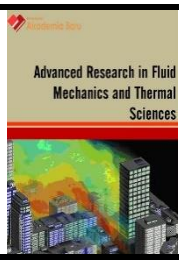
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



A Short Review on Biodiesel Production and Costing

Open Access

Muhammad Farhan Mirus[1,*], Nurul Fitriah Nasir[1,2], Ishkrizat Taib[1], Azian Hariri[1], Normayati Nordin[1], Norasikin Mat Isa[1]

[1] Centre for Energy and Industrial Environment Studies (CEIES), Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia
[2] Plant Reliability and Process Technology Focus Group (PROTECH), Universiti Tun Hussein Onn Malaysia, Batu Pahat, Johor, Malaysia

ARTICLE INFO

Article history:
Received 3 October 2018
Received in revised form 10 November 2018
Accepted 27 November 2018
Available online 10 January 2019

Keywords:
Biodiesel, renewable fuel, biodiesel costing

ABSTRACT

Biodiesel has been introduced to reduce the dependency on fossil fuel. It is derived from vegetable oil, alcohol with the presence of a catalyst. One of the most significant issues in biodiesel market is the selling price. This paper will review the research conducted on the production of biodiesel, including the equipment, raw materials and cost. These three elements are crucial to reduce the price and enable biodiesel to be a competitive alternative fuel in the market. This paper also discusses recent developments in production, market values and suggestions for improving the biodiesel process. The results presented in this review may facilitate improvements in biodiesel production and costing.

1. Introduction

As an alternative source of energy, the introduction of biodiesel is aimed at replacing conservative fossil fuels. Biodiesel can be used directly (B100) or by blending it with petroleum diesel (B6 B20) according to the standard in ASTM D6751. The use of biodiesel can reduce pollution due to the low emission of carbon dioxide, less harmful emissions due to vegetable-based oils and improve the economy through the use of renewable and waste material [1]. The use of biodiesel blends can reduce the amount of particulate matters with slight increase in nitrogen oxide [2-5]. When used in combustion engines, waste cooking oil and acid oil show variations in performance. This is because the oxygen and cetane number affect the combustion rate of biodiesel [3] due to the difference in chemical compositions of the feedstock [6,7].

Recently, EIA reported that United States biodiesel import has increased by 65% in 2016. Out of the total biodiesel that is imported, 64% is from Argentina, 15% Indonesia, and 14% is from Canada [63]. Around the globe, United States has produced the highest amount of biodiesel in 2016 with 5.5 billion litres followed Brazil with 3.8 billion litres, Germany, Indonesia and Argentina each producing

* *Corresponding author.*
E-mail address: farhanmirus@gmail.com (Muhammad Farhan Mirus)

3 billion litres. Other countries such as Belgium, Colombia, China, India, Singapore and Spain are also biodiesel producing countries in the world [64].

One of the reasons is the fall in oil price occurring in mid-2014. Still, the biodiesel production in major producing countries can be maintained with the help of the government through mandates and tax exemptions. Using target subsidies as strategies, this can also help in controlling the market and maintain biodiesel price [8]. The biofuel production in Asian regions is expected to grow, with Malaysia and Indonesia leading the biodiesel production. India and Thailand will be producing ethanol and Philippines will be producing both ethanol and biodiesel [9]. Asian regions are rich in agricultural activities and resources ensuring the sustainability of biodiesel production, thus have the potential to become the biggest biodiesel producing region in the world. Although biodiesel has yet to be able to fully replace fossil fuels [10], the ever-increasing price of crude may drive biodiesel as the market priority in the future.

2. Biodiesel Raw Material

2.1 Feed Stock

Vegetable oil from rapeseed, palm oil, soybean and sunflower are the main source of feedstock for biodiesel production with a total production of about 70.6 Metric Tonnes between 1993 to 1997 [11]. Considering the suitable amount of free fatty acid content, other crops have been experimented with to handle the demand from industries such as hazelnut oil and corn oil [12]. However, the demand of edible oil from the energy industry raised a spark of debate from food industries [13]. The development of biodiesel from non-edible oil such as castor oil [14] has reduced the demand problem and recently more crops have been found to be a potential feedstock for biodiesel production. Salvia Macrosiphon, a wild plant found in Iran contains about 30-40% of oil in the kernel [3]. Ocimum Basilicumor, also known as sweet basil, grows in tropics and subtropics. The plant can grow quickly under suitable climate any time of the year, which means that it can ensure the sustainability for supply in the industry [15].

Other than vegetable oil, microalgal also has started to make an impact in the biodiesel industry. Microalgal can be cultivated in marine water and wastewater, and some species of microalgal are expected to grow in local conditions [16]. With the ability to be converted into various energy carriers other than biodiesel such as ethanol and gasoline, microalgal has a good quantity of lipid, fat and enzyme to be utilized in chemical and medical division [17]. Spirulina microalgae is a type of newfound microalgae to be used in biodiesel production and has been able to yield 99.32% of biodiesel via transesterification near supercritical method [18]. Cultivation of microalgae requires a huge water catchment area and a huge area can provide a breeding place for dengue mosquito. Therefore, safety precautions must be taken to ensure a safe environment.

