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Performance characteristics of automotive diesel engine fueled with diesel and blends of biodiesel produced from waste soybean cooking oil

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ABSTRACT

The world consumption of fuels is undoubtedly unstable causing world economic crisis so this factor has urged all nations especially the government and the academics to find another alternatives to replace the usage of petroleum. Thus, by using biodiesel as alternative, the problem could be tackled, therefore, an experimental investigation has been conducted on water cooled multi cylinder 45 KW automotive diesel engine widely used in transport sector of India, fuelled with the various blends of bio-diesel extracted from the waste cooking oil (Soybean). Engine performance is also evaluated using diesel fuel without any modification in a present engine. A single step batch transesterification process of waste cooking oil to obtain biodiesel fuel was studied in order to optimize the process variables such as catalyst concentration, reaction time and reaction temperature which affect the product yield during transesterification process. The variable that was fixed throughout the whole experiment was the molar ratio of methanol to raw oil (6:1).The important properties of waste cooking oil bio-diesel were also determined as per standards. Experiments were conducted using different blends of biodiesel and diesel such as B15, B25, B35 and B45 and its effect on brake power, specific fuel consumption, break thermal efficiency, mechanical 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 test results indicate that the B-15 blend of bio-diesel can act as alternative fuel.

Keywords: Biodiesel, Transesterification, waste soybean cooking oil, performance characteristic

INTRODUCTION

Fuels derived from renewable biological resources for use in diesel engines are known as bio-diesel [1]. Among the alternative fuels for the petroleum fuel, vegetable oil esters (bio-diesel) have gained suitability for their use in compression ignition engine. Bio-diesel is eco-friendly, alternative diesel fuel prepared from domestic renewable resources such as vegetable oils and animal fats. Increasing environmental concern, diminishing petroleum reserves and agriculture based economy of our country are the driving forces to promote bio-diesel as an alternate fuel [1].

Moreover, it is superior fuel than diesel because of lower sulphur content, high flash point and lower aromatic content [2]. The lower sulfur means a reduction in the formation of acid rain by sulfate emissions which generate sulfuric acid in our atmosphere. The reduced sulfur in the blend will also decrease the levels of corrosive sulfuric acid accumulating in the engine crankcase oil over time. The lack of toxic and carcinogenic aromatics (benzene and xylene) in Bio-diesel means the fuel mixture combustion gases will have reduced impact on human health and the environment. The high cetane rating of Bio-diesel (ranges from 49 to 62) is another measure of the additive's ability to improve combustion efficiency. Also it contains no petroleum, but it can be blended with petroleum diesel to create a bio-diesel blend [6] and used in compression ignition engine without any engine modification [1].

Rising fuel costs and impending emission regulations have sharpened the automotive industry's focus on efficiency. Moreover the rapid depletion of fossil fuels due to widespread use has forced to search for some low emission and renewable fuel. The environmental concern about pollution coming from automobile emission, biodiesel is emerging as a developing area of high concern. The high cost of biodiesel is mainly due to the high cost of virgin vegetable oil. Therefore, it is necessary to find ways to reduce the cost of production of biodiesel. The use of waste cooking oil instead of virgin oil, to produce biodiesel is an effective way to reduce the cost of biodiesel production [4].

Generally, transesterification process is used to produce biodiesel from vegetable/animal fat. The vegetable oil was chemically reacted with an alcohol in presence of a catalyst to produce methyl esters. Glycerol was produced as a by-product of transesterification reaction. The transesterification reaction is given by three consecutive and reversible equations. The first step is the conversion of triglyceride to form diglycerides, followed by the conversion of diglycerides to monoglycerides, and of monoglycerides to glycerol, yielding one methyl ester molecule per mole of glyceride at each step. The step wise reactions are reversible and a little excess of alcohol is used to shift the equilibrium towards formation of esters.

