

Performance And Emission Analysis of waste vegetable oil on C.I. Engine

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Abstract : *A design methodology for biodiesel production from waste cooking oil is proposed. The proposed method is flexible to the biodiesel process using various catalyst types: alkali and acid catalyst in homogenous and heterogeneous forms, and different process: enzyme process and supercritical process. A two-step approach of hydrolysis and esterification processes is also considered. Waste cooking palm oil consists of a mixture of triglyceride (e.g., trilaurin, tripalmitin, triolein, tristearin, trilinolein and trilinolenin) and free fatty acids e.g. palmitic acid, stearic acid, oleic acid, linoleic and linolenic acid). A driving force approach and thermodynamic insight are employed to design separation units (e.g., flash separator and distillation) minimizing the energy consumption. Steady-state simulations of the developed biodiesel processes are performed and economic analysis is used to find a suitable biodiesel process. The results show that based on a net present value, the heterogeneous acidcatalyzed process is the best process for biodiesel production. With the design methodology, the proposed biodiesel process can save the energy requirement of 41.5 %, compared with a conventional process.*

Keywords - Process design; biodiesel production; waste cooking oil; Transesterification; Superstructure;

I. INTRODUCTION

Due to a limited availability of fossil fuels and an increased price of petroleum diesel, biodiesel, known as a fatty acid alkyl ester, has become an important alternative fuel that offers several advantages including its renewability and low emission profile of carbon monoxide and unburned carbon. Biodiesel production using an alkali catalyst is a common way due to its low temperature and pressure operation.[1] However, alkali catalyst is quite sensitive to free fatty acid in biodiesel feedstock and thus, expensive pure vegetable oil, which contains free fatty acid of lower than 1 wt.%, is required. In the case of using vegetable oils with high content of free fatty acid, an esterification process based on acid catalyst can be applied to eliminate free fatty acid before further processing via the conventional transesterification process. Presently, a number of biodiesel processes have been developed. Apart from the development of biodiesel processes, an economic analysis is also important to prove a feasibility of the developed process. The best alternative process for biodiesel production should be determined by considering profitability indicators such as a net profit, return on investment and net present value. In general, pure refined vegetable oils are used as feedstock for biodiesel production; however, their price highly increases a biodiesel production cost [2]. Alternatively, use of waste cooking oil with a lower cost seems to be an attractive option. The objective of this study is to propose a design methodology for a biodiesel production from waste cooking oil, which contains 10 wt. % of free fatty acid. A thermodynamic insight and a driving force technique are used to design the biodiesel process. The proposed methodology is flexible to biodiesel production using various catalysts: alkali and acid catalysts in both the homogenous and heterogeneous forms, and different processes: enzyme process and supercritical process [2]. The production of biodiesel based on a two-step approach: hydrolysis of triglyceride followed by esterification of free fatty acid, is also considered. The best process is determined with respect to the highest net present value and the lowest energy consumption.

II. PROCESS

Process followed for preparation of bio-diesel are as:

1. Refining
2. Esterification
3. Transesterification
4. Settling
5. Mixing

These processes are discussed below in details [3].

2.1 Refining:

Vegetable oil recycling is increasingly being carried out to produce a vegetable oil fuel. All waste cooking oil collections need to be carried out by a company registered as a waste carrier by the environment agency. Waste transfer notes need to contain:

- Their waste registration details
- Full details of who the waste is being transferred from
- Date
- Signatures from both parties

Used cooking oil can be refined into different types of biofuels used for power generation and heating. A significant benefit is that biofuels derived from recycled cooking oil typically burn clean, have a low carbon content and do not produce carbon monoxide. This helps communities to reduce their carbon footprints. The recycling of cooking oil also provides a form of revenue for restaurants, which are sometimes compensated by cooking oil recyclers for their used deep fryer oil. Cooking oil recycling also results in less used oil being disposed of in drains, which can clog sewage lines due to the build-up of fats and has to be collected there as "brown grease" by grease traps.

Vegetable oil refining is a process to transform vegetable oil into fuel by hydrocracking. Hydrocracking breaks larger molecules into smaller ones using hydrogen while hydrogenation adds hydrogen to molecules. These methods can be used for production of gasoline, diesel, and propane. The diesel fuel that is produced has various names including green diesel or renewable diesel.

In Physical Refining, Vegetable Oil is subject to distillation to remove free fatty acids. The alkali treatment is completely avoided. This reduces the amount of waste water and eliminates production of soap. This process is becoming more popular [3].

The purpose of Degumming Vegetable Oils is to remove Gums. All oils have hydratable and non-hydratable gums.

a. Water Degumming: Hydratable gums are removed by treating oils with water and separating the gums. The gums can be dried to produce lecithin.

b. Acid Degumming: Non-Hydratable gums are removed by treating oils with acids and separating the gums.