Spent coffee grounds is an example of using waste product in biodiesel production by extracting coffee oil. Using two-step transesterification, it can yield 98% of biodiesel under 70°C and 12 hour reaction condition using H2SO4 as catalyst [19]. The black soldier fly is an insect that feeds on waste material containing about 30% fat that can be utilized in biodiesel production [20]. It is a concern that when cultivating an insect like the black soldier fly, there will be a risk of disease spreading in the cultivation area. It is not limited to the workers but also to their families and the population nearby.

2.2 Catalyst

The catalyst’s role in biodiesel production is to control the kinetic reaction when converting fatty acid and alcohol into fatty acid methyl ester (FAME). Different catalysts react differently with fatty acids, depending on their own reaction condition [21]. Until today, the review on catalyst development is still pursued by researchers in order to keep up with numerous newly found catalysts. The basic idea in a catalyst is using an acid catalyst such as H2SO4 and HCL [22], or a base catalyst such as NaOH and KOH. Homogeneous acid catalysts can react with a low cost feedstock that has a high amount of fatty acid, but it will excrete contamination that requires extra separation and purification process. Therefore, heterogenous acid catalyst is developed to counter the effect by homogeneous acid catalyst, and it also reduces the reaction time and reduces corrosion. Reaction speed can be improved by increasing alcohol to oil molar ratio, but it also increases the cost [23]. Edgar *et al.*, [24] reported that a 30:1 alcohol to oil molar ratio is needed to yield 98.4% of biodiesel under 240°C and 70 bar reaction condition. Nandagopal *et al.*, [25] used sulfonated zirconia as heterogeneous acid catalyst and with 9:1 alcohol to oil molar ratio, it can yield 95% of biodiesel under 65°C of reaction temperature. The base catalyst reacts faster than acid catalyst, but it is insensitive to FFA content in oil. Soap formation will occur if the FFA content is more than 2% which can reduce the percentage of biodiesel produced. The difference between heterogeneous and homogeneous base catalyst is heterogeneous catalyst can be reused and the separation step is simpler. Base catalysts can react in mild conditions and are cheap and widely available [26]. Sharma and Singh [27] compared the effect of homogeneous catalyst NaOH and KOH and it was found that NaOH yields more biodiesel, 85% and 83% respectively using 9:1 molar ratio. CaO as a commonly used heterogeneous catalyst possessing the ability to be the main catalyst in biodiesel production as it is ecologically friendly and can be obtained from natural resources and waste material [28]. Liu *et al.*, [29] said that transesterification by using 12:1 alcohol to oil molar ratio can help to yield up to 95% of biodiesel.

The study on catalyst has diverted from using basic types of catalysts to genetically modified catalysts such as FeCl3 which has been mixed with hydrogen type cation-exchange resin and it yields 92% biodiesel [30]. Sulfonated graphene formed from the reaction of inexpensive graphite with sulfonic acid tends to be very reactive, resulting 98% biodiesel yield [31]. Another source of green catalyst is halloysite that are modified to be suitable in biodiesel production. The mineral is available in Indonesia and has the potential to yield 83% biodiesel using 8:1 alcohol to oil molar ratio. The catalyst that can still be further developed as halloysite itself consists of different chemical components [32]. Recap from the literature of catalyst, a new catalyst is being developed to overcome the issues with conventional catalyst such as reaction rate, contamination, pollution, availability and price. Industries usually tend to choose the catalyst with lower handling cost and high yield percentage, therefore the development of a catalyst should revolve around these characteristics.

3. Biodiesel Plant Equipment

3.1 Reactor

The reactor has a significant impact for biodiesel production. The production process includes a wide range of selection of raw materials, types of production, conditions of the reaction, which involves a complex and costly process. The design of the reactor depends on how the biodiesel is produced, either in batches or as a continuous process. A batch reactor requires a huge amount of alcohol, has a tendency of reverting reaction and a need for a proper separation unit [33]. A study from Hosseini *et al.*, [3] stated that a previous study has found that the factors involved in designing a reactor are the size of the reactor, construction material, the agitation system, hydrodynamic studies, physical properties of reactant and the supply and removal of heat. The action of qualifying the factors will have an impact on product quantity, quality and process economics [34]. Continuous study, on the other hand, has been of interest in biodiesel production due to its huge quantity production, consistent product quality and cost and time efficiency. Therefore, more studies have been done on the optimization of the continuous process than batch process. A list of reactors developed by previous researchers is briefly described in Table 1.

