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Biodiesel Production From Indian Sesame Oil and the Performance of a Diesel Engine Fueled with Sesame Biodiesel Blends

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To achieve the target of 20% replacement of diesel by biodiesel, set by the Government of India, a huge amount of renewable feedstock will be required for biodiesel production in near future. In this study, experiments were carried out to investigate the suitability of Indian sesame oil as a potential feedstock for biodiesel production. Optimum biodiesel yield of 95.5% was obtained by reacting Indian sesame oil with methanol in presence of NaOH catalyst, with 6:1 molar ratio of methanol to oil, 0.5% (w/w) catalyst concentration, 55^{0}C reaction temperature and a reaction time of 1.5 hr while stirring at 1000 rpm. Yield of biodiesel was low when heterogeneous catalyst was used. Important fuel properties of the sesame methyl ester were estimated and found to be within the ranges specified in IS 15607:2005. Experiments were carried out on a diesel engine fueled with blends of sesame methyl ester and diesel fuel to evaluate the performances of the compression ignition (CI) engine with sesame biodiesel. Brake thermal efficiency of lower blends of sesame biodiesel (B5 and B10) were very close to diesel fuel. The maximum BTE, at 88.4% rated load, for B5 and B10 were 35.52% and 35.46%, respectively which was 35.87% for pure diesel.

KEYWORD

Biodiesel, Feedstock, Indian sesame oil, Transesterification, Sesame biodiesel yield, Brake thermal efficiency.

INTRODUCTION

Biodiesel is recognized as one of the most important alternative fuels for compression ignition (CI) engines. There is no need to modify the compression ignition engine when it is operated with biodiesel because the properties, like viscosity and cetane number of biodiesel are close to those of diesel fuel (Cheung *et al*., 2009). Petroleum diesel has an essential function in the economic growth of a developing country, like India and is mainly used in transport and agriculture sectors (Meher *et al*., 2006). In 2014-15, Government of India imported 189.432 million tonne of crude oil and spent 6873.5 billion INR for this purpose (Ministry of Petroleum and Natural Gas, 2015). Annual diesel oil consumption in India, in 2014-15, was 67.77 million tonne and the major consumer of diesel was the road-transportation sub sector (60.4%) followed by the agriculture sector (12.2%) Ministry of Petroleum and Natural Gas, 2015; Mukesh, 2012). The National Policy on Biofuels, Govt. of India, has set a target of 20% replacement of diesel by biodiesel by the year 2017. To achieve this target a huge amount of basic feedstock will be required for biodiesel production. Chemically biodiesel is monoalkyl esters of long chain fatty acids derived from vegetable oils and animal fats (Mehar *et al*., 2006). Although non-edible plant oil, such as Jatropha Curcas is used as feedstock for biodiesel but at present mainly edible oils, like soybean, sunflower, rapeseed, peanut and palm oil are used for biodiesel production which puts a stain on the developing countries using these oils for cooking purposes (Banerjee *et al*., 2014). The solution of this problem lies with the identification of indigenous alternative feedstock suitable for biodiesel production to meet the future demand for the alkyl esters in the developing countries. Sesame (*Sesamum indium L.*) can be a potential alternative feedstock for biodiesel production by transesterification process. Sesame is an oilseed crop with high oil content of 57-63% (Tunde-Akintunde and Akintunde, 2004). It is grown in tropical and subtropical climates. Sesame is cultivated in many countries including India, China, Bangladesh, Sri Lanka, Thailand, Afghanistan, Saudi Arabia, Guatemala and Turkey (Karmakar *et al*., 2010). Present sesame production in West Bengal, an agricultural-based State in India, was estimated to be 72.44 X 10^3 tonne/year and ranks second in India, after Gujrat in the net annual sesame production in the country (Das and Jash, 2009). Sesame oil is an edible oil but in West Bengal, like in most of the States in India, sesame is not used as a cooking oil. Although perfumed sesame oil is used in religious offerings and also used as raw materials in a few pharmaceutical industries, but the demand is low. Thus, sesame cultivation is also carried out on a limited scale. Sesame is a short duration crop and fits well in a number of multiple cropping systems either as a cash crop or a sequence crop. If sesame can be used for biodiesel production more farmers will incline to cultivate sesame on a large-scale to supply the feedstock for biodiesel which, in turn, will improve the economic conditions of the Indian farmers acutely distressed by loans, especially the rice and potato growers in West Bengal. Besides reduction in air pollution and curtailment in import of crude oils, implementation of biodiesel will provide economical support to agriculture and rural areas (Nalgundwar *et al*., 2016).

