Chapter

Nanocatalyst Mediated Biodiesel Production from Waste Lipid as Feedstock: A Review

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Abstract

Petroleum-based fuels are widely utilized and pose a threat to the environment, necessitating an urge to bring up an equally effective substitute. Globally, research is focused on biofuel production from various sources which is renewable, highly affordable, and has lesser carbon emission. Biomass is used as raw material to produce biodiesel to achieve clean, green, and renewable fuel. Edible and nonedible raw materials are utilized for the production of biodiesel. Biodiesel from lipid sources produced through the transesterification process serves as an effective alternative for the production of renewable fuel with reduced carbon emissions and greenhouse gases. The cost of biodiesel is dependent on raw materials and catalysts. The acidic and basic homogeneous catalysis reaction has a corrosive effect during synthesis and poses a risk in scalability. The heterogeneous reaction is costlier and has poor performance in the transesterification of lipids. Raw material contributes to 70–80% of the overall production cost. Municipal sewage sludge (MSS) is rich in lipid content and serves as promising raw material for biodiesel production. Nanocatalyst has superior activity in producing pure products with fewer side reactions. This paper reviews the lipid extraction techniques and biodiesel production from MSS using various nanocatalysts.

Keywords: biodiesel, municipal sewage sludge, nanocatalyst, transesterification, lipid extraction

1. Introduction

Petroleum-based fuels contribute a significant impact on the business economy in developing countries toward various applications such that the transport of goods from industries and agricultural products, in operating diesel tractors and pump sets in the agricultural lands. Economic growth is associated with the rate of transportation. The energy demand is always incorporated with the industrialized world and domestic sector. Due to high energy demand, the fossil fuel necessity also increases which leads to a large amount of pollution, hence it is necessary to develop renewable energy sources. Therefore, it is a stipulated time to focus on alternative sources. Mainly focus on alternative fuels should have technically economically feasible, smaller environmental impact, and be readily available [1]. The MSS is one of the high lipid sources, it is obtained mostly from the domestic sector which includes long-chain fatty acids, grease, and fats, and an interesting factor is the microorganisms contain phospholipids present in their cell membranes, and during cell lysis, some of the byproducts and their metabolites acted as a major lipid source in MSS. This could be substantiated by the research work that has indicated that the lipid content in the sewage could be a conceivable feedstock for biodiesel production [2].

Biodiesel could be one of the solutions to overcome the issues of petroleum-based fuels, as, it is a fresh and renewed form of energy and it could own the worldwide markets due to its non-toxicity, biodegradability, environmentally beneficial, and similar ignition characteristics to fossil fuels [3]. Lower emissions of carbon monoxide, sulfur, and other hydrocarbons make biodiesel a carbon-neutral fuel [4]. It is a sustainable energy source used to reduce global warming [5]. Studies and recent research works revealed that using biodiesel can minimize CO_2 release to 78% which helps to prevent nature from pollution [6]. With the help of non-edible feedstocks, India produces 10–250,000 tons of biodiesel per year. According to the survey of 2014, the overall consumption of biodiesel is 1000 barrels/day. The usage of biodiesel economically supports the growth of India's early $1.47 billion foreign currency. Rapid growth in Industrial sectors and transport sectors are causes of polluting environment. Renewable energy sources are the best way to overcome this environmental crisis. Biodiesel production is one of them which supports technically and economically to the society.

2. Why biodiesel?

India's growing economy, multiplying population, and rapid urbanization result in increasing energy demand. Accordance to the report from International Energy Agency (IEA), the energy requirement is more due to the high depletion of energy in the past few decades. The IEA report says that a 6 million barrels a day increase in oil consumption results in major energy demand in India. The rise in energy demand is mainly due to the increase in individual vehicle ownership. The planning commission's 2002 statement is that "The primary commercial energy demand has grown at the rate of 6% between the years 1981-2001". On the other hand, India is facing a coal shortage of 23.96 million tons in the past few decades due to the depletion of energy sources and an increase in energy demand. For a decade of years, the demand for natural gas is increasing at the rate of about 6.5%. Renewable energy sources offer an alternate supply of energy to face the energy crisis. India is the highest potential for renewable energy sources. The significant renewable energy sources are wind energy, small hydrothermal energy, solar energy, and biomass. Though India produces more renewable forms of energy, the energy dependence is expected to increase further by 8% to achieve the gross domestic product growth rate of the tenth five-year plan. To solve this issue Government of India has agreed on a high priority for the energy sector and renewable energy resources. Tamil Nadu is a pioneer state in promoting the production of renewable energy resources. At the Indian level, Tamil Nadu contributes 27% (29989.21 MW) of total renewable energy via renewable energy sources. There is a steady increase in non-conventional energy sources in the past 10 years. The main contributors of non-conventional energy sources are wind energy (61%), biomass (35%), and other renewable forms of energy contributing to the remaining energy sources. Tamil Nadu is facing a major power crisis as Tangedco (The state power utility) is running short of coal. Tangedco imported 1.4 million tons of coal by the year 2018. Due to climatic changes and cyclonic storms in the Arabian Sea, there is a drop in wind energy generation on the south side of Tamil Nadu. Therefore, there is a high demand for energy supply in the state as coal and non-conventional energy sources are kept on depleted.

3. Municipal sewage sludge (MSS) as a promised raw material

Sewage is untreated municipal waste generated by domestic, industrial, and commercial sources. The level of wastewater production is increased rapidly due to the population, economic development, urbanization, and improving living conditions. Central Pollution Control Board (CPCB) surveys depict that "There are a total of 269 sewage treatment plants in India of which 213 are in proper working condition. In urban centers of the nation, the total sewage generated per day is about 38 billion liters a day but the total sewage treatment plant capacity is around 12 billion liters a day". The Ministry of New and Renewable Energy (MNRE) suggests that there is a probability to produce nearly 226 MW of energy from sewage sludge of treated and untreated sewage sludge sources. Sewage sludge is the waste generated in huge amounts in the waste treatment processes after primary and secondary treatment processes [7]. Also, the sludge is rich in lipid content as the surface of the sludge is proficient enough to adsorb different forms of lipids [8].

