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Combustion and Vibration Analysis of Idi- Diesel Engine Fuelled With Neat Preheated Jatropha Methyl Ester

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Abstract:
Experimentation is conducted on an IDI diesel engine and the results of combustion and vibration on IDI -Diesel engine fueled with the preheated Jatropha Methyl Ester (JME) are presented. The Present research trend is to replace conventional diesel by renewable alternative fuels in view of fast depletion of petroleum reserves and to reduce the exhaust emissions from the engines without altering the basic design of the engine. Due to moderately higher viscosity effects, the direct use of biodiesel in C.I. engines is limited to 20% and the limitation is based on the NO emission also. In this work, the biodiesel is preheated using on line electronically controlled electrical preheating system before it enters into the injector. Experiments are conducted on a four stroke single cylinder IDI engine to find combustion and vibration characteristics of the engine with the preheated Jatropha Methyl Ester (JME) heated to temperatures viz. 60,70,80,90 and 100^0C. Normally thin oils due to heating may trigger fast burning leading to either detonation or knocking of the engine. This can be predicted by recording vibration on the cylinder head in different directions. The cylinder vibrations in the form of FFT and time waves have been analyzed to estimate the combustion propensity. Experiments are done using diesel, biodiesel and biodiesel at different preheated temperatures and for different engine loading conditions keeping the speed constant at 1500 rpm. Biodiesel preheated to 60^0C proved encouraging in all respects.
Keywords: IDI engine, JME, preheating, Biodiesel, combustion, emission, vibration.

I. INTRODUCTION

In relation to the increasing oil prices and air contamination caused by photochemistric smog and greenhouse gas produced by emission gases of internal combustion engines, studies on alternative fuels are actively being conducted [1,2].Despite this, pollutants such as smoke, particulate matter and NOx that are discharged during the combustion process of diesel engines directly affect the environment. Accordingly, various related regulations have been enforced. To solve this problem, various methods of reducing the discharge of pollutants by diesel engines are being studied, focusing on pretreatments to reduce emission gases by changing the properties of the fuels prior to combustion. Improvements in combustion conditions such as changes in the engine design and the method of high-pressure injection [2], and post processing of the emission gases using catalytic converters, a diesel particulate filter and exhaust gas recirculation (EGR) [3,4] outside the combustion chamber after the combustion are among the methods. In particular, the pretreatment method is being adopted by many researchers because it can basically control the generation of emission gases without entailing great expenditure for external treating appendages.

The rapid growth of transportation systems mostly using internal combustion (IC) engines has led to a wide range of challenges demanding immediate attention. Maintenance and condition monitoring of an IC engine is a very crucial activity required to ensure optimum performance and minimum load on the environment by restricting emissions to bare minimum levels ensuring reliability of engine parts by the way of lesser vibrating engine. In most of the studies with biodiesel fuel, the researchers concentrated on the engine performance measured through thermal efficiency, power output, and specific fuel consumption, emissions, etc. The long term effects are yet to be studied. Assessment of the impact of these fuels with different operating parameters on engine life is extrapolated from short-term trials without giving any weightage to the maintenance problems arising with these changes.

Also the quality of combustion depends on the parameters leading to erratic or smooth running of the engine. The irregular and erratic combustion inside the combustion chamber results in knocking leading to erosion and damage to combustion chamber and piston head. This also sets the engine to vibrate more leading to early failure of structure and parts. Therefore to anticipate the maintenance requirements and quality of combustion in the cylinder of CI engines, vibration signatures may provide a strong diagnostic tool.

Misfire in IC engine in case of alternate fuel suggestion is a major factor leading to undetected emissions and performance reduction [5]. The monitoring of fuel combustion processes in internal combustion engines has in recent years become increasingly important due to a continuous demand of lower fuel consumption and increasingly stringent emission legislation. One of the most efficient and straightforward ways to monitor the fuel combustions is to measure the in-cylinder pressures, which contain extensive information about the fuel combustion process and can easily be used for balancing the cylinder-wise torques and detecting misfire [6].A vibration is indicating the malfunction of engine. That is varying the injection profile strongly affect the bulk motion settling inside the combustion chamber. The maximum amplitude of the vibration provides information about combustion intensity, high amplitude may indicate early ignition or presence of a large amount of fuel in the cylinder prior to ignition, lower amplitude may indicate late ignition, injection malfunction or engine compression malfunction [7].Many researchers have tried the biodiesel and its blends in direct injection compression ignition (DI-CI) engines. The fuel characteristics of biodiesel are approximately the same as those of fossil diesel fuel and thus may be directly used as a fuel for diesel engines without any prior modification of the design up to a blend ratio of 20 with improvement in emissions with a slight loss in thermal efficiency [8-11].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 [12]. 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 [13]. Knocking aspect leads to rapid erosion and damage to combustion chamber and the piston head. This also sets the engine to vibrate more leading to early failure of structure and parts. Therefore to anticipate the maintenance requirements and quality of combustion in the cylinder of CI engines, vibration signatures may provide a strong diagnostic tool.

