

# Biodiesel—Technical Viability for India

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**Abstract** The aim of the article is to investigate the different technologies for the production of biodiesel, which includes process description, pre-treatment of raw feedstock, esterification/transesterification and product purification/standardization. Further, technology comparison has been carried out for homogeneous acid/alkaline catalysis process, heterogeneous acid/alkaline catalysis process, supercritical methanol process and enzymatic (biochemical) process. In a technology viewpoint, the homogeneous (acid/alkaline) catalyst is mostly used for commercial production of biodiesel from batch and continuous processes. In India, sodium-based catalyst (e.g. NaOH) is preferred for a small-scale commercial production as it is inexpensive and easy to handle in transportation and storage. Presently, Indian commercial producers are using a two-stage homogenous process. The market price of biodiesel is Rs. 55 ( $\pm 2$ ), excluding tax. This price is a little high in the market due to the cost of feedstocks which makes up to 80–90% of the total production cost, operating cost and the capital cost in the view of business experts. The market price is almost near to the petroleum diesel price (approximately Rs. 60). However, in using biodiesel, there are enormous benefits towards the environment-friendly factors such as fewer emissions of CO, SO<sub>2</sub>, NO<sub>x</sub> and less particulate matter.

**Keywords** Feedstocks • Biodiesel • Technology assessment • Commercial view Product purification and Standards

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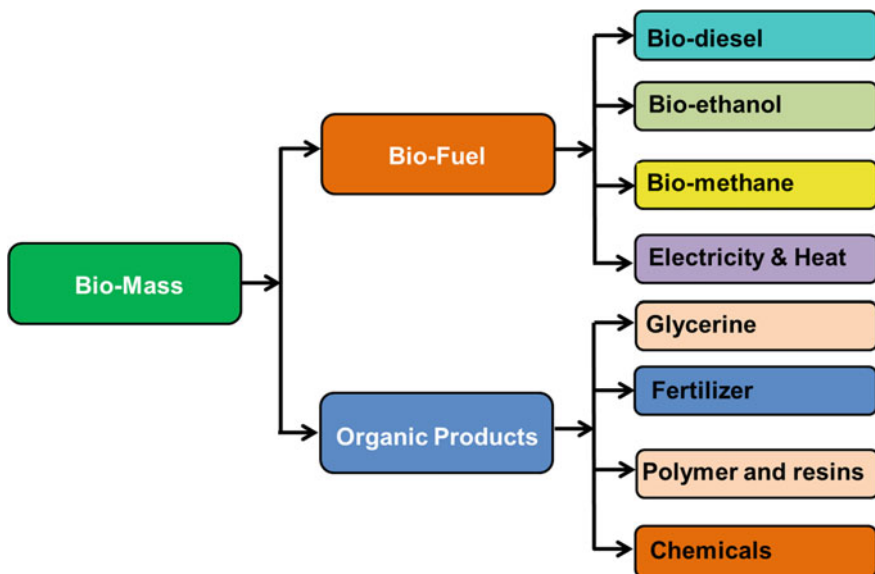
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## 1 Introduction

Bioenergy is obtained from various biological resources, such as Oil crops, Sugarcane, Wood waste, Agricultural wastes, Grasses, Sawdust, Aquatic plants, algae, animal waste and municipal solid waste. The various prime processes employed to extract the bioenergy from these sources include Thermochemical (combustion, gasification, pyrolysis and supercritical), Biochemical (fermentation, anaerobic digestion, aerobic conversion and enzymatic processes) and Chemical processes (esterification, pulping, catalytic processes, methanization and hydrogenation) (Sengutpa and Pike 2012). The derivative of biomass is classified into two main categories: (1) Biofuel and (2) Organic Products, as shown in Fig. 1.

Around the world, there are many potential feedstocks identified for biodiesel production. The availability of wide range of potential feedstocks offers more flexibility in the process and helps in accommodating the local demands. However, the production of biodiesel from the edible oil such as sunflower, mustard, rapeseed, soybeans, palm oil, canola, safflower, corn, coconut and peanut, which are considered as the first generation of feedstock, is not suggested for commercial scale production due to depletion of the food supply. According to the Indian national biofuel policy, usage of edible oils for biodiesel production is forbidden (or) not recommended due to social issues and economic view. The government recommends that biodiesel should only be produced from non-edible oils as second-generation feedstocks, such as non-food crops, biomass sources, algae, waste vegetable oils and fats, forestry residues etc. The second-generation



**Fig. 1** Derivatives of biomass

feedstocks can be an encouraging parameter for the sustainable production of biodiesel (Atabani et al. 2013) with affordability and with greater environmental benefits. The non-edible plants can be grown in harsh and marginal lands which require less maintenance, less soil fertility and less water as opposed to the arable lands used for farming edible vegetable oils (Bhuiyaa et al. 2016).

