Experimental Investigations on the Engine Performance and Emission Characteristics of Indirect Injection (IDI) Diesel Engine using Preheated Jatropha Methyl Ester as Alternate Fuel

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***Abstract*— Biodiesel is renewable fuel which can reduce the use of petroleum based fuels which is known for lesser green house gas emissions of internal combustion engines. Therefore, to reduce emissions, researchers have focused their interest in the area of biodiesel as an alternative fuel for diesel engine. Investigations have shown that blending of biodiesel with diesel up to 20% by volume has good performance and emission (based on NO limitation) characteristics in CI engines. Further increase of biodiesel fraction will increase the viscosity of the injected oil, decrease the performance and increase emissions like NO because biodiesel is an oxygenated fuel. Higher viscosity fuel injection means retarded fuel spray diffusion and lower air entrainment characteristic. This is the reason that change over has been mooted to IDI engines because of better and complete combustion in both the chambers even there is certain compromise on the quality of the fuel. The two combustion chambers of IDI engine (tested now) are connected by an orifice and not a nozzle as was conventionally defined. To increase the fraction of the biodiesel or to replace the conventional diesel fuel by biodiesel it is required to reduce the viscosity to restore or enhance the functioning of the engine. In the present work an experimental investigation is carried out on a four stroke single cylinder IDI engine to find out the performance and emission characteristics with the preheated Jatropha Methyl Ester (JME) with the viscosity4.36cSt. JME is preheated at 60,70,80,90 and 100^0 C temperatures using online electronic preheating system. Experiments were done using diesel, biodiesel and biodiesel at different preheated temperatures and for different engine loading conditions keeping speed constant at 1500rpm. Improvement in performance and emission characteristics is obtained with biodiesel preheated to 60^0C and showed increase in break thermal efficiency over unheated biodiesel at 2.7kW load.**

Keywords*— *Transesterification, preheating, Jatropha biodiesel, IDI engine.

I. Introduction

Due to the depletion of the world's petroleum reserves and the increasing environmental concerns, it become more obvious the world is going to need to consider alternative fuels.

The total estimated world greenhouse gas (GHG) emissions in the year 2005 amounted to 44 billion tonnes of CO_2 equivalent, of which 66.5% were associated with energy services. Of the total emissions, the share from transportation, electricity and heating was 39.2% corresponding to 59% of the emissions related to energy services [1]. Much research has been done to investigate the use of vegetable oils derived from biomass sources as a fuel for automotive engines. Biodiesel is a good promising alternative to petro diesel. It is renewable, nontoxic and can be produced locally from agriculture and plant resources. Biodiesel is a form of biomass particularly produced from vegetables oils, has recently been considered as the best candidate for a diesel fuel substitution. *Jatropha curcas L.* is non-edible oil being singled out for large-scale plantation on waste lands. Jatropha plant can thrive under adverse conditions. It is a drought- resistant plant, living up to fifty years and has capability to grow on marginal soils. It requires very little irrigation and grows in all types of soils (from coast line to hill slopes). The oil content of jatropha seed ranges from 30% to 40% by weight and the kernel itself ranges from 45% to 60%. Fresh jatropha oil Slow-drying, odor less and colour less oil, but it turns yellow after aging .Pramanik tried to reduce viscosity of jatropha oil by heating it and also blending it with mineral diesel [2]. Acceptable thermal efficiencies of the engine had obtained with blends containing up to 50% of Agarwal *et al*. observed that engine operated on jatropha oil (pre heated and blends), performance and emission parameters were found to be very close to mineral diesel for lower blend concentration..However, for higher blend concentrations, performance and emissions were

observed to be marginally inferior [3]. The use of biodiesel fuel showed reasonably good performance and the use of 100% esterified jatropha oil gave reduction in NOx levels, increase in smoke while maintaining almost same fuel consumption values with 100% diesel fuel operation [4].
The oil contains primarily six fatty acids viz.Myristic, palmitc, stearic, Oleic, Linoleic, and Arachidic.Raw Jatropha oil has high viscosity and poor combustion characteristics which cause poor atomization, fuel injector blockage, and excessive engine deposit and engine oil contamination. In India the prohibitive cost of edible oils prevents their use in biodiesel preparation, but non-edible oils are affordable for biodiesel production. McDonald et al. [5] investigated soybean oil methyl ester as a fuel on a caterpillar indirect injection diesel engine and found that overall combustion characteristics were quite similar as for diesel except shorter ignition delay for soybean methyl ester. Kumar et al. [6] found that for Jatropha oil methyl ester, ignition delay was higher as compared to ignition delay for diesel as a fuel on a constant speed diesel engine.Selim et al. [7] tested jojoba oil methyl ester as a fuel on Ricardo compression swirl diesel engine and found that the pressures and pressure rise rates for jojoba oil methyl ester are almost similar to that as gas oil. jojoba oil methyl ester, however, exhibits slightly lower pressure rise rate than gas oil, and jojoba oil methyl ester seems to have slightly delayed combustion. Vander Walt and Hugo [8] used the sunflower oil in direct and indirect injection diesel engines. In that study, indirect injection (IDI) diesel engines showed no adverse effects when sunflower oil was used for over 2000h.But, direct injected engines showed that the power loss due to severely coked injectors, carbon build-up in the combustion chamber, and stuck piston rings. Hawkins et al. [9] reported similar findings for indirect and direct injection diesel engines using sunflower oil–diesel fuel blend (20:80 v/v %). They explained that injector coking was the problem by using sunflower oil in the direct injection (DI) diesel engines. Although the mentioned engine problems were generally related to the direct usage of vegetable oils, sometimes successful results were obtained for long -term usage.Karaosmanogluet al. [10, 11]used the sunflower oil for 50 h in a direct injection diesel engine (Pancar Motor E-108). The researchers did not see any significant differences in the power and fuel consumption, and did not find any engine problems during the tests. In the same engine, O¨ zektasx [12]investigated the effect of used sunflower oils–diesel fuel blend (20:80 v/v %) on the engine characteristics and exhaust emissions. The NOx emission of the fuel blend was found considerably lower (62%) than that of No. 2 diesel fuel at low engine speeds, but the difference diminished with the increasing engine speed. The researchers [13–16]saw that the preheating method is effective and practicable without any modifications on the diesel engines for short -term usage of vegetable oils. Cetinkaya [17] investigated the effect of heated sunflower oil and sunflower oil–diesel fuel blends on diesel engine performance. The results showed that the sunflower oil and its blends are promising as an alternative diesel fuel for diesel engines. The results of the literature review have indicated that thecombustion characteristics of an IDI diesel engine fuelled withpreheated biodiesel (with marginal increase in viscosity over diesel fuel) was not investigated in detail. Itis well known that the IDI diesel engines exhibit two importantadvantages; not depend on fuel quality and produce lowexhaust emissions depending on combustion chamber design. Experiments are conducted on indirect injection diesel (IDI) engine run at constant speed of 1500 rpm running with with neat diesel, pure JME and JME preheated to 60,70,80,90 and 100 degree centigrade respectively .Engine is run at five discrete part load conditions viz. No Load, 0.77 kW, 1.54 kW, 2.31 kW and 2.70 kW keeping in mind performance and emissions. Even though thermal efficiency suffers due to higher combustion surface area and higher compression ratio, there will be betterment in other aspects like crank case oil dilution and lower emissions from the engine. Therefore, the main purpose of thisstudy is to determine the performance and emission characteristics of preheated JME and to compare themwith those of reference petroleum based diesel fuel (PBDF) and unheated JMEunder the identical stable engine speed at 2.70kW load condition. This study has been taken up in conceptualizing the combination of fuel keeping in view lesser or no review of work presented in the literature with the preheated pure biodiesel.