The vibration induced in any machine due to its moving parts is only of lower frequency. But high frequency vibrations are also present in IC engine due to abnormal combustion of charge (fuel-air mixture).

Vibrations produced in diesel engine are mainly in two directions:

- Vibrations in radial direction in the cylinder.
- Vibrations in a direction of the piston movement.

The piston impact on the cylinder liner is known as piston slap. This piston slap causes the vibrations in lateral direction. Lateral vibrations leads to greater wear of piston rings and liner surface and structural failure and the wear due to this is more as compared to axial vibrations. During abnormal combustion, multi point ignition occurs. This ignition causes rise in in-cylinder pressure in a short duration of crank angle. The rise in in-cylinder pressure forces on piston, and due to this parting force some high frequency vibrations are generated in longitudinal direction.

Vibration as a diagnostic tool for combustion anomalies has been studied by many researchers. Azonic et al. [14] used an indicator based on the crankshaft velocity fluctuations and proved that this indicator is able to distinguish with sufficient precision the occurrence of misfire. Ball et al. [15] tested a diagnostic system based on the measurement of environmental noise. Among the diagnostic techniques applied to internal combustion engines, those based on the analysis of accelerometer data have earned a greater success. Chun and Kim [16] measured oscillations at the upper part of the cylinder block center for knock in SI (spark signal provided by an accelerometer placed externally. Othman [17] placed the accelerometer horizontally on the side wall of a SI engine to monitor the combustion anomalies like misfiring. Antoni et al. [18] used vibrations to indicate malfunctioning. Blunsdon and Dent [19] showed that varying the injection profile strongly affect the bulk motion settling inside the combustion chamber. The maximum amplitude of the vibration provides information about combustion intensity, high amplitude may indicate early ignition or presence of a large amount of fuel in the cylinder prior to ignition, lower amplitude may indicate late ignition, injection malfunction or engine compression malfunction. It has been proved by Carlucci et al. [20] that injection pressure and injected quantities, over an energy release threshold, really affect the vibration signals in a peculiar way; injection timing affects the engine block vibration in a less evident way. Gideon et al. [21] used vibration measurement to identify malfunctioning in a multi cylinder engine. In the area of DI diesel engine endeavors made to analyze engine vibration with the introduction of neat biodiesel and biodiesel with additives [22-25]. DI engines also reveal an economical point at which the engine vibrations are minimized.

Our study deals with finding the effect of preheating the biodiesel on the engine combustion, performance and vibration characteristics of variable speed IDI engine and to finally to arrive at the fruitful temperature for the preheating of the oil. Experiments are conducted on indirect injection (IDI) diesel engine run at constant speed of 1500 rpm running 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, emission and vibrations. 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 this study is to determine the performance and vibration characteristics of preheated JME to increase engine reliability and to compare them with those of reference petroleum based diesel fuel (PBDF) and unheated JME under the identical stable engine speed at 2.70kW load condition. This study has been taken up keeping in view lesser or no review of work presented in the literature with the preheated pure biodiesel.

II. EXPERIMENTATION:

The experimental setup consists of the following equipments:

1. Single cylinder IDI diesel engine loaded with eddy current dynamometer.
2. Engine Data Logger (make: APEX INNOVATIONS)
3. Exhaust gas Analyzer (1600L, German make)
4. Smoke Analyzer
5. Electronic heating gadget with Programmable temperature controller for preheating the Jatropa Methyl Ester
6. DC-11 Vibration analyzer made in Canada.

Four stroke single cylinder IDI diesel engine details as shown in below and figure.1 shows the schematic diagram.

