Membrane biodiesel production and refining technology: A critical review

Abdul Aziz Abdul Raman, University of Malaya

Available at: https://works.bepress.com/abdulaziz_abdulraman/33/
Membrane biodiesel production and refining technology: A critical review


Chemical Engineering Department, Faculty of Engineering, University Malaya, 50603 Kuala Lumpur, Malaysia

Contents

1. Introduction ......................................................................................................................... 5051
2. Application of membranes for the production of biodiesel fuel ..................................................... 5052
   2.1. Issues governing conventional biodiesel production ............................................................ 5053
   2.1.1. Types of non-membrane reactors used for biodiesel production ................................... 5053
   2.1.2. Challenges in producing biodiesel using conventional reactors .................................... 5053
   2.2. Membrane reactor ......................................................................................................... 5053
   2.2.1. Membrane reactor operation ......................................................................................... 5054
   2.2.2. Performance of membranes ......................................................................................... 5055
   2.2.3. Conversion of triglycerides to biodiesel product using membrane reactor ................. 5056
   2.3. Prospects and challenges of producing biodiesel using membrane reactor ...................... 5056
3. Membrane biodiesel refining technology .............................................................................. 5056
   3.1. Conventional refining technology and its challenges ....................................................... 5056
   3.2. Biodiesel membrane separation processes ....................................................................... 5057
   3.2.1. Biodiesel separation through ultra-filtration process ............................................... 5058
   3.2.2. Biodiesel separation through micro-filtration process ............................................... 5059
   3.2.3. Biodiesel separation through pervaporation process ............................................... 5059
   3.3. Biodiesel purity via membrane refining ......................................................................... 5060
4. Conclusions and recommendations ...................................................................................... 5060
References ............................................................................................................................... 5060

1. Introduction

Biodiesel as a source of energy has been receiving great attention among the futurist and the world policy makers [1]. This is so because of its renewability, biodegradability, and better quality of exhaust gas emission [2]. The idea of vegetable oil based fuel to run diesel engines has been on the world stage over a century ago. The discovery of the potentials of vegetable oil to serve as fuel was made by one of the most famous scientist of the nineteenth century called “Rudolf Diesel”. Rudolf Diesel, in 1912 stated that “the use of vegetable oils for engine fuels may seem insignificant today. But such oils may become in course of time as important as petroleum and the coal tar products of the present time” [3]. The interest to develop the technology of biodiesel fuel over the years was low due to availability and low cost petroleum products. The renewed and increasing interest in the growth and development of
biodiesel fuel is driven mainly by its potentials to solve three main challenges confronting the global economy. These include among others: how to attain energy independence, reduce environmental impact and achieve fuel of affordable prices that can compete favorably with the conventional diesel fuel. Thus, biodiesel fuel in large quantities could be achieved if certain technologies are developed. Some of these technologies include: (1) Establishment of a scheme to generate low cost feedstocks. (2) Development of sound technology for the purification of crude biodiesel. (3) Development of good catalysts that can give higher yields of biodiesel with less refining difficulties. (4) Establishment of a sound policy that can improve the production of biodiesel fuels. (5) Exploration and exploitation of biodiesel production systems with the aim of minimizing energy and water use [1].

Biodiesel fuel is produced via different techniques such as: direct blends [4,5], microemulsion [6,7], pyrolysis [8,9], and transesterification [10,11]. Among these techniques, transesterification reaction is the most adopted technique used to convert fats and oils into biodiesel fuel [10,12,13]. Fig. 1 presents transesterification of tri glyceride to biodiesel. Whereas Fig. 2 depicts the structure of triglyceride used as a feedstock to produce biodiesel fuel [14]. The process of transesterification reaction is usually catalyzed by either homogeneous or heterogeneous catalysts. The most notable catalysts are: NaOH, KOH, CH3ONa, and CH3OK. Recently heterogeneous catalysts such as solid catalysts (Ca(NO3)2-Al2O3, CaO-Al2O3, Sr(NO3)2-ZnO, ZnO/Al2O3, zeolite HY, and zeolite X) and enzymes (Pseudomonas fluorescens, Rhusops Oryzae, Candida rugosa and Pseudonas cepacia) are applied for the production of biodiesel. In addition, feedstocks such as virgin and used oils, animal fats, and microalgal oil are used as raw materials for the production of biodiesel fuel as shown in Table 1.

