
Recent Trends in
Biotechnology
MEDDOCS
International

Biodiesel from Sewage Sludge: An Alternative to Diesel

Sonica Sondhi[1]*; Pawan Kumar[2]*

[1]Department of Biotechnology, Chandigarh College of Technology, CGC Landran, Mohali-140307, Punjab, India

[2]Department of Mechanical Enineering, Chandigarh Enineering College, CGC Landran, Mohali-140307, Punjab, India

Corresponding Author: Sonica Sondhi & Pawan Kumar

Department of Biotechnology, Chandigarh College of Technology, CGC Landran, Mohali-140307, Punjab, India.

Email: sonicasondhi@gmail.com

Published Online: Jul 07, 2020

eBook: Recent Trends in Biotechnology

Publisher: MedDocs Publishers LLC

Online edition: http://meddocsonline.org/

Keywords: Sewage sludge; Biodiesel; Transesterification

Abstract

Increasing urbanization and development in developing and developed countries lead to shortage of fossil fuel. This fuel crisis results in demanding alternatives which can combat the advantages of fuel. Biodiesel, a substitute for diesel, is in hue demand as it possesses the chemical properties similar to commercial diesel. Biodiesel can be made from anything which contains oil. However, the cost of the raw material is a major obstacle in the path of biodiesel commercialization. Sewage sludge is a waste by-product of sewage treatment plant and can be used as a cheap raw material for biodiesel production. Sewage sludge is generated daily on large basis and contains more than 65% oil. This oil cannot be utilized for any other purpose. Utilization of sewage biosludge for biodiesel formation can be a cheap alternative to vegetable oil. This chapter deals describes the potential of sewage sludge to be converted into biodiesel. It also deals with various steps underlying the process and describes the properties of sewage biodiesel to be used at commercial scale.

Introduction

Energy has become to be a critical component for humanity. Currently, modern society consumes huge amounts of energy to hold a high trendy of residing and to make certain economic boom and development. As the world populace and industrialization maintains to grow, humanity will constantly devour more energy year after year. The enlargement of the global economy, the development of novel technologies, new enterprises and an increase in the world's population will definitely increase the demand for world energy. According to a report, world energy demand rises by 1.3% every year to 2040 [1]. Developing countries including China and India will demand more energy resources due to their strong economic growth [2].

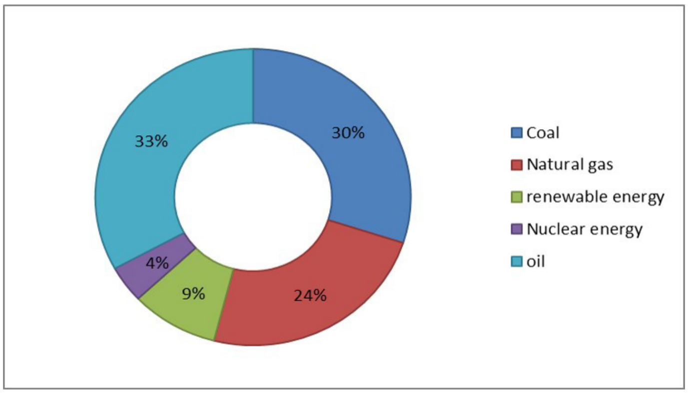

Figure 1: World primary energy consumption.

Currently 87% of all energy consumed worldwide is from gasoline sources (**Figure 1**). The fossil fuel resources are non-renewable, and may be depleted in near future. It is anticipated that coal reserves could be available up to 2112 while oil and gas will be depleted by 2040 and 2042, respectively [3]. In addition, the environmental problems associated with excessive usage of fossil fuels including air pollution, Greenhouse Gas Emissions (GHG), and global warming, consequently limits the utilization of these assets in the future.