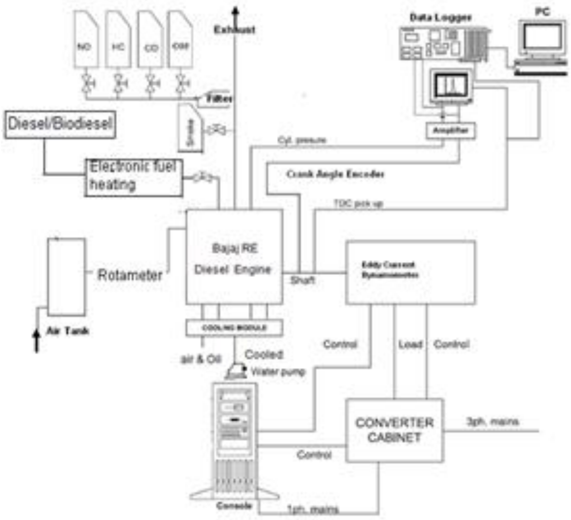

Fig. 1 Schematic arrangements of the engine test bed, Instrumentation and data logging equipment

Fig.2 DC-11 Vibration analyzer

Fig.3 Experimental test rig set up with inset of online electrical heating

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.

The DC-11 vibration analyzer made by DPL group, Canada is a digital spectrum analyzer and data collector specifically designed for machine condition monitoring, advanced bearing fault detection and measurement diagnostics. The following are the measurements that can be made by the instrument.DC-11.vibration analyzer.

This FFT data recorded is collected by Vast an doss based software designed by Vast, Inc Russia. The Time waveforms are obtained on the cylinder head by DC-11 in the OFF-ROUT mode. Three strategic points on the engine cylinder body and the foundation are chosen to assess the engine vibration. These three points are

i) Vertical on top of the cylinder head,
ii) Radial on the cylinder and perpendicular to the axis of the crank shaft,
iii) On Engine foundation

The vibration data recorded at these three points encompasses the engine vibration in the vertical direction, the radial direction and the vibration transmitted to the foundation respectively. The vibration data is recorded with the help of an accelerometer analyzed graphically in acceleration, velocity and log-log modes.

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 experimentation 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-1 Characterization of fuels used

S.No	Property	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	Auto ignition temperature(^{0}c)	235	>300
7	Latent Heat of Vaporization (MJ/kg)	0.280	0.259

Table-2 Specifications of Bajaj RE Diesel

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

3.1 Combustion pressure signatures and Heat Release Rate curves:

Figre.4 depicts the combustion pressure variation at maximum pressure variation at maximum load operation for the fuel samples appended in the right column.

Pressure signatures in the main combustion chamber are recorded and presented in the figure 5. Close observation of the variation of the pressures in figure 4 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 6 &7) in the case of heated oil at 60^0 C. It can be observed that as the temperature of the input biodiesel is increasing the rate of pressure development is decreasing as can be observed from the figure.4, but for the cases like 60 and 80 degrees centigrade heated oil. The delay period is increasing fraction of a degree following the rise in 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 the temperature increase further, 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.

