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Cover Page Footnote

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A Qualitative Study of Multi-Cylinder Conventional CI Engine using Madhuca Indica oil as fuel

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ABSTRACT

The present work is mainly discussed with a qualitative study of engine's significant characteristics fuelled with mahua bio-diesel & its different types of mixtures with neat diesel. The significant technical properties of various mixtures are tabulated. A 4-S multi-cylinder (6-Cylinder) DI conventional CI engine is used for the study under different speed modes. All types of characteristics for various mixtures are estimated in running the engine. Pure diesel is indicated by B-0 and pure mahua bio-diesel is represented by B-100. From the test results, it is found that B-25 gives almost the same BTE as B-0 at maximum load, compared to all the blends. The blend B-0 and B-25 give the least SFC of 0.332 and 0.268 kg/kWh at minimum speed (1200 rpm) and maximum speed (2400 rpm) at maximum load as contrasted to all mixtures. The B-100 gave 3.01% of NO_x while related to B-0 @ lower speed.

Keywords: Raw Mahua (Madhuca Indica) oil, Pure Diesel (B-0), Mahua Oil Methyl Ester (MOME), Pure Bio-diesel (B-100), Performance, Emissions

NOMENCLATURE

4S - Four-Stroke
AFR - Air-Fuel Ratio
B-0 - 100% Petro-diesel & 0% Bio-Diesel (Pure Diesel)
B-25 - 75% Petro-diesel & 25% Bio-Diesel
B-50 - 50% Petro-diesel & 50% Bio-Diesel
B-75 - 25% Petro-diesel & 75% Bio-Diesel
B-100 - 0% Petro-diesel & 100% Bio-Diesel (Pure Bio-diesel)
BTE - Brake Thermal Efficiency
EGT - Exhaust Gas Temperature
O_2C - Oxygen Concentration
CA - Crank Angle
CH_3OH - Methanol
C_2H_5OH - Ethanol
C_3H_7OH - Propanol
C_4H_9OH - Butanol
CI - Compression Ignition
CP - Cylinder Pressure
CR - Compression Ratio
CN - Cetane Number
CO_2 - Carbon-di-oxide
CO - Carbon monoxide
cSt - Centi Stroke
CV - Calorific Value
DI - Direct Injection
H_2SO_4 - Sulphuric Acid
HC - Hydrocarbon
HRR - Heat Release Rate
NaOH - Sodium Hydroxide
NOP - Nozzle Opening Pressure
NO_x - Oxides of Nitrogen
MOME - Mahua Oil Methyl Ester
MOEE - Mahua Oil Ethyl Ester
SD - Smoke Density
SFC - Specific Fuel Consumption
SG - Specific Gravity
SIT - Static Injection Timing
SOC - Start of Injection
SOI - Start of Combustion

rpm - Revolution Per Minute
% - Percentage

1. INTRODUCTION

In the present scenario, an increasing interest is evinced relating the non-conventional and future fuels. The above promising fuels are non-conventional edible/non-edible oils, their imitative and their blends with petro-diesel. For the past 100 years, lot of researchers have been doing their research on neat vegetable oils for the successful operation for diesel engine. Nevertheless, easily available fuel such as petro-diesel, in the last century the technical research on edible/non-edible oil based conventional engine fuels lost significance interest with time. Now, bio-fuel technical research has again got its important one due to cost of the petroleum hike. By using transesterification chemical process, the bio-diesel is imitative from edible/non-edible oils, for example, Groundnut, Cotton-seed, Pongamia, Madhuca Indica and Neem. Out of the above-mentioned edible/non-edible oils, raw non-edible oils are chosen for the operation of conventional engine process. The present experimental investigation is focused on mahua oil methyl ester (MOME). Mahua bio-diesel & its mixtures with pure diesel are mostly utilized to study the engine important parameters including performance and emissions.

Clark et al. (1984) concluded that soybean bio-diesel (B-100) gives greater SFC and lesser engine's emissions except oxide of nitrogen as related to B-0. Kyle Scholl, and Spencer Sorenson (1993) observed that while balanced to B-0, soybean bio-diesel gave lower CO, HC, SD and NO_x. Saravanan et al. (2010) studied on a conventional engine with neat mahua bio-diesel (B-100) & neat diesel (B-0). Finally, B-100 gave the least exhaust emissions as compared to B-0. Puhan et al. (2005) prepared the bio-diesel and briefed about its important engine's parameters & emission qualitative studies fuelled with B-0 and B-100 was done. The B-100 burn efficiently than B-0 and the emissions of B-100 are lesser than B-0. Sukumar Puhan et al. (2007) tested a CI engine and conducted fuelled with mahua oil methyl ester (MOME) & mahua oil ethyl ester (MOEE). While compared with MOEE, MOME gave significant test results.

