

Production of biodiesel from soybean oil biomass as renewable energy source

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Abstract

Transesterification of vegetable oils with short-chain alcohols is used to produce biodiesel. In the present study, crude soybean oil was investigated on the basis of three principal variables, such as optimum reaction temperature (60°C), the amount of catalyst concentration from 0.5, 1.0, 1.5, 2.0 and 2.5% and molar ratio of methanol 1:1, 1:2, 1:3, 1:4, 1:5 and 1:6, respectively affecting yield of biodiesel. Under optimum condition, at molar ratio 1:6 in the presence of 0.5% NaOH and 60°C reaction temperature and 350 rpm approximately 99.1% biodiesel yield was obtained.

Key words

Biodiesel, Methanol, Transesterification, Soybean oil

Introduction

Biodiesel, an excellent alternative fuel for compression-ignition engines, is defined as monoalkyl esters of long-chain fatty acids obtained from renewable feedstocks such as vegetable oils or animal fats (Sujan *et al.*, 2009; Fan *et al.*, 2011; Singh *et al.*, 2015). Biodiesel produced from soy oil follows alkaline-catalyzed transesterification. Alkali catalysts used in transesterification can be potassium hydroxide, sodium hydroxide or alkali methoxides. Usually, methanol is preferred alcohol for producing biodiesel because of its low cost (Neha *et al.*, 2013; Bobade *et al.*, 2013). Biodiesel obtained by transesterification process is a mixture of mono-alkyl esters of higher fatty acids. Transesterification is alcoholysis of triglyceric esters resulting in a mixture of mono-alkyl esters and glycerol. Biodiesel contains 10–11% oxygen, a high cetane number and flash point, almost sulfur less and non-aromatic alternative diesel fuel. These properties of biodiesel make it environmental friendly and help to reduce the emissions of carbon monoxide, hydrocarbons, and particulate matter from the exhaust gas (Math *et al.*, 2010). Production of biodiesel from soybean oil has been exclusively produced by many researchers (Singh and Singh,

2010; Santos *et al.*, 2009; Xie and Huang, 2006). Soybean oil has five fatty acids: approximately equal amount of palmitic acid, oleic acid, and linolenic acid (about 13% each), linoleic acid (approximately 55%), and stearic acid (approximately 4%). In India the average production of soybean oil from 2001 to 2012 was 1242 metric tons. Use of low-quality oil requires extra processing steps to eliminate free fatty acids from oil before it enters alkaline-catalyzed process. The search of liquid fuel alternative to diesel has been increasing in demand in transport, agriculture, industrial, commercial and domestic sectors due to rise in import bill (Barnawal and Sharma, 2005). High viscosity of vegetable oil interferes with the injection process and leads to poor fuel atomization (Bobade *et al.*, 2013; Deshpande and Kulkarni, 2012; Sujan *et al.*, 2009). Use of vegetable oil such as soy, palm, coconut, sunflower, pea nut and rape seed oil as an alternative fuel for diesel engines entirely depends on the climatic and edaphic factors of a country (Ofori-Boateng *et al.*, 2012; Li *et al.*, 2011). Currently, United States is looking for applicability of soybean and rapeseed oil, European countries are relying over sunflower oil, Philippines on coconut oil and South-east Asia over palm oil (Atadashi *et al.*, 2011; Singh *et al.*, 2010) for the production of biodiesel. The production of oil seeds, percentage oil recovery and their costs indicates high yield

required to use as alternative to diesel fuel feed stocks. High cost of vegetable oils, which could be up to 75% of total manufacturing cost, has led to the production costs of biodiesel becoming approximately 1.5 times higher than that for diesel (Aworanti *et al.*, 2013). In light of the above, the present study was undertaken to investigate the importance of various parameters such as methanol to oil molar ratio, catalyst (NaOH) concentration, reaction time and reaction temperature on transesterification of soybean oil.