In India, many varieties of oil bearing seeds/crops are available. For example, *Jatropha curcas* (Jatropha), *Pongamia pinnata* (karanja), *Madhuca indica* (mahua), *Azadirachta indica* (neem), *Shorea robusta* (Sal), *Scheleichera oleosa* (Kusum), *Salvadora oleoides* (Pilu), *Citrullus colocynthis* (Tumba), Simarouba (*Simarouba glauca*), Jojoba (*Simmondsia chinensis*), Cheura (*Diploknema butyracea*), Kokum (*Garcinia indica*), wild Apricot (*Prunus armeniaca*), wild Walnut (*Aleurites moluccana*), Kusum (*Schleichera oleosa*), Tung (*Vernicia fordii*), *Ricinus communis* (Castor), *Argemone mexicana* L (Mexican prickly poppy), *Cerbera odollam* (sea mango), *Pinus roxburghii* (Lucky bean tree), Mukorossi (Soapnut), *Hevea brasiliensis* (Rubber tree), *Calophyllum inophyllum* (Polanga), *Melia azedarach* (Syringa or Persian lilac), *Schisandra chinensis* (Jojoba), *Thevetia peruviana* (Yellow oleander), etc. These crops can be grown in a piece of wasteland and under varied agro-climatic conditions (Kumar and Sharma 2011; Dhyani et al. 2015). Other categories of feedstocks are microalgae and waste/used cooking oils, which are primarily used by academic/industrial researchers at a laboratory level. In particular, the microalgae are considered as one of the potential feedstocks for biodiesel production, as it has high oil content than the other traditional crops.

Although many non-edible feedstocks have been identified thus far, there remains a primary concern. The availability of feedstocks in the domestic market would largely decide the economic viability of the process, especially in developing countries. In India, the major feedstocks for the production of biodiesel have been identified as Jatropha, Karanj, Neem and Mahua which contain more than 30 wt% (wt) oil in their seeds (Padhi and Singh 2011).

## ***1.1 Process of Biodiesel Production***

The following three key sequential steps are primarily involved in the production of biodiesel process (1) Pre-treatment, (2) Esterification/Transesterification reaction and (3) Product purification and Standardization.

### **1.1.1 Pre-treatment of Feedstock**

The oil feedstock will have a lot of undesirable compounds, such as water, pigments, colloidal mater, extraction residues, particles and other impurities like gums, waxes, etc. These impurities must be removed prior to transesterification

reaction as it interferes with the reaction pathway and reduces the process efficiency/yield. Many methods/techniques are suggested for the removal of these impurities. The gum can be removed by adding phosphoric acid or citric acid (Mitchell 2011). The particulate matter and colloidal matter can be removed by filtration. Mostly, filters like baghouse filter, pressure leaf filter and cartridge filter are used. The filter selection depends mainly on factors such as the type of the particulate matter, size or cake discharge, filter unit size in combination with the plant capacity, space requirement, batch or continuous process conditions and cost. Free Fatty Acid (FFA) content is one of the most process hindering compounds for a biodiesel production. The FFA could reduce the quality, yield and the product separation efficiency (i.e. separation of ester, glycerine and wash water) due to the formation of soap. The FFA content can be reduced to a desired level (<1%) by using an acid catalyst process (i.e. called as esterification reaction) before transesterification. It could also be achieved by integration of the two-stage processes, i.e. esterification and transesterification reaction, as it would be economically viable for treating oil having higher FFA content.

Similarly, the water/moisture content (>0.1 wt%) in the feedstock would reduce the conversion of triglycerides to biodiesel. Besides, the presence of water/moisture causes more negative impact than the presence of FFA in oil. Thus, it is suggested that the water content should be removed prior to the transesterification reaction, by using a suitable preheating method (Ma and Hanna 1999; Atadashi et al. 2012).

### 1.1.2 Esterification/Transesterification Reaction

Transesterification is a chemical reaction of triglycerides/oil with short-chain alcohol (e.g. methanol or ethanol) in the presence of a catalyst. The resultant products of this reaction are biodiesel (called as ester) and glycerol as by-product, as shown in Fig. 2. The transesterification reaction is reversible and excess alcohol (1:6 mol ratio of oil and methanol) is used to shift the reaction to the product side. The alcohols that are commonly employed for transesterification are methanol, ethanol, propanol, butanol and amyl alcohol. These are primary and secondary monohydric alcohols having 1–8 carbon atoms. Among them, methanol and ethanol are usually preferred due to their low cost and favourable physical and chemical properties compared to that of other alcohols. Most of the academic and industrial researchers are using methanol which is a polar and a short-chain alcohol that quickly reacts with triglyceride. Esterification is the conversion of FFA into ester in the presence of an acid catalyst. Transesterification/esterification reaction can be carried out in a batch mode or in a continuous mode. The yield of biodiesel mainly depends on the feedstock quality (e.g. water content, FFA, etc.) process conditions (temperature, pressure, batch/continuous mode) and operating process parameters (ratio of oil/methanol), catalyst type and their amount, residence time, etc.