Transesterification is the chemical reaction of oils and fats with alcohols in the presence of catalyst to produce monoesters called biodiesel (Kumar *et al*., 2015). The yield of biodiesel from a oil depends on different process parameters, like alcohol to oil ratio, reaction temperature, catalyst type, catalyst concentration, reaction time and stirring rate. But the final properties of biodiesel are influenced by the characteristics of the feedstock used for the biodiesel production. As transesterification does not alter the fatty acid composition of the feedstock, thus the types and composition of fatty acids present in the feedstock will play an important role in some important properties of the biodiesel, like the cetane number, cloud point and viscosity (Karmakar *et al*., 2010). Vegetable oils contain both saturated and unsaturated long-chain fatty acids (C10 to C22) but the oils containing mainly unsaturated fatty acids with one or two double bonds are preferred feedstock for good quality biodiesel production. Sesame oil contains 40-50% olelic acid (C18:1) and 35-45% linoleic acid (C18:2) which indicates that sesame can be an emerging feedstock for biodiesel production (Karmakar *et al*., 2010). No work appears to have been reported regarding biodiesel production from Indian sesame oil.

In this study, experiments were carried out to investigate the suitability of Indian sesame oil as an alternative feedstock for biodiesel production. Biodiesel was produced from Indian sesame oil by transesterification of the sesame oil with methanol in presence of a catalyst. Both homogeneous and heterogeneous catalysts were tried for sesame biodiesel production. Process parameters, like methanol to oil ratio, catalyst concentration, reaction time and reaction temperature have been optimized. Important fuel properties of the methyl ester produced from Indian sesame oil have been estimated. The biodiesel was blended with diesel at different proportion by volume and tested in a diesel engine for an extended period of time to evaluate its performance. The brake specific fuel consumption and brake thermal efficiency were estimated. The results were compared with the performance of the engine while run with pure petroleum diesel.

MATERIAL AND METHOD

Material used

Indian sesame oil procured from a oil press in Kolkata was used as a raw material for biodiesel production. All through the experiment this sesame oil was used as a single feedstock. Methanol and sodium hydroxide