Table 1
Biodiesel Reactors and Their Features

Reactor	Condition and feature	Remarks
Zig-zag microchannel [35]	- 99.5% biodiesel yield. - Low residence time. - Process in mild condition - Continuous process	- suitable for small fuel plant for distributive application
Supercritical continuous reactor [36]	- 88% of biodiesel yield - Fixed bed reactor - Solid acid catalyst – SAC 13 - Mass flow rate – 6-24 ml/min - 200 °C in 20 min reaction time - 25:1 methanol to oil molar ratio	- Supercritical carbon dioxide was added as co-solvent to increase the rate of supercritical methanol transesterification.
Helicoidal reactor [37]	- 60°C in 75 min reaction time. - NaOH as catalyst. - Use recycled oil. - 12:1 methanol to oil molar ratio - Helicoidal tube submerges in water bath.	-Transesterification occurred continuously in tubular reactor.
Hybrid reactor [38]	- Kaner seed oil. - 95% biodiesel yield. - 40 min reaction time. - Batch process. - NaOH as catalyst.	- Combine hydrodynamic cavitation and mechanical stirring process. - Cheap, high yield, efficient and environmentally friendly.
Hydrodynamic cavitation reactor [39]	- Using used frying oil as feedstock - 95% conversion rate in 5 min. - 60°C reaction temperature. - Reservoir with 10L capacity connected to cavitating orifice plate	- Rate of transesterification increased with an increase in operating pressure subjected to orifice plate.
Integrated continuous reactor system [40]	- Continuous stirred tank reactor with 2 packed beds reactor in series. - 0.74 mL/min substrate feeding rate. - Enzyme catalyst – IIT-SARKZYME - 15:1 methanol to oil molar ratio. - Soybean oil	- Methanol and oil were stirred together into partially converted oil. - Environmentally friendly and economical.
Jet flow stirred reactor [41]	- 98% conversion rate. - 9L cylindrical reactor with conical bottom discharge connect to two centrifugal pumps. - NaOH as catalyst. - 85% soybean oil + 15% sunflower oil.	- Does not use heating mechanism. - 88% reduction of transesterification time.
Liquid-liquid film reactor [42]	- Membrane reactor. - jathropa oil. - 85% conversion rate. - 9:1 methanol to oil molar ratio.	- Use poly (ether sulfone) - Apply the principle of Darcy's Law

	- NaOH as catalyst. - 50°C reaction temperature. - Consist of stainless steel column packed with semi structured stainless steel packing.	- Simultaneous reaction and separation
Magnetically fluidized bed reactor [43]	- Use waste cooking oil. - Biocatalyst Pseudomonal Mendocina. - 3.74:1 methanol to oil ratio. - Magnetic field intensity – 136.63 OE - 91.8% conversion rate. -35°C and 48h reaction time. - a jacketed plexiglass column covered by coaxial coils.	- Biocatalyst can be reused with 87.5% conversion rate after 10 cycles.
Metal foam reactor [44]	- Metal foam reactors combined with passive mixer. - Soybean oil. - 10:1 methanol to oil molar ratio. - NaOH as catalyst. - Continuous reaction. - 59.85°C reaction temperature.	- Less energy consumption compared to zigzag microchannel and conventional stir reactor. - Yield 60 times more than zigzag microchannel and conventional stir reactor.
Rotating packed bed reactor [45]	- Use soybean oil. - Candida sp. 99-125 lipase as biocatalyst. - 96% conversion rate. - 40°C and 6h reaction time. - 2:1 methanol to oil molar ratio.	- Rotor in rotating bed reactor creates a centrifugal environment.
Piezo based ultrasound reactor [46]	- Use waste cooking oil. - 91% conversion rate. - 6:1 methanol to oil molar ratio. - 60°C reaction temperature. - 5L reactor stainless steel equipped with piezo based ultrasound modular.	- No catalyst needed. - High exergy efficiency with low environmental effect.

Table 1 illustrates the types of reactors used in the production of biodiesel both in commercial use and pilot studies. Each of the reactors mentioned in Table 1 was designed to achieve a conversion rate of 90% and above. This is to ensure that excellent quality of biodiesel is produced and to reduce the waste product from the unreacted raw material. It is noted that a commercialized reactor can produce biodiesel in large quantities within a short period of time. Temperature and pressure are manipulated to increase the reaction rate. Ultrasound or wave is introduced to replace the use of stirrer, but a bigger the surface area makes it more difficult for the wave to reciprocate and reach the centre of the reactor. Another concept would be the microchannel and jet flow that rely on pressure and achieved a high conversion rate. However the production using microchannel and jet flow reactors are slower because the flow rate of reactant is low and therefore, a bigger reactor is needed to fulfill product demand.

3.2 Separation Unit

The separation unit is the other crucial part in biodiesel production. Separation units will separate the main product, by-product and recycling unreacted/excess methanol back into the system. The separation system can be divided into 3 based on the mechanisms used in each tank that are pressure, temperature and gravity. Separation of methanol using temperature is used to recycle the reactant by heating the mixture of product and methanol. Methanol, which has a lower boiling point, will evaporate and be released back into the methanol storage tank before being pumped back into the system. This method is shown by Atadashi *et al*., [21]. The method ensures that only pure methanol is being recycled and it is cost saving, as the evaporation/distillation method does not require extra effort to obtain the methanol. Separation by gravity is related to the density of the solution, and normally a settling tank is used to separate glycerol and biodiesel as both of them form 2 layers of solution based on density after some time. The sediment is then filtered out from the bottom of the tank leaving the upper layer for next process. This method is the easiest because there is no mechanical or chemical interference, but for the solution to separate into layers, the product must be put into residing for some time. For a faster and efficient process, pressure is applied in a flash tank. The method is similar in a way, but instead of waiting for the fluid to flow out, pressure is applied to rapidly separate the 2 layers [47]. By referring to previous methods, the separation of methanol and glycerol require different equipments [48]. Srilatha *et al*., [49] show that both methanol and glycerol separation processes can be done simultaneously with the use of a single equipment called the evaporator. Although the method is time and space saving, the equipment used in the process is costly. With proper maintenance, a high revenue can be achieved and it can benefit the plant.