Biodiesel has been conventionally produced using reactors such as batch reactors, CSTR and plug flow reactors. However, the recent introduction of membrane reactor is significant in producing biodiesel for its ability to block the passage of unreacted triglyceride to final biodiesel product. This phenomenon has the benefits of providing high-quality biodiesel fuel. This is so because unreacted triglycerides constitute one of main impurities that need to be removed after transesterification is completed.

Production of biodiesel with full conformity to biodiesel international standard specification (EN 14214) is technically difficult, especially meeting the needs of biodiesel fuel standard of biodiesel yield of 96.5 wt. % (EN 14214) [26]. The crude biodiesel product obtained from both conventional and membrane reactors comes with impurities such as glycerol, soap, residual catalyst and excess alcohol that need to be removed. Purification of crude biodiesel from these impurities is necessary so as to make biodiesel suitable for diesel engines consumption and other applications. The presence of these impurities in biodiesel fuel could cause severe engine problems and damages [43]. The removal of these impurities via conventional separation and purification techniques poses severe difficulties such as huge amount of water usage, high energy consumption, time wasting and treatment of wastewater [44,45]. This has led to the recent application of organic/inorganic separative membranes for the refining of crude biodiesel. Membrane biodiesel separation processes seem to provide high-quality biodiesel fuel [24,46,47]. Also, a large portion of membrane separation processes are carried out under moderate temperature and pressure conditions and their scale up are less cumbersome. Furthermore, membranes are generally most preferred in the refining processes for the following reasons: low energy consumption, safety, simple operation, elimination of wastewater treatment, easy change of scale, higher mechanical, thermal and chemical stability, and resistance to corrosion [48]. Therefore, this study critically examined the production and refining of biodiesel using membrane technology.

**2. Application of membranes for the production of biodiesel fuel**

Membrane system exploits the inherent characteristics of high selectivity, high surface area per unit volume, and their potential for controlling the level of components mixing between the two phases [49]. The application of membranes for biodiesel production
is usually designed in two phases, one phase is the membrane reactor to transesterify fats and oils to biodiesel, and the other phase is the separative membrane to separate the crude biodiesel from its impurities such as: catalysts, soap, glycerol, and alcohol without necessarily using water, acids, organic solvents and absorbents. Membranes are usually classified into organic, inorganic or combination of the two. Organic membranes are mostly avoided for processes involving high acidic and basic environments due to their less resilience. However, inorganic membranes such as metallic, ceramic, zeolitic or carbon-made are mostly preferred because of their ability to withstand harsh conditions such as higher temperatures, high acidic and basic environments. Thus the term ceramic membranes are porous fine ceramic filters sintered from alumina or titania, zirconia oxides under ultra high temperature and usually have an asymmetrical structures with porous support active membrane layer. The mechanical resistance whereas the active layer allows microfiltration, ultrafiltration separation process. Also, ceramic membranes always runs at a across flow filtration mode [51]. In the cross flow mode, the fluid to be filtered flows parallel to the membrane surface and permeates through the membrane due to a pressure difference [49]. This characteristic of ceramic membranes reduces fouling effects and improve high filtration rate [51].

2.1. Issues governing conventional biodiesel production
Homogeneously catalyzed transesterification in a stirred tank reactor is most favored technique for biodiesel production [52]. Homogeneous catalysts such as NaOH, KOH, CH3ONa and CH3OK are well established to provide excellent catalytic activities in the production of biodiesel [53]. However issues such as difficulties in refining, cost of refining process, and waster water generation have been the major problem of this technology. Therefore to overcome these problems heterogeneous catalysts are explored and exploited, these catalysts can be easily removed with a resultant high-quality biodiesel product.

2.1.1. Types of non-membrane reactors used for biodiesel production
The non-membrane reactors that have been employed for the production of biodiesel include among others: batch reactors [54–56], plug flow reactors [57], continuous stirred tank reactors (CSTR) [16,57,58], fixed bed reactors [59–61], helicoidal reactor [62], transport riser reactor [63] and oscillatory flow reactor [64]. Using batch reactors, a good number of researchers have reported higher conversions of triglycerides to biodiesel fuel [65–67].