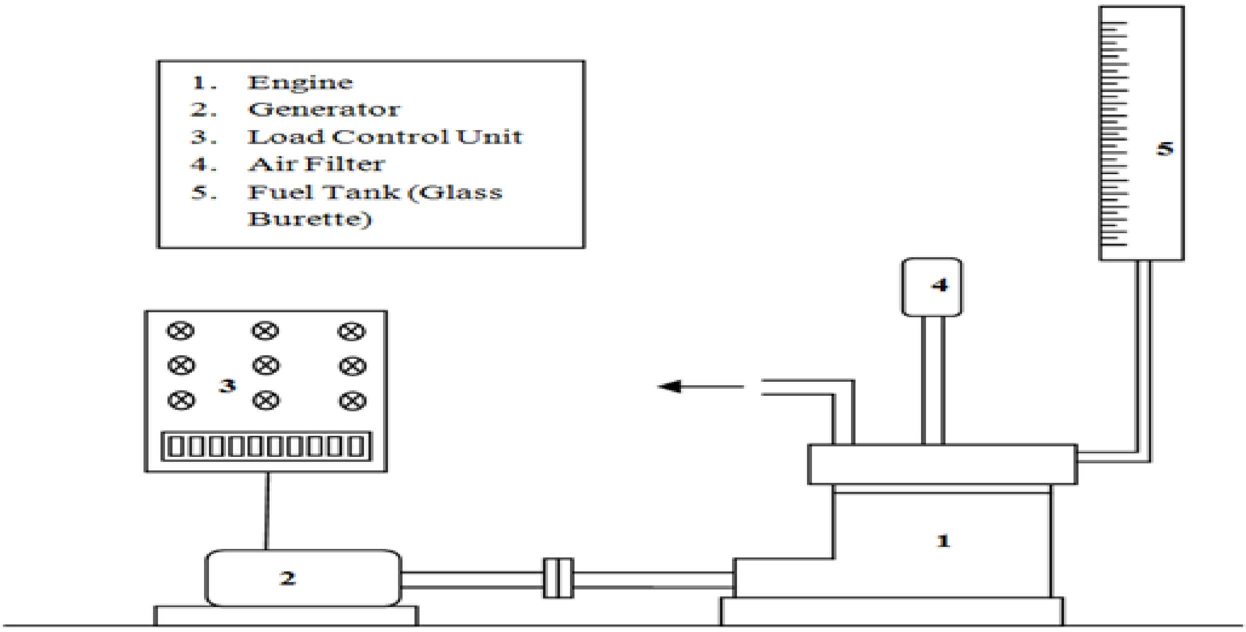

Figure 1. *Diesel engine experimental setup*

used in this study were of analytical grade. In most of the trials NaOH was used as catalyst. In a few trials, solid sulphonated carbon was used as a heterogeneous catalyst for biodiesel production. For the preparation of sulphonated carbon catalyst in the laboratory, food quality cane sugar and analytical grade sulphuric acid were used.

Experimental setup for biodiesel production

Transesterification of sesame oil was carried out in 500 mL conical flask, fitted with reflux condenser, placed on a hot-plate with magnetic stirrer (model no.1-MLH, REMI). Water was passed through the condenser to prevent the alcohol from escaping out of the reactor during heating of the reaction mixture. Separating funnel was used to separate biodiesel from glycerol by gravity settling. A small air pump, normally used in aquarium, was employed for bubble washing of sesame biodiesel during its purification process.

Engine test setup

The test for engine performance with sesame biodiesel was conducted on a single cylinder, four stroke, air cooled direct injection diesel engine (model no. CDZ170F, Chinese make) coupled to a generator. The maximum power output of the engine was 2.94 Kw and the rated speed was 2600 rpm. Loading on the engine was done by tungsten filament lamps (500 W, 200 W, and 100 W) through a multi-socket switch board connected with the generator. Load was varied by using different combinations of the filament lamps. The fuel tank of the compression ignition engine was replaced by a graduated glass burette. The fuel supply to the injector of the engine was monitored with the help of the burette. A schematic diagram of the engine test setup is shown in figure 1.

Biodiesel production from Indian sesame oil

In this study, biodiesel has been prepared from Indian sesame oil by reacting the oil with methanol in presence of a catalyst. The experiments were carried out by refluxing 200 gm sesame oil obtained from the single source with known amounts of methanol and NaOH at constant temperature while stirring. Initially measured quantity of methanol and sodium hydroxide was stirred until NaOH dissolved completely. Then 200 gm sesame oil was added to it and the resultant mixture was refluxed for 1.5 hr with stirring in a 500 mL conical flux fitted with a reflux condenser. After completion of the transesterification re-

Table 1. *Yield of biodiesel from Indian sesame oil under different reaction condition*

Sesame oil taken, gm	Molar ratio of methanol to oil	Reaction tempera ture, °C	Catalyst used	Catalyst conc., wt%	Reaction time, hr	Biodiesel yield, %
200	6:1	55	NaOH	0.5	1.5	95.5
200	6:1	60	NaOH	0.5	1.5	87.6[a]
200	6:1	55	NaOH	1.0	1.5	-
200	3:1	55	NaOH	0.5	1.5	62.0
100	15:1	55	Sulphonated carbon	5.0	12.0	73.0

[a] Methyl ester separation was difficult due to large soap formation
Stirring rate: 1000 rpm

action, the mixture was cooled to attain the room temperature and then allowed to settle in a separating funnel for 12 hr. The glycerol settled in the lower part of the funnel while the crude biodiesel settled on top. The biodiesel was collected by phasewise separation from the separating funnel.