2.1.1 Neutralizing:

The purpose of Neutralizing Vegetable Oils is to remove Free-Fatty Acids (FFAs). Traditionally, FFAs are treated with caustic soda (NaOH) [3]. The reaction produces Soaps which are separated from the oil. Because trace amounts of soaps remain in the oil, the oil is either washed with water or treated with Silica.

Some processors prefer not to perform caustic neutralizing. Instead, they prefer Physical Refining in which the FFAs are evaporated from the oil under high temperature and vacuum. This process can be combined with deodorization step described under FFA stripping.

Physical Refining process is preferred because

- (a) It does not produce soaps
- (b) It recovers fatty acids that provide better cost recovery
- (c) There is smaller yield loss compared to caustic refining—especially for oils with higher FFA
- (d) It is a chemical-free process.

2.1.2 Fatty-Acid recovery:

Fatty-Acids are evaporated (distilled) in FFA Stripping. The Fatty-Acid vapors are condensed by direct contact with liquid Fatty-Acids to recover the evaporated Fatty-Acids. The distillation and condensation of Fatty-Acids is accomplished under very high vacuum to lower the boiling point of Fatty-Acids and prevent them from oxidizing [7].

2.1.3 Hydrogenation:

Vegetable Oils have varying degrees of saturation levels. Some food products can only be prepared in saturated oils & fats. Hence, some food companies hydrogenate vegetable oils to produce desired level of saturation in the Oils & Fats. Vegetable oils can be hydrogenated under high temperature and pressure in the presence of a catalyst.

Fatty acid recovery process is as shown in Fig 1.

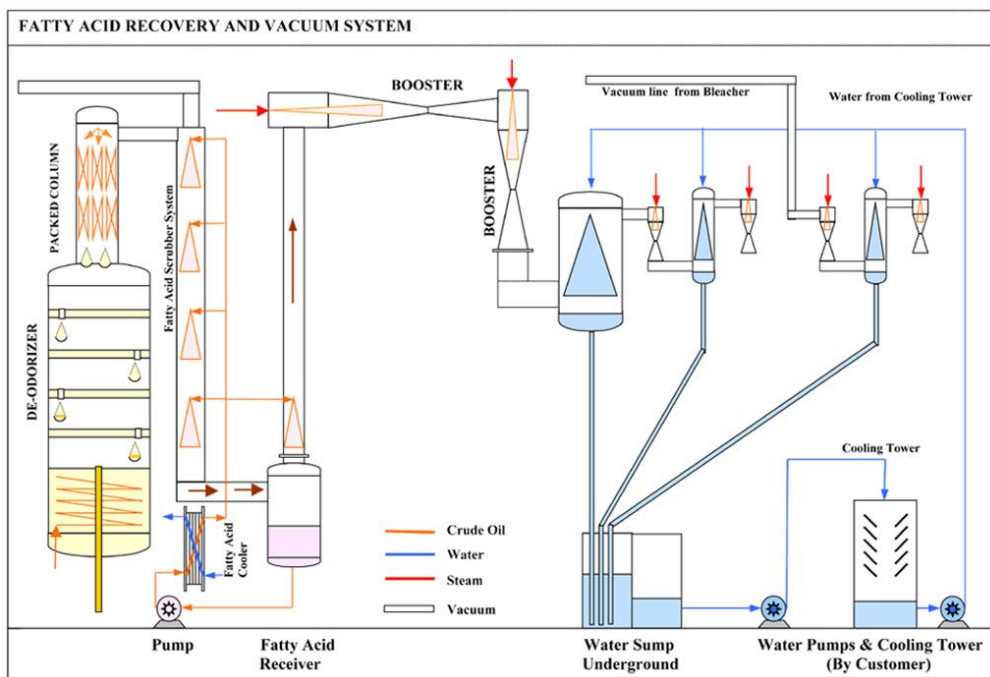
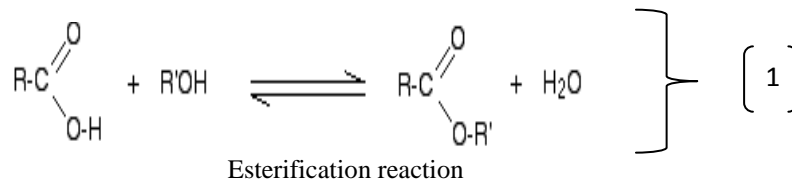


Fig. 1 Fatty Acid Recovery

2.2 Esterification:

Esters are derived from carboxylic acids. A carboxylic acid contains the -COOH group, and in an ester the hydrogen in this group is replaced by a hydrocarbon group of some kind.

