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**Journal of Chemical and Pharmaceutical Research, 2015, 7(5):1075-1082**

**Research Article**

**ISSN : 0975-7384**
**CODEN(USA) : JCPRC5**

# Biodiesel production & its performance characteristics measurement: A review and analysis

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**ABSTRACT**

*The successful alternative fuel is one which should fulfil environmental and energy security needs without sacrificing its operating performance. Every nation has locked their eyes on biodiesel as main replacement of crude oil specially diesel. Bio-diesel is fatty acid of ethyl or methyl ester made from unused or used vegetable oils and animal fats. Bio-diesel is eco-friendly, alternative diesel fuel prepared from domestic renewable resources such as vegetable oils and animal fats exclusively for diesel engines. Experimental investigation was carried out on used mustard oil to study its properties and to check its suitability as a biodiesel and also a replacement for diesel oil in future. The biodiesel from used mustard oil was prepared by the process of Transesterification. In Transesterification process the mixture of Mustard oil and alcohols was constantly mixed, in the presence of base catalyst potassium hydroxide (KOH) at $60^0$C with the help of water bath shaker. The concentration of catalyst which affects the yield of product was studied during Transesterification process to optimize its effects. The other parameter which also effect the yield of process were the time of reaction, concentration of alcohol (%) were also optimized during Trans esterification process. In this work, three process variables used for standardization of transesterification process, various fuel properties of biodiesel produced from waste cooking oil are determined and the different blends of waste cooking oil and diesel are tested on multi-cylinder automotive diesel engine to evaluate its performance characteristics. Hence the problem formulated can be named as "Study of performance characteristics of compression ignition automotive engine powered by various blends of bio-diesel extracted from waste cooking oil".*

**Keywords:** Mustard Oil, Transesterification, catalyst KOH, methanol, Performance Characteristics

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## INTRODUCTION

The worldwide concern about the protection of environment and the conservation of non-renewable natural resources, has given a cause to alternate development of sources of energy as substitute for traditional fossil fuels [1]. Today's most of industries as well as household activities are accomplished by using energy derived from fossil fuels (petroleum, coal and natural gas). However, the sources for these are limited and will probably get exhausted in the future[2] . Thus, looking for the alternative sources of new and renewable energy such as biomass, hydro, solar, wind, geothermal, nuclear and hydrogen is of vital importance. Alternative source of new and renewable fuels have the potential to solve many of the current social problems and concerns, from air pollution, global warming, greenhouse effect and other environmental improvements and sustainability issues. Vegetable or Biodegradable oils have become more attractive recently because of its environmental advantages and the fact that it is made from renewable sources. Examples of renewable fuels are the biodiesel produced from vegetable oils and ethanol produced from plant's biomass [3].

Sadeghinezhad *et al* studied the play of biodiesel as an attractive source of renewable energy in order to make up with the oil crisis. However, it was realised that extensive utilisation of bio-fuels would lead to ecological imbalance and lead to food shortage. Use of bio diesel assumes significance on many counts such as it can straight away replace petro –diesel without much change in the present CI engine system, it is environment friendly, it is a renewable source of energy, it can be produced locally saving precious foreign exchange, it can prolong the existing petroleum –diesel reserves, the country can become self-reliant in energy field devoid of all International pressures. NOx emission is increased for biodiesel due to combustion, oxygen content and some properties of the fuel. It can be reduced by recirculation of the exhaust air of the engine called exhaust gas recirculation (EGR), which creates longer ignition delay improves fuel air mixing resulting in reduction of NOx and particulate matter (PM) emission. Retarded fuel ignition timing can reduce NOx while maintaining the other emission reductions. Biodiesel blends have the ability to give greater lubricant to the engine which gives greater life span to the engine. Biodiesel can be used in pure form in the IC engine without or certain modifications. Vegetable oils have high viscosity when compared to conventional diesel. Recent studies shows that CO, HC and particulate matter emissions improved due to preheating which reduced the viscosity of the vegetable oil, almost to the level of diesel fuel which caused improvement in the combustion[4] .