The crude biodiesel contains impurities, like unreacted alcohol, catalyst and some soap. The crude methyl ester was repeatedly washed with warm distilled water to remove the excess catalyst by using bubble washing technique until a neutral pH was obtained. The mixture was then transferred into a separating funnel and kept for an hour. Due to gravity separation, biodiesel formed the upper layer and water formed the lower layer. Water was drained out. Finally, the separated biodiesel was heated at 80^0C for 15 min to remove traces of moisture.

Two molar ratios of methanol to sesame oil (3:1 and 6:1) were tried. The catalyst (NaOH) concentration was varied from 0.5 to 1% (w/w). Two reaction temperatures, 55^0 and 60^0C, were chosen for the alkali-catalyzed transesterification reaction. The stirring was done at 1000 rpm. The effects of selected variables, like reaction temperature and catalyst concentration on the yield of biodiesel from sesame oil were studied by using methanol to oil ratio at 6:1. In all the trials duplicate experiments were carried out to monitor reproducibility. The yields of biodiesel from sesame oil under different reaction conditions are given in table 1.

Biodiesel production from sesame oil using heterogeneous solid catalyst

Separation and purification of methyl ester becomes difficult when homogenous catalysts, like acids or alkalis are used. For efficient recovery of the ester and to avoid soap formation use of solid catalysts were recommended (Karmakar *et al*., 2010). A solid heterogeneous catalyst in the transesterification process not only reduces the number of washing required, but it also makes ester recovery easier (by centrifuge) and the catalyst can be reused multiple times (Dehkoda *et al*., 2012). The activity of sulphonated carbon catalyst prepared from common sugar was reported to be higher than conventional solid catalysts (Toda *et al*., 2005). In the present study, sulphonated carbon catalyst was prepared in the laboratory from white sugar according to the procedure described by Toda *et al*.(2005) and experiments have been carried out for transesterification of sesame oil with methanol using sulphonated carbon as catalyst. Methyl ester was prepared by reacting 100 gm sesame oil, 70 mL methanol (molar ratio of alcohol to oil 15:1) and 5 gm sulphonated carbon catalyst (5% w/w). The reaction was carried out at 55^0C for 12 hr with stirring. After completion of the reaction, the reaction mixture was centrifuged at 10000 rpm for 10 min at 10^0C to separate the solid catalyst. The solid catalyst was washed with distilled water and used again after drying. The me-

Table 2. *Fuel properties of sesame biodiesel and crude sesame oil*

Fuel property	Crude sesame oil	Sesame biodiesel	IS 15607:2005*	Diesel
Density, gm/cm^3	0.90	0.88	0.86-0.90	0.8
Kinematic viscosity at 40^{0}C, cSt	34.5	5.7	2.5-6.0	2.5-3.5
Calorific value, MJ/kg	33.1	33.4		42.7
Flash point, ^{0}C	250	173	120 min	52 min
Cetane number		57.7	51 min	49-55

*BIS specification for biodiesel

thyl ester and glycerol was separated in a separating funnel. Unreacted methanol was removed by distillation. The reaction conditions and the biodiesel yield from sesame oil using sulphonated carbon catalyst are given in table 1. Experiments were also carried out to produce biodiesel using the heterogeneous catalyst at lower methanol to oil ratio, 9:1 and 12:1, but were discarded due to very low yields of biodiesel (<50%).

