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Biodiesel production process optimization and characterization to assess the suitability of the product for varied environmental conditions

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ABSTRACT

In this study, both edible (coconut oil, palm oil, groundnut oil, and rice bran oil) and non-edible oils (pongamia, neem and cotton seed oil) were used to optimize the biodiesel production process variables like catalyst concentration, amount of methanol required for reaction, reaction time and reaction temperature. The fuel properties like specific gravity, moisture content, refractive index, acid value, iodine number, saponification value and peroxide value were estimated. Based on the cetane number and iodine value, the methyl esters obtained from palm and coconut oils were not suitable to use as biodiesel in cold weather conditions, but for hot climate condition biodiesel obtained from the remaining oil sources is suitable.

1. Introduction

The increased use of diesel fuel resulted in depletion of its fossil reserves. This triggers for many initiatives to search for alternate fuel, which can supplement or replace such fossil fuel. In recent years, research has been directed to explore plant-based fuels and plant oils and fats as fuels have bright future [1]. The most common that is being developed and used at present is biodiesel, which is fatty acid methyl esters of seed oils and fats and have already been found suitable for use as fuel in diesel engine. Biodiesel is found to be environmentally safe, non-toxic and biodegradable [2].

The raw material being exploited commercially by the developed countries constitutes the edible fatty oils derived from rapeseed, soybean, palm, sunflower, coconut, linseed, etc. [3]. Use of such edible oil to produce biodiesel in India is not feasible in view of a big gap in demand and supply of such oils in the country. Increased pressure to augment production of edible oil has also put limitation on the use of these oils for production of biodiesel. Under such conditions, those crops that produce non-edible oil in appreciable quantities can be grown in large scale in non-cropped marginal lands and wastelands only considered for biodiesel production [4].

Long list of trees, shrubs and herbs is available plenty in India, which can be exploited for fuel production. In this study we have utilized both edible and non-edible oils for the biodiesel production process optimization and fuel property characterization to assess the suitability of the different methyl esters to the varied environmental conditions.

2. Materials and methods

Edible (coconut oil, palm oil, groundnut oil, rice bran oil, and gingelly oil) and non-edible (pongamia, cotton seed oil and neem oil) oils were used in this experiment.

All the oils were first filtered by cloth mainly to remove the dirt and other inert materials from the oil and then placed in a conical flask equipped with magnetic stirrer, thermometer and condenser. Under agitation the raw oil was heated up to nearer to the boiling point to remove the water contaminant present in the oil. After that oil is allowed to cool down under room temperature, and the treated oil alone was taken for biodiesel production purpose. Again, under agitation, the above treated oil was heated up to a desired temperature on a hot plate. A fixed amount of freshly prepared sodium hydroxide–methanol solution was added into the oils, taking this moment as the starting time of the reaction. When the reaction reached the preset reaction time, heating and stirring were stopped. The products of reaction were allowed to settle overnight. During settling two distinct liquid phases were formed: crude ester phase at the top and glycerol phase at the bottom. The crude ester phase separated from the bottom glycerol phase was then washed by cold or warm de-ionized water several times until the washed water became clear. The excess methanol and water in ester phase were then removed by evaporation under atmospheric condition.

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After that weight of the ester was taken for product yield calculation.

The reaction was investigated step by step. The optimal value of each parameter involved in the process was determined while the rest of the parameters were kept constant. After each optimal value was attained, this value was adopted for the optimization of the next parameter.

Physical and chemical properties of methyl esters were estimated [5,6] under laboratory conditions. The cetane number (CN) and higher heating values (HHVs) were calculated [4,6] from the following equation by using the estimated saponification value (SV) and iodine value (IV).

$$CN = 46.3 + 5458/SV - 0.225IV \quad (1)$$

$$HHV = 49.43 - [0.041(SV) + 0.015(IV)] \quad (2)$$

3. Result and discussion

3.1. Effect of catalyst concentration

The effect of sodium hydroxide concentration on the transesterification of the edible and non-edible oils was investigated with its concentration varying from 0.5 to 2.5 wt.% (based on the weight of raw oil). The operation conditions during the whole reaction process were fixed at the optimal level: reaction temperature of 55 °C, reaction time of 90 min. and 180 and 210 ml of methanol for edible and non-edible oils, respectively.

Experimental results showed changes in ester yield content with varied catalyst concentration. As the sodium hydroxide concentration increased, the conversion of triglyceride as well as the ester content also increased. Insufficient amount of sodium hydroxide resulted in incomplete conversion of triglycerides into the esters as indicated from its lower ester content. The ester content reached an optimal value when the sodium hydroxide concentration reached 1.5 wt.%, and further increase in catalyst concentration in all the cases, ester production amount decreased as shown in Fig. 1. Large amount of soap was observed in excess amount of sodium hydroxide added experiments. This is because addition of excess alkaline catalyst caused more triglycerides' participation in the saponification reaction with sodium hydroxide, resulting in the production of more amount of soap and reduction of the ester yield [7].

