Performance Analysis and Emission Characterization of Various Blends of Mustard Oil Biodiesel on Automotive C.I. Multi Cylinder Engine

Deepak Ashri[1] Supreet Singh[2] Mayank Chhabra[3] Rajeev Kumar[4]
[1,2,3,4] Mechanical Engineering Department
[1]M.Tech Scholar, Galaxy Global Group of Institutions, Ambala, India
[2, 4]PhD Scholar, PTU, Punjab, India
[3]Asst. Prof., Amity University, Noida, India

Abstract—*The Bio fuels, fuels derived from biomass have been gaining the attention as of highly renewable, biodegradable and locally available. Bio fuels are carbon-neutral, nontoxic and reduce emission of volatile organic compounds. These fuels are not only green in nature but also help to reduce dependence on imported oil. Biodiesel, obtained from vegetable oil or animal fats and Bio crude, synthetic oil was directly used as a fuel. Vegetable oil also has low volatility, which leads to incomplete burning and formation of deposits in the fuel injectors. To improve the properties of these vegetable oils for use in diesel engines, transesterification appears to be a promising approach which reduces viscosity. In this present research work experiments are conducted after transesterification using blends such as B15, B25, B35 and B45 of Mustard oil Bio Diesel with diesel to study the effect of reduced blend viscosity on emissions and its effect on fuel consumption, specific fuel consumption, brake thermal efficiency and smoke density etc with respect to the load on the engine were reported. The results of experimental investigation were compared with that of pure diesel. The objective of the present research was also to explore technical feasibility of Mustard oil bio-diesel in direct injection CI Automotive multi cylinder engine without any substantial hardware modifications.*

Keywords: -Biodiesel, Viscosity, Brake Power, BSFC (Brake Specific Fuel Consumption), Smoke Opacity, BTE (Brake Thermal Efficiency), Blends

I. INTRODUCTION

The amount of greenhouse gas emissions, generating energy from renewable resources is being possessed a high priority gradually to decrease both over-reliance on imported fossil [2]. Biodiesel is advised for use as an alternative fuel for conventional petroleum-based diesel chiefly because it is a renewable, domestic resource with an environmentally friendly emission profile and is readily biodegradable [1,8] . Biodiesel is defined as a fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats [4]. The high viscosity and poor volatility are the major limitations of vegetable oils for their utilization s fuel in diesel engines. Because high viscous vegetable oils deteriorate the atomization, evaporation and air-fuel mixture formation characteristics leading to improper combustion and higher smoke emission [10]. Moreover this high viscosity generates operational problems like difficulty in engine starting, unreliable ignition and deterioration in thermal efficiency. Converting to biodiesel is one of the options to reduce the viscosity of vegetable oils [3, 7]. Take an example , for process of biodiesel making,100 pounds of Mustard oil or fat or other oils are reacted with 10 pounds of a short-chain alcohol (usually methanol) in the presence of a catalyst (usually sodium hydroxide [NaOH] or potassium hydroxide [KOH]) to form 100 pounds of biodiesel and 10 pounds of glycerin. Glycerin is a sugar, and is a co product of the biodiesel process as shown in figure 1 & 2 [9].

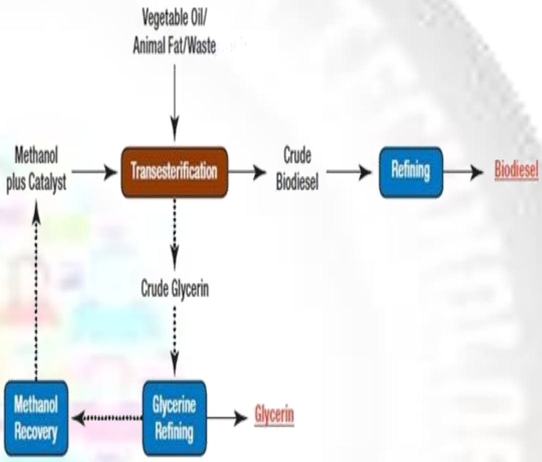

Fig. 1:[9]

Fig. 2:

A. *Performance Characteristics of Compression Ignition Engines*

The application of the engine decides the relative importance of these parameters. The specific power output is more important for marine engine whereas specific fuel consumption is more important for industrial engines. The basic parameters which are considered for evaluating the engine performance are:

a. Brake power.
b. Thermal efficiency.
c. Specific fuel consumption.
d. Volumetric efficiency.
e. Exhaust emission.