In the present study, the waste cooking oil, a edible type vegetable oil is chosen as potential alternative for producing biodiesel and use as fuel in compression ignition automotive engine. The used cooking oil after prolonged use becomes unhealthy as its FFA increases which make it unfit for human use so it becomes necessary to dispose it off. This increasing production of used cooking oil from household, restaurants and industrial sources is a growing problem in world. This residue is regularly poured down the drain, resulting in problems for waste water treatment plants or integrated into food chain through animal feeds thus becoming a potential cause of human health problems. Moreover, disposing it into water bodies will lead to water pollution. The conversion of the waste cooking oil into fuel also eliminates the environmental impacts caused by the harmful disposal of these waste oils, such as disposal into drains [2]. The production of biodiesel from such waste cooking oil reduces the cost of biodiesel as compared to production from virgin edible oil [2, 4]. The kinematic viscosity of waste cooking oil is however several times higher than that of diesel oil and this leads to problem in pumping and atomization in injection system of a diesel engine. The combined effect of high viscosity and low volatility of waste cooking soybean oil causes poor cold engine start up, misfire and ignition delay. Hence, it is necessary to bring their combustion related properties closer to those of diesel oil. The transesterification aimed at reducing the viscosity of vegetable oils to get rid of the flow related problems [3, 5]. The free fatty acid (FFA) content of waste cooking oil is about 1.6% so base catalyzed transesterification process is suitable to produce esters from waste cooking soybean oil as base catalyzed transesterification process takes place only with oils having free fatty acid value less than 2% [6]. Hence, the present efforts are aimed at the production of esters (biodiesel) from waste cooking oil and to analyze its suitability as fuel in diesel engines.

Also, the performance and smoke emissions of multi-cylinder four stroke diesel engine which is widely used in automotive sector in India was experimentally investigated using the different blends of waste cooking oil (Soybean) bio-diesel and diesel and the results were compared with the conventional diesel fuel. The transesterification of waste cooking oil with alcohols, in the presence of base catalyst potassium hydroxide (KOH) and methanol as solvent, by means of single step batch transesterification process in order to obtain biodiesel fuel was studied. The process variables such as catalyst concentration, reaction time and reaction temperature which affect the product yield during transesterification process were investigated experimentally to optimize the parameters.

II. PRESENT WORK

A. Conversion of Waste Cooking Soybean Oil into Biodiesel

The process of converting vegetable oil into bio-diesel is called **transesterification**, a chemical process that removes the glycerin stem from the molecule, resulting in a much smaller molecule, called an ester, which improves its characteristics for use as an engine fuel. The important parameter affecting transesterification process such as catalyst concentration, reaction temperature and reaction time were analyzed. Transesterification reaction was carried out in a water bath and 250 gm of waste cooking oil was taken in a conical flask and it was preheated to the temperature of 60˚ C for 30 minutes. In a separate flask 1.25% of potassium hydroxide (catalyst) & 20% of methanol (Alcohol) by weight of waste cooking oil was mixed and then this mixture was poured into preheated oil sample. The reaction was carried out in water bath at temperature of 60˚ C for 60 min at constant stirring after which the two phase product formed as result of transesterification was separated using a separating funnel. Upper layer consists of biodiesel, alcohol and moisture. Lower layer consists of Glycerin, Catalyst and traces of unreacted oil. Upper layer which was biodiesel was boiled to the temperature of 110˚ C to obtain pure moisture free biodiesel to be used in engine. Experiments were repeated to optimize the catalyst concentration, reaction temperature and reaction time.

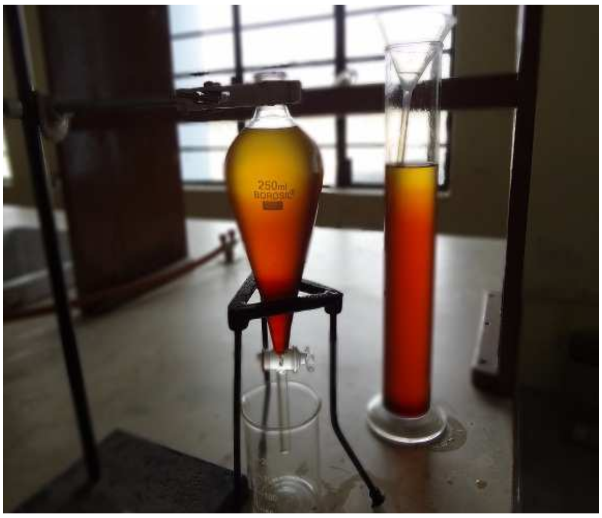

Fig.1 (a)

Fig. 1. (b)

Fig.1 (a), 1. (b) Set up for phase separation of waste cooking oil biodiesel

B.Characterization of Biodiesel

The properties of waste cooking soybean oil biodiesel (methyl esters) were quite comparable to that of diesel fuel. Transesterification improves the desirable fuel properties of oil like density, kinematic viscosity, flash point, fire point, cloud point, pour point and calorific value. The comparisons show that the biodiesel has fuel properties relatively closer to diesel fuel. The viscosity was substantially got reduced from a value of 32.6 to 4.4 cSt. The flash and fire point of waste cooking biodiesel were higher than that of conventional diesel. A small percentage of biodiesel addition with diesel can definitely improve the flash point of resultant blend, hence this blend is safe to store and transport. The cloud and pour point of waste cooking oil biodiesel were lower than that of conventional diesel. Viscosity was measured by using Redwood viscometer. Flash point and fire point were measured by closed cup apparatus. Cloud point and pour point were measured using cloud and pour point apparatus whereas calorific value was determined using bomb calorimeter. The table I shows the various equipments used to determine fuel properties. The table II shows the fuel properties of waste cooking oil bio-diesel as compared to diesel.