Measurement of fuel property

Important fuel properties, like density, kinematic viscosity, calorific value and flash point of the sesame biodiesel and crude sesame oil were estimated to find out the quality of biodiesel produced from Indian sesame oil. The kinematic viscosity was estimated at 40^{0}C by Ostwald's viscometer, using water as the reference liquid. Calorific value was estimated using a digital bomb calorimeter and the flash point was determined by using Pensky Martens closed tester. The cetane number of sesame biodiesel was estimated using the mathematical model developed by Sivaramakrinshnan and Ravikumar (2012). The fuel properties are given in table 2.

Engine performance study with sesame biodiesel

A series of tests have been conducted in a single cylinder, air cooled 2.94 Kw diesel engine coupled with a generator with different blends of sesame methyl ester and diesel fuel to evaluate the compression ignition engine performances with sesame biodiesel. After production of sesame biodiesel in the laboratory, different blends of sesame methyl ester and petroleum diesel were prepared on a volume basis. The engine trials were performed with 4 types of fuel blends: 20% sesame biodiesel + 80% diesel (B20); 10% sesame biodiesel + 90% diesel (B10); 5% sesame biodiesel + 95% diesel (B5); 0% sesame biodiesel + 100% diesel (B0). Brake specific fuel consumption (BSFC) and brake thermal efficiency of the engine were evaluated using each blend of fuels at different loads of 0.5 Kw, 1Kw, 1.7 Kw, 2.2 Kw and 2.6 Kw on the engine, that is at 17%, 34%, 57.8%, 74.8% and 88.4% of the rated load, respectively. The experiments were repeated for 3 times for each trial. Brake specific fuel consumption is the amount of fuel consumption per unit brake power output per hour and the brake thermal efficiency is defined as the ratio of the power output of the engine to that of the chemical energy input through the fuel consumption. BSFC and brake thermal efficiency values obtained for different blends of sesame methyl ester (B20, B10 and B5) and also for 100% petroleum diesel (B0) are presented in figures 2 and 3, respectively. The engine trial with B100 (100% sesame biodiesel) was not done because unusual engine vibration and abnormal engine sound were noticed.

RESULT AND DISCUSSION

Sesame biodiesel production

Table 1 shows that optimum biodiesel yield of 95.5% was achieved from Indian sesame oil by NaOH catalyzed transesterification reaction with catalyst concentration of 0.5% (w/w), 6:1 molar ratio of methanol to oil, reaction time 1.5 hr, reaction temperature 55^{0}C and stirring rpm 1000. Biodiesel yield obtained in the present study was 21.5% higher than that of the yield reported by Saydut *et al.* (2008) who obtained a maximum biodiesel yield of 74% from Turkish sesame oil by alkali-catalyzed transesterification process. If it is possible to carry out the reaction at lower alcohol to oil ratio the cost of production of biodiesel will be lower because of requirement of lesser amount of alcohol. But it is observed from table 1 that at lower alcohol to oil ratio (3:1) the yield of methyl ester was considerably low (62%). Although stoichiometric ratio for transesterification of oil requires 3 moles of alcohol and one mole of triglyceride to produce 3 moles of fatty acid esters but as transesterificationis an equilibrium reaction, excess alcohol is required to drive the reaction to the right (Mehar *et al.,* 2006). Experiments were carried out to find the effect of reaction temperature on the yield of biodiesel from sesame oil. Biodiesel yield decreased at higher temperature (60^0C). When the transesterification reaction was carried out with higher NaOH concentration (1% w/w), biodiesel could not be recovered because of large soap formation. An excess amount of catalyst could be the reason for soap formation (Dorado *et al*., 2002).

Separation of biodiesel becomes easier if heterogeneous catalyst is used instead of homogeneous catalyst, like NaOH. But, table 1 shows that the yield of biodiesel was only 73% when solid sulphonated carbon was used as a catalyst, which is considerably lower than the yield obtained in NaOH catalyzed reaction. Although the separation and purification of methyl ester was easier with sulphonated carbon catalyst but a longer reaction time (12 hr) and a very high methanol to oil ratio (15:1) have raised the question of economic viability of the heterogeneous catalyzed biodiesel production process.

