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Circular Bioeconomy for Sustainable Development:Biohydrogen Production From Different Lignocellulosic Wastes

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ABSTRACT

The production of bio-hydrogen on a large scale came into thought after the rapid depletion of fossil fuels. It has been known for more than 70 years that algae can make bio-hydrogen under illumination. The substrates used in the present study were lignocellulosic wastes (agricultural wastes), sewage wastes and livestock wastes. Bioreacter used was stirred tank reactor, pH acidic, temperature for microalgaee was 20 to 30 degrees Celsius. Operation mode was continuous. Methods used were direct biophotolysis, dark fermenter and gassification. The evolution of hydrogen was induced in the cells when pre-incubation in the dark was performed on the cells. Hydrogen production is due to the hydrogenase enzyme expressed during the period of incubation. The co-digestion of cassava wastewater along with buffalo dung for biohydrogen production gave a maximum hydrogen production rate. This method is considered to be an effective process for producing hydrogen without the generation of oxygen. Organic components are decomposed under the presence of light by anaerobic or photosynthetic bacteria via the nitrogenase-catalyzed reaction.

KEY WORDS: CIRCULAR BIOECONOMY, SUSTAINABLE DEVELOPMENT, WASTE RECYCLING

INTRODUCTION

Around 180 million tons per year of lignocellulose materials are produced as byproducts or in the form of agricultural residues, which can be used as an inexpensive source for the production of biofuels.1 The sources selected for the production of hydrogen gas are low cost, biodegradable and having high level of carbohydrate content with the presence of simple sugars such as glucose, lactose, and sucrose, which can be used as reliable biodegradable substrates for bio-hydrogen production.

It is done by photolysis of water using cyanobacteria, microalgae, and photosynthetic an oxygenic bacterium which are most suitable as they utilize major natural resources such as sunlight, water, etc. These microorganisms either supply electrons as an alternate source for the sake of survival in minimal optimum conditions or the need to prevent the reduction of the electron transport chain and act as a security valve. In addition to these biochemical reactions, hydrogen gas can also be produced during nitrogen fixation by the nitrogenase enzyme, which is a major mechanism in the heterocyst forming blue-green algae.

The production of bio-hydrogen on a large scale came into thought after the rapid depletion of fossil fuels. It has been known for more than 70 years that algae can make bio-hydrogen under illumination. The evolution of hydrogen was induced in the cells when pre-incubation in the dark was performed on the cells. Hydrogen production is due to the hydrogenase enzyme expressed during the period of incubation. The co-digestion of cassava wastewater along with buffalo dung for biohydrogen production gave a maximum hydrogen production rate and hydrogen yield of 839 mL H_2/L/d and 16.90 mL H_2/g, respectively. [2]

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METHODOLOGY

The substrates used in the present study were lignocellulase wastes (agricultural wastes), sewage wastes and livestock wastes. Bioreacter used was stirred tank reactor, pH acidic, temperature for microalgae was 20 to 30 degrees Celsius. Operation mode was continuous. Methods used were direct biophotolysis, dark fermenter and gassification.

Lignocellulose waste

Waste such as residues of plants, agricultural waste, and the logging of wood is considered to be lignocellulosic wastes and they are degraded slowly. They consist of a hetero polymeric substance, and in order to break the complex, the raw materials are pre-treated. A large number of monomeric sugars are obtained by hydrolysis of cellulose and hemicellulose.

126 + 22 mlH2/g. Maximum yield - 214 + 62 ml H/g.

High yields of biohydrogen have been obtained by following the steps: Pretreatment--hydrolysis--hydrolysate--fermentor-biohydrogen reactor--hydrogen. 367 + 43 ml H2/g.

Livestock Wastes

Livestock wastes include fodder, manure, and slaughterhouse and poultry farm wastes. Biohydrogen production from livestock waste is illustrated as manure--complex organic matter---hydrolysis---simple sugars by acidogenic microbes---organic acids--acetogenesis--hydrogenesis---hydrogen fermentor---hydrogen. From cow manure-218 + 2.4 ml H2/g. From swine manure 126 + 2.2 ml H2/g. From buffalo dung- 167 + 3.4 ml H_2/g.

RESULTS AND DISCUSSION

The fermentative hydrogen production depends on the type of inoculum used, the reactor type, and its temperature settings. Many types of inoculums are used for hydrogen production and must be pure cultures of hydrogen-producing bacteria, mixed cultures of anaerobic bacteria obtained from compost piles, and anaerobic sludges. Around 180 million tons per year of lignocellulose materials are produced as byproducts or in the form of agricultural residues, which can be used as an inexpensive source for the production of biofuels.[1,2]

These materials, due to their low fiber porosity, heterogeneity, and crystalline nature, are not readily fermentable, and pre-treatment is required for the process of forming fermentable sugars.3 Lateef et al. [4] produced biohydrogen with cow manure as a source along with waste milk as a co-substrate. After adding the organic load, which is obtained from the co-digestion of cow manure, the production of biohydrogen is increased. Tenca et al.5 have obtained biohydrogen with a yield of 126 ± 22 mL H2/g VS-added when swine manure was used, along with fruit and vegetable waste.