4. Treatment methodologies of MSS

In the sewage treatment plant, there are mainly 4 steps involved in the treatment of sewage sludge (**Figure 1**). The main 4 steps are

a. Pretreatment and grit removal

b. Primary treatment

c. Secondary treatment

d. Tertiary treatment

In the pretreatment process, easily removable materials like waste material, liters from trees, and large-sized materials will be removed from the raw sewage. The influent is passed into the bar screen where larger objects like plastic packets, liters, and cansticks present in the sludge were removed. Grit is composed of sand, gravel, heavy materials, organic material, fine solid particles, etc. The grit removal is done for the treatment of equipment with closely machined metal surfaces such as commuters, fine screens, centrifuges, heat exchangers, and high-pressure pumps. A grit removal system is present in sewage treatment plants for reasons which include; reducing the necessity for frequent cleaning of digester due to the accumulation of grit and lessening the settling of grit in the treatment tanks and passage pipes. The removal of grit also protects the digesters and clarifiers from wear and abrasion. The sewage flows through large tanks called "pre-settling basins" in primary sedimentation. This leads to a rise in the level of grease and oil on the surface of these tanks due to the continuous agitation of the sludge. The primary settling tanks have a scrapper and agitation tank and they continuously direct the collected sludge toward the sludge treatment facilities. After the primary clarification, the primary sludge is collected. The primary sludge is the combined form of free-floating grease and settled solid matter [9]. The secondary treatment involves the degradation of the biological content which could be human/food waste, and the removal of the organic content and the suspended solids which passes the primary treatment. In the secondary treatment, the settled

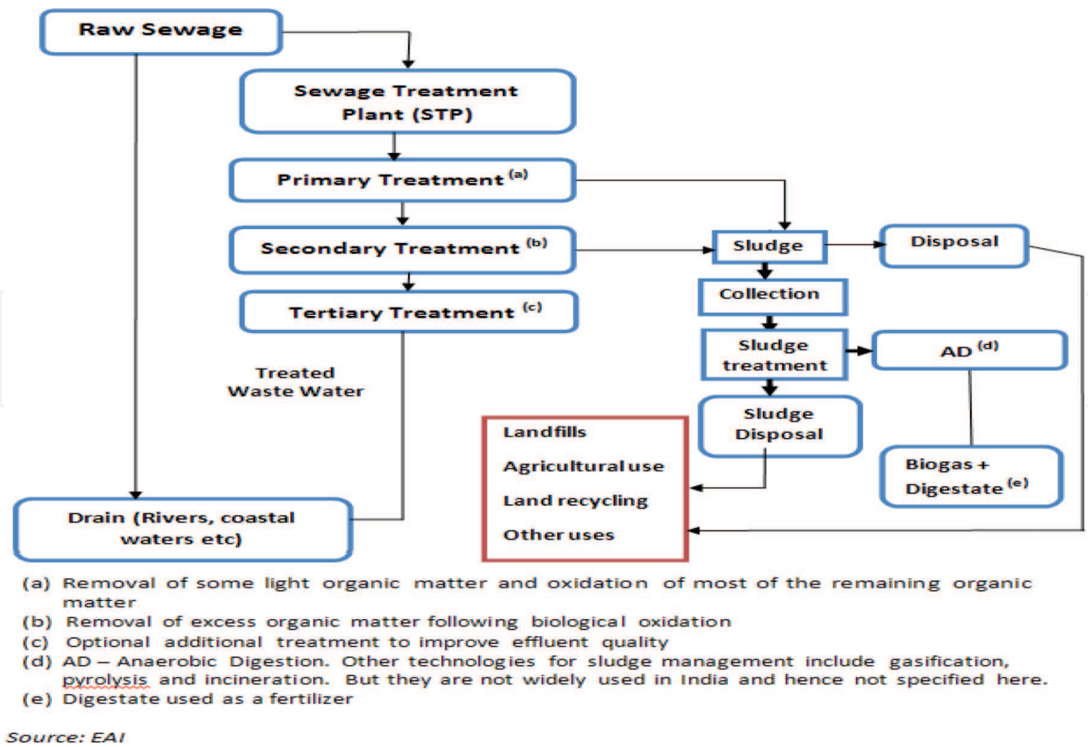

Figure 1.
Overall view of sewage treatment plant.

sewage liquor is treated with an aerobic biological process. The secondary treatment methods use filtration and aerobic treatments to separate and break down the content received in the secondary treatment unit [10]. The secondary sludge primarily encompasses microbial biomass and settled solids produced during the aerobic biological treatment of primary treated wastewater. Thus, the secondary sludge comprises the lipids from the lysed cell with lesser free fatty acids compared to the primary sludge [11]. The final stage of treatment is tertiary treatment. It is also known as effluent polishing. It is done to improve the quality of effluent when discharged into environments such as the sea, rivers, and lakes. The eradication of chemical pollutants obtained from pharmaceutical industries, particles present in household chemicals, chemical effluents for small-scale industry, and agricultural pesticides is quite difficult in the conventional sludge treatment procedures hence these waste/effluents might pollute the water bodies in the disposal areas. In spite of the lesser concentration of the disposal, these pollutants are sufficient enough to be toxic to aquatic life. Also, pharmaceutical disposals that could induce genotoxicity and microbial resistance are considered to be toxicologically relevant pharmaceutical pollutants. The reduction of the fourth stage of treatment is being followed in many countries recently. Additional to this odor control, biological nutrient removal, phosphorous removal, nitrogen removal, and disinfectants were also added before disposal.

