Recent development on sustainable biodiesel production using sewage sludge

Neha Srivastava¹ · Manish Srivastava² · Vijai Kumar Gupta³ · Ambepu Manikanta¹ · Kajal Mishra⁴ · Shipra Singh^{1,5} · Sangram Singh⁶ · P. W. Ramteke⁷ · P. K. Mishra¹

Received: 8 February 2018 / Accepted: 25 April 2018 / Published online: 8 May 2018
© Springer-Verlag GmbH Germany, part of Springer Nature 2018

Abstract

Biodiesel as a renewable energy is an important alternative to biofuels in current scenario to explore green energy sources. It is well known that the major cost involved in biodiesel production technology is dependent upon the used feedstock. This review presents an overview of biodiesel production using municipal sewage sludge as a cost-effective substrate. Municipal sewage sludge which possesses high lipid content with zero cost availability can meet the characteristics of a potential feedstock to produce biodiesel. Different types of substrates based processes to produce biodiesel have been also explored in brief. In addition, limitations of the existing process technology for biodiesel production with sustainable solutions have been also discussed.

Keywords Biodiesel · Biofuels · Sewage sludge · Transestrification · Pyrolysis

Introduction

Increasing concern with environmental pollution due to the combustion of conventional fossil fuels is receiving huge attention towards the development of sustainable alternative energy sources. Additionally, fossil fuels are non-renewable source of energy, but a potential source of pollutants that causes global warming and change in the climate pattern. Alternative renewable energy options can be helpful in overcoming the limitation of fossil fuels, specifically for the transportation sector. Transportation sector covers ~30% total world's demand among all industrial sector based on fossil energy consumption (Atabani et al. 2011, 2012). Based on the report of United Nation Inter-governmental Panel on climate change, 23% energy related to green house gas is emitted by the transportation sector and about 45% of it is due to the passenger vehicles (International Council on Clean Transportation, ICCT 2011). Further, demand of fuel has increased from 85 million barrels of liquid fuel per day in 2006 and is likely to further increase up to 107 million barrels of liquid fuel per day in 2030 (Revellame et al. 2010). Moreover, oil is known as one of the biggest sources of energy on the earth, but its share is expected to decline from 35% in 2007 to 30% in 2035 (US Energy Information Administration 2010; Atabani et al. 2012). Based on the report of International Energy Agency (IEA) (2007), there

✉ Neha Srivastava
sri.neha10may@gmail.com

✉ P. K. Mishra
pkmishra.che@itbhu.ac.in

¹ Department of Chemical Engineering and Technology, Indian Institute of Technology, Banaras Hindu University, Varanasi 221005, India

² Department of Physics and Astrophysics, University of Delhi, Delhi 110007, India

³ Department of Chemistry and Biotechnology, ERA Chair of Green Chemistry, School of Sciences, Tallinn University of Technology, Tallinn, Estonia

⁴ School of Chemical Technology, G.G.S.I.P.U., New Delhi 110078, India

⁵ School of Environmental Sciences, Jawaharlal Nehru University, New Delhi 110067, India

⁶ Department of Biochemistry, Dr. R.M.L. Awadh University, Faizabad 224001, India

⁷ Department of Biological Sciences, Sam Higginbottom University of Agriculture Technology and Sciences, Formerly Allahabad Agricultural Institute, Allahabad, Uttar Pradesh 221007, India

will be 50% more increase in demand for energy in 2030 than today, of which the maximum amount (~45%) will be consumed by the two highly populated countries, i.e., China and India (Atabani et al. 2012). To fulfil the energy demand, biofuels are one of the most potential options among currently available renewable energy sources (Agarwal et al. 2017). Besides, among various existing technologies of biofuels production, biodiesel production is one of the promising and sustainable options (Mahmudul et al. 2017). Biodiesel offers several benefits for the environment like capability to reduce CO emissions, particulate matter and unburned hydrocarbons (Daud et al. 2015; Churchill and Srinivasan 2017; Mardhiah et al. 2017). Though biodiesel has several advantages, lack of suitable substrate and process technology are the major bottlenecks to make the process economically viable (Fig. 1). Being non-food and lipid rich in nature, secondary sludge waste has enormous potential for biodiesel production. Biodiesel production from secondary sludge waste may also contribute strongly in environmental remediation. Therefore, the objective of this review is to provide an overview to enhance biodiesel production using secondary sludge waste as a potential substrate. Moreover, limitations and possible approaches to improve biodiesel production have been also discussed.

Biodiesel

Biodiesel production is considered as one of the potential options among existing biofuels production technologies due to its renewable nature, low toxicity and has a low

environmental impact as compared to the petroleum-based diesel (Daud et al. 2015). Composition of biodiesel includes fatty acid methyl esters (FAMEs), obtained from reacting lipids with alcohol supported by catalyst (Qi et al. 2016). At industrial scale, production of biodiesel is carried out *via* transesterification process using triglycerides and methanol in the presence of homogeneous base catalysts (Atadashi et al. 2013). In this context, high lipid content of the feedstock such as sludge can be a promising substrate for biodiesel production (Qi et al. 2016).