Sharanappa Godiganur et al. (2009) reported the performance and emission particles evaluated by mahua bio-diesel and its various mixtures on conventional CI engine. It has been found that the B-20 identified as optimum blend among the blends. Raheman and Ghadge (2007) chosen mahua methyl ester mixed with petro-diesel & elaborately examined the performance with various blends. The researchers have found that a blend of 20% bio-diesel and 80% neat diesel was more appropriate for their engine. Ramesha et al. (2009) investigated the engine by transesterified mahua oil & its different mixtures with standard engine setup of the diesel engine. They suggested that 20% of bio-diesel mixed with 80% of diesel (B-20) gives lower emission and better combustion among the blends. They have also studied the B-20 blend, with varying nozzle opening pressures. They concluded that the higher injection pressure gives lower oxide of nitrogen (NO_x) emissions. Priyanka Sharma et al. (2017) studied a diesel engine fuelled with pongamia bio-diesel. It was concluded that pongamia bio-diesel with 20% combination performs reasonably well as compared with neat diesel.

Ingle and Nandedkar (2013) operated a CI engine with castor oil bio-diesel and found that there was a significant reduction in smoke density in the case of castor oil bio-diesel as compared with neat diesel. It was concluded that methyl esters of castor oil can be used as a substantial alternate fuel for diesel engines without any changes on it. Solaimuthu and Govindarajan (2015) operated a mono-cylinder CI engine with transesterified mahua oil and its mixtures with diesel. B-25 gave greater performance and lesser emissions. Ravikumar et al. (2013) operated mono-cylinder engine with coated engine, the B-25 provides greater performance and lesser emissions. However, the NO_x emission is seen to be greater @ maximum load. Sundarraj et al. (2010) studied and analysed on CI engine with 1, 4 dioxine-ethanol-diesel (1, 4 D-E-D) mixtures with &without thermal barrier coating (TBC). At last, 10D-20E-70D mixture by volume gave better performance and lesser emissions. Sukumar Puhan and Nagarajan (2008) operated the CI engine fuelled with various mixtures of transesterified mahua oil and diesel. It has been concluded that there was a reasonable drop in emissions including NO_x. The oxides of nitrogen reduction may be due to specific fatty acid composition. Salunkhe Karan Vishwas et al. (2018) operated the CI engine with punnai oil using egg shell combination. The punnai/tamanu bio-diesel was produced by using transesterification method by using calcined egg shell as a catalyst. At the end of the process, it has been found that better performance and less emissions were produced by bio-diesel as compared with neat diesel fuel.

Kapilan et al. (2008) compared the engine parameters of bio-diesels extracted from non-edible oil (mahua) & edible oil (gingili). It was found that not much difference between mahua & gingili with respect to engine all kinds of parameters. Kapilan and Reddy (2008) used mahua oil methyl ester as a substantial fuel for diesel engine operations. The mahua oil methyl ester gave the lesser exhaust emissions than that of neat diesel. Kapilan et al. (2009) operated the diesel engine to calibrate the effect of injection time fuelled with mahua bio-diesel. The B-100 could be used as a substantial fuel for conventional diesel engine with higher static fuel spray timing for getting good condition of performance and lesser exhaust emission parameters.

Oniya and Bamgboye (2016) studied a diesel engine with loofah bio-diesel. It was found that there is a significant reduction in emissions and slight variation in performance and hence, it could be suitable for diesel engine operation.

Kale et al. (2009) studied a conventional engine with transesterified mahua oil in different blends. An increasing trend was found in BTE of the engine with pre-heated raw vegetable (mahua) oil blended with flow improvers. Miqdam Tariq Chaichan (2016) operated the multi-cylinder engine with all types of mixtures of transesterified corn oil with petro-diesel and found that significant part on smoke density. In Iraq based petro-diesel, lesser amount of Particulate Matters has been observed. Rajendiran et al. (2013) investigated research on 6-cylinder DI CI engine which was operated with mixtures of B-0 blended with important additives. It has been found that better results of performance and lower in emissions. Vijayaraj and Sathiyagnanam (2016) found that the non-edible bio-diesel gives similar parameters to that of neat diesel. The BTE, UBHC and SD were noticed to be lesser non-edible bio-diesel mixtures than B-0. The CO exhaust emission for B-25, B-50 and B-75 is noticed to be lesser than diesel at maximum load condition, whereas for B-100 it is greater. Akhilendra Pratap Singh et al. (2021) studied reactivity-controlled compression ignition (RCCI) provides lowest oxides of nitrogen and particulate matter as compared with conventional engine method. However, the emissions of carbon monoxide, hydrocarbon was greater while compared with base engine type.

Suraj et al. (2021) focused a neat diesel, new and aged karanja bio-diesel to study the various combustion parameters by varying injection pressures. Finally, the test results reveal that decreased flow rate of mass at lesser fuel injection pressure with new and aged karnaja bio-diesel while compared with B-0. At last, the study concluded that similar atomization analysis results were obtained for new and aged karanja bio-diesel.