5. Production methodology of biodiesel from MSS

The primary sludge flocs and secondary sludge has utilized as efficient raw materials for biodiesel production via the transesterification process. Initially, the lipids are extracted using various solvents. The stagewise extraction process was used to separation of lipid content from MSS. The efficiency of lipid extraction depends on the types of solvents or mixed solvents and the number of stages. Bharathi and Pennarasi [12] reported that using various solvents and their extraction efficiency of lipids from MSS (**Table 1**).

Lipids extraction is followed by the transesterification process for the production of biodiesel It is a chemically Fatty Acid Methyl Ester (FAME), formed by the transesterification reaction (**Figure 2**). Transesterification is a process that involves the swapping of the R (alkyl) group of triglyceride's esters with the R′ (alkyl) group of the alcohol compound [1].

The transesterification reaction may be a catalytic or non-catalytic process. Among these, the noncatalytic reactions are very slow and result in lesser yield compared to catalytic reactions. Hence, the transesterification reaction is manifested with the help of the catalysts and is a high-yielding process. Briefly, the complete transesterification process includes:

i. conversion of triglycerides to diglycerides,

ii. conversion of diglycerides to mono-glycerides and ultimately,

iii. conversion of mono-glycerides to glycerol along with the formation of biodiesel

6. Prominent status of nanotechnology

Nanotechnology is a wide field in which nano-sized materials are used for various applications. Nano-sized materials are in the size of 10^{-9} nm. Such particles are said to be nanoparticles. The nanoscale ranges from 1 to 100 nm (**Figure 3**). The advantage of nanoparticles is the reactive area gets increased as the size reduces from bulk size. This has been used in the past few decades in the form of silver and gold glittering paints in the church, palaces, etc. Such old technology has been tuned even better to increase the application in all the emerging fields. There are various things in nature in nano size, apart from that; mankind played a major role in creating new nanomaterials for their relevant applications.

There are a lot of industries and researchers concentrated on nanotechnology and its applications (**Figure 4**). They explore the technology in various fields like improvement in energy efficiency, telecommunication fields, cosmetics, textile industry, foods, medicines, etc. The efficiency of fuel production is considerably improved using nanotechnology. One of the fuel production methods is from natural materials and low-grade

Solvents	Lipids extracted from primary sludge (g)		Total (g)	Lipids extracted from secondary sludge (g)		Total (g)
	Stage1	Stage2		Stage1	Stage2	
Chloroform-Methanol	2.75	0.50	3.25	1.90	0.55	2.45
N- Hexane	1.83	0.62	2.45	1.65	0.45	2.00
Diethyl ether	1.72	0.60	2.32	1.70	0.45	2.15
Ethanol	1.10	0.40	1.50	1.26	0.50	1.76

Table 1.
Quantity of lipids extracted from MSS [12].

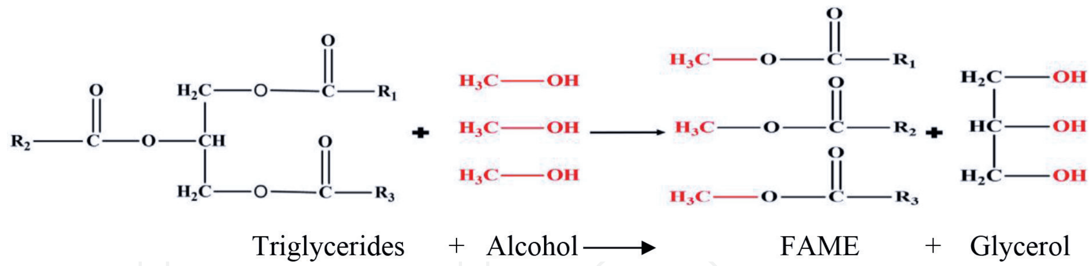

Figure 2.
General equation of transesterification of triglycerides [12].

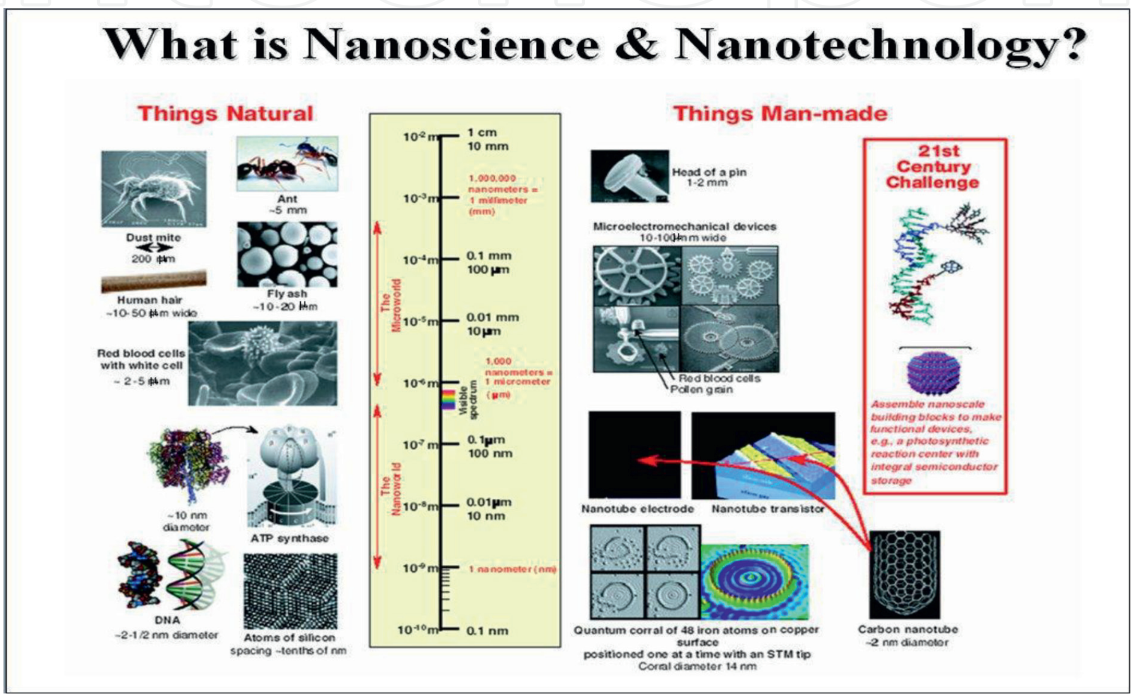

Figure 3.
Natural and artificially produced nano-sized things (https://philebersole.files.wordpress.com/2012/04/nanotechnology.jpg).