Renewable fuels for the transportation sector

Transport sector is consuming more than 95% energy in the form of petroleum [4]. Moreover, 27% of the total world CO_2 emissions come from the transport sector [5]. In order to reduce down the immoderate petroleum use and CO_2 emission in transportation sector, the utilization of alternative fuels from renewable resources is a promising solution [6]. Biofuels are the fuels obtained from biomass which have the potential to reduce CO_2 and other Green House Gases (GHG) emitted by vehicles [6]. Furthermore, liquid biofuels are considered as the most promising alternatives to petroleum oil as they can directly be used in conventional engine without any major modifications [7].

Although the volume of biofuel consumed in the transport sector has been increasing constantly since 2011, nevertheless, the contribution of biofuels to transport sector is still a little low when compared to petroleum products. At present, the share of biofuels towards road transport is very small [8]. The EU's 2009 directive on renewable energy established a mandatory target of 10% of the final energy consumption in transport sector for all the countries [9]. Across the continents, incorporation rates vary. Latin America continuing to lead the sphere with more than 9.6% share due to its ethanol market. North America and Europe follow, with respective rates of 6.4% and 4.7% (energy). Asia accounts for only 1.2% but the extensive investments and government policies supporting biofuels are the most prevalent here. In other countries the biofuel market has been developing rapidly with the growth in the demand for road fuels. In 2017, only Finland (18.8%) and Sweden (38.6%) had already met the 2020 objective of the European Union's RED directive setting a renewable target of 10% in the transport sector. Austria was close to the threshold with 9.7%. In 2017, France was still ranked 4th (9.1% incorporation. The European average (EU28) rose from 7.2% in 2016 to 7.6% in 2017. It should be noted that Norway has proactive policies, with renewable energy rates in the transport sector already above 15%.

From different types of biofuels, bioethanol, a substitute for gasoline and biodiesel, a substitute for diesel constitutes the most studied fuels. The present chapter is focused on biodiesel, environmentally friendly and renewable fuel, produced predominantly from vegetable oils or to a lower extent from animal fats.

Biodiesel origin and characteristics

The first engine ran by Rudolf Diesel using peanut oil had led the future possibility open of using vegetable oils as an engine fuel. Nevertheless, the wide availability and low cost of petroleum fuel at that time had suppressed the use of vegetable oils as a fuel. Furthermore, the high viscosity of vegetable oils becomes a major drawback of its use as fuel. In 1937, George Chavanne patented the procedure for transformation of vegetable oils to reduce their viscosity using transesterification reaction with methanol and ethanol. However, biodiesel gets its full attention when the depletion of fossil fuel was recognized [7].

At present, biodiesel is produced through the transesterification reaction of vegetable oils or animal fats with alcohol (usually methanol) in the presence of a catalyst (usually base), which yields Fatty Acid Methyl Esters (FAMEs). This renewable fuel represents an excellent alternative to conventional diesel, as it has chemical properties similar to conventional diesel, and it is compatible with current commercial diesel engine and refuelling technology. Biodiesel may be effectively used as both, blend with conventional diesel fuel and in a pure form. Additionally, biodiesel possesses significant environmental benefits as it is highly biodegradable (four times faster than conventional diesel), nontoxic, safe for storage and handling, it burns much cleaner then petroleum diesel and therefore reduces most exhaust emission (CO_2, CO, hydrocarbons, particulate, except NO_x) and essentially eliminates emissions of SO_x and sulfates as it does not contain sulphur [6].

Biodiesel production

The past few years have witnessed the production of biodiesel significantly. Global production of biodiesel reached around 41.3 billion litres in 2018 [10]. Biodiesel production is more geographically diverse than ethanol production (due to policy priorities) and is spread among many countries. The top five countries in 2018 accounted for 53% of global production were Europe (the largest biodiesel producer) followed by the United States (17%), Brazil (13%), Indonesia (10%), Germany (8%) and Argentina (5%). The United States and Brazil accounts for 6.9 and 5.4 billion liters biodiesel production respectively, in 2018 [11]. The United States is expected to reach production levels of over 1 billion gallons of biodiesel by 2025.