Materials and Methods

Soybean oil was purchased from Jalandhar, Punjab and stored in glass bottle. The chemicals used in the current research were of analytical grade. Fatty acid composition was determined by gas chromatography. The reactions were carried out in 500 ml round bottle flask. The oil was heated to desired 55°C temperature before starting the reaction. At this point, methanol and sodium hydroxide (NaOH) solutions were added to oil under mechanical stirring (350 rpm). Transesterification reaction was used in the present study for synthesis of methyl ester. The variables of transesterification reaction were oil to methanol molar ratio (1:1, 2:1, 3:1, 4:1, 5:1, 6:1), catalyst concentration (0.5, 1.0, 1.5, 2.0, and 2.5% of oil), reaction temperature (50 °C and 60 °C), reaction time (20, 40, 60, 80 and 100 minutes) at 250 and 350 rpm. Biodiesel purification of methyl ester was achieved by washing with distilled water which was preheated at 55 °C for an hour. Gravitational settling process was used to separate glycerine from methyl ester at the end of the reaction in a decantation funnel. pH of biodiesel was observed at each washing process and repeated until pH of biodiesel turn on neutral. The less dense phase, composed of esters, was then removed and stored for further analysis and purification as per method of Atadashi *et al.*, (2011). Acid value of the reaction mixture was determined by acid base titration technique (Ghadge and Raheman, 2005). A standard solution of one mole potassium hydroxide solution was used.

GC-MS analysis of methyl esters was used to determine the chemical composition of soy bean oil (Stavarache *et al.*, 2005; Monteiro *et al.*, 2008). The compositions of biodiesel were analysed by Gas Chromatography of Thermo Fisher Scientific model (polaris-Q) equipped with flame ionization detector, and the column used (DB-5 30m × 0.25mm × 0.25µm) following the method of Tariq *et al.* (2011). Helium as a carrier gas was used @ 0.3 m min⁻¹. Analysis of sample by Gas Chromatography was carried out by injecting 1 µm of sample (biodiesel) solution to the column by performing GC-MS.

Results and Discussion

Quantification of biodiesel were conducted, after separation and purification steps, in terms of (weight percent)

fatty acid methyl esters (FAME) yield, obtained by transesterification of soybean oil with methanol, in the presence of NaOH as catalyst. Table 1 reveals the fuel properties of biodiesel derived from soybean oil as per American Society for Testing and Materials (ASTM), standards organization (Kumar *et al.*, 2015).

The molar ratio of methanol to oil is most important variable that affects the yield of methyl ester. Transesterification of soybean oil was carried out by using various molar ratio of oil to methanol 1:1, 2:1, 3:1, 4:1, 5:1, 6:1 and other parameters were kept constant such as catalyst concentrations 0.5, 1.0, 1.5, 2.0 and 2.5% NaOH of oil, 60 °C reaction temperature, 1.5 hrs reaction time and at 350 rpm (Fig. 1). Optimization of oil to methanol molar ratio was done and it was found that methyl ester yield increased as molar ratio increased. Maximum, 99.1% of methyl ester yield was obtained at a molar ratio of 6:1 and 0.5% NaOH as catalyst. A considerable decrease in methyl ester yield (70%) was observed at a molar ratio 1:1 and 0.5% NaOH. Which might be due to equal amount of methanol to oil ratio which decreased the yield of methyl ester.

Hossain *et al.* (2010) formulated 71.2% biodiesel from waste soybean oil under 1:1 volumetric oil-to-methanol weight ratio, 0.5% NaOH catalyst at 50°C reaction temperature and 320 rpm. In a similar study was Sun *et al.* (2014) reported 87.4% biodiesel yield from soybean oil catalyzed by Al-Ca hydrotalcite loaded with K₂CO₃ as heterogeneous solid base catalyst. Similarly Ye *et al.* (2013) reported 90% biodiesel production from soybean oil catalyzed by attapulgite loaded with C₄H₃O₆KNa catalyst at 65°C.

Catalyst (NaOH) is an important variable that affects transesterification reaction. The concentrations of catalyst from 0.5, 1.0, 1.5, 2.0 and 2.5% of oil were optimized. It was observed that catalyst attributed significant effect on methyl ester yield. The estimated methyl ester yield at catalyst concentration of 0.5% oil and 6:1 molar ratio was 99.2%. Higher concentrations of catalyst such as 2.0 and 2.5% of oil formed soap and saturated fatty acids during transesterification reaction and revealed that higher

Table 1 : Fuel properties of biodiesel from soybean oil

Property of biodiesel	ASTM D6751-06 standard	Soybean biodiesel
Density	860-890 (kg m ⁻³)	880 (kg m ⁻³)
Viscosity	-	90 (Redwood second)
Flash point	> 130 (°C)	162°C
Acid value	0.8 max (mg KOHg ⁻¹)	0.20 (mg KOHg ⁻¹)
Saponification value	169-280 (mg KOHg ⁻¹)	137 (mg KOHg ⁻¹)
Cloud point	-3 to 12 (°C)	10°C