TABLE I DIFFERENT APPARATUS AND STANDARDS USED FOR FUEL CHARACTERIZATION

Name of fuel property	Method / Standard
Kinematic viscosity	Redwood Viscometer, IS: 1448 [P:25] 1976
Flash point and fire point	Closed cup flash and fire point apparatus, IS: 1448 [P: 32]: 1992
Cloud point and pour point	Cloud and Pour point apparatus, IS: 1448 [P:10] 1970
Calorific value	Bomb Calorimeter, IS: 1448 [P:6] 1984
FFA content	Titration with 0.1 N NaOH

TABLE II FUEL PROPERTIES OF WASTE COOKING OIL BIODIESEL AS COMPARED TO DIESEL

S.No	Properties	ASTM Standards	Diesel	Waste cooking oil biodiesel
1	Density, g/cc	-	0.83	0.89
2	Viscosity@40℃,cSt	1.9-6.0	2.049	4.4
3	Flash Point,℃	Min 130	78	177
4	Fire point,℃	Min 53	82	184
5	Cloud Point,℃	-3 to 12	<10	-1
6	Pour Point,℃	-15 to 10	-6	-7
7	Calorific value, KJ/Kg	Min 33000	43472	39375.6

Fig.2. Multi cylinder CI Engine Test Rig

TABLE IIIENGINE 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

C. Performance Test on Automotive Diesel Engine

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 2 consist of a variable speed 1400cc, four cylinder, 4-stroke, TATA make, DI Diesel Engine coupled to hydraulic brake dynamometer. The specification of the engine used for experimentation is given in table III. The set-up enables the study of engine brake power, fuel consumption, air consumption, heat balance, thermal efficiency, volumetric efficiency etc. The Neptune OPAX2000*II*/ DX200P smoke meter was used to measure the smoke opacity of exhaust gas emitted from diesel engine. The performance tests were carried out on the compression ignition automotive diesel engine using various blends of waste cooking oil biodiesel and diesel as fuels. The tests were conducted at the constant speed of 1650 rpm at various loads. The experimental data generated was documented and presented here using the biodiesel –diesel mixture for 1 hr engine test operation. In each experiment, engine performance parameters such as brake power, brake specific fuel consumption, brake thermal efficiency and mechanical efficiency were measured. In addition to that, the engine emission parameter such as smoke opacity was also measured.

RESULTS AND DISCUSSION

A.Brake Power

The brake power for different blends of bio-diesel and that of conventional diesel at different load was reported in figure 3. The test was conducted for pure diesel fuel which was base line fuel and then for different blends of WCO 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 WCO bio-diesel blends. Generally, the brake power was approximately similar at any load for diesel and blends of waste cooking 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. The increase in fuel consumption on account of lower calorific valve of blends enables the engine to carry similar load.

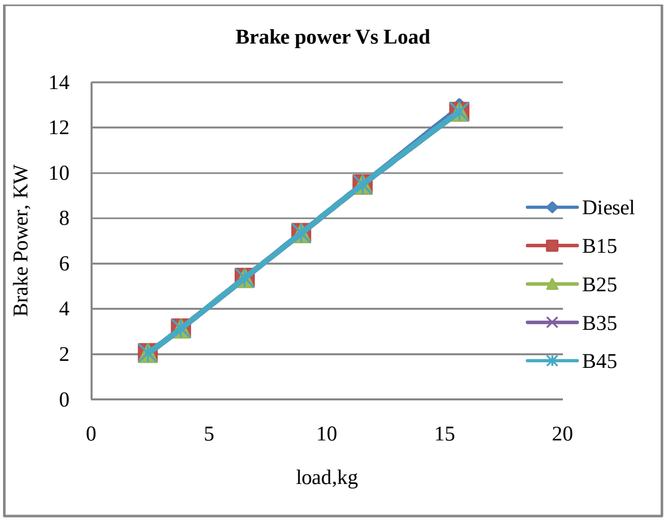

Fig.3. Variation of brake power with respect to load

B.Brake Thermal Efficiency

The brake thermal efficiency for different blends of fuel and that of conventional diesel at different load is reported in fig 4.