3.3 Utilities

Study has proven that by employing heat integration, it can reduce utility cost and save energy. As stated by Ojeda *et al*., [50], using heat exchanger equipment allows calculation of energy that needs to be removed or added into the system. In order to carry out heat integration strategy, it is necessary to obtain the temperature for the streams using ASPEN HY-Net2006.5^{TM} software. Reaction temperature needs to be controlled to avoid thermal shock. Ojeda *et al*., [50] also stated that the minimum energy requirement was calculated using pinch analysis and information from the hot and cold streams were also taken for the heat target and demand. Mansouri *et al*., [51] claim that the optimizer program in PRO/II software can maximize the production rate of biodiesel and minimize energy loss. To obtain the result, several parameters have been set such as

- All heat exchanger is counter current type.
- Minimum temperature approach is 10°C
- Pump and compression efficiency is set to 80%
- Heat and pressure loss during the process is negligible
- Heat exchanger consists of two parts that are heat donor and heat receptor

A recent study on heat exchangers by Santana *et al*., [52] involved a micro heat exchanger that consists of a microchannel in plate exchanger. The heat exchanger uses the indirect transfer of heat from hot to cold in a system that contains two microchannels. Usually water is used as a cooling medium, but a recent study conducted by Vishwas [53] has found out that there are some other substances that can replace water, such as ionic liquid. However, there are limits to how far the idea of using ionic liquids can be taken. Further modifications on heat exchanger type and its configuration, and enhancement of technology are required to replace the use of water as a cooling liquid. The advantages of ionic liquid are low volatility, low toxicity and low flammability, but it is very costly. Vishwas [53] also stated that nano liquid can be used to replace the ionic liquid but it is still being studied.

Simultaneous optimization is a method to achieve high energy and cost savings using a model of reduced order. The model is developed in terms of mass flow, component mass flow, component mass fractions and temperature of streams using the information from mass and energy balance and design equation. The result from the study produced a higher conversion, lower production cost and lower energy consumption when compared to previous literature [54]. Kralj *et al.*, [55] conducted heat integration simulation between two biodiesel processes using a 3-step method. The first step involves using a stage-wise model with Mixed Integer Nonlinear Programming (MINLP), stage two is pinch analysis and stage three is internal integration of individual process. The method can be done using stage one and three or stage three only, depending on the situation. New alternatives can be used to optimize external integration between the individual processes.

4. Biodiesel Production Cost

Up until April 2017, biodiesel price was reported as 2.49 $/gallon (3.8 litres). The price decreased from 2.57 $/gallon in January 2017, but it is still higher compared to diesel and gasoline at 2.55 $/gallon and 2.38 $/gallon respectively. Biodiesel production is often associated with high production cost due to the cost of raw materials, equipments, and utilities. However, a wide selection of raw materials is available at a cheaper cost. Waste cooking oil has been a popular choice for researchers to turn it into a cheaper but high-quality biodiesel. Waste cooking oil is a daily waste material that can be acquired in a substantial amount from residential areas and food businesses. Hussain *et al.,* [56] carried out a survey on the disposal of waste cooking oil in United Arab Emirates (UAE). In their survey, they concluded that waste cooking oil is disposed into the sewer system or mixed into domestic waste that can cause clogging and flash flood. It was also reported that Dubai recycled 50,000 gallons of waste cooking oil every day and by looking at the food industry statistic, it can be assumed that most of them were from food industry. In 2015, the price of treated waste cooking oil used in biodiesel manufacturing was 0.36 $/L compared to vegetable oil that is 1.01 $/L [57]. Therefore the use of pre-treatment waste cooking oil in plants can reduce production time and cost.

Use of catalysts for reducing production cost such as using eggshells as a solid catalyst is found to be feasible [58]. Eggshells are collected from bakeries at zero cost, and by calcining the eggshell, it can produce a highly reactive, reusable and environmentally friendly catalyst. A process model of production plant has been designed by Kasteren and Nisworo [58] with plant capacity of 125,000, 80,000 and 8,000 tonnes/year. The biodiesel produced by the authors achieved 99.8% purity and can be sold at 0.17 $/L, 0.24 $/L and 0.52 $/L, respectively. The study also stated that the important economic feasibility factors affecting biodiesel production plants are raw material price, plant capacity, glycerol price and capital cost. Another process model simulation done by Zhang *et al.,* [59] has designed 4 types of processes that are alkali catalysed (NaOH) using virgin oil (process 1), alkali catalysed (NaOH) using waste cooking oil (WCO) (process 2), acid catalysed (H_2SO_4) using WCO (process 3) and acid catalysed (hexane extraction) using WCO (process 4). The study also set a few boundaries that are

I. Production capacity is 8000/year with 800 h/year of operating hours.
II. WCO and virgin oil are free from water and impurities; the cost for pure oil and transportation are included.
III. Pump efficiency is set to 70% and motor efficiency at 90%.
IV. Heating medium is superheated; low and high-pressure steam and water is used for the cooling medium.
V. All the costs shown are in US dollars and equipment prices are updated from mid-1966 to 2000 using chemical plant index.