From studies it is concluded that biodiesel can play a increasingly a good role in support of meeting energy demand in transport areas and also there have been a consistent trends for the performance of biodiesel engine and different range of gases emission during varied biodiesel blends and operating conditions or driving cycles . Since this paper covers a wide range in biodiesel area, it gives the basic idea about biodiesel production and its performance characteristics measurement and it also be used as research reference for biodiesel production from vegetable oils. Therefore, selection of vegetable oil and production technology is vital for growth in biodiesel industries. In the present experimental investigation, mustard oil methyl ester (MOME) was produced by the trans-esterification process, using mustard oil and methanol with KOH as catalyst [5]. Properties of mustard oil were calculated and studied. Characterization of mustard biodiesel was done. Twin Cylinder Internal combustion engine (TATA Indica V2) was used for the performance characteristics using mustard biodiesel blends (B15, B25 and B35) as fuel. Performance for biodiesel blends were compared to the fuel[ 8, 9].

## EXPERIMENTAL SECTION

The Mustard oil used in this present study was bought from cafeteria of Amity University Noida, Uttar Pradesh. All the chemicals (Methanol, Ethanol, Phenolphthalein, KOH catalyst and NaOH) are provided by chemistry lab of Amity School of Engineering & Technology, Amity University .Water bath and Water Bath stirrer which was used for trans-esterification of Mustard oil was also provided by the chemistry lab of the college. Numbers of sample bottles were also available in chemistry lab to put different samples of biodiesel during experimentation.

The fuel properties like viscosity ,flash point, cloud point ,pour point etc. were determined by using equipments such as Redwood Viscometer for kinematic viscosity, Pen sky- Martens apparatus for flash point etc. Some of the properties like calorific value were determined at Bharat Test House, Rai, Sonepat (Haryana). The whole process of biodiesel preparation was done at Amity School of Engineering & Technology, Amity University Noida. In this process of ester or biodiesel preparation the vegetable oil reacts with simple alcohol like methanol in the presence of a catalyst. The fatty acid of the vegetable oil is replaced with the (OH) group of the alcohol producing the glycerol and methyl fatty acid ester. The concentration of catalyst effects yield of the ester and therefore it is very important for experimental optimization as if concentration of catalyst is less than the required value, the reaction between vegetable oil and alcohol will not be completed if the concentration of catalyst is more than the required value, the saponification will takes place which will lead to soap formation. Hence the optimization of catalyst concentration is important. The parametric process effects were studied to standardize the Transesterification process. There are infinite number of experiments for different concentration and number of parameters which gives different yields. For reducing the number of experiment to be performed for best and optimized results the Taguchi Orthogonal Method was applied for experiment design which fixes the number of parameters and the number of levels in which experiments have to be performed for which we get the array and we perform the experiments according to that array. By this method the least number of experiments are obtained with maximum ester yield as well as recovering ester with least possible viscosity.

In order to standardize the catalyst concentration, four levels of catalyst (KOH) concentration (.75%, 1%, 1.25%, 1.5%) was set and the reaction time of 30 minutes, 40 minutes, 50 minutes and 60 minutes respectively and concentration of alcohol 10%, 15%,20% & 25% and temperature of $60^0$C were taken in this research paper.

**Transesterification**

The vegetable oils must be chemically altered or blended with diesel fuel to prevent premature engine failure. Blending, cracking, emulsification or transesterification of vegetable oils may overcome the problems such as formation of deposit, carbon formation and contamination of lubricating oil which otherwise causes premature engine failure. Transesterification of vegetable oils to bio-diesel with methanol can be carried out using both homogeneous (acid or base) and heterogeneous (acid or base) catalysts. Homogeneous base catalysts provide much faster reaction rates than heterogeneous catalysts in transesterification [6]. Homogeneous catalysts include acids such as sulfuric acid or hydrochloric acid and bases, such as sodium or potassium hydroxides. Base catalyzed transesterification has been most frequently used industrially because of its fast reaction rates whereas acid catalyzed transesterification has received less attention because it has slow reaction rate and requires more expensive materials for construction. The vegetable oil was chemically reacted with an alcohol in presence of a catalyst to produce methyl esters. The by-product of transesterification reaction was Glycerol.