Mohammed El-Adawy et al. (2018) operated diesel engine with a speed variety from 1000 to 2000 rpm @ 250 rpm gaps and 3 different CRs (14:1, 16:1 and 18:1) under maximum load, and various intake air pressures. It has been found that using the concept of supercharger gave better results of the multi-fuel mode by 25percentage at the greater CR of 18:1 while compared to normal aspiration mode. Shyam Pandey et al. (2018) studied a diesel engine and found that there was a significant improvement in fuel economy and reductions in particulate matters and NO_x by using alternate fuels like alcohol, hydrogen natural gas and bio-fuels. Solaimuthu et al. (2015) concluded that B-25 gave suitable fuel along with SCR device which gives significant reduction in NO_x.

From the above literature review, it has been observed that there is a considerable interest in the bio-diesel applications to cram the significant parameters of a conventional diesel engine without much change. This qualitative study focuses a detailed experimental investigation of four-stroke multi-cylinder cylinder DI CI engine with NOP of 220 bar and SIT of 18° bTDC with eddy current dynamometer using neat diesel, combination of Diesel and bio-diesel in various blend ratios.

2. EXPERIMENTAL INVESTIGATION PROCEDURE

Table 1: Six-Cylinder Diesel Engine' Specifications

Category of the Engine	4S Six-Cylinder DI Diesel Engine
Make	HINO W06D and manufactured by Ashok Leyland
Cylinders' Count	Six
Cubic Capacity (CC)	5759 CC
Nozzle Opening Pressure (NOP)	220 bar
Bore Diameter x Stroke Length	104 mm x 113 mm
Fuel Static Injection Timing (SIT)	18° bTDC
Firing Order	1-4-2-6-3-5
Full Torque	@ Minimum Speed of 1600 rpm, 290 N-m
Compression Ratio (CR)	17.9:1

An experimental test procedure has been investigated on a 4-S, HINO W06D with 6-cylinder with producing output power of 71 kW @ maximum load connected. Figure 1 indicates that the schematic line configuration of the engine and Table 1 shows that the important engine details. The modified NOP of 220 bar and SIT of 18° bTDC is employed during the whole trials for the engine under steady state condition. Under steady state condition, using a device, AVL 437 smoke meter, the Smoke Density can be measured accurately. Using AVL 444 digital gas analyzer, the calibration of emissions such as NO_x, CO_2, CO & HC can be done.

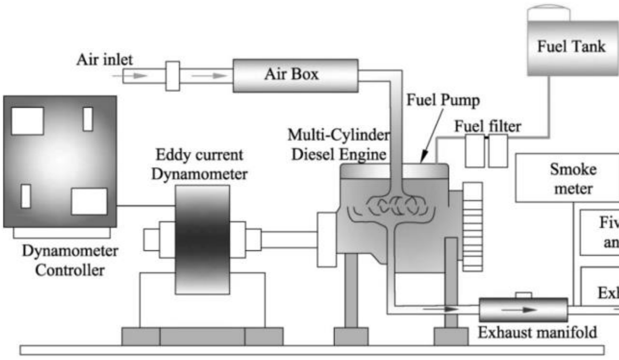

Figure 1: Line Diagram of the Six-Cylinder CI Engine

3. VARIOUS PROPERTIES OF DIESEL, BIO-DIESEL AND ITS BLENDS

Table 2: Properties of the fuels

Property's Name	B-0	B-25*	B-50	B-75	B-100
Acidity	0.065	0.067	0.070	0.083	0.26
Cloud Point (Deg ºC)	-15.1	4.1	8.0	11.0	13.1
Flash Point (Deg C)	65.0	71.0	78.0	112.0	170.0
Fire Point (Deg C)	70.0	79.0	88.1	123.1	183.0
Cetane Number	46	51.6	51.7	51.8	52.4
Kinematic Viscosity @ 40ºC, cSt	2.60	3.48	4.16	4.97	6.03
Gross Calorific Value (kJ/kg)	45596	43976	43268	42523	41819
Specific Gravity	0.82	0.83	0.85	0.87	0.88

Table 2 indicates the values of pure diesel (B-0) to pure bio-diesel (B-100). Using quantitative standard measurement facilities, various technical characteristics of transesterified mahua (Madhuca Indica) & its different mixture with petro-diesel are calibrated and tabulated systematically. In Table 2, it could be seen that Mahua oil category has lesser gross calorific value but greater density, representing that CV of volumetric content of mahua oil approaches the qualitative CV of pure diesel.

