Production Of Biofuel From Sesame Oil And Its Characterization As An Alternative Fuel For Diesel Engine

Kuber Singh Mehra\textsuperscript{a}, Gaurav Pant\textsuperscript{b}
\textsuperscript{a} Birla Institute of Applied Sciences, Bhimtal
\textsuperscript{b} Department of Mechanical Engineering, GLA University, Mathura

mehrakubersingh@gmail.com, gauravpant.me@gla.ac.in

Abstract. Depletion of petroleum fuels and their rising cost have directed towards an intensive search for substitute fuels. In the present work, a potential feedstock for biodiesel production is identified as sesame oil biodiesel. Raw sesame oil is collected from the market and biodiesel from raw oil is produced through the trans-esterification process in the laboratory. A highest biodiesel yield of 92.1% was achieved, when esterification process is performed with 10:1 ethanol to oil ratio and 2.3% sodium hydroxide at 60 °C for 90 min. Thermo-physical properties are investigated with the help of different experimental apparatus. Comparison with Bureau of Indian Standards (IS 15607:2016) reveals the suitability of sesame oil biodiesel used as an alternative fuel for compression–ignition engine. Experimental study is performed for different blends of sesame oil biodiesel and diesel fuel (SOEE20, SOEE40, SOEE60, SOEE80, SOEE100), mineral diesel and raw sesame oil to recognize the suitability of blends to be use as a fuel for diesel engine.

1. INTRODUCTION

The social and economic development of a nation majorly based on its access to Energy. India possess renewable energy in its various terrain like hydro, wind, bio decompose etc. It includes only 0.3% of the total world’s proven crude oil reserves (763.48 million tons) and 0.8% of the total world’s natural gas reserves (1,488.49 billion cubic meters). Renewable energy has significantly contributed to the global energy consumption in current years. Indian consumption is up to 5.3% oil of the total world consumption while,36.1% account for rest Asia pacific region [1]. With reference to the present scenario, India is greatly dependent on petroleum energy fuels for agricultural and transportation machinery. Diesel fuel is broadly acknowledged and used in locomotives, generators and mining equipment etc. [2], [3]. Fuel emissions have been always harmful for surroundings and rest ecosystem. Factors such as environment hazard, long term availability arises a necessity to develop its substitute [4].While accounting such concern, vegetable oil (Bio Diesel) is considered as a capable alternative to develop eco-friendly, sustainable, renewable energy. Many researchers investigated and found that its chemical properties are like diesel up to some extent [5], [6]. Hence, such substitute fuels have an edge of diesel fuel and evidently it is sustainable for economy and environment [7], [8].There are studies which reveals the potential of production of biodiesel from edible and non- edible vegetable oil. Experiments were also carried out to confirm suitability of
biodiesel made from raw palm oil and favorable outcomes were reported[9]. Studies on Neem oil biodiesel were conducted and enhancement in performance, improvement in peak cylinder pressure and decrease in emissions were reported[10],[11]. [12] Optimized biodiesel production from jatropha oil with high free fatty acids using RSM. [13] Transesterification process was optimized for animal fat oil ester, whereas [14] used RSM tool for optimization of rapeseed oil with very high FFA converted to biodiesel. Also, RSM is used for the Zanthoxylum bungeanum seed oil transesterification process for converting it to biodiesel .[15]. Transesterification process variables optimization was done using RSM for biodiesel production from raw cottonseed oil [16]. [17] Pongamia oil as an substitute fuel for diesel engine was used with ignition improver DEE. Successful results were reported for diesel engine fuelled with biodiesel (sesame oil methyl ester) and diesel blend along with ignition improver [18].

It is inferred from the literature that there are rare studies carried out considering sesame oil as an alternative engine fuel. Further, the existing reports used sesame oil methyl ester as an substitute fuel for diesel engine. Therefore, in the present work ethyl esterification of sesame oil is done and feasibility of using sesame oil ethyl esters as fuel is determined.