Biodiesel feedstock

Biodiesel is predominantly obtained from vegetable oils such as rapeseed (84%), sunflower oil (13%), palm oil (1%), soybean oil and others (2%) [12]. However, the high cost of common oils *viz*. Soybean, canola, rapeseed, sunflower, palm, and coconut oils, which accounts for 70-85% of overall biodiesel production cost, led to the decreased production of biofuel from oils [13]. In addition, lack of agricultural lands for growing biodiesel feed stocks limits biodiesel expansion and has contributed to the increase of food prices over the past few years, raising the concerns of food shortage versus fuel crisis [13]. As more vegetable oils are converted to fuels less are available for food, which could have a direct impact on the food price increases over the past few years.

Thus, there is an urgent need to find an alternative, cheaper feedstock, non-edible, readily available and in large quantities. The most attention has been paid to non-edible plant oils (e.g. Jatropha, castor, neem, karanja), microalgae, waste cooking oil and municipal sewage sludge. Non-edible plant oils are grown in marginal and waste lands with no possibility of land use competing with food production. However, their excessive cultivation would cause deforestation and destruction of the ecosystem [12]. The production of microalgae, an alternative to edible and non-edible oils, is still economically challenging due to high cost associated with biomass production [14]. Waste cooking oil is also a promising option because the production step is eliminated; however the major issue is associated with the collection infrastructure and logistics in order to generate sufficient quantities, as the sources are generally scattered [15]. As municipal sewage sludge is an inevitable waste, generated in large quantities during treatment of wastewater, the cost of biomass production is eliminated. Therefore, the sewage sludge can be envisaged as a non-cost, readily available and non-edible feedstock, which can make biodiesel production profitable.

Municipal sewage sludge

Sewage sludge refers to residual material left behind from the treatment of municipal wastewater. The municipal waste water includes household waste liquid from toilets, baths, showers, kitchens, sinks and so forth that is disposed of via sewers. Sewage sludge is a complex heterogeneous mixture of microorganisms, undigested organics such as paper, plant residues, oils and faecal material, inorganic materials and moisture [16].

Sewage sludge generation and management

A typical municipal Sewage Treatment Plant (STP) is shown in **Figure 2**. WWTP consists of two main types of sludge, primary and secondary, with significant differences between their compositions. The primary sludge is collected after screening and grit removal at the bottom of the primary settler comprised of floating grease, solids and simple organic components (cellulose, lipids, and proteins) [17]. The secondary or activated sludge is a complex biomass, composed mainly of microbial cells and suspended solids produced during the aerobic biological treatment of primary treated wastewater and collected in the secondary settler [17].

The remainder of secondary sludge, after thickening is mixed with thickened primary sludge and a blend of them is the by-product after wastewater treatment, which usually consists of 60% primary and 40% secondary sludge [17]. In most of the municipal WWTPs, the blended sludge feeds anaerobic digester to reduce the level of pathogens, odours and solids, after which process stabilized sludge is obtained [18]. At present, approximately 120 million tonnes of dry sewage sludge are produced annually among the USA (7.1 Mt), China (30 Mt), Japan (70 Mt) and the EU (10.2) [19]. Moreover, the sludge production is expected to increase in near future due to urbanisation and industrialisation.

The sludge generated during wastewater treatment from sewage is an unavoidable waste which further needs specific treatment before disposal leading to major cost in STP operation (50%-60%) [20]. Furthermore, the disposal of sewage sludge creates many environmental challenges. The conventional way of sludge disposal via incineration, land application as fertilizer, landfill or ocean disposal has the potential of releasing toxic substances and heavy metals into the environment [21]. Government has posed strict regulation on sludge disposal criteria. Therefore, the valorisation of raw untreated sludge for renewable energy recovery, to achieve more sustainable sludge management strategy, is being increasingly studied [22].