Table-1 Characterization of fuels used

S.No	Propertity	Diesel	JME
1	Viscosity(cSt)	2.41	4.36
2	Density(kg/m^3)	830	875
3	Cetane number	45	52
4	Calorific value (kJ/kg)	43000	38468
5	Boiling temperature(^{0}c)	180-330	370
6	Autoignitiontemperature(^{0}c)	235	>300
7	Latent Heat of Vaporization (MJ/kg)	0.280	0.259

II. EXPERIMENTATION:

The experimental setup consists of the following equipments:

1. Single cylinder IDI diesel engine loaded with eddy
2. current dynamometer
3. Engine Data Logger (make: APEX INNOVATIONS)

4. Exhaust gas Analyzer (1600L,German ma German make)
5. Smoke Analyzer

Four stroke single cylinder IDI diesel engine details as shown in below and figure.1 is the schematic diagram showing various equipment modules.

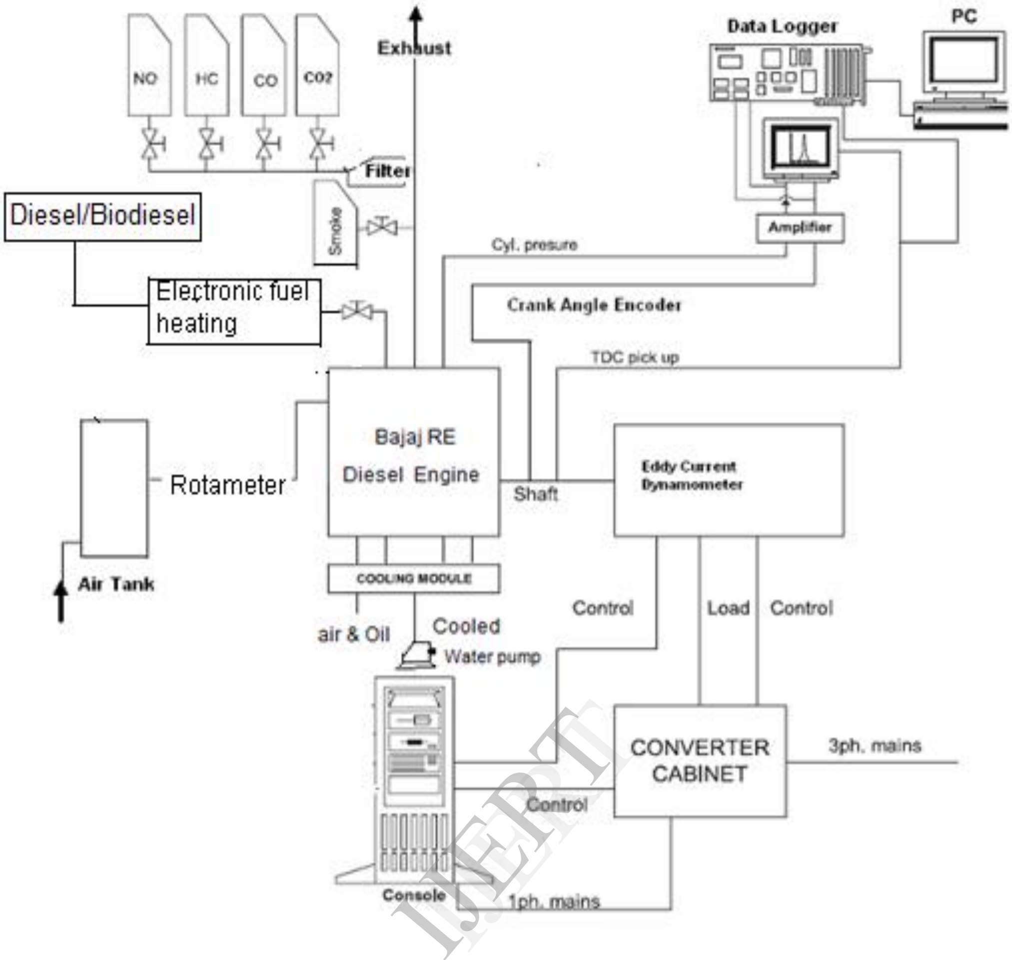

Fig. 1 Schematic arrangements of the engine test bed, Instrumentation and data logging system

Fig.2 Experimental test rig set up

The pressure transducer is fixed (flush in type) to the cylinder body (with water cooling adaptor) to record the pressure variations in the combustion chamber. Crank angle encoder sends signals of crank angle with reference to the TDC position on the flywheel and will be transmitting to the data logger. The data logger synthesizes the two signals and final data is presented in the form of a graph on the computer using C7112 software designed by "Apex Innovations" Pune, India.

Fuel consumption is measured to calculate BSFC, fuel air ratio and thermal efficiency. Exhaust gas temperatures were also recorded for all loads.