From the results, Zhang *et al*., [59] has stated that process 1 has low capital investment, but the cost can be further reduced by choosing another raw material that is less costly. For process 2, the usage of WCO has increased the equipment cost as the pre-treatment step is needed. Acid catalysed biodiesel production also contributes in increasing the equipment cost because of the corrosion properties of acid catalyst. The reactor must be designed using stainless steel to avoid corrosion thus increasing the cost. Raw materials can still be used to maintain a lower raw material cost as the acid catalyst reacts very well with WCO. The process model has been used to study biodiesel production economically and Haas *et al*., [60] provides an estimation of capital and operating cost of a moderately sized biodiesel production plant by using degummed soybean oil in a continuous tank. Production capacity of the plant was set at 10 million gallons, and the cost of building the facility for the production is 11.3 million gallons. The biodiesel plant equipped with a storage tank that can store about 25 days worth of feedstock supply, and it consumes one third of the cost. The study also reported that soybean oil price is about 88% from the estimated total production cost.

A variety of plant capacity, feedstock, catalyst and reactor type have been simulated to obtain the optimum production and capital cost. West *et al*., [61] simulated four types of biodiesel production plants of 8000 ton/year capacity, 7920 hr/year of operating hours in 330 operating days in a year. An estimation method with an accuracy of +30% to – 20% is considered to calculate the total capital investment and total manufacturing cost. The heterogeneous acid catalysed plant showed the lowest total capital investment (0.63 million dollar), while the supercritical method had the highest total capital investment (2.15 million dollar). Although the supercritical method requires the highest amount of capital investment, the manufacturing cost using this method is lower. It only cost 4.59 million dollars compared to pre-treated alkali catalysed and acid catalysed production that cost 5.2 million dollars and 4.76 million dollars respectively. This simulation conducted by West *et al*., [61] seems to be more detailed than other previous research as the calculation includes equipment sizing, operator salary, profit, revenue and tax return.

In another study, a method of reducing the cost indirectly is by glycerol utilization to be sold in the market such as in the chemical compound industry and as an animal feedstock ingredient [51]. Unfortunately, in 2016, glycerol price decreased, such as in June 2017 which is 740 $/ton and was estimated to fall even further to 640 $/ton by the end of the year. The price of non-refined glycerol in the market is approximately 1/3 from the refined glycerol. In addition, glycerol from biodiesel plants has high toxic methanol contamination, salt and free fatty acid content. It also has a colour which is not suitable to be applied in most of the glycerol markets [62]. It is suggested that biodiesel plants perform glycerol treatment to produce refined glycerol, thus increasing its value.

5. Conclusions

This review paper has highlighted the main issues in biodiesel production. This study also focuses on equipment and cost for biodiesel production. The cost of raw materials that consist of approximately 70% of total production cost has made biodiesel market price to be slightly higher than fossil fuel. The availability and readiness of the types of oil feedstock has influenced the fluctuation of the biodiesel selling price. Although there have been many developments of catalysts, the use of catalysts only affects about 10% of the price. Furthermore, the process optimization has been studied previously and can be applied in the industry to foresee the effectiveness in terms of quality and quantity. However, the implementation of the new system in the industry depends on the manufacturers' willingness to stray from the conventional method. Another important factor is the optimization in utilities, which also contributes to significant energy and cost saving. Therefore, to ensure affordable biodiesel price, a low cost method with an abundance of raw materials is the key for biodiesel to be sustainable.

Acknowledgement
The authors would like to thank the Ministry of Education Malaysia and Universiti Tun Hussein Onn Malaysia for supporting this research under the Research Acculturation Grant Scheme (RAGS) Phase 1/2015, Vot No R071.