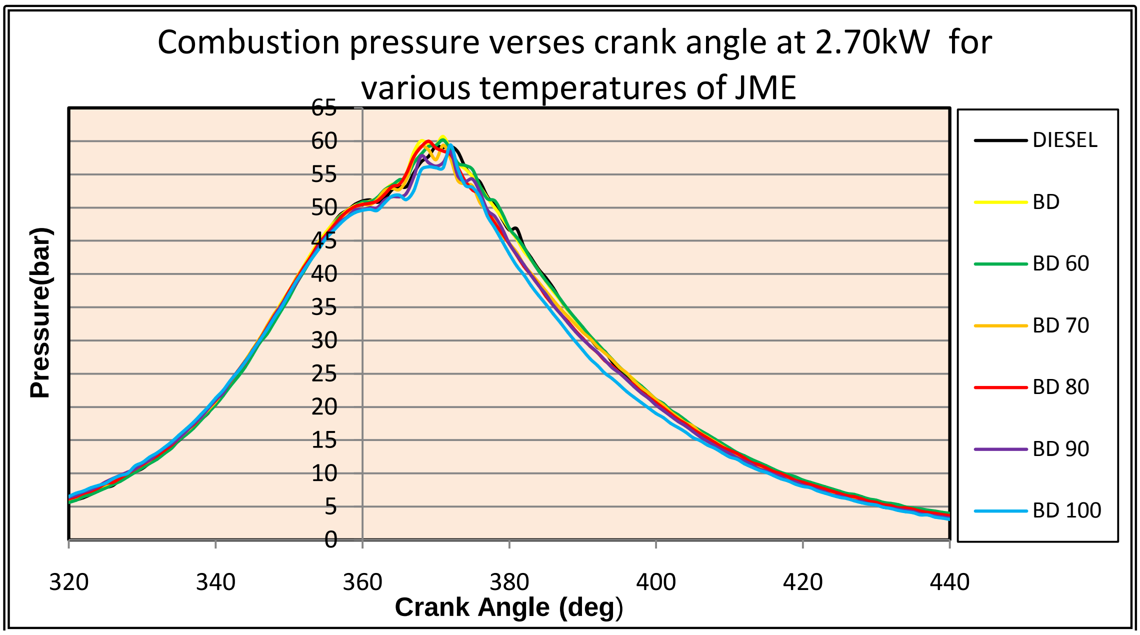

Fig.4 Combustion pressure variation in shorter duration of crank angle

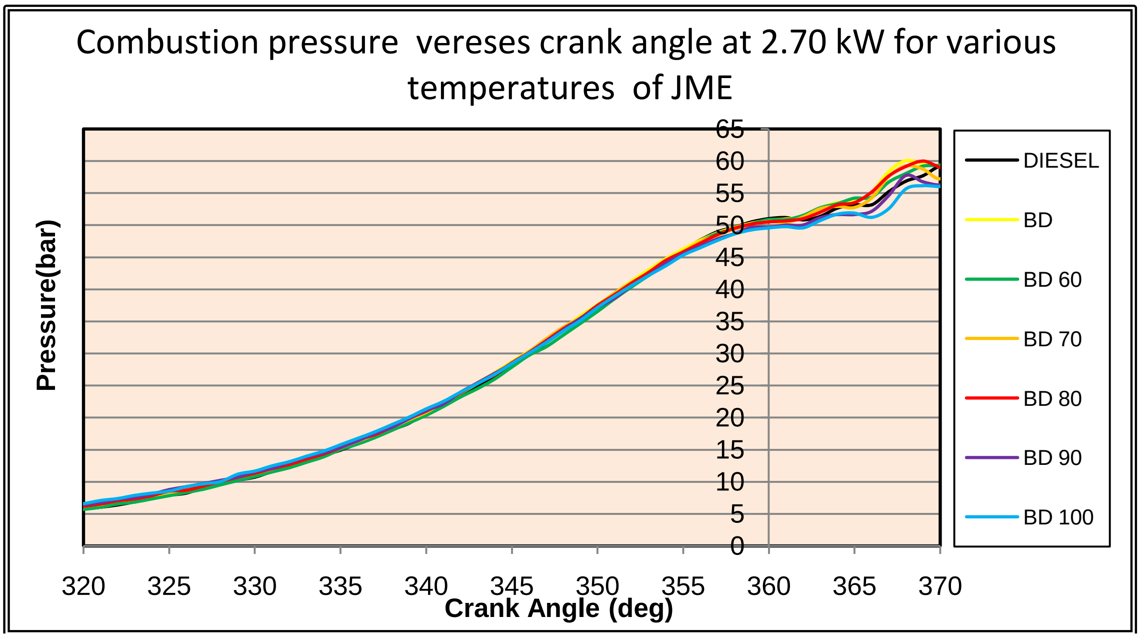

Fig: 5 Combustion pressure trend to analyze the delay period