Delta 1600-L exhaust gas analyzer(German Make) is used to measure CO_2, CO, HC, NO in exhaust gases at all loads and graphs are drawn to compare. Fuel consumption is measured to calculate BSFC, fuel air ratio and thermal efficiency. Exhaust gas temperatures were also recorded for all loads.

Experimental test rig comprising loading device (eddy current dynamometer) and combustion data logger is established in the department of marine engineering, Andhra University. IDI variable speed diesel engine (Bajaj Make) for automobile purpose is chosen.

Experiments were conducted with neat diesel, pure JME and JME preheated to 60,70,80,90 and 100 degree centigrade respectively .Engine is run at five discrete part load conditions viz. No Load, 0.77 kW, 1.54 kW, 2.31 kW and 2.70 kW. In this experiment neat JME fuel at different temperatures viz.60, 70, 80, 90 and 100 degree centigrade respectively have been tested to evaluate the neat biodiesel performance

.Table 4.1 Specifications of the IDI- Diesel Engine.

Engine manufacturer	**Bajaj RE Diesel Engine**
Engine type	Four Stroke, Forced air and Oil Cooled
No. Cylinders	One
Bore	86.00mm
Stroke	77.00mm
Engine displacement	447.3cc
Compression ratio	24±1:1
Maximum net power	5.04 kw @ 3000 rpm
Maximum net torque	18.7 Nm @ 2200 rpm
Idling rpm	1250±150 rpm
Injection Timings	8.5^0 to 9.5^0 BTDC
Injector	Pintle
Injector Pressure	142 to 148 kg/cm^2
Fuel	High Speed Diesel
Starting	Electric Start

III. RESULTS AND DISCUSSION

A. Cylinder pressure signature study and Heat Release Rate curves:

Figre.3 depicts the combustion pressure variation at maximum pressure variation at maximum load operation for the fuel samples appended in the right column.

- Close observation of the variation of the pressures in figure.3 reveal that biodiesel heated up to 60^0 C attain peak pressure 60.20 bar 371^0 of crank angle at 2.70kW load but reaches the position late in the stroke.

- Biodiesel heated up to 80^0 C is the next contender which reaches 60 bar at 369^0 crank angle at the same load. Diffused combustion in the case of 60^0 heating is comparatively better than other heated oil operations which can be observed from the rise in the pressure levels after reaching peak pressures. The net heat release rate and cumulative heat release rate envisage better diffused combustion (figures 5 &6) for the heated oil at 60^0 C.
- The delay period is increasing by fraction of a degree following the rise in the temperature of the input biodiesel. At 60^0C of the biodiesel injected, as discussed there is a match of viscosity with the diesel fuel and as one increase further the temperature, the viscosity variation is more and the fuel loses its oiliness leading to variation in the latent heat of the oil which finally tells on the combustion of the fuel. This may be the possible reason in the degradation of the combustion with the increase in biodiesel temperature.

Figure.4 demonstrate delay period of the various samples.Figure.5 gives an idea about the net heat release rate derived with the pressure variation in the main chamber assuming the pressure prevailed at any time in both the chambers are same. Figure 6 represent the derived plot for the cumulative heat of combustion and for the heated biodiesel at 60^0 C the curve is jacked up indicating better combustion at the load indicated.