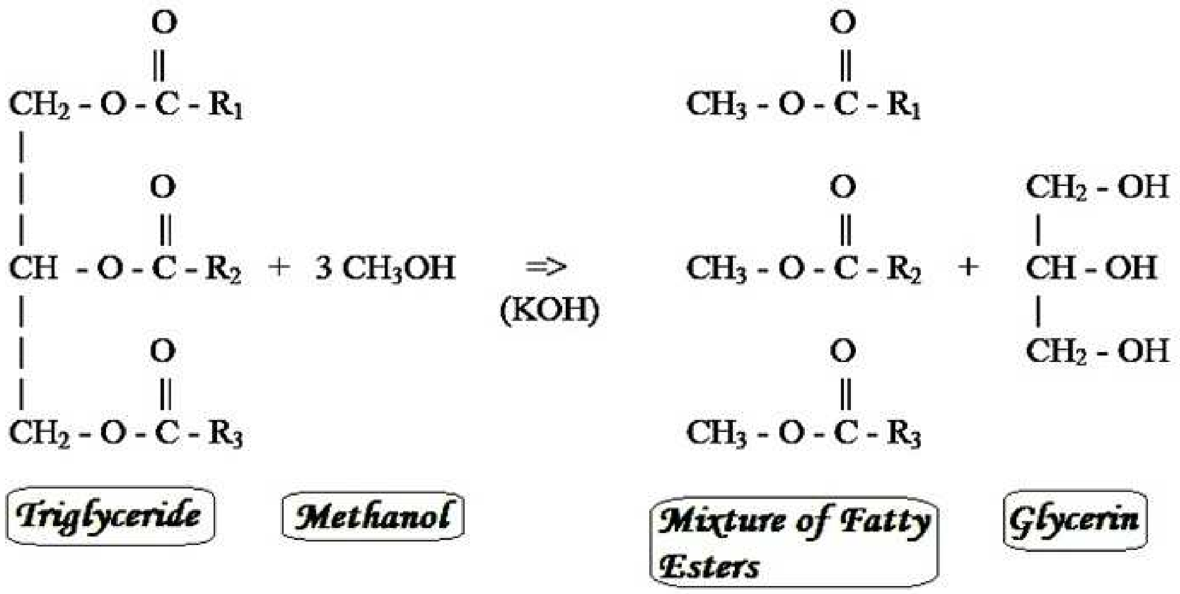


**Fig: 1 Used Cooking Oil + Methanol + Potassium Hydroxide ——> Biodiesel Fuel + Glycerin**

Glycerol is the byproduct in the production of biodiesel. It is a sugar compound which has 3 hydroxyl groups and it is the reason for its water solubility. It is basically very useful for medical and personal operations, like, in cough syrups,toothpaste,skin care products,shaving cream, soaps etc.

The gycerol is denser in nature as compare to biodiesel. That's why the bottom portion of above diagram is glycerol and upper portion is biodiesel. According to the type of feedstock, we generally select catalysts like KOH,NaOH etc. in order to accelerate the reaction to make purified feedstock [7]. With an intermediate temperature of 60 degree celsius the reaction happens at atmospheric pressure alongwith the reaction time of about 6 hours. This is how a biodiesel can be prepared.


**Fig:2 Glycerin and Waste Cooking Oil Methyle Ester**

## I. Procedure for Transesterification

1. Take 200 grams of Mustard oil and in conical flask (A).
2. Preheat the oil at 60 degree celsius for 30 minutes. Do not heat it directly, use a water bath.
3. In a new flask (B) add catalyst KOH and the content should be according to the designed experiment [ref. Table 3]. (KOH is the catalyst that we will be using since the free fatty acid content of your oil was less than 3%).
4. In flask (B) add methanol with respect to the weight of oil as given in Table 3.
5. Shake the solution for a minute and add it to flask (A).