1) Brake power (B.P)

The part of power developed inside the engine cylinder is used to overcome the internal friction. The net power available at the shaft is known as brake power and it is denoted by B.P. It depends on speed of engine (R.P.M) and the load.

Mathematically, B.P = 2πNT/ 60000 KW. .

2) Mechanical efficiency (η_m)

It is the ratio of the brake power to the indicated power of the engine and expressed in percentage. It is the indication of the power lost in overcoming the friction. More is the friction; less is the mechanical efficiency of the engine.

Mathematically, η_m = B.P/ I.P, %
Where, B.P = Brake power, kW
I.P = Indicated power, kW

3) Thermal Efficiency (η_{th})

Thermal efficiency is defined as the ratio of work output at the engine shaft to the energy supplied by fuel. It is a measure of the engine's ability to make efficient use of fuel. Higher thermal efficiency indicates better utilization of fuel and running cost of engine is low.

Mathematically, η_{th} = B.P/ Heat supplied
Heat supplied = mf × C.V, kJ/ Sec.

4) Specific fuel consumption (SFC)

Specific fuel consumption is defined as the fuel consumed by engine in kg for per kW per hour. It is a measure of the engine's ability to make efficient use of fuel. Lower specific fuel consumption indicates better utilization of fuel and running cost of engine is low. Specific fuel consumption determined on the basis of brake power is called brake specific fuel consumption (BSFC) whereas specific fuel consumption determined on the basis of indicated power is called indicated specific fuel consumption (ISFC).

Mathematically, BSFC = Mf / B.P, Kg / kW-hr.
ISFC = Mf / I.P, Kg / kW-hr.

5) Volumetric efficiency (η_v)

Volumetric efficiency is the ratio of the actual volume of air inducted during suction stroke in the engine cylinder to the swept volume of engine cylinder and it is expressed in percentage. It is an indication of the breathing ability of the engine. It is important as it puts a limit on the amount of fuel which can be efficiently burned in an engine because power output is also proportional to the amount of air inducted during suction stroke.

Mathematically, η_v = Actual volume inducted during suction stroke measured at inlet conditions Swept volume of the engine cylinder.

6) Smoke & other Emissions

Smoke & other exhaust emissions such as Oxides of Nitrogen, Unburned HC etc. are nuisance of public environment. In addition to this CO_2 emission has global effect known as greenhouse effect. The performance of the engine should be such that the harmful emissions should be as small as possible and within the limits enforced by the Government authorities [5].

B. Desirable requirement of I.C Engines fuel

The basic requirement of I.C engine fuel is, the combustion should be fast with maximum amount of heat release without forming any deposits and should not have destructive effects on the engine parts and atmospheric air by exhaust gases. The good I.C engine fuel must possess the following properties.

1. It must have high energy density (kJ/kg) and good combustion qualities.
2. It should be easy to handle and store.
3. It should not have chemical reactions with the engine components, through which it flows.
4. Product of combustion should not be corrosive to the engine parts.
5. Its effect on air pollution should be minimum and possess low toxicity.
6. It must have low deposits forming tendency and must have thermal stability.
7. It should be economically available in large quantities. [6].

II. Literature Review

*A. D. Rachel Evangelene Tulip and K.V. Radha (2013) studied that*Fuel properties were determined for the mustard biodiesel. Performance and emission characteristics were investigated on internal combustion engine, smoke analyzer and emission analyzer. The results of the experimental study were concluded as follows:

– The CO emission of B20 was increased than diesel, while B40 and B60 reduced significantly.
– The CO_2 and smoke emissions were found to be slightly lesser than diesel fuel.
– When compared to diesel, NO_x emissions of all the blends of mustard biodiesel were found to be increased. As the blend ratio increased, the emission also increased respectively.
– HC emission reduced significantly due to the higher cetane number of the biodiesel.
– The exhaust temperature was increased with B20. B40 and B60 biodiesel mixture reduced the temperature as the blend ratio increased.
– The brake thermal efficiency of B20 was slightly higher to diesel due to the enough oxygen content. B40 and B60 were found to be inferior to B20.
– Brake specific fuel consumption of the blends was determined to be suitable at the mid load for the CI engine [11].

B. ***Kleinova (2011)***studied thatthe results of engine tests of these fuels show a decrease in maximum power and maximum torque in comparison to fossil diesel due to a lower energy content of triacylglycerols. These values are influenced also by a type of the engine used at testing. When compared to fossil diesel, the opacity of oil/fat based fuels is higher for an engine with lower injection pressures while it is lower for an engine with higher injection pressures. The level of both controlled and uncontrolled emissions was low for all tested bio fuels and was low also for the reference fossil diesel. The results of performance and emission tests for rapeseed oil containing 3 and 6 vol. % of anhydrous ethanol are comparable to those obtained for pure oil [12].

