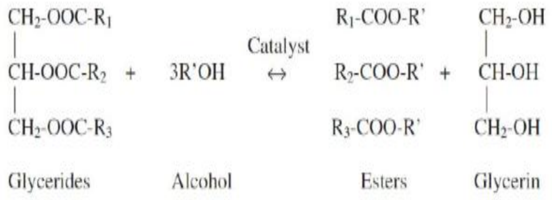

Fig. 1 Transesterification Reaction [1]

Vegetable oils, animal fats and waste oils are major sources of biodiesel. Jatropha, karanja, rapeseed, rice bran, cottonseed are sources of vegetable oils. Vegetable oils have comparable energy density, cetane number, heat of vaporization, and stoichiometric air/fuel ratio to that of mineral diesel [2].

Jatropha is well known biodiesel fuel. Jatropha biodiesel has closest viscosity values and cetane number to mineral diesel compared to other vegetable oil biodiesels. Calorific value of Jatropha oil is lower than of diesel.

Jatropha biodiesel is highly oxygenated which results in more complete combustion hence resulting in more power. Ethanol is also an alternative fuel which is renewable and can be easily obtained by bio-based resources. Ethanol is also oxygenated fuel. Ethanol is a good spark ignition engine fuel as its octane rating is good but in smaller blend concentrations it can be used as compression ignition fuel. Addition of ethanol into diesel has shown lower NO_x emissions due to temperature lowering effect of ethanol [3,4].

Ethanol Diesel blends are not stable at 10^oC due to phase separation problem. Hence ethanol cannot be blended alone with diesel. Hence an emulsifier or surfactant must be used to stop this phase separation problem. From literature there are some additives such as iso-pentane, diethyl ether which can be used as surface active reagent. Some researchers used small percentage of biodiesel as blending medium to ethanol-diesel blend preparation. Biodiesel acts as co-solvent and properties enhancer medium. It improves blend stability, cetane number and flash point [5,6].

Agarwal et al. [7] studied performance and emission characteristics of Jatropha biodiesel on direct injection CI engine. BSFC was found to increase with higher proportion of Jatropha oil in the blend. It was attributed to lower calorific value of jatropha biodiesel.

Rakopoulos, D. et al. [4] studied performance and emission characteristics of diesel ethanol blends on a six cylinder, turbocharged diesel engine. Significant reduction

DOI 10.17148/IARJSET.2016.31206

in soot was observed due to blending of ethanol. NO_x emissions were slightly lowered with ethanol blending. CO emissions were decreased with increase in blending percentage.

X. Shi et al. [8] performed emission analysis of four cylinder DI diesel engine fuelled with blends of methyl soyate-ethanol-diesel. The result showed that due to oxygenated fuels had shown effect on reducing smoke and PM emissions BE20 had shown greater ability to eliminate soot emissions and maximum reduction of PM about 48% of diesel. BE20 reduced CO emissions. Methyl soyate has higher cetane number than diesel, which result in more complete combustion, hence B20 had low THC emissions.

Hulwan et al. [5] carried out engine performance, emission and combustion analysis of three cylinder four stroke diesel engine fuelled with Diesel-ethanol-Jatropha biodiesel blends. Blends used were D70/E20/B10, D50/E30/B20, D50/E40/B10. BSFC was increased for blends, the thermal efficiency improved slightly. Smoke reduced remarkably for blends especially at medium and high loads. Advancing injection timing reduced the smoke for all blends and diesel fuel.

II. EXPERIMENTAL DETAILS

The Jatropha oil biodiesel is blended in to petroleum diesel in different percentages by volume i.e. 10%, 25%, 30% and labelled as J10, J25 and J30 respectively. Also ethanol is blended into diesel in 5% by volume and referred as E5. The performance of the blends is studied on a single cylinder four stroke compression ignition engine whose specifications are given in Table 1 and actual test rig is shown in Figure 2.