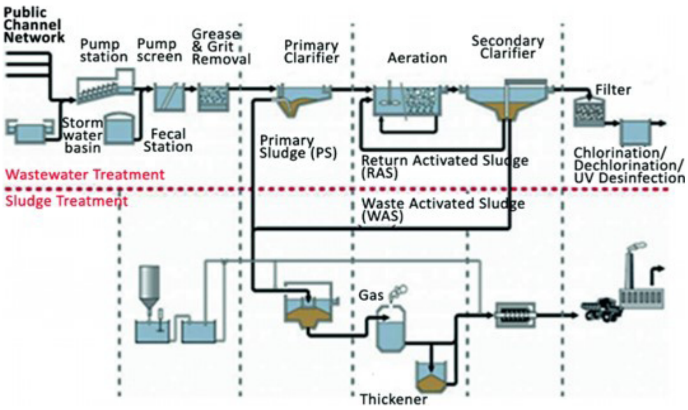

Figure 2: Sewage Treatment Plant (STP) scheme [17].

Sewage sludge as a promising lipid feedstock

Sewage sludge is a promising source of lipid which has potential to be converted into biodiesel by transesterification reactions [23]. Municipal sewage sludge contains 30% lipids suitable for biodiesel production [23]. The non-edible nature of sewage lipid, costless feedstock, availability in large quantity makes sewage sludge a potential candidate for the production of biodiesel [18]. Moreover, as the waste is being utilized, environment contamination is reduced.

Lipid extraction from sewage sludge

The commercialization of biodiesel production from sewage sludge starts from the extraction of lipid from sludge. Therefore, the optimisation of lipid extraction is a major challenge that may affect the economy of the process [24]. Routinely, organic solvents like methanol, ethanol, methane, hexane, chloroform etc. are widely being used to extract lipids from sewage sludge on the basis of their polarity, immiscibility with water, boiling point, cost and environmental issue [25]. Chloroform and toluene although giving higher results but are not environmentally friendly therefore are not used routinely [26]. Non-polar solvents extract non-polar/saponifiable lipids (glycerides and free fatty acids) which can be converted to biodiesel and are more suitable for biodiesel production than polar solvents [25]. Furthermore, the final cost of biodiesel production using polar solvents (methanol, ethanol) is much more than using non-polar solvents (hexane) [25]. Hexane is also environmentally friendly than toluene [25].

Biodiesel synthesis

Transesterification

The conversion of vegetable oil and alcohol to fatty acid alkyl esters and glycerol is called transesterification reactions. These reactions are the basis of biodiesel production. The reaction is catalyzed by a strong base like sodium and potassium hydroxide or sodium methylate [27]. Acid catalysts cannot convert triglycerides to biodiesel effectively; however, they can convert free fatty acids to biodiesel. Thus, pre-treatment with an acid to esters can be followed by alkali treatment to convert triglycerides into biodiesel [27]. Transesterification reactions reduce the viscosity of oil.

Sewage sludge is converted into biodiesel by utilizing two processes:

1. Extraction of biolipids
2. Conversion of extracted lipids into biodiesel

In the first step, primary sludge samples are produced through mechanical wastewater treatment process. The composition of primary sludge depends upon the area from which the sludge is taken. It consists of high proportion of organic matters. Primary sludge is the major source of oil and recovery of biodiesel from primary sludge is maximum. Sludge samples are first dried and oil is then extracted with solvents like hexane. After that the lipids are transesterified into biodiesel (**Figure 3**).

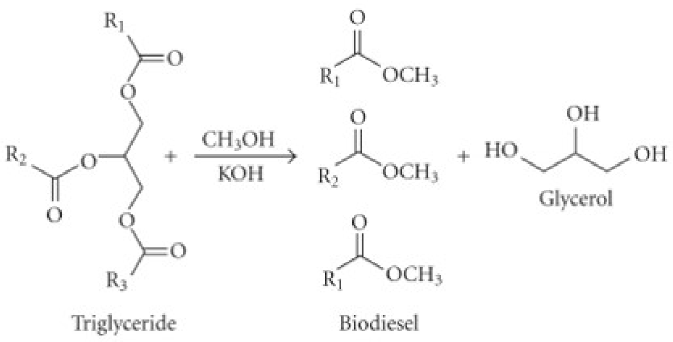

Figure 3: Base catalyzed transesterification with methanol to produce biodiesel [28].

