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Experimental Investigation of a Diesel engine fuelled by Diesel–Jatropha biodiesel Blends with Special Attention to Exhaust Emission.

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ABSTRACT

The world is getting modernized and industrialized day by day. Environmental impact assessment is one of the key essential factors to prevent global warming by reducing carbon monaoxide and NOx emissions from various sources. The aim of the present work is to investigate the influence of Jatropha biodiesel properties on various characteristics of a direct injection compression ignition engine. A direct injection (DI) diesel engine was tested by diesel,100% biodiesel (B100), and blends of 70% diesel and 30% biodiesel (B30). The engine characteristics with Jatropha biodiesel were compared against those obtained using diesel fuel..From the results, it is observed that the biodiesel performance and emission are lower than that of diesel fuel. However, the NOx emission of Jatropha biodiesel is more than that of diesel fuel. B 100 showed a significant reduction in exhaust odor than diesel. The experimental results show that the retarded injection timing is necessary when using Jatropha biodiesel in order to reduce NOx emission without worsening other engine characteristics. Results also indicate improved performance with the application of preheated biodiesel. The only penalty for using preheated biodiesel is the increase of smoke (soot). A significant reduction in CO and PM was obtained with B100 and B 30 with an increase in NOx than diesel.

Keywords ---Bio-diesel, Jatropha oil, performance and exhaust emissions.

INTRODUCTION

As civilization is growing, transport becomes essential part of life. Low emissions and high efficiency are continuous goals of engine development program. Biofuels provided 1.8% of the worlds transport fuel in 2008 [1].l According to the International Energy Agency, biofuels have potential to meet more than a quarter of world demand for transportation fuels by 2050[2]. This necessitates the search for alternative of oil as energy source. Several countries including India have already begun substituting the conventional diesel by certain amount of biodiesel [3]. Meeting the targets established by the European parliament for 2010 and 2020 would lead to a biofuel market share of 5.75% and 10% respectively [4].

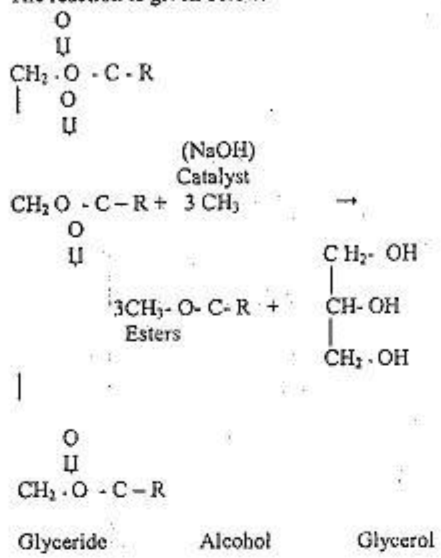
Biodiesel is most common biofuel for diesel engine. It is produced from oils or fats using transesterification and is a liquid similar in composition to fossil/mineral diesel. It is a domestic, renewable fuel for diesel engine derived from natural oil like Jatropha oil. Biodiesel has an energy content of about 12% less than petroleum-based diesel fuel on a mass basis. It has a higher molecular weight, viscosity, density, and flash point than diesel fuel. Till today several biodiesel fuels for CI engines have beeninvestigated. Most investigations show that the use of biodiesel results in lower emissions of carbon monoxide (CO), HC and smoke, where as the emissions of Nox increases [5-9]. The use of biodiesel results in lower emissions of carbon monoxide (CO),HC, and smoke, where as the emissions of NOx increases [10-13]. A very important factor in engine out NOx emission is the injection timing [14-15]. Various researchers have shown that the physical properties of density, viscosity, and isothermal compressibility strongly effect injection timing, injection rate and spray characteristics [16-17]. An experimental investigation was carried out on an indirect injection engine and aimed at evaluating the overall performance, the emissions and the combustion with biodiesel fuel [18]. Pure biodiesel and blends of biodiesel combined with 10% methanol have been evaluated in details. A remarkable reduction of smoke was obtained. There are several reported results of biodiesel emissions [19-20]. A slight increase in NOx emissions for biodiesel was reported.