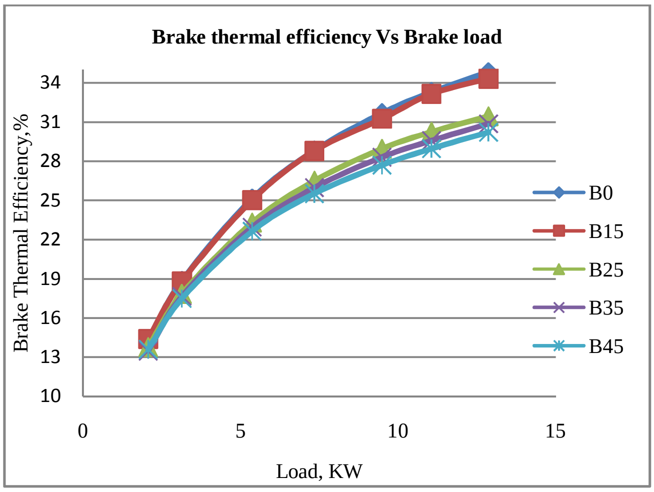

Fig. 4. Variation of brake thermal efficiency with respect to load

The test was conducted for pure diesel fuel which is base line fuel and then for different blends of WCO 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 WCO bio-diesel blends. This was due to reduction in heat loss and increase in power with increase in load. The brake thermal efficiency of B15 blend was almost similar to conventional diesel fuel. The reason for comparable efficiency up to B15 may be because of better combustion due to inherent oxygen and higher cetane number. 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.

C. Brake Specific Fuel Consumption

The brake specific fuel consumption for different blends of fuel and that of conventional diesel at different load was reported in figure 5. The test was conducted for pure diesel fuel which was base line fuel and then for different blends of WCO 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 WCO bio-diesel blends. 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.

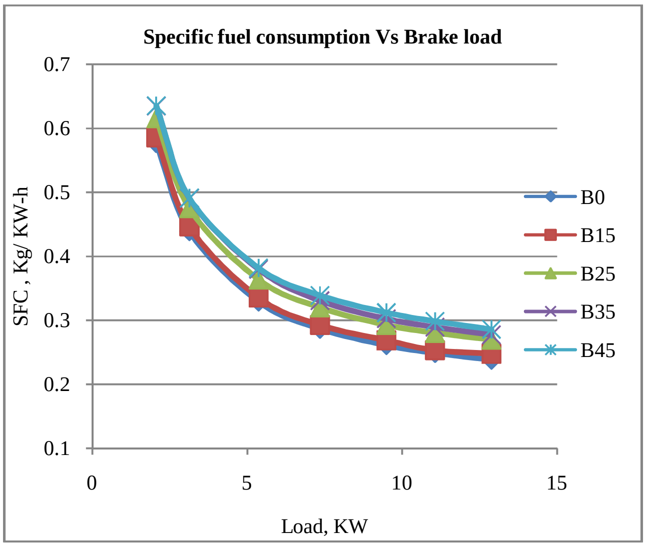

Fig.5. Variation of brake specific fuel consumption with respect to brake load

D. Mechanical Efficiency

The mechanical efficiency for different blends of fuel and that of conventional diesel at different load was reported in figure 6.The test was conducted for pure diesel fuel which was base line fuel and then for different blends of WCO bio-diesel B15, B25, B35, B45 samples and the load on engine was varied from 2KW to 13KW. It was observed that mechanical efficiency increases when the load was increased for all operations of diesel and WCO bio-diesel blends. This was due to increase in power with increase in load and frictional power remains constant as engine was running at constant speed of 1650 r.p.m and frictional power depends on the speed of the engine and was independent of load. It was also observed that mechanical efficiency was better when WCO bio-diesel proportion in the blend was higher for any given load. The reason for the improved mechanical efficiency for higher concentration blends was that as the proportion of biodiesel in blend was raised, the viscosity of blend increases which reduces the friction on account of its better lubricity. Also the bio-diesel was more viscous as compared to diesel so it reduces friction due to its lubricating property and hence improves mechanical efficiency. The mechanical efficiency for all the blends was better as compared to diesel. The mechanical efficiency of B25, B35 and B45 was 4.5%, 5.1% and 5.7% higher than diesel at full load.