Although, traditional food crops have been utilized as the substrate to produce biodiesel, they are not suitable due to the food versus fuel concept (Khan et al. 2014; Mardhiah et al. 2017). Hence, non-foody substrates have been started to explore as the feedstock to produce biodiesel (Haas et al. 2006; Daud et al. 2015). Figure 2 represents a flow chart for the overall biodiesel production technology. As discussed above, sewage sludge is a promising non-edible feedstock offering substantial potential to produce biodiesel at low cost (Mondala et al. 2009; Qi et al. 2016; Mulchandani and Westerhoff 2016; Arazo et al. 2017) yet, its disposal is the biggest challenge for waste water treatment plants. Nevertheless, the cost involved in biodiesel production will be low as compared to seed oils when sewage sludge will be used as feedstock (Fonts et al. 2012; Mulchandani and Westerhoff 2016; Arazo et al. 2017). Additionally, sludge is rich in lipid content because triglycerides, diglycerides, monoglycerides, phospholipids and free fatty acids are easily adsorbed onto the sludge (Kargbo 2010). Thus, use of sludge as the feedstock will not only promote bioremediation, but also help to produce low-cost biofuels in an eco-friendly manner.

Fig. 1 Advantages of biodiesel production using sewage sludge

Fig. 2 Overall biodiesel production scheme

Feedstock for biodiesel production

The biggest advantage and increasing interest towards the biodiesel production is mainly due to its ability to use unlimited range of feedstocks (Shahid and Jamal 2011; Janaun and Ellis 2010; Atadashi et al. 2010). The most considerable features of ideal feedstocks are low production cost and high yield. Generally, the cost of raw material involved in the process of biodiesel covers ~60 to 80% of the total production cost of biodiesel (Juan et al. 2011; Silitonga et al. 2011a, b; Ahmad et al. 2011; Atabani et al. 2012). Oil percentage and yield per hectare are the significant factors which ensure economic feasibility of the process. At first time, biodiesel from vegetable oil came into limelight in the year 1890 and referred as the first-generation feedstock to produce biodiesel (Daud et al. 2015). At present ~95% biodiesel production is carried out from edible oils around the world (Atabani et al. 2012; Mardhiah et al. 2017). Edible vegetable oil which are used in the form of substrate for biodiesel production are rapeseed, palm oil, soybean oil, sunflower, cottonseed, peanut, coconut, groundnut oil, sesame seed oil, olive oil, canola oil, poppy seed oil, safflower seed oil, walnut oil, and Chinese tallow tree oil (Atabani et al. 2012; Daud et al. 2015; Churchill and Srinivasan 2017; Mahmudul et al. 2017). Figure 3 shows various types of feedstocks utilized in biodiesel production (Atabani et al. 2012; Silitonga et al. 2011a, b; Friday and Okano 2011; Masjuki 2010; Kumar and Sharma 2011). Moreover, the excess use of edible oil leads to the food crisis and a big controversy erupted on fuel

for rich or food for the poor (Khan et al. 2014). It also led to major environmental problems such as forest encroachment, destruction of soil quality and the availability of arable land (Lim et al. 2010; Daud et al. 2015). Additionally, increasing cost of edible oil has drastically affected the economy of biodiesel engine, resulting in preference of biodiesel production using non-edible oil and was regarded as second generation (Soccol et al. 2017). They are easily available, and the merit of non-edible oil as feedstock is that they can be cultivated on waste land; less expensive than edible oils and cultivations do not require extra fertiliser and moisture conditions. Non-edible oils combine jatropha oil, neem oil, caper spurge oil, rice bran oil, honge oil, oleander oil, mahua oil, crambe oil, tamanu oil, linseed oil, castor oil, rubber seed oil, tobacco oil, argemone oil, azedarach oil, etc. (Atabani et al. 2012; Khan et al. 2014; Mahmudul et al. 2017; Kamel et al. 2017). However, productions of biodiesel through non-edible oils has some technical challenges and require multiple chemical processing because of high free fatty acid contents, are relatively wild and more importantly there is a lack of knowledge about many species (Mardhiah et al. 2017). Additionally, they have higher amount of impurities, therefore, additional purification step is required which adds more cost in the production process. Besides non-edible oil, biodiesel production was also reported from microalgae and macroalgae and referred to as the third-generation feedstock (Daud et al. 2015; Piloto-Rodríguez et al. 2017; Wu et al. 2017). They exhibit high photosynthetic rate which leads to greater productivity per cultivation area and also absorbs a large

Fig. 3 Main biodiesel feedstocks: **a** edible and **b** non-edible (Adapted from Atabani et al. 2012)

amount of CO₂ from the atmosphere (Piloto-Rodríguez et al. 2017). It produces oil 25-fold higher than that of palm oil and 250-fold than that of soybean. They are easier to cultivate and also have the capability to meet the global demand, offering a sustainable environment (Piloto-Rodríguez et al.

2017). Although the process has no fight with the land and cultivation techniques, it requires advanced bioreactor for its pre-treatment which increases the production cost.

A research study conducted by Kligerman and Bouwer (2015) elaborates that microalgae have potential to play

dual role like bioremediation of waste water and biomass for biodiesel production. Further Kligerman and Bouwer (2015) have reported that using waste water from only 40% of Brazil municipalities for microalgae production would enhance the biodiesel production by 21.4% in Brazil. Hence, there is much scope in this area to explore the utilization of microalgae as the feed for biodiesel production.