2.1.2. Challenges in producing biodiesel using conventional reactors
Commercial production of biodiesel fuel via batch reactors is mostly discouraged due to their tedious mode of operations. Besides, cost of biodiesel production due to labor. These problems have led to using plug flow reactors, CSTR and fixed bed reactors for the production of biodiesel. These reactors have the potentials of being used for the production of biodiesel fuels, but problems ranging from lower conversion efficiencies, difficulties in processing low quality feedstocks, mass transfer limitation [68], non-uniform product distribution, low quality biodiesel products, poor biodiesel yields, higher reaction conditions [69], labor and reactor facility degradation due to chemical attacks have discouraged their commercial applicability. Helwani et al. [70] reported the main drawback of the continuous stirred tank reactors or tubular reactors is that the temperature of reaction is narrowed to the boiling point of alcohol: 65 °C for methanol, if the reactor is operate at atmospheric pressure. The authors noted that if for industrial size reactor, significant mass transfer resistance is expected even when higher shear mixing is employed. These problems have eventually led to the exploration and exploitation of membrane technology for the production of biodiesel fuel. Dubé et al. [71] and Dubé [72] remarked that the technical difficulties such as immiscibility of triglycerides and alcohols and reversibility problems commonly encountered with conventional reactors can be overcome via membrane reactor.

2.2. Membrane reactor
Development of a membrane reactor and its successful application in producing biodiesel has renewed the strong interest to develop alternative renewable and sustainable fuel to replace petro-diesel fuel. Membrane reactors can serve different purposes such as intensify the contact between reactants and catalyst, selectively remove the products from the reaction mixture, and control the addition of reactants to the reaction mixture [73]. These reactors can be employed to avoid the equilibrium conversion limits of conventional reactors. Besides, the reactors can efficiently improve the maximum achievable conversion of reversible reactions and the general reaction pathways [74]. Furthermore, membrane reactors provide the potential of higher selectivities and yields in many different processes as well as being safe and more environmentally friendly [75]. Dubé et al. [71] developed a novel membrane reactor that enabled both acid- or base-catalyzed-transesterification of canola oil as well as separation of unreacted canola oil from reaction products. The membrane reactor consisted of membrane pore size of 0.05 μm, inside and outside diameters of the membrane were 6 and 8 mm, length of carbon membrane tube of 1200 mm and a surface area of 0.022 m². The membrane reactor was charged with canola oil (100 g) and sealed. Following circulation time of 10 min, the reactor was operated continuously at a pressure of 138 kPa with feed (mixture of methanol and acid) pump flow rate of 6.1 ml/min. The heat exchanger was switched on to achieve temperatures of reaction (60, 65 and 70 °C) which was monitored by a thermocouple. Therefore after starting the heat exchanger a stable reaction (±0.1 °C) time was achieved with 30 min for 60 °C, 40 min for 65 °C and 45 min for 70 °C. The experiments were all conducted for 6 h. The authors remarked that an additional experiment was also performed to study the effects of methanol/acid catalyst feed flow rate on conversion for both acid- and base-catalyzed transesterifications. The flow rates were 2.5, 3.2 and 6.1 ml/min. The schematic diagram of the membrane reactor is depicted in Fig. 3 [71]. Similarly, Cao et al. [69] transesterified a number of vegetable oils such as canola, soybean, palm, and yellow grease lipids via a membrane reactor. The authors noted that despite the wide range of feedstocks used, the membrane reactor presented a moderately consistent performance at one set of operating conditions and enabled the production of high-quality biodiesel fuel which was confirmed by GC analysis based on the ASTM D6584 standard. The biodiesel from all the feedstocks met the ASTM D6751 standard. Also, the glycerol content of biodiesel produced using a membrane reactor was significantly lower than that produced via a conventional batch reaction. Another study conducted by Cao et al. [76] compared three different recycling ratios for production of biodiesel via membrane reactor: 100%, 75% and 50% by volume, for instance, 75% recycling entails that every 0.75L of polar phase was mixed with 0.25L of methanol with 1 wt% (by weight of oil) NaOH catalyst and pumped into the reactor circulating loop at a feed rate of 3L/h, while the feed rate of canola oil was also kept at 3 L/h. The authors noted that the catalysts and glycerol were also recycled. Furthermore, to maintain biodiesel-rich non-polar phase containing 85 wt%, the permeate was consistently removed as well as methanol/glycerol polar phase. Consequently, at maximum recycle ratio, the fatty acid methyl esters (FAME) concentration ranged from 85.7 to 92.4 wt%. It was found in biodiesel-rich non-polar phase. In addition, the overall
molar ratio of methanol:oil in the reaction system was significantly decreased to 10:1 while maintaining a FAME production rate of 0.04 kg/min. Also in biodiesel-rich non-polar phase no triglycerides (TG), monoglycerides (MG) or glycerol were observed. The authors noted that despite the samples not being water washed prior to analysis, high purity biodiesel product free of non-saponifiable materials was produced. As a result, a high purity biodiesel product was produced. Although the yield obtained via homogeneous catalyst in membrane reactor was below EN14214 standard [69]. Therefore, to circumvent the problems associated with use of homogeneous catalyst, which despite use of membrane reactor still poses difficulties. Baroutian et al. [52] developed a novel continuous packed bed membrane reactor (a tubular ceramic (TiO2-Al2O3) membrane) to produce biodiesel fuel using solid alkaline catalyst (potassium hydroxide catalyst supported on activated carbon). The membrane reactor comprised; length, inner diameter, outer diameter and pore size of the membrane 40 cm, 1.60 cm, 2.54 cm and 0.05 μm, respectively. The filtration surface area for the entire membrane was 0.0201 m². Three digital Masterflex L/S peristaltic pumps were employed to feed the raw materials and to prepare circulation inside the system. The Chem-Durence chemical resistant pump tubing with a size of 16 (ID=64 mm, OD=2.36 mm) was also used. The temperature and pressure were monitored via pressure gauges and temperature indicator. The authors noted that during transesterification the membrane reactor was able to block the triglycerides, but biodiesel and by-product glycerol alongside methanol passed through the membrane pore size due to their smaller molecular sizes. As discussed earlier the ability to block the triglycerides provided high-quality biodiesel fuel. Conversion of 94% was obtained at 70 °C reaction temperature. 157.04 g catalyst per unit volume of reactor and 0.21 cm/s cross flow circulation velocity. The characteristics of the product under the optimum condition were within the ASTM standard.