*C. Ram Rattan et al (2012)*determined the actual performance of mustard oil based bio diesel as an alternative fuel to diesel engine experiment was performed on small diesel engine (Kirloskar specified). The following conclusions may be find out from the experiment,

1. Biodiesel can be produced from mustard oil by transesterification reaction,
2. To reduce the density and viscosity of the higher blending biodiesel fuel, there must be a need of preheated of bio diesel up to a specific temperature. We can use the exhaust gas camber for pre heating the bio diesel by passing the inlet pipe through exhaust gas, so it is also a proper utilization of wastage heat
3. The higher blending of biodiesel must cause for higher Bsfc, because the mustard oil bio diesel have low calorific value as compare to pure diesel. [13].

*D. Gaurav Sharma et al (2013)*concluded that the conversion of biomass to energy (also called bio energy) encompasses a wide range of different types and sources of biomass, conversion options, end user applications and infrastructure requirements. Mustard oil biodiesel performed very well in vehicles. Fuel consumption increased compared to fossil diesel because biodiesel has slightly less energy per gallon than diesel fuel. The fuel filter had to be changed more often compared to what would normally be experienced with petroleum diesel. This may have been because the fuel filter material did not hold up well with biodiesel. This is due to the combined effects of the fuel density, viscosity and lower heating value of blends [14].

III. METHODOLOGY

A. Preparation of test blend samples

The various blends of bio-diesel and diesel were prepared in the chemistry laboratory of Ambala college of Engineering and Applied Research, India using splash blending technique. In splash blending technique the known quantity of pure bio-diesel was poured into the measuring cylinder containing the known quantity of conventional diesel from the top so that bio-diesel will get properly mixed with diesel and will not separate out on standing as bio-diesel density was more as compared to diesel. This was a very simple technique. The figure 3 and figure 4 shows the test sample prepared by splash blending technique.

Fig. 3: Splash Blending

Fig. 4: Blended Sample of Bio-diesel

B. Evaluation of Performance parameters and Smoke opacity

1) Experimental setup

The compression ignition engine set-up along with hydraulic dynamometer, load cell, fuel input measuring system, air intake measuring system, digital panel board, thermocouples for temperature measurement, digital tachometer and arrangement for measuring heat carried away by cooling water from engine jacket was supplied by K.C. Engineers Pvt Ltd., Ambala Cantt, Haryana, India. The set-up shown in the figure 5 consist of a variable speed 1400cc, four cylinder, 4-stroke, TATA make, DI Diesel Engine coupled to hydraulic brake dynamometer. The calibrated temperature sensors were used for temperature measurement. The hydraulic dynamometer was used to apply the load on the engine. The control panel shown in figure has digital meters to display the water temperature (inlet and outlet) for engine and calorimeter, exhaust gas temperature to and from the calorimeter, digital load indicator which displays the load acting on the engine. The set-up enables the study of engine brake power, fuel consumption, air consumption, heat balance, thermal efficiency, volumetric efficiency etc.

2) Engine test procedure

A four stroke, four cylinder water cooled diesel engine was employed for the present study. The detail specifications of the engine used are given in table and experimental set up as shown in table 1 & 2. Neptune OPAX2000*II*/ DX200P Smoke meter was employed to measure the smoke opacity of exhaust gas emitted from the diesel engine. The performance and emission tests were carried out on the C.I. engine using various blends of biodiesel and diesel as fuels. The tests were conducted at the constant speed of 1650 rpm at various loads. The experimental data generated were documented and presented here using appropriate graphs and observation and calculation tables. These tests were aimed at optimizing the concentration of ester to be used in the biodiesel-diesel mixture for engine test operation. In each experiment, engine parameters related to thermal performance of engine such as brake thermal efficiency, brake specific fuel consumption, exhaust gas temperature and smoke opacity were measured.