Waste cooking oil as well as animal fats are also considered as important feedstock (Mahmudul et al. 2017; Kamel et al. 2017) to produce biodiesel. However, increasing population and urbanisation are leading tremendous increase in the consumption of cooking oil. Biodiesel is formed due to high heating of edible vegetable oils. In this process, chemical reactions like hydrolysis, polymerisation and oxidation take place, leading to the formation of toxic compounds which are not suitable for the environment. Therefore, its utilization as a biodiesel feedstock can help from being discharged into the drainage system and blocking it, but the higher content of free fatty acid in them leads to an improper transesterification step (Yaakob et al. 2013).

Further, advanced technologies and various researches have given birth to microbial oil and genetically engineered plants (Hegde et al. 2015; Soccol et al. 2017). Microbial oil can be extracted more easily as they have a shorter life-cycle, are less influenced by climate, have no need of larger area for production and last but not the least require nearly no labour, though production cost is very high (Soccol et al. 2017). Genetically engineered plants, for example, poplar, switch grass as well as big bluestem have been also added to the list of feedstocks for biodiesel

production. Henceforth, researches are focusing on to increase the yield and lower the production cost of biodiesel (Hegde et al. 2015; Soccol et al. 2017; Ishak et al. 2017; Kamel et al. 2017; Piloto-Rodríguez et al. 2017).

In this regard, sewage sludge is a striking substrate for biodiesel production due to rich amounts of organic matter (e.g. lipids) and are easily available (Boocock et al. 1992; Willson et al. 2010; Siddiquee and Rohani 2011; Olkiewicz et al. 2012; Zhu et al. 2014; Mulchandani and Westerhoff 2016; Qi et al. 2016; Arazo et al. 2017; Demirbas 2011). Furthermore, being a waste source, sewage sludge is economically viable and their eco-friendly transformation not only leads to develop biofuels, but also treats pollution problem. The summary of various types of method to produce biodiesel has been provided in Fig. 4. Melero et al. (2015) investigated different approaches [one step (in situ and two-step (ex situ)] for biodiesel production using sewage sludge which was dewatered by centrifugation and dried in an oven. One step process involved simultaneous extraction and conversion of lipid fraction present in sewage sludge whereas two-step process involved lipid fraction extraction followed by conversion in to biodiesel. Further, these authors noticed that FAME yield in one step process was 15.5 wt% for primary sludge and 10.0 wt% for secondary sludge whereas in two-step process FAME yield was less than 6 wt% for primary and negligible for secondary sludge. Moreover, it was suggested that heterogeneous acid catalyst (Zr-SBA-15) has a high potential for the biodiesel production from low-quality oleaginous feedstock such as sewage sludge.

Fig. 4 Methods for biodiesel production (Adapted from Khan et al. 2014)

Biodiesel production process

Because of the availability of various types of feedstocks to be used for biodiesel production, a big demand to develop such types of process which is well suitable for the feedstock to achieve high yield of the product is raised (Daud et al. 2015). Therefore more researches have focussed on finding out various processes to enhance the yield and reduce the cost of the process. In the series of various available processes, four processes are being used for the biodiesel production including (Vyas et al. 2010; Siddiquee and Rohani 2011; Atadashi et al. 2013): (1) direct use or blending, (2) micro emulsions, (3) pyrolysis and (4) transesterification.

Direct use or blending

Direct blending is the process in which vegetable oils are directly diluted with diesel, therefore, it is also known as dilution (Mahmudul et al. 2017). It is used to reduce the viscosity and enhances the performance (Abbaszaadeh et al. 2012). There is no requirement of chemical processing (Balat and Balat 2010; Chauhan et al. 2010) and a ratio of 1:10 and 2:10 is found to be most suitable for this process; however, it is not suitable for long-term use. The major disadvantage of this process is the high viscosity, free fatty acid content, acid composition and gum formation.

Micro emulsion

Micro emulsions are defined as thermodynamically stable isotropic liquid mixtures of oil, water and surfactant, commonly in a blend with a co-surfactant. This process was developed to resolve the problem in reference with high viscosity of vegetable oil (Abbaszaadeh et al. 2012; Mahmudul et al. 2017). It is made by mixing vegetable oil with solvents such as methanol, ethanol, butanol and hexanol.

But this process leads to incomplete combustion and high amount of carbon deposits.

Pyrolysis

Pyrolysis is a process where conversion of a substance into another form is carried out by heat treatment (Mahmudul et al. 2017). It can be done in the presence or absence of a catalyst, but in the absence of oxygen. This process is also termed as thermal cracking. Biodiesel obtained from this process is suitable for diesel engines, but due to the absence of oxygen low-value materials are produced (Abbaszaadeh et al. 2012). This process is effective, easy and pollution free (Singh and Singh 2010), but requires expensive equipments. According to Ito et al. (2012), this method is applicable for waste cooking oil. Pyrolysis of vegetable oil leads to biodiesel production consisting of high cetane number, low viscosity and acceptable amount of sulphur, water, sediment content, and copper corrosion values, although, ash content, carbon residues and pour points are below the acceptable limit (Sharma et al. 2008).

Recently, Capodaglio and Callegari (2017) have discussed that pyrolysis, in particular microwave assisted pyrolysis, has the capability of producing biodiesel from sewage sludge with high efficiency compared to other methods. But still, the quality of produced biodiesel does not meet the required characteristics of diesel for commercialization.

