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Effect of ammonia on biohydrogen production from food waste via anaerobic fermentation

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ABSTRACT

The effect of different additive ammonia (0–10 g/l as nitrogen) on hydrogen production from the anaerobic batch mesophilic fermentation of food waste was studied at two feed-to-microorganism ratios (F/M), 3.9 and 8.0. Anaerobic sludge taken from an anaerobic digester was used as inoculum. The hydrogen yield at F/M 3.9 and 8.0 without additive ammonia was 77.2 and 51.0 ml-H_2/gVS, respectively. At F/M 3.9, the hydrogen production was enhanced by adding additive ammonia in the system when the total ammonia nitrogen (TAN) concentration was no higher than 6.0 g/l. A maximum hydrogen yield of 121.4 ml-H_2/gVS was obtained at a TAN concentration of 3.5 g/l. At F/M 8.0, the enhancement of hydrogen production was found in a narrower range of additive TAN concentrations, with a highest yield of 60.9 ml-H_2/gVS at the TAN of 1.5 g/l. Hydrogen production was inhibited at higher additive TAN concentrations for both F/M ratios. This study provides a novel strategy for controlling ammonia for production of hydrogen from food waste via anaerobic fermentation.

1. Introduction

Hydrogen (H_2) has the highest energy yield per unit weight (122 kJ/g) among all known fuels and has been widely used in various energy and industrial applications [1]. H_2 is also well recognized as a non-polluting energy fuel and is expected to be one promising alternative of depleting fossil fuels in the near future [2]. However, the current H_2 consumed globally is almost completely produced from nonrenewable fossil fuels or by electrolysis of water [3]. Generation of H_2 from renewable resources can be a promising alternative way to save fossil fuels [4].

Anaerobic fermentation is one of the environmentally friendly technologies that can convert renewable biomass to H_2. Food waste, resulting from consumption and processing is the largest component of the municipal solid waste streams in many countries. Food waste is characterized by a high content of organic solids, which usually takes more than 80% of total solids [5]. Carbon and nitrogen are two main elements of the organic solids of food waste. Under anaerobic conditions,

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organic carbon could finally be degraded to methane and carbon dioxide. Organic nitrogen in proteinaceous materials is hydrolyzed to ammonia, most of which is accumulated in the fermentative reactor [6]. This byproduct, ammonia is reported toxic to organisms because unionized ammonia has the capability to pervade through the cell membrane [7]. Thus, anaerobic digesters used for the treatment of food waste often encounter serious ammonia inhibition due to high content of proteinaceous materials. There is a vital need to investigate the impact of ammonia on biohydrogen production from food waste via anaerobic fermentation.

This study was carried out to study the effect of ammonia on H_2 production from food waste using an Anaerobic Phased Solids Digester System (APS-Digester). The APS-Digester is a US patented two-stage anaerobic fermentation system [8] which showed successful operation to converse various solid organic residuals to biogas energy production at high loading rates [9]. It consists of one or more batch hydrolysis reactors in the first stage and one continuous methanogenesis reactor in the second stage in one system. The batch hydrolysis reactors are fed in cycle with organic materials at high loading rates to produce biogas and organic acids or alcohols. The acids/alcohols in the first stage are then collected and delivered to the continuous methanogenesis tank at constant loading rates for further conversion into biogas. For each batch hydrolysis reactor, microorganisms recycled from the previous batch as well as the anaerobic microorganisms recycled from the continuous methanogenesis reactor are used as inoculum. The accumulation of ammonia in the APS reactor may become serious due to high loading rates of organic wastes and recycling of the effluent from the methanogenesis reactor. Therefore, the purpose of this study was to investigate the effect of ammonia on biohydrogen production from food waste via anaerobic fermentation and thus improve biohydrogen production from the food waste using APS-Digester system. However, it is necessary to define a suitable initial feed-to-microorganism ratio (F/M) for H_2 production before the study of the impact of ammonia on H_2 production because F/M ratio showed a significant impact on H_2 production according to our previous study [10]. The study focuses on two aspects of this approach, including optimizing the initial F/M for a local mesophilic anaerobic sludge inoculum and then studying the impact of ammonia on H_2 production using this inoculum at two optimal F/Ms.

The objectives of this study were to determine the suitable F/Ms and more important, ammonia concentration for successful biohydrogen production from food waste under a mesophilic condition. Experiments were carried out to determine the biogas content and production yield under different F/Ms and ammonia concentrations using batch digesters inoculated with the mesophilic anaerobic sludge taken from a mature mesophilic digester in Hangzhou, China.

2. Materials and methods

2.1. Sludge inoculum and food waste

The inoculum was the mesophilic anaerobic sludge collected from the bottom settlement of an existing one-stage anaerobic digester in Hangzhou, China. The digester was a 300 m^3 tank that was fed with livestock manure, food waste, straw, and grass, which was operated at a hydraulic retention time (HRT) around 20–25 d, with the gas production rate of about 0.5 $m^3/(m^3\ d)$. Before sampling, the digester was stopped stirring for 1 d. After the raw sludge arrived at the Agricultural and Biological Environmental Engineering Research Laboratory, Zhejiang University, Hangzhou, China, it was diluted by ten times with distilled water in order to decrease the ammonia concentration. After the diluted sludge was settled for 1 d at room temperature (about 25 °C), the supernatant was decanted and the remainder was screened with a sieve of 2-mm openings to remove impurities such as sands. The screened sludge was then diluted again by 2.45 times with distilled water to adjust the volatile solid (VS) content to 1.5% which was near to the VS level in the source digester. Thus the ammonia concentration of the final sludge was finally diluted by 24.5 times compared to the raw sludge while most microorganisms (i.e. VS) were remained. The final sludge was then stored at room temperature (about 25 °C) for further use. The characteristics of the final inoculum are shown in Table 1.

The food waste was collected from one campus restaurant in Zhejiang University, Hangzhou, China, over two months in the summer of 2011. Impurities such as wood, bones, plastics and wastepaper, were removed manually. Then the food waste was ground with a food grinder (Model CPEL-23, Shanghai Guo Sheng, China). The homogenized food waste samples were packed in plastic bags and frozen at −20 °C in a freezer to prevent spoilage. The food waste sample was thawed overnight in a 25 °C incubator before its use in the test. Characteristics of the homogenized food waste are presented in Table 1.

2.2. Batch fermentation system

Each batch fermentation system consisted of 1-l fermentation glass bottle (VWT Inc., USA), 1-l gas collection glass bottle (VWT Inc., USA) and 500-ml liquid collection beaker. In a typical batch fermentation system, the fermentation bottle was loaded with inoculum and food waste. The biogas produced in the fermentation bottle was automatically distributed to the gas collection bottle once it was produced. The gas collection bottle was filled with hydrochloric acid solution (pH < 3). When the headspace of the gas collection bottle was filled with the produced biogas, an equivalent volume of acid solution to the biogas was discharged to the liquid collection

Table 1 – Characteristics of inoculum and food waste (Note: w.b. is wet base; d.b. is dry base).

Parameter	Inoculum	Food waste
TS (%)	3.03 ± 0.01	25.7 ± 0.1
VS (% w.b.)	1.50 ± 0.01	24.2 ± 0.1
VS/TS (%)	49.5 ± 0.1	94.1 ± 0.1
pH	7.70 ± 0.00	4.75 ± 0.01
TAN (% w.b.)	106.8 ± 0.2	–
TC (% d.b.)	–	50.4 ± 0.3
TN (% d.b.)	–	2.66 ± 0.01
C/N	–	19.0 ± 0.2