Esters are produced when carboxylic acids are heated with alcohols in the presence of an acid catalyst. The catalyst is usually concentrated sulphuric acid. Dry hydrogen chloride gas is used in some cases, but these tend to involve aromatic esters (ones containing a benzene ring). The esterification reaction is both slow and reversible. The Eq.1 for the reaction between an acid RCOOH and an alcohol R'OH (where R and R' can be the same or different) is:



Carboxylic acids and alcohols are often warmed together in the presence of a few drops of concentrated sulphuric acid in order to observe the smell of the esters formed. Because the reactions are slow and reversible, we don't get a lot of ester produced in this time. The smell is often masked or distorted by the smell of the carboxylic acid. A simple way of detecting the smell of the ester is to pour the mixture into some water in a small beaker [3].

Apart from the very small ones, esters are fairly insoluble in water and tend to form a thin layer on the surface. Excess acid and alcohol both dissolve and are tucked safely away under the ester layer. If you want to make a reasonably large sample of an ester, the method used depends to some extent on the size of the ester. Small esters are formed faster than bigger ones. To make a small ester like ethyl ethanoate, you can gently heat a mixture of ethanoic acid and ethanol in the presence of concentrated sulphuric acid, and distil off the ester as soon as it is formed. This prevents the reverse reaction happening. It works well because the ester has the lowest boiling point of anything present. The ester is the only thing in the mixture which doesn't form hydrogen bonds, and so it has the weakest intermolecular forces. Larger esters tend to form more slowly. In these cases, it may be necessary to heat the reaction mixture under reflux for some time to produce an equilibrium mixture. The ester can be separated from carboxylic acid, alcohol, water and sulphuric acid in the mixture by fractional distillation [3,4].

Other ways of making ester

1. Making esters from alcohols and acyl chlorides (acid chlorides)
2. Making esters from alcohols and acid anhydrides

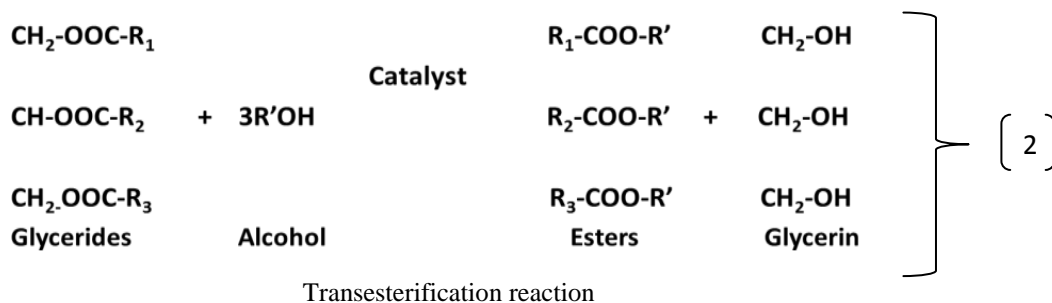
2.3 Transesterification:

Transesterification is the process of exchanging the organic group R'' of an ester with the organic group R' of an alcohol. These reactions are often catalysed by the addition of an acid or base catalyst. Also the tranesterification process is the reaction of triglyceride (fat/oil) with an alcohol in the presence of acidic, alkaline as a catalyst to form mono alkyl ester that is biodiesel and glycerol. The transesterification was carried out in a three-neck glass flask connecting with a reflux condenser using tap water to condense methanol vapour and a thermocouple probe. The mixture was agitated by using a stainless steel stirrer comprising of a turbine. The reactor was placed in a heated water bath [3,4].

The reaction was kept at a desired temperature for 20 min, 40 min, 60 min, 90 min or 120 min. The molar ratio of methanol and WVO varied from 5:1 to 12:1 while the amount of NaOH catalyst was ranging from 0.5 wt% to 1.5 wt% of the WCO. After a certain time, the mixture was poured into a separating funnel. The ester layer was separated by gravity and located in the upper layer. The glycerol, extra methanol and undesired products were in the lower layer and were decanted. The ester layer was washed several times with a small amount of hot water each until the washings were neutral. The ester layer was then dried over sodium sulphate and filtered [4,5].

Transesterification of the waste vegetable oil reduced the viscosity from 31.8 mm²/s to 4.15 mm²/s. This achievement paved the way to use the produced biofuel as diesel engine fuel without any engine modifications.

Transesterification is the chemical reaction between triglycerides and short-chain alcohol in the presence of a catalyst to produce mono-esters. The long- and branched-chain triglyceride molecules are transformed to mono-esters and glycerin. Commonly-used short-chain alcohols are methanol, ethanol, propanol and butanol. Methanol is used commercially because of its low price. The overall transesterification reaction can be shown by the reaction equation given below,



This process is a reversible reaction; the output of biodiesel will be directly influenced by the proportion of reactants, the type and the dosage of the activator and the reaction conditions. From the principle of reversible reaction, it follows that a higher usage of carbinol leads to a higher output of biodiesel. However, the higher density of carbinol can cause a polycondensation reaction; as a result, it will reduce the effective concentration of carbinol, and cause difficulties for the separation of biodiesel. Furthermore, more carbinol is associated with higher costs. In the process of batch reaction or continuous reaction activated by an alkalescence catalyst, a 6:1 mol ratio has been used widely [3,5].