Transesterification

Transesterification is regarded as the most suitable process and so applied in the majority of industries (Mahmudul et al. 2017). It is highly popular because of its low cost and simplicity and it reduces the viscosity of oil, making it suitable for engines and equipment (Abbaszaadeh et al. 2012; Koutsouki et al. 2016). Transesterification derived biodiesel has lowest viscosity compared to biodiesel produced from other methods (Capodaglio and Callegari 2017). Transesterification is the process of converting triglyceride and alcohol to fatty acid alkyl ester and glycerol (Koutsouki et al. 2016) (Fig. 5).

Fig. 5 The general form of transesterification reaction (Adapted from Siddiquee et al. 2011)

The process of transesterification can be categorized as catalytic and non-catalytic process. The catalytic process, as the name suggests, involves the use of a catalyst to enhance the reaction rate and course of the time. The non-catalytic process, on the other hand, does not involve the use of any catalyst. The catalytic method can be further divided into homogenous catalysts and heterogeneous catalyst on the basis of the type of catalysts used in the production process (Atadashi et al. 2013; Mardhiah et al. 2017). Homogenous catalysts can be either acid or alkaline catalysts (Bharathiraja et al. 2014; Mahmudul et al. 2017). Examples of acid catalysts include sulphuric acid, hydrochloric acid, ferric sulphate, phosphoric acid, etc. (Atadashi et al. 2013; Aransiola et al. 2014; Bharathiraja et al. 2014; Ishak et al. 2017). Acid catalysts are more suitable for the feedstocks having high amount of free fatty acids and water contents as it is helpful in lowering the free fatty acids content (Mardhiah et al. 2017; Ishak et al. 2017). But the main demerits of using acid catalysts are that, they consume much time and a large amount of water is required for washing the biodiesel (Aransiola et al. 2014; Bharathiraja et al. 2014). Alkali catalysts like sodium hydroxide and potassium hydroxide are the widely used catalysts (Atadashi et al. 2013; Bharathiraja et al. 2014; Churchill and Srinivasan 2017). It has been reported that this is the fastest and most economical method for biodiesel production (Siddiquee et al. 2011). Though the conventional catalysts used in the production process of biodiesel are cheap, sensitive to free fatty acids as well as water content in oils (Aransiola et al. 2014; Bharathiraja et al. 2014), the presence of water in oil leads to its hydrolysis into free fatty acids and if the free fatty acid content exceeds 3%, the performance of the catalyst decreases (Atadashi et al. 2013; Aransiola et al. 2014; Ishak et al. 2017). The other drawback of using alkali catalyst is soap formation that creates hindrance in the separation process of glycerol and methyl ester thus reducing the overall yield (Atadashi et al. 2012; Aransiola et al. 2014; Mardhiah et al. 2017; Ishak et al. 2017). Similar to acid catalysts they are also a bit slow in operation.

Heterogeneous catalysts, on other hand, include enzymes and other catalysts like titanium silicates, alkaline earth metal, amorphous zirconia, titanium and potassium zirconias (Atadashi et al. 2013; Bharathiraja et al. 2014; Mardhiah et al. 2017). Unlike alkaline catalysts, enzymes do not form soap. Enzymes are substances that increase the rate of reaction without altering any overall chemical change. Lipase catalysts like diazomethane CH_2N_2 have high forbearance for the free fatty acid level of substrate (Aransiola et al. 2014). It tends to attack on the long-chain fatty alcohols which are better than on short-chain fatty alcohols. In this reaction, there is no involvement of complicated processes for the retrieval of glycerol with removal of catalyst and soap (Aransiola et al. 2014; Bharathiraja et al. 2014; Ishak

et al. 2017). Disadvantages of the lipase catalyst are higher reaction time and high production cost for large-scale industrial production (Aransiola et al. 2014). Now researchers have been involved on lipases and developing cost-effective enzymes. Although these shortcomings are failed to see in case of non-catalytic transesterification methods. Moreover, supercritical methanol process applies a lower amount of energy and the reaction completes in a couple of minutes (Bharathiraja et al. 2014). It can overcome the demerits of the catalytic process in the way, it involves no use of catalyst and the purification step of biodiesel and glycerol recovery is quite easier (Karmakar et al. 2010; Atabani et al. 2012; Aransiola et al. 2014). However, technologies used in the process makes it costly and there is increased consumption of methanol (Shahid and Jamal 2011; Deng et al. 2011; Atabani et al. 2012).

In situ transesterification needs single step for extraction followed by conversion of algal lipids to biodiesel for simplifying the processing (Qi et al. 2016; Koutsouki et al. 2016). Olkiewicz et al. (2014) studied that liquid–liquid extraction of lipids from acidified sewage sludge using hexane as solvent reflects considerable enhancement in lipid efficiency. Also, these authors concluded that the liquid–liquid extraction applying hexane is viable compared to the other drying methods like thermal treatment which is not cost effective and further suggested that the left over sludge after lipid extraction can be used for energy production through anaerobic digestion.

Olkiewicz et al. (2015) investigated the effect of pretreatment (ultrasonic and mechanical disintegration) on primary, secondary and blended sewage sludge with and without previous acidification for lipids extraction by Soxhlet using hexane. Through the above investigation, it was found that pretreatment methods (ultrasonic and mechanical disintegration) did not increase the lipids extraction significantly. Moreover, earlier sludge acidification exhibited lower yield of lipids from primary, secondary and blended sludge, though the amount of saponifiable lipids was higher and hence keeping the whole biodiesel yield remained (Olkiewicz et al. 2015).