2.2.1. Membrane reactor operation

The term membrane reactor is usually referred to a system in which membranes separation and chemical reactions are combined. It is an appliance use to simultaneously carry out a reaction and a membrane-based separation in the same physical enclosure [77]. During chemical reaction, the immiscibility of the reactants (alcohol and fats oil) is slightly affected by temperature, thus the two phases are usually considered to be immiscible. Lack of miscibility of the reactants is the root of mass transfer problems faced during biodiesel production. In membrane reactor operation, a two-phase emulsified system formation is the exact thing that is required. The two-phase membrane reactor was mainly useful in removing unreacted canola oil from the FAME product. This phenomenon has been remarkable in shifting the reaction equilibrium to the product side and yielding high purity and quality biodiesel fuel [69,71,77]. Thus, the transesterification of triglyceride to fatty acid alkyl esters is suitable to operate in a membrane reactor. Also due to various surface forces and lack of miscibility of vegetable and alcohol, oil mostly exists as an emulsion. Thus, transesterification could be envisaged to occur at the surface of oil droplet. The occurrence of a permeable membrane consisting of smaller pore sizes normally blocks the larger oil droplets. However, the solubility of fatty acid alkyl esters (FAEE) in alcohol and its smaller molecular size enables the FAEE and glycerol, catalyst and alcohol to permeate through membrane pores. Additionally, because of the reversibility of transesterification, boosting FAEE production needs the removal of either FAEE or glycerol to move the equilibrium to the product side (in accordance with Le Chatelier’s Principle) [52,71].