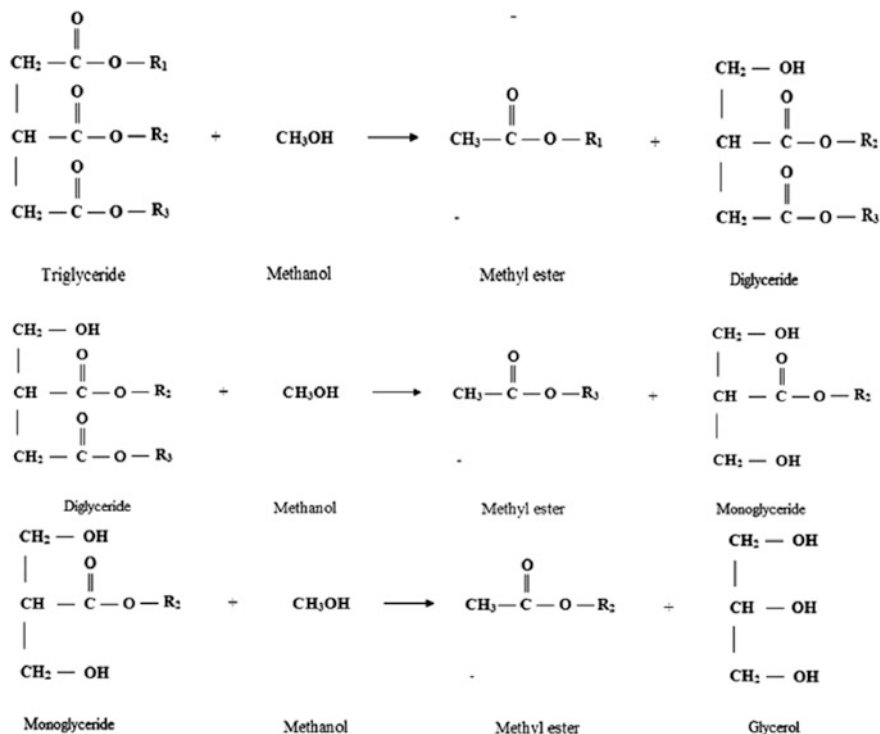


Fig. 2 Transesterification reaction

### 1.1.3 Product Purification and Standardization

The quality of biodiesel depends on several factors, including the quality of feed-stock, composition of fatty acid in the parent vegetable oil, process operating conditions and handling and storage of biodiesel (Bankovic-Ilic et al. 2012).

Typically, the product mixture contains an ester, glycerol as by-product, excess alcohol, traces of un-converted oil (i.e. mono-, di and triglycerides), un-converted FFA, catalyst metals and water content. The product is to be brought to desired standard level (Indian Standard: IS 15607, European standard: EN14214, American standard: ASTM D6751) for the purpose of diesel engine function. Conventionally, the separation and purification processes are carried out by the following steps.

1. Biodiesel and glycerol are commonly separated by using gravitational or centrifugal filtration, as the density of biodiesel ( $\sim 0.88 \text{ g/cm}^3$ ) is lower than the density of glycerol ( $\sim 1.26 \text{ g/cm}^3$ ). However, recently several other techniques which employ membrane/ion exchange resins/solid adsorbents (e.g. magnesium silicate) are suggested for the separation of glycerol from the product of biodiesel (Saleh et al. 2010).

2. Excess/residual methanol is typically recovered by distillation and it can be reused.
3. The FAME (Fatty Acid Methyl Ester) is separated from product mixture by vacuum distillation method. This separation and purification step leads to increase in operating costs for producing the biodiesel.
4. Exchange resin (Masato and Hidaka 2013) and Deep Eutectic Solvents (DES) (Hui min et al. 2015) techniques are used to remove the trace of catalyst contaminant/inorganic salts from the product mixture. In a small-scale production, the glycerin and catalyst contaminant removal is achieved simply by 'water wash'. However, it leads to a range of issues (Wal et al. 2011): (a) Water wash creates a large amount of wastewater that must be treated subsequently, which can increase the processing time and also the operating cost of the plant as it involves additional units of operations, such as drying, multiple washes and water-biodiesel separation (b) Deionized water should be used to avoid further product contamination (c) The final product of biodiesel would have traces of water content which will bring down the standard level desired and (d) It also leads to formation of emulsion if biodiesel has a high content of soap which would eventually effect on the loss of yield significantly.

