Biodiesel Production from High Free Fatty Acid Content Sesame oil and Effect its blends on the performance of Diesel Engine

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Abstract:

The interest on alternative e fuels is continuously increasing to meet the growing energy needs and protect the environment. A successful alternative fuel fulfills the environmental and energy security needs without sacrificing operating performance. One of the successful alternative fuels is biodiesel which is gaining attention in the present day. Biodiesel blends perform very similar to conventional diesel in terms of performance and emission without major modification of engine because the properties of biodiesel and conventional diesel are similar. Sesame is used for production of biodiesel. The calorific value of sesame biodiesel is 38600 MJ/kg while density is 879 kg/m^3, flash point is 147°C, viscosity is 3.96 mm^2/s and cetane number is 49. A single cylinder, 4 stroke, water cooled diesel engine of Kirlosker Oil Engine is used for evaluating performance of sesame biodiesel blends and diesel. The engine performance for various sesame biodiesel blends at various loads are comparatively equal to that of diesel fuel. Brake power of various blends is comparatively equal to brake power of diesel. Brake Thermal Efficiency increases comparatively for 50% sesame blends. Specific Fuel Consumption for sesame blends is slightly higher than diesel. Indicated power of sesame blends is less than indicated power of diesel.

Key Words: Diesel Engine; Diesel Fuel; Sesame Oil; Brake Thermal Efficiency; Specific Fuel

Consumption

Introduction

Petroleum based fuels are limited reserves concentrated in certain regions of the world. Therefore, countries lacking such resources are facing foreign exchange crisis, mainly due to the import of crude oil.[2][3] The development of fossil fuels and their effects on environmental pollution necessitate the usage of alternative renewable energy sources in recent years. Biodiesel is a renewable and energy efficient fuel that is non-toxic, biodegradable in water and has lesser exhaust emissions. It can also reduce greenhouse gas effect and does not contribute to global warming due to lesser emissions because it does not contain much pollutant and its sulphur content is also lower than the mineral diesel. Biodiesel can be used, stored safely and easily as a fuel besides its environmental benefit. Also it is cheaper than the fossil fuel which affects the environment in a negative way. It requires no conventional diesel engine [1][4] Biodiesel (Fatty acid alkyl esters) is an alternative fuel for diesel engines. It is an alcohol esters product from the transesterification of triglycerides in vegetable oil or animal fats. This can be accomplished by reacting lower alcohols such as methanol or ethanol with triglycerides. The reaction proceeds well in the presence of some homogeneous catalysts such as sodium hydroxide and sulfuric acid, or heterogeneous catalysts such as metal oxides or carbonates or enzymes. Sodium hydroxide is very well accepted and widely used because of its low cost and high product yield, but the solubility of potassium hydroxide in methanol is higher than that of sodium hydroxide[5][6]. Although the reaction system is simple, one drawback that prevents wider use of biodiesel is its high energy consumption and production cost, partly resulting from the complicated separation and purification of the product. Therefore, to perform the reaction without the presence of a catalyst is one effective way to reduce the biodiesel cost.[7-9]

Biodiesel is the name given to fuel for Diesel engines created by the chemical conversion of animal fats or vegetable oils. Pure vegetable oil works well as a fuel for Diesel engine itself, as Rudolf Diesel demonstrated in his engine at the 1900 world's fair with peanut oil as the fuel. However, vegetable oil is inherently viscous and cannot be burned efficiently at ambient temperature in modern over the road vehicle. Conversion to biodiesel fuel has the following advantages:-

1. Rapidly mixes with petroleum diesel fuel in any ratio.
2. Restores lubricity of low-sulfur diesel fuel by mixing as little as 1% biodiesel.
3. Is made from renewable sources.
4. Reduction in viscosity over vegetable oil.
5. Can be burned in modern diesel with little or no modification.
6. Reduction in emissions of
   - 6.1. Sulfur dioxide by 100%
   - 6.2. Soot emissions by 40-60%
   - 6.3. Carbon monoxide by 10-50%
   - 6.4. Hydrocarbon by 10-50%
   - 6.5. Nitrous oxide by 5-10%, depending on engine tuning and the age of the engine.