Fig. 5: Multi cylinder CI Engine Test Rig

Table 1 Test Rig Specification and Value of Constants

1	Diameter of orifice	0.0265 m
2	Cross-sectional area of orifice	0.000551 m^2
3	Coefficient of discharge	0.64
4	Density of air at 0 ˚C	1.293kg / m^3
5	Density of water	1000 kg/m^3
6	Specific gravity of diesel	0.845 gm/cc
7	Acceleration due to gravity	9.81 m/s^2
8	Specific heat of water	4.18 kJ/ Kg ˚C
9	Dynamometer constant	2000

Table 2 Engine Specification

1	Engine	4-cylinder, 4-stroke, DI engine
2	Horse Power	60 H.P
3	Bore Diameter	75 mm
4	Stroke Length	79.5 mm
5	Brand	TATA

3) Experimentation Methodology

First the experimentation was performed with diesel for getting the base line data of the engine and then with various blends of Mustard oil methyl ester and diesel such as B15, B25, B35, and B45. The performance of the engine was evaluated in terms of brake thermal efficiency, brake specific fuel consumption, mechanical efficiency and emission of the engine was analyzed in relation with smoke opacity or smoke density (HSU%).

4) Experimentation Procedure

1. Check for all electrical connections and proper earthlings for the equipments.
2. Ensure water in the main water supply tank.
3. Ensure selected fuel about 2 liters' in quantity in the fuel supply tank.
4. Fill the manometer up to half of the height of manometer with water.
5. Fill the burette with diesel by opening the valve provided at the lower side of burette.
6. Supply the diesel to the engine by opening the valves provided in the fuel supply line.
7. Open continuous cold water supply to the engine jacket.
8. Start electric power supply to the smoke meter and the control panel.
9. Start the engine by electric start motor. Let the engine run for five minutes on the minimum load so that engine gets stabilized and smoke meter warmed up simultaneously.
10. When engine starts running smoothly, firstly load the engine to desired value with the help of hydraulic dynamometer and as load increases R.P.M decreases so increase the fuel supply to maintain the desired constant R.P.M.
11. Run the engine for two minutes so that it can stabilize.
12. Note the reading of load cell and note the R.P.M of engine with the help of hand tachometer.
13. Close the diesel supply valve and open the valve of burette. Note down the quantity of fuel consumed in 15 seconds. It will give fuel consumption.
14. Now open the diesel supply valve which refills the burette.
15. After refilling the burette close the burette valve and continue the diesel supply by opening the diesel supply valve.
16. Note down the reading of manometer to calculate the air intake by the engine.
17. Note the temperature of inlet and outlet of water circulating through the engine jacket, displayed digitally on control panel
18. Note the temperature of exhaust gas expelled from the engine on the digital display control panel.
19. Measure the flow rate of water with the help of water meter and stop watch.
20. Note down the reading of smoke with the help of smoke meter.
21. Repeat the procedure for loads of 3.8, 6.5, 8.9, 11.5, 13.4, 15.6 kg maintaining the R.P.M constant.
22. Repeat the experiment for the B15, B25, B35 and B45 blends of bio-diesel and diesel.
23. When experiment is over reduce the load on engine and put off the engine.
24. Close the fuel supply and water supply to the engine.

C. Measurement of Parameter regarding engine performance and exhaust emission

The multi cylinder compression ignition (CI) engine set up along with digital control panel, hydraulic dynamometer with load cell, thermocouples with digital display for temperature measurement, exhaust gas calorimeter was supplied by K.C. Engineers Pvt. Ltd., Ambala Cantt, India. Following parameters were measured from the experimental multi cylinder CI engine set up.

1. Brake power
2. Fuel consumption
3. Air consumption
4. Cooling water temperature (inlet and outlet)
5. Speed of the engine
6. Exhaust smoke.

D. Measurements of Performances: Brake power is one of the most important parameter in the engine experiment. The hydraulic brake dynamometer was used for present investigation. The fuel consumption of an engine was measured by determining the time required for consumption of given volume of fuel using a glass burette. The mass of fuel was calculated by multiplying volumetric fuel consumption to its density. An air box with orifice meter and manometer was used for accurate volumetric measurement of air consumption and finally mass flow rate was determined. Digital type temperature sensor (thermocouples) was used for temperature measurement. On the basis of result Brake power, Brake specific fuel consumption, and Brake thermal efficiency are calculated & graphs are plotted.

E. Measurements of Exhaust smoke density or smoke opacity

1) Smoke Meter

The Hartridge type smoke meter was used to measure the smoke density. In this method the reduction in intensity of light beam when it passes through the smoke was used to obtain the value of smoke density and hence opacity. In the present work Neptune OPAX2000*II*/ DX200P -smoke meter manufactured and marketed by M/S Neptune India Pvt. Ltd, Gurgaon, and tested and approved by ARAI Pune was used for measuring the smoke density as shown in figure 6.