Biodiesel is separated from glycerol phase which is heavy and settles down quickly (**Figure 4**). The optimum production of biodiesel involves huge challenges. The extraction of maximum oil is one such challenge. There are many factors which affects the production of biodiesel. These are discussed as follows:

Figure 4: Separation of biodiesel from glycerol.

Temperature

Yield of biodiesel is affected by temperature. Increase in temperature increases the rate of reaction and decreases the reaction time due to the reduction in viscosity of oils. Nevertheless, increasing the reaction temperature above optimal values can lead to decreased biodiesel yield as at higher temperature, saponification of triglycerides occurs [29]. Moreover, higher temperature also resulted in vaporization of methanol thereby decreasing the yield of biodiesel [30]. Therefore, the transesterification reaction occurs at below the boiling point of methanol. A temperature range of 50-60°C is found to be optimal [31]. Room temperature is also found to be appropriate in some studies [32].

Reaction time

Reaction time also has great influence on fatty acid esters conversion. Maximum conversion can be achieved in 60-90min of reaction. This is because at initial stages reaction proceeds very slowly due to mixing and dispersion of alcohol and oil [33]. After that the reaction proceeds very fast. Further increase in reaction time can lead to reduction of biodiesel production as reversible transesterification can results into loss of esters as well as soap formation [33].

Methanol to oil molar ratio

The molar ratio of alcohol to triglyceride is the most influencing parameter affecting biodiesel yield. The reaction rate is found to be highest when 100% methanol is used [34]. Increase in concentration of methanol, thus, increases the yield of biodiesel. Most of the researchers recommend a 6:1 M ratio for methanol and a 9:1 M ratio for ethanol [34].

Catalyst

Transesterification of oil is severely affected by the nature and type of catalysts. At present, chemical and biological catalysts are being used as catalyst. Most common chemical catalyst used is NaOH, CH_3ONa or KOH. NaOH is preferred over KOH because it dissolves quickly in methanol. Moreover, NaOH is available in highly pure form and at low cost. In addition, a relatively low quantity is needed as compared to KOH [27]. Alkali metal oxides are also found to be more effective hydroxide [27]. The reaction between NaOH and methabol leads to the formation of certain amount of water which with Free Fatty Acids (FFAs) results in the formation of soap by hydrolysis of the triglycerides. Saponification may hinders the product recovery and hence yield of biodiesel [27]. Thus, to prevent the formation of soap, two step transesterification reactions are carried out- acid first and alkali next. Acid esterification reduces the FFAs and further alkali catalysis yields better product. Sulphuric, phosphoric, hydrochloric and sulphonic acids are used in such esterification as well as transesterification reactions [27].

Heterogenous catalysts, on the other hand, can improve the transesterification process by lowering down the extra processing costs and pollutants in homogeneous catalysis [35]. Modified zeolites, anionic clays (hydrotalcite), calcium carbonate rock, EST-4 (Eni Slurry Technology), Li/CaO, MgO/KOH and Na/NaOH/λ-Al2O3 are efficient heterogeneous catalysts for transesterification reaction [36]. Nanocatalysts having immobilized lipase on magnetic nanoparticles has also proved to be a versatile biocatalyst for biodiesel production. The biodiesel conversion rate by lipase nanocatalyst is much higher than chemical catalyst [37].

Properties of sewage biodiesel

Biodiesel produced from sewage sludge has no sulphur content [38]. The lubrication property of sewage biodiesel is very high. It has higher flash point than commercial diesel [39]. Calorific value measured the heating value of diesel. The calorific value of biodiesel is around $37.27mJL^{-1}$. Biodiesel can be used as a substitute of petroleum diesel in its pure or blended form. It is suitable for the existing diesel engine. The flash point of biodiesel (the point at which fuel ignite) is greater than 93.3 °C thus making it easier to handle, use and store. In addition, its energy content, i.e., the heating value is like petroleum diesel [40]. Thus, biodiesel has physical and chemical properties similar to petro-diesel and hence can be used in place of petroleum diesel.