Generally, exhaust emissions of regulated pollutants are widely studied and the results favor biodiesels on CO, HC and particulate emissions; however, unregulated pollutants, such as carbonyl compounds, which are also important indicators for evaluating available vehicle fuels are also important. A study examined the effects of the biodiesel blend fuel on aldehyde emissions from diesel engine exhausts in comparison with those from the diesel fuel [21]. Dominant aldehydes of both fuels' exhausts were formaldehyde and acetaldehyde. These compounds together account for over 75% of total aldehyde emissions. Total aldehyde emissions for B20 (20% waste cooking oil biodiesel and 80% diesel) was less than that of diesel; especially formaldehyde emission was dropped by 23% on the average. Lower aldehyde emissions found in B20 correspond to lowerozone formation potentials. As a result, use of biodiesel in diesel engines has the beneficial effect in terms of aldehyde emissions. It was reported in above references that engine parameters have significant effect on performance and emissions of diesel engine when run with biodiesel and its blend with diesel. Engine tests were carried out at different engine speeds and loads. This research aimed to investigate the effect of biodiesel and its blends on emissions including exhaust odor of a DI diesel engine. Investigation of exhaust odor with biodiesel as a fuel in DI diesel engines is a new dimension of work.

II METHODOLOGY

Jatropha oil has golden yellow color and is prepared from the seeds of *Jatropha Curcus*. These seeds are black in color and oval in shape [22]. It has been found that transesterification is the most effective way to reduce the viscosity of vegetable oils and to make them fit for their use in the present diesel engines without any modification. In this process an ester reacts with an alcohol to form another ester and another alcohol. The catalyst for this reaction is KOH or NaOH. To accomplish the transesterification reaction described above, the oil, methanol, and catalyst are mixed together in a stirred reactor. 55 °-60 ° C temperatures will cause the reaction to reach equilibrium more rapidly.

The reaction is given below:



Transesterification Reaction

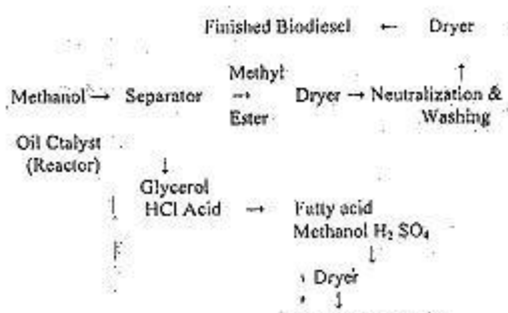


Fig.1: Schematic of Biodiesel Processing.

As shown in the reaction equation above, three moles of methanol react with one mole of triglyceride. In practice , most producers will use at least 100% excess methanol (6:1 molar ratio) to force the reaction equilibrium towards a complete conversion of the oil to biodiesel. The reaction is slowed by mass transfer limitations since at the start of the reaction the methanol is only slightly soluble in the oil and later on, the glycerin is not soluble in the methyl esters. A two-stage process is used for the esterification of the Jatropha oil [23-24]. The first stage of the process is called esterification, and this is used to reduce the FFA (Free fatty acids) content in jatropha oil by esterification with methanol (99%pure) and acid catalyst (sulfuric acid-98% pure) in one hour reaction at 60°C. In the second stage, called transesterification, the triglyceride portion of the jatropha oil reacts with methanol and base catalyst (potassium hydroxide-99% pure), in one hour reaction at 65 °C, to form an ester and glycerol. In this process, the triglyceride is converted stepwise to diglyceride, monoglyceride, and finally glycerol A two-stage process is used for the esterificationof the jatropha oil [25-26]. After transesterification, two layers were observed on cooling. The top layer was rawbiodiesels and the bottom layer was glycerin. The glycerol layer was separated and the raw fatty acid methyl ester was water washed to remove unreacted methoxide by the process of water washing with air bubbling. It was then heated to remove the water traces to obtain clear biodiesel. Finally, after drying the found methyl ester is converted to the required biodiesel. Hence, it is seen that 900 ml of biodiesel is produced from 1 liter of Jatropha oil. Properties of diesel, biodiesel and blends as shown in Table 1.