Fig. 6: Smoke Meter to measure smoke opacity

It measures the opacity of the polluted air, in particular diesel exhaust gases in a measurement chamber of defined measurement length. Opacity is the extinction of light between the light source and receiver. The smoke level or smoke density is defined as the ratio of electric output from photocell when sample is passed through the column to the electric output when clean air is passed through it. The smoke opacity is the extinction of light between light source and receiver. A light beam is projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particle in the exhaust. The remaining portion of the light falls on a photocell, generating a photoelectric current, which was a measure of smoke density in Hartridge unit.

IV. Results & Discussions

The biodiesel is produced by various methods among which transesterification of edible and non-edible oils are widely used worldwide. The concept of transesterification is gaining attention as methanol is derived from renewable biomass sources. The fuel consumption test and rating test of a 45 kW, four cylinders, and four stroke water cooled CI engine was conducted to evaluate the performance of the engine on diesel and on different blends of Mustard oil bio-diesel and diesel. A 45 kW, automotive, variable speed, four cylinders, and four-stroke diesel engine was tested on diesel and on B15, B25, B35, B45 blends of Mustard oil methyl ester and diesel. The brake thermal efficiency, mechanical efficiency, fuel consumption, brake specific fuel consumption and smoke opacity were measured. The results of parameters measured and their analytical interpretation with discussion are presented in this chapter.

A. Engine Performance and Exhaust Emission Analysis

1) Brake Power

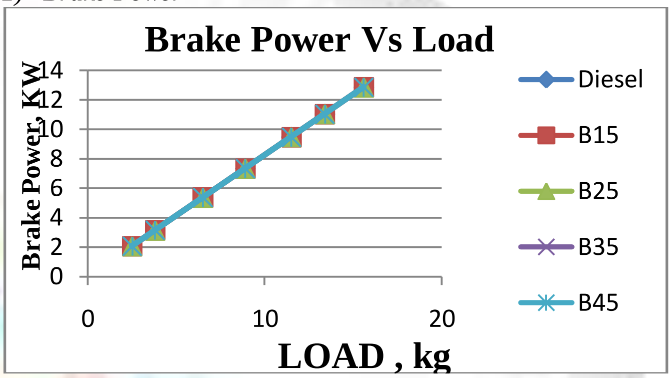

Fig. 7: Variation of brake power with respect to load.

The power developed in the engine cylinder is known as indicated power and the part of the power developed in the engine cylinder is used to overcome the internal friction. The net power available at the shaft is known as brake power. The test was conducted for pure diesel fuel which was base line fuel and then for different blends of Mustard bio-diesel B15, B25, B35, B45 samples and the load on engine was varied from 2.5 to 15.6 Kg. It was observed that brake power increases when the load was increased for all operations of diesel and Mustard bio-diesel blends. Generally, the brake power was approximately similar at any load for diesel and blends of Mustard oil biodiesel and diesel. This may be due to the higher fuel consumption of blends due to lower calorific value as compared to diesel to carry same load which resulted in same brake power of engine at any load for all blends and diesel. Figure 7 shows the rise in fuel consumption with load was more for the blends as compared to base line diesel fuel. This increase in fuel consumption on account of lower calorific valve of blends enables the engine to carry similar load.

2) Brake Thermal Efficiency

The Brake thermal efficiency is defined as the ratio of work output at the engine shaft to the energy supplied by fuel. It is a measure of the engine's ability to make efficient use of fuel. The brake thermal efficiency for different blends of fuel and that of conventional diesel at different load is reported in figure 8. The test was conducted for pure diesel fuel which is base line fuel and then for different blends of Mustard bio-diesel B15, B25, B35, B45 samples and the load on engine was varied from 2KW to 13KW. It was observed that brake thermal efficiency increases when the load was increased for all operations of diesel and Mustard bio-diesel blends. This was due to reduction in heat loss and increase in power with increase in load. Brake thermal efficiencies of all the blends of Mustard bio-diesel with

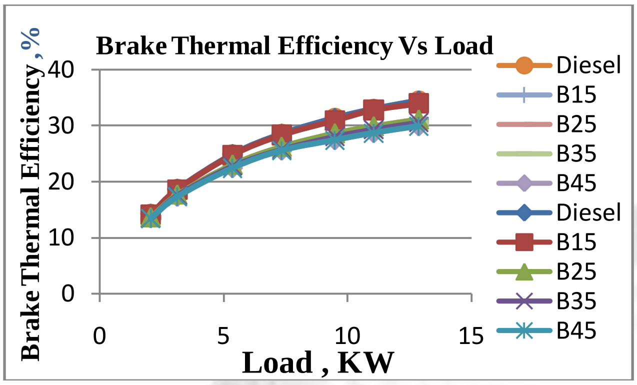

Fig. 8: Variation of brake thermal efficiency with respect to load.