crude oil by improving catalysis. Through nanotechnology, the fuel efficiency in vehicles and power plants is improved through friction, which increases efficiency and reduces combustion. Nanotechnology plays a vital role in telecommunication transceivers. The nanoscale-based transceivers reduce the system complexity and improve the Quality of Service (QoS). Faster and more power-efficient electronic devices are constructed using nanoscale transistors and diodes. Nowadays, nanoscale type memory devices are used to equip supercomputers eg. Magnetic Random Access Memory (MRAM), which enabled tunnel junctions of magnetic nanoparticles, which quickly and effectively saves the data during a system shutdown or crash. Such nano-based chronic devices are used in aircraft communication as well as the resumption of play and used for the collection of accident data vehicles. Advancements in various cosmetic products like lotions, dermatological creams, shampoos, sunscreen lotions, and specialized makeup products are prepared by superimposed nanomaterials. In the cosmetic field, nanomaterials provide greater clarity and good coverage in cleansing, absorption, customization, antioxidant, and anti-microbial. Nanotechnology not only plays the role in the cosmetic industry but also in the food industry. Nano-engineered nanocomposite materials support food packaging in the food industry. Food packaging reduces the escape of carbon dioxide from the

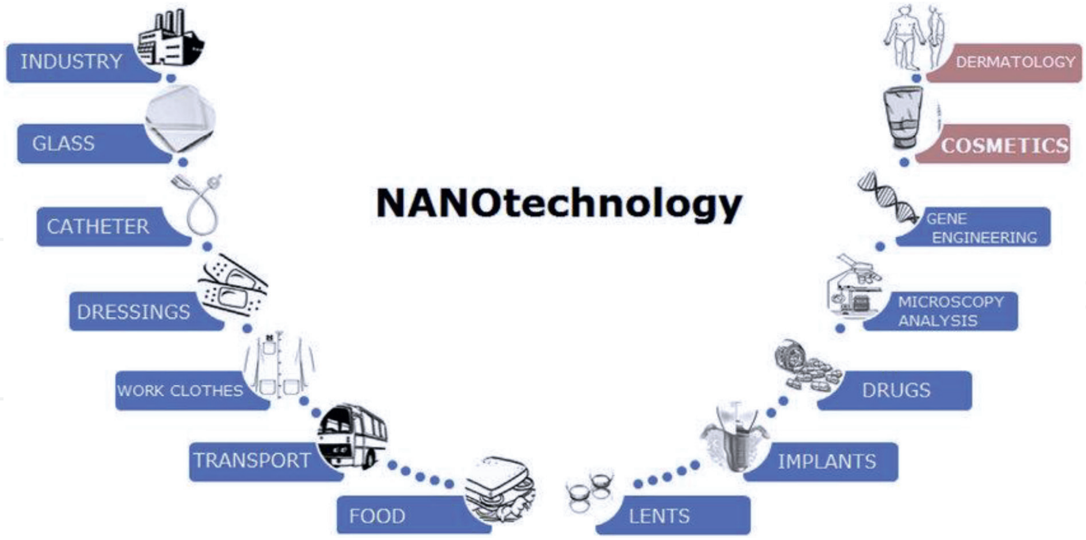

Figure 4.
Applications of nanotechnology (https://www.researchgate.net/profile/Karolina_Niska/publication/317719241/figure/fig 2/AS:555489508900864@1509450427466/Applications-of-nanotechnology.png).

soda and reduces the amount of oxygen, humidity, or the growth of bacteria to keep fresh and safest food for a longer period. Nanosensors embedded in plastic containers warn of spoiled food and are currently being developed nanosensors for the detection of pesticides and other contaminants in food before packaging and distribution. The use of nanotechnology in the medical field has vast appliances. It is used to stimulate the neurological systems and their growth. Nano-sensors are used to predict the damage to spinal and brain tissues. One of the methods supports structured nano gel filling the space between existing cells and encouraging new cells' growth. Quantum dots are semiconductor nanocrystals that can improve biological imaging for medical diagnosis. Researchers are developing customized nanoparticles that can deliver drugs directly to diseased cells in the body. When it is perfected, this method greatly reduces the damage during the treatment (eg: chemotherapy) done to the patient's healthy cells. Marvelous support of nanotechnology to the environment is to meet the need for clean drinking water which is affordable through low-cost rapid detection of impurities, purification, and water treatment systems. For example, researchers have discovered unexpected magnetic interactions between the very small spots that can help in the removal of arsenic or carbon tetrachloride from water and are currently being developed filters that can remove virus cells from nanostructured water and they were investigating how the ionization electrode using nano-sized fibers reduce the energy requirements and costs of removing salts from water. It is also used to degrade solid waste with less time when compared to the naturally occurring degrading process. It is also helpful in the process of conversion of waste sources to renewable energy available for use. Manufacturing the fabric with nanoparticles allows the introduction of upgraded fabric properties without a substantial increase in weight, thickness, or stiffness, unlike the other modification techniques. The photocatalytic activity of the nano TiO_2 in the fabric treated with Nano TiO_2 could impart an anti-bacterial effect and might reduce the staining. Nanoparticles are primarily used in the catalysis of chemical reactions. Hence, the usage of nanoparticles possibly reduces the need for additional catalysts that are necessary to achieve the desired results, with lesser capital and pollutants. The main applications involved in the field of oil refining, catalytic converters in cars, and catalytic reactions in renewable bioenergy production. The functional nanomaterials with antimicrobial properties can be used to build high-performance systems on a small-scale or point of use to increase the robustness of the network water supply and water networks that are not connected to the center and the emergency response network after catastrophic events. Nanotechnology can also be applied in the detection of even the minute quantity of gas and vapors with the highest sensitivity. Nanomaterials, such as quantum dots, carbon nanostructures, metal-based nanomaterials, and metal oxide semiconducting nanomaterials can be used as the gas sensing elements in the nanosensors. The nanoscale dimension of these nanomaterials helps in sensing the lesser level of the gas molecules that are adequate enough to tune the electrical properties of the detecting element, allowing the detection of the tiny concentration of gas vapors when nanoparticles are used. Nanotechnology can enhance the catalyst performance in transforming the vapor released from automobiles or industrial plants into harmless gasses as nanoparticles have a larger surface area which improves the interaction with the reacting chemicals compared to traditional catalysts. In addition, the larger surface area allows more chemicals to interact with the catalyst, making them ideal for sensing with higher sensitivity.