## 2 Technologies for Biodiesel Production

The technologies such as pyrolysis (thermal cracking), micro-emulsification, dilution and transesterification are used for the production of biodiesel (Ruhul et al. 2015). This section focuses on the transesterification process only. The biodiesel production by transesterification of vegetable oils with alcohol can be carried out by using the following processes (Martin and Grossmann 2012) and the details are given in Fig. 3.

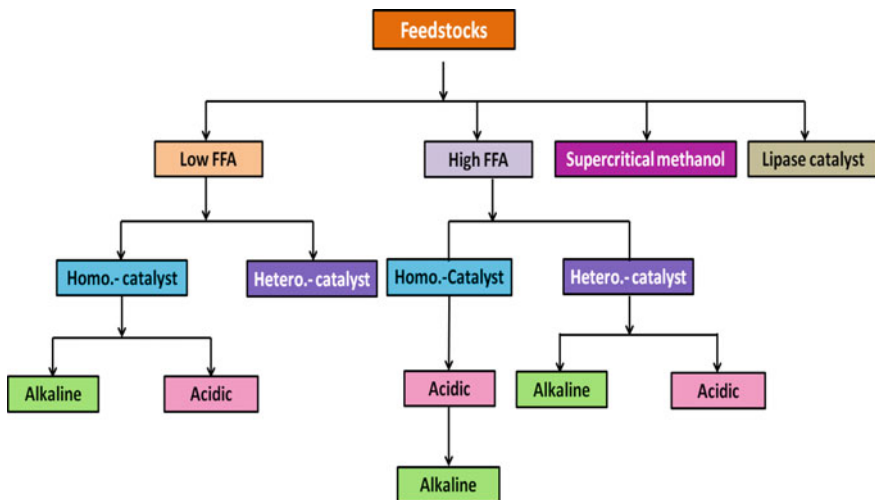


Fig. 3 Various processes of biodiesel production

- (i) Homogeneous acid/alkaline catalysis process
- (ii) Heterogeneous acid/alkaline catalysis process
- (iii) Supercritical methanol process
- (iv) Enzymatic (biochemical) process.

## 2.1 Homogeneous Catalysis Process

In the homogeneous alkali transesterification process, catalysts, such as sodium hydroxide (NaOH) (Ranganathan and Sampath 2011), potassium hydroxide (KOH) (Meher et al. 2006), sodium methoxide ( $\text{NaOCH}_3$ ) (Zeng et al. 2014), sodium ethoxide ( $\text{NaOCH}_2\text{CH}_3$ ) (Lima et al. 2006) or potassium methoxide ( $\text{KOCH}_3$ ) were used along with alcohol (preferably methanol/ethanol). When the feedstock has higher free fatty acid (FFA), it was found that usage of alkaline catalyst leads to the formation of soap, which in turn reduces the yield of biodiesel in the transesterification reaction and inherently results in poor separation of biodiesel from the by-product of glycerol.

The selection of suitable catalysts is mainly based on higher kinetic reaction rates, stability, reusability, regeneration and product yield. (Singh et al. 2006) studied and reported the performance of various catalysts like NaOH, KOH,  $\text{KOCH}_3$  and  $\text{NaOCH}_3$  for the production of biodiesel via transesterification between crude canola oil and methanol. They reported that potassium (KOH)-based catalysts were found giving better yields than the sodium-based (NaOH) catalysts which is attributed to the fact that the dissolution rate of KOH is extremely faster than NaOH, in methanol. Consequently, the rate of reaction and the subsequent yield are high. Similarly, methoxide catalysts were found giving higher yields than the corresponding hydroxide catalysts. The order of catalysts on the basis of better yield are illustrated as  $\text{KOCH}_3 > \text{NaOCH}_3 > \text{KOH} > \text{NaOH}$ .

In India, sodium-based catalyst (i.e., NaOH) is preferred for a small-scale commercial production as it is inexpensive and easy to handle in transportation and storage. Further, a few more reasons for using NaOH for commercial purposes, are given below:

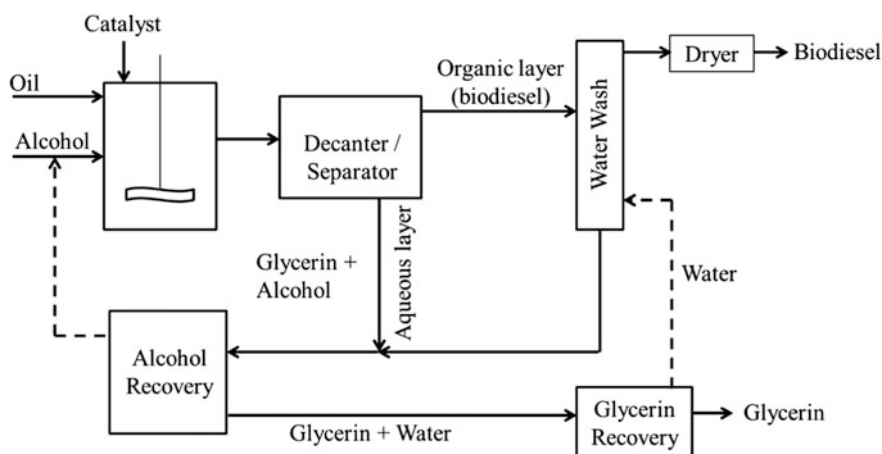
- (a) The required quantity of KOH in transesterification reaction is higher when compared to NaOH to obtain the same yield. It is mainly attributed to the difference in the density and molar ratios between the two catalysts. The market price of KOH is about two and a half (2.5) times more expensive than NaOH.
- (b) At very high temperatures, methanol boils very violently when it contacts with KOH. However, the same is not true for NaOH. This might be due to the fact that NaOH takes a longer time to dissolve in methanol.

However, the alkaline catalyst process results in increased operating costs due to water washing of the product and cost of the catalyst recovery and regeneration. Hence, the alkaline catalyst is typically useful for conversion of edible oil/used

cooking oil (i.e., less than 1% of FFA content) or low FFA content oil. To overcome the problems in using alkaline catalyst, transesterification process was investigated under an acidic system using homogeneous catalysts. In the homogeneous acidic transesterification process, sulphuric acid ( $H_2SO_4$ ) (Wang et al. 2006), hydrochloric acid (HCl) (Matthew et al. 2008),  $H_3PO_4$  and  $BF_3$  are used as catalysts. The acid catalyst could simultaneously carry out esterification of FFAs and transesterification of triglycerides, which is of great interest for biodiesel production. In general, esterification reactions are faster than transesterification. It was found that the acid catalysts are better substitutes for base catalysts since they do not show measurable susceptibility to FFAs and can catalyze esterification and transesterification simultaneously. Generally, there are a few common issues in both the processes of alkaline/acid homogeneous catalyst such as

- (a) Sensitive to FFA and water content
- (b) Formation of soap with high FFA
- (c) Recovery and regeneration of catalyst
- (d) Formation of salts during the catalyst neutralization
- (e) Generation of wastewater in large quantity for product recovery.

Many researchers (Berrios et al. 2010) have studied on the integration of two-step processes like esterification (as a pre-treatment of FFA) and transesterification process and to minimize the soap formation and maximize the product yield. In the first step of esterification, FFA reacts with methanol in the presence of an acid catalyst to form biodiesel (which is also called as fatty acid methyl ester, FAME) and water. Further or next step of transesterification, triglycerides react with methanol in the presence of an alkaline catalyst to form biodiesel and glycerol. The schematic diagram of the homogeneous process is shown in Fig. 4.