Conclusion

Sewage sludge is a prominent source of biodiesel production. Huge amount of sewage is generated daily. Disposal of sewage sludge is always a big problem. On the other hand, primary sewage sludge is an efficient source of oil which can be converted into biodiesel. Biodiesel thus produced is comparable to diesel in market and have properties similar to it. The use of sewage biodiesel can effectively reduce the problem of short fall of fuel.

References

1. www.iea.org/reports/world-energy-outlook-2019.
2. www.weforum.org/agenda/2020/01/can-emerging-economies-leapfrog-the-energy-transition/
3. Shafiee, Shahriar and Topal E. When will fossil fuel reserves be diminished? Energy policy. 2009; 37: 181-189.
4. www.eia.gov/energyexplained/use-of-energy/transportation.php.
5. National emissions reported to the UNFCCC and to the EU greenhouse gas monitoring mechanism provided by European Environment Agency (EEA). 2019.
6. Atabani AE, Abdulaziz. Alternative fuels research progress. Chapter: Biodiesel: A promising alternative energy resource, Publisher: International Energy and environmental foundation, Editors: Maher AR, Sadiq Al-Baghdadi. 2013: 187-278
7. Carlsson, Anders. Plant oils as feedstock alternatives to petroleum-a short survey of potential oil crop platforms. Biochimie. 2009; 91: 665-670.
8. Erik O, Ahlgren, Martin B, Hagberg, Maria G. Transport biofuels in global energy-economy modeling-a review of comprehensive energy systems assessment approaches. GCB Bioenergy. 2017; 9: 1168-1180.
9. DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union, pp. 1-17.
10. Global biodiesel production by country 2018, Published by T. Wang. 2019.
11. Purohit P, Dhar S. Biofuels in India: Current perspectives, potential issues and future prospects. AIMS Energy. 2018; 6: 453-486.
12. Zahan KA and Kano M. Biodiesel production from palm oil, its by-products, and mill effluent: A Review. Energies. 2018; 11: 2132.
13. Gnanaprakasam A, Sivakumar VM, Surendhar A, Thirumarimurugan M, Kannadasan T. Recent strategy of biodiesel production from waste cooking oil and process influencing parameters: A Review. Journal of Energy. 2013: 926392.
14. Sawaengsak W, Silalertruksa T, Bangviwat A, Gheewala SH. Life cycle cost of biodiesel production from microalgae in Thailand. Energy for sustainable development. 2014; 18: 67-74.
15. Mohammadshirazi A, Akram A, Rafiee S, Kalhor E. Energy and cost analyses of biodiesel production from waste cooking oil. Renewable and Sustainable Energy Reviews. 2014; 33: 44-49.
16. Xuemin W, Fenfen Z, Juanjuan Q, Luyao Z. Biodiesel production from sewage sludge by using alkali catalyst catalyze. Procedia Environmental Sciences. 2016; 31: 26-30.
17. Serdarevic A, Dzubur A. Importance and practice of operation and maintenance of wastewater treatment plants. In: Avdaković S. (eds) Advanced technologies, systems, and applications III. IAT 2018. Lecture notes in networks and systems. 2019; 60.
18. Demirbas A. Biodiesel from Municipal Sewage Sludge (MSS): Challenges and cost analysis. Energy Sources, Part B: Economics, Planning, and Policy. 2017; 12: 351-357.
19. Ernie K, Eamon T. Wastewater treatment sludge and septage management in Vermont. 2018: 1-125.
20. Capodaglio AG, Callegari A. Feedstock and process influence on biodiesel produced from waste sewage sludge. Journal of Environment Management. 2018; 15: 176-182.
21. Lu Q, He ZL, Stoffella PJ. Land application of biosolids in the USA: A review. Applied and Environmental Soil Science. 2012: 201462.
22. Smoliński A, Karwot J, Bondaruk J, Bąk A. The Bioconversion of Sewage Sludge to Bio-Fuel: The Environmental and Economic Benefits. Materials. 2019; 12: 1-9.
23. Revellame E, Hernandez R, French W, Holmes W, Alley E. Biodiesel from activated sludge through in situ transesterification. Journal of Chemical Technology and Biotechnology. 2010; 85: 614-620.
24. Mubarak M, Shaija A, Suchithra TV. Optimization of lipid extraction from Salvinia molesta for biodiesel production using RSM and its FAME analysis. Environmental Science and Pollution Research. 2016; 23: 14047-14055.
25. Clarke CJ, Tu WC, Levers O, Bröhl A, Hallett JP. Green and sustainable solvents in chemical processes. Chemical Reviews. 2018; 118: 747-800.
26. Gomaa MA, Gombocz N, Schild D, Mjalli FS, Al-Harrasi A, et al. Effect of organic solvents and acidic catalysts on biodiesel yields from primary sewage sludge, and characterization of fuel properties. Biofuels. 2018.
27. Thangaraj B, Solomon PR, Muniyandi B, Ranganathan S, Lin L. Catalysis in biodiesel production-a review. Clean Energy. 2019; 3: 2-23.
28. Kolesarova N, Hutnan M, Bodík I, Špalková V. Utilization of biodiesel by-products for biogas production. Journal of Biomedicine & Biotechnology. 2011; 2011.
29. Istiningrum RB, Aprianto T, Udin Pamungkas FL. Effect of reaction temperature on biodiesel production from waste cooking oil using lipase as biocatalyst. AIP Conference Proceedings. 2017; 1911: 020031.
30. Akhihiero ET, Audu TOK, Aluyor EO. Effect of variation of temperature on the transesterification of jatropha seed oil using homogeneous catalyst. Advanced Materials Research. 2013; 824: 473-476.
31. Abdulrahman RK. Effect of reaction temperature on the biodiesel yield from waste cooking oil and chicken fat. International Journal of Engineering Trends and Technology. 2017; 44: 186-188.
32. Babu NS, Sree R, Prasad PS, Lingaiah N. Room-temperature transesterification of edible and nonedible oils using a heterogeneous strong basic Mg/La catalyst. Energy & Fuels. 2008; 22: 1965-1971.