In the present work sesame oil biodiesel was prepared from raw sesame oil purchased from the market. Blends were then made from diesel and sesame ethyl ester. Physio-chemical properties of all fuel samples are experimentally investigated and compared to the Bureau of Indian Standards (IS: 15607) to determine the suitability of using sesame oil biodiesel as a fuel for CI engine.

2. MATERIAL AND METHODS

Oil Processing

The sesame vegetable oil used in this study was obtained from M/S Gattumal Aausdhalya, Bareilly. The method that was used to process the oil is described below.

PROCEDURE FOR BIODIESEL PREPARATION

The process developed for biodiesel (Sesame ethyl ester) preparation is shown here in the form of a flowchart (fig. 2.1)
PURIFICATION

Raw sesame oil temperature was raised to 100°C and kept at this temperature for around thirty minutes while constantly stirring to decrease water content in the oil. The oil was later passed through a strainer while to remove solid particles and debris from the oil.

TITRATION

The acid value of prepared different fuel sample was calculated as per method explained by [19]. The method selected for measuring acid value is described below:

- First Dissolve oil (1 to 10 g) and 50 ml of solvent (which is of neutral nature and combination of 25 ml alcohol, 25 ml ether, and 1 ml of 1% phenolphthalein solution and neutralized with alkali of Normality N/10) in a conical flask of capacity 250 ml. Now, add a some drops of phenolphthalein. Titrate it against 0.1N NaOH. Shake the content constantly till a pink colour is noticed which persists for 15 seconds. Every sample was replicated three times to achieve accuracy in the study. The acidity of the prepared fuel samples was then measured using the equation given below:

\[ A_v = \frac{56.1N \times T_v}{W_s} \]

where,

- \( A_v \) = Acid value (mg of NaOH/g), \( T_v \) = Titrate value in ml,
- \( N \) = Normality (Sodium hydroxide solution), \( W_s \) = Weight of the sample, g

TRANSESTERIFICATION

- Sodium-methoxide was made by dissolving some amount of NaOH (around 0.8% w/v oil) in ethanol (around 20% v/v oil) for any amount of cleaned oil (raw) which is to be processed. The oil temperature was raised to 60°C and then mixed with sodium-methoxide solution on magnetic stirrer. The mixture was vigorously stirred and maintained at 60°C for 90 minutes then shifted to the settling container for the initiation of separation of glycerol from biodiesel.

SEPARATION PROCESS

Since glycerol possess higher density compared to biodiesel, it get settled at the bottom of container as shown in fig. 2.2. After the 24 hours of separation process, the tap attached to the container was set opened, resulting in draining of glycerol.

![Fig. 2.2 showing the separation of biodiesel (upper layer) and glycerol (lower layer) after 24 hours in a separating funnel](image-url)
WATER WASHING AND DRYING OF BIODIESEL

Biodiesel was washed with warm water three times to remove traces of ethanol and NaOH from oil. After every wash, the oil was kept in settling container for four hour to separate washing residue from biodiesel. Separation of biodiesel after washing is shown in fig. 2.3. The water quantity used in every wash was around 10-20% of oil. Water residue was then removed by setting the tap open after separation. At last, the prepared biodiesel was heated to 110°C temperature for around thirty minutes while constantly stirring to evaporate the residual water content.

![Fig. 2.3 Showing the separation of biodiesel (upper layer) after washing in a separating funnel.](image)

BIODIESEL YIELD

It was observed during the experiment that yield of biodiesel is affected by the factors like ratio of ethanol and vegetable oil, sodium hydroxide usage, temperature of reaction and total time for the reaction. Therefore it is noticed that, highest biodiesel yield of 92.1% was achieved, when esterification was performed with 10:1 ethanol to oil ratio and 2.3% w/v oil sodium hydroxide (NaOH) at 60 °C for 90 min.

PREPARATION OF DIFFERENT BLENDS OF SESAME OIL BIODIESEL AND DIESEL

Due to the high viscosity of sesame oil it makes them unsuitable to use as a replacement of diesel fuel for CI engine. Therefore, biodiesel (sesame oil ethyl ester (SOEE))-diesel blends were made by blending 20% to 100% biodiesel with diesel. The terminology used in this study for blends made from biodiesel (SOEE) with diesel fuel for evaluation of fuel properties are shown in the table 2.1.