Table-1: The observed properties of oil and fuels

Properties	Jatropha oil	Biodiesel	30% Biodiesel& 70% Diesel	Diesel
Density[gm/sec]		0.62	0.67	0.84
Kinematic viscosity at 30^0 C	55	5.34	6.73	4.0
Calorific value [MJ/kg]	39.5	41	40.9	45
Cetane number	43	---	----	47
Solidifying point °C	-10	--	--	-14
Boiling point °C	286	255	--	248

III EXPERIMENTAL SET-UP AND PROCEDURE

The engine used in this study was a diesel engine. The tested engine specification is shown in Table 2 and photo graph is shown in figure 2.

Table 2: Engine specifications

Engine type One	4-stroke DI diesel engine
Number of cylinders	one
Bore x Stroke	80 x 110 mm
Swept volume	553 cc
Compression ratio	16.5:1
Rated power	4.476 kW @1800 rpm
Start of injection	24^0 BTDC
Fuel injection pressure	14 MPa (up to 1099 rpm)20 MPa (1100-2000 rpm)

The engine has been run using biodiesel and required data are collected to calculate the engine performance parameters. All experimental data are recorded 25 minutes after engine starts, at which the exhaust line temperature becomes constant and at zero emission fluctuations. Tests were carried out at the warm up condition of the engine under three engine speeds. The engine speeds were 700 rpm, the lowest speed of the engine, 1150 rpm, the best torque speed of the engine, and 900 rpm, intermediate speed of the engine. Water cooled pressure sensor is used for pressure measurement, and APEX innovations, Calcutta, India: soft ware E9114 is used to record the combustion pressure in the cylinder. In cylinder pressure and crank angle was recorded using the data acquisition system consisting of PC class computer with data acquisition board. The system was placed with crank shaft encoder at 360 points per engine revolution. The cylinder pressure signal is based on the data acquired during zero consecutive working cycles of the engine. Thermocouple was placed in the exhaust manifold to measure the temperature of the exhaust gases. Engine performance characteristic parameter were monitored and recorded. All other data necessary for final evolution including air flow, fuel flow, pressures, and temperatures were also recorded. The eddy current dynamometer is used to measure the power (or torque) and brake load was varied in five equal steps.

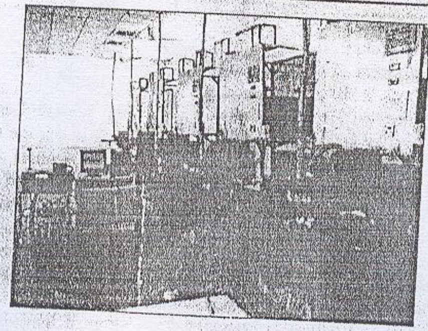


Fig.2: Photograph of Experimental Set-Up

Table 3: The observed engine performance using diesel and biodiesel

Performance	Diesel	Biodiesel	30% Biodiesel& 70% Diesel
Brake power , kw	0.466	0.895	0.435
Specific fuel consumption, g/kwhr	784	629.74	1303
Mass of fuel, kg/hr	0.712	0.62	0.56
Brake thermal efficiency,%	11.76	24.09	9.6
Mass of air, kg/hr	7.94	5.52	8.7
Air fuel ratio	31.15	8.9	23.8

The engine is started with diesel and once the engine warms up, it is switched over to biodiesel or blends. After concluding the tests with biodiesel or blends, the engine was again switched back to diesel before stopping the engine until the biodiesel or blends was purged from the fuel line, injection pump and injector in order to prevent deposits and cold starting problems. The Exhaust gas analyzer (Model: Delta 1600 L) is used for measuring gaseous emissions and PM is measured by filter cloth method.