Fuel properties

Estimation of the properties of biodiesel, like density, kinematic viscosity, calorific value, and flash point are essential before using it in compression ignition engines as a supplementary fuel to petroleum diesel. Some of the important fuel properties of sesame biodiesel prepared in the laboratory, crude sesame oil, and diesel are given in table 2. Density of the sesame biodiesel is about 3.5% higher than diesel fuel. The viscosity of the sesame methyl ester was estimated to be 5.7 cSt which is slightly higher than diesel fuel but much lower than that of crude sesame oil. The calorific value of sesame biodiesel is about 21.8% lower than diesel fuel. The flash point of the sesame methyl ester was estimated to be 173^0C which shows that the fuel is safe for handling and storage. Table 2 also shows that the important fuel properties of the biodiesel produced from sesame oil match with the biodiesel fuel specification standard of Bureau of Indian Standards (IS15607:2005) which is the Indian adoption of ASTM D6751 and EN14214. Cetane number of sesame methyl ester was estimated to be 57.7 which is higher than diesel fuel (Table 2). Cetane number of palm biodiesel and jatropha biodiesel were reported to be in the range of 53 to 57 and 53 to 61, respectively (Nalgundwar *et al*., 2016). The results clearly show that the transesterification reaction improved the important fuel properties of the oil, like kinematic viscosity, density and flash point. Table 2 indicates that the sesame biodiesel produced in the laboratory is suitable for use in compression ignition engine.

Engine performance

Figure 2 shows the variation of brake specific fuel consumption with respect to load for sesame biodiesel blends (B5, B10 and B20) and diesel fuel (B0). It is observed that BSFC decreased with increase in load on the engine for all the sesame biodiesel blends and diesel fuel. For sesame biodiesel blended fuels, the BSFC are higher than that of diesel under all loading conditions and higher the proportion of biodiesel in the blended fuels, the higher the BSFC. Brake specific fuel consumption for B5, B10, B20 and B0 at 88.4% of rated load were 0.24 kg/Kwh, 0.243 kg/Kwh, 0.28 kg/Kwh and 0.235 kg/Kwh, respectively. Because of lower calorific value of biodiesel blends, more amount of fuel is consumed to produce the same power output (Sharon *et al*., 2012).

The variation of brake thermal efficiency (BTE)

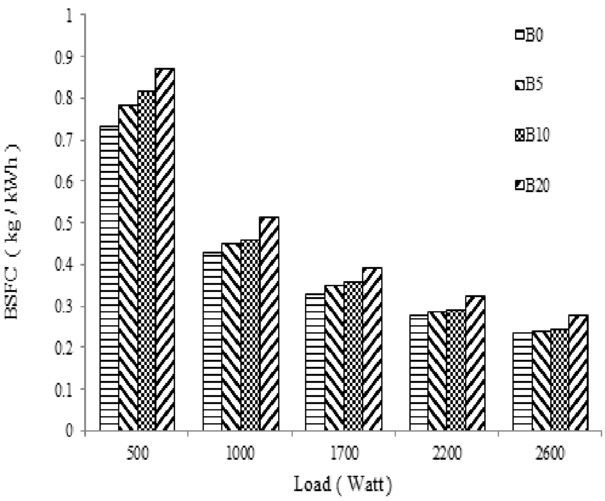

Figure 2. *Variation in brake specific fuel consumption with load conditions for sesame biodiesel blends and diesel*