FUEL CHARACTERIZATION

The density at 15°C, viscosity at 38°C, flash and fire point and calorific value were determined for the diesel, sesame oil, sesame-diesel blends in Chemical Reaction Laboratory of Chemical Engineering Department, B.T.K.I.T Dwarahat. The equipments and procedures used are as described below.
Table 2.1 Prepared sesame oil ethyl ester-diesel fuel blends terminology

| S.No. | Fuel Samples          | Nomenclature   |
|-------|-----------------------|----------------|
| 1.    | Diesel                | Diesel         |
| 2.    | Sesame oil            | SO             |
| 3.    | 20% Sesame oil ethyl ester + 80% Diesel | SOEE20         |
| 4.    | 40% Sesame oil ethyl ester + 60% Diesel | SOEE40         |
| 5.    | 60% Sesame oil ethyl ester + 40% Diesel | SOEE60         |
| 6.    | 80% Sesame oil ethyl ester + 20% Diesel | SOEE80         |
| 7.    | 100% Sesame oil ethyl ester + 0% Diesel | SOEE100        |

**VISCOSITY**

A Saybolt viscometer was used to determine the viscosity of the oil samples. The viscosity of a liquid is a measure of internal friction of the liquid in motion.

A Saybolt Viscometer of Ark International make is used for the study as shown in Fig. 2.4 was The instruments evaluates the time of flow under gravity for the fixed volume of fluid which is 60 ml passed through pre-specified orifice manufactured in an agate piece as per the standard IS: 15607:2016.
Viscosity was computed using the following equation.
\[
cSt = 0.224 \text{ SUS}^{-1.85}/\text{SUS} : \quad \text{For 34 to 115 SUS (2)}
\]
\[
cSt = 0.223 \text{ SUS}^{-1.55} : \quad \text{For 115 to 215 SUS}
\]
\[
cSt = 0.2158 \text{ SUS} : \quad \text{Above 215 SUS}
\]

where, \(cSt\) - Kinematic viscosity of the oil in centistokes, SUS- Saybolt Universal Second

**CALORIFIC VALUE**

Calorific value (Heat content of fuel) was evaluated using a bomb calorimeter apparatus present in the lab. To standardize the calorimeter benzoic acid was used. Sample (One gram) was kept in a crucible and weighed. Then it was placed in the bomb (pressurized to 23 atm with oxygen). The bomb was then further placed in a vessel containing already measured amount of water (2000 ml). The ignition circuit was activated, the stirrer switched on and the temperature of water was noted down. After the temperature been stabilized, the bomb was fired and the temperature increase was recorded every minute until a constant temperature was noted. Lastly, the pressure was released and the bomb was inspected to ensure that the sample was completely burnt.

\[
\text{Calorific value} = \frac{\text{Effective water equivalent} \times \text{temperature rise}}{\text{Weight of sample}}
\]  

Temperature rise = \(t_f - t_i\)

where,

\(t_i\) = temperature at the moment of firing
\(t_f\) = first temperature after the rate of change of temperature becomes constant

**FLASH AND FIRE POINT**

Tendency of a fuel to form a flammability mixture with air is measured by the property flash Point. This is an important property which decides the overall flammability and hazardness of material. The Fire Point is the property whose value is more than Flash Point because it reflects the situation at which vapor burns constantly for at least five seconds. The Fire Point is always observed to be higher than flash point by around 5 to 8°C.
Fig. 2.5 Pensky Marten Apparatus Used for Measurement of Flash and Fire point

A Pensky Marten Flash and Fire Point used for measuring the Flash and Fire Point of the fuel samples. In this, the sample was first filled in the test cup up to the pre-specified level and heated by the air bath with the help of a electric heater. The fuel sample was continuously stirred at a slow rate. Heating was done in such a way that temperature rise rate was around 5°C per min. Temperature measurement was done constantly with the use of a thermometer (-10 to 400°C range). Flame was introduced at each 1°C temperature rise with the use of a shutter. The temperature (Flash point) is recorded at which a flash emerged in the form of sound and light. The Fire Point was noted as the temperature value at which vapor of fuel catches fire for at least five seconds.