Alkali catalysts used in transesterification can be potassium hydroxide, sodium hydroxide, sodium hydroxide or alkali methoxides. However, potassium hydroxide was considered as a best catalyst for transesterification of used frying oils. After transesterification process the mixture was taken to a tank to be settled.

2.4 Settling:-

The mixture of WVO, methanol and NaOH is stirred continuously and then allowed to settle under gravity in a separating funnel. Two distinct layers form after gravity settling for 24 hours. The upper layer is of ester and lower layer is of glycerol. The lower layer is separated out.

The separated ester is mixed with some warm water (around 10 % volume of ester) to remove the catalyst present in ester and allowed to settle under gravity for another 24 hours. The catalyst gets dissolved in water, which is separated and removes the moisture [6,7]. The methyl ester is then blended with mineral diesel in various concentrations for preparing biodiesel blends to be used in CI engine for conducting various engine tests.

2.5 Mixing:-

Biodiesel obtained after settling is made from 100% waste vegetable oil to make it useable blends are prepared.

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As explained above blends are mixture of Diesel and Biodiesel. This is done by mixing directly and then stirring it for an hour [7].

Once it is mixed properly by stirring for an hour it is allowed to settle for 10-12 hours if layers are obtained then biodiesel made is useless it contains impurities.

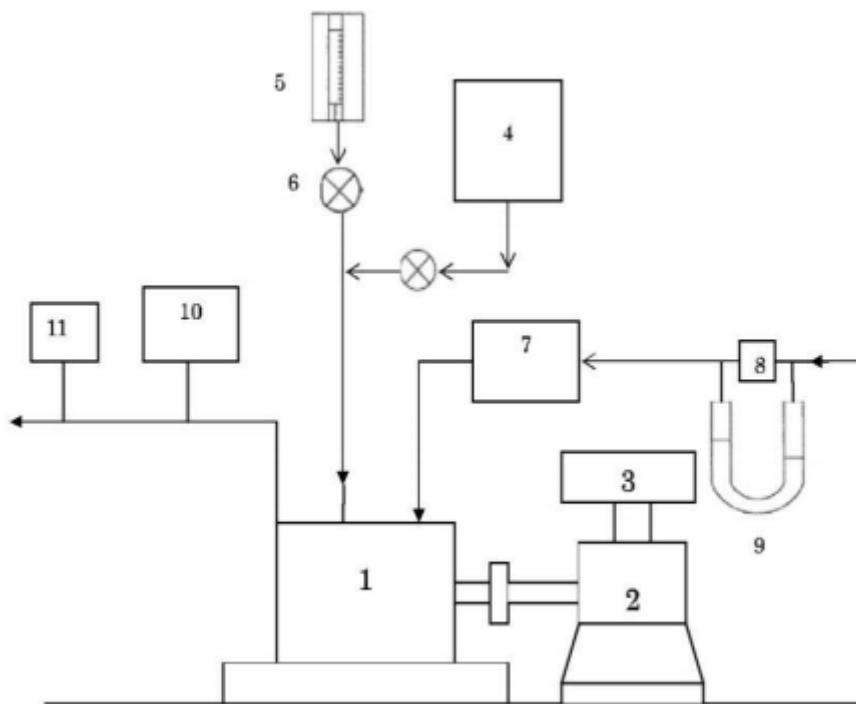
III. PROPERTIES OF BIODIESEL

The properties of biodiesel prepared by the processes explained in section II are shown in Table 1.

Table 1

Fuels	Specific Gravity (gm/cm ³)	Kinematic Viscosity	Calorific Value (MJ/KG)	Flash Point °C
Diesel	0.83	2.70	42.500	64
B10	0.833	2.90	42.390	70
B20	0.839	3.05	42.255	77
B30	0.844	3.45	42.100	86
B50	0.859	3.9	40.100	103
B65	0.869	4.3	39.580	117

IV. TESTING ON DIESEL ENGINE



(1) Engine (2) Alternator (3) Electrical Load Bank (4) Fuel tank (5) Burette (6) Two way control valve (7) Air box (8) Orifice plate (9) U tube manometer (10) Exhaust Gas Analysis (11) Exhaust gas thermocouple.

Fig.1.Layout of Diesel Engine

The layout diesel engine on which biodiesel was tested is as shown in Fig. 1.

Specifications of the diesel engine are as given in Table 2.