TABLE I SPECIFICATIONS OF TEST RIG

Make	Kirloskar
Bore	87.5mm
Stroke	110mm
Connecting Rod Length	234 mm
Rated Power	3.5 kW at 1500rpm
Compression Ratio	18
Cooling	Water cooled
Dynamometer	Eddy current
Fuel Injection Timing	23^o BTDC

Fig. 2. Engine Test Rig

Engine has sensors for pressure, crank-angle, airflow, fuel flow, and temperature measurement. Computerised data acquisition system is provided for data logging.

III.RESULTS AND DISCUSSION

The fuel samples are tested in a single cylinder compression ignition engine at a constant speed of 1500 rpm under variable load condition. The blends J25 and E5 given optimum performance. Hence, they are blended in petroleum diesel to form a new blend JDE (a blend have 25% Jatropha biodiesel, 5% ethanol and 70% diesel by volume). Its performance is also studied and compared with other samples.

A. Combustion characteristics

In combustion analysis, variation of cylinder pressure, rate of pressure rise and net heat release rate is discussed.

1) Cylinder Pressure:

It is noted that maximum value of peak pressure for all test fuels nearly equal. P-theta diagram shows with addition of ethanol position of maximum pressure is moved further away from TDC. A reduction of 0.5 bar is observed by adding 5% ethanol. JDE has shown similar combustion characteristics Pressure rise for JDE is noted to be shifted by 5^o CA. Addition of ethanol lowers cetane number and causes increase in ignition delay. Ignition delay will cause more fuel to be burnt in premixed phase and increases rate of pressure rise[9]. Jatropha blends are showing earlier pressure rise compared to the neat diesel depicting lower ignition delay (high cetane number). Additionally combustion starts earlier also due to advance injection timing because of higher bulk modulus and higher density of Jatropha oil [7]. At higher loads, ignition delay period become shorter for Jatropha blends hence premixed combustion phase shifts closer to TDC[9]. Ignition delay for all fuels decreases as residual gas temperature inside the cylinder is very high at high engine loads which leads to reduce physical ignition delay.

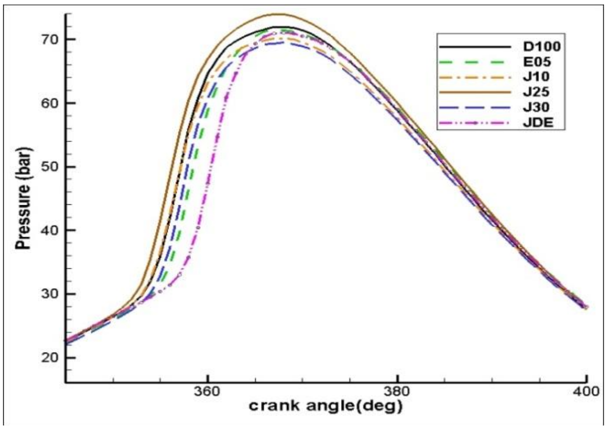

Fig. 3. Variation of cylinder pressure with crank angle

2) Rate of Pressure Rise:

Rate of pressure rise is a factor which determines smooth working of engine. Two peaks are observed. In figure 4 first peak of pressure rise is due to start of combustion is shown. J25 shows highest peak pressure amongst test fuels. As Jatropha concentration in blend increases peak of the curve shifts away from TDC. As molecules of Jatropha oil are heavier, takes more time to burn resulting into second peak [9]. At higher loads rate of pressure rise increases for Jatropha blends due to higher amount of fuel being injected and burned with increase in load. Due to phase separation issue of ethanol blends more blend percentage cannot be used [10].

