Chapter 18

Current trend in the application of nanomaterials in biofuel and bioenergy

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18.1 Introduction

Nanotechnology is the field that employs techniques involved in the synthesis and manipulation of substances in the range of about one billionth of a meter (Raheem et al., 2017). Such a reduced size facilitates nanomaterials with beneficial physicochemical and electrical conductivity properties that are not found in the bulk structures (El-Seesy, Hassan, Ookawara, Attia, & Abd-Elbar, 2018). The fabrication of nanomaterials from the bulk material results in the maximum utilization of the potential of the material with an increased surface area to volume ratio (El-Seesy, Hassan, Ookawara, Attia, & Abd-Elbar, 2018; Sahoo & Seckbach, 2015), which makes it more optimal for use in a wide range of industrial operations that need better technologies to reduce the amount of raw materials used and increase the efficiency of the process and product output. Nanomaterials have such exemplary properties that if they are used on a large scale that can revolutionize the materials science field, reducing material losses and attaining effective optimized products in terms of size and operation. Nanotechnology can be used to reduce the environmental impact and usage of fossil fuels.

The decreasing fossil energy reserves pose an alarming threat for the need to produce biofuel on a large scale (Antunes et al., 2017). Governments and research institutions have been facilitating funding of such projects to help increase the development sources of such eco-friendly and sustainable alternative fuels. The increasing global population and industrial activities have increased the need for these fuels, which have lower carbon emissions, thus reducing the adverse effects of vehicle emissions and depletion of nonrenewable energy resources (Antunes et al., 2017). The biofuels are

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completely reliable as they use organic waste compounds as substrate that in turn decreases the rate of investment on substrate and also facilitates effective management of solid wastes (Ramsurn & Gupta, 2013). Solid waste from organic compounds is considered as organic hazards that, when dumped in land and water bodies, form an undesired biological layer that can affect the health of local inhabitants (Ramsurn & Gupta, 2013).

The need and demand for bioenergy is increasing tremendously and it is developing as a field that generates many employment opportunities and sustainable national revenue and also a source of employment for rural populations (Sahoo & Seckbach, 2015). Despite having greater advantages and sustainable technologies that would help in the large-scale production of biodiesel, it has the disadvantage of difficulty in attaining the desired performance to run internal combustion engines.

In addition to the use of nanomaterials in the production of biofuel they have also been used in the design of various energy systems that could reduce the difficulties encountered in the usage of expensive and conventional energy technologies. Nanotechnology has been used in the development of nanomembranes that facilitate the effective transfer of hydrogen ions and result in the production of compact and simple devices that are an effective option for existing conventional systems.

Nanostructures are also used at different stages of biofuel production (Basha, 2017). They are used to increase the efficiency of the process, thereby ensuring product quality and reducing product losses. The use of nanotechnology devices facilitates an increased rate of heat transfer and also helps in achieving the critical parameters set for the optimal running of an operation.

Nanotechnology has been used to increase the durability and stability of existing energy systems and also increases the recycling potential. It also results in the development of greener and cleaner technologies that would be far better functional and improving the efficiency of power-producing systems (Basha, 2017; Sahoo & Seckbach, 2015).

18.2 Utilization of biofuel on a global scale

The increase in price of crude oil and also the cost involved in its purification process have also forced the world to seek an alternative fuel that can get rid of all the drawbacks of conventional fuels. It is also estimated that global fuel reserves will be almost exhausted by 2050. This in addition has set a new method for the implementation of effective technology to compete in the global fuel market.

Liquid fuel consumption has been estimated at a global level of the order of 80 million barrels/day (equivalent to 12.7 million m^3/day) (Kramb, 2011). This is equivalent to an ethanol volume of about 700 million hectares, assuming a yield of 6.5 m^3/ha/year of ethanol. This is equivalent to 100

times the sugarcane-cultivated area in Brazil, which is the second largest producer of biofuel. In 2010, biofuel and biodiesel combined replaced 3% of the global oil use (Kramb, 2011). Currently, alcohol-based biofuel is the largest part of the biofuel production within the conventional bioenergy industry.