Table2: Specification of Diesel Engine

1.	Number of Cylinders	2
2.	Number of Strokes	4
3.	Engine Power (kw)	14.92
4.	Rated Speed (rpm)	1500
5.	Cylinder Bore Diameter (mm)	102
6.	Stroke length (mm)	116
7.	Compression Ratio	17:1
8.	Orifice Diameter (mm)	21.5
9.	Generator (3 phase) 440V (kVA)	15
10.	Load Bank (Heaters) (kw)	12
11.	Method of Cooling	Water

V. RESULT AND DISCUSSION

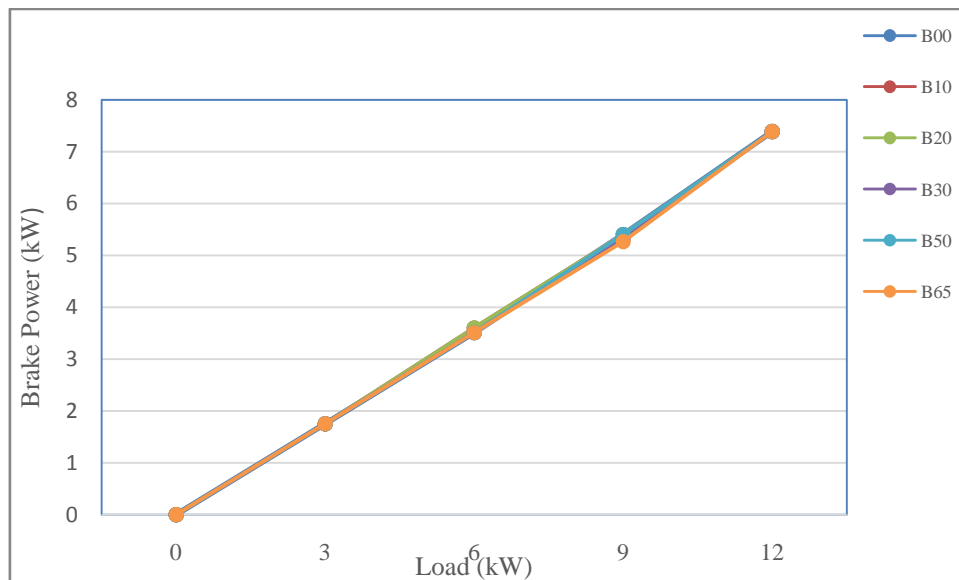


Fig.2 Load versus Brake Power

Fig.2 shows the graph between break power and the load applied. As we increase the load the break power tends to increase linearly. Power requirement is same so the break power values are all same.

As shown in Fig 3, it is between indicated power and the load applied on the engine. For different types of blends of bio-diesel the curve between the indicated power and the load applied on the engine is linear indicating the linear increase in indicated power.

The Fig.4 is obtained by plotting the different valued between mechanical efficiency. It is observed that mechanical efficiency of B30 is maximum as compared to other blends at all load conditions. B30 is maximum because there is complete burning of fuel and hence optimum results are obtained.

From Fig.5, it is observed that break specific fuel consumption is minimum for B20 at 6kW and it is maximum for B65. But as load increases B30 proves to be more efficient since there is a maximum combustion of B30.