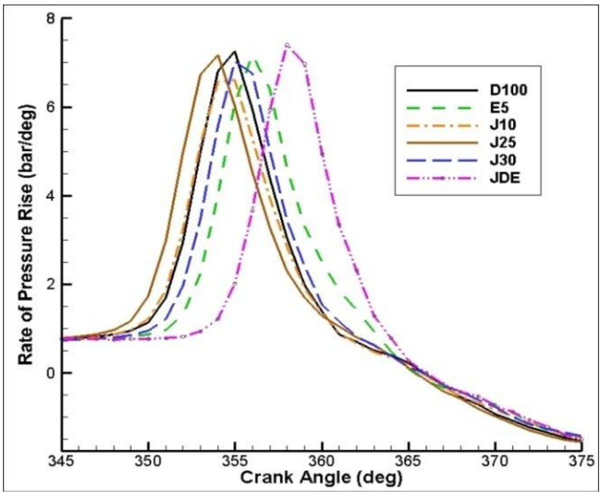

Fig. 4. Variation of rate of pressure rise with crank angle

3) Heat Release Rate:

From figure 5, J30 have higher heat release than D100. Because of vaporization of the fuel accumulated during ignition delay at the beginning, negative heat release is observed, as combustion starts heat release becomes positive. E5 shows similar heat release characteristics as D100.Rate of heat release for JDE blend in premixed phase is found highest amongst all test fuels. Combustion starts earlier for all test Jatropha blends [9]Heat release rate of biodiesel fuel has been advanced due to its bulk modulus effect on injection timing. D100 shows higher heat release due to its high volatility and better mixing with air.

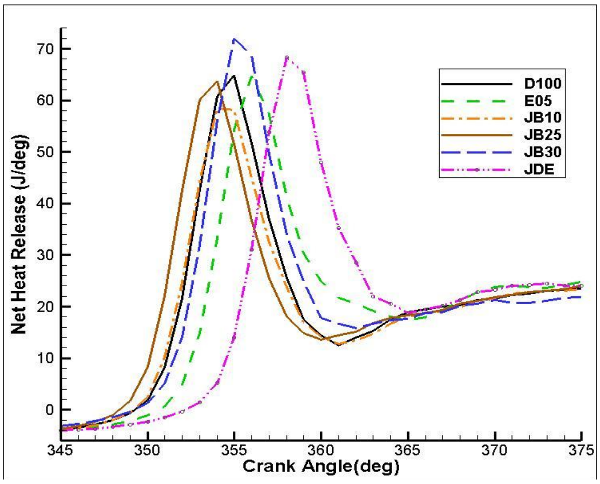

Fig. 5. Variation of rate of pressure rise with crank angle

Also due to longer ignition delay of diesel, amount of fuel accumulation in the combustion chamber at the premixed combustion stage leads to higher rate of heat release [7,11].

B. Performance characteristics

Performance characteristic include Brake Specific Fuel Consumption and Brake Thermal Efficiency.

1) Brake Specific Fuel Consumption (BSFC)

Brake specific fuel consumption (BSFC) is the ratio between fuel mass flow rates to the brake power at engine shaft. BSFC variation of all test fuels with load is shown in figure 6. At 50% load condition test fuels shown higher BSFC than diesel, this is due to the lower heating value of the Jatropha [2,12]. At full load Jatropha blended fuels show same fuel consumption as of pure diesel. Increase in blending percentage leads to decrease in calorific value and burning more fuel to get rated power. Also due to higher viscosity and higher specific gravity are the reasons of increased BSFC [12]. BSFC of JDE blend is found lower than mineral diesel. Jatropha blends have lower volatility and higher flash point which causes slower burning Jatropha blends [9].

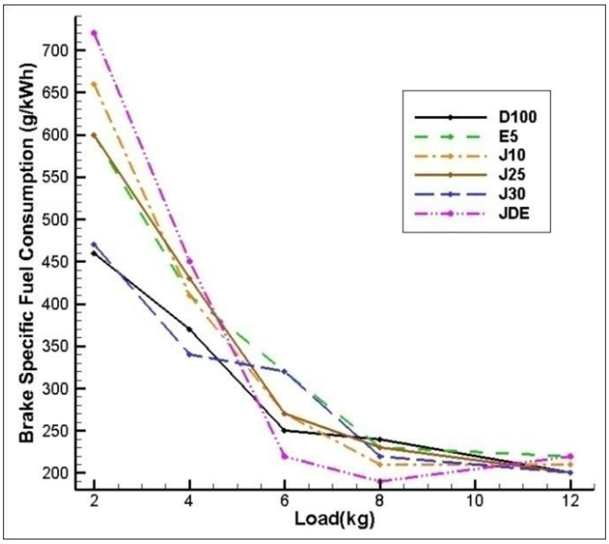

Fig. 6. Variation of brake specific fuel consumption with load

2) Brake Thermal Efficiency (BTE)