7. Role of nanocatalysts in various fields

The nanocatalysts have their own property which was usually targeted for specific applications. The four major properties are

- Magnetic property
- Optical property
- Electronic property
- Catalytic property

Nanocatalysts have placed their impact on almost all fields due to their multiple properties and uses toward the problem, thereby creating the best solution for the problems. Nanoscience contributes to the reduction in the size of devices and technologies with upgraded properties. The key applications of nanotechnology include, water purification, energy storage devices, biodiesel production, medical applications, dye reduction, fuel cell, carbon nanotubes, etc. [13].

Nanocatalysts are widely used in the following fields for a huge number of applications as follows:

- Chemical sensors
- Better air quality
- Electronics
- Sporting goods
- Batteries
- Fuel cells

- Solar cells
- Catalysis
- Medicine
- Textile industry
- Environment
- Water treatment
- Cosmetics
- Fuels
- Energy
- Food
- Space

Nanocatalyst is used against environmental pollution like wastewater treatment, soil remediation, waste degradation, chemical pesticide degradation etc. Nanoparticles are used as a catalyst in biodiesel production and plays the main role in photodegradation of methylene blue. Nanoparticles have applications in soil-plant systems in many ways like the delivery of pesticides and biopesticides, pesticide degradation, nanosensors for plant-pathogen detection, and also in fertilizer-controlled delivery [14]. Nanoparticles are employed in the delivery of genetic materials, in plant protection and nutrition like soil remediation, slow release of fertilizers, pesticide degradation, and in seed treatments [15]. The main important application of nanoparticles in agriculture was nanofertilizers. Nanofertilizers improve crop growth, yield, quality, and reduce fertilizer usage and cost for cultivation. It increases plant growth mainly by increasing the photosynthesis rate and also prevents plants from abiotic and biotic stress [16]. Applications of nanotechnology in precision agriculture are nano biosensors, early detection of viral disease in plants, nanoparticles serving as micronutrients for plants, nano herbicides, nano fungicides, and in insect pest management [17].

8. Nanocatalyzed transesterification process

Nanotechnology has an increasing impact in the fields of biotechnology, pharmaceutical technology, and pure technological applications. Nanotechnology places its main role in the conversion of biomass to bio-energy in various renewable resources. Implementing nanotechnology in the bioenergy production process gives a high impact on bio-energy research. Four categories of nanoscale area units are investigated as useful materials for water purification which are metal-containing nanoparticles, carbon nanostructures, zeolites, and dendrimers [18]. Nanotechnology reveals good results than the other techniques used in water treatment as they exhibit higher interaction with high surface area (surface/volume ratio) [19]. The present investigation of the potential applications of nanotechnology in water and wastewater treatments are adsorption, membrane processes, photocatalysis, antimicrobial efficiency, sensing, and monitoring [20]. Copper-doped zinc oxide nanocomposite (CZO) comes under heterogeneous catalyst as it contains both copper and zinc oxide nanoparticles in it. It shows a positive sign in the field of emerging catalysts as they are non-corrosive and can be easily separated from the product mixture. Doping is significantly used in enhancing the optical and electrical properties of semiconductors. Doping with transition metals leads to improving the interesting properties of zinc oxide [1]. CZO nanocomposite comes under heterogeneous nanoparticles, it can also be recycled and reused. CZO nanocomposite is a bifunctional heterogeneous catalyst. They gain attention because they carry out transesterification and esterification processes for both acid and base-containing reactions. The use of nanoparticles/nanocomposites as catalysts provides higher catalytic activity and selectivity due to its nano-dimension and morphological structure. Thus, the CZO nanocomposite can be used as a catalyst for the transesterification of lipids obtained from municipal primary sewage sludge. It increases the yield of biodiesel and can be recovered, recycled, and reused [21]. After the transesterification process, the mixture was separated and the byproducts are separated. The biodiesel had to be subjected to washing subsequent to the transesterification process to eliminate excess catalysts, methanol, glycerol, and soap. After washing, the biodiesel sample must be heated to evaporate solvents and water present in the mixture [22]. Gas chromatography-mass spectrometry (GC-MS combines the features of gas chromatography and mass spectroscopy to identify the different substances present in the test sample. Applications of GC-MS include drug discovery, fire investigation, environmental check, explosives examination, and documentation of unknown samples. In addition, it can help in the identification of the trace elements in the samples which were earlier assumed to have disintegrated beyond identification. GC-MS is broadly used in the analysis of the compounds such as esters, fatty acids, alcohols, aldehydes, terpenes, etc. The below process flow chart clearly shows the production of biodiesel from MSS via the nanocatalyst transesterification process (**Figure 5**).