**Fig. 4** Schematic diagram for homogeneous catalytic transesterification process



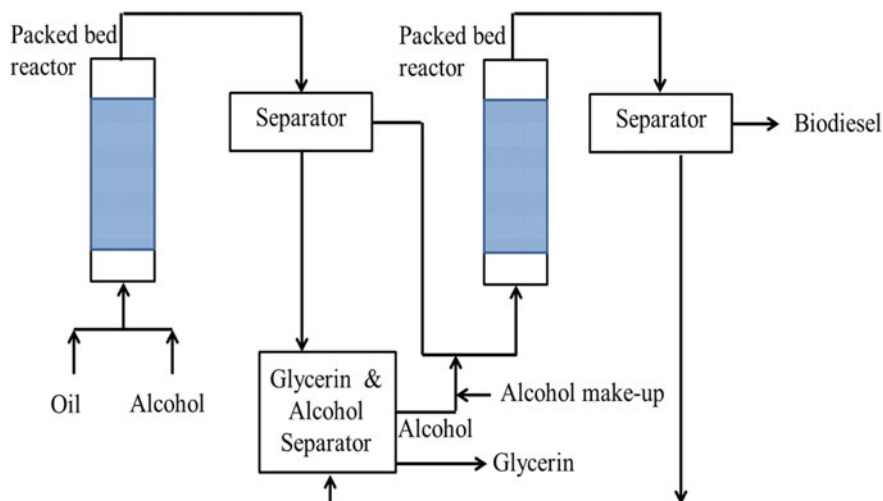


Fig. 5 Flow diagram for heterogeneous catalytic transesterification process

## 2.2 Heterogeneous Catalysis Process

The heterogeneous acid catalysis has some specific benefits such as easy product separation, recycling, more stability, usage of continuous packed bed reactor and in reducing waste generation. The flow diagram of heterogeneous catalysis process for biodiesel production is shown in Fig. 5. In this process, an alkaline catalyst such as MgO (Wang and Yang 2007), CaO (Granados et al. 2007), SrO (Liu et al. 2007), Mg/La<sub>2</sub>O<sub>3</sub> (magnesium–lanthanum mixed oxide) (Seshu et al. 2008), KOH/Naxzeolite (Wenlei et al. 2007) or KF/A<sub>2</sub>O<sub>3</sub> (Amish et al. 2009) are used for transesterification process. However, the solid heterogeneous alkaline catalyst reduces the yield of biodiesel, if the feedstock contains higher FFA and water content as similar to homogenous alkaline catalyst. Thus, the heterogeneous acid catalyst could be used instead of heterogeneous alkaline catalyst to overcome these issues. The heterogeneous acid catalyst is capable of accomplishing both transesterification and esterification reactions together (Halder et al. 2013). Even, if the oils contain a higher amount of FFA, it could be converted into a methyl ester.

Catalysts such as zinc oxide, zirconium oxide (Matthew et al. 2008), Zine oxide supported on tungstated zirconia (Furuta et al. 2004), vanadium phosphate (Di Serio et al. 2007), zeolites, silica and alumina are widely used in heterogeneous acid catalysis process. These catalysts should possess highly interconnected system such as large pore sizes and moderate to strong acid sites. It is also inferred that heterogeneous acid catalysts give better conversion without accelerating any side reactions. The comparison of homogeneous and heterogeneous catalyst for production of biodiesel is given in Table 1.

**Table 1** Comparison of homogenous and heterogeneous catalysts

| Property          | Homogeneous             | Heterogeneous        |
|-------------------|-------------------------|----------------------|
| Reaction rate     | High                    | Low                  |
| Temperature (°C)  | Moderate (<80)          | High (>150)          |
| Thermal stability | Poor                    | Good                 |
| Catalyst recovery | Difficult and expensive | Easy and inexpensive |
| Selectivity       | Excellent               | Good                 |

### Influence of co-solvent

In spite of all the advantages, one of the demerits with both heterogeneous acid and the alkaline catalyst is the formation of different phases in presence of alcohol (aqueous phase) and oil (organic phase) which leads to diffusion limitations thus lowering the rate of the reaction. The organic phase of oil and aqueous phases of methanol in a transesterification system of homogeneous and heterogeneous process are immiscible. The mass transfer rate between reactants and catalyst is limited. The methanol is a significant factor for enhancing the rate of reaction. Although the miscibility could be enhanced by increasing the temperature, it is highly an energy consuming process (Guan et al. 2009). This limitation can be overcome by adding co-solvent which has the following advantages (Sakthivel et al. 2013).

- (i) The disappearance of inter-phase mass transfer resistance enhances the rate of separation of two phases (biodiesel and glycerol) more easily
- (ii) Suppresses the rate of formation of soap significantly
- (iii) Increases the biodiesel yield.

Recently (Calgaroto et al. 2013; Encinar et al. 2016), many researchers have studied extensively on transesterification of oils with the presence of co-solvent using homogeneous, heterogeneous and supercritical methanol processes. It is suggested that co-solvent could significantly influence the reduction of operating temperature, pressure and molar flow ratio for the supercritical methanol and enhance the reaction rate for homogeneous process. Various co-solvents like propane, hexane, heptanes, tetrahydrofuran (THF), carbon dioxide (CO<sub>2</sub>), mixture of THF and hexane, alkyl ether (dimethyl ether, diethyl ether, etc.) are used to increase the biodiesel yield due to enhancement of the miscibility of the two phases. However, in spite of the increase in yield of biodiesel, the operating cost increases, particularly resulting from separation of co-solvent from methanol or the final product. To overcome the above-mentioned issues is to use “biodiesel” as co-solvent. As we know, the biodiesel is an effective green solvent to oil due to its methyl ester component, which considerably lowers the viscosity and biodegradable nature. Sakthivel et al. (2013) conducted the experiments in both batch/and continuous modes to investigate the effect of co-solvent on the

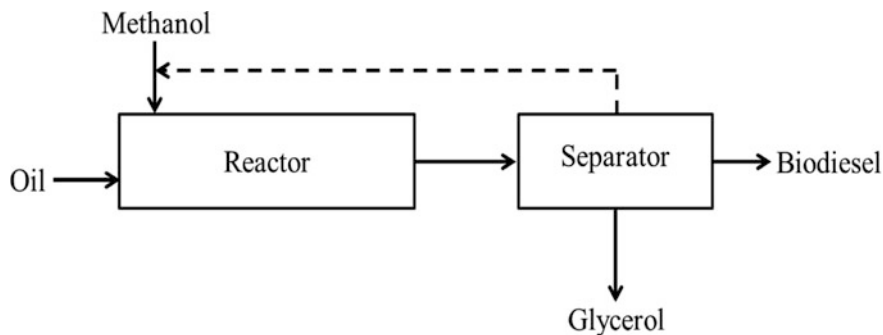


Fig. 6 Schematic diagram of SCM process

production of biodiesel from *Jatropha* oil. The result shows that the co-solvent (added in the range of 5–15% wt of biodiesel) enhances the mass transfer between triglyceride and methanol and, thereby the rate of reaction. It was also observed that there was about 20% increase in the yield of biodiesel with the presence of co-solvent.