Table 1 Structural formula, melting and Boiling Points for Fatty Acids

Fatty Acid	No. of Carbon and Double bonds	Chemical Structure	Melting Point deg C	Boiling Point deg C
Caprylic	C8	CH3(CH2)6COOH	16.5	239
Capric	C10	CH3(CH2)8COOH	31.3	269
Lauric	C12	CH3(CH2)10COOH	43.6	304
Myristic	C14	CH3(CH2)12COOH	58	332
Palmitic	C16:0	CH3(CH2)14COOH	62.9	349
Palmitoleic	C16:1	CH3(CH2)5CH=CH(CH2)7COOH	33	------
Stearic	C18:0	CH3(CH2)16COOH	69.9	371
Oleic	C18:1	CH3(CH2)7CH=CH(CH2)7COOH	16.3	------
Linoleic	C18:2	CH3(CH2)4CH=CHCH2CH=CH(CH2)7COOH	-5	------
Linolenic	C18:3	CH3(CH2)2CH=CHCH2CH=CHCH2CH=CH(CH2)7COOH	-11	------
Arachidic	C20:0	CH3(CH2)18COOH	75.2	------
Eicosrnoic	C20:1	CH3(CH2)7CH=CH(CH2)9COOH	23	------
Behenic	C22:0	CH3(CH2)20COOH	80	------
Eurcic	C22:1	CH3(CH2)7CH=CH(CH2)11COOH	34	------

Experimentation:

The present section is discussed in two segments namely preparation of bio diesel and performance and emission test of biodiesel.

1.1 preparation of Biodiesel

1.2 Biodiesel is commonly produced by the transesterification of the vegetable oil or animal fat feed stock. Though there are several processes for transesterification, batch reaction process is adopted due to the simplicity and adoptability in the laboratory. The percentage of free fatty acid present in the sample of the fuel is estimated by titration process and the amount of NaOH and methanol is calculated. Following are the sequence of processes in the preparation of biodiesel.

Step 1: Estimates of free fatty acid.

Step 2: Calculation of mass of NaOH required for the solution.

Step 3: Calculation of mass of methanol required for the reaction.

Step 4: Calculation of volume of methanol required per liter of Sesame oil

Step 5: Calculation of weight of KOH required per liter of Sesame oil.

Step 6: Preparation of Biodiesel.

Biodiesel Production Process

1. Titration

Free fatty acid present in vegetable oil may be corrosive to some engine parts. At elevated temperatures, free fatty acid may react with many metals producing fatty acid metal salts thus increasing wear. Acid value is, therefore, an important characteristic to be measured. The acid value or number defined as the mg KOH required to neutralize the free fatty acid present in one gram of sample. However, free fatty acid content is expressed as oleic acid equivalents. The procedure described below was followed in order to determine total acidity of various fuels selected for the study:

- Dissolve 1 to 10 g of oil 50 ml of neutral solvent (neutral solvent is the mixture of 25 ml ether, 25 ml alcohol and 1 ml of 1% phenolphthalein solution and neutralize with N/10 alkali) in a 250 ml conical flask.
- Add a few drops of phenolphthalein.
- Titrate the contents against 0.1N KOH
- Shake constantly until a pink colour which persists for 15 seconds is obtained.