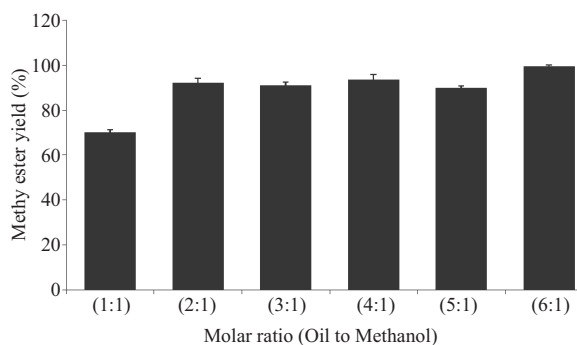


Fig. 1 : Effect of molar ratio on methyl ester yield in the presence of 0.5% NaOH w/v of oil at 60°C temperature

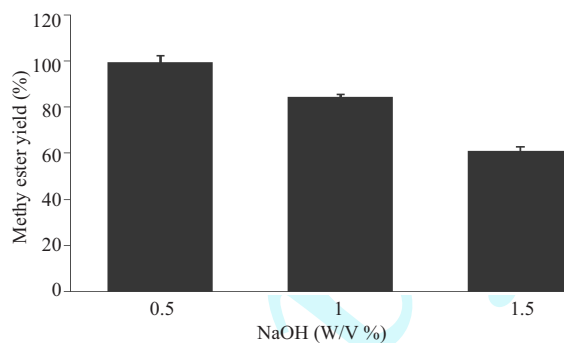


Fig. 2 : Effect of catalyst concentrations on methyl ester yield at molar ratio 6:1 and 60°C temperature

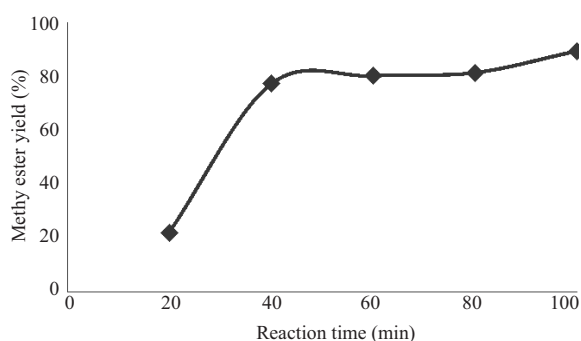


Fig. 3 : Effect of reaction time on methyl ester yield at 6:1 molar ratio in the presence of 0.5% NaOH w/v of oil and 60°C temperature

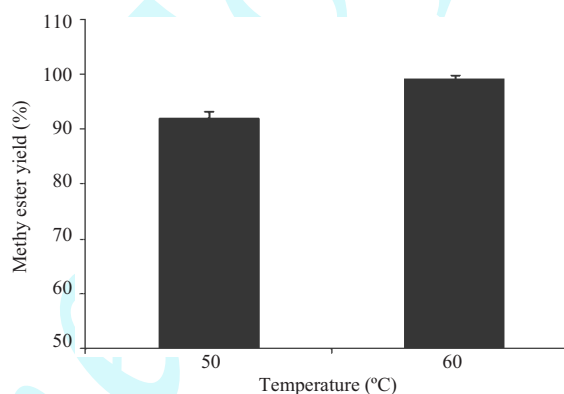


Fig. 4 : Effect of reaction temperature on methyl ester yield at molar ratio 6:1 in the presence of 0.5% NaOH of oil

concentration was not suitable for production of methyl ester yield (Fig. 2).

Royon *et al.* (2007) studied the effect of t-butanol as a solvent for enzymatic production of biodiesel from cotton seed oil. Tiwari *et al.*, (2007) reported biodiesel production from *Jatropha* oil with high free fatty acids. Xie *et al.* (2014) studied the effect of biocatalyst as immobilized lipase on Fe_3O_4 /poly (styrene-methacrylic acid) magnetic microsphere for the production of biodiesel from soya oil. Paris *et al.*, (2009) described more efficient energy conversion process of soy based biodiesel. Atadashi *et al.* (2013) reported the effects of catalysts in biodiesel production. Kumar *et al.*, (2015) also described different methodologies for biodiesel production.