References

[1] Jaichandar, S., and K. Annamalai. "The status of biodiesel as an alternative fuel for diesel engine–an overview." *Journal of Sustainable Energy & Environment* 2, no. 2 (2011): 71-75.
[2] Tripathi, Shweta, and K. A. Subramanian. "Experimental investigation of utilization of Soya soap stock based acid oil biodiesel in an automotive compression ignition engine." *Applied Energy* 198 (2017): 332-346.
[3] Hoseini, S. S., G. Najafi, B. Ghobadian, A. Rahimi, Talal Yusaf, Rizalman Mamat, N. A. C. Sidik, and W. H. Azmi. "Effects of biodiesel fuel obtained from Salvia macrosiphon oil (ultrasonic-assisted) on performance and emissions of diesel engine." *Energy* 131 (2017): 289-296.
[4] Gharehghani, Ayatallah, Mostafa Mirsalim, and Reza Hosseini. "Effects of waste fish oil biodiesel on diesel engine combustion characteristics and emission." *Renewable Energy*101 (2017): 930-936.
[5] Cordiner, Stefano, Vincenzo Mulone, Matteo Nobile, and Vittorio Rocco. "Effects of waste cooking oil biodiesel use on engine fuel consumption and emissions: a study on the impact on oxidation catalyst and particulate filter." *Energy Procedia* 61 (2014): 953-957.
[6] Giakoumis, Evangelos G., and Christos K. Sarakatsanis. "Estimation of biodiesel cetane number, density, kinematic viscosity and heating values from its fatty acid weight composition." *Fuel* 222 (2018): 574-585.
[7] Mostafaei, Mostafa. "ANFIS models for prediction of biodiesel fuels cetane number using desirability function." *Fuel* 216 (2018): 665-672.
[8] Naylor, Rosamond L., and Matthew M. Higgins. "The political economy of biodiesel in an era of low oil prices." *Renewable and Sustainable Energy Reviews* 77 (2017): 695-705.
[9] Zhou, Adrian, and Elspeth Thomson. "The development of biofuels in Asia." *Applied Energy* 86 (2009): S11-S20.
[10] Y Yusuf, N. N. A. N., Siti Kartom Kamarudin, and Z. Yaakub. "Overview on the current trends in biodiesel production." *Energy conversion and management* 52, no. 7 (2011): 2741-2751.
[11] Murphy, Denis J. "Engineering oil production in rapeseed and other oil crops." *Trends in Biotechnology* 14, no. 6 (1996): 206-213.
[12] Pinto, Angelo C., Lilian LN Guarieiro, Michelle JC Rezende, Núbia M. Ribeiro, Ednildo A. Torres, Wilson A. Lopes, Pedro A. de P. Pereira, and Jailson B. de Andrade. "Biodiesel: an overview." *Journal of the Brazilian Chemical Society* 16, no. 6B (2005): 1313-1330.
[13] Ashnani, Mohammad Hossein Mohammadi, Anwar Johari, Haslenda Hashim, and Elham Hasani. "A source of renewable energy in Malaysia, why biodiesel?." *Renewable and Sustainable Energy Reviews* 35 (2014): 244-257.
[14] Da Silva, N. L., L. F. Rios, and MR Wolf Macieland R. Maciel Filho. "Biodiesel production: process and characterization." (2013).
[15] Amini, Zeynab, Hwai Chyuan Ong, Mark D. Harrison, Fitranto Kusumo, Hoora Mazaheri, and Zul Ilham. "Biodiesel production by lipase-catalyzed transesterification of Ocimum basilicum L.(sweet basil) seed oil." *Energy Conversion and Management* 132 (2017): 82-90.
[16] Abomohra, Abd El-Fatah, Wenbiao Jin, Renjie Tu, Song-Fang Han, Mohammed Eid, and Hamed Eladel. "Microalgal biomass production as a sustainable feedstock for biodiesel: current status and perspectives." *Renewable and Sustainable Energy Reviews* 64 (2016): 596-606.
[17] Rizwan, Muhammad, Jay H. Lee, and Rafiqul Gani. "Optimal processing pathway for the production of biodiesel from microalgal biomass: A superstructure based approach." *Computers & Chemical Engineering* 58 (2013): 305-314.
[18] Shirazi, Hamed Mohamadzadeh, Javad Karimi-Sabet, and Cyrus Ghotbi. "Biodiesel production from Spirulina microalgae feedstock using direct transesterification near supercritical methanol condition." *Bioresource technology* 239 (2017): 378-386.
[19] L Liu, Yang, Qingshi Tu, Gerhard Knothe, and Mingming Lu. "Direct transesterification of spent coffee grounds for biodiesel production." *Fuel* 199 (2017): 157-161.
[20] Nguyen, Hoang Chinh, Shih-Hsiang Liang, Thien Thanh Doan, Chia-Hung Su, and Pei-Cheng Yang. "Lipase-catalyzed synthesis of biodiesel from black soldier fly (Hermetica illucens): Optimization by using response surface