6. Now, in a water bath shaker heat the sample for time given in Table 3 at 60 degree Celsius. The RPM of the shaker should be moderate.
7. Put this solution in a separating flask for at least 24 hours. This way the glycerine and crude biodiesel will be separated. Glycerine will be and the bottom and crude biodiesel at the top.

**Fig: 3 Glycerine and waste cooking oil methyl ester mixture, before and after separation**

**Table 1: Different apparatus and standards used for fuel characterization**

| S. No. | Name of the fuel property | Method/Standards |
|---|---|---|
| 1. | FFA content (%) | Titration with 0.1 N NaOH |
| 2. | Viscosity | Redwood Viscometer<br>IS: 1448 [P:25]:1976 |
| 3. | Flash Point and Fire Point | Closed cup flash(Pen ski- martin) and fire point apparatus,<br>IS:1448 [P:32]:1992 |
| 4. | Cloud Point & Pour Point | Cloud & Pour Point Apparatus<br>IS: 1448 [P:10]:1970 |
| 5. | Calorific Value | Bomb Calorimeter,<br>IS: 1448 [P:6]:1984 |

## II. Design of Experiments

There are lots of methods to design the experiment to get best yield out of the experiment. But the method used in this test is Taguchi's Orthogonal Array Method. The main motive of using this method is to reduce the no. of experiment. This Orthogonal array method provides best set of well-balanced experiments. Taguchi's orthogonal array is set of array which are predefined and are available on internet. These arrays are generally named as L4, L8, L9 etc. and can be selected according to the no. of parameters and no. of levels.

**Table 2: Experiment Variables**

| | | | | |
|---|---|---|---|---|
| **Catalyst (%)** | 0.75 | 1.0 | 1.25 | 1.5 |
| **Alcohol (%)** | 10 | 15 | 20 | 25 |
| **Time (minutes)** | 30 | 40 | 50 | 60 |

From the above table we can see that no. of parameters are 3(catalyst, alcohol and time) and the no. of levels are 4. Therefore according to Taguchi's Orthogonal Array the array selected for 3 no. of parameters and 4 no. of levels is L'16. Therefore according to L'16 the experiments are designed as follows:

**Table 3: Design of Experiments by Taghuchi Orthogonal Array**

| S. No. | Reaction Temperature ($^0$C) | Catalyst Conc. (%) | Alcohol Conc. (%) | Time (minutes) | Yield (%) | Viscosity |
|---|---|---|---|---|---|---|
| 1. | 60 | 0.75 | 10 | 30 | 91.66 | 4.91 |
| 2. | 60 | 0.75 | 15 | 40 | 99.24 | 4.61 |
| 3. | 60 | 0.75 | 20 | 50 | 89.20 | 4.52 |
| 4. | 60 | 0.75 | 25 | 60 | 98.10 | 4.79 |
| 5. | 60 | 1.00 | 10 | 30 | 92.10 | 5.10 |
| 6. | 60 | 1.00 | 15 | 40 | 96.50 | 4.51 |
| 7. | 60 | 1.00 | 20 | 50 | 92.99 | 4.65 |
| 8. | 60 | 1.00 | 25 | 60 | 94.17 | 4.94 |
| 9. | 60 | 1.25 | 10 | 30 | 88.62 | 5.07 |
| 10. | 60 | 1.25 | 15 | 40 | 91.17 | 4.75 |
| 11. | 60 | 1.25 | 20 | 50 | 97.80 | 4.40 |
| 12. | 60 | 1.25 | 25 | 60 | 96.19 | 5.01 |
| 13. | 60 | 1.50 | 10 | 30 | 99.60 | 4.56 |
| 14. | 60 | 1.50 | 15 | 40 | 98.60 | 4.89 |
| 15. | 60 | 1.50 | 20 | 50 | 88.16 | 4.50 |
| 16. | 60 | 1.50 | 25 | 60 | 94.71 | 4.86 |