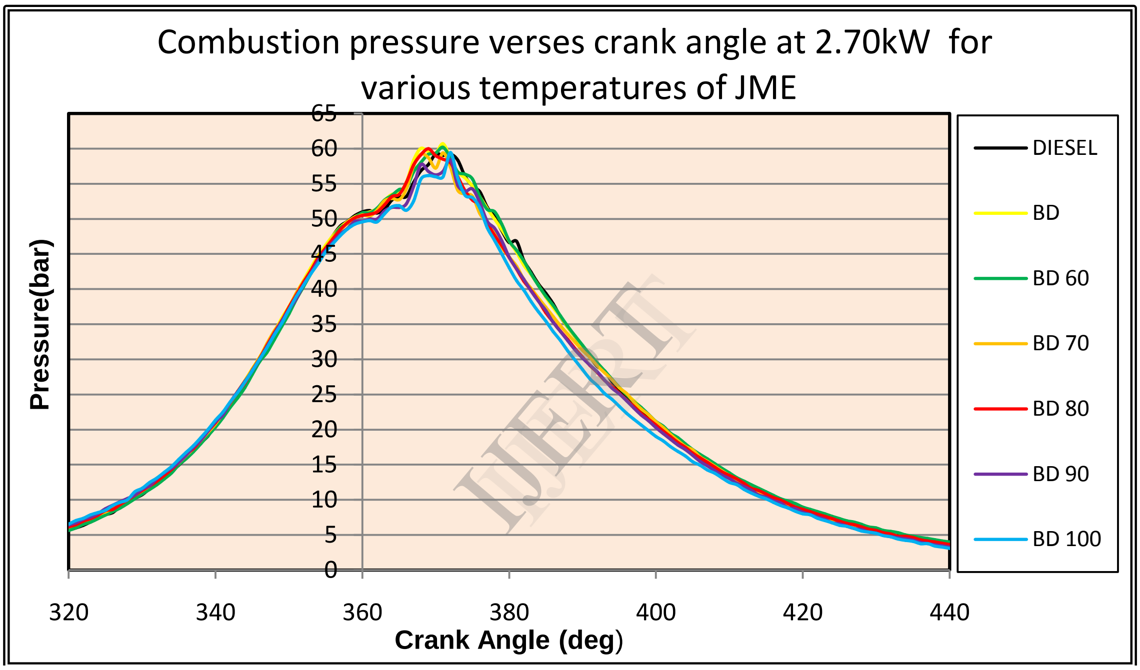

Fig.3 Combustion pressure variation in shorter duration of crank angle

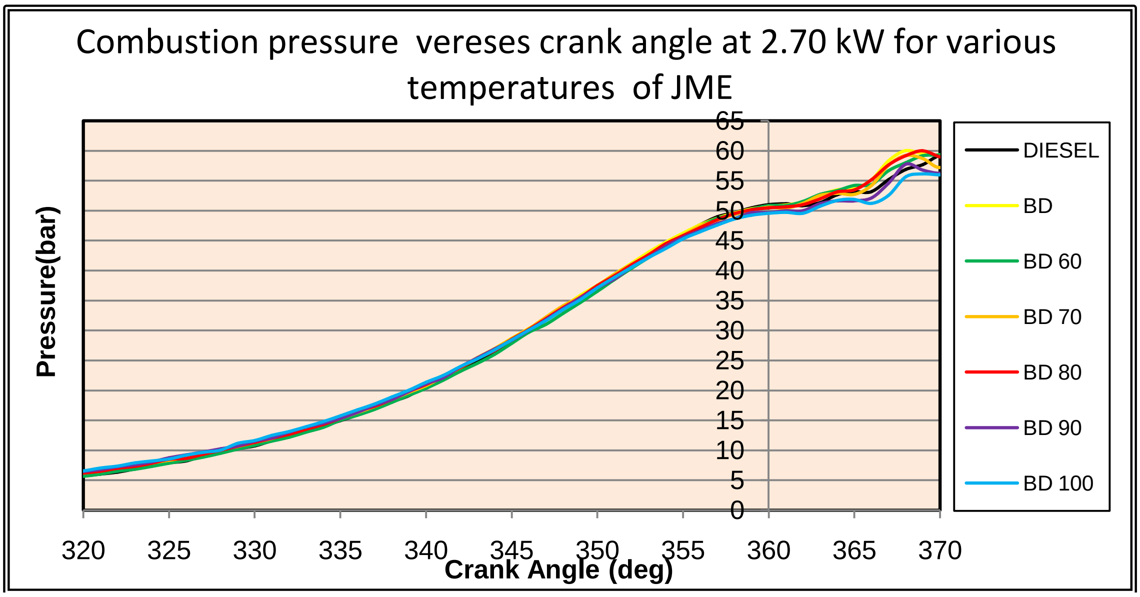

Fig: 4 Combustion pressure trend to analyze the delay period

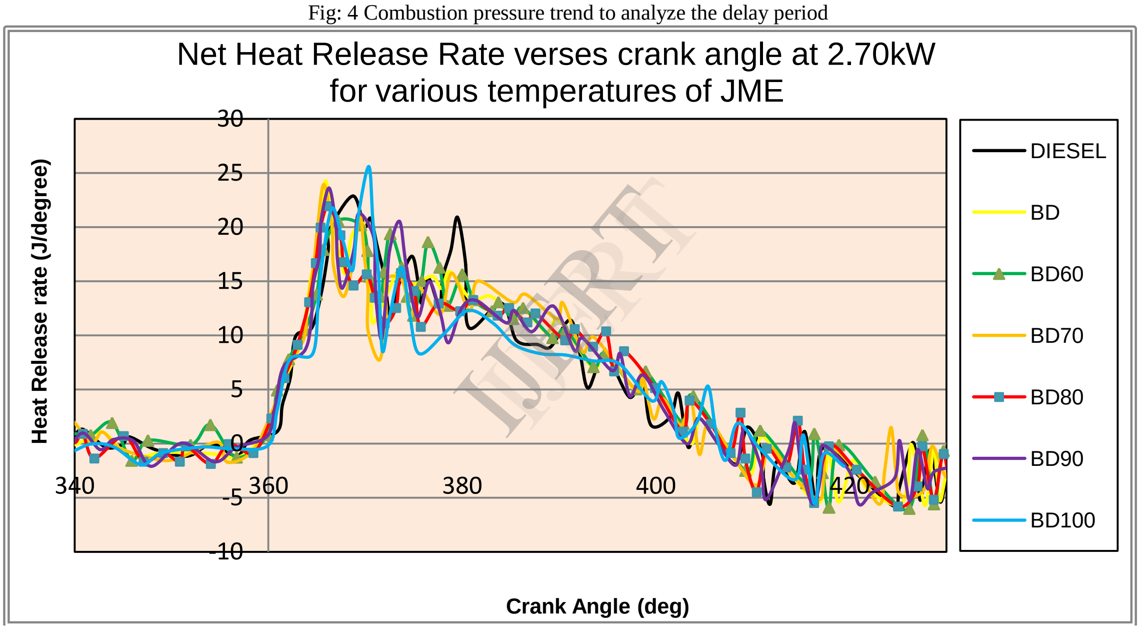

Fig:5 Net heat release rate derived traces.