Two-stage filtration is used to better separate the PM from exhaust. Two filters are weighed before setting to exhaust. Then those are set to the exhaust and full flow of exhaust is passed through the filters. Again, filters are weighed with PM loading. Difference of the two readings before and after their use indicates the PM in the exhaust at that condition. Backpressure is measured by a U-tube mercury/water manometer. Exhaust odor was measured by sensual assessment method. This method is used to assess exhaust odor. In other study, pH measurements by cold trap methods under various conditions were attempted [23], but due to the poor reproducibility of the tests, the author suggested the bag sampling method. This study also used bag sampling method for pH determination. The bag used to sample gas is of 15% volume and the sampling time is only about 5 s. After sampling the gas, 25 cc of pure water is poured into the bag to create a solution. The bag containing the sample solution is then cooled to −10°C about 5min to condense the odorous components. After that, the pH value of the solution is measured by a pH meter. There is a very good correlation between exhaust odor and the pH value of the aqueous solution of exhaust gases [27]. Every odor data point was verified by the pH value at that point.

IV. COMBUSTION ANALYSIS

Emission Analysis:

Energy sources being considered diesel, biodiesel and their blends, for the purpose of present work. After the engine reached the stabilized working condition fuel consumption, air consumption, engine load and exhaust emissions were measured. Maximum torque of the engine for diesel was varied from 11 N-m to 27 N-m when engine speed changed from 700 rpm to 1150 rpm. Similar trend of torque was found for B20 and B100 at different loads and engine speeds

Oxidation Mechanism:-.

NOX production in CI engines is very complex, because it is influenced by many factors and many of these factors interact at different levels. NOX is mainly a function of temperature in the combustion chamber. The combustion timing relates to the start of combustion relative to the piston position in the cylinder. The combustion timing relates to the start of combustion (SOC) relative to the piston position in the cylinder. Early combustion timing causes combustion to occur closer to TDC and perhaps during compression process, increasing pressure, temperature, and the NOx emission. A number of fuel properties have been shown to effect the emissions of NOx [28]. Usually at a temperatures of above 2100 K, the nitrogen and oxygen disassociate and participate in a series of reactions (Eqn.(a), Eqn.(b), Eqn.(c), Eqn.(d), and Eqn.(e)) [29] and this oxidation mechanism is known as Zeldovich mechanism as shown in equation 1.

(a) $O + N2 \rightarrow NO + N$------------ (1 a)
(b) $N + O2 \rightarrow NO + O$ ----------- (1 b)
(c) $N + OH \rightarrow NO + H$------------ (1 c)
(d) $NO + HO2 \rightarrow NO2 + OH$------ (1 d)
(e) $NO2 + O \rightarrow NO + O2$---------- (1 e)

Oxidation mechanisms (Zeldovich) for NOx formation

Biodiesel fuel has different physical properties such as higher density, speed of sound, and bulk modulus which can also lead to an earlier start of injection. Early injection timing and higher CN, advance the combustion timing which tends to increase the NOX. The combustion rate , as indicated by the heat release rate, also has an effect on NO_X production. More premixed combustion means a high initial rate of combustion, which increase NO_X. Premixed combustion corresponds to the fuel that is mixed with air and prepared to burn during the injection period. When the fuel auto ignites it usually burns very quickly. Cetane number and fuel volatility are the two most important properties that determine the combustion rate. High cetane number and low volatility lowers the combustion rate. A biodiesel with a high cetane number is expected to shorten the ignition delay period and thus the lower the amount of fuel that involved with the premixed portion of the biodiesel combustion, thus lowering NO_X emission.

V. RESULTS AND DISCUSSION

Performance:- After the engine reached the stabilized working condition fuel consumption, brake specific energy consumption, and brake thermal efficiency which are discussed as follows.