During the course of study, each sample was replicated three times. The total acidity of a fuel sample was then calculated using equation given below:

$$A_v = \frac{56.1 N \times T_v}{W_s}$$

Where,

A_v = Acid value, mg of KOH/g

T_v = Titrate value, ml

N = Normality of the potassium hydroxide solution

W_s = Weight of the sample, g

Calculation of the mass of methanol required for the reaction

Molecular weight of fatty acid in Sesame oil sample:-

Oleic acid : 282.465 (42.25%)

Fig 1 Titration Process

Stearic acid : 284.481 (4.75%)

Palmitic acid : 256.428 (9.5%)

Linoleic acid : 280.450 (42.25%)

Linolenic acid : 278.434 (0.5%)

Palmitioleic acid : 254.408 (0.25%)

Eicosenoic acid : 310.51 (0.5%)

The molecular weight of fatty acids in Sesame oil sample =282.465*0.4225 + 284.481*0.0475 + 256.428*0.095 + 280.540*0.4225 + 278.434*0.005 + 254.408*0.0025 + 310.51*0.0005

=279.28 gm

Therefore the molecular weight of Fatty acids in Sesame oil sample is =279.28 gm

Molecular weight of triglycerols of Sesame oil = 173.10+3*279.28 = 1011 gm

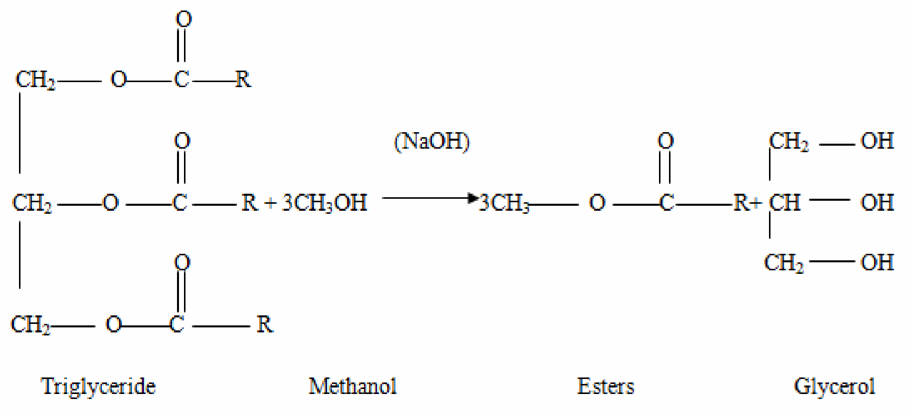
Selecting a mole ratio of 6:1 the weight of methanol required per 1011 gm of Sesame oil as

6*32.04=192.24 gm

2. Transesterification Process

Transesterification (alcoholysis) is a chemical reaction between triglycerides present in the vegetable oils and primary alcohols in the presence of a catalyst to produce mono-esters (biodiesel) and glycerol. Nevertheless, transesterification is not always possible. Oils, which have high free fatty acid (FFA) content can't be transesterified by this reaction. The process rather leads to saponification i.e. formation of soap. Formation of soap makes it very difficult to separate the layers of biodiesel and glycerol. Many different thresholds of FFA contents are proposed in literature, but commonly, it is accepted that above 5% FFA level in the vegetable oils, it becomes very difficult to produce biodiesel by transesterification process. The FFA content of the oil influences the yield of biodiesel from this oil. Lower FFA results into easier production and higher yield of biodiesel. FFA content of vegetable oils is very sensitive to different parameters. From one single batch of oil seeds, oils with different FFA content could be produced depending on the process used to produce the oil, conditions of storage, moisture content and quality of the initial feedstock. For producing low cost biodiesel, methods for utilization of low cost feedstock which generally have high FFA needs to be investigated.

The FFA content of the vegetable oils increases with duration of storage of seeds/oils and leads to degeneration of the quality of vegetable oils. To deal with these parameters, which have an adverse impact on the properties of the vegetable oils and biodiesel, solutions must be found to produce biodiesel even from low or medium quality vegetable oils, which have high FFA content. For such oils, one of the most frequently used pre-treatment step is to lower FFA content of the vegetable oils is 'esterification'. In the present study, FFA of Sesame oil was reduced (from 20.3%) by esterification reaction. This reaction is traditionally catalyzed by acids such as sulphuric acid.