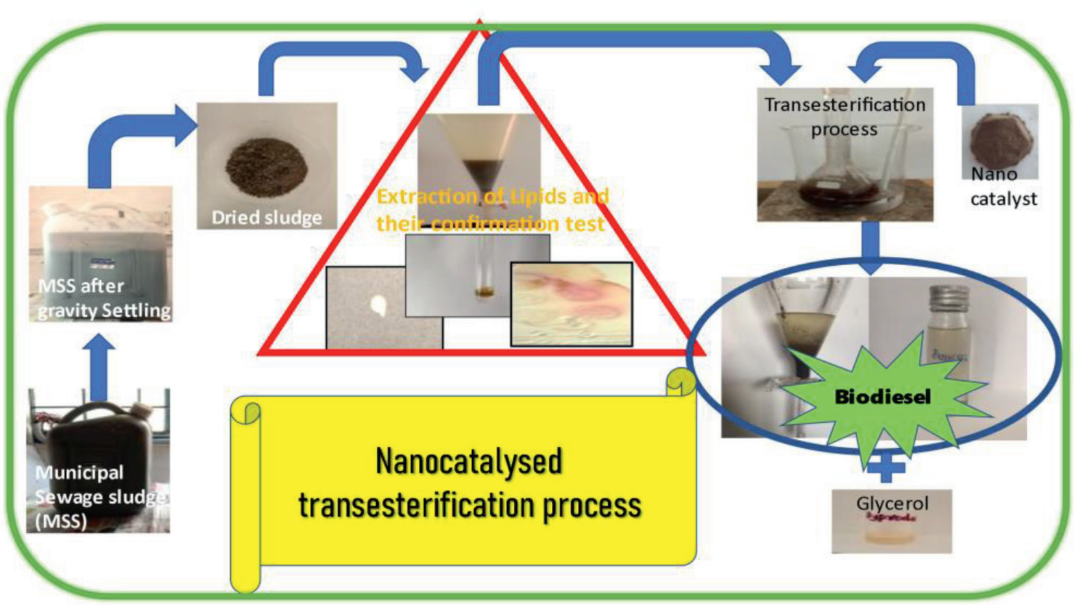

Figure 5.
Process flow chart of biodiesel production from MSS.

9. Quality standards of biodiesel

Quality is meant for long time goals, exactly successful use, without any technical problems of biofuel. It can be depending on many factors: mainly, the quality of the raw material chosen, lipid content composition. The physicochemical properties of biodiesel were the most significant parameters to speak about the quality of biodiesel. Some of the important physical and chemical properties are listed in **Table 2** with their ASTM standards (ASTM D6751-06).

These quality standards of biodiesel on the market are affected by various factors, which vary from place to place, and country to country. Mainly, it compares the characteristics of the existing diesel fuel standards, types of diesel engines commonly used in practice region and their emissions, and climatic properties around the regions. Therefore, the quality standards of biodiesel are varied on country/region. Not surprising that there are some considerable differences between the regional standards. **Table 3** shows a worldwide important biodiesel quality standard.

Notable properties of biodiesel

i. Cetane number (CN)

It is used to measure the combustion properties of diesel fuel. It is a measurement of the quality of fuel. Modern highway diesel engines require a CN ranging from 45 to

Properties	SI Unit	ASTM limits	ASTM methods
Physical			
Flash Point	°C	7130 min	D93
Density	kg/m^3	N/A	D4052
Kinematic viscosity	mm^2/s	1.9–6.0	D445
Water & sediment	Vol%	0.050 MAX	D2709
Cloud point	°C	N/A	D2500
Pour point	°C	N/A	D975
Distillation temperature	°C	360	D1160
Chemical			
Acid value	Mg KOH/g	0.8	0.664
Cetane No.	—	47 min	D613
Free glycerin	Mass%	0.020	D6584
Sulfated ash	Mass%	0.240	D6584
Carbon residue	Mass%	0.05	D4530
Sulfur	Mass%	0.05	D5453
Copper strip corrosion	—	3 Nos. max.	D130
Phosphorus	Mass%	0.001	D4951
Oxidation stability	Hours	3	EN15751
Methanol content	Mass%	0.2	EN14110

Min – minimum, Max – maximum, N/A – Not available.

Table 2.
Physical and chemical properties of biodiesel compared with ASTM standards (ASTM D6751-06).

Country/Area	Specifications	Title
EU	EN 14213	Heating fuels - Fatty acid methyl esters (FAME) - Requirements and test methods
EU	EN 14214	Automotive fuels - Fatty acid methyl esters (FAME) for diesel engines - Requirements and test methods
The U.S.	ASTM D 6751 -11a	Standard Specification for Biodiesel Fuel Blend Stock (B100) for Middle Distillate Fuels
Australia	—	Fuel Standard (Biodiesel) Determination 2003
India	IS 15607	Bio-diesel (B 100) blend stock for diesel fuel - Specification
Japan	JASO M360	Automotive fuel - Fatty acid methyl ester (FAME) as a blend stock
South Africa	SANS 1935	Automotive biodiesel fuel

Table 3.
Biodiesel standards [23].

55. The higher CN, the more fuel burns better within the engine. And also, it is associated with ignition delay time, engine knock, carbon monoxide emissions, combustion efficiency, smoothness, and hydrocarbon and nitrous oxide emissions [24, 25]. The length of the hydrocarbon chain increases with increasing CN, which leads to a decrease in the saturation state in the carbon chain of the Fames. The estimation of the CN formula was given below for individual fatty acids. These models were developed using a combination of [26, 27].

$$CN = 1.068\, \Sigma\, (CN_i m_i) - 6.747$$

Where CNi – Cetane number, m_i – The mass percentage of FAME

ii. Viscosity

It is the predominant parameter with an impact on the fuel quality, since it plays a vital role in the fuel atomization process. High viscosity can lead to the coking process, and affect the combustion and emission rates from the engine. Generally, viscosity decreases as temperature decreases which leads to fuel components being saturated and causing precipitate problems. This may arise from clogging the fuel lines, pumps, and filters [25, 26]. As per the EN14214 guidelines, the specification for viscosity is 3.5–5 mm^2s^{-1} for 40°C. The degree of saturation of compounds depends on the viscosity of the fuel [28].