Similarly, Marone et al.[6] produced biohydrogen with a maximum yield of 117 mL H2/g VS-added through the co-fermentation of buffalo slurry with cheese whey and crude glycerol using a mixed microbial culture. The maximum hydrogen production rate and hydrogen yield was 109.55 mL H2/L per day and 0.84 mol H2/mol of total sugar consumed, respectively, when elephant dung was used as the inoculum for sugarcane bagasse hydrolysate.[7]

The maximum hydrogen production rate and hydrogen yield were 215.4 (±62.1) mL H2/L/d 152.2 and (±43.9) mL H2/g respectively, achieved at an organic loading rate of 2.1 g VS/L/d of cheese whey via the dark fermentation method using buffalo manure as a buffering agent.[8]

The co-digestion of cassava wastewater along with buffalo dung for biohydrogen production gave a maximum hydrogen production rate and hydrogen yield of 839 mL H_2/L/d and 16.90 mL H_2/g, respectively.[2] Perera and Nirmalakhandan,[9] produced a maximum hydrogen yield of 2.9–5.3 M hydrogen/M sucrose when sucrose along with dairy cattle manure was used for production. Biohydrogen was produced when the liquid swine manure was co-fermented with molasses of which the hydrogen production rate and hydrogen yield of 31.9 L/d and 1.52 L/g sugar, respectively, was obtained.10 Zhu et al.[11] obtained significant quantity of biohydrogen with swine manure co-fermented with glucose as a substrate.

Cai et al.[12] also successfully worked upon the release of biohydrogen from sewage sludge and reported that the hydrogen yield of alkali pre-treated sludge was higher than dry sludge. The yield increased from 9.1 mL of H_2/g of dry solids (DS) to 16.6 mL of H2/g of DS when alkali-pre-treated sludge was used. Yin and Wang,13 produced hydrogen using waste sludge and reported that the irradiation and gamma irradiation combined with the alkali pretreatment was able to produce biohydrogen by dissolving the waste-activated sludge. The co-fermentation of sewage sludge and fallen leaves produced biohydrogen.

The mixing ratio of 20:80 of fallen leaves and sewage sludge produced biohydrogen with a yield of 37.8 mL/g. Natural sludge was used as an inoculum to produce biohydrogen using corn stalks via anaerobic fermentation, and the maximum hydrogen yield was observed to be 126.22 mL g−1-CS [14]. A Continuous Mixed Immobilized Sludge Reactor (CMISR) using activated carbon as a support carrier was used for hydrogen production via dark fermentation from enzymatic hydrolyzed food waste.

The production of bio-hydrogen via dark fermentation involves the use of anaerobic or facultative anaerobic bacteria in anaerobic conditions. Anaerobic bacteria are responsible for using the organic substance as the source of electrons and the energy required for converting it into hydrogen. The reactions taking place during dark fermentation occur as a rapid process as there are no requirements for solar radiation. Large quantities of biomass are treated using a large fermenter. Photosynthetic and Non-Sulfur (PNS) bacteria have the ability to convert the volatile fatty acid into carbon dioxide and hydrogen under anoxygenic conditions.[15]

PNS bacteria is a non-taxonomic group that is capable of growing as photoautotrophs, photoheterotrophs, and chemoheterotrophs, depending on the availability of carbon, oxygen, and light sources.[16] The optimum growth conditions for PNS bacteria are pH 7 and temperatures ranging between 30 and 35 °C. This method is considered to be an effective process for producing hydrogen without the generation of oxygen. Organic components are decomposed under the presence of light by anaerobic or photosynthetic bacteria via the nitrogenase-catalyzed reaction. Various physical parameters such as the temperature, pH, medium composition, and intensity of light affect the productivity of hydrogen by bacteria.[17]

PNS bacteria have the ability to reduce H+ ions to hydrogen in the gaseous phase by extracting power from the oxidation of certain compounds such as fatty acids of low molecular weight and light energy.18 For the PNS organism to grow and produce hydrogen, photo heterotrophy is generally preferred. This photo fermentation is carried out via the catalytic action of two enzymes involving hydrogenase and nitrogenase via the Tricarboxylic Acid (TCA) cycle.

The production of hydrogen gas by PNS bacteria is possible as a result of one of the important enzymes-nitrogenase. It is highly sensitive to oxygen as it is an iron sulfur molybdenum enzyme. The main source for photo fermentation is light, which is most required for developing a photobioreactor with a greater illumination facility for industrial purposes.

The production of hydrogen under dark fermentation is usually lower compared to photo fermentation, but a 14 h light and 10 h dark cycle can improve the rate of hydrogen production. After biological conversion, gasification became the most widely studied field. More studies on gasification have been performed by China and the United States of America, while the UK, Italy, Malaysia, Canada, and Japan have also contributed many findings in the field of producing hydrogen using gasification. At high temperatures and high pressures, organic feedstock undergoes partial oxidation, which is termed gasification. During this process, several byproducts can also be produced such as tar, biochar and light hydrocarbons.[19]

Biomass is considered to be a very good source for gasification because of its low sulfur content, and if the moisture content is less than 35% for any kind of biomass, then it can be converted into fuel gas.20 Gasification is considered to be a biological process that converts biomass into carbon monoxide, carbon dioxide, hydrogen, and methane with controlled amounts of steam and oxygen used at high temperatures.[21]

CONCLUSION

The production of bio-hydrogen on a large scale came into thought after the rapid depletion of fossil fuels. The substrates used in the present study were lignocellulase wastes (agricultural wastes), sewage wastes and livestock wastes. Bioreacter used was stirred tank reactor, pH acidic, temperature for microalgaee was 20 to 30 degrees Celsius. Operation mode was continuous. Methods used were direct biophotolysis, dark fermenter and gassification.

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Conflict of interest

Author declares no conflict of interest

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