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Biodiesel from Sewage Sludge: An Alternative to Diesel

Sonica Sondhi*; Pawan Kumar**

*Department of Biotechnology, Chandigarh College of Technology, CGC Landran, Mohali-140307, Punjab, India
**Department of Mechanical Engineering, Chandigarh Engineering College, CGC Landran, Mohali-140307, Punjab, India

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.

Keywords: Sewage sludge; Biodiesel; Transesterification

Introduction

Energy has become to be a critical component for humanity. Currently, modern society consumes huge amounts of energy to hold a high trend 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].
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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, CO\textsubscript{2}, hydrocarbons, particulate, except NO\textsubscript{x}) and essentially eliminates emissions of SO\textsubscript{2} 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 quanti-
ties. 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 (cel lulose, 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).

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:

**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 cata-

ysts are being used as catalyst. Most common chemical catalyst used is NaOH, CH₃ONa 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 methanol 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 (hydratolclate), calcium carbonate rock, EST-4 (Eni Slurry Technology), Li/CaO, MgO/KOH and Na/NaOH/AI₂O₃ 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 37.27kJL⁻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**

2. www.weforum.org/agenda/2020/01/can-emerging-economies-leapfrog-the-energy-transition/
5. National emissions reported to the UNFCCC and to the EU greenhouse gas monitoring mechanism provided by European Environment Agency (EEA). 2019.