Allen et al. [29] proposed a mixture model for the estimation of viscosity,

$$\ln \mu_m = \sum_{i=1}^{n} y_i \ln \mu_i.$$

where μ_m is the viscosity of the mixture and Yi and μ_i mole fraction and viscosity of individual component I respectively.

iii. Oxidation properties

It is a difficult parameter to understand properly not unlike other properties such as cetane number since it is dependent on the bulk composition of the fuel. The double bonds present in the Fames are prone to autoxidation, which leads to deterioration problems in the fuel system [28]. It is used to measure the fuel resists oxidative degradation property which determines the fatty acids occurrence with double bonds in feedstocks. A non-linear relationship between oxidation rate increases with an increasing double bond in a Fame. Minor components provide disproportionate effects on oxidative stability inhibiting oxidation. Therefore, to change the oxidative stability, any of the other properties to be improved by additives.

iv. Density

It is a significant parameter, with an impact on fuel quality. The density of biodiesel usually varies between 0.86 and 0.90 g/cm^3 [30]. The non-edible biodiesel densities are also in the range of 800–965 kg/cm^3 [31]. Generally, molecular weight is one of the important factors that contribute to fuel density. Densities are calculated with respect to various temperatures, instead of the standard value at 15°C, available at EN 14214. The ASTM standard procedures are also available at 15°C, required by D1298 [31]. The liquid densities are calculated by following the formula using the relationship between the molecular weight and molar volume.

$$\rho = \Sigma\, x_i\, MW_i / \Sigma x_i\, V_i.$$

where x_i is the molar fraction of the component and Vi is the molar volume of a liquid [32].

v. Flashpoint

It is the lesser temperature at which the liquid gives off its vapor, the lower the flash point the easier to ignite the material. Mostly the flash point of the combustible liquid is 104°C. It is used to analyze the hazards of fuels, which are less than 37.8°C are called flammable, whereas above that temperature are called combustible. Each biodiesel has its own flash point. Moreover, the flash point is affected by many factors including the number of double bonds, the number of carbon atoms, the chemical composition of the biodiesel, pressure, oxidant, and apparatus sheltering [33]. Different test methods are available to determine the flash point of biodiesel which includes the EN test method and the ASTM test method. In addition to the observation that both boiling point and flashpoint decrease with decreasing pressure, the literature, and the ATSM standard D6751 recommend a flash point of biodiesel is 130°C except for non-edible biodiesel.

vi. Cloud point and pour point

It is the minimum temperature at which the first nuclei crystal formation takes place. The pour point is the minimum temperature below which a liquid loses its flow characteristics. Comparatively, the cloud point is of a high value with high temperature and a low value with low temperature. Generally, biodiesel has higher cloud and pour points than conventional fuel [34]. Specifically, the standard ASTM D2500 and D97 test methods are available to measure the cloud and pour point. Generally, most biodiesel properties are matched with diesel fuel except cloud and pour point. These are low-temperature properties. Much literature indicated that the cloud point of pure biodiesel is around 13°C, and for pure biodiesel is 0°C. Cloud points may be achieved by adding liquid additives. It has a very low solidifying temperature and is highly soluble in biodiesel.

10. Economic impact of biodiesel

Energy consumption is of great concern globally due to its availability. Also, global energy consumption is increasing day by day. To IEO 2016 projection, over the years 2010 to 2040, the total energy consumption is expected to increase by 50% compared to previous decades. The major part of the energy is being utilized by the developed countries due to their richness in economy and population. Apart from energy sources like coal, natural gas, and crude oil; petroleum-based fuels are in great demand. These fossil fuels are scarce and impose a negative impact such as the production of greenhouse gases and causes air pollution. Also, the excessive utilization of these fossil fuels is heading toward the global depletion of natural resources, demanding an equal and effective alternative, giving birth to renewable energy resources such as biodiesel. Biodiesel is generally produced by trans-esterifying fat-based feedstocks like waste cooking oil, oil-based industrial effluents, vegetable oil, and animal fat, waste sludge. The cost of the final product (biodiesel) will vary according to the kind of feedstock. Shifting fossil fuel to biodiesel is not easier due to less yield and high production cost. Researchers continued exploring the various options of biodiesel synthesis to reduce production costs, as it poses a major challenge in the extensive utilization of biodiesel.

Considering the traditional biodiesel etproduction technique, the most important costs in the production of biodiesel are capital investment costs and operating costs. The costs covered under capital investment are equipment and plant establishment costs. The plant establishment includes the cost of installation of equipment, instrumentation, pipelines, electrical lines, and a few other auxiliary developments. The operation costs include feedstock, catalyst, utility, labor charge, maintenance, and repair of equipment [35, 36]. Among these expenses, the feedstock significantly impacts biodiesel's economy, imparting more than 75% of the total production cost [35]. To reduce the feedstock cost, the poor quality of feedstock or reuse of feedstock is much preferred. These will influence the excessive release of free fatty acids (FFA) and increase the water content. The presence of excess FFA and water content in turn reduces the yield and quality of biodiesel [37]. To improve the yield and quality, additional processing steps should be carried out which in turn increases the production cost. A better and good quality of feedstock without compromising the food demand and environmental impact and which could reduce the final cost is much preferred and being in trials by many researchers and scientists. The choice of feedstock varies country-wise by their utilization of crops. Argentina prefers soybean as a feedstock owing to its less cost. While China does not choose soybean as a biodiesel feedstock as soybean oil is a staple demand in Chinese foods [38]. Jatropha and castor oil-based feedstocks are favorites in India [39]. Waste cooking oil and animal fats are ideal in countries like Japan, Canada, and Australia [40].