Brake thermal efficiency (BTE) is defined as the ratio between power at engine shaft to the energy release rate of the injected fuel. The BTE was found to increase steadily with increase in brake load for all the test fuels as shown in figure 7. This is because at higher engine loads more power is generated and wall heat loss is reduced. It was found that the full load BTE for D100 was 40.3% which got reduced to 38% for J25 and increased to 51% for E5 blend. Full load BTE is found higher than D100 but low to medium load it is lower than all test fuels. Overall thermal efficiency of Jatropha blends was lower than diesel. Oxygen present in fuel molecules improves combustion but due to higher viscosity and poor volatility lead to poor atomization and combustion [7]. Hence thermal efficiency was found lower for higher blend upto 70% load conditions were noted. At higher loads due to higher temperature in combustion chamber Jatropha oil molecules burns more effectively due to excess of oxygen molecules hence increase thermal efficiency.

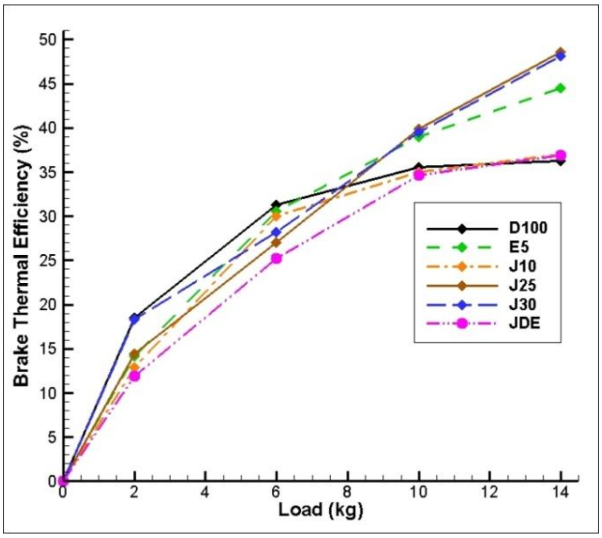

Fig 7. Variation of brake thermal efficiency with load

IV. ENGINE SIMULATION

Engine simulation is done using AVL BOOST tool. AVL BOOST model of test rig is shown in figure 8. In this simulation all engine data is fed to model, combustion model is selected and given a fuel property file and had run for various loading condition using either mass flow rate or air fuel ratio.

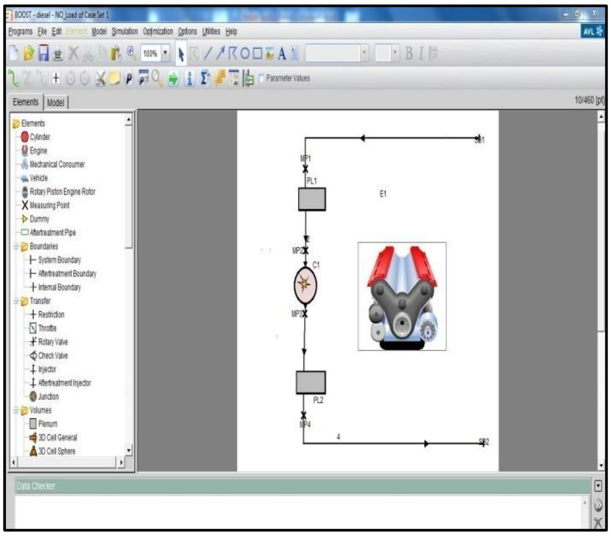

Fig. 8. AVL BOOST Engine Model

A. Validation

Engine model is validated by comparing of pressure crank angle diagram shown in figure 9. From figure model values are very close to experimental values. D100 AVL BOOST model has shown 2 bar difference in peak pressure values and JDE AVL BOOST model has shown 1.6 bar difference in peak pressure values.