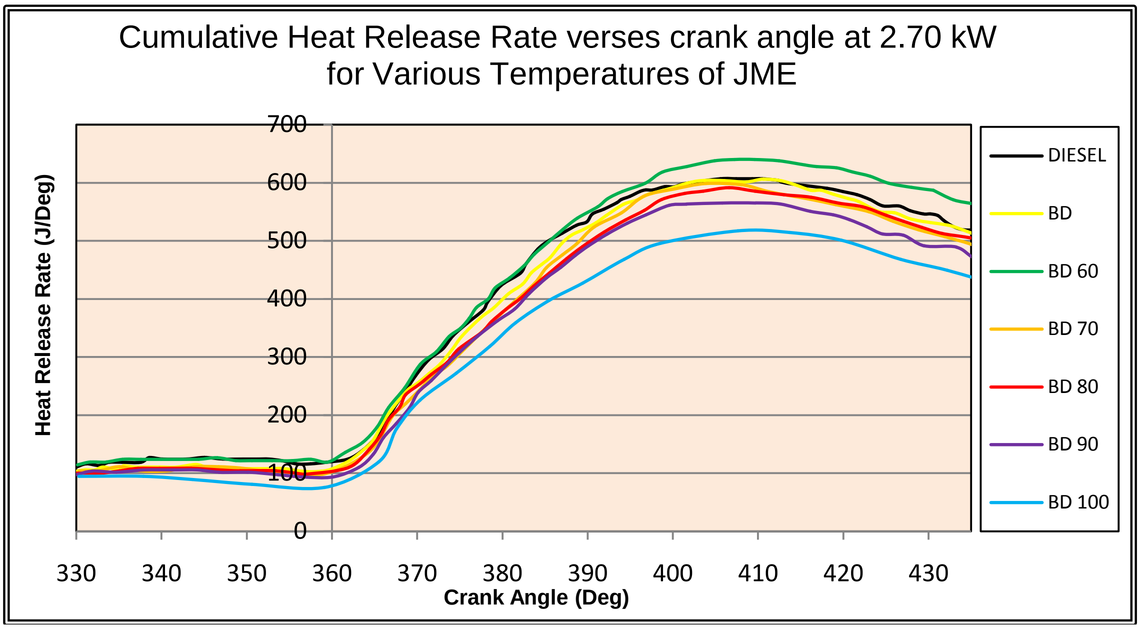

Fig.6 Cumulative heat release rate derived traces

B. Engine performance and Emissions:

- Break Specific Fuel Consumption: The brake specific fuel consumption is increasing with the increase of temperature. Figure 7 illustrates the effect of temperature in modifying the specific fuel consumption. For example at 2.31 kW engine power, the specific fuel consumptions are 0.2754, 0.3039, 0.309, 0.3124, 0.3151, 0.3262 and 0.3232 kg /kW –hr starting from diesel fuel to biodiesel oil heated to 100^0 C, with prefixed heated oils. Density property variation of JME is the main reason for this change.
- Break Thermal Efficiency: Figure.8 gives the details of break thermal efficiency verses break power. Thermal efficiency increased to maximum levels at 2.31 kW part load of the engine and the values are as follow: diesel: 30.39%, BD: 30.78%, BD 60:30.28%, BD70: 29.9%, BD80: 29.69%, BD 90: 28.68%, for BD100: 28.9%. There is a decrease of maximum of 1.42% in thermal efficiency of the engine referring to the diesel fuel.

Exhaust temperatures and smoke levels are presented in figures 9 and 10.There is a trend of the increasing exhaust temperatures with the increase in the bio-fuel temperature at any load chosen. It is observed that there is a difference of 45^0 C to 70^0 C in exhaust temperatures scanned at different loads with reference to diesel exhaust temperature. This may be due to the combustion refinement in diffused combustion zone as can be observed in the cumulative heat release rate curves.

Smoke levels have altogether decreased in general (with reference to diesel fuel) by 15 to 20 HSU at upper part loads as can be seen from the figure 10. Biodiesel normally will generate lower smoke levels as per the research conducted. Heating of the oil further reduced the smoke levels by 10 HSU with reference to the neat biodiesel. This is positively an indication of better combustion when the input oil is being heated over biodiesel.

The figures 11 to 14 envisage tail pipe emissions from the engine. The monitored emissions are HC, CO, NO and CO_2.

- Hydrocarbon emissions are comparatively very much lower in the case of IDI engine for the diesel fuel operation. This reduction is drastic over the DI engine HC emission which is in the range of 40 ppm to 130 ppm in the load range approximately equal to that of IDI engine. Heating further reduced HC levels to 1 ppm from 4ppm which is in the case of neat diesel operation.
- CO levels in the figure 13 indicate the CO emission level in the case of IDI engine. These vary in between 0.01 to 0.07 % by volume. In the case of DI diesel engine, the range is from 0.09 to 1.7 % by volume for almost the same power range of engine operation.
- CO emission in the case of heated fuel by 60^0 C is emitting of 0.01% by vol. which is minimum in the series and thought to be efficient point of fuel heating.
- CO_2 levels have increased decimally with reference to the diesel fuel and there is very small increase in the level in the case of fuel heated to 60^0C. This may be due to the decrement in the CO emission level owing to better combustion.
- In the case of NO emission it is an established fact that biodiesel fuel emits more NO because of additional Oxygen content in its molecular structure. Generally all loads the NO emission more for neat biodiesel and heated biodiesel but for

some occasions where there is insignificant rise in the NO emission especially at lower loads of the engine as plotted in the figure 15. At higher loads on the engine the NO level for the heated oil at 60^0 C has decreased from 45ppm. And in general, there is increase in NO levels at lower loads and decrease at higher loads.

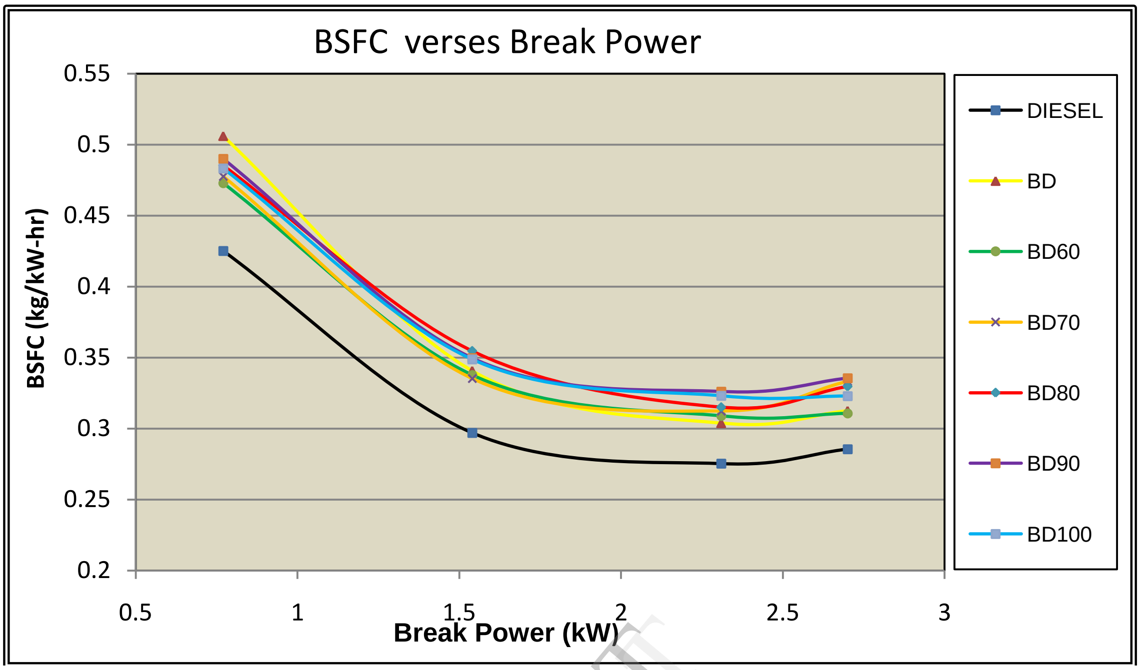

Fig.7 BSFC Vs Brake power.