3. RESULTS AND DISCUSSION

FUEL PROPERTIES

Characterization of diesel, sesame oil and sesame-diesel blends are done to find the physio-chemical properties. The standards for diesel and biodiesel were used to ascertain the suitability of the fuel.

KINEMATIC VISCOSITY

Table 3.1 presents the kinematic viscosity of diesel, sesame oil and different ester blends at 38°C. The kinematic viscosity of mineral diesel fuel was observed to be 2.82cSt. The viscosity of diesel fuel at 38°C ranges between 2.0 to 7.5 cSt (IS: 15607:2016). The raw sesame oil kinematic viscosity found to be 34.8 cSt at 38°C. SOEE20, SOEE40, SOEE60, SOEE80, SOEE100 were found to have kinematic viscosity of 3.11, 3.48, 3.83, 4.39, 4.85 cSt respectively. The results points that the sesame oil kinematic viscosity was 12.34 times higher than the diesel. The results also points that SOEE and their blends have kinematic viscosity more than diesel fuel. However, all blends of sesame oil biodiesel and diesel fuel having kinematic viscosity within the standard biodiesel range prescribed by the Bureau of Indian Standards (IS: 15607:2016).

The kinematic viscosity of sesame oil as reported is 34.98cSt [20]. [18] Reported the kinematic viscosity of Diesel and sesame oil methyl ester as 3.5 and 5.34cSt respectively. Hence it is seen that kinematic viscosity of sesame oil and its esters are in line with the outcomes reported by the previous researchers.

Table 3.1 Viscosity of prepared different Fuel samples at 38°C

| S. No. | Fuel Types | Kinematic Viscosity(cSt) | Percent higher than Diesel | BIS (IS:)|
|-------|------------|--------------------------|---------------------------|----------|
|       |            |                          |                           |          |
The kinematic viscosity of diesel at 38°C range between 2 to 7.5 cSt.

Table 3.2 Gross Heat content of Different Fuel samples

| S. No. | Fuel Types | Gross Heat of combustion (MJ/kg) | Percent less than Diesel |
|--------|------------|---------------------------------|--------------------------|
| 1      | Diesel     | 43.5                            | -                        |
| 2      | Raw SO     | 39.565                          | 9.04                     |
| 3      | SOEE20     | 42.75                           | 1.72                     |
The gross heat content of diesel fuel and sesame oil methyl ester reported was 43 and 39.34 MJ respectively [18]. It was observed that the gross heat content of all fuel samples are in agreement with the results reported earlier.

**RELATIVE DENSITY AND API GRAVITY**

At temperature 15°C, relative density and API gravity of diesel fuel, raw sesame oil and different blends are evaluated and presented in table 3.3. The API gravity of mineral diesel and relative density of diesel were observed to be 37.96 and 0.835 respectively. The sesame oil relative density was seen to be 0.898, which is noticed as 7.5 percent higher than diesel relative density. The density of SOEE20, SOEE40, SOEE60, SOEE80, SOEE100 were found to be 0.8, 1.6, 2.5, 3.35 and 4.19 percent more than diesel fuel respectively. Variation of density for different fuel is presented in fig.3.3.

The results found during the experiments points that relative density of all SOEE blends was almost near to that of diesel.

| S.No | Fuel Types   | Relative Density | API Gravity | Percent higher than Diesel | BIS (IS: 15607:2016) |
|------|--------------|------------------|-------------|----------------------------|-----------------------|
| 1    | Diesel       | 0.835            | 37.96       | -                          | The density of diesel at 15°C range between 860 to 900 kg/m³. |
| 2    | Raw SO       | 0.898            | 26.072      | 7.5                        |                       |
| 3    | SOEE20       | 0.842            | 36.55       | 0.8                        |                       |
| 4    | SOEE40       | 0.849            | 35.16       | 1.6                        |                       |
| 5    | SOEE60       | 0.856            | 33.80       | 2.5                        |                       |

Fig. 3.2 Variation of Gross Heat of Combustion for different Fuels
It is clear from the results that the relative density increases with the increase in sesame oil ethyl ester (SOEE) concentration.