Waste cooking oil is one of the better preferences of feedstock in producing biodiesel. By utilizing waste cooking oil, roughly 1.5 ratios of energy output to input, can be obtained and approximately two times income can be obtained compared to the total expenses [41]. A study on biodiesel production from *Calophyllum inophyllum* oil gave an idea of the economic performance of heterogeneous catalyst-based production of biodiesel. The influence of the cost of feedstock on the net present value and payback time was investigated in detail. The cost of the feedstock is in the range of 0.2–0.5 $/kg. In the case of a lesser feedstock price of 0.2 $/kg, the net present value is about 31 million dollars, with a payback time of 0.41 years. While the feedstock purchase cost of 0.5 $/kg and above poses a negative impact on net present value with the payback period being the time past the project completion time. Apart from lesser feedstock cost, the recovery and utilization of methanol and heterogeneous nanocatalyst could greatly reduce the cost of biodiesel [42]. The non-edible source of feedstock like microalgae is used to reduce the exploitation of food crops and oils in the production of biofuels. Microalgae as a feedstock are advantageous concerning their higher production rate, lesser environmental impact, and lesser requirement of land for setting up a biodiesel plant, which could in turn reduce the cost of biodiesel. In recent years, microalgae have been one of the most promising feedstock choices to produce biofuel which could replace approximately 50% of the fossil fuel demand as the mass cultivation of microalgae and its availability could greatly bring down the production price of biodiesel [43].

In addition, the cost of biodiesel varies greatly, in accordance with the type of catalyst used, which can be either homogeneous or heterogeneous. A heterogeneous catalyst has the limitations like deprived interaction as there might be restricted diffusion of the catalyst when it exists in different phases of reagents. In the case of a homogeneous catalyst, the separation and reuse of the catalyst are quite tedious. The behavior of nanocatalysts lies in between homogeneous and heterogeneous catalysts, with notable advantages like good selectivity, sensitivity, separation, and reuse of catalyst [44, 45]. The careful selection of catalyst reduces the number of processing steps and favors the reusability of the catalyst, which in turn supports minimizing the total production cost of biodiesel [46]. The magnetic nanomaterial-based catalyst is proven to be very effective in biodiesel production compared to the conventional catalyst, owing to its availability, size, surface area, high surface-to-volume ratio, stability to different reaction conditions, resistance to saponification, reusability, and wide synthesis options [46]. Also, the higher surface-to-volume ratio of the nanocatalyst favors simultaneous reactions to take place at the same time which in turn accelerates the process [47]. The acceleration of the reaction process contributes to minimizing the production cost. In addition, magnetically separable nanomaterials can easily eliminate the separation protocol for the recovery of catalysts [23, 48]. Bharathi and Pennarasi [12] estimated the cost of sludge biodiesel (**Table 4**). The overall production cost is 3.11 USD per gallon, but they did not include the byproduct (glycerol) sale cost. Surely it will reduce the overall biodiesel production cost as well.

Particulars	Cost per gallon (US $)
Centrifuge O&M	0.43
Drying O&M	1.29
Extraction O&M	0.34
Biodiesel processing O&M	0.60
Labor	0.10
Insurance	0.03
Tax	0.02
Depreciation	0.12
Capital P&I service	0.18
Total cost	3.11

Table 4.
Cost estimation for sludge biodiesel [39].

11. Summary

Biodiesel has several benefits over diesel fuel. The production cost only is a major problem compared to petro-diesel. And also, vegetable oil and animal fats are the raw materials for biodiesel production causing the cost of biodiesel to increase. MSS is a waste and lipid source readily available for the extraction of lipids for biodiesel production. MSS treatment for biodiesel production may be used in a waste treatment facility with limited expenditure on raw materials. Also, municipal waste might not contribute to the landfill issue and renewable sewage waste can be considered for biodiesel production instead of depending on edible sources of raw material. But there are some disputes with MSS. The pre-treatment process includes collection, dewatering, drying, etc. The lipid extraction steps also need more amount of organic solvents which will increase the production cost. However, the amount of lipids depends on the type of sludge. Sludge-to-solvent ratio, extraction time, and solvent recovery are the factors that affect the efficiency of lipid extraction and cost. Optimization is only one solution to reduce the cost concerning the above factors. The role of catalyst for biodiesel production is also the most important. Acid and alkali transesterifications are high-cost and slow processes. Comparatively nanocatalyst transesterification is less costly and fast. Factors such as the choice of nanocatalyst based on its properties and type of feedstock will be highly favorable in improving the transesterification reaction. Based on the demand of the biodiesel market, the designing of these factors can be modified and improved. The nanocatalysts which are being developed in the recent past are highly preferred for the heterogeneous catalysis reaction as they are highly suitable for improving the efficiency of the transesterification process. Nanocatalysts can play a major role in improving the yield of biodiesel as they possess good surface area which could favor the catalytic efficiency and trigger the overall catalytic reaction. In spite of all these advantages, extensive research work is necessary to get optimization for biodiesel production from MSS and to study the toxicity levels of nanocatalysts before utilizing them in biofuel production and making a good profit from any source of raw material. Nanocatalysts could serve as efficient catalysts as they are recyclable, have less production cost, and possess a good life which could greatly influence the overall production cost of biodiesel. It is observed that the primary energy demand is set to double by 2040, therefore the use of alternative fuels such as biodiesel is bound to grow as well. In the meantime, it is observed that the percentage of MSS also increased due to the high population. This review insists on the methodology available for the production of biodiesel from MSS. It strongly helps future research thereby there is one forward step to save the environment and increase the global economy values.

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