At 700 rpm, the brake specific fuel consumption is decreased from 0.65 kg/ KWh at low load to 0.4 kg/ kWh at full load for diesel fuel. With B30, the brake specific fuel consumption (bsfc) is decreased from 0.825 kg/kWh at low load to 0.4 kg/kWh at full load. The bsfc with B100 is decreased from 0.75 kg/kWh at low load to 0.59 kg/kWh at full load. For all loads, the fuel consumption of Jatropha bio diesel is more than that of diesel fuel and at maximum power output the fuel consumption for diesels. At low load condition, bsfc with B30 is about 21% and with B100 33% higher than that diesel.

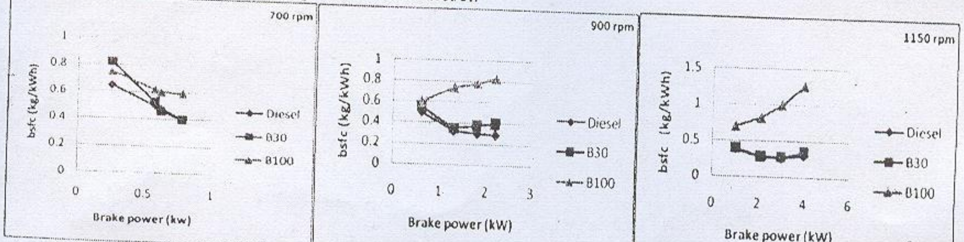


Fig 3: Brake specific fuel consumption with various fuels at different engine speeds and loads.

At 900 rpm and 1150 rpm under full load operation, penalty in bsfc is 25-35 % for B100 in comparison to diesel fuel. At full load operation maximum power of the engine is produced that needs higher amount of fuel energy. The Jatropha biodiesel contains more percentage of oxygen and consequently less percentage Hydrocarbons and calorific value than that of diesel fuel. Therefore due to lower calorific value of Jatropha biodiesel, this behaviour of more fuel consumption was expected for all power outputs.

Brake thermal efficiency:

Fig 4. Shows the variation of brake thermal efficiency with power output. The brake thermal efficiency increases as the output power increases for both the fuels. At 700 rpm , the brake power was increased from 0 to 1.1 kW. The brake thermal efficiency was increased from 11 % at low load to 20 % at full load for diesel. B30 showed very similar full load efficiency to diesel, but low load efficiency was about 3 % lower. B100 showed a little lower efficiency at full load operation than diesel, and low load efficiency also lower than diesel. At 900 rpm, the thermal efficiency with diesel fuel was higher than biodiesel and blends up to 70 % load. At 1150 rpm, B30 showed about 2% lower efficiency than diesel throughout. B100 showed about 8% lower efficiency than diesel up to 75% load. At full load operation. B100 showed higher penalty in efficiency about 3 % than diesel.

. Exhaust gas temperatures:-

Temperature of exhaust gases, leaving the cylinder represents the extent of temperature reached in the combustion chamber during combustion. It is observed that, with increasing load the cylinder pressure increases and more amount of fuel is burnt leading to an increase in temperature. The temperature of exhaust gases is observed to be higher with diesel as compared to Jatropha biodiesel for entire range of power output. This is expected as the calorific value of fossil diesel is more than that of Jatropha biodiesel, therefore greater amount of heat is released in the combustion chamber leading to higher temperature. Also there is an advanced combustion of Jatropha biodiesel due to its higher bulk modulus and cetane number, when compared to diesel. Therefore the heat released by fossil combustion is late by few degrees and thus more heat gets exhausted.

Whereas the exhaust gas temperature of B30 is higher than that of Jatropha biodiesel, which indicates increase in diffused combustion due to high rate of evaporation and improved mixing between Jatropha biodiesel and air. Therefore, as the fuel temperature increases, the ignition delay decreases and the main combustion phase increases, these in turn raise the temperature of exhaust gases.