## RESULTS AND DISCUSSION

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, two cylinder, four stroke water cooled CI engine was also conducted to evaluate the performance of the engine on diesel and on different blends of waste cooking oil bio-diesel and diesel. The recovery of ester as well as its kinematic viscosity is affected by the catalyst concentration used. The catalyst concentration was standardized to obtain methyl ester of waste cooking oil with lowest possible kinematic viscosity and highest level of recovery. The fuel properties such as kinematic viscosity, heat of combustion, cloud and pour point, flash and fire point of diesel and methyl ester of waste cooking oil with diesel were compared. An automotive two cylinder 4-stroke diesel engine have been tested on diesel and on B15, B25, B35 blends of waste cooking oil methyl ester and diesel. The brake thermal efficiency, mechanical efficiency, fuel consumption, brake specific and fuel consumption were measured. The results of parameters measured and their analytical interpretation with discussion are presented in this paper.

### Performance Characteristics
### 1. Brake Power

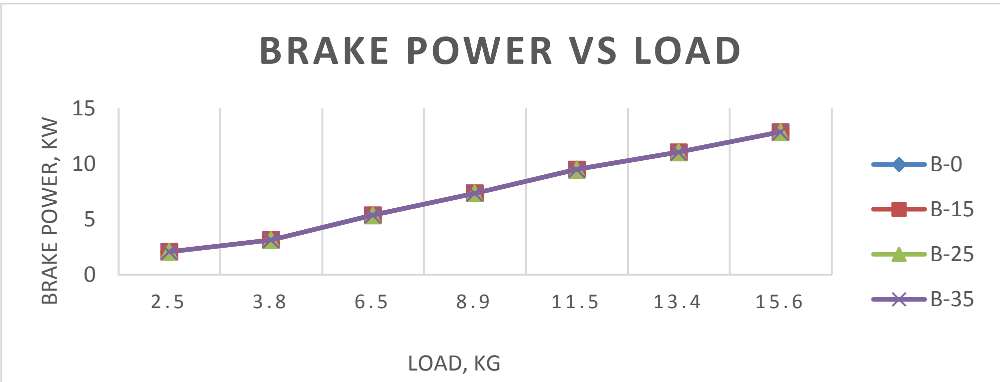


**Fig: 4. Variation of brake power with respect to Load**

The power developed in the engine cylinder is indicated power which is also used to overcome the internal friction. The net power available at the shaft is known as brake power. The brake power for different blends of bio-diesel and that of conventional diesel at different load is reported in figure 4.

The test was conducted for pure diesel fuel which was base line fuel and then for different blends of waste cooking oil bio-diesel B15, B25, B35 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 waste cooking oil bio-diesel blends. Generally, the brake power was approximately similar at any load for diesel and blends of waste cooking oil biodiesel and diesel.