Where, R is long chain hydrocarbons.

Main parameters ruling esterification are amount of catalyst (W/W oil), molar ratio of alcohol to oil, temperature of reaction, time of reaction. For our experiment, optimized process parameters for esterification reaction are: 5% catalyst, 8:1 alcohol to oil molar ratio, 90 min reaction time and 45 °C temperature. FFA content of the oil decreased from 20.0% to 4.2 % in this esterification step. Further reduction in FFA takes place during the transesterification reaction. This is because of neutralization of FFA by the basic catalyst (KOH). For this reason, a slightly higher amount of basic catalyst was taken for the transesterification in order to ensure presence of enough catalyst to catalyze the transesterification reaction even after this neutralization reaction for the FFA. Biodiesel was thus produced by transesterification step on this low FFA Sesame oil from esterification.

Preparation of Sesame oil ethyl ester (NOEE) is done by mixing ethanol and sulphuric acid for the esterification process step. Catalyst used for the process of esterification and transesterification steps are sulphuric acid (Merck 98% purity), and potassium hydroxide (RFCL, 97% Purity) respectively. Ethanol used in both of these process steps was having density 0.789 kg/l with a purity of 99%. For the esterification process step, 8:1 molar ratio of alcohol to oil and 5% catalyst (w/w oil) was used. The reactants are heated in the round bottom flask to 45 °C in shaking water bath (Plate 3.1) for 90 min. After the completion of the reaction, the products are kept in a separating funnel for 24 h for gravity separation. The lower layer formed is dark brown, which mostly contains water while the upper layer contains reduced FFA Sesame oil. Lower layer is removed and upper layer is used for transesterification process step for conversion into biodiesel. For this, 8:1 molar ratio of alcohol to oil with 1% (w/w oil) KOH is mixed with reduced FFA Sesame oil. The reactants in the round bottom flask are heated at 60 °C in shaking water bath. After the completion of the reaction, products are again poured in a separating funnel for gravity separation of the products for 24 h. The lower layer formed is deep dark brown and mainly contains glycerol while the upper layer is biodiesel, which also contains traces of catalyst Traces of the catalyst are removed by water washing the biodiesel. However before washing the biodiesel, it is necessary to remove the ethanol content in biodiesel in order to avoid soap formation. Since the boiling point temperature of ethanol is 78.3 °C, it can be easily removed by heating biodiesel up to 85 °C. Biodiesel is heated and kept at this temperature for 5 min and then the biodiesel is mixed with 10% (v/v) warm water and kept in separating funnel for few hours. The lower layer contains water with traced of catalyst and this layer is removed. The pH of biodiesel is checked. If it is more than 7, water washing step is repeated. The upper layer is biodiesel, which is again heated at 105 °C for 5–10min so as to remove the traces of moisture before final storage.