### 2.3 *Supercritical Methanol (SCM) Method*

Supercritical fluids exhibit the properties of both liquid and gases when their temperature and pressure are above the critical point. The beneficial effect of supercritical fluid (alcohol) also is exploited in the production of biodiesel. One of the main advantages is the transesterification reaction between supercritical alcohol and triglycerides could proceed in the absence of any catalyst (Demirbas 2002). The significant decrease in hydrogen bond energy between alcohol molecules in the supercritical region allows them to be an acid catalyst (D’Ipolito et al. 2007). The schematic diagram of SCM process is shown in Fig. 6.

The SCM has several merits compared to that of homogeneous/heterogeneous catalytic process. This includes high production efficiency and eco-friendly process (Sawangkeawa et al. 2010). Besides supercritical alcohol, carbon dioxide and acetic acid at supercritical conditions have also been added to improve the process conditions. The supercritical carbon dioxide reduces the reaction temperature, while acetic acid reduces the glycerol by-product and increases the hydrolysis of fatty acids. The transesterification yield of 97+ % and the product composition with FAME content of >96% were obtained at a reaction temperature of 280 °C and a pressure of 20 MPa (Wei et al. 2013). Also, feedstock with high FFA and water

content could be handled at supercritical conditions as it won't affect the process yield. Overall, the SCM process gives a higher yield than the other conventional processes.

## 2.4 Enzymatic (Biochemical) Process

The enzymatic process is able to convert high-FFA feedstock by a two-step process. The glycerides are hydrolyzed to FFA, and then the FFA reacts with methanol to form biodiesel through esterification reaction. In the esterification step, water is produced and it is absorbed into the heavy phase, which also consists of glycerol, excess methanol and enzymes. Lipases (intracellular or extracellular lipase) act as a catalyst for biodiesel production at ambient temperatures and at atmospheric pressures. The enzymatic route is providing higher yield with purity, easy separation of product and by-product than the catalytic process of alkali/acid. This enzymatic process can be handled for feedstocks that are high in both FFA content and water. However, the enzymatic process has a few demerits for production of biodiesel such as slow rate of reaction, long residence time without the presence of a solvent, more expensive lipases and the frequent possibility of de-activation at the end of the reaction. The enzyme immobilization as a biocatalyst is one of the suitable catalysts and it would overcome the above-mentioned problems.

Recent studies report different types of enzymes like *MucorMehei*, *Geotrichum candidum*, *Candida antarctica*, *Pseudomonas fluorescens*, *Pseudomonas cepacia* and *Candida rugosa* available for biodiesel production. Generally, esterification and transesterification of triglycerides are to form methyl ester by methanol by using lipase (Fjerbaek et al. 2009). The polar short-chain alcohols affect the performance of the enzymatic process and inactivate the lipase (Shimada et al. 2002). To overcome the above problems three different options such as (i) methanol stepwise addition, (ii) acyl acceptor alterations and (iii) usage of solvent were suggested.

## 3 Technology Comparison

As many parameters, such as feedstock availability, process conditions, product quality, purification cost (removal of glycerol, catalyst and alcohol), operating cost and capital cost, are involved in the different technologies employed for biodiesel production, the comparison of the technologies with respect to these parameters are shown in Table 2.

**Table 2** Comparison of technologies for production of biodiesel (Marchetti and Errazu 2010)

| Variable                         | Alkaline Catalyst              | Acid catalyst                  | Supercritical   | Lipase catalyst     |
|----------------------------------|--------------------------------|--------------------------------|-----------------|---------------------|
| Temperature (°C)                 | 50–70                          | 60–80                          | 240–350         | 35–50               |
| Pressure (MPa)                   | 0.1                            | 0.1                            | High (35 MPa)   | 0.1                 |
| FFA in raw material              | Saponified products            | Ester formation                | Ester formation | Ester formation     |
| Yield                            | Normal                         | Normal                         | High            | High                |
| Product separation               | Difficult                      | Difficult                      | Easy            | Easy                |
| Recovery of glycerol             | Difficult                      | Difficult                      | Easy            | Easy                |
| Removal for purification         | Methanol and catalyst          | Methanol and catalyst          | Methanol        | Methanol and lipase |
| H <sub>2</sub> O in raw material | Low yield                      | Low yield                      | No influence    | No influence        |
| Purification of methyl esters    | Repeated H <sub>2</sub> O wash | Repeated H <sub>2</sub> O wash | Easy            | Easy                |
| Cost of catalyst                 | Inexpensive                    | Inexpensive                    | None            | Expensive           |
| Process                          | Complicated                    | Complicated                    | Simple          | Complicated         |
| Catalyst loss                    | Low                            | Low                            | None            | High                |