methodology." *Energy Conversion and Management* 145 (2017): 335-342.
[21] Atadashi, I. M., M. K. Aroua, AR Abdul Aziz, and N. M. N. Sulaiman. "The effects of catalysts in biodiesel production: A review." *Journal of industrial and engineering chemistry* 19, no. 1 (2013): 14-26.
[22] Sagiroglu, Ayten, Selen Şebnem Isbilir, Mevlut Hakki Ozcan, Hatice Paluzar, and Neslihan M. Toprakkiran. "Comparison of biodiesel productivities of different vegetable oils by acidic catalysis." *Chemical Industry and Chemical Engineering Quarterly/CICEQ* 17, no. 1 (2011): 53-58.
[23] Talha, Nur Syakirah, and Sarina Sulaiman. "Overview of catalysts in biodiesel production." *ARPN Journal of Engineering and Applied Sciences* 11, no. 1 (2016): 439-448.
[24] Lotero, Edgar, Yijun Liu, Dora E. Lopez, Kaewta Suwannakarn, David A. Bruce, and James G. Goodwin. "Synthesis of biodiesel via acid catalysis." *Industrial & engineering chemistry research* 44, no. 14 (2005): 5353-5363.
[25] Muthu, H., V. SathyaSelvabala, T. K. Varathachary, D. Kirupha Selvaraj, J. Nandagopal, and S. Subramanian. "Synthesis of biodiesel from Neem oil using sulfated zirconia via tranesterification." *Brazilian Journal of Chemical Engineering* 27, no. 4 (2010): 601-608.
[26] Lam, Man Kee, Keat Teong Lee, and Abdul Rahman Mohamed. "Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: a review." *Biotechnology advances* 28, no. 4 (2010): 500-518.
[27] Sharma, Y. C., and B. Singh. 2008. "Development of Biodiesel from Karanja, a Tree Found in Rural India." *Fuel* 87 (8–9): 1740–42.
[28] Marinković, Dalibor M., Miroslav V. Stanković, Ana V. Veličković, Jelena M. Avramović, Marija R. Miladinović, Olivera O. Stamenković, Vlada B. Veljković, and Dušan M. Jovanović. "Calcium oxide as a promising heterogeneous catalyst for biodiesel production: current state and perspectives." *Renewable and Sustainable Energy Reviews*56 (2016): 1387-1408.
[29] Liu, Xuejun, Huayang He, Yujun Wang, Shenlin Zhu, and Xianglan Piao. "Transesterification of soybean oil to biodiesel using CaO as a solid base catalyst." *Fuel* 87, no. 2 (2008): 216-221.
[30] Ma, Yingqun, Qunhui Wang, Zhen Gao, Xiaohong Sun, Nan Wang, Ruxuan Niu, and Hongzhi Ma. "Transesterification of waste cooking oil using FeCl3-modified resin catalyst and the research of catalytic mechanism." *Renewable energy* 86 (2016): 643-650.
[31] Nongbe, Medy C., Tchirioua Ekou, Lynda Ekou, Kouassi Benjamin Yao, Erwan Le Grognec, and François-Xavier Felpin. "Biodiesel production from palm oil using sulfonated graphene catalyst." *Renewable Energy* 106 (2017): 135-141.
[32] Fatimah, Is, and Septian P. Yudha. "KF-Modified Natural Halloysite as Green Catalyst in Microwave Assisted Biodiesel Conversion." *Energy Procedia* 105 (2017): 1796-1805.
[33] Noshadi, I., N. A. S. Amin, and Richard S. Parnas. "Continuous production of biodiesel from waste cooking oil in a reactive distillation column catalyzed by solid heteropolyacid: optimization using response surface methodology (RSM)." *Fuel* 94 (2012): 156-164.
[34] Benavides, Pahola T., and Urmila Diwekar. "Optimal control of biodiesel production in a batch reactor: Part II: Stochastic control." *Fuel* 94 (2012): 218-226.
[35] Wen, Zhenzhong, Xinhai Yu, Shan-Tung Tu, Jinyue Yan, and Erik Dahlquist. "Intensification of biodiesel synthesis using zigzag micro-channel reactors." *Bioresource technology* 100, no. 12 (2009): 3054-3060.
[36] Maçaira, José, Aline Santana, Francesc Recasens, and M. Angeles Larrayoz. "Biodiesel production using supercritical methanol/carbon dioxide mixtures in a continuous reactor." *Fuel* 90, no. 6 (2011): 2280-2288.
[37] Avellaneda, Fredy, and Joan Salvadó. "Continuous transesterification of biodiesel in a helicoidal reactor using recycled oil." *Fuel processing technology* 92, no. 1 (2011): 83-91.
[38] Yadav, Ashok Kumar, Mohd Emran Khan, and Amit Pal. "Kaner biodiesel production through hybrid reactor and its performance testing on a CI engine at different compression ratios." *Egyptian journal of petroleum* 26, no. 2 (2017): 525-532.
[39] Ghayal, Dyneshwar, Aniruddha B. Pandit, and Virendra K. Rathod. "Optimization of biodiesel production in a hydrodynamic cavitation reactor using used frying oil." *Ultrasonics sonochemistry* 20, no. 1 (2013): 322-328.
[40] Chattopadhyay, Soham, and Ramkrishna Sen. "Development of a novel integrated continuous reactor system for biocatalytic production of biodiesel." *Bioresource technology* 147 (2013): 395-400.
[41] Reyes, J. F., P. E. Malverde, P. S. Melin, and J. P. De Bruijn. "Biodiesel production in a jet flow stirred reactor." *Fuel* 89, no. 10 (2010): 3093-3098.
[42] Reyes, J. F., P. E. Malverde, P. S. Melin, and J. P. De Bruijn. "Biodiesel production in a jet flow stirred reactor." *Fuel* 89, no. 10 (2010): 3093-3098.
[43] Chen, Guanyi, Jing Liu, Jingang Yao, Yun Qi, and Beibei Yan. "Biodiesel production from waste cooking oil in a magnetically fluidized bed reactor using whole-cell biocatalysts." *Energy Conversion and Management* 138 (2017): 556-564.
[44] Y Yu, Xinhai, Zhenzhong Wen, Ying Lin, Shan-Tung Tu, Zhengdong Wang, and Jinyue Yan. "Intensification of biodiesel