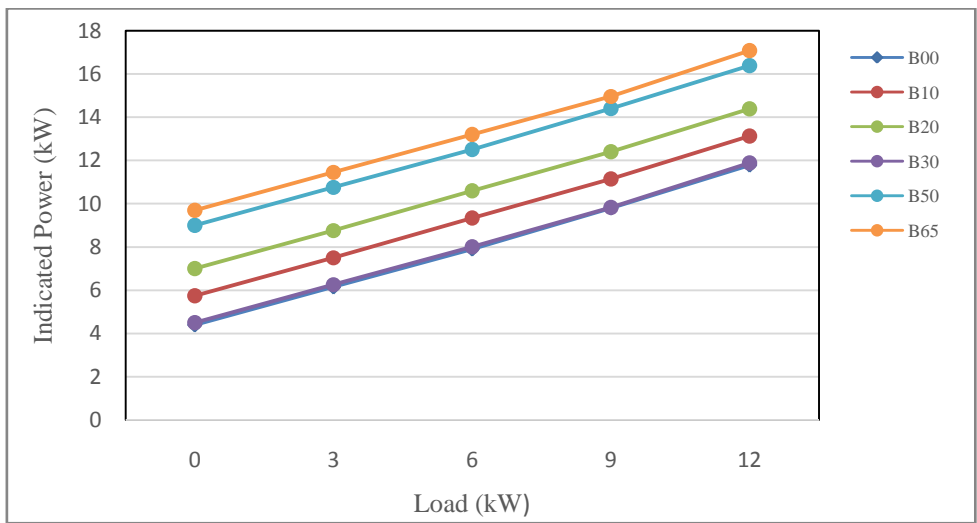


Fig.3 Load Vs Indicated Power

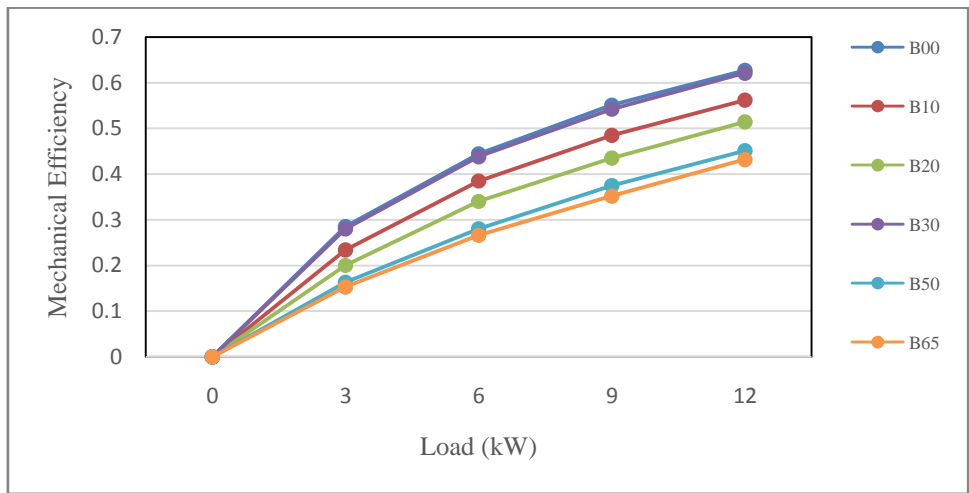


Fig.4 Load versus Mechanical Efficiency

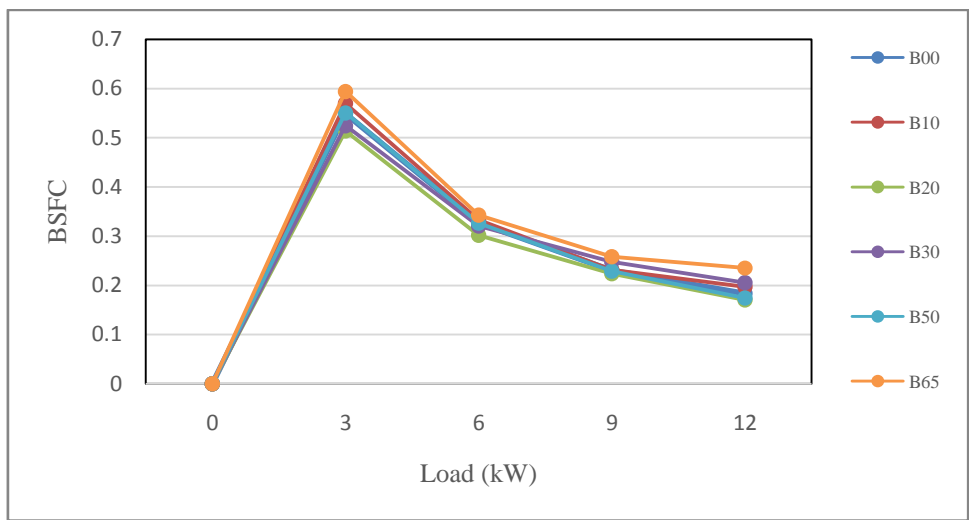


Fig.5 Load versus Brake Specific Fuel Consumption

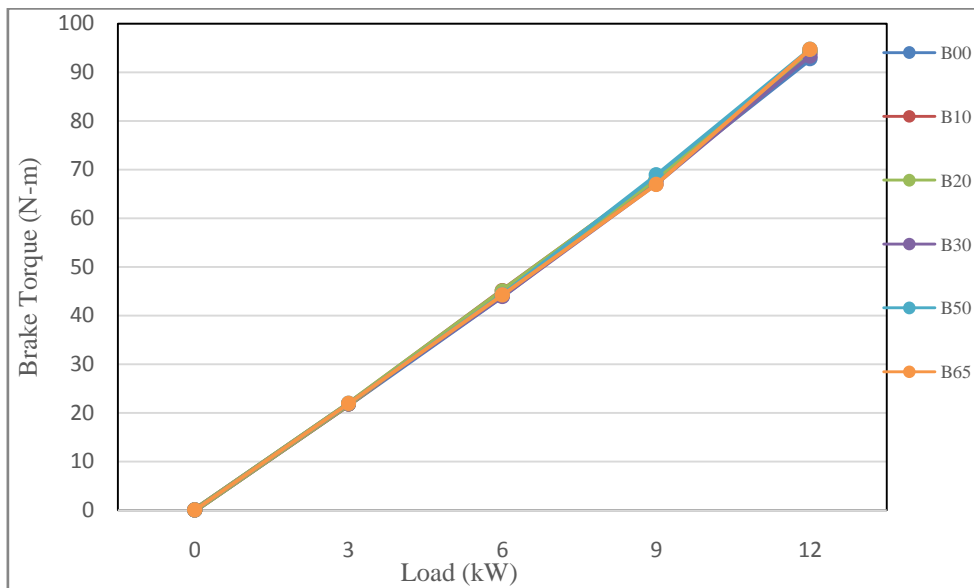


Fig.6 Load versus Brake Torque

As shown in Fig 6, the graph is obtained between break torque and the increasing load. As it can be seen that the relation between break torque and the increasing load is linear that is as we increase the load in the engine the break torque also tends to increase.