It could also be seen that the transesterified mahua oil, cetane number (CN) rises along with flash & fire point while related to B-0. Volumetric proportions of mixtures are as follows: B-0 (pure diesel), B-25 (75% diesel and 75% transesterified mahua oil), B-50 (50% diesel and 50% transesterified mahua oil), B-75 (25% diesel and 75% transesterified mahua oil) and B-100 (pure transesterified mahua oil). Kinematic Viscosity, Density, cloud point, flash & fire point and acidity increases with bio-diesel content increases. Reasonable rise in fire point indicates that volatility of mixture with bio-diesel content increased will diminish. Net CV reduces as increase in bio-diesel content. This may be due to O_2 in fuel & it needs more amount of fuel content to be burnt for a specified causes of heat phenomena. Table 3 indicates that accuracy details of smoke meter and AVL Di-Gas analyser.

Table 3: Smoke meter and AVL Di-Gas Analyser's Accuracy Details

Measuring Device	Accuracy Details	Range Value
Crank Angle Encoder	0.1° Crank Angle (CA)	0 to 20,000 rpm
Engine Pressure Sensor	0.1 bar	0 to 250 bar
Exhaust Smoke meter	± 2%	0 to 100% opacity
Inlet air of Manometer	± 2%	0 to 1000 mm of Hg
Dynamometer	± 0.20%	0 to 750 N-m
Flow Meter of the Fuel	0.50%	0 to 500 ml
Oxide of Nitrogen	1 ppm	0 to 5000 ppm
Hydrocarbon	1 ppm	0 to 20,000 ppm
Carbon di-oxide	0.1 vol.%	0 to 20 vol.%

4. BIO-DIESEL PRODUCTION

Table 4: Raw Mahua Oil's Fatty Acid Proportions

Formula	Fatty Acid	Structure	Weight (%)
$C_{18}H_{34}O_2$	Oleic Acid	18:1	37.00
$C_{20}H_{40}O_2$	Arachidic Acid	20:0	1.50
$C_{18}H_{32}O_2$	Linoleic Acid	18:2	14.30
$C_{16}H_{32}O_2$	Palmitic Acid	16:0	24.50
$C_{18}H_{36}O_2$	Stearic Acid	18:0	22.70

In general, straight vegetable oil will have fatty acids (olenic, linoleic, palmitic, lingnoceric, stearic, behenic, eicosenoic and arachidic). Of this mahua oil includes the waterlogged fatty hexadecanoic and octadecanoic acid and the unsaturated octadec-9-enoic acid and 9, 12-octadecadienoic acid. In general, the raw mahua oil is naturally and easily obtainable in all kinds of market. Table 4 indicates that the fatty acid proportion of straight vegetable (mahua) oil. Transesterification process is one of the best processes which create the reaction between an alcohol content and triglyceride content in the occurrence of a reasonable quantity of catalyst to generate glycerol & required amount of ester content. An optimized proportion, 3:1 molar ratio of alcohol and triglycerides is required for transesterifcation process which helps to produce bio-diesel content. Among all types of alcohol categories that can be utilized in the transesterification mechanism are CH_3OH, C_2H_5OH, C_3H_7OH and C_4H_9OH. CH_3OH and C_2H_5OH are mostly utilized and particularly CH_3OH because of its less cost[9]. Straight edible/non-edible oil is finished to react with CH_3OH in the presence of catalyst which generates mixture of glycerol and alkyl ester. This oil can be generated by a 2-step base-acid chemical process. Raw mahua oil is transesterified by adding CH_3OH as reagent & H_2SO_4 and NaOH as catalysts, to succumb bio-diesel (mahua oil methyl ester).

5. RESULTS AND DISCUSSION

5.1 Brake Thermal Efficiency (BTE)

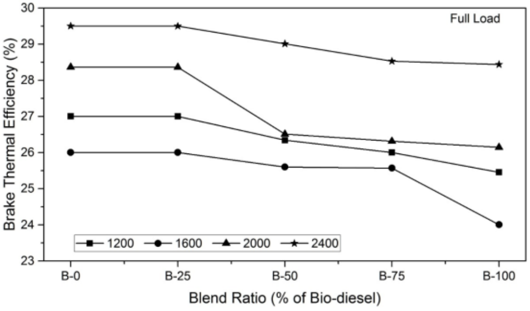

Figure 2: Brake Thermal Efficiency vs Mixture Ratio

The technical difference of brake thermal efficiency (BTE) & blend ratio for minimum speed (1200 rpm) to maximum speed (2400 rpm) is shown in Figure 2. As can be seen, B-0 and B-25 have almost the similar maximum BTE. It could be observed that at all types of loads, pure bio-diesel (B-100) gives lesser BTE. At minimum load & maximum load, the BTE for B-100 is 8.41% & 6.39% is lesser while related to B-0 & B-25. For all mixtures, the same observation has been noted. From Table 2, it is evident that CV of pure diesel (B-0) is greater than that of pure bio-diesel (B-100). Specific gravity and heating value are purely depends for BTE. The amalgamation of heating value & flow rate of mass represent input of energy to the CI engine. The present input of energy to the CI engine in case of B-50, B-75 and B-100 are greater while related to B-0. This could be the main factor to have lesser BTE for all mixtures of fuel as related with B-0. The same results were reported by Puhan et el. (2005).