2.2.1.1. Characteristics of membrane. Dubé et al. [71] stated that the life of membrane used in the reactor is most significant when dealing with high acid or base catalyst concentration. The authors noted that the carbon membrane resisted the high acid and base environments. They reported that membrane reactors can have several advantages over conventional reactors such as resistance to corrosion. Also, Barredo-Damas et al. [78] stated that ceramic carbon membranes offer many advantages over polymeric membranes such as high chemical, mechanical and thermal resistance to degradation and show higher permeability rates. The authors noted that
the cost of ceramic carbon membranes is being recently decreased. According to Brunetti et al. [79] membrane technology offers fundamental engineering and economic advantages over competing separation technologies. Therefore the ability to withstand the reaction conditions, chemical and thermal stabilities also allow the ceramic carbon membrane to be cleaned more proficiently when unrefined feedstocks such as used/waste cooking oils are employed [69]. Baroutian et al. [52] observed that the performance of ceramic used was not affected after operating the membrane in a reactor media containing methanol and solid alkaline catalyst for 1 year, this due to its excellent chemical and physical stability. Salahi et al. [10] stated that membrane structure has an important influence in improving permeate flux.

2.2.1.2. Effects of membrane pore size. The membrane pore size is significant in realizing high purity and quality biodiesel, since separation of crude biodiesel is to some extend dependent on the molecular size of the constituents comprising biodiesel mixture. Cao et al. [77] found out the use of four carbon membranes having different pore sizes of 0.05, 0.2, 0.5, and 1.4 μm, with four different initial methanol volume fractions of 0.29, 0.38, 0.47, and 0.64 to produce biodiesel fuel. The authors reported the canola oil used was retained by all the four membranes in the reactor. As discussed earlier retaining oils by membrane system served to provide better quality biodiesel fuel to be efficiently used in compression-ignition engines as shown in Fig. 4 [1].

2.2.1.3. Effects of catalyst. Catalysts are of great importance during transesterification triglycerides to biodiesel, in that they improve reaction rates [26]. Dubé et al. [71] employed base- and acid-catalyzed transesterification reaction to convert canola oil to biodiesel via membrane reactor. Catalyst concentration of 1 wt.% NaOH was used at different flow rates. Both homogeneous base catalyst and heterogeneous base catalyst provided high conversions compared to the acid-catalyzed process as shown in Table 2. For the base catalyzed process, little amount of soap was formed, which was detected during water washing [71]. The authors noted that the canola oil might have contained considerable amount of FFAs which most have being transformed to soap instead of biodiesel during base-catalyzed process. On the other hand no soap was formed for acid catalyzed process. Therefore acid catalyst will present both economical and technical advantage, despite slower rate of reaction when low quality feedstocks are used for the production of biodiesel [80]. However, to overcome problems associated with homogeneously catalyzed process via membrane reactor, Baroutian et al. [52] have experimented use of heterogeneous alkaline catalyst in packed bed membrane reactor. The authors employed a tubular ceramic (TiO₂-Al₂O₃) membrane as a reactor and separator, which was filled with potassium hydroxide catalyst supported on activated carbon KOH/AC. The catalyst was reused several times, and after each run the catalyst was removed, dried and reutilized. The catalytic activity remains 85 % of the fresh catalyst when the activated carbon supported catalyst was employed for the third time. The catalytic decay could be due to leaching of the active site into reaction media. The authors noted the active site phase leaching into the alcoholic phase might be as a result of bond breaking and formation of K⁺ and CH₂O⁻.

2.2.2. Performance of membranes

The overall membrane performance is strongly dependent on the membrane selectivity [81]. Mahua [82] noted that membrane performance is mostly affected by several numbers of parameters such as; membrane composition, temperature, pressure, velocity of flow, and interaction between components of the feedstocks with the membrane surface. Similarly, Petr and Irí [83] stated the performance of membrane separation process can be characterized by permeate flow rate yielded by a given membrane device which can be, in the simplest case, calculated by the product of constant permeate flux and total filtration area. Also, Ahmad et al. [84] reported the higher the selectivity factor the better the membrane performance. They noted that selectivity factor sometimes is independent of temperature but dependent on the nature of material used in the membrane preparation. In addition, higher temperature does not necessarily produce higher selectivity. The authors stated that extensive researches must be carried out in the near future using various types of materials to form membrane with better selectivity.