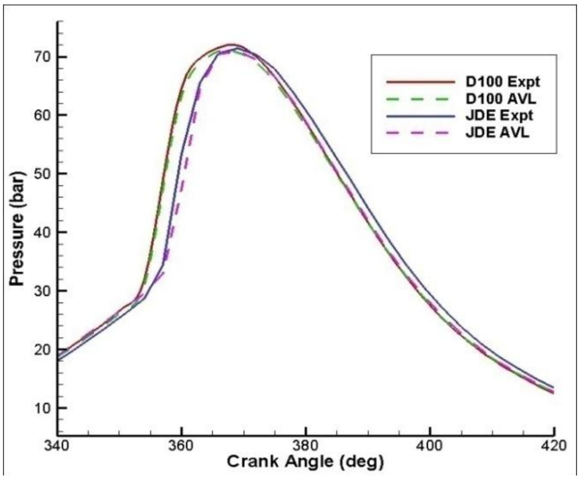

Fig. 9. Validation of AVL BOOST model

B. NO_x Emissions

At the full load every Jatropha blend showing higher amount of NO_x as shown in figure 10. Also ethanol blending sufficiently reduced NO_x emissions. Addition of Biodiesel increases NO_x whereas addition of ethanol decreases NO_x . JDE has shown reduction in NO_x emission with respect to J25 blend. Addition of ethanol in the J25 diesel blend has lowered NO_x emissions. Jatropha biodiesel blends have higher viscosity that reduces injection timings in combustion process. Higher density, viscosity and higher bulk modulus leads to early fuel injection which leads to early combustion. Therefore advanced combustion timings gives higher temperature and increased NO_x [13]. Biodiesel have slightly higher adiabatic flame temperature which tend to increase NO_x . Combustion temperature was reduced for Ethanol blends due to lower heating values of blends [3]. The amount of NOx produced depends on combustion temperature, oxygen concentration and residence time for the reaction to take place [14]. Reduction in NO_x due to ethanol addition in diesel is due to temperature lowering effect of ethanol (due to its lower calorific value).

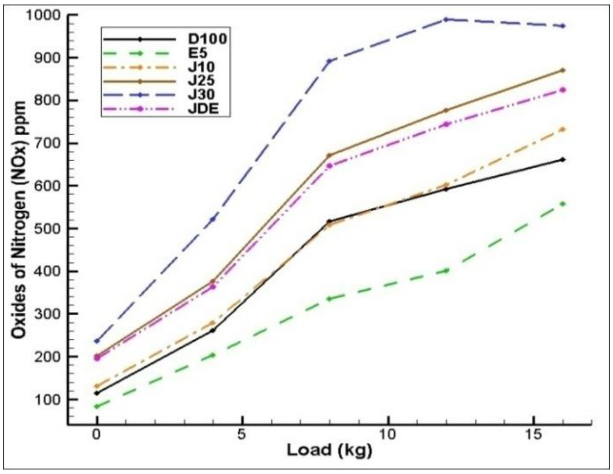

Fig. 10. Variation of NOx with Load

DOI 10.17148/IARJSET.2016.31206

V. CONCLUSION

Jatropha Biodiesel can be used upto 30% blend percentage in existing CI engine without any modification in engine hardware. J25 is selected as optimum blend fuel. But, increase in NO_x emissions (31% than D100) is observed. But this NO_x emissions can be controlled by using Exhaust Gas Recirculation (EGR) or Selective Catalytic Reduction (SCR) methods. There are additives such as Diethyl ether which reduce NO_x when added into the biodiesel. Ethanol tests shown that NO_x can be sufficiently reduced as they are useful in lowering the temperature of gases. Blend JDE reduced NO_x emissions by 7% compared to J25. Brake thermal efficiency was found to higher than D100 for full load conditions.

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