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Quantification of temperature effect on batch production of bio-hydrogen from rice crop wastes in an anaerobic bio reactor

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ABSTRACT

Rice is an important cereal crop and different types of wastes are produced from it such as; rice straw as a crop residue, rice husk and rice bran as agro-industrial waste and rice waste as a food waste, which are needed to be tested for bio-hydrogen production under similar set of experimental conditions. The bio-hydrogen production potential of these wastes was compared by co-digestion with heat shocked sludge under mesophilic thermophilic temperatures by using an anaerobic bio reactor under no pH control conditions. It was observed that the bio-hydrogen production potential increased with an increase in temperature from 37 °C to 55 °C for all wastes, except for rice waste. Although, the highest experimental yield of 40.04 mL/VS_{rem} was produced from thermophilic rice straw, but the maximum bio-hydrogen production rate of 97.08 mL/h was observed from rice bran after 29.03 h under thermophilic conditions. The bio-hydrogen production period of rice bran was 33–38% smaller than rice straw due to which the highest yield was observed from rice straw. The lignin content of rice husk was 19.34%, which was double than rice straw and hence the rice husk produced the least experimental yield of 23.05 mL/VS_{rem} under mesophilic conditions. Increasing the temperature from mesophilic to thermophilic conditions changed the final pH by 1.79%, −8.33%, 5.17% and 5.41% for rice straw, rice bran, rice husk and rice waste, respectively. The optimum pH range of bio-hydrogen production from rice straw, bran and husk was observed from pH 7 to pH 6. The average yield of wastes produced from rice crop was 30.36 and 33.16 mL/VS_{rem} under mesophilic and thermophilic conditions, respectively. The quadratic modeling found useful in order to explain more than 90% variation caused by incubation time and temperature on cumulative bio-hydrogen production, drop in pH and VFA production. The 3D and 2D plots developed on

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the basis of quadratic modeling explained the process parameter is in better way as compared to conventional representation of experimental results. As a whole, increasing temperature not only increased bio-hydrogen yield, but also decrease the volatile fatty acid production.

Introduction

Rice is one of the most popular staple food in the world and Asia has 90% share in worldwide rice production out of which 28.7% is produced by China alone. The rice was planted over 29.8 million hectare area of China, which produced 196.7 million tons of paddy in the year 2009 [13,50]. The major residues obtained upon the cultivation of rice crop are straw, husk and bran. Rice straw is produced at the time of harvesting and termed as agricultural waste, whereas rice husk and rice bran are obtained as a byproduct of the milling process and termed as agro-industrial wastes [53]. In China, rice straw has a share of 62% in total crop residues and 1.35 tons of rice straw are produced for every ton of rice grain harvested [21,55]. The straw is utilized in the paper making industry, building construction, animal feed and home warming, but still a lot of straw is left in the field. The leftover straw is burned which causes serious environmental threats. On the other hand, 0.2–0.33 tons of rice husk is produced per ton of paddy during milling process, which is used as animal feed, insulating material and fertilizer [22,27]. Apart this, many power plants in China are producing electricity through gasification of rice husk [30]. Even after the multidirectional use of rice husk, still lot of rice husk is burnt causing serious environmental issues [22,23]. Along with husk, 0.1–0.12 tons of rice bran is also produced per ton of paddy, which is used to extract oil as well as in food products and animal feed. Another type of waste is also produced from rice crop as part of organic fraction of municipal solid waste and termed as rice waste. The rice waste has 10–15% share in food waste produced at canteens [47].

Apart from the conventional utilization of wastes produced from rice crop, converting the said wastes into more valuable products like methane, ethanol and bio-hydrogen are better options by which environmental concerns as well as energy challenges can be addressed together. The conversion can be done by gasification and pyrolysis, but it can cause a threat to the environment. This issue can be resolved by opting biological means, such as; anaerobic fermentation, which is an environmental friendly and accommodate wide range of substrates [10,35,49]. In this regard, bio-hydrogen production through anaerobic fermentation is more advantageous over other fuel, as hydrogen producing microorganisms could utilize a wide range of sugar hydrolysates as compared to other microbes [19]. The sugar hydrolysates were available in the form of holo-cellulose in rice straw and husk, whereas in case of ice bran and rice waste, carbohydrates are the sources of sugar hydrolysates. The holo-cellulose in bounded by lignin and is not easily bio-degraded. To overcome this issue, the common pretreatment is comminution in which the ultrastructure of lignocellulosic biomass is changed. In this technique final particle size of 0.2–2 mm is achieved, which increases the surface area and reduces the cellulose crystallinity for better biodegradability [28,34]. The mix consortia of *Clostridium* are the common group of microorganism that can be used for this purpose as they are easily available in the form of sludge [12]. The sludge also contains hydrogen consumers like methanogens, which can be deactivated by exposing sludge to higher temperature, UV radiations, extremely high or low pH and hazardous chemicals [39]. Among all these methods, heat shock is the most suitable as it is an easy and economical method [11]. In heat shocked sludge, methanogens are unable to survive, but *Clostridium* can survive by forming protective spores [52]. Apart *Clostridium*, sludge can provide some nutrients to fulfill the nutritional requirement for bacterial growth, which can make the process more economical and simple [24,40].

The incubation temperature is an important parameter for optimum bio-hydrogen production from wastes co-digested with heat shocked sludge. In case of rice crop wastes, the effect of temperature was not intensively studied. Previously, Alemahdi et al. [2] reported the bio-hydrogen yield of 14.7 mL/VS under mesophilic condition, which was improved to 21 mL/VS by Kim et al. [24] by opting thermophilic condition. In case of rice husk, few studies are conducted by using rice husk or its hydrolysate for bio-hydrogen production under mesophilic conditions only [31,40]. Similarly, bio-hydrogen production was reported under mesophilic conditions from rice bran [1,38]. Even if the bio-hydrogen is produced from said wastes under both temperature conditions, but still it is not comparable as the experimental conditions are different. The effect of temperature on rice waste was studied by Fang et al. [12] and Arslan et al. [9] under similar set of experimental conditions, but still further work is needed to verify the experimental results over larger scale.

Although intensive research is done on methane and ethanol production from agricultural waste still there is a gap for research on bio-hydrogen production from the wastes produced from rice crop [5,6]. So, the following study was designed to quantify and compare the bio-hydrogen production potential of lignocellulosic wastes like rice straw and rice husk along with carbohydrate rich wastes like rice bran and rice waste produced from rice crop when they were co-digested with treated sludge under mesophilic thermophilic conditions. The volatile solids, volatile fatty acids, soluble chemical oxygen demand and pH were also measured to observe various aspects of the fermentation process.