33. Daniyan IA, Adeodu AO, Dada OM, Adewumi DF. Effects of reaction time on biodiesel yield. Journal of Bioprocessing and Chemical Engineering. 2015; 3: 1-3.

34. Musa IA. The effects of alcohol to oil molar ratios and the type of alcohol on biodiesel production using transesterification process. Egyptian Journal of Petroleum. 2016; 25: 21-31.

35. Xie W, Huang X, Li H. Soybean oil methyl esters preparation using NaX zeolites loaded with KOH as a heterogeneous catalyst. Bioresource technology. 2007; 98: 936-939.

36. Endalew AK, Kiros Y, Zanzi R. Inorganic heterogeneous catalysts for biodiesel production from vegetable oils. Biomass and Bioenergy. 2011; 35: 3787-3809.

37. Xie W, Huang M. Immobilization of Candida rugosa lipase onto graphene oxide Fe3O4 nanocomposite: Characterization and application for biodiesel production. Energy Conversation Management. 2018; 159: 42-53.

38. Anguebes-Franseschi F, Bassam A, Abatal M, May Tzuc O, Aguilar-Ucán C, et al. Physical and chemical properties of biodiesel obtained from amazon sailfin catfish (pterygoplichthys pardalis) biomass oil. Journal of Chemistry. 2019; 2019.

39. Karmakar R, Kundu K, Rajor A. Fuel properties and emission characteristics of biodiesel produced from unused algae grown in India. Petroleum Science. 2018; 15: 385-395.

40. Piloto-Rodríguez R, Sánchez-Borroto Y, Melo-Espinosa EA, Verhelst S. Assessment of diesel engine performance when fueled with biodiesel from algae and microalgae: An overview. Renewable and Sustainable Energy Review. 2017; 69: 833-842.