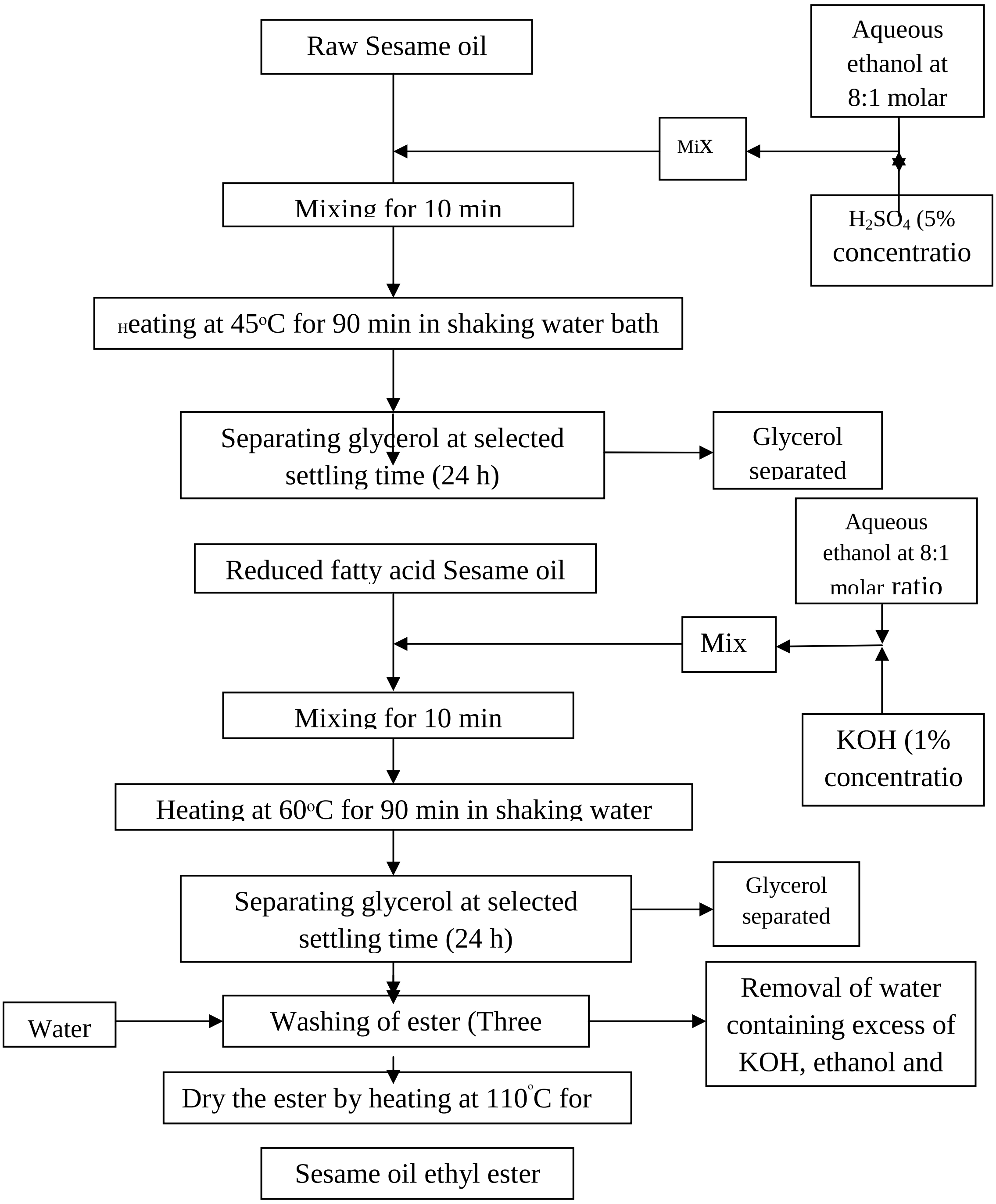


Fig 2 Biodiesel Production of Sesame Oil

Preference was given in production of ethyl ester because ethyl esters have higher heat content and cetane number due to extra carbon atom brought by ethyl alcohol during esterification process. Moreover, ethanol is non toxic, not poisonous, cheaper and can be derived from renewable source like

sugarcane, bagasse, potato, sweet sorghum etc.

3. Draining of Glycerol

After the transesterification reaction, one must wait for the glycerol to settle to the bottom of the container. This happens because glycerol is heavier then biodiesel. The settling will begin immediately, but the mixture should be left a minimum of eight hours to make sure all of the glycerol has settled out. The glycerol volume should be approximately 20% of the original volume.

4. Washing of Fuel

The purpose is to wash out the remnants of the catalyst and other impurities. There are three main methods:

1. Water wash only (a misting of water over the fuel, **Fig 3** Separation of Biodiesel and Glycerol draining water off the bottom)
2. Air bubble wash (Slow bubbling of air through the fuel)
3. Air/Water bubble wash (with water in the bottom of the tank, bubbling air through water and then fuel)

After the water is drained, the air washing process can start. At this point, the biodiesel is usually a pale yellow color. Air should be bubbled through the biodiesel mixture for approximately 8 hours. The bubbling should be just enough to agitate the biodiesel surface. A final drain of accumulated contaminants is done immediately after the air bubble wash is finished.