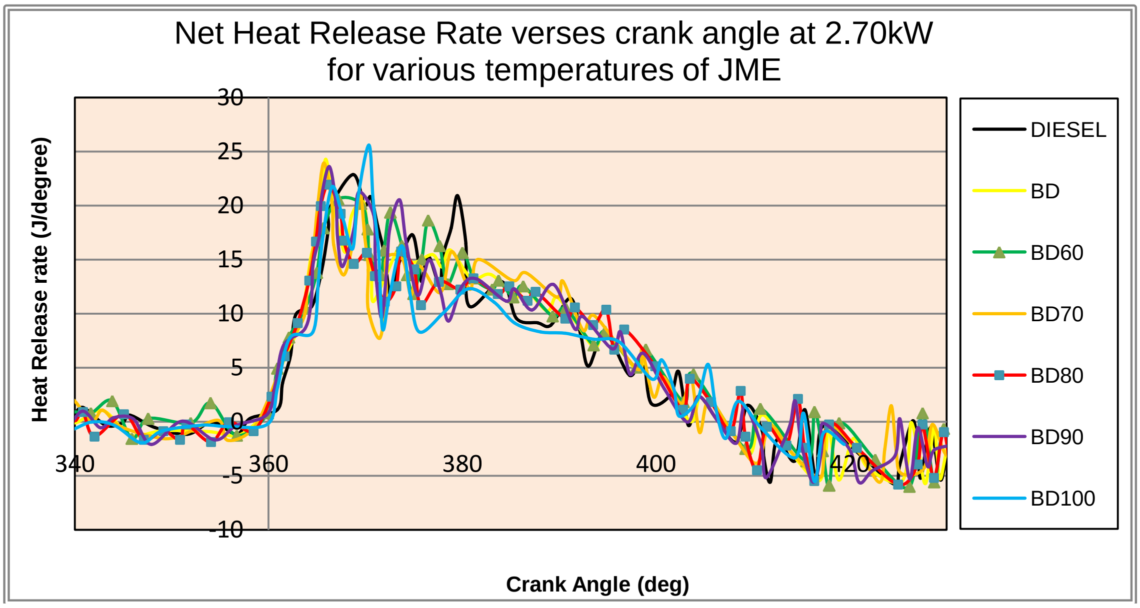

Fig:6 Net heat release rate derived traces.

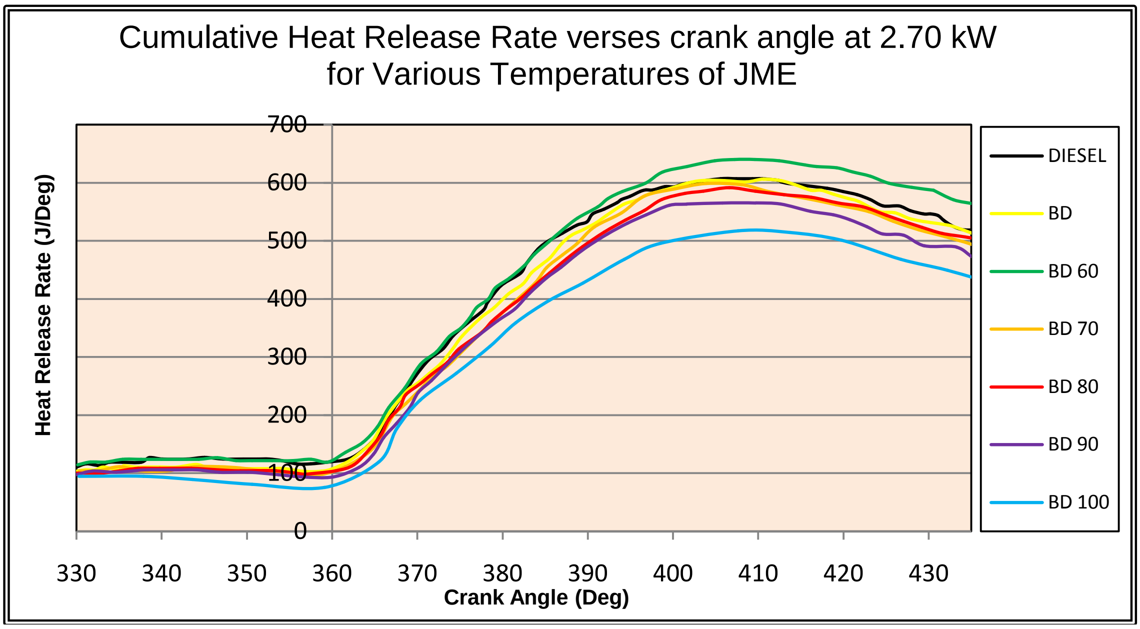

Fig.7 Cumulative heat release rate derived traces.