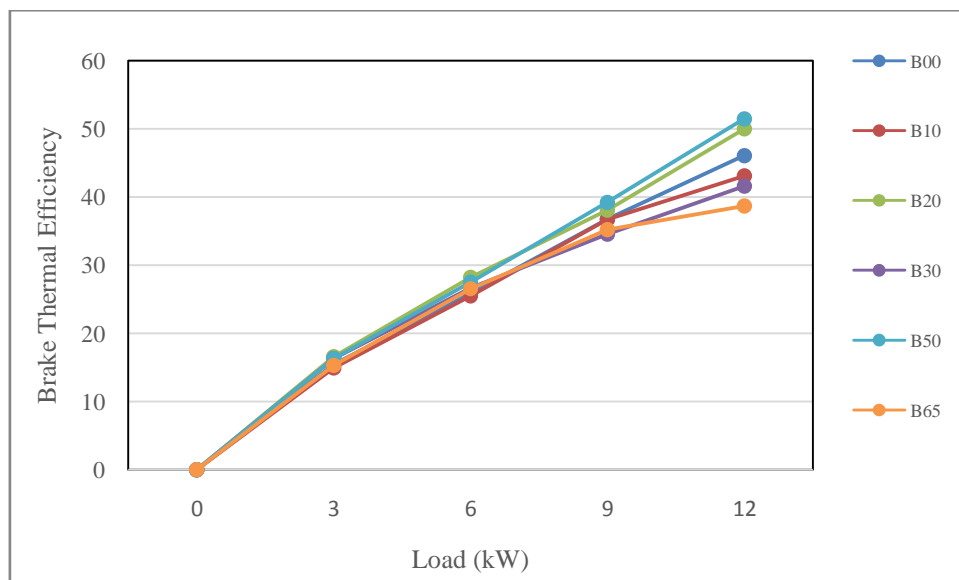


Fig.7 Brake Thermal Efficiency versus Load

The above Fig.7, from the results obtained is between break thermal efficiency and the increasing load on the engine. The break torque obtained is maximum for B50 as it can be seen from Fig.7

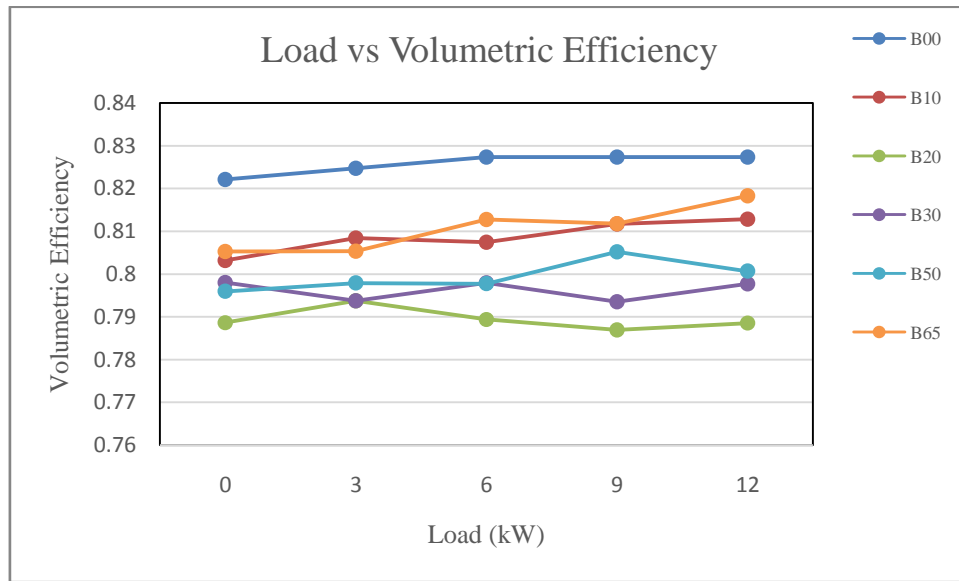


Fig.8 Load versus Volumetric Efficiency

Fig.8 shows Volumetric efficiency is lower for biodiesel as compared to diesel. But from the graph it is seen that volumetric efficiency for B10 is maximum.