Physicochemical properties of biodiesel

Biodiesel is fatty acid alkyl esters, produced by base or acid catalysed transesterification of lipids using alcohol. FAME is said when methanol is used as the alcohol. It has no sulphur content and its lubricating property is also high (Aransiola et al. 2014; Kamel et al. 2017). Its physical property can vary based on the feedstock implemented. It has a higher flash point than that of a petroleum diesel (Aransiola et al. 2014; Mahmudul et al. 2017). Its calorific value is $\sim 37.27 \text{ MJ L}^{-1}$ (Aransiola et al. 2014). The variations in

biodiesel energy density differ greatly because of different feedstocks used rather than the production process (Aran-siola et al. 2014; Mahmudul et al. 2017). Biodiesel can be used as a substitute in different engines without its modification as it is much attuned to the engine (Mahmudul et al. 2017; Soccol et al. 2017). Majority of the countries use a system termed “B” factor to declare the amount of biodiesel in any fuel mix. Around 20% or lower can be used in diesel equipment with no or minor modifications (Mardhiah et al. 2017). Biodiesel can also be used in its pure form (B100), using certain engine modifications to avoid any technical problem (Mardhiah et al. 2017). Additionally, biodiesel may be mixed with mineral diesel up to 20% (w/w) and named as B5, B10, B20, B100, where 5, 10, 20, and 100 indicate the percentage amount of biodiesel in petroleum diesel (Janaun and Ellis 2010). Since it is highly biodegradable with less toxicity; it may be substitute diesel fuel for many different applications like in boilers and internal combustion engines without major modifications (Ahmad et al. 2011; Silitonga et al. 2011a, b; Kamel et al. 2017; Soccol et al. 2017). The properties of biodiesel can be characterized on the basis of physicochemical properties such as calorific value (MJ/kg), cetane number, density (kg/m³), viscosity (mm²/s), cloud as well as pour points (°C), flash point (°C), acid value (mg KOH/g-oil), ash content (%), copper corrosion, carbon residue, water content and sediment, distillation range, sulphur content, glycerine (% m/m), phosphorus (mg/kg) and oxidation stability (Mahmudul et al. 2017). The physicochemical properties of biodiesel is highly rely on the type and fatty acid composition of feedstock (Murugesan et al. 2009; Atadashi et al. 2010; Lin et al. 2011; Jena et al. 2010; Atabani et al. 2012). Biodiesel having a flash point greater than 93.3 °C makes it easier to handle, use and store and hence safer to use. In addition, its energy content, i.e. the heating value is like petroleum diesel. But some demerits like fuel pumping problems, cold storage, poor low temperature flow and the higher copper strip corrosion can be faced by the people (Yaakob et al. 2013; Mahmudul et al. 2017). High cost due to expensive feedstock is the main hurdle in the development and smooth implementation of biodiesel (Mahmudul et al. 2017).

Limitation in cost-effective biodiesel production

Unavailability of sustainable feedstock and process

Prices of biodiesel are currently higher than the price of fossil diesel thus it is of low significance (Mardhiah et al. 2017). The biggest hindrance for biodiesel production is its high production cost and limited availabilities of oil resources. The major factors acting as a challenge in its production are

the cost of raw material (feedstock), multi-step production process, high amount of water consumed in the washing process, resulting in huge amount of waste water (Mahmudul et al. 2017; Wu et al. 2017). The major segment is grabbed by the cost of feedstock that alone implies for 70–80% in the production cost and the rest by above-indicated factors (Siddiquee et al. 2011). Increasing population is also leading to decrement in the free land area as much of them are consumed for housing purposes, industries and other purposes that add comfort to their lives. Therefore, switching over to non-edible oils and other sources such as sewage sludge can be advantageous and may be helpful in cost reduction and certify sustainable development of the environment (Zhu et al. 2012; Arazo et al. 2017). Feedstock selection is the foremost important process in determining the price of biodiesel produced (Mardhiah et al. 2017). The multistep production process that includes pre-treatment of the raw material, extraction of lipids, production of biodiesel and the wet washing process is time and cost consuming (Koutsouki et al. 2016). Sometimes the efficiency and capacity of the appliances may be significant and lead to a tremendous decline in its production. Transesterification is the process which can elevate production and is also a short-term process. Further, in situ transesterification is gaining much attention as it is merely a single step process and also production amount varies to a great extent (Koutsouki et al. 2016). Use of high-frequency ultrasound treatment also helps in minimisation of cost (Koutsouki et al. 2016). Recovery of glycerol after the production of biodiesel should also be kept in mind as it also helps in minimization of cost and balancing the input output ratio (He et al. 2017). High-quality glycerol production that can be used in cosmetics laboratories and lubrication of machinery should be produced. Researches on biodiesel production should be endorsed and technologies such as one step process should also be used to reduce the time factor as well as the cost. Thus, biodiesel can be more effective if used as oil for diverse energy sources.

Environmental issues

Use of biodiesel has remarkable impact to decline global warming by reducing green-house gases. It also claims in reducing the particulate matters from the atmosphere and also reduces smoke due to the presence of free soot. But, it failed in reducing the concentration of NO₂ due to the presence of a greater amount of oxygen (Daud et al. 2015). Biodiesel made from waste products or unwanted materials helps in managing the huge amount of waste collected in one way or the other, e.g., sewage sludge, microalgae (Mulchandani and Westerhoff 2016; Agarwal et al. 2017; Arazo et al. 2017). Nevertheless, it is very safe regarding the environment and human health.