5.2 Specific Fuel Consumption (SFC)

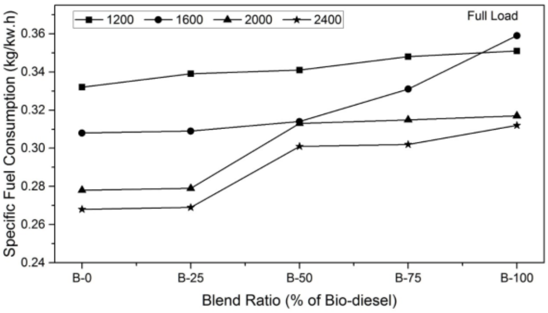

Figure 3: Specific Fuel Consumption vs Mixture Ratio

The difference in specific fuel consumption (SFC) for B-100 to B-0 is indicated in Figure 3. From this figure, it could be observed that the B-0 and B-25 give lesser SFC of 0.332 & 0.268 kg/kW.h. However, the B-100 gives the greater SFC of 0.351 & 0.312 kg/kW.h respectively @ minimum speed load & maximum speed at maximum load condition. For B-100, the % increase in SFC at minimum load & maximum load is 13.01% and 15.32% respectively while compared to B-0 & B-25. The similar tendency is noticed for all mixtures. It could be noted from Table 2 that all the mixtures have lesser CV compared to pure diesel (B-0). SFC reduces with the increase in load for all mixtures. Nevertheless, at every load B-0 and B-25 have the least SFC & these rise with the mixed value. This could be due to reasonably greater kinematic/dynamic viscosity and lower CV. This may be due to higher in fuel amount with higher in load which roots satisfied utilisation of atmosphere air leading to improved engine combustion process. At minimum load, CI engines function with very lean blend. The blend B-0 and B-25 give the lowest SFC.

5.3 Heat Release Rate (HRR)

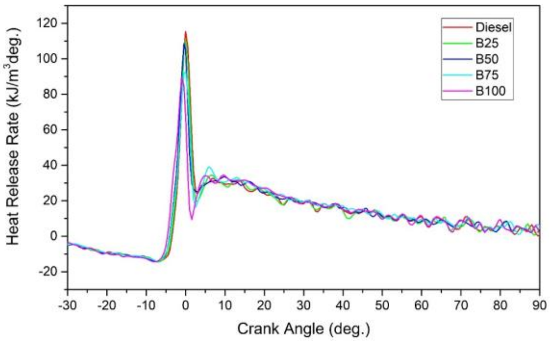

Figure 4: Heat Release Rate vs CA @ Maximum Load

The graphical representation between Heat Release Rate (HRR) and crank angle for B-100 to B-0 is shown in Figure 4. From the graphical representation, it could be found that the B-0 provides maximum HRR followed by B-25 at 0-degree CA @ maximum load condition. The present study represents better combustion for B-0 while related to all the mixtures. However, while compared with B-0, the % diminution in HRR for B-100 is 40.93% at 0-degree CA. This may be due to the decrease in CV for B-100 when compared to B-0. Lower injection timing gave better combustion. The similar test results were reported by Kyle Scholl, C. Spencer Sorenson (1993).

5.4 Combustion Cylinder Pressure (CCP)

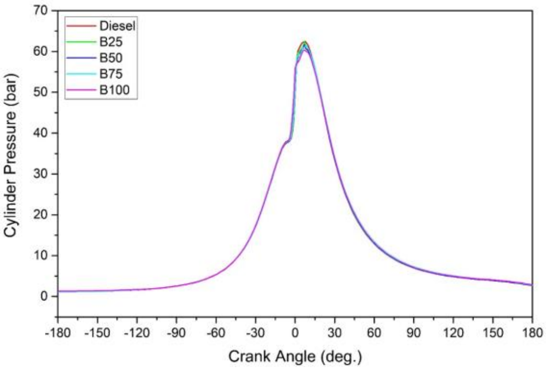

Figure 5: Combustion Cylinder Pressure vs CA @ Maximum Load

The variation of combustion cylinder pressure (CCP) and CI engine CA for B-100 to B-0 at maximum load is represented in Figure 5. The optimum pressure occurs at 8±1° CA for every mixture of fuel at maximum load could be seen. The pure diesel gives maximum peak pressure while compared to other mixtures. However, B-25 gives almost same optimum pressure at the same load condition. It could be noted that there is no significant variation between B-0 and B-25. The delay period has been evaluated as 8±1 degree CA between the SOI and the SOC at maximum load. According to combustion, among all blends, B-25 will be a better option to operate the CI engine without any modification on it. From Table 2, it could be noted that the B-25 gives higher caloric value while compared to other mixtures even as compared to B-0, this variation is only slightly lesser. The % reduction of CV for B-25 is 3.59% while related with B-0. This result may be as compared to B-0, slight reduction in the cylinder pressure B-25 (Kyle Scholl, C. Spencer Sorenson, 1993).