18.3 Nanotechnology in biofuel production

In the process of biofuel production, the distillation process is an energy-consuming part (up to 60% of the total energy required). The distillation process involves the separation of water from the liquid fuel to attain the desired concentration (Rai, Ingle, Gaikwad, Dussán, & da Silva, 2017). Water removal from ethanol distillates is a crucial step and various nanostructures have been deployed in this process, such as nanoporous carbon and zeolite (Rai, Ingle, Gaikwad, Dussán, & da Silva, 2017). Zeolite has been found to be efficient in the selective adsorption of ethanol and n-butanol.

There are factors that should be considered for reducing the carbon emissions from a diesel vehicle, as follows (Antunes et al., 2017):

1. Adjustment of the combustion process for a compression ignition engine;
2. Alternative fuels;
3. Application of after-treatment techniques (Antunes et al., 2017).

To meet the above conditions the most commonly exploited biofuel is biodiesel, which is considered to be a sustainable source, nontoxic, and also exhibits excellent lubricity performance. It has been claimed that the necessary mitigation of hydrocarbon, carbon monoxide, and nitrogen oxide emissions can be reached through the use of biodiesel from different feedstocks (Antunes et al., 2017).

Nanotechnology has been utilized in the field of biodiesel production for developing nanostructures that facilitate the mechanism of biodiesel production from organic substrates such as agriculture residues, starch from corn, sugarcane, animal fats, and oil. The successful uses of nanotechnology in biofuel technologies include transesterification, anaerobic digestion, pyrolysis, gasification, and hydrogenation for the production of fatty esters, biogas, and renewable hydrocarbons (Lee & Juan, 2017). A very popular method of harnessing biofuels involves the removal of water from fractional distillation products from ethanol (Ziolkowska, 2018).

Metal nanoparticles have been of particularly special interest with respect to energy requirements. They have been employed as nanocatalysts, nanoclusters, and nanostructures of amorphous alloys, metals, and metal oxides to improve the efficiency of energy-yielding chemical reactions (Kramb, 2011). The available industrial methods for this purpose are not energetically favorable as they require high temperature and pressure. The oxidation of cyclohexanol by direct attack of oxygen is an endothermic process. The real ambition is to find alternative oxidizers which can help in overcoming the

endogenicity of the reaction and save a substantial amount of energy. This has resulted in the incorporation of several alternative oxidizers for this process (Wong, Perilla, & Paddon, 2014).

One such alternative is nanocatalysts that have been used in biodiesel production as they have been found to be effective in increasing the yield and rate of biodiesel production (Mguni, Meijboom, & Jalama, 2012). A study by Murashi et al. successfully employed iron powder for this process which enabled the oxidation of cyclohexane to be carried out in a very easily controllable manner and also under ambient room temperature and pressure conditions. They obtained a conversion rate of 11% and selectivity of 70% for the formation of cyclohexanol and cyclohexanone. In order to improve the selectivity, the reaction can also be performed at 70°C and pressure of 8 atm of oxygen in the presence of a solvent. This provides a great insight and scope to the use of nanophased catalysts for efficient bioconversions as they have larger surface areas (Rai & Da Silva, 2017). It has been demonstrated that, with the use of cobalt nanoparticles as catalysts at 70°C and under 40 atm of oxygen for about 8 hours, the conversion extent of cyclohexane goes up to 67% (Rai & Da Silva, 2017). These findings successfully demonstrated that nanophased catalyst particles are very potent energy savers in terms of their excellent product yields.

Nano-fly ash and nano-bottom ash have been also found to have an effect on anaerobic digestion as they tend to provide more habitats for anaerobic organisms (Rai & Da Silva, 2017; Rai, Ingle, Gaikwad, Dussán, & da Silva, 2017). Nano-fly ash was found to increase biogas production by 2.9 times and nano-bottom ash was found to increase biogas production by 3.5 times.

18.4 Nanostructures used in biodiesel production

Biodiesel is a mixture of esters produced by transesterification of vegetable oils or animal fats with short-chain alcohols like methanol or ethanol (Rai, Ingle, Gaikwad, Dussán, & da Silva, 2017). Biodiesel can be produced from many biological sources such as animal fats, vegetable oil, algae, and nonedible oil seed crops such as *Jatropha* (Rai, Ingle, Gaikwad, Dussán, & da Silva, 2017). Microbial enzymes have been bound with nanomaterials to enhance biodiesel production. Enzyme lipase *Pseudomonas cepecia* has been found to be effective in the process of transesterification.