Socio-economic issues

When the technology was not much advanced and the only means to produce biodiesel was through the edible oils, it had a negative impact on the livelihood of common peoples. Excess use of edible oils leads to their excess supply and thus raised the price. The increased cost of edible oils leads to common people to hunger, strive for food and indirectly affected the whole economy of the nation. Cultivation of huge amount of edible oils also created a problem of too much land consumption that leads to living problems for human beings. However, non-edible oils and others sources of feedstocks (e.g. sewage sludge) can help people for their survival and also a reduction in production cost of biodiesel is possible, as they do not compete with the food production and also can be cultivated on wasteland.

Conclusions

In this modern era, where pollution and population both have crossed their threshold limit, the developing technologies are playing a great role in maintaining the ecological balance of the ecosystem. Due to increasing urbanisation and lack of awareness among peoples, there is increased waste generation, and no proper method for their disposal. Scientists with their extra knowledge are still finding novel processes that convert waste into the useful form of energy. However, the methods found till date are facing various problems and they also have some demerits, as discussed earlier in this review.

Based on various studies, it is concluded that biofuel production has gained much attention due to the limitation of fossil fuels. Additionally, biodiesel production has attracted much interest of the researchers because of its wide range of feedstock availability and their potential properties. Nevertheless, storage of dried sludge after wastewater treatment is a big issue. Some countries have banned using sewage sludge as a fertiliser because it contains a high amounts of toxic chemicals that can enter the food chain causing biomagnifications. Therefore, effective utilization of sewage sludge for biodiesel production is the potential way for a sustainable environment. Studies are going on to reduce the production cost and increase the yield, leading to biodiesel production that can meet the global energy demand.

Acknowledgements Author N. S. thankfully acknowledge to IIT (BHU) Varanasi, India for providing Institute Post-Doctoral fellowship. P. K. Mishra, N. S., S. S. and A. M. acknowledge Department of Chemical Engineering and Technology IIT (BHU) Varanasi. M. S. acknowledges the Department of Science and Technology, Govt. of India for DST INSPIRE Faculty (IFA13-MS-02) 2014 award. P. Singh thankfully acknowledges Department of Chemistry, IIT (BHU), Varanasi, India.

Compliance with ethical standards

Conflict of interest Authors of the manuscript declare there is no conflict of interests.

References

- Abbaszaadeh A, Ghobadian B, Omidkhah MR, Najafi G (2012) Current biodiesel production technologies: a comparative review. *Energy Convers Manag* 63:138–148
- Agarwal AK, Gupta G, Dhar A (2017) Potential and challenges for large-scale application of biodiesel in automotive sector. *Prog Energy Combust Sci* 61:113–149
- Ahmad AL, Mat Yasin NH, Derek CJC, Lim JK (2011) Microalgae as a sustainable energy source for biodiesel production: a review. *Renew Sustain Energy Rev* 15(1):584–593
- Aransiola EF, Ojumu TV, Oyekola OO, Madzimbamuto TF, Ikhu-Omoregbe DIO (2014) A review of current technology for biodiesel production: state of the art. *Biomass Bioenergy* 61:276–297
- Arazo RO, Luna MDGD., Capareda SC (2017) Assessing biodiesel production from sewage sludge-derived bio-oil. *Biocatal Agric Biotechnol* 10:189–196
- Atabani AE, Badruddin IA, Mekhilef S, Silitonga AS (2011) A review on global fuel economy standards, labels and technologies in the transportation sector. *Renew Sustain Energy Rev* 15(9):4586–4610
- Atabani AE, Silitonga AS, Badruddin IA, Mahlia TMI, Masjuki HH, Mekhilef S (2012) A comprehensive review on biodiesel as an alternative energy resource and its characteristics. *Renew Sustain Energy Rev* 16(4):2070–2093
- Atadashi IM, Aroua MK, Aziz ARA (2010) High quality biodiesel and its diesel engine application: a review. *Renew Sustain Energy Rev* 14(7):1999–2008
- Atadashi IM, Aroua MK, Aziz ARA, Sulaiman NMN (2012) High quality biodiesel obtained through membrane technology. *J Membr Sci* 421–422:154–164
- Atadashi IM, Aroua MK, Aziz ARA, Sulaiman NMN (2013) The effects of catalysts in biodiesel production: a review. *J Ind Eng Chem* 19:14–26
- Balat M, Balat H (2010) Progress in biodiesel processing. *Appl Energy* 87:1815–1835
- Bharathiraja B, Chakravarthy M, Kumar RR, Yuvaraj D, Jayamuthunagai J, Kumar RP, Palani S (2014) Biodiesel production using chemical and biological methods—a review of process, catalyst, acyl acceptor, source and process variables. *Renew Sustain Energy Rev* 38:368–382
- Boocock DGB, Konar SK, Leung A, Ly LD (1992) Fuels and chemicals from sewage sludge: 1. The solvent extraction and composition of a lipid from a raw sewage sludge. *Fuel* 71(11):1283–1289
- Capodaglio AG, Callegari A (2017) Feedstock and process influence on biodiesel produced from waste sewage sludge. *J Environ Manage.* <https://doi.org/10.1016/j.jenvman.2017.03.089>
- Chauhan BS, Kumar N, Jun YD, Lee KB (2010). Performance and emission study of preheated Jatropha oil on medium capacity diesel engine. *Energy* 35(6):2484–2492
- Churchill GV, Srinivasan CA (2017) Experimental investigations on combustion and emission characteristics of biodiesel blends in CI engine. *Int Res J Eng Technol* 4(1):1523–1529
- Daud NM, Abdullah SRS, Hasan HA, Yaakob Z (2015) Production of biodiesel and its wastewater treatment technologies: a review. *Process Saf Environ Prot* 94:487–508
- Demirbas A (2011) Competitive liquid biofuels from biomass. *Appl Energy* 88:17–28