5.5 Exhaust Gas Temperature (EGT)

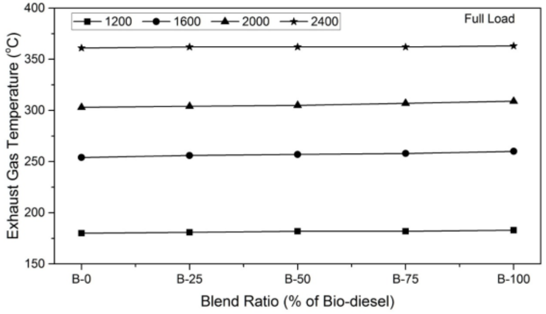

Figure 6: Exhaust Gas Temperature vs Mixture Ratio

The deviation of exhaust gas temperature (EGT) and mixture ratio of B-0 to B-100 is shown in Figure 6. It is observed that B-0 gives lowest exhaust gas temperature, whereas the B-25 gives slightly higher exhaust gas temperature. The similar method is noticed for all types of mixtures. For B-25, the percentage increase in EGT is not much different from B-0 at minimum load and maximum load whereas for B-100, the % increase in exhaust gas temperature is 6.23% and 0.545 respectively at minimum load and maximum load. From the figure 6, it could also be found that as the load rises, the EGT also rises for all types of mixtures. This may be due to the raised losses of heat of the greater mixtures, which is also clear from their lesser BTE while matched to B-0 (Raheman and S.V. Ghadge, 2007).

5.6 Oxygen Concentration (O_2C)

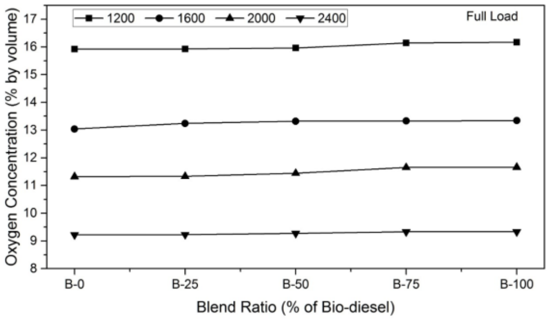

Figure 7: Oxygen Concentration vs Mixture Ratio

Figure 7 represents that the variation of Oxygen concentration (O_2C) for B-100 to B-0. The O_2C decreases for B-0 than that of the remaining mixtures. From the experimental investigation results, it is noted that at lower speed & higher speed, the B-0 gives smallest O_2C of 15.92% and 9.22% respectively, whereas the B-25 produces almost the same O_2C as that of B-0. At the same time, B-100 produces greater O_2C of 15.93% and 9.23%

compared to all the mixtures. The same trend is experienced for other mixture. As compared with B-0, the % increase of O_2C for B-100 is 1.58% and 1.19% respectively at minimum speed and maximum speed conditions.

From the test outcome, when the engine load rises the O_2C reduces. The O_2C in the exhaust indicates that there is reasonable deprived utilization of atmosphere air in an engine combustion chamber. The ester-based fuel content, as it includes O_2, the AFR necessity is lesser related to B-0 for successful burning process. At minimum load, the % increase in O_2 is greater than maximum load for B-100 while related to B-0. Therefore, when the load increases, there is a diminishing trend of O_2C oxygen. It implies that B-100 tends towards incomplete combustion during the operation (Sukumar Puhan et al. 2007).

5.7 Carbon di-oxide (CO_2)

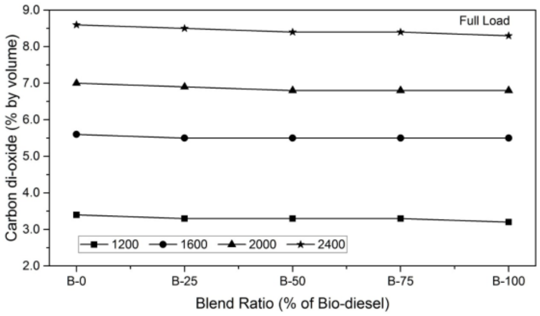

Figure 8: CO_2 vs Mixture Ratio

The graphical representation of carbon dioxide (CO_2) and mixture ratio for minimum speed (1200 rpm) to maximum speed (2400 rpm) is represented in Figure 8. From the present outcome, it could be noted that the neat diesel (B-0) emits highest, and B-100 emits lowest CO_2 emission for all loads compared to all other mixtures. The B-25 gives almost the same as that of B-0. Not much variation between B-0 and B-25 is found in terms of percentage variation in CO_2. For B-100 at minimum speed and maximum speed condition, the % reduction in CO_2 is 59.12% and 35.23% respectively as compared with B-0. The same trend is noted for all other mixtures. It seems that the B-0 gives better combustion with highest CO_2 emissions. The same is observed in oxygen concentration for B-0 which is lower than that of other mixtures.

