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A comparative study of biodiesel production by microwave assisted and conventional transesterification methods

Nowaday's use of biofuels for both power generation and automobiles is more relevant because of the need for energy security, environmental concerns, foreign exchange savings and socio-economic issues. Non-edible oils are considered as second generation alternative fuels and use of these oils avoids conflict between food and energy security. Therefore various locally available vegetable oils of edible and non-edible nature were selected for their biodiesel production. Subsequent characterization of these biodiesels was carried out to ensure their suitability as alternative fuels in diesel engines. Subsequently characterization of both raw vegetable oils and their respective biodiesels was done according to ASTM standards. The experimental investigation also suggests that the fuel processing with conventional transesterification method is a laborious and time consuming one. On the other hand microwave assisted transesterification (MATM) is found to be better in terms of shorter reaction time, lower consumption of power and resources compared to conventional transesterification process. MATM method reduces the reaction time drastically for both edible and non-edible oils. For edible oils the reaction time is found to be 1 minute while for non-edible oils it varies from 3 to 6 minutes. The biodiesel production from pressure reactor uses same resources required by the conventional transesterification method [CTM], but it is conducted in a closed vessel. This feature enhances the chemical kinetics, thereby reducing the reaction time up to 66% compared to conventional method.

Keywords: Biodiesel, non-edible oil, microwave assisted transesterification, pressure reactor, oxidation stability.

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1.0 Introduction

India is said to be one of the seven largest consumers of energy, but the growing gap between consumption and domestic output is a cause of concern. India's share in global oil reserves is about 0.5 per cent, whereas its share in global consumption is about 3 per cent. India is still dependent to the extent of 30 to 35 per cent on non-commercial fuel sources like vegetable oils, cow dung, firewood, agricultural waste, etc [1]. Using vegetable oils in a diesel engine is not a new idea. Rudolph Diesel ran diesel engine with use of peanut oil during the late 1800 [2]. The contribution of biofuels (vegetable oils) in the use of total renewable energy is very less. The move from fossil fuels to biofuels will create new industries and bring increased economic activity. Moreover; Indian formers have got rich experience of managing commercial energy plantations in varied climatic condition. India's biofuel policy is looking at ways to limit rising oil imports by promoting use of bio-fuels as an alternative renewable source of energy. At present, it is estimated that India will be able to produce 288 metric tonnes of biodiesel by the end of 2012, which will supplement 41.14% of the total demand of diesel fuel consumption [3, 4-8]. Biodiesel production by transesterification is achieved with use of methanol and ethanol in the presence of alkali catalysts [9-14]. Biodiesel production by using ethanol instead of methanol has an advantage of increasing agricultural benefit and the extra carbon brought by ethanol molecule slightly increases the heating value and cetane number [15-18]. This biodiesel can be used conveniently in a diesel engine. From the literatures, it is observed that, identifying the physical and chemical properties of vegetable oil such as viscosity, free fatty acid composition (FFA), acid value, chemical structure etc is important for determining the suitability of the vegetable oil for transesterification process; this can be performed to get better conversion and properties of the biodiesel [6, 16-22]. The transesterification method has been found to be the most effective, low cost and viable one for the production of biodiesel.

2.0 Materials and methods

Transesterification is the chemical process of converting vegetable oils into diesel like fuel. In transesterification process, a triglyceride reacts with three molecules of alcohol in the presence of a catalyst, producing a mixture of fatty acids and glycerol (Fig.1). A specified amount of methanol or ethanol is mixed and allowed to react with the vegetable oil in the presence of a catalyst like NaOH or KOH at a temperature of 700^{o}C. Conversion of vegetable oil to biodiesel is affected by different parameters namely time of reaction, reactant ratio (Molar ratio of alcohol to vegetable oil), type of catalyst, amount of catalyst, temperature of reaction. To complete a transesterification process stoichiometrically, 3:1 molar ratio of alcohol to triglycerides is needed. However, in practice, higher ratio of alcohol to oil ratio is generally employed to obtain biodiesel of lower viscosity and high conversion.