Dieselwas close. The brake thermal efficiency of B15 blend was almost similar to conventional diesel fuel. It indicates that higher cetane number and inherent presence of oxygen in biodiesel results in better combustion. The reason for comparable efficiency up to B15 may be because of better combustion due to inherent oxygen and higher cetane number. It was also observed that brake thermal efficiency is almost similar when Mustard bio-diesel proportion in the blend was lower for any given load. The reason for the improved thermal efficiency for lower concentration blends was due to more complete combustion due to inherent oxygen and higher cetane number and additional lubricity of oil. But beyond B15, the brake thermal efficiency was slightly lower to that of diesel which may be due to lower calorific value and higher viscosity which was more dominating over inherent oxygen and higher cetane number. Because of higher viscosity of blends beyond B15, the atomization of fuel will not be as good as it will be for lower viscosity at same level of pressure developed by injector pump. The brake thermal efficiency of B-45, B-35 and B-25 blends was 13.23%, 11.36%, 9.7% less than diesel at full load condition whereas for B-15 blend it was only 1.4% less than diesel at full load condition.

3) Fuel consumption

The test was conducted for pure diesel fuel which is base line fuel and then for different blends of Mustard bio-diesel B15, B25, B35, B45 samples and the load on engine was varied from 2KW to 13KW. It was observed experimentally that the fuel consumption increases when the load was increased for all operations of diesel and Mustard bio-diesel blends as shown in figure 9.

It was also observed that fuel consumption increases when Mustard bio-diesel proportion in the blend was increased for any given load. Also for B45 blend, the increase in fuel consumption was more than that of other blends and diesel operations at higher load conditions. This was due to the higher viscosity and lower calorific value of B45 as compared to other blends and conventional Diesel fuel. At full load operation maximum power of the engine was produced that needs higher amount of fuel energy and due to lower energy content of B45 as compared to conventional diesel and other blends, fuel consumption increases for B45 as compared to diesel and the other blends at higher loads. For B45, the fuel consumption was 20.33% higher than conventional diesel fuel at full load condition. Also, the calorific values of various blends of bio diesel

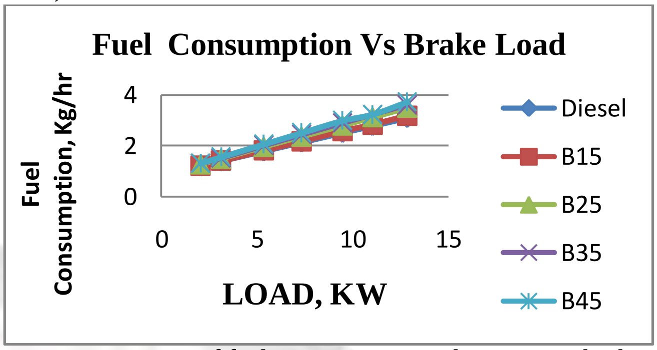

Fig. 9: Variation of fuel consumption with respect to brake load.

Were found to be lower than diesel thereby making the engine to consume more fuel to overcome identical load.

4) Brake Specific Fuel Consumption.

The brake specific fuel consumption is defined as the fuel consumed by engine in kg for per kW per hour. The brake specific fuel consumption for different blends of fuel and that of conventional diesel at different load is reported in figure 10. The test was conducted for pure diesel fuel which was base line fuel and then for different blends of Mustard bio-diesel B15, B25, B35, B45 samples and the load on engine was varied from 2KW to 13KW. It was observed experimentally that the brake specific fuel consumption decreases when the load was increased for all operations of diesel and Mustard bio-diesel blends.

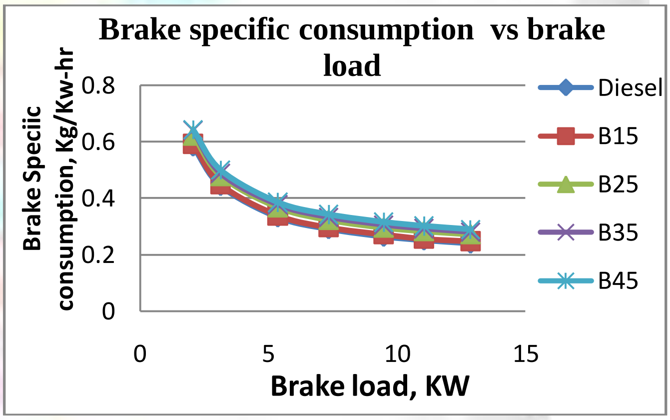

Fig. 10: Variation of brake specific fuel consumption with respect to brake load.