5.8 Carbon monoxide (CO)

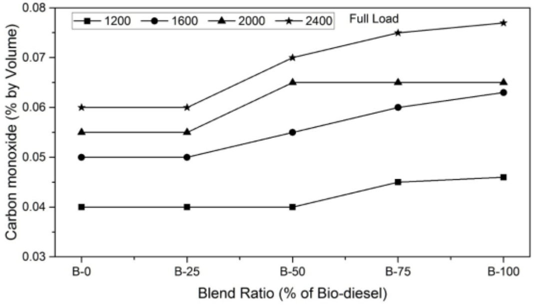

Figure 9: CO vs Mixture Ratio

The graphical representation in CO for B-100 to B-0 is indicated in Fig. 9. From the test outcome, it is evident that the B-0 & B-25 give least CO of 0.04% and 0.06% at minimum speed and maximum speed conditions, whereas B-100 produces greater CO of 0.046% and 0.077% respectively. The % increase in CO for B-100 is 19.56% & 46.12% at maximum speed and maximum load condition as compared with B-0 and B-25. It largely depends upon the various qualitative possessions. It can be seen (From Table 2) that B-0 possessions are favourable to have lesser carbon monoxide while compared to B-100. The present result may be due to the O_2 and CN of the fuel mixtures. Since the transesterified mahua based fuel includes O_2 in the fuel itself & it acts as a lower combustion supporter inside the engine.

5.9 Smoke Density (SD)

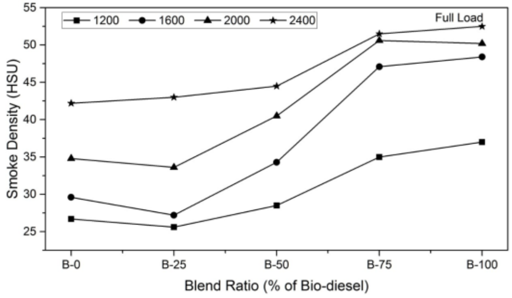

Figure 10: Smoke Density vs Mixture Ratio

Figure 10 shows that the graphical representation of smoke density (SD) over the complete mixture proportion for various speed from 1200 rpm to 2400 rpm. It could be noted from Fig. 10 that for each mixture, the SD rises with engine load including B-0. This could be likely accepted, because in all types of CI engine a device which is a quality governed one, it purely depends upon the local AFR. Rising in engine load @ steady engine speed is attained by rising the burning content extent. It has been noticeably clear that @ minimum speed (1200 rpm), B-25 has the least SD of 25.6 HSU, whereas B-100 has the greatest SD of 37.0. It is remarkably interesting to observe that B-25 generates lesser SD while related to pure diesel (B-0). Because of the chemistry of fuel mixture which may promise conducive atmosphere for lesser

SD for B-25 related to B-0. It is clear that SG change for B-25 while related to B-0 is quite petite and fire point rise is less than 10 deg C. Furthermore, there is considerable rise in cetane number (CN) between B-0 & B-25 which is seen from Table 2.

Most probably, this is the main motive for the shrinkage in SD @ minimum engine load. Further at minimum load, the CI engine is functioning at very lean mixture. As the load is rise from minimum load to 75 percentage there is only uniform rise in SD. Nevertheless, the SD for B-25 is lesser than B-0 over their engine brake power assortment for the causes described above B-75 & B-100 are nearly bunching together due to the fire point qualitative property which is greater than 100 deg C. From Figure 10, as the load rises from 75 to 100 percentage, there is a sheer rise in the SD for every other various mixture, as well as B-0. This is to be accepted since supplementary fuel is sprayed it. As the CI engine is operating @ uniform speed of 1500 rpm, there is fewer time for success burning process to take place which can reason for SD rise.