Table 2

<table>
<thead>
<tr>
<th>Exp.</th>
<th>Flow rate (mL/min)</th>
<th>Temperature (°C)</th>
<th>Conversion via acid-catalyst (%)</th>
<th>Conversion via base-catalyst (%)</th>
<th>Conversion via heterogeneous catalyst</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.5</td>
<td>65</td>
<td>35</td>
<td>95</td>
<td>94</td>
<td>[52]</td>
</tr>
<tr>
<td>1</td>
<td>3.2</td>
<td>65</td>
<td>48</td>
<td>96</td>
<td>96</td>
<td>[71]</td>
</tr>
<tr>
<td>3</td>
<td>6.1</td>
<td>65</td>
<td>64</td>
<td>96</td>
<td>96</td>
<td>[71]</td>
</tr>
</tbody>
</table>

Fig. 4. Cross flow filtration configuration.
factor. In another study, Saracco et al. [50] noted a change in interest from improving the equilibrium limited reactions through membrane separation of one of the products, to selectivity increase through membranes. Additionally the retention coefficient for the oil or FFAs (SR) can be calculated as:

\[
SR = \frac{(C_{fa} - C_{per})}{C_{fa}} \times 100
\]

where \( C_{fa} \) and \( C_{per} \) are the concentration of those components, in the feed and permeate respectively [85].

2.2.3. Conversion of triglycerides to biodiesel product using membrane reactor

Higher conversions/selectivities of membrane processes are usually achieved via selective removal of products or controlled and spatially distributed supply of reagents [86]. Christine and Gonzalez [87] stated that membranes can be used in reactions to improve conversion or selectivity. Gao et al. [69] reported that if the residence time or catalyst concentration is increased, conversion will increase, which increases the concentration of FAME in the reactor. However, lowering the catalyst concentration and/or decreasing the residence time can reduce the FAME concentration and prevent the occurrence of diglyceride (DG) in permeate. The authors also noted that when the FAME concentration is higher than 35 wt.% in the permeate stream, the diglyceride will solubilized into the permeate stream. They stated that after recycling, the average diglyceride concentrations in the FAME-rich non-polar permeate phase were 0.34, 0.34, and 0.32 wt.% for the 100%, 75% and 50% recycle ratio cases, respectively [76].

2.3. Prospects and challenges of producing biodiesel using membrane reactor

The use of membrane technology to produce biodiesel has shown promise in providing biodiesel whose physicochemical properties is comparable to those of petro-diesel. This is certainly a positive step in the development of biodiesel fuel for future application. Additionally, the use membrane reactor is solidly aimed to overcome problems associated with conventional reactors, which has been demonstrated in their works [52, 71, 88]. However, several issues are still yet to be resolved. Thus, Table 3 presents prospects and challenges of using membrane reactors for the production of biodiesel fuel.

3. Membrane biodiesel refining technology

3.1. Conventional refining technology and its challenges

After transesterification reaction, biodiesel is first separated from glycerol before being subjected to other refining processes. The separation of biodiesel from by-product, glycerol is usually fast due to difference in their densities. This separation process is usually performed by either decantation or centrifugation [92]. Other separation process includes gravitational settling [15], filtration [47], and sedimentation [93]. In decantation separation technique, the mixture of biodiesel and glycerol is rested in the tank. Although the cost of separation is low, however the process is slow and inefficient [90]. On the other hand, separation via centrifugation requires that the mixture of biodiesel and glycerol be fed into centrifuges for separation process to occur. The process of separation is fast, but its cost of operation and investment are considerably high [2, 90].

Following removal of glycerol, biodiesel is further purified to remove impurities such as tri-, di-, and monoglycerides, catalyst, soap and traces of alcohol [93, 94]. The removal of these impurities is essential so as to produce biodiesel that conform to international standard specifications (ASTM 6751-3 and EN 14214) as shown in Table 4 [26]. This is because presence of these impurities poses great impact on the purity and quality of biodiesel as fuel for use in compression-ignition engines [95].

Conventionally, purification of biodiesel is done via alcohol removal using vacuum distillation or flash evaporation, and wet or dry washings to remove triglycerides, catalyst, and soap [96]. Wet washing technique is done in several ways; it could be distilled water washing alone, washing with acids then followed by washing with distilled water or washing with organic solvent followed by washing with water. Even though, the process provides biodiesel that can be conveniently used in diesel engines. But the process is known for huge water consumption, large wastewater discharges, huge amount of energy need, high cost of wastewater treatment and drying of final biodiesel products [96].