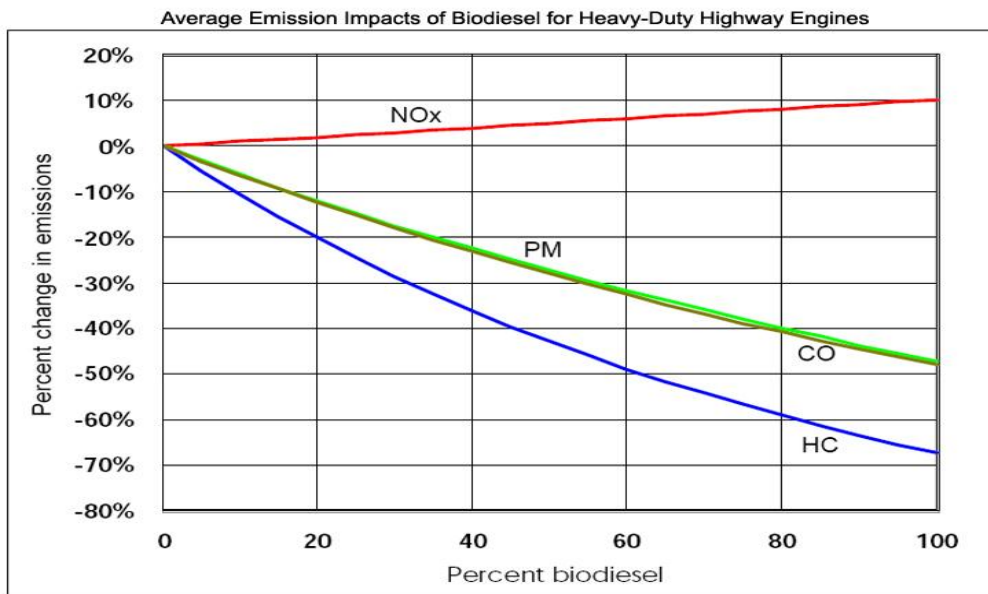


Fig.9 Average Emission Impacts of Biodiesel for Heavy Duty Highway Engines

From Fig.9 it is observed, that percentage of Nitrogen Oxide (NO_x) goes on increasing while carbon dioxide (CO_x), Hydrocarbons(HC) goes on decreasing for biodiesel which means Biodiesel are more environmental friendly as compared to diesel.

VI. FUTURE SCOPE

The present work compares the performance of various biodiesels with fossil diesel in multiple engine applications such as combined cooling heating and power (CCHP) systems, turbocharging, and the use of biodiesel as a transportation fuel. The goal of this work is to determine the usefulness of various biodiesels in a

fully integrated combined cooling heating and power (CCHP) system, as well as in a single cylinder test engine. The CCHP performance will determine the suitability of biodiesel for stationary diesel engine cogeneration plants. The turbocharger installed in the diesel engine for the CCHP system will be instrumented and the turbocharger efficiency will be monitored. The single cylinder test engine will provide data on the general performance of biodiesel in diesel engines along with detailed P-v (indicator) diagrams.

1. Need to improve the Waste vegetable oil methyl ester (Biodiesel) yield by increasing the surface area of sodium oxide catalyst.
2. Combustion characteristics of single cylinder 4-stroke diesel engine can be analyzed.
3. Performance, combustion & emission characteristics of 4-stroke multi cylinder turbocharged direct injection diesel engine with blends of waste vegetable oil methyl ester produced using calcinated sodium oxide catalyst can be carried out.
4. Performance, combustion & emission characteristics of homogeneous charge compression ignition engine with blends of waste vegetable oil methyl ester produced using calcinated sodium oxide catalyst can be carried out.
5. Performance, combustion & emission characteristics of low heat rejection engine with blends of J waste vegetable oil methyl ester produced using calcinated sodium oxide catalyst can be carried out.
6. Performance, combustion & emission characteristics of homogeneous charge compression ignition engine with blends of waste vegetable oil cake need to be studied.
7. Need to study the effect of biodiesel derived from waste vegetable oil oil and its blend with diesel when directly injected at different injection pressures & injection timings in a single cylinder water-cooled compression ignition engine.

VII. CONCLUSION

Cost of biodiesel can be reduced by using waste cooking oil as feed stock. High fatty acid content in waste cooking oil could be reduced by pretreating waste cooking oil with acid catalyst. Water produced during the esterification process can inhibit acid catalyst and this can be eliminated by stepwise reaction mechanism. Methanol is the most suitable alcohol because of its low cost and easy separation from biofuel. Methanol to oil ratio for the acid-catalyzed reaction depends on amount of free fatty acid. For base-catalyzed reaction, 6:1 is optimum ratio for transesterification reaction. Concentration of catalyst depends on nature of catalyst used either heterogeneous or homogenous. Stirrer speed helps to enhance rate of reaction. In most cases, optimum speed of stirrer was maintained in the range of 200–250 rpm. As observed from graphs B30 is the most efficient biodiesel of waste vegetable oil and can be used in daily life.

Acknowledgement

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