5.10 Hydrocarbon (HC)

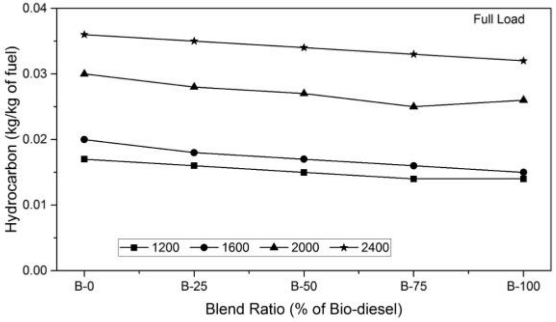

Figure 11: Hydrocarbon vs Mixture Ratio

The hydrocarbon (HC) graphical representation for B-100 to B-0 is represented in Figure 11. The hydrocarbon decreases for B-100 and B-75 than that of B-0 fuel at maximum brake power. From the experimental outcomes, it is noted that there is a very small difference of 0.01 in HC (g/kW.h) for B-100 and B-0 fuel at minimum speed condition. At minimum speed condition, the % reduction in HC is 4.42% for B-0 as compared with B-100. At maximum speed condition, for B-0 the % reduction in HC is 9.81% as compared with B-100. However, the B-75 mixture produces better reduction in HC as compared with all other blends at higher speed condition. The % reduction in HC for B-75 is 7.02% as compared with B-0 fuel at maximum load whereas at minimum speed the % reduction in HC is zero as compared to B-0 fuel. This may be due to the surface tension and kinematic/dynamic viscosities that affects the diffusion rate, ceiling diffusion & dimension of fuel droplet, which in turn affects the blending of working substance & atmosphere air. CN also acts an imperative position in detonation process. It could be noted from Table 2, that the CN of B-100 greater than that of B-0. Therefore, the B-0 emits more hydrocarbon than that of B-100 (Sukumar Puhan et al. 2007).

5.11 Oxides of Nitrogen (NO_x)

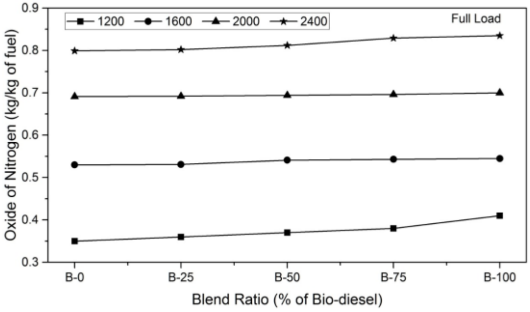

Figure 12: Oxides of Nitrogen vs Mixture Ratio

Figure 12 indicates that the difference in NO_x for B-100 to B-0. The maximum NO_x (kg/kW.h) is 0.41 for B-100 whereas for B-0 is 0.35 at lower speed. At higher speed, the maximum NO_x of 0.835 for B-100 whereas 0.799 is noticed for B-0. The deviation in NO_x @ maximum load is greater @ minimum speed condition of B-100 as compared with B-0. At maximum speed (2400 rpm), the % reduction in oxides of nitrogen for B-100 is 8.63% as compared with B-0 whereas at lower speed the variation in oxides of nitrogen is 3.01%. However, the B-75 mixture produces better reduction in oxides of nitrogen as compared with all other mixtures at maximum load. The % reduction in oxides of nitrogen for B-75 is 10.89% as compared to B-0 fuel at maximum speed whereas at minimum speed, the % reduction in NO_x is 3.12% for B-75. The % reduction in NO_x for B-100 is 0.97% while related to B-75 mixture. This result may be due to diminish in EGT. It is known that straight edible/non-edible based fuel contains a tiny quantity of N_2. Due to the above results, it could be stated that there is a possibility of generation of oxides of nitrogen (Puhan et al. 2005).

6. CONCLUSIONS AND FUTURE SCOPE

From the present qualitative study, it could be stated that the B-0 and B-25 give, optimum performance, whereas B-100 and B-75 give the inferior emissions of HC and NO_x. At last, it could also be concluded that B-25 could be used as a substantial fuel to run 4S, 6-cylinder DI CI engine with NOP of 220 bar and SIT of 18° bTDC. Due to this, 25% of the valuable pure diesel can be saved.

The present research has immense potential in finding ways to reduce environmental pollution and global warming, two major problems requiring due attention. In support of achieving the goal it is suggested to extend the research work in the following possible ways.

* By changing some other methyl esters of vegetable oil using EGR and SCR techniques in DI mono and multi-cylinder diesel engine and CRDi.
* By adding the oxygenated additives with diesel fuel and different blends of mahua bio-diesel for analyzing the performance, combustion and emission characteristics of direct injection mono and multi-cylinder diesel engine and as well as CRDi.
* By using different blends of mahua bio-diesel with fossil diesel and as well as oxygenated additives with diesel fuel in a semi adiabatic and as fully adiabatic DI mono and multi-cylinder diesel engine.
* By using ethyl ester/propyl ester/butyl esters of mahua oil and some other vegetable oil with SCR and EGR techniques in a mono and multi-cylinder DI / CRDi.
* By adding thermal barrier coatings in an engine cylinder and its parts using conventional mono and multi-cylinder diesel engine with mahua bio-diesel/esters of vegetable oil.
* By changing Variable Compression Ratio (VCR) diesel engine.

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