**2. Brake Thermal Efficiency**

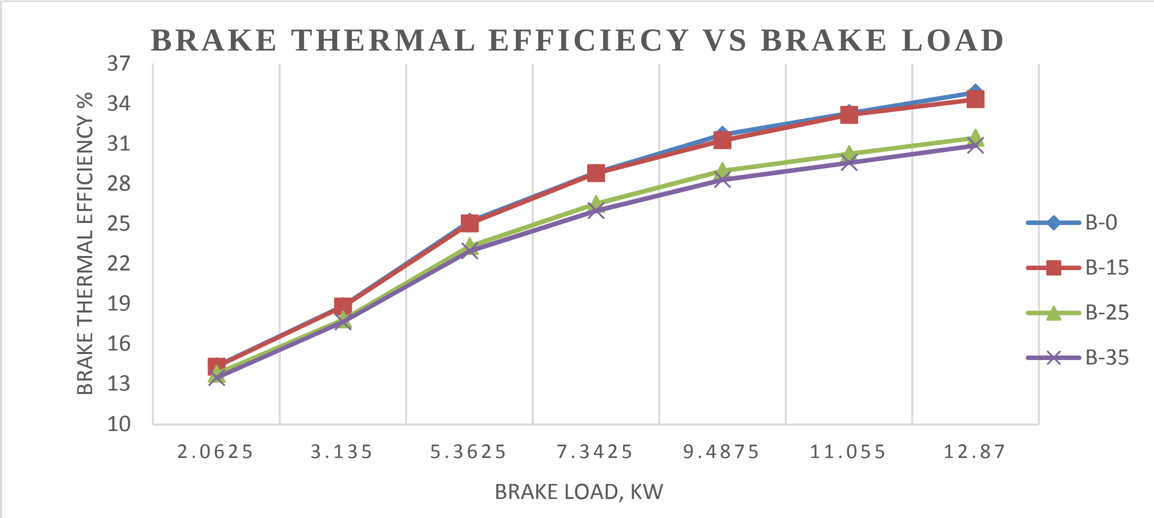


**Fig 5: Variation of brake thermal efficiency with respect to brake load**

The Brake thermal efficiency is defined as the ratio of work output at the engine shaft i.e. brake power 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 4.

The test was conducted for pure diesel fuel which is base line fuel and then for different blends of waste cooking oil bio-diesel B15, B25, B35 samples and the load on engine was varied from 2KW to 13KW. It was observed that the brake thermal efficiency increases with the increasing load for all diesel and waste cooking oil bio-diesel blends operations. This was due to reduction in heat loss and increase in power with increase in load. Brake thermal efficiencies of all the blends of waste cooking bio-diesel with diesel were 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 waste cooking 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 the 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-35 and B-25 blends was 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 WCO bio-diesel B0, B15, B25 and B35 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 WCO bio-diesel blends as shown in figure 6.

It was also observed that fuel consumption increases when waste cooking oil bio-diesel proportion in the blend was increased for any given load. Also for B35 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 B35 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 B35 as compared to conventional diesel and other blends, fuel consumption increases for B35 as compared to diesel and the other blends at higher loads.

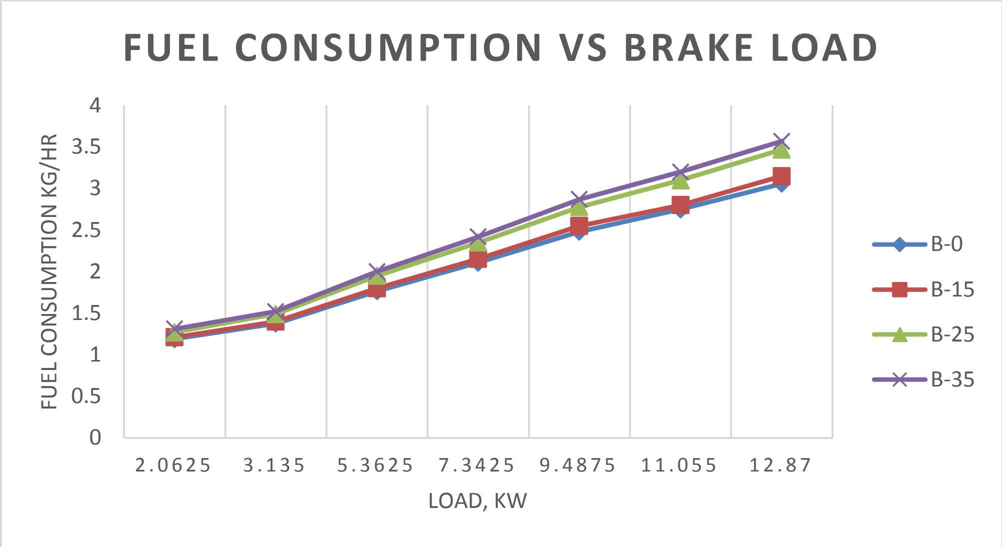


**Fig 6: Variation of fuel consumption with respect to brake load**

**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 7.

The test was conducted for pure diesel fuel which was base line fuel and then for different blends of waste cooking oil bio-diesel B15, B25, B35 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.