5. Experimental Set up and Experiments:

Table 2. Engine test setup specification

Make of engine	Kirloskar , TV1
General Details	Four stroke, compression ignition, constant speed, vertical, water cooled, computerized diesel engine
No. of cylinder	One
Bore	87.5 mm
Stroke	110 mm
Swept Volume	661 cc
Compression Ratio	17.5:1
Rated Output	5.2 kw at 1500 rpm
Injection Nozzle	3 hole
Fuel Injection Pressure	205 bar

Table 3. The observed engine performance using Sesame biodiesel and diesel at zero load

Performance	Diesel	B10	B15	B20	B25	B30	B50
Brake power (kW)	0.43	0.43	0.41	0.46	0.44	0.46	0.43
Specific fuel consumption (kg/kW-hr)	0.792	0.865	0.82	0.71	0.78	0.72	1.09
Torque (N m)	0.27	0.27	0.26	0.29	0.28	0.29	0.25
Brake thermal Efficiency (%)	10.32	9.86	10.32	12.65	11.78	12.32	8.65
Indicated power (kW)	4.32	1.78	1.65	1.69	1.98	1.21	1.78
Mechanical efficiency (%)	8.98	24.32	24.77	26.21	22.32	32.51	23.21

Table 4. The observed engine performance using Sesame biodiesel and diesel at full load

Performance	Diesel	B10	B15	B20	B25	B30	B50
Brake power (kW)	4.79	4.78	4.79	4.84	4.78	4.86	4.89
Specific fuel consumption (kg/kW-hr)	0.254	0.261	0.228	0.312	0.319	0.305	0.215
Torque (N m)	3.31	3.36	3.29	3.29	3.28	3.25	3.28
Brake thermal Efficiency (%)	31.19	32.18	37.54	29.58	29.39	31.65	46.67
Indicated power (kW)	5.47	5.78	5.79	5.92	5.67	4.92	5.81
Mechanical efficiency (%)	88.64	84.67	82.73	81.08	82.19	93.79	84.52

6. Result and Discussion

6.1 Brake Power

Figure 4 (a) shows variation of brake power of SESAME blends and diesel with load. The results show there is no noticeable difference in brake power of SESAME blends and diesel. At different load brake power of SESAME blends increases with increase in load because of the higher density of blends containing a higher percentage of SESAME biodiesel and has led to more discharge of fuel for the same displacement of the plunger in the fuel injection pump, thereby increasing the brake power. Maximum brake power is 4.79 N m for diesel at full load.

6.2 Effect of load on brake thermal efficiency

The variation of brake thermal efficiency of the engine for different sesame biodiesel and diesel blends is shown in Figure 4 (b) and compared with the brake thermal efficiency obtained with diesel. From the test results it was observed that initially with increasing load the brake thermal efficiencies of the sesame biodiesel blends and the diesel increases and the maximum thermal efficiencies were obtained and then tended to decrease with further increase in load. The brake thermal efficiency of sesame 50 biodiesel has an increasing trend with increase in load and brake thermal efficiency of other SESAME blends is close to brake thermal efficiency of diesel upto 80% load. Maximum brake thermal efficiency is 46.67% at overload condition for sesame50 and minimum of 8.65% for sesame50 at no load.