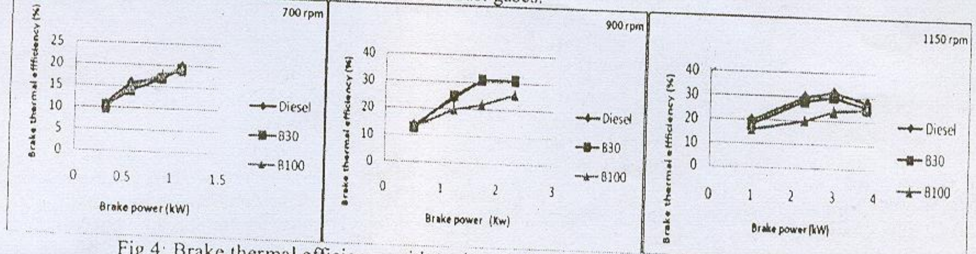


Fig 4: Brake thermal efficiency with various fuels at different engine speeds and loads.

Exhaust gaseous emissions:-

NOX, CO and PM are measured as emissions in this study.

1. NOX Emissions:-

The NOX emissions of diesel and Jatropha biodiesel fuels are plotted in the graph as shown in Fig 5. It shows for both the fuels, the increased engine load promoting NOX emission. Since the formation of NOX is very sensitive to temperature, which is responsible for thermal NOX formation. The Jatropha biodiesel is producing more NOX than diesel. At 700 rpm, 900 rpm and 1150 rpm NOX increased with the load. Overall NOX increase with B30 was about 4 % and with the B100 was 15 % . The increase in NOX B30 and B100 was found in good agreement with the oxygen content of B30 and B100. However, at low speeds no load conditions where ther was much excess of air, there was no increase in NOX emissions with biodiesel and blend as compared to diesel. Here, there is excess oxygen in the cylinder, but cylinder temperature is not enough to produce thermal NOX.

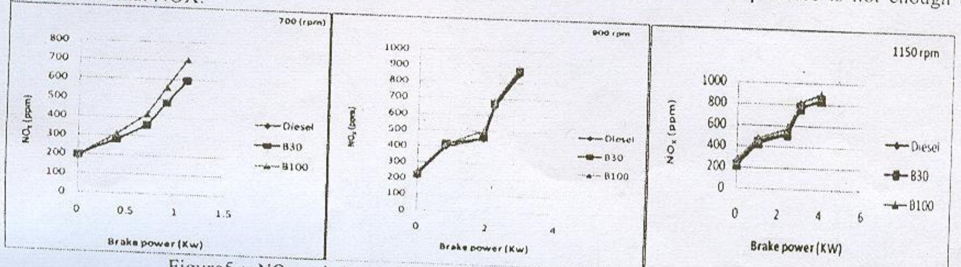


Figure5.: NO_X emissions with various fuels at different engine speeds and loads.

2. CO emission:

Fig 6. explains increasing trend of carbon monoxide emission levels for diesel, B30 andB100. This are observedwith power output, increasing trend of CO emissions is due to increase in volumetric fuel consumption and knock with the engine power output. At 700 rpm, 900rpm, CO decreased gradually from no load to about 75-85 % load, but increased sharply to about double at full load operation than its lowest value for all types of fuels. Less excess air at full load operation is responsible for very high CO emissions. CO decreased about 25 % with B30 and about 52 % with B100 than diesel throughout the whole operation range. At MBT speed of the engine (1150 rpm), very similar trend of CO reduction with biodiesel and blend than diesel was found. The maximum CO emissions with different fuels were observed at this condition due to least excess of air. Higher oxygen content in the local mixture favours better combustion producing less CO in case of biodiesel and blend