This reduction could be due to higher percentage of increase in brake power with load as compared to increase in fuel consumption. Also as load increases the cylinder wall temperature also increases, which reduces the ignition delay. Thus shortening of ignition delay improves combustion and reduces fuel consumption. However the rate of decrease in brake specific fuel consumption was more during lower loads than that of higher loads. The brake specific fuel consumption of B45, B35, B25, B15 was 20.21%, 16.55%, 13.27% and 2.81% higher than diesel at full load. Also for B45 blend, the increase in brake specific fuel consumption was more than that of other blends and diesel operations at higher load conditions. This was due to the higher viscosity and lower calorific value of B45 as compared to other blends and conventional Diesel fuel. At full load operation maximum power of the engine was produced that needs higher amount of fuel energy and due to lower energy content of B45 as compared to conventional diesel and other blends, BSFC increases for B45 as compared to diesel and the other blends at higher loads. Also, the calorific values of various blends of bio diesel were found to be lower than diesel thereby making the engine to consume more fuel to overcome identical load.

5) Smoke Opacity

Smoke was formed due to incomplete combustion. The Smoke opacity for different blends of fuel and that of conventional diesel at different load is reported in figure 11. The test was conducted for pure diesel fuel which was base line fuel and then for different blends of Mustard bio-diesel B15, B25, B35, B45 samples and the load on engine was varied from 2KW to 13KW. It was observed that smoke opacity increases when the load was increased for all operations of diesel and Mustard bio-diesel blends. The diesel smoke opacities were generally high at the entire load

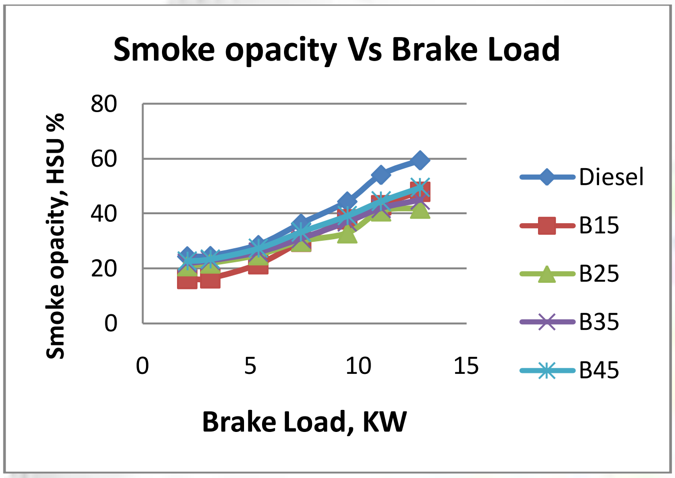

Fig. 11: Variation of smoke opacity with respect to brake load.

Range. The Mustard bio-diesel blends produced lower smoke opacities at the entire load range. Blends of all Mustard bio-diesel and diesel did not show any general correlation. Whiles in some cases emissions were low at some load for a particular blend; emission suddenly rose at another load. Lower opacities of all the Mustard bio-diesel blends as shown in figure 11 is perhaps due to the absence of aromatic compounds in vegetable oils which are known to contribute to soot formation. Also, the presence of oxygen in the chemical composition of vegetable oils was known to enhance combustion and thus contributed to lower soot formation. At any load the smoke opacity increases when Mustard bio-diesel proportion in the blend was higher. It increases due to the higher viscosity and poor volatility of higher blends of Mustard bio-diesel as compared to lower blends which was more dominating over inherent oxygen and higher cetane number and it was mainly due to emission of heavier molecules of hydrocarbon and particulates. But still it was lower than diesel at any load. This was due to more complete combustion due to inherent oxygen and higher cetane number and additional lubricity of oil. Smoke was formed due to incomplete combustion. As smoke was low then better combustion of tested fuel takes place.