The reaction time is an essential variable that affects transesterification reaction of soybean oil. The reaction time was furthermore greater persuade on methyl ester yield. The reaction time was investigated on 6:1 molar ratio, 0.5% NaOH and 60 °C. The reactions were carried out for 20, 40, 60, 80 and 100 min. It was observed that the increasing reaction time had greater influence on methyl ester yield.

Higher methyl ester yield of 89% was obtained at 100 min reaction time. Methyl ester yield of 10% was obtained at 20 min reaction time and showed that lower reaction time was adverse for transesterification reaction and methyl ester yield (Fig. 3).

Increase in conversion rate with reaction time was also documented by Ma and Hanna (1999). Freedman (1984) found an approximate fatty ester yield of 99% in one hour for soybean and sunflower oil by using 0.5% sodium methoxide catalyst at 60°C, under optimum condition of methanol to oil ratio of 6:1 in transesterification of soybean and sunflower oils.

Reaction temperature was also the most significant variables that affected transesterification reaction and methyl ester yield. The molar ratio 3:1 was constant while concentrations of catalyst varied between 0.5% to 2.0% and temperature 50 °C and 60°C were changed for each of the transesterification reactions. Methyl ester yield was evaluated and it was found that the reaction temperature of 60 °C gave maximum yield of methyl ester as compared to reaction temperature of 50 °C (Fig. 4). Liu *et al.* (2008)

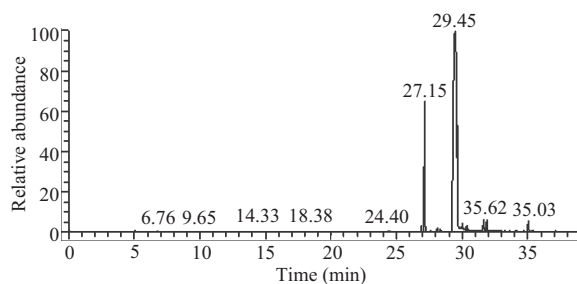


Fig. 5(a) : Analysis of biodiesel sample by GC method

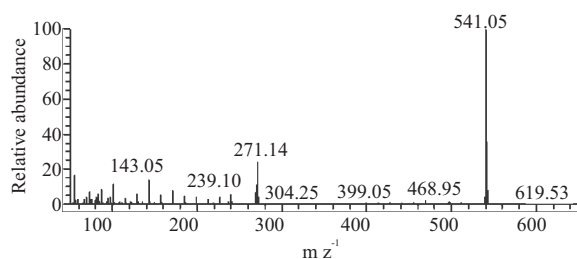


Fig. 5(b) : Analysis of biodiesel sample by GC-MS method

achieved more than 95% biodiesel yield in three hours subjected to 12:1 molar ratio of methanol to oil using 8% CaO catalyst at 65 °C reaction temperature and 2.03% water content in methanol.

Gas chromatography was carried out to produce biodiesel; conditions were optimized as oil to methanol molar ratio of 6:1 and concentration of catalyst was 0.5% of oil. The gas chromatography oven temperature was maintained at 50°C for 2 min, and then ramped at 8°C min⁻¹ to 280 °C with a hold for 8 min and the total analytical time was found to be 29.45 min.

Biodiesel yield was determined by gas chromatography and expressed in terms of percentage (weight percent) of FAME formed. The FAME profile of soy bean oil sample was identified by comparing of their retention times with that of FAME standards. The peak areas were used to calculate concentration and mass to charge ratio was found to be 541.05 (Fig. 5a, b).

Ramadhass *et al.* (2005) used of low cost substrate such as rubber seed oil for the production of biodiesel by combination of acid esterification and alkali esterification to reduce free fatty acid value of crude rubber seed oil. Biodiesel production from non edible oil using wild variety of *Pongamia pinnata*, *Jatropha curcas*, *Simarouba glauca*, reported by (Meher *et al.*, 2006). Gie *et al.* (2008) reported the feasibility of edible oil vs non-edible oil vs waste edible oil as biodiesel feedstocks.

Variations in the concentration of catalyst had significant affect on the yield of methyl ester, and further molar ratio considerable effect on the yield of methyl ester. On the basis of the results obtained of the present study, it is concluded that biodiesel can be obtained by transesterification of soy bean oil using methanol as transesterification agent.

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