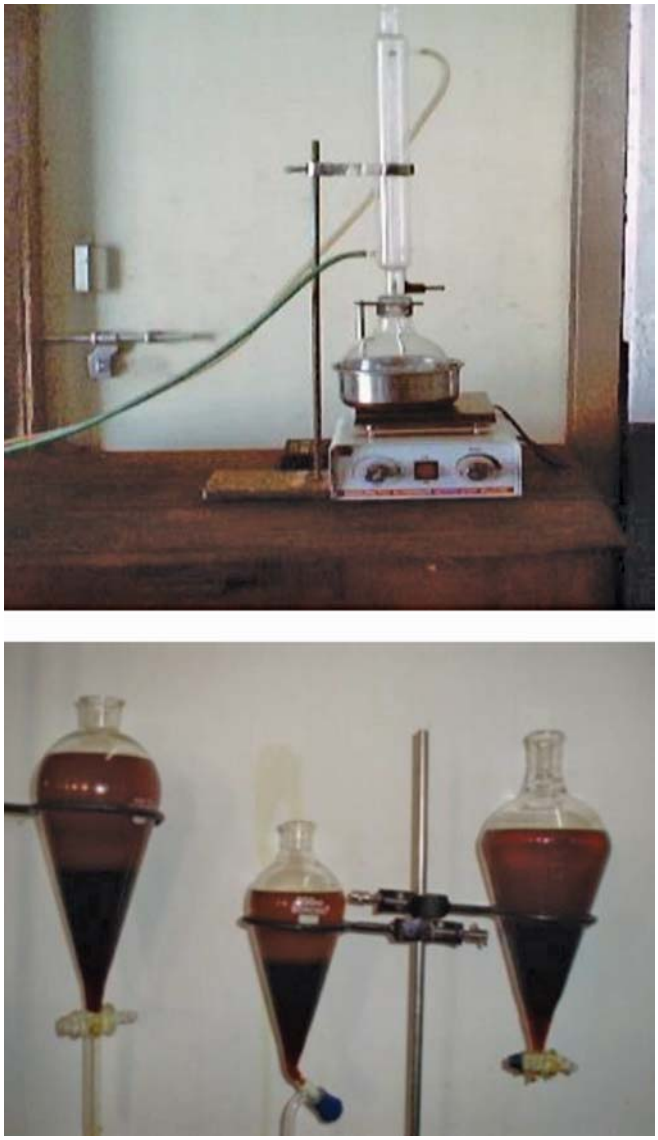

Fig.1: Equipment for conventional transesterification

The effect of transesterification is to reduce the level of free fatty acid (FFA) greatly and reduce the viscosity, boiling point, flash point and for removal of the complete glycerides from the vegetables oils. In the process cetane number is also improved. It has been reported that the methyl ester of vegetable oils offers low smoke levels and high thermal efficiencies than neat vegetable oils.

Microwave assisted transesterification method offers many advantages in terms of lower reaction time, reduced catalyst requirement and lower alcohol/oil ratio. In this method, less that 0.2% (weight basis) catalyst, 5:1 to 9:1 molar ratio was used. The process was conducted at 60-700^{o}C for 10 -20 minutes. From which, about 95-98% conversion can be obtained. In view of this, an attempt has been made to develop the microwave and pressure based reactors for biodiesel production. The present study was conducted mainly to carry out simple, low cost and efficient transesterification process using pressure reactor. The experimental results show that these methods take very less time of about 20 minutes with pressure of 25 bar and it saves 66% of power consumption. In MAT method the reaction time is further reduced from several hours to less than a minute.

The detailed transesterification method for Honge, palm and jatropha oil is only reported here as the process is more or less similar to all the cases. The materials required for Honge, palm and jatropha oil, biodiesel production include NaOH, methanol/ethanol, Na_2SO_4. Initially the FFA content of all the oils were measured by standard titration methods which had an acid value of 4 for Honge and jatropha oils. This is slightly higher than the required value of 1% limit for satisfactory transesterification reaction. Therefore FFA values are first reduced in a multistep pretreatment process using acid catalyst (H_2SO_4, 1% v/v) to reduce the acid value below 1%. Then the Honge oil sample was heated to about 1000^{o}C, at which all moisture was evaporated. The transesterification set up is shown in Fig.1.

In the MAT method, a house hold 800W 2450Hz, microwave (kenstar) was modified to act as a biodiesel reactor. In operation vegetable oil, palm oil and methanolic NaOH solution were fed separately via 2 pumps and mixed at the tee connector at the inlet. Reaction time and molar ratio of the oil to alcohol were controlled via a combination of flow control valves of the pumps such that for 1 LPM output of oil pump a mixture of 6 gm of NaOH dissolved in 240 ml of methanol should be pumped per minute from the other pump. The outlet was slightly bended upward to keep the reactor filled at all flow rates. The esters fraction (upper layer) was separated and washed twice with half volume of de-ionized water and dried over anhydrous sodium sulfate. Working set up is shown in Fig.2.

Honge oil is stored in one container and methanol with crystals of NaOH in other container. The catalyst NaOH is dissolved into the methanol by vigorous stirring in a small

Fig.2: Continuous microwave assisted transesterification method for palm biodiesel preparation

reactor (for 240 ml of methanol 6 gm of NaOH is added). Most carboxylic acids are suitable for the reaction, but the alcohol should generally be a primary or secondary alkyl. Tertiary alcohols are prone to elimination, and phenols are usually too unreactive to give useful yields. Two gear pumps are used to pump palm oil and methanolic NaOH solution separately. Flow control valves (ball valve) used to control the flow rates of oil and methanolic NaOH solution.