**FLASH AND FIRE POINT**

The flash point result and fire point result of diesel fuel, sesame oil and prepared blends of SOEE with diesel are presented in Table 3.4. The flash point of mineral diesel observed to be 51 °C and fire point of diesel was observed at 57 °C. The fire and flash point of sesame oil (raw) was found to be 187 °C and 180 °C respectively. The table also reveals that SOEE20, SOEE40, SOEE60, SOEE80, SOEE100 were having the flash point of 59, 67, 77, 94, 132°C and fire point of 67, 75, 84, 101, 137 °C respectively. Fig. 3.4 shows the variation of flash and fire point. The observed results are in agreement with the results reported by [21] who reported flash point of sesame oil methyl ester 162°C.

Table 3.4 Flash Point and Fire Point of prepared different Fuels

| S.No. | Fuel Types     | Flash Point (°C) | Fire Point (°C) |
|-------|----------------|------------------|-----------------|
| 1     | Diesel         | 51               | 67              |
| 2     | Raw Sesame Oil | 180              | 187             |
| 3     | SOEE20         | 59               | 67              |
| 4     | SOEE40         | 67               | 75              |
| 5     | SOEE60         | 77               | 84              |
| 6     | SOEE80         | 94               | 101             |
| 7     | SOEE100        | 132              | 137             |

**Fig. 3.3 Variation of Relative Density and API Gravity at 15°C for Different Fuels**

The observed results are in agreement with the results reported by [21] who reported flash point of sesame oil methyl ester 162°C.
4. CONCLUSIONS
The sesame oil biodiesel is developed with from raw sesame oil purchased from the market. Optimum production of biodiesel from raw oil was experimentally examined. Characteristic fuel properties such as kinematic viscosity relative density, gross heat content, flash and fire point of mineral diesel, sesame oil, its ethyl ester (SOEE) and their blends with diesel were experimentally investigated. Further, comparative study is done with the BIS norms to find the suitability of using sesame oil biodiesel as an alternative fuel for diesel engine. Some other researchers also have done a significant work related to the given fields in different manners [22-27].

- The maximum recovery of sesame oil ethyl ester observed to be 92.1% at following parametric conditions:

  **Transesterification:**
  - Catalyst (NaOH) concentration: 2.3 % (w/v oil)
  - Reaction temperature: 60ºC
  - Molar ratio (ethanol to oil): 10:1
  - Reaction time for process: 90 min
  - Settling time: 24 h

- The relative density of raw sesame oil found to be 7.5 % higher than the diesel fuel and SOEE100 had the relative density 4.19 % higher than diesel. All blends and sesame oil biodiesel density are in line with the BIS norms.

- The kinematic viscosity of sesame oil (raw) used to make sesame oil ethyl ester (SOEE) was found to be 12.34 times more than the diesel and SOEE100 kinematic viscosity was about 1.71 times higher than the diesel. All blends and sesame oil biodiesel viscosity found to be in accordance with the BIS norms.

- The gross heat content of sesame oil (raw) is found to be 9.04 % lesser than the diesel but SOEE100 had the gross heat of combustion 11.841 % lesser than the diesel. All blends and SOEE calorific value observed to be close to the diesel calorific value.

- Flash point and Fire point for all the blends and sesame oil biodiesel were found to be in accordance with the BIS.
The experimental study reveals that 100 percent sesame oil ethyl ester (SOEE100) may be recommended as Compression Ignition (CI) engine fuel. However, for the better performance SOEE20 can be considered as an alternative fuel for diesel engine, which saves the additional cost of diesel resulting in economic development of nation.

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