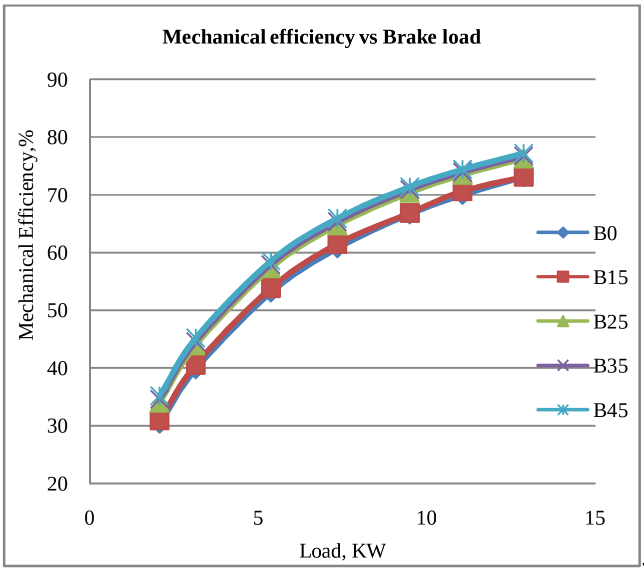

Fig.6. Variation of mechanical efficiency with respect to brake load

E.Smoke opacity

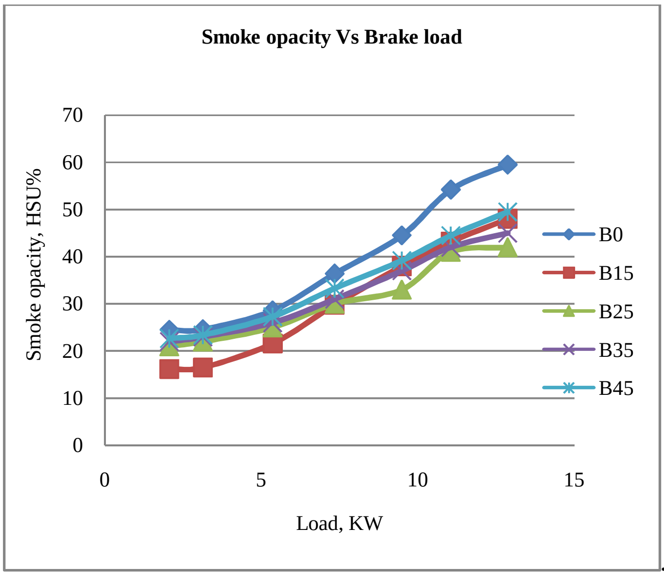

Fig.7. Variation of smoke opacity with respect to brake load

Smoke was formed due to incomplete combustion. The Smoke opacity for different blends of fuel and that of conventional diesel at different load was reported in figure 7. The test was conducted for pure diesel fuel which was base line fuel and then for different blends of WCO 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 WCO bio-diesel blends. The diesel smoke opacities were generally high at the entire load range, the WCO bio-diesel blends produced lower smoke opacities at the entire load range. Blends of all WCO 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 WCO bio-diesel blends as shown in figure 7 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 WCO bio-diesel proportion in the blend was higher. It increases due to the higher viscosity and poor volatility of higher blends of WCO 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. As smoke was low then better combustion of tested fuel takes place.

CONCLUSION

1. The viscosity of waste cooking oil biodiesel was found to be close to that of diesel and within range of ASTM standards. The flash and fire point of biodiesel was higher than that of diesel. The vital properties of biodiesel produced from waste cooking soybean oil can be a prospective fuel or performance improving additive in compression ignition engines.
2. The result also reveals that the cloud and pour point waste cooking oil methyl ester were found to be lower than those of diesel. The cloud and pour point of diesel and waste cooking oil methyl ester were found as <10℃, -1℃ (cloud point) and -6℃, -7℃ (pour point).
3. 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.

4. The brake power increases when the load is increased for all operations of diesel and WCO bio-diesel blends. Generally, the brake power is approximately similar at any load for diesel and blends of waste cooking oil biodiesel and diesel.
5. 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.
6. The mechanical efficiency for all the blends is better as compared to diesel. The mechanical efficiency of B25, B35 and B45 is 4.5%, 5.1% and 5.7% higher than diesel at full load.
7. Pure diesel produced higher smoke densities at almost all load condition whiles the blends of waste cooking 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 WCO bio-diesel proportion in the blend is higher.
8. Use of 15% blends of Waste cooking oil methyl ester as partial diesel substitutes can go a long way in conservation measure, boosting economy, reducing uncertainty of fuel availability and making more self-reliant.

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