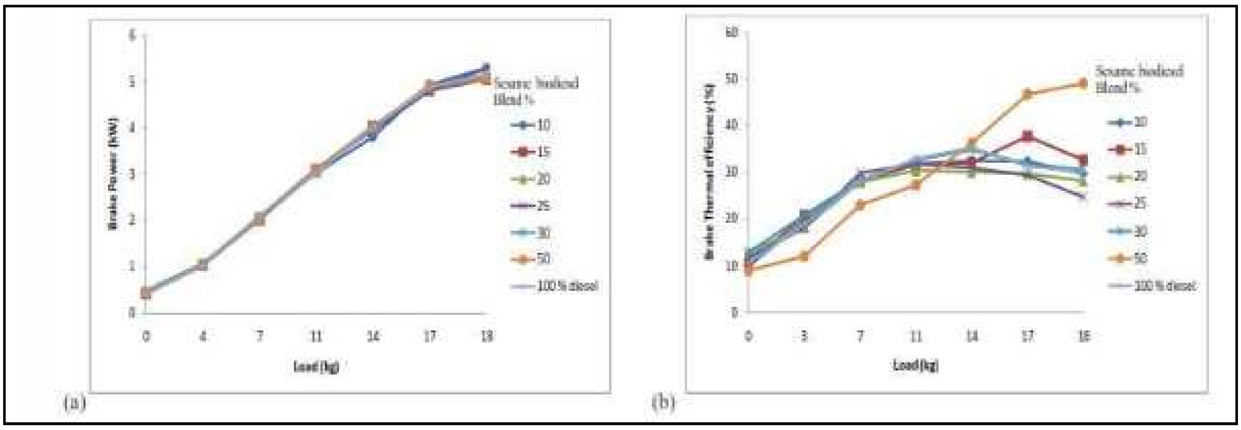


Figure 4 (a) Effect of load on brake power (b) Effect of load on Brake Thermal Efficiency

6.3 Effect of load on specific fuel consumption

Figure 5(a) compares the specific fuel consumption of diesel and various sesame blends. It was observed that the specific fuel consumptions of the diesel as well as the blends were decreased with increasing load. It is also found that fuel consumption of sesame blends is slightly higher than diesel. The fuel consumptions were also found to increase drastically with sesame50 biodiesel diesel blends. This is mainly due to the combined effects of the relative fuel density, viscosity, and heating value of the blends. Maximum specific fuel consumption is 1.09 kg/kW hr for sesame50 at no load and minimum is 0.244 kg/kW hr for diesel at 80% load.

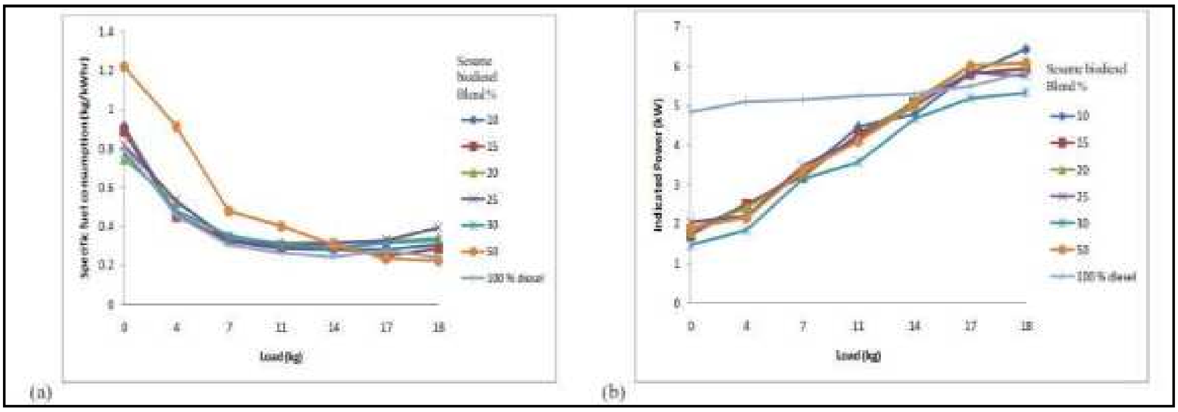


Figure 5 (a) Effect of load on S.F.C (b) Effect of load on Indicated power

6.4 Effect of load on indicated power

Figure 5(b) shows indicated power of various sesame blends and diesel at different loads. The indicated power of sesame blends increases with increase in load. Indicated power of sesame blends is quite less than indicated power of diesel. This could be due to lower heating value and higher density of sesame blends than diesel. Maximum value of indicated power is 5.92 kW for sesame20 at full load and minimum is 1.21 kW for sesame30 at zero loads.