synthesis using metal foam reactors." *Fuel* 89, no. 11 (2010): 3450-3456.
[45] Xu, Juntao, Changsheng Liu, Meng Wang, Lei Shao, Li Deng, Kaili Nie, and Fang Wang. "Rotating packed bed reactor for enzymatic synthesis of biodiesel." *Bioresource technology* 224 (2017): 292-297.
[46] Aghbashlo, Mortaza, Meisam Tabatabaei, Soleiman Hosseinpour, Zahra Khounani, and Seyed Sina Hosseini. "Exergy-based sustainability analysis of a low power, high frequency piezo-based ultrasound reactor for rapid biodiesel production." *Energy conversion and management* 148 (2017): 759-769.
[47] Nasir, N. F., Wan Ramli Wan Daud, S. K. Kamarudin, and Zahira Yaakob. "Process system engineering in biodiesel production: A review." *Renewable and Sustainable Energy Reviews* 22 (2013): 631-639.
[48] ISAHAK, WANNORRW, Jamaliah Md Jahim, Manal Ismail, Nurul Fitriah Nasir, Muneer M. Ba-Abbad, and Mohd Ambar Yarmo. "Purification of crude glycerol from industrial waste: Experimental and simulation studies." *Journal of Engineering Science and Technology* 11, no. 8 (2016): 1056-1072.
[49] Srilatha, K. B. L. A., BLA Prabhavathi Devi, N. Lingaiah, R. B. N. Prasad, and PS Sai Prasad. "Biodiesel production from used cooking oil by two-step heterogeneous catalyzed process." *Bioresource technology* 119 (2012): 306-311.
[50] Sánchez, E., K. Ojeda, M. El-Halwagi, and V. Kafarov. "Biodiesel from microalgae oil production in two sequential esterification/transesterification reactors: Pinch analysis of heat integration." *Chemical engineering journal* 176 (2011): 211-216.
[51] Mansouri, Seyed Soheil, Muhammad Imran Ismail, Deenesh K. Babi, Lida Simasatitkul, Jakob K. Huusom, and Rafiqul Gani. "Systematic sustainable process design and analysis of biodiesel processes." *Processes* 1, no. 2 (2013): 167-202.
[52] Santana, Harrson S., Geovanni B. Sanchez, and Osvaldir P. Taranto. "Evaporation of excess alcohol in biodiesel in a microchannel heat exchanger with Peltier module." *Chemical Engineering Research and Design* 124 (2017): 20-28.
[53] Wadekar, Vishwas V. "Ionic liquids as heat transfer fluids–an assessment using industrial exchanger geometries." *Applied Thermal Engineering* 111 (2017): 1581-1587.
[54] Chen, Yang, John C. Eslick, Ignacio E. Grossmann, and David C. Miller. "Simultaneous process optimization and heat integration based on rigorous process simulations." *Computers & Chemical Engineering* 81 (2015): 180-199.
[55] Kralj, Anita Kovač, Peter Glavič, and Zdravko Kravanja. "Heat integration between processes: Integrated structure and MINLP model." *Computers & chemical engineering* 29, no. 8 (2005): 1699-1711.
[56] Hussain, Mohammed Noorul, Tala Al Samad, and Isam Janajreh. "Economic feasibility of biodiesel production from waste cooking oil in the UAE." *Sustainable Cities and Society*26 (2016): 217-226.
[57] Karmee, Sanjib Kumar, Raffel Dharma Patria, and Carol Sze Ki Lin. "Techno-economic evaluation of biodiesel production from waste cooking oil—a case study of Hong Kong." *International journal of molecular sciences* 16, no. 3 (2015): 4362-4371.
[58] Van Kasteren, J. M. N., and A. P. Nisworo. "A process model to estimate the cost of industrial scale biodiesel production from waste cooking oil by supercritical transesterification." *Resources, Conservation and Recycling* 50, no. 4 (2007): 442-458.
[59] Zhang, Yen, M. A. Dube, D. D. L. McLean, and M. Kates. "Biodiesel production from waste cooking oil: 1. Process design and technological assessment." *Bioresource technology* 89, no. 1 (2003): 1-16.
[60] Haas, Michael J., Andrew J. McAloon, Winnie C. Yee, and Thomas A. Foglia. "A process model to estimate biodiesel production costs." *Bioresource technology* 97, no. 4 (2006): 671-678.
[61] West, Alex H., Dusko Posarac, and Naoko Ellis. "Assessment of four biodiesel production processes using HYSYS. Plant." *Bioresource technology* 99, no. 14 (2008): 6587-6601.
[62] Valerio, Oscar, Tessa Horvath, Christopher Pond, Manjusri Misra, and Amar Mohanty. "Improved utilization of crude glycerol from biodiesel industries: Synthesis and characterization of sustainable biobased polyesters." *Industrial Crops and Products* 78 (2015): 141-147.
[63] Kotrba, Ron. 2016. "Biodiesel Magazine - The Latest News And Data About Biodiesel Production". (Biodieselmagazine.com)
[64] "MajorBiodieselProducingCountries2017|Statistic". (Statista,2017)