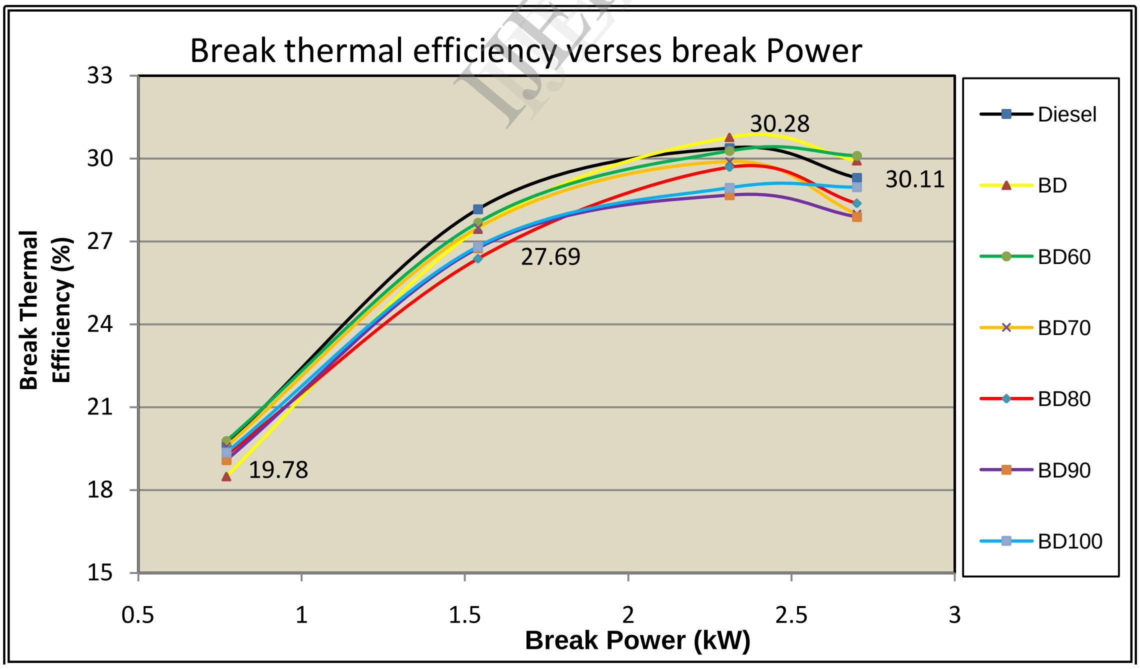

Fig.8 Thermal efficiency Vs Brake power.