Fig. 5 depicts conventional schematic diagram for fatty acid alkyl esters (biodiesel) production and purification. Thus, wet washing process is disliked for its significant and intolerable negative contributions to environmental pollution and degradation. Presently, concern of large amount of biodiesel contaminated wastewater disposal is rising in Thailand [45].

Furthermore, problems associated with wet washing have led to the introduction of dry washing process to purify crude biodiesel. This process involves the use of absorbent such as carbon, silica, bleaching clay, and activated bleaching clay, zeolite, ion exchange...
Table 4
International biodiesel standard specifications.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Units</th>
<th>ASTM method</th>
<th>EN14214</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ester content</td>
<td>% (m/m)</td>
<td>96.5</td>
<td></td>
</tr>
<tr>
<td>Flash point</td>
<td>°C</td>
<td>130 min.</td>
<td>&gt;101</td>
</tr>
<tr>
<td>Water and sediment</td>
<td>vol%</td>
<td>0.050 max.</td>
<td>0.05</td>
</tr>
<tr>
<td>Kinematic viscosity, 40 °C</td>
<td>mm²/s</td>
<td>1.5-4.0</td>
<td>3.5-5</td>
</tr>
<tr>
<td>Sulfated ash</td>
<td>% (m/m)</td>
<td>0.020 max.</td>
<td>0.02</td>
</tr>
<tr>
<td>Sulfur</td>
<td>mg/kg</td>
<td>15 max.</td>
<td>&lt;10</td>
</tr>
<tr>
<td>515 grade</td>
<td>ppm</td>
<td>500 max.</td>
<td></td>
</tr>
<tr>
<td>5500 grade</td>
<td>ppm</td>
<td>47 min.</td>
<td>≥51</td>
</tr>
<tr>
<td>Copper strip corrosion</td>
<td>cm</td>
<td>report</td>
<td></td>
</tr>
<tr>
<td>CETANE</td>
<td>°C</td>
<td>0.50 max.</td>
<td></td>
</tr>
<tr>
<td>Carbon residue 100% sample</td>
<td>% (m/m)</td>
<td>0.020 max.</td>
<td>0.02 max.</td>
</tr>
<tr>
<td>Acid number</td>
<td>% (m/m)</td>
<td>0.25 max.</td>
<td></td>
</tr>
<tr>
<td>Free glycerol</td>
<td>% (m/m)</td>
<td>0.001 max.</td>
<td>0.001 max.</td>
</tr>
<tr>
<td>Total glycerol</td>
<td>% (m/m)</td>
<td>0.005 max.</td>
<td></td>
</tr>
<tr>
<td>Phosphorus content</td>
<td>ppm</td>
<td>5 max.</td>
<td></td>
</tr>
<tr>
<td>Distillation temperature, atmospheric equivalent temperature, % recovered Sodium/potassium</td>
<td>ppm</td>
<td>5 max. combined</td>
<td>5 max.</td>
</tr>
</tbody>
</table>

Max.: maximum; min.: minimum.

Thus, problems associated with both conventional biodiesel separation and purification processes have resulted to the exploration and exploitation of membrane technology to separate biodiesel product from impurities.

3.2. Biodiesel membrane separation processes

Membranes are selective either by pore size (porous membrane) or because of their chemical affinity for permeating component [100]. Ceramic membrane biodiesel separation and purification technology is fast growing due to their stability in organic solvents [101]. Hua et al. [102] noted that over the last 30 years, membrane separation processes have enjoyed great popularity and is

![Conventional schematic diagram for fatty acid alkyl esters production and purification.](http://ac.els-cdn.com/S1364032111002929/1-s2.0-S1364032111002929-main.pdf?_tid=5c99cda0-1b78-11e3-a44e-00000aacb35f&acdnat=1378969131_f9b2fe90a3a27190e0ec0f6a761eccc6)

Full text is available at:

http://ac.els-cdn.com/S1364032111002929/1-s2.0-S1364032111002929-main.pdf?_tid=5c99cda0-1b78-11e3-a44e-00000aacb35f&acdnat=1378969131_f9b2fe90a3a27190e0ec0f6a761eccc6