## 4 Current Status in India

Currently, India has five to six large bio-refineries plants, with the capacity of producing 10000 to 250000 metric tons (mt) per year. At present, the total production of biodiesel is only 130–140 million litres from multiple feedstocks like non-edible vegetable oils, unusable edible oil waste (used-once) and animal fats. India has long preferred to produce biodiesel from the non-edible oils such as *J. curcas*, *P. pinnata*, *M. indica* and *A. indica* in India. Based on the literature survey, *J. curcas* and *P. Pinnata* have been identified as the potential feedstocks for biodiesel production in India. It is estimated that the potential availability of such oils in India is about 2 million tons per year (Agarwa 2007; Dwivedi et al. 2014).

The biodiesel production (in terms of yield) process mainly depends on free fatty acid (FFA) content, feed quality, type of alcohol and molar ratio (oil:alcohol), catalyst type and its concentration, reaction temperature and time (Puneet and Sharma 2016). But the cost of biodiesel depends on the raw material, processing cost, catalyst cost, nature of products separation, purification and storage. Typically, the feedstock consumes around 80–90% of the total operating cost of biodiesel production (Demirbas 2007). Baskar and Aiswarya (2016) have mentioned that the choice of catalyst and feedstock are the most important criteria for the effective production of biodiesel. In addition, the biodiesel producers must consider the following points to optimize the product price:

- (i) Price of feedstock oil, alcohol (mostly methanol) and catalyst

- (ii) Capital and operating costs of the plant, including services, product storage and buildings
- (iii) By-product of glycerol, which provides secondary revenue to biodiesel producers.

In contemporary India, the commercial production cost of biodiesel is higher than the petroleum-derived diesel due to the cost of feedstocks and their operating costs including product wash. The academic and industrial researchers have to focus on cultivation and the feasibility of producing biodiesel at commercial scale from tree-borne oil seeds such as *Jatropha*, as pongamia (*P. pinnata*), neem (*A. indica*), kusum (*S. oleosa*), mahua (*Madhuca longifolia*), as well as waste edible oils.

## 5 Closing Remarks

The non-edible plant oils of *J. curcas*, *P. pinnata* are significant and promising feedstocks as per Indian climate conditions and they can be grown in dry climatic conditions with less maintenance, less water and less soil fertility. However, these seed oils have more than 10% of FFA that could hinder the yield as well as efficiency of the process. This is the biggest challenge for a biodiesel producer/manufacture to get maximum yield in a cost-effective manner.

In a Technology viewpoint, the homogeneous (acid/alkaline) catalyst is mostly used for commercial production of biodiesel from batch and continuous processes. In addition, the homogenous methods have high rate of reaction, moderate temperature (<80 °C) and good selectivity. It could also be operated by a semi-skilled operator. The main disadvantage of a homogeneous method is the practical difficulty of removing the catalyst. The removal of catalyst from the product creates a large amount of wastewater, which increases the overall cost of the process. Thus, the total cost of the biodiesel production based on homogeneous catalysis, is not yet sufficiently competitive as compared to the cost of the diesel produced from petroleum.

The heterogeneous (acid/alkaline) catalysis is most favourable for the continuous processes with environmental friendly. The heterogeneous system requires more than 150 °C of reaction temperature and their respective methanol vapour pressure also to be considered, which could increase the operating and maintenance costs. Particularly, acid-catalyzed transesterification reaction requires higher alcohol to oil molar ratios than an alkaline catalyzed process. The low-quality feedstocks could be effectively converted into biodiesel by using heterogeneous catalyst methods. Other methods of Supercritical methanol process and enzymatic (biochemical) process are not yet economically viable for commercial production in India

Presently (2017), Indian commercial producers are using a two-stage homogeneous process. The market price of biodiesel is Rs. 55 ( $\pm 2$ ), excluding tax. This price is a little high in the market due to the cost of feedstocks which makes up to

80–90% of the total production costs, operating costs and the capital cost in the view of business experts. The market price is almost near to the petroleum diesel price (approximately Rs. 60). However, in using biodiesel, there are enormous benefits towards the environment-friendly factors such as fewer emissions like CO, SO<sub>2</sub>, NO<sub>x</sub> and less particulate matter.

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