TABLE 1: COMPARISON OF BIODIESEL QUALITY WITH CONVENTIONAL AND MATM METHOD

	Properties	Pome	
		CTM	MATM
1	Viscosity @ 40°C (cst)	5.7	5.8
2	Flash point °C	164	166
3	Calorific Value in KJ/kg	33500	——
4	Specific gravity	0.88	0.89
5	Density Kg/m^3	880	890
6	Percentage of yield	96%	94%
7	Type of oil	Edible oil	
	Properties	Home	
		CTM	MATM
1	Viscosity @ 40°C (cst)	5.6	5.8
2	Flash point °C	163	167
3	Calorific value in KJ/kg	36,010	-
4	Specific gravity	0.87	0.89
5	Density Kg/m^3	890	890
6	Percentage of yield	98%	95%
7	Type of oil	Edible oil	
	Properties	Jome	
		CTM	MATM
1	Viscosity @ 40°C (cst)	5.65	5.8
2	Flash point °C	170	176
3	Calorific value in KJ/kg	38,500	-
4	Specific gravity	0.87	0.88
5	Density Kg/m^3	870	880
6	Percentage of yield	96%	94%
7	Type of oil	Edible oil	

The reaction temperature attained during the transesterification in microwave oven is around 65-800°C. Microwave energy is delivered directly to the reacting molecules, which undergo chemical reaction. The product obtained is collected in conical separator for settling. A successful transesterification reaction produces two liquid phases: ester and crude glycerin. Crude glycerin, the heavier liquid, will collect at the bottom after several hours of settling as shown in Fig.2. Phase separation can be observed within 10 min and completed within 2h of settling. Complete settling can take as long as 20h. Similar procedure is followed for the other oil samples for respective biodiesel production.

3. Results and discussion

3.1. COMPARISON OF BIODIESEL QUALITY WITH BOTH METHODS

The properties of biodiesel obtained with both methods were comparable and is listed in the Table 1. The yields obtained by the conventional batch transesterification were marginally higher compared to continuous microwave assisted biodiesel reactor methods as shown in Table 1.

3.1.1 Fuel properties

The properties of respective esters of all vegetable oils used in the study were determined in the laboratory and are shown in Table 1. The reason for the conversion of raw vegetable oil to methyl esters is to reduce viscosity and density and to improve the cold flow properties of Honge, palm and jatropha oils (vegetable oil) and its biodiesels. The properties of all the biodiesels were found to be closer to diesel fuel. These properties include viscosity, density, cloud and pour points, flash point, calorific value.

4.0 Conclusions

Vegetable oil has significantly higher viscosity at normal temperature and also has slight compressibility, than edible vegetable oils. This feature makes the oil difficult during extraction and injection.

Saturated components of oil possess favourable features like higher cetane number and heating value compared to their unsaturated counterparts, but it also has a higher viscosity and pour point.

Presence of oxygen in both edible and non-edible vegetable oil reduces calorific value.

Use of non-edible oils for energy applications avoids the conflict between food and fuel security.

The number of double bonds present in the fatty acids are strongly related to emissions. The difference in the physico-chemical properties greatly affects the performance and emission characteristics of diesel engine.

Vegetable oils usually have palmitic and stearic saturated fatty acids. They are the responsible for higher cetane number.

Biodiesel production from conventional transesterification method:

This conventional transesterification method is suitable only to produce a biodiesel on a large scale base.

This method requires a vegetable oil which must have no moisture and lower acid value.

The conversion obtained for Honge and sunflower oils are 96 and 98%.

Biodiesel production from continuous microwave transesterification method:

The quantity of catalyst and methyl alcohol used is crucial for successful reaction. Washing is necessary to drain away undesired contaminants in the biodiesel. The biodiesel should be finally heated to remove excess moisture.

The optimum values of the parameters that result in highest biodiesel yield of Home and Some are 96% and 98% are 1% NaOH catalyst, 5:1 molar ratio of methyl alcohol, 60 minutes and 65^{o}C respectively.

In microwave assisted transesterification method system, the experimental results have shown rapid reaction rate and higher conversion yield of trans-methylation oils to biodiesel.

For sunflower oil the reaction time was reduced to 60 seconds as against 1 hour in conventional method.

For non-edible oils of Honge and jatropha the time taken will vary between 5 and 10 minutes as compared to 1-3 hours of conventional method.

All the biodiesel obtained from MATP resulted in slightly reduced performance due to their comparatively higher viscosity. Also the smoke opacity, HC and CO emissions increased with such oils.

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