3.3 Engine Knocking Prediction:

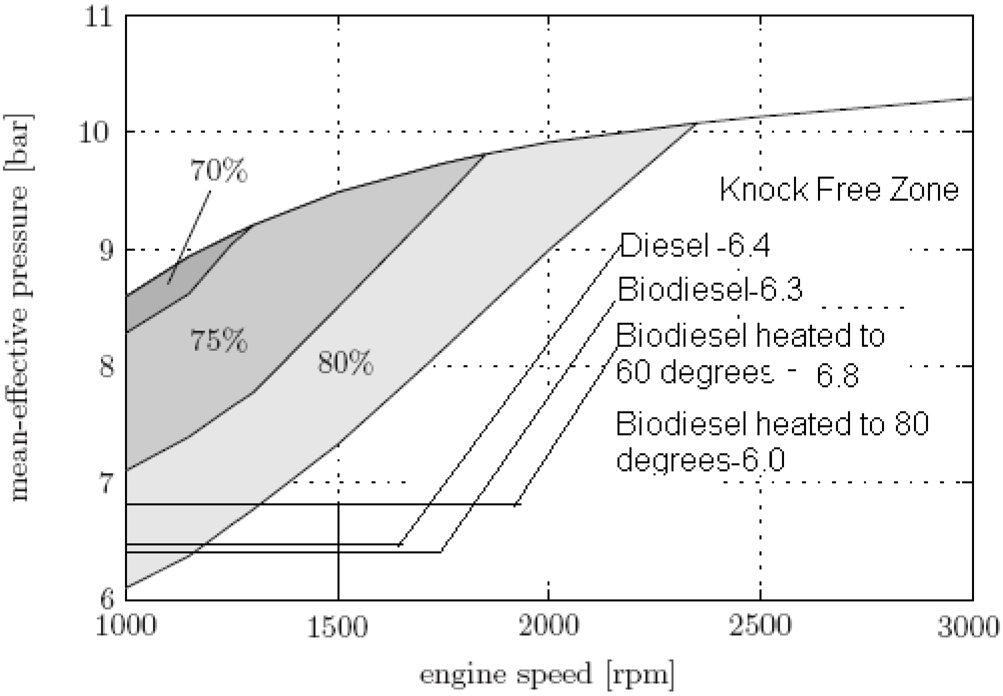

Fig.8 Knock identification with indicated mean effective pressure and engine speed
ref [26] : Franzke D.E. (1981)]

Figure.8 gives out the zones of unburned fractions in which severe knock occurs. The tested fuel samples at different oil temperatures are also represented with their IMEP in the plot and found that they are not in the knocking zone. The knocking trend also was presented with the sonic velocity in the combustion chamber, the major dimension being the diameter of the cylinder (B) at the time when the combustion starts and ends was considered for calculation. The knocking frequency calculated for the engine diameter ‘B’ is around 6.18 kHz and it is observed any amplitude at this frequency in any of the FFT plots indicating no knocking trend with the fuel samples.

$$C_{cyl} = \sqrt{k.R.\vartheta_{cyl}} = \sqrt{1.4.287\frac{J}{kg.K}.2000K} \approx 896\frac{m}{s}$$

$$f_{knock} = \frac{C_{cyl}.\alpha_{m,n}}{\pi.\mathrm{B}}$$

$$f_{knock} = \frac{C_{cyl}.\alpha_{1,0}}{\pi.\mathrm{B}} = \frac{896\frac{m}{s}.1.841}{\pi.0.086m} \approx 6.18kHz$$

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- 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.

3.4 Vibration Analysis

Vibration of the cylinder and that of the foundation frame are measured for comparison and to verify the combustion smoothness. The Jatropha methyl ester heated to different temperatures has been tested on the engine to verify the vibration intensity, which can be attributed to the smoothness/roughness of operation of the engine.

The vibration measured in vertical direction gives appropriate measure of the combustion propensity in the case of vertical cylinder engine. Considerable reduction in the vibration is observed in the high frequency regions with the JME preheated to 60^0C.

Any abrupt amplitude rise in the FFT waveform measured in any direction on the cylinder head or the base of the engine at any mean effective pressure generated in the cylinder, at 6.18 kHz, means 'knocking' phenomenon in the combustion.

Log-log graphs ascertained vertical on the cylinder head at 2.70 kW, envisage the combustion phenomena with diesel, biodiesel, and biodiesel at two different temperatures (fig.9).The graph for the biodiesel heated to 60^0 C envisage better combustion since the at higher frequencies more than 10000 Hz , the amplitudes are lower comparatively <50dB V. It can be observed for diesel fuel, there is more high frequency vibration followed by biodiesel and heated oils.

Figure 10. reveals FFT trace radial on the cylinder head perpendicular to the crank shaft. In the case of oil heated to 80^0 C, there is an upsurge in the amplitude at 1000 Hz. This amplitude hike is not there in the case of biodiesel heated to 60^0 C.

Figure 11. depicts vibration signature on the base of the engine at 2.70 KW. It is obvious that the log-log graph for the fuel heated to 60^0 C is smoother than others shown.

Figure 12 envisage the time waves measured on the cylinder head at 2.70 kW for diesel fuel and biodiesel heated to 60^0 C and 80^0 C. Heated oils display better combustion in the pre-combustion chamber as indicated in the figure for diesel combustion.