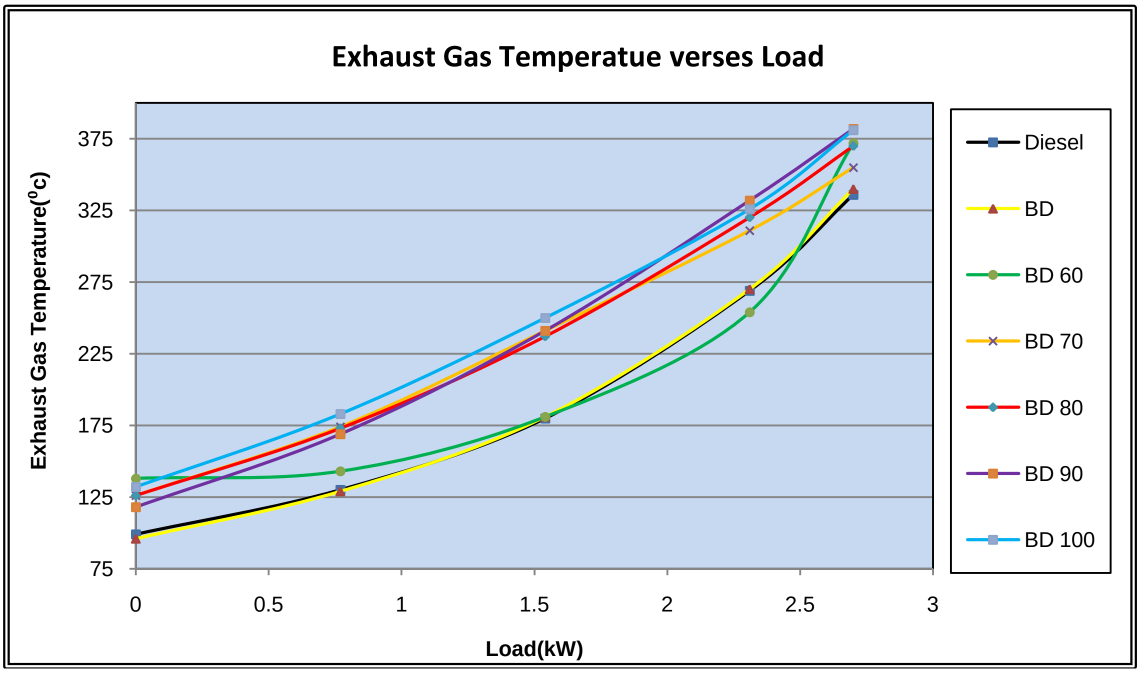

Fig.9 Exhaust Gas Temperature Vs Load with various temperatures of JME

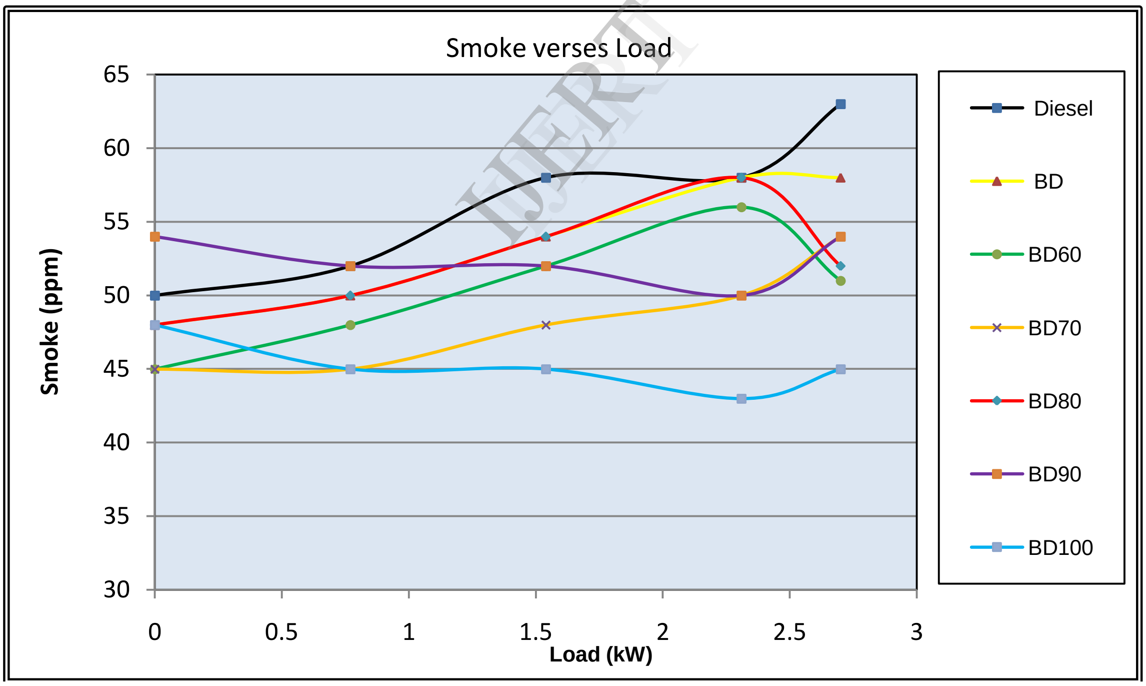

Fig.10 Smoke Vs Load with various temperatures of JME.

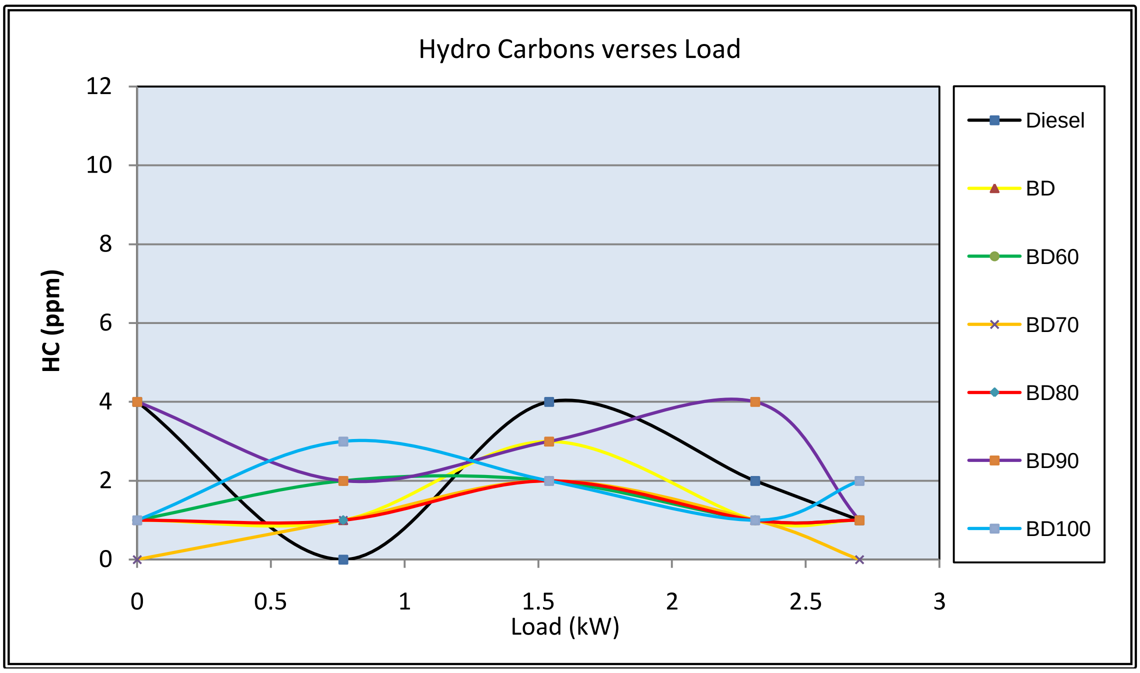

Fig.11 Hydro carbons Vs Load with various temperatures of JME.

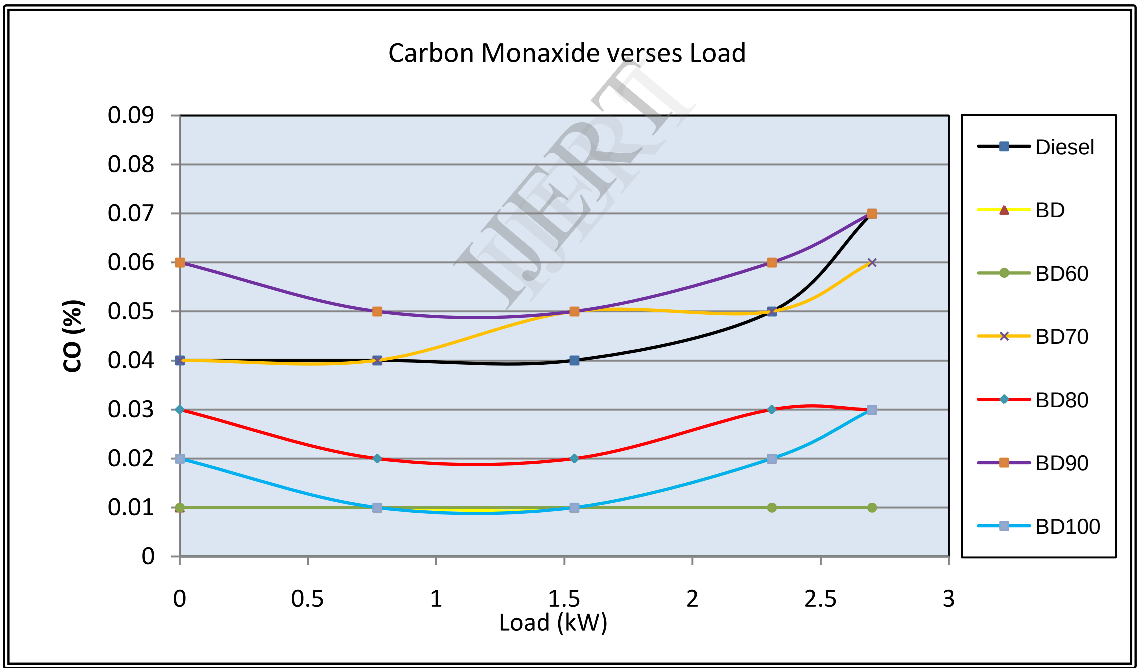

Fig.12 Carbon monoxide Vs Load with various temperatures of JME.