Carbon-based nanostructures and sodium titanate nanotube structures have also been found to be effective in increasing biodiesel production. The most exploited organic source is algae which are preferred for their growth rate and abundant yield meaning they use a small area in comparison with traditionally used sources of diesel.

Algal resources are used for the production of biodiesel as they have the potential to generate a huge volume of biodiesel and do not depend on large areas of land for operation (de Lourdes Oshiro et al., 2017). Researchers

have developed different production systems for the growth and harvesting of algal species on a large scale. Algal ponds and photobioreactor systems are currently used in the process of growing algal species (Verziu et al., 2008). They provide a larger surface area for the growth of algae by facilitating the organisms with sunlight, oxygen, and CO_2. The algal cells contain triglycerols (a precursor of biodiesel) at up to 80% of their dry cell weight, which is the maximum capacity attainable in their lifetime and under optimal growth conditions (Verziu et al., 2008). The large-scale algal ponds tend to provide a higher yield than photobioreactor systems and the operating cost and maintenance are more feasible in the large-scale algal ponds as compared with the photobioreactor systems (Ma, Liu, & Meng, 2017).

Researchers have also reported that the efficiency is less than 40% in photobioreactor activity in terms of the algal biomass yield capacity in addition to the rate of biofuel production (Pattarkine & Pattarkine, 2012). The major challenges faced by commercialization of algal biofuels can potentially be solved using nanotechnology (Hussain et al., 2017).

Nanofarming technology has thus proved to be very effective by enabling the synthesis of biofuels without the disruption of biocatalysts (Nizami & Rehan, 2018). Nanoporous carbons and a variety of other inorganic derivatives are currently on the verge of being established and developed as adsorbents for biofuel separation (Madhuvilakku & Piraman, 2013; Malik & Sangwan, 2012).

The problem behind using lignocellulosic-based biomass for biofuel production is the lack of an efficient technology which can provide a good output for efficient conversion of biomass into liquid fuel. Advances in nanotechnology have made it possible to control molecular-scale chemistry, which in turn has enabled better control over the conversion of biomass into biofuel (do Nascimento, Rebelo, & Sacher, 2017).

With the development of nanofiltration techniques, along with the principles of ultrafiltration, the efficiency of the separation of glucose from the lignocellulosic compounds has been increased fourfold (Basha, 2017). Nanotechnology can pave the way for better biogas production through the use of nanocatalysts, which ensure efficient bioconversion strategies, better breakdown of substrates, and more optimized output delivery (Trindade, 2011). The nanotechnology-based materials which include everything from nanocatalysts to nanoparticles as construction agents of the plant design could prove to be a huge asset in harnessing this renewable energy (Kim & Lee, 2015; Pugh, McKenna, Moolick, & Nielsen, 2011).

Carbon nanotubes (CNTs) are effective in the delivery of enzymes with high enzyme-loading capacity. However, these structures have been exploited on a large scale for various purposes, but the development of CNTs for biodiesel production and the study of its operation have shown effective functioning and performance in delivering the target molecules to increase the transformation on the bioconversion process (Goh et al., 2012).

Research can be directed toward the production of bioactive nanometal oxides and nano-zero valence metals in various proportions. Another method to increase methane production is to explore the research activities of bioactive nanometal oxides and nano-zero valence metals in different proportions.

18.5 Conclusion

Nanotechnology has therefore solved some very crucial global problems ranging from the energy crisis to manpower requirement. It has also supported quicker and more reliable productivity. It has been the backbone of energy mitigation over the past two decades. There is no doubt that the distribution of the developmental and application reforms remain abruptly distributed throughout the world, however this technology is on the verge of rapid acceptance and application by the most developed nations also. It has provided a much needed boon to the everyday problems of mankind which are dependent on increasing requirements for energy. The solutions provided by the successful intervention of nanotechnology are highly significant and that is why projects on nanotechnology-mediated devices improved energy harnessing and are receiving a very welcomed increase throughout the world.

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