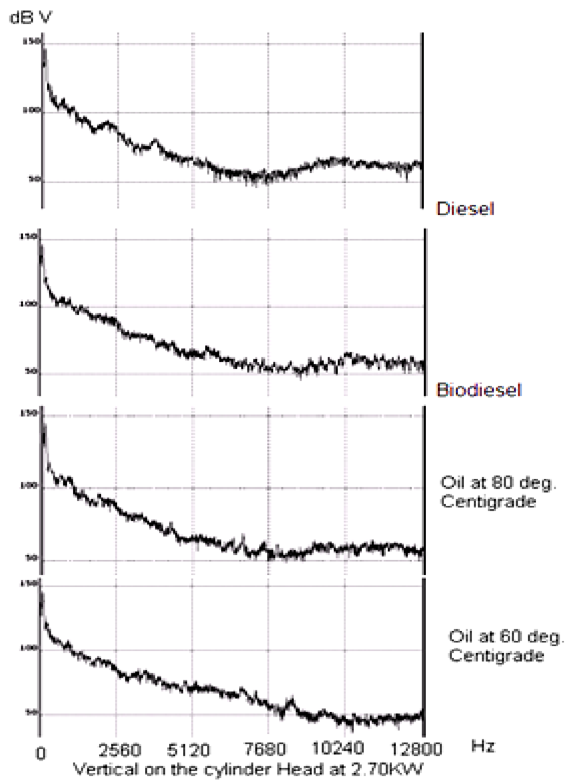

Fig.9. Logarithmic graph of FFT trace vertical on the cylinder head.