3. PM emissions:

Figure 7. Shows PM emissions at different engine speeds and loads for various fuels. At 700 rpm, PM emission at no load with diesel fuel is about 39 mg/m3 of exhaust gas. It increased to about 153 mg/m3 at full load operation, about four times than no load condition. At 900 rpm, PM emission at no load with diesel fuel is about 79 mg/m3 of exhaust gas. It increased to about 246 mg/m3 at full load operation, about three times than no load condition. At 1150 rpm, PM emission at no load with diesel fuel is about 97 mg/m3 of exhaust gas. It increased to about 639 mg/m3 at full load operation, about seven times than no load condition. B30 showed the PM about 20% and B100 about 30% less than diesel throughout the operation range. Particles are mainly formed during diffusion combustion, and most of the combustion process is diffusive at high load.

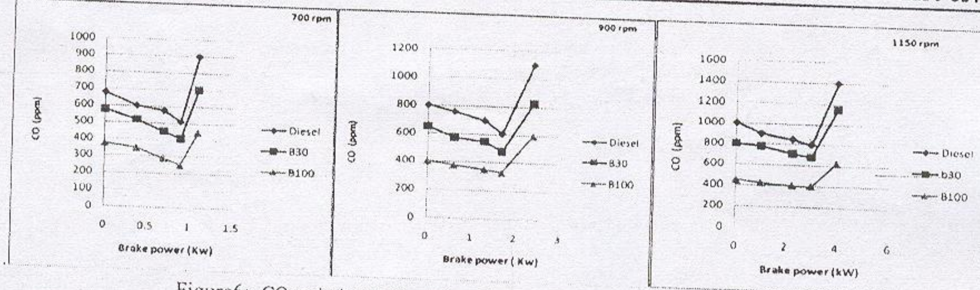


Figure6: CO emissions with various fuels at different engine speeds and loads.

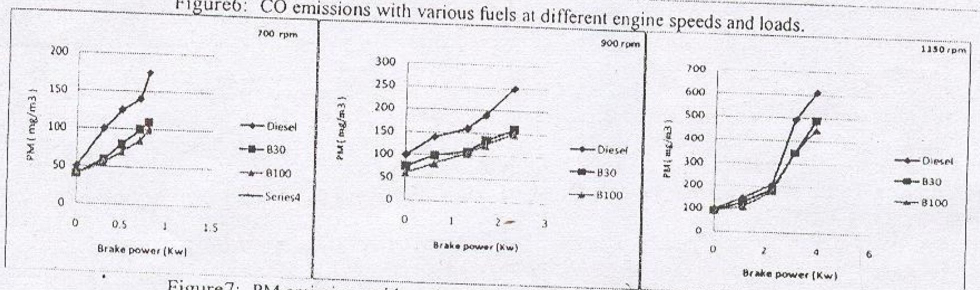


Figure7: PM emissions with various fuels at different engine speeds and loads.

VI. CONCLUSIONS

The present work confirms the influence of the higher bulk modulus of Jatropha biodiesel on combustion timing, the performance of a biodiesel and its blends as a diesel substitute on a small engine.The advanced combustion timing results increased NO_X emission. Overall NO_X increase with B30 was about 4 % and that B100 was about 12 % than diesel. The increase in NO_X emission of Jatropha biodiesel is attributed to the mono and poly unsatured fatty acids.

The average fuel consumption with B30 and B100 is higher than diesel. At low load low speed and high speed full load operations, the fuel consumption with biodiesel is much higher than diesel as compared to other conditions.The performance of the engine is increased when Jatropha biodiesel injected at diesel fuel viscosity.When engine speed and load are too low or too high bio diesel and blends have a greater penalty in efficiency in comparison to diesel. At low speeds- no load conditions where there was much excess air, there was no increase in NO_X emissions with bio diesel and blends as compared to diesel. Higher Oxygen content in the local mixture favours better combustion producing less CO in case of biodiesel and blends. B30 and B100 showed about 20 % and 50 % reduction in CO emissions, respectively than diesel.

B30 showed the PM 30 % and B100 about 45 % less than diesel at all operating conditions.

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