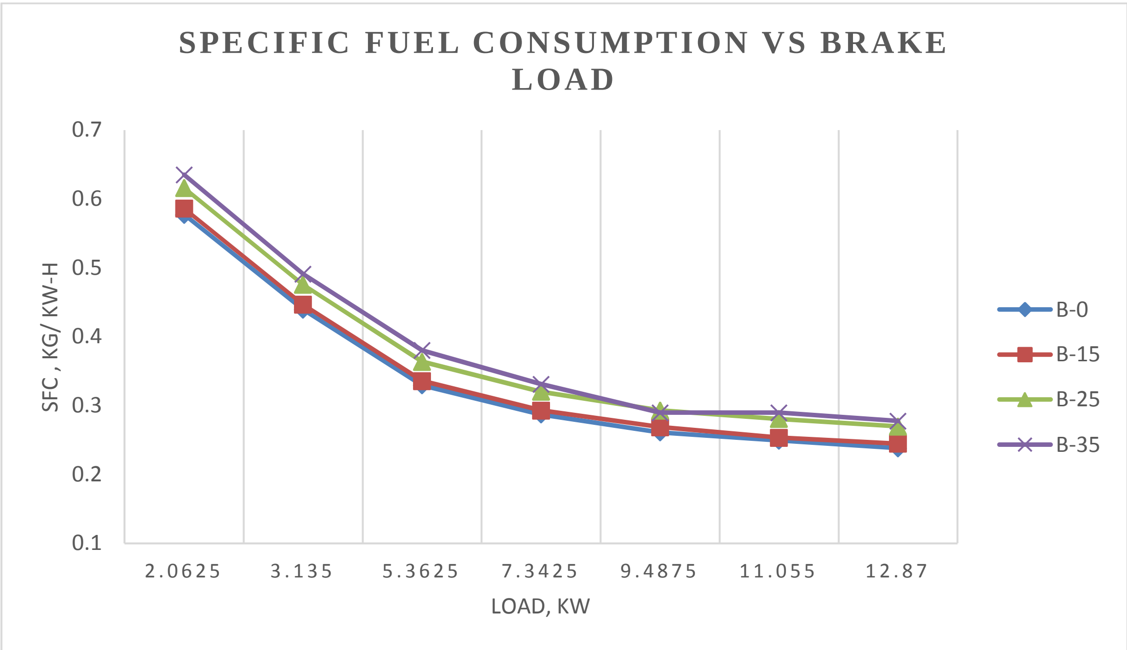


**Fig. 7: - Variation of brake specific fuel consumption with respect to brake load**

This reduction could be due to higher percentage of increase in brake power with load as compared to increase in fuel consumption. The temperature of cylinder wall also increases with load which in turn reduces the ignition delay which improves the combustion process and reduces the fuel consumption. Also the reduction in the rates of brake specific fuel consumption was more as compared to that of at higher loads. The brake specific fuel consumption of B35, B25, and B15 was 16.55%, 13.27% and 2.81% higher than diesel at full load. 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 B35 as compared to conventional diesel and other blends, BSFC increases for B35 as compared to diesel and the other blends at higher load conditions. Also, the calorific values of fuel blends were found to be lower than diesel thereby increasing the engine's fuel consumption to overcome identical load.

## CONCLUSION

The overall testing based on the preparation, characterization of fuel, performance of waste cooking oil methyl esters were carried out on the engine and the following conclusions can be drawn:

The recovery of waste cooking mustard oil methyl ester of lowest kinematic viscosity (4.4mm$^2$/sec) with 97.8% recovery is possible at the catalyst concentration of 1.25%.

In terms of engine performance, the lowest value of brake specific fuel consumption was obtained using diesel i.e. B-0 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 B-35, B-25, and B-15 is 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. 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. 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-35 and B-25 blends is 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. As the performance of engine on B-15 blend was closest to conventional diesel fuel so use of 15% blends of Waste cooking oil bio-diesel as diesel fuel alternative can contribute in reducing.

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