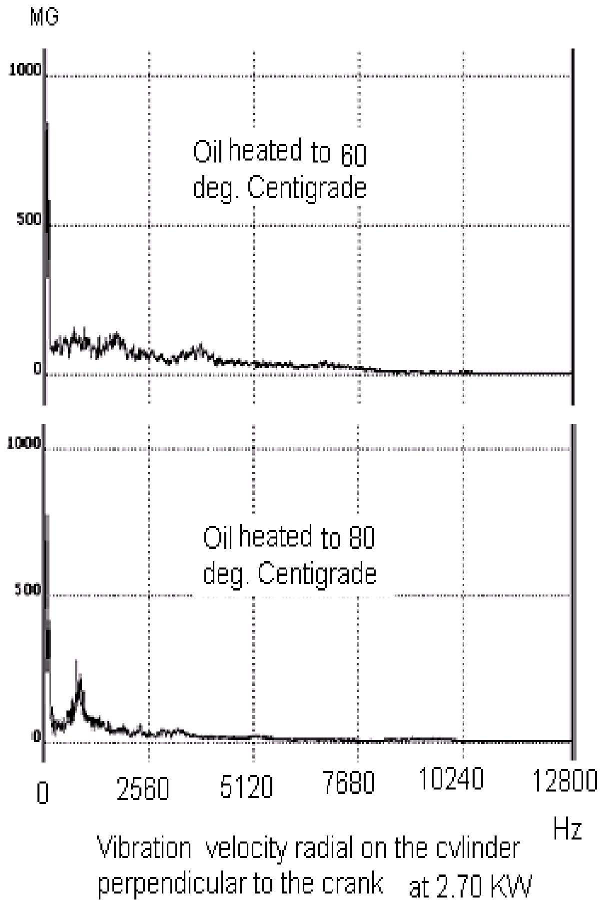

Fig.10. FFT trace radial on the cylinder head

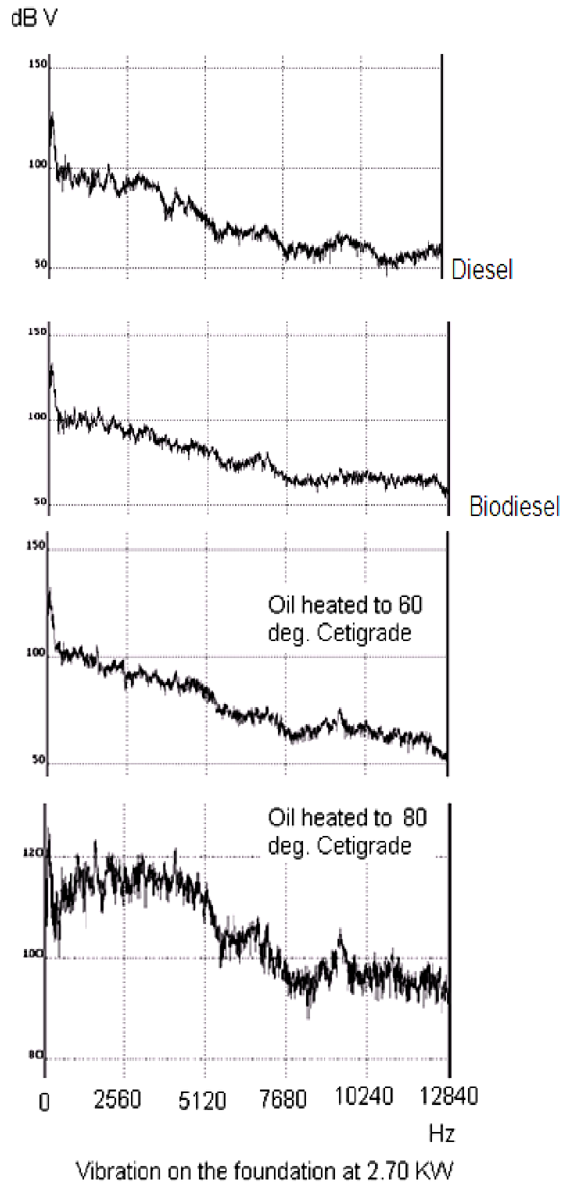

Fig.11. Vibration on the foundation at 2.70 kW load

IV. Conclusions

Diesel fuel in the conventional diesel engine is replaced totally with biodiesel (JME) and various trials made with different loads. The performance emission and engine vibration are measured and analyzed for the run of both diesel, unheated and preheated biodiesel. Based on the result the following conclusions are drawn:

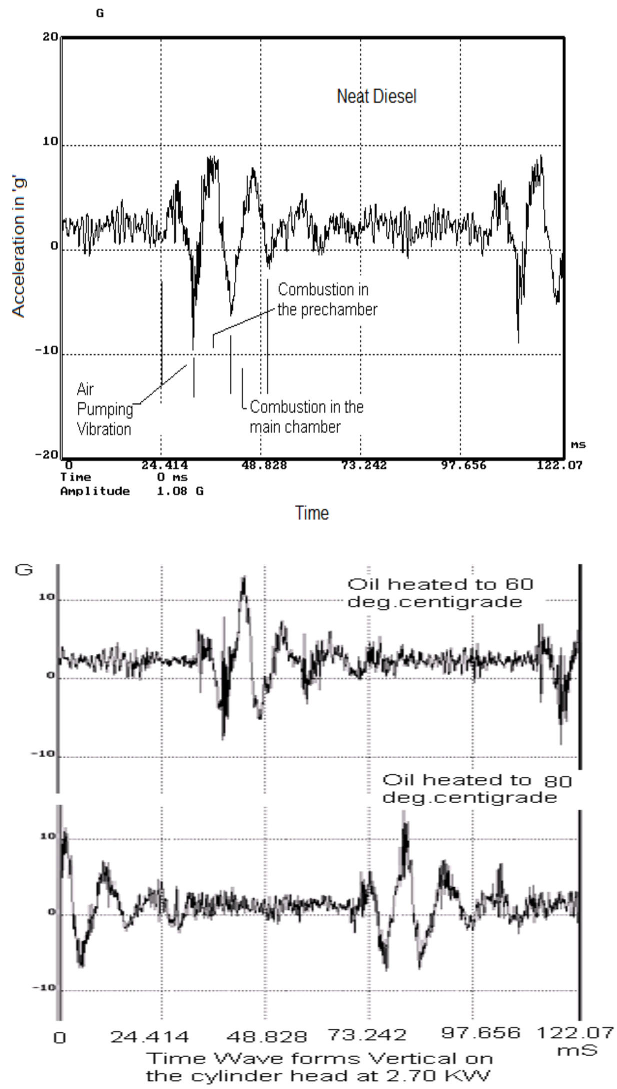

Fig. 12. Time waves vertical on the cylinder head with fuels with neat diesel and biodiesel at two different temperatures.

1. Smooth rise of combustion pressure despite of delayed peak pressure.
2. Net heat release rate computed from the combustion pressure values is better.
3. Jacked up cumulative heat release rate throughout, indicating better premixed and diffused combustion.
4. Biodiesel heated to 60^0 C envisage better combustion since the at higher frequencies more than 10000 Hz , the amplitudes are lower comparatively <50dB V. It can be observed there is more high frequency vibration for diesel followed by biodiesel and heated oils.

It can be concluded based on the merits displayed by the oil heated to 60^0 C is the efficient one in view of the engine performance, combustion performance and the vibrational aspects described in the results.

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