- Deng X, Fang Z, Liu Y, Yu C (2011). Production of biodiesel from *Jatropha* oil catalysed by nanosized solid basic catalyst. *Energy* 36(2):777–784
- Fonts I, Gea G, Azuara M, Ábrege J, Arauzo J (2012) Sewage sludge pyrolysis for liquid production: a review. *Renew Sustain Energy Rev* 16(5):2781–2805
- Friday JB, Okano D (2011) *Calophyllum inophyllum* (kamani). <http://www.agroforestry.net/tti/Calophyllum-kamani.pdf>. Accessed 05 Jan 2011
- Haas MJ, McAlloo AJ, Yee WC, Foglia TA (2006) A process model to estimate biodiesel production costs. *Bioresour Technol* 97(4):671–678
- He Q(S), McNutt J, Yang J (2017) Utilization of the residual glycerol from biodiesel production for renewable energy generation. *Renew Sustain Energy Rev* 71:63–76
- Hegde K, Chandra N, Sarma SJ, Brar SK, Veeranki VD (2015) Genetic Engineering Strategies for Enhanced Biodiesel Production. *Mol Biotechnol* 57:606–624
- International Council on Clean Transportation (ICCT) (2011) Passenger vehicles. <http://www.theicct.org/passenger-vehicles/>
- International Energy Agency (IEA) (2007) World energy outlook 2007. http://www.iea.org/textbase/nppdf/free/2007/weo_2007.pdf
- Ishak ZI, Sairi NA, Alias Y, Aroua MKT, Yusoff R (2017) A review of ionic liquids as catalysts for transesterification reactions of biodiesel and glycerol carbonate production. *Catal Rev* 59(1):44–93
- Ito T, Sakurai Y, Kakuta Y, Sugano M, Hirano K (2012) Biodiesel production from waste animal fats using pyrolysis method. *Fuel Process Technol* 94(1):47–52
- Janaun J, Ellis N (2010) Perspectives on biodiesel as a sustainable fuel. *Renew Sustain Energy Rev* 14(4):1312–1320
- Jena PC, Raheman H, Kumar GVP, Machavaram R (2010) Biodiesel production from mixture of mahua and simarouba oils with high free fatty acids. *Biomass Bioenergy* 34(8):1108–1116
- Juan JC, Kartika DA, Wu TY, Hin TYY (2011) Biodiesel production from *jatropha* oil by catalytic and non-catalytic approaches: an overview. *Bioresour Technol* 102:452–460
- Kamel DA, Farag HA, Amin NK, Fouad YO (2017) Biodiesel synthesis from non-edible oils by transesterification using the activated carbon as heterogeneous catalyst. *Int J Environ Sci Technol* 14:785–794
- Kargbo DM (2010) Biodiesel production from municipal sewage sludges: a review. *Energy Fuels* 24(5):2791–2794
- Karmakar A, Karmakar S, Mukherjee S (2010) Properties of various plants and animal's feedstocks for biodiesel production. *Bioresour Technol* 101(19):7201–7210
- Khan TMY, Atabani AE, Badruddin IA, Badarudin A, Khayoon MS, Triwahyono S (2014) Recent scenario and technologies to utilize non-edible oils for biodiesel production. *Renew Sustain Energy Rev* 37:840–851
- Kligerman DC, Bouwer EJ (2015) Prospects for biodiesel production from algae-based wastewater treatment in Brazil: a review. *Renew Sustain Energy Rev* 52(C):1834–1846
- Koutsouki AA, Tegou E, Badeka A, Kontakos S, Pomonis PJ, Kontomina MG (2016) In situ and conventional transesterification of rapeseeds for biodiesel production: the effect of direct sonication. *Ind Crops Prod* 84:399–407
- Kumar A, Sharma S (2011) Potential non-edible oil resources as biodiesel feedstock: an Indian perspective. *Renew Sustain Energy Rev* 15:1791–1800
- Lim S, Hoong SS, Teong LK, Bhatia S (2010) Supercritical fluid reactive extraction of *Jatropha curcas* L. seeds with methanol: a novel biodiesel production method. *Bioresour Technol* 101(18):7169–7172
- Lin L, Cunshan Z, Vittayapadung S, Xiangqian S, Mingdong D (2011) Opportunities and challenges for biodiesel fuel. *Appl Energy* 88(4):1020–1031
- Mahmudul HM, Hagos FY, Mamat R, Adam AA, Ishak WFW, Alenezi R (2017) Production, characterization and performance of biodiesel as an alternative fuel in diesel engines—a review. *Renew Sustain Energy Rev* 72:497–509
- Mardhiah HH, Ong HC, Masjuki HH, Lim S, Lee HV (2017) A review on latest developments and future prospects of heterogeneous catalyst in biodiesel production from non-edible oils. *Renew Sustain Energy Rev* 67:1225–1236
- Masjuki HH (2010) Biofuel engine: a new challenge. Inaugural lecture. University of Malaya, Malaysia
- Melero JA, Sánchez-Vázquez R, Vasiliadou IA, Castillejo FM, Bautista LF, Iglesias J, Morales G, Molina R (2015) Municipal sewage sludge to biodiesel by simultaneous extraction and conversion of lipids. *Energy Convers Manag* 103:111–118
- Mondala A, Liang K, Toghiani H, Hernandez R, French T (2009) Biodiesel production by in situ transesterification of municipal primary and secondary sludges. *Bioresour Technol* 100(3):1203–1210
- Mulchandani A, Westerhoff P (2016) Recovery opportunities for metals and energy from sewage sludges. *Bioresour Technol* 215:215–226
- Murugesan A, Umarani C, Chinnusamy TR, Krishnan M, Subramanian R, Neduzchzhain N (2009) Production and analysis of biodiesel from non-edible oils—a review. *Renew Sustain Energy Rev* 13(4):825–834
- Olkiewicz M, Fortuny A, Stüber F, Fabregat A, Font J, Bengoa Ch (2012) Evaluation of different sludges from WWTP as a potential source for biodiesel production. *Procedia Eng* 42:634–643
- Olkiewicz M, Caporgno MP, Fortuny A, Stüber F, Fabregat A, Font J, Bengoa C (2014) Direct liquid–liquid extraction of lipid from municipal sewage sludge for biodiesel production. *Fuel Process Technol* 128:331–338
- Olkiewicz M, Fortuny A, Stüber F, Fabregat A, Font J, Bengoa C (2015) Effects of pre-treatments on the lipid extraction and biodiesel production from municipal WWTP sludge. *Fuel* 141:250–257
- Piloto-Rodríguez R, Sánchez-Borroto Y, Melo-Espinosa EA, Verhelst S (2017) Assessment of diesel engine performance when fueled with biodiesel from algae and microalgae: an overview. *Renew Sustain Energy Rev* 69:833–842
- Qi J, Zhu F, Wei X, Zhao L, Xiong Y, Wu X, Yan F (2016) Comparison of biodiesel production from sewage sludge obtained from the A2/O and MBR processes by in situ transesterification. *Waste Manage* 49:212–220
- Revellame E, Hernandez R, French W, Holmes W, Alley E (2010) Biodiesel from activated sludge through in situ transesterification. *J Chem Technol Biotechnol* 85(5):614–620
- Shahid EM, Jamal J (2011) Production of biodiesel: a technical review. *Renew Sustain Energy Rev* 15(9):4732–4745
- Sharma YC, Singh B, Upadhyay SN (2008). Advancements in development and characterization of biodiesel: a review. *Fuel* 87(12):2355–2373
- Siddiquee MN, Rohani S (2011) Lipid extraction and biodiesel production from municipal sewage sludges: a review. *Renew Sustain Energy Rev* 15(2):1067–1072
- Siddiquee MN, Kazemian H, Rohani S (2011) Biodiesel production from the lipid of wastewater sludge using an acidic heterogeneous catalyst. *Chem Eng Technol* 34(12):1983–1988
- Silitonga AS, Atabani AE, Mahlia TMI, Masjuki HH, Badruddin IA, Mekhilef S (2011a) A review on prospect of *Jatropha curcas* for biodiesel in Indonesia. *Renew Sustain Energy Rev* 15:3733–3756
- Silitonga AS, Atabani AE, Mahlia TMI, Masjuki HH, Badruddin IA, Mekhilef S (2011b) A review on prospect of *Jatropha curcas* for biodiesel in Indonesia. *Renew Sustain Energy Rev* 15(8):3733–3756
- Singh SP, Singh D (2010) Biodiesel production through the use of different sources and characterization of oils and their esters as