3.2. Effect of reaction time

The reaction time of the transesterification reaction conducted at 55 °C was optimized with the highest achievable mixing degree, an excess amount of alcohol (220 ml per liter of oil) and optimal sodium hydroxide concentration of 1.5 wt.% for all the oils.

The changes in product composition with reaction time during the transesterification of the oils and the distribution of various components in the reaction system can be clearly seen. When the reaction time reached 90 min, no triglyceride was left in the product mixture, indicating complete conversion. In this experiment, glycerol started to separate within 15 min. The ester content increased with reaction time from 15 min onwards and reached a maximum at a reaction time of 90 min at 55 °C, and then remained relatively constant with increasing further the reaction time (Fig. 2). The results indicated that an extension of the reaction time from 90 to 150 min had no significant effect on the conversion of triglycerides but leads to a reduction in the product yield. This is because longer reaction enhanced the hydrolysis of esters (reverse reaction of transesterification), resulted in loss of esters as well as causing more fatty acids to form soap.

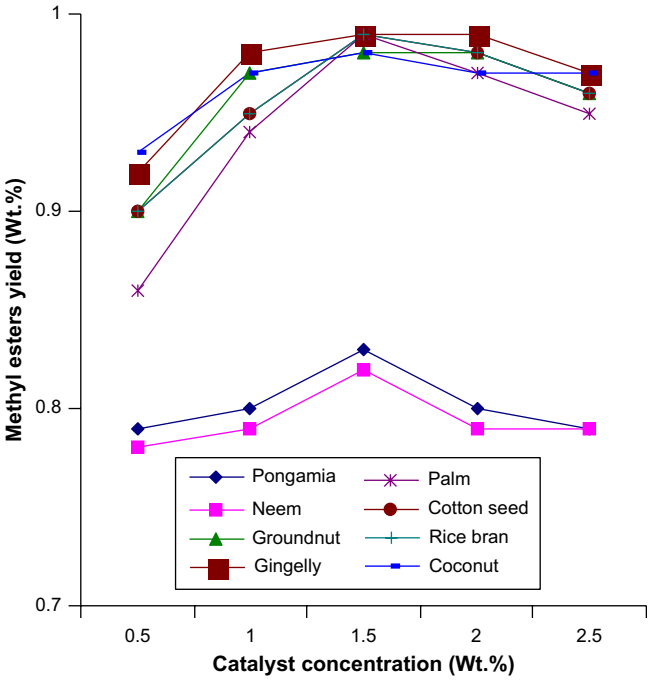

Fig. 1. Effect of catalyst concentration on methyl esters' yield.

3.3. Effects of methanol amount

The effect of alcohol amount on yield of the transesterification experiments was conducted with different amounts of methanol to oil in the range of 120–240 ml. The optimized catalyst concentration and reaction time as obtained in the above sections were adopted. Maximum ester content was obtained at a methanol amount of 180 ml for edible oil and 210 ml for non-edible oils. With further increase in the methanol to oil amount above 210 ml, a very little effect on the biodiesel yield was observed

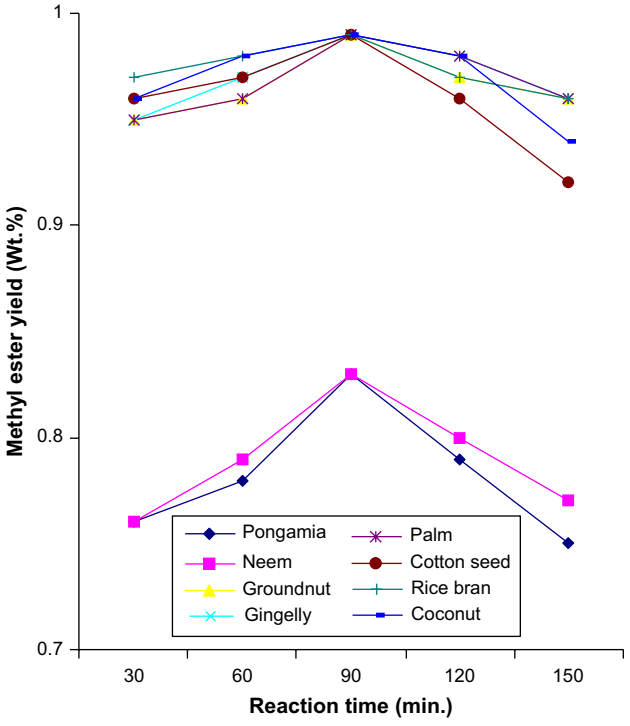

Fig. 2. Effect of reaction time on methyl esters' yield.