V. Conclusions

The overall studies based on the production, fuel characterization, engine performance and exhaust smoke opacity of Mustard oil methyl esters were carried out. The following conclusions can be drawn:

1. In terms of engine performance, the lowest brake specific fuel consumption was obtained using diesel at all load conditions. Results obtained indicate that engine performance in terms of BSFC were lower for all the blends than diesel. However, 15% substitution of diesel with any of the three vegetable oils did not differ significantly from results obtained using pure diesel. The brake specific fuel consumption of B45, B35, B25, B15 is 20.21%, 16.55%, 13.27% and 2.81% higher than diesel at full load. The brake specific fuel consumption of B15 blend is almost similar to conventional diesel fuel.
2. The brake power increases when the load is increased for all operations of diesel and Mustard bio-diesel blends. Generally, the brake power is approximately similar at any load for diesel and blends of Mustard oil biodiesel and diesel.
3. Thermal efficiency of the engine was generally lower for all the blends than for diesel. However, the results were quite close. The brake thermal efficiency of B-45, B-35 and B- 25 blends is 13.23%, 11.36%, 9.7% less than diesel at full load condition whereas for B- 15 blend it is only 1.4% less than diesel at full load condition. The brake thermal efficiency of B15 blend is almost similar to conventional diesel fuel.
4. Fuel consumption increases when Mustard bio-diesel proportion in the blend is increased for any given load. It is highest for B-45 blends and decreases for lower blends. Fuel consumption of B-15 blend is almost similar to conventional diesel fuel at any load.
5. Pure diesel produced higher smoke densities at almost all load condition whiles the blends of Mustard oil biodiesel and diesel produced the lowest smoke densities. The smoke densities of all the blends were generally lower than that of diesel at all load conditions. At any load the smoke opacity increases when Mustard bio-diesel proportion in the blend is higher.
6. As the performance of engine on B-15 blend was closest to conventional diesel fuel so use of 15% blends of Mustard oil bio-diesel as partial diesel substitutes can go a long way in conservation measure, boosting economy, reducing uncertainty of fuel availability and making more self-reliant.\

VI. References

[1] Zhang, Y., M. A. Dube, D. D. Mclean and M. Kates, 2003. Biodiesel production from wastecooking oil: 1. Process design and technological assessment. Bioresource Technology, 89: 1-16.

[2] Blanco-Canqui, H. and R. Lal, 2007. Soil and crop response to harvesting corn residues for biofuel production. Geoderma, 141: 355-362.

[3] Paugazhabadivu, M. and K. Jeyachandran, 2005. Investigations on the performance and exhaust imissions of a diesel engine using preheated waste frying oil as fuel. Renewable Energy, 30: 2189-2202.

[4] Vicente, G., M. Martinez and J. Aracil, 2007. Optimization of integrated biobiesel production. Part 1.

A study of the biodiesel purity and yield. Biores. Technol., 98: 1742-33.

[5] Domkundwar, V.M. (2009), "A course in internal combustion engines", Dhanpat Rai and CO. (Pvt) Ltd., pp. 17.1- 20.18, pp. 22.1-22.84.

[6] A Agarwal, K Avinash. "Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines", Progress in Energy and Combustion Science, vol 33, 2007, pp. 233–71.

[7] A.Avinash, D.Subramaniam, A.Murugesan, "Bio-diesel—A global scenario", "Renewable and Sustainable Energy Reviews ", vol 2, 2014, pp. 517–527.

[8] A Demirbas, "Progress and recent trends in biodiesel fuels" Sila Science, Trabzon, Turkey Energy Conversion and Management, vol. 50, 2009, pp 14–34.

[9] Alberta Education: Biodiesel: A fuel for the future: A student booklet 2008-09, p. 33.

[10] An okullo, K. temu, ogwok, ntalikwa, "physico-chemical properties of biodiesel from jatropha and castor oils", international journal of renewable energy research, vol.2, 2012, p.1.

[11] D. Rachel Evangelene Tulip and K.V. Radha, "Production of biodiesel from mustard oils its performance and emission characterization on internal combustion engine", Advanced Engineering and Applied Sciences: An International Journal, vol 3(3), 2013, pp. 37-42.

[12] Kleinova, Vailing , J. Labaj , J. Mikulec , J. Cvengroa , " Vegetable oils and animal fats as alternative fuels for diesel engines with dual fuel operation" , Fuel Processing Technology vol 92, 2011, pp. 1980–1986.

[13] R. McCormick, J. Alvarez, M. Graboski, K. Tyson, and K. Vertin, "Fuel additive and blending approaches to reducing NOx emissions from biodiesel," SAE Tech. Pap, 2002, p. 1658.

[14] G Sharma, D Dandotiya, S. K. Agrawal , "Experimental Investigation of Performance Parameters of Single Cylinder IC Engine Using Mustard Oil", International Journal of Modern Engineering Research (IJMER) ,Vol.3, Issue.2, March-April. 2013 , pp-832-838.