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Bio methanation potential of lignocellulosic waste for biofuel production

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Abstract

Technological development and industrialization have put a huge burden on fossil fuels for meeting energy requirements. Over-use of these non-renewable energy currencies is greatly deteriorating the environment. Therefore, biomass for biofuel production is contemplated as the best alternative. Lignocellulosic biomass such as paddy straw which is produced abundantly can be anaerobically digested for fulfilling energy needs. However, it suffers from certain limitations such as an unbalanced C: N ratio which reduces energy yield. This problem can be alleviated by the use of certain nitrogen-rich substrates such as microalgae as co-feedstock. Co-digestion of paddy straw with microalgae solves a dual purpose, first, it produces clean biofuel which is a renewable energy source and second, it alleviates the nationwide problem of paddy straw management.

Introduction

The most crucial factor for human existence is energy. A substantial portion of total energy demand is quenched by the use of fossil fuels such as petrol, coal, and natural gas (Fernandes *et al* 2007). Primary energy consumption rate has enhanced during the last 50 years owing to increasing population, growth of industries, and development of technologies further creating two exigent situations including energy crisis and environmental contamination (Gupta and Tuohy 2013). Several noxious and harmful gases and contaminants are released by the burning of these fuels causing the elevation in temperature creating water

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scarcity in arid areas, torrential rainfall, and glacier melting with an increase in sea water level. Escalating fossil fuel demand and detrimental effects caused by its overuse have persuaded environmentalists to search for some alternate source of renewable energy.

Renewable energy sources can effectively manage issues like energy security and other environmental concerns at the global level by reducing emissions of greenhouse gases and cleaner fuel production. Some oilseeds, aquatic plants, and wastes such as food wastes, municipal wastes, agricultural wastes, etc. have been recognized and employed as energy fuels (Kodihalli *et al* 2018). Recently, biofuel production from biomass is the topic of extensive research. Many commendatory properties of biofuels such as low toxicity, renewability, biodegradability, and easy production of animal fats, starch, vegetable oils, and microalgae make them the most viable and suitable alternative to fossil fuels (Aro 2016). Another advantage is that the biomass-to-biofuel conversion cycle emits no net carbon dioxide (CO_2) as it is a CO_2-neutral process (Schenk *et al* 2008).

India is an agricultural land with about 600 Mt of crop residues produced per annum (Jain *et al* 2014), among which paddy straw is the major contributor to the total residues generated. Burning of crop residues is practiced in some states which emit contaminants such as methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2), nitrogen oxide (NO), carbon monoxide (CO), aerosols which is the root cause of several respiratory diseases. Besides, loss of nutrients such as carbon, nitrogen, phosphorus, potassium, and sulfur result in soil erosion, disturbance of nutrient cycling, and organic carbon pool depletion (Mittal *et al* 2009). However, paddy straw or other lignocellulosic crop residues can be effectively managed by anaerobic digestion. The article presents a comprehensive overview of biofuel production by anaerobic co-digestion of lignocellulosic waste along with microalgae biomass.

Lignocellulosic waste as a suitable substrate

Lignocellulose waste is comprised of hemicellulose, lignin, cellulose, phenolics, and other inorganic substances. It is not only an economical and renewable source, but it also produces higher biomass yield along with carbon dioxide sequestration during the whole year. Some prominent examples of lignocellulosic wastes are manure, crop residues, agro-industrial wastes, sugarcane, bagasse, and sawdust (Ishaq *et al* 2020).

What is anaerobic digestion technology?

Anaerobic digestion is the eco-friendly approach for the utilization of biomass such as

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lignocellulose for bioenergy production. Anaerobic digestion of paddy straw for biofuel production offers technology for cleaner energy production and decreases the practice of open burning. In this process, methane gas is produced as a major product by the conversion of organic matter along with biofertilizer as a by-product. Hence, it is pondered as the most eco-friendly and economically stable process for biomass to biofuel conversion (Candia-García *et al* 2018).

Structure of paddy straw

Paddy straw is a lignocellulosic waste with fibrous nature and is primarily composed of cellulose and hemicellulose fibrils lodged into lignin molecules through covalent and non-covalent bonds (Shafie *et al* 2013). The typical composition of paddy straw is 38-40% glucan, 20-22% xylan, 3-4% arabinan, 13-15% lignin, and 17-20% ash (Kadam *et al* 2000). Structural complexity, high C: N ratio, and silica concentration are some of the major challenges associated with its anaerobic digestion (Teghammar *et al* 2014). However, factors such as abundance, pretreatment methods adaptation, and co-digestion with nitrogenous substances help in increasing the biodigestibility and overall efficacy of the process.

Why is co-digestion technology required?

Anaerobic co-digestion is the process of digestion of two or more substrates simultaneously with higher biogas yield and co-treatment of several wastes in a single unit. The substrates must be cheap with low moisture content and detention time along with high biogas production potential (Asam *et al* 2011).

Earlier, Yen and Brune (2007) reported that the optimal C: N ratio for efficient anaerobic digestion is 25 to 30 while the C: N ratio of paddy straw is 90:1. Consequently, a lower yield is obtained by the mono-digestion of paddy straw alone. That surplus amount of carbon is acted upon by microbes for fulfilling their energy needs for rapid completion of the hydrolysis step which causes the pH to fall in the acidic range and ultimately stops the process (Mussoline *et al* 2013). However, by the exogenous supply of nitrogen source, C: N ratio can be balanced (Sharma *et al* 2014). Therefore, co-digestion of lignocelluloses or paddy straw with co-feedstocks such as microalgae, dairy waste, manures, food wastes, and aquatic plants which are nitrogen-rich substrates is preferable.

Microalgae as co-feedstock for anaerobic digestion

Microalgae are classified as photosynthetic microscopic organisms ranging in size from 2 to 200 µm and may be prokaryotic or eukaryotic in nature with the capability to survive in harsh conditions (Greenwell *et al* 2010). These biological resources have a wider range of adaptability to varying environments and can grow both autotrophically as well as mixotrophically with simple requirements of water, nutrients, light, and CO_2 (Daneshwar *et al* 2019). The cultivation of microalgae is a function of several physical and chemical factors such as temperature, light, pH, nutrients, and salt concentration (Singh and Dhar 2011).

Advantages of co-digestion

Co-digestion of two or more substances for biofuel production is a very advantageous process. Besides, it offers several other benefits also which are given below (Nkemka and Murto 2010):

1. Dilute toxic compound substances.
2. Maintains nutrient balance.
3. Shows Synergistic effects on microbial population.
4. Enhances biodegradable organic matter load.
5. Increased methane yield.

Conclusion

The present article shows that the burning of crop residues such as paddy straw in countries like India is a serious environmental menace. Biomethanation of paddy straw not only serves the purpose of waste management and reduction of environmental pollution but also produces biofuel which is the best alternative to non-renewable pollution-causing fossil fuels. There are certain constraints such as an imbalanced C: N ratio of paddy straw which prevents efficient methanation. It can effectively be handled by using strategies such as co-digestion with nitrogen-rich substrates. Moreover, digested slurry obtained as a by-product of anaerobic digestion makes the process more eco-friendly and economical. However, deeper insights into the study are needed for making the process more sustainable and viable commercially.

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