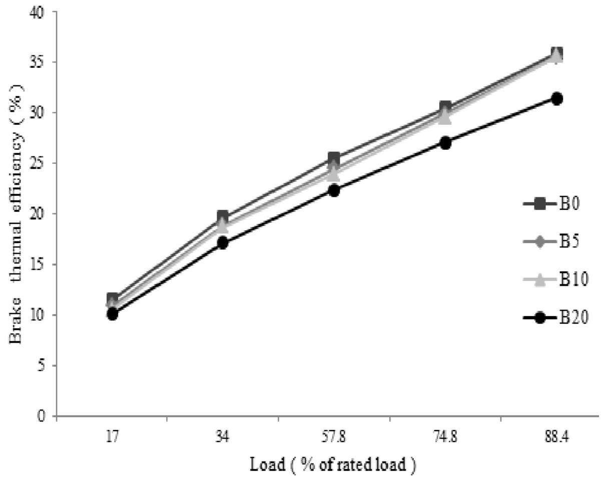

Figure 3. *Variation in brake thermal efficiency with load conditions for sesame biodiesel blends and diesel*

with load for sesame biodiesel blends and diesel is shown in figure 3. In general, brake thermal efficiency increases with load for all the fuels tested. This is because of reduction in heat loss and increase in power with increase in load on the engine. Brake thermal efficiency varied from 10.88 to 35.52% for B5, 10.53 to 35.46% for B10 and 10.13 to 31.48% for B20, at 17 to 88.4% of rated load. The variation of brake thermal efficiency for diesel fuel (B0) was 11.53 to 35.87% for the same load variation. From figure 3 it is observed that brake thermal efficiency for lower blends of sesame biodiesel were very close to that of diesel fuel. For example at 88.4% of the rated load brake thermal efficiency for B5 and B10 were 35.52% and 35.46%, respectively while with diesel fuel the brake thermal efficiency was 35.87%. But it is also observed that with higher blend of sesame biodiesel (B20) decrease in brake thermal efficiency was more.This is because of decrease in calorific value and increase in viscosity of the fuel with higher percentage of methyl ester in comparison with 100% diesel fuel result in lower brake thermal efficiency of the higher blend of sesame biodiesel.

CONCLUSION

The main objective of the present study was to produce biodiesel from Indian sesame oil and to evaluate suitability of sesame biodiesel as a fuel for diesel engine by conducting engine performance tests. The results reveal that Indian sesame oil is an excellent feedstock for biodiesel production. Optimum biodiesel yield of 95.5% has been achieved from sesame oil by transesterification of the oil with methanol with 6:1 ratio of alcohol to oil, in presence of NaOH catalyst (0.5% w/w) under reflux at 55^{0}C for 1.5 hr while stirring at 1000 rpm. Lower methanol to oil ratio has been found unsuitable so far as the yield of methyl ester is concerned. The yield of biodiesel was low (73%) when solid sulphonated carbon was used as a heterogeneous catalyst. Fuel properties of the biodiesel produced from Indian sesame oil were within the ranges of biodiesel fuel specification standards.The calorific value of sesame biodiesel has been estimated as 33.4 MJ/kg which is comparable with the heating values of biodiesel prepared from sunflower oil and soybean oil (Karmakar *et al*., 2010). Brake specific fuel consumption of sesame biodiesel blends are higher than diesel fuel. In general, BSFC decreases with increase in load on engine. Brake thermal efficiency for both sesame biodiesel blends and diesel fuel increase with increase in load. Brake thermal efficiency for lower blends of sesame biodiesel (B5 and B10) are very close to diesel. The highest brake thermal efficiency for sesame biodiesel blend was obtained for B5 which is 35.52% at 88.4% of rated load and is 0.97% lower than that of diesel fuel under the same loading condition. Annual diesel consumption in India is about 68 million tonne and a 20% replacement by biodiesel will create a huge demand for feedstock for biodiesel production. Sesame is one of the potential feedstock. If the demand for sesame can be made to increase for biodiesel production, more Indian farmers especially the farmers in West Bengal will incline to cultivate sesame as an alternative crop which will help them to get rid of distress.The results obtained during the study confirmed that sesame biodiesel produced from Indian sesame oil could be used as a fuel in diesel engine after blending with diesel fuel. A very high yield of sesame biodiesel supports the viability of large scale production of biodiesel from sesame oil.

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