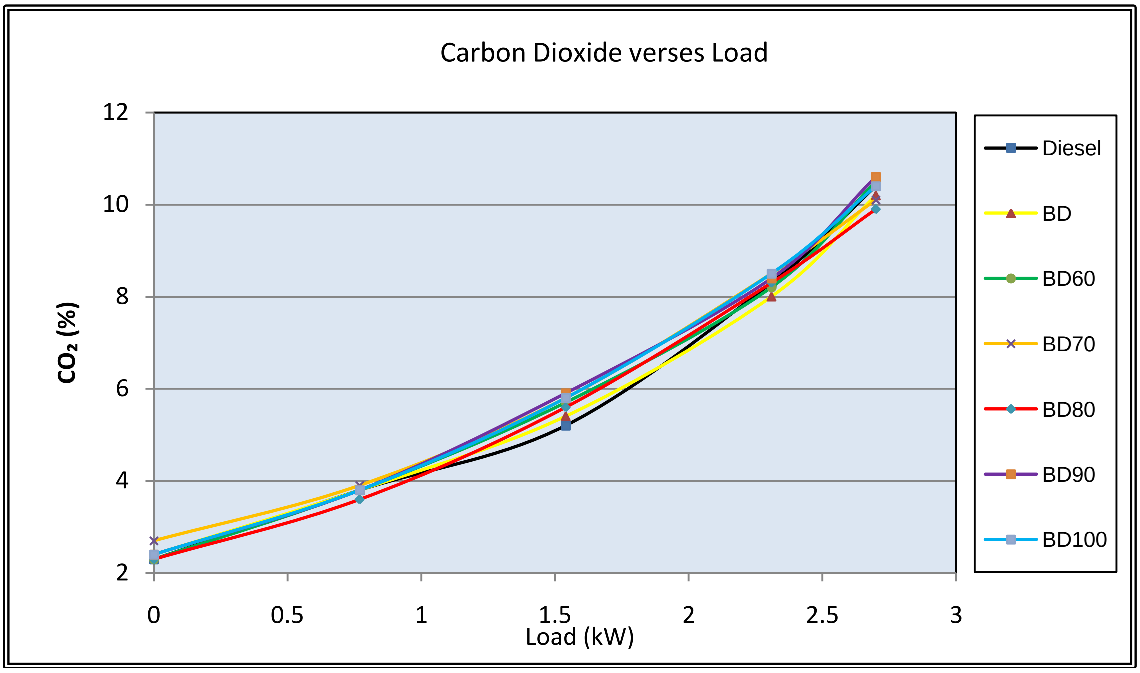

Fig.13 Carbon Dioxide Vs Load with various temperatures of JME.

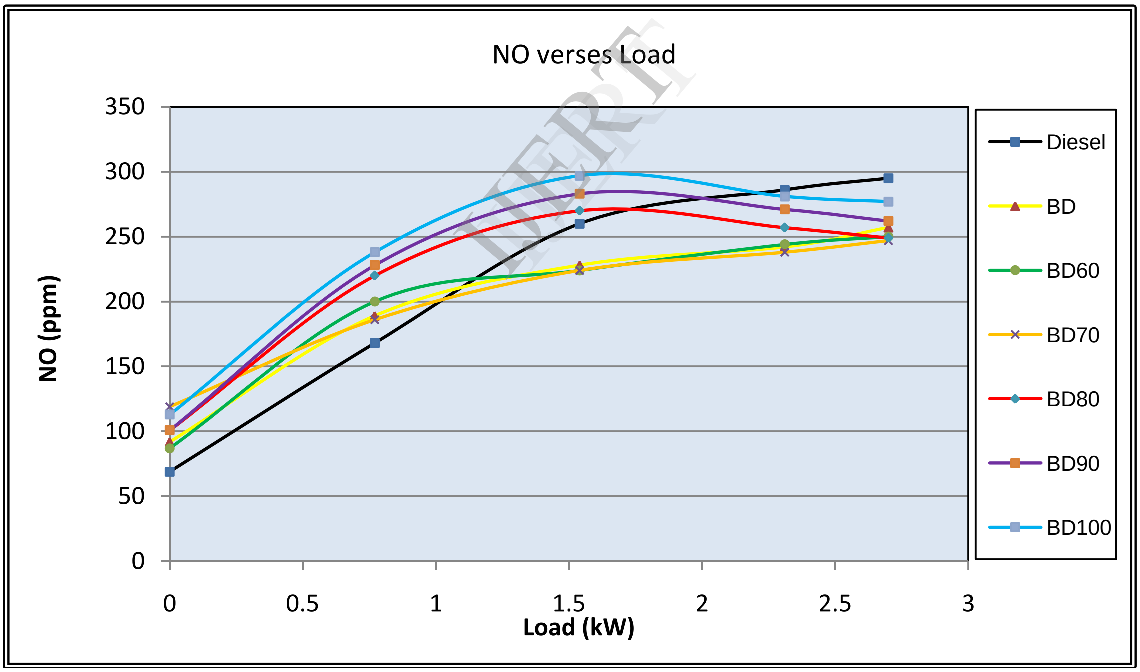

Fig.14 NO Vs Load with various temperatures of JME.

C. Conclusion :

The performance emission and combustion were evaluated. Biodiesel heated at 60^0C is the efficient one in view of the engine performance, combustion performance and the emission aspects described in the results. The benefits are as follows.

1. Smooth combustion pressure rise despite delayed peak pressure.
2. Better net heat release rate computed from combustion pressure values.
3. Jacked up cumulative heat release rate curve throughout indicating better premixed and diffused combustion.
4. Smoother thermal efficiency rise and better performance at the highest load.
   Economical BSFC when compared to unheated biodiesel.
5. Lower exhaust gas temperatures at higher part loads indicating better torque conversion.
6. Average smoke level lesser than the unheated

biodiesel in general.

7. Reduced CO, HC levels in exhaust.
8. Parity with the unheated biodiesel at all loads the emission context of NO.

Hence it can be concluded that the biodiesel heated to 60^0 C electronically before injection into the cylinder, entails better fuel injection, air entrainment, conservative heat transfer and better combustion in the main chamber with economical torque conversion.

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