- the substitute of diesel: a review. *Renew Sustain Energy Rev* 14(1):200–216
- Soccol CR, Neto CJD, Soccol VT, Sydney EB, Costa ESFD., Medeiros ABP, Vandenberghe LPDS (2017) Pilot scale biodiesel production from microbial oil of *Rhodospiridiumtoruloides* DEBB 5533 using sugarcane juice: performance in diesel engine and preliminary economic study. *Bioresour Technol* 223:259–268
- U.S. Energy Information Administration. International energy outlook 2010. 2010. <http://www.eia.doe.gov/oiaf/ieo/pdf/0484%282010%29.pdf>
- Vyas AP, Verma JL, Surahmanyam N(2010). A review on FAME production processes. *Fuel* 89(1):1–9
- Willson RM, Wiesman Z, Brenner A (2010) Analyzing alternative bio-wastefeedstocks for potential biodiesel production using time domain (TD)-NMR. *Waste Manage* 30(10):1881–1888
- Wu S, Song L, Sommerfeld M, Hu Q, Chen W (2017) Optimization of an effective method for the conversion of crude algal lipids into biodiesel. *Fuel* 197:467–473
- Yaakob Z, Mohammad M, Alherbawi M, Alam Z, Sopian K (2013) Overview of the production of biodiesel from Wastecooking oil. *Renew Sustain Energy Rev* 18:184–193
- Zhu F, Zhao L, Zhang Z, Jiang H (2012) Preliminary study at lipids extraction technology from municipal sludge by organic solvent. *Procedia Environ Sci* 16:352–356
- Zhu F, Zhao L, Jiang H, Zhang ZL, Qi JJ, Wang JW (2014) Comparison of the lipid content and biodiesel production from municipal sludge using three extraction methods. *Energy Fuels* 28(8):5277–5283