6.5 Effect of load on torque

The variation of engine torque with load is shown in Figure 6(a). Torque for sesame blends increases with increase in load. Torque for various SESAME blends is equal to torque of diesel. Maximum torque is 3.36 N m at full load for sesame10 and minimum is 0.25 N m at zero load for sesame50.

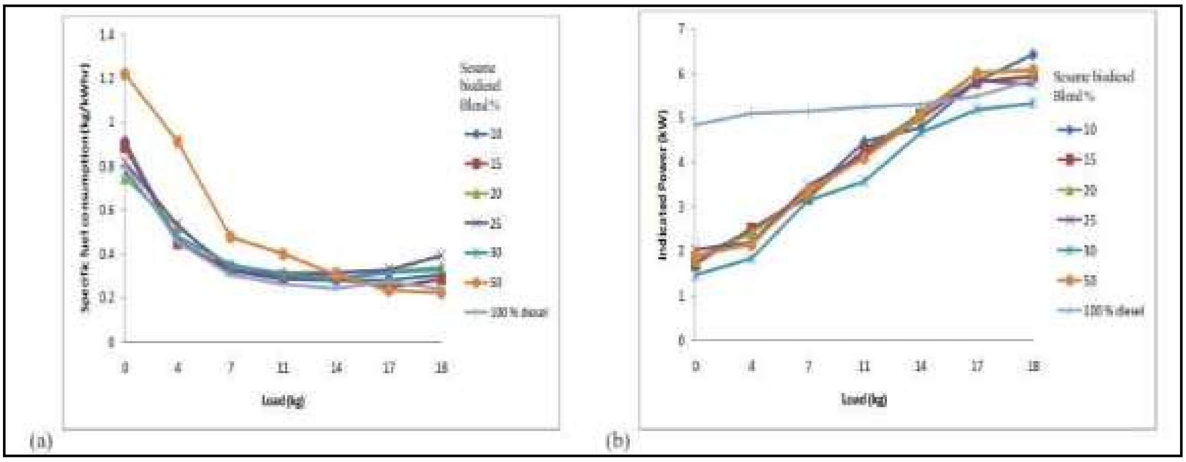


Figure 6 (a) Effect of load on torque (b) Effect of load on mechanical efficiency

6.6 Effect of load on Mechanical efficiency

The variations of mechanical efficiency of sesame blends with load are shown in Figure 6(b). As brake power increases with increase in load the mechanical efficiency of sesame blends increases. Minimum mechanical efficiency is 8.98% for diesel at zero load and maximum is 93.79% for sesame30 at full load.

Conclusion:

Biodiesel is a domestic fuel alternative and can contribute to a more stable supply of energy. The biodiesel fuel production process has evolved considerably to minimize the original problems with viscosity. Today, biodiesel is an increasingly attractive, non-toxic, biodegradable fossil fuel alternative that can be produced from a variety of renewable sources. Sesame oil has potential as an alternative energy source. But it is not possible for oil alone to solve dependency on foreign oil within any particular time frame. Significant commitment of resources would require increasing production of Sesame oil. These needs are being met with recent advances in instrumentation technology. The emphasis should be made to invest in agriculture sector for exploitation of existing potential by establishing model seed procurement centers, installing preprocessing and processing facilities, oil extraction unit, transesterification units etc. The organized plantation and systematic collection of Sesame oil, being potential bio-diesel substitutes will reduce the import burden of crude petroleum.

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