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Effect of pre-treatment and hydraulic retention time on biohydrogen production from organic wastes

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ABSTRACT

This study investigated the effect of pre-treatment and hydraulic retention time (HRT) on biohydrogen production from organic wastes. Various pre-treatments including thermal, base, acid, ultrasonication, and hydrogen peroxide were applied alone or in combination to enhance biohydrogen production from potato and bean wastewater in batch tests. All the pre-treated samples showed higher hydrogen production than the control tests. Hydrogen peroxide pre-treatment achieved the best results of 939.7 and 470 mL for potato and bean wastewater, respectively. Continuous biohydrogen production from sucrose, potato and bean wastewater was significantly influenced by reducing the HRT as 24, 18 and 12 h. Sucrose and potato showed similar behavior, where the hydrogen production rate (HPR) increased with decreasing the HRT. Optimum hydrogen yield results of 320 mL-H₂/g-VS (sucrose) and 150 mL-H₂/g-VS (potato) were achieved at HRT of 18 h. Bean wastewater showed optimum HPR of 0.65 L/L.d with hydrogen yield of 80 mL-H₂/g-VS at 24 h HRT.

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Introduction

Hydrogen can be considered as a promising energy source for the future because it shows several advantages over other fuels such as it is carbon neutral fuel and it can be produced from renewable substrates such as waste/wastewater raw materials [1]. Recently, biohydrogen production from organic waste has gained a remarkable attention because it can achieve the dual effect of waste stabilization a long with

production of clean energy [2]. Various organic wastes such as municipalities, agro-industrial residues and food waste have been used as substrates for biohydrogen production [3]. Among these raw materials, agricultural waste has gained a considerable attention as promising substrates for biohydrogen production because of their abundance, low cost and reliability [2]. Previous works have investigated the feasibility of biohydrogen production from agricultural waste such as beer lees biomass [4], cornstalk [5,6], potato [7,8], and bean [2,9,10]. The authors reported that fermentative

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hydrogen production from such kind of substrates has some limitations. The main drawback of biohydrogen production from agricultural waste is the low hydrogen yield [11,12]. An explanation for this behavior is the complex nature of the waste due to the presence of starch, cellulose, hemicellulose and lignin, which could have a negative impact on the biodegradability of the substrates [13]. Researchers reported that the application of pre-treatment could improve the solubilization of the organic waste and thus achieve higher hydrogen yield [4,9,14]. Pre-treatment methods such as thermal, ultrasonication, chemical methods (acidic, alkaline and oxidative pre-treatment using H_2O_2), etc., have been recognized as effective methods. They play a significant role in increasing the solubilization of the substrate [2,14,15]. However, to date, few studies have investigated the effect of the pre-treatment on biohydrogen production. For this purpose, more research work should be done to study the influence of pre-treatment on biohydrogen production from waste/wastewater as well as how the type of substrate can have a direct effect on the determination of the optimum pre-treatment method to be used to achieve optimal hydrogen yield.

In addition, previous studies have found that HRT can be considered as a key parameter in biohydrogen production process and the hydrogen-producing bioreactor should be operated at optimal HRT [16]. HRT has been reported to play an important role in maximizing the hydrogen yield [17,18], can have a considerable impact on the composition of the produced VFAs mixture [19], and inhibition of methanogenesis [20]. Zhu et al. [8] reported that the optimal HRT for biohydrogen production can be changed depending on the type and concentration of substrate and the type of the reactor. Other researchers stated that waste composition showed a great impact on fermentative hydrogen production in that substrates with high carbohydrate content can achieve higher hydrogen yields than protein- and lipid-rich substrates [21–23].

The present study was conducted to (i) study the effect of several pre-treatment methods on biohydrogen production from potato and bean wastewater in batch tests, (ii) investigate the effect of HRT as 24, 18 and 12 h on continuous biohydrogen production using three different substrates of sucrose, potato and bean wastewater.

Materials and methods

Seed sludge

The batch tests were inoculated with sludge samples collected from wastewater treatment plant (Kasslerfeld, Duisburg, Germany) and sieved using a mesh (2 mm) to eliminate waste materials. Heat shock pre-treatment (100 °C for 2 h) was carried out to harvest the hydrogen-producing bacteria such as *Clostridium* species as well as to suppress the activity of unfavorable species such as methanogens, homoacetogenes, etc. Activation of these species in the hydrogen-producing bioreactor may have a negative effect on the biohydrogen process. The heat shock pre-treatment was chosen because it is fast, highly efficient and simple process [24].

The continuous experiments were started up by inoculating continuous stirring tank bioreactors (CSTRs) with 2 L sludge. The inoculum was obtained from other lab-scale CSTR operated for biohydrogen production from artificial sucrose wastewater at concentration of 10 g/L, HRT of 9 h, mesophilic temperature (35 °C), and pH 5.5.

Feedstock preparation and characterization

Synthetic sucrose wastewater was prepared by diluting sucrose in tap water. The concentration of sucrose was maintained at 10 g/L. Potato wastewater was prepared using commercialized potato. The potatoes (without washing and peeling) were cut using knife and homogenized using a blender for 5 min with proper addition of water at a 1:4 ratio (w/w). Bean wastewater was prepared by mixing bean waste with tap water at a 1:2 ratio (w/w), and homogenized using a blender for 5 min. The resulting liquid mixtures (potato and bean) were screened to remove the large particles and then the solutions were diluted to have nearly equal total solid (TS) concentrations. The substrates were characterized for pH, chemical oxygen demand (COD), TS and volatile solids (VS).

Experimental procedures

Batch tests

Batch experiments were conducted in 500 mL glass bottles with effective volume of 250 mL. The fermentation liquid in each bottle consisted of 210 mL wastewater, 30 mL sludge, and 10 mL nutrient solution. The food to microorganisms (F/M) ratio was maintained at 0.3 g-VS/g-VS. Air in the headspace was removed by purging nitrogen gas for 5 min. The batch experiments were performed under mesophilic conditions (35 °C), and the bottles were continuously mixed using magnetic bar. One batch reactor was taken as blank which contained untreated waste. Each experimental condition was carried out in triplicate. The experimental results noted were the averages of the values obtained in independent experiments conducted in triplicate. At the end of the dark fermentation, liquid samples were collected from each bottle, filtered with cellulose acetate membranes (0.45 μ m), and analyzed for pH, COD, VFAs, and volatile suspended solids (VSS).

Pre-treatment of potato and bean substrates

Various pre-treatment methods as thermal, acid, base, ultrasonication, and hydrogen peroxide were applied alone or in combination on substrates before conduction of biohydrogen fermentation tests. Waste substrates was heated at 100 °C for 30 min. Acid and base pre-treatments were performed by adding aqueous 5% HCl and NaOH (2 N) solutions to pH values of 4 and 10, respectively, and these conditions were lasted for 30 min with proper mixing. The waste materials were also treated using an ultrasonic processor (Fritsch, Laborgeräte, Idar-Oberstein, W.-Germany) for 30 min. Hydrogen peroxide pre-treatment was performed by mixing 1 L of wastewater with 3 mL H_2O_2 . For combined thermal/acid pre-treatment, the wastewater was boiled for 30 min at 100 °C and mixed with 5% HCl (pH = 4). The mixtures were then neutralized to pH 7.0 by addition of dilute NaOH and/or HCl aqueous solution.

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