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Effect of the initial total solids concentration and initial pH on the bio-hydrogen production from cafeteria food waste

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ABSTRACT

In this paper, the influence of the initial pH and the total solids (TS) concentration on hydrogen production from the organic fraction of cafeteria food waste at mesophilic conditions in batch reactors was determined. It was found that the yield and specific hydrogen production rate were influenced by the initial pH and the initial total solids concentration. The highest hydrogen production rate, 2.90 mmolH_2/d, was obtained at 90 gTS/L and a pH of 5.5. Under this condition, the TS and chemical oxygen demand (COD) removal were the lowest (10% as TS and 14% as COD). However, considering the specific values, the highest specific degradation rate (192.2 mLH_2/g$VS_{removed}$/d) was obtained with the lowest TS concentration and an initial pH of 7.0. It was found that the influence of the TS concentration on hydrogen production was more significant than that of the initial pH for this type of residues.

1. Introduction

Currently, there is great interest in hydrogen (H_2) production as a clean fuel because, during its combustion, only water is produced as a by-product and because hydrogen has a high specific energy content (33.3–39.4 kWh/kg) compared with those of other fuels [1]. Hydrogen is an alternative to conventional fossil fuels, which can be produced by steam reforming, electrolysis, gasification and biological processes. Because fossil fuel processing and water electrolysis are expensive, the biological production of hydrogen is more cost effective, particularly when organic wastes can be used [2].

The application of the hydrolytic-acidogenic stage of the anaerobic digestion process is a viable alternative to produce hydrogen and to obtain an effluent rich in dissolved organic matter composed of volatile fatty acids (VFA), primarily acetic, propionic and butyric acid, lactate and solvents (acetone and ethanol). In this case, H_2 production is an economically viable process due to the possibility of using a wide variety of non-expensive residues as the organic fraction of municipal solids waste (OFUSW) [3–5].

The OFUSW include fruit- and vegetable-based market waste, uneaten food and food preparation leftovers from residences and restaurants and organic residues from industrial food production. The OFUSW is a significant environmental problem, particularly in large cities in developing countries, where the typical disposal method is using a sanitary landfill or open dumping, due primarily to their simplicity and low cost [6]. For this reason, the use of this waste can reduce the environmental problem with the valorization of products as hydrogen.

The initial total solids (TS) concentration affects hydrogen production in several ways [7]. A high initial TS content can limit the mass transfer between the substrate and microorganisms,

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which reduces the hydrogen production [8]. In addition, the initial concentration of the substrate may result in inhibition of H_2-producing bacteria due to an increase in volatile fatty acids production. It has been observed that hydrogen production from OFUSW at mesophilic temperatures (34–37 °C) is influenced by the initial pH, initial total suspended solids and inoculum characteristics [8–12].

The optimal initial TS concentration to obtain hydrogen depends on the composition of the residue, the type and configuration of the reactors and the activity of the biomass. The initial TS values used by several authors varied from 1.3 to 50 g/L [9–16]. It has been reported that as the initial TS increased, the hydrogen production also increased until a variable maximal concentration was reached, which depended on the residues' characteristics [12–18]. However, it was observed that the yield of hydrogen production varied when different initial TS were used [12–17]. Relatively low TS concentration have been reported for residues from cafeteria [19] or they are used mixed with night soil sludge and sewage sludge from a wastewater treatment plants [16]. Because diluting OFUSW demands fresh water, it is worthwhile to investigate the potential in using higher TS concentrations than those that have already been studied and without the addition of co-substrates.

Selecting a proper pH is also crucial to enhance hydrogen production due to the effects of pH on the hydrogenase activity or metabolic pathways. Fan et al. [20] and van Ginkel et al. [21] have reported that the maximum hydrogen yield occurred at a pH value of 5.5, whereas Lee et al. [22] reported that the maximum hydrogen yield was achieved at an initial pH of 9.0. Dávila-Vazquez et al. [17] found that the maximum hydrogen yield occurred with an initial pH of 7. These conflicting results seem to be due to a lack of buffering capacity that would prevent the pH from decreasing. From a practical point of view, it is important to investigate how the initial pH influences the hydrogen production when no pH control is used during fermentation.

In this study, the influence of the initial pH and high total solids concentration on hydrogen production from the organic fraction of cafeteria food waste at mesophilic conditions in batch reactors was determined.

2. Materials and methods

2.1. *Inoculum*

Anaerobic granular sludge obtained from an upflow anaerobic sludge blanket reactor treating brewery wastewater was used as the inoculum after thermal conditioning as described by [23].

2.2. *Waste characteristics*

The OFUSW was obtained from the cafeteria at the Juriquilla-UNAM campus. The waste was collected once a week and refrigerated at 4 °C for preservation. In each collection, bones and inert material (paper and plastic) were discarded; only the fermentable matter was preserved. After selecting the waste, it was crushed and homogenized in a blender. Finally, the waste was frozen until it was used. The characteristics of the OFUSW used in this study are presented in Table 1.

2.3. *Experimental procedure*

A batch reactor with a useful volume of 150 mL was used in this study (glass Schott bottles, 300 mL of total volume). To help purge the biogas, the reactors were mixed using an orbital mixer (150 rpm) at a constant temperature of 36 °C during a reaction time of 2.1 d. Different total solids concentrations were used: 1, 5, 10, 40 and 90 g/L. To evaluate the influence of the initial pH, each batch bottle was adjusted using 0.1 N HCl or 0.1 N NaOH until an initial pH of 5.5, 6.0 and 7.0 was obtained. The pH was fixed at the beginning of the test and decreased as fermentation in the batch reactors occurred. It has been reported that alkalinity affects the hydrogen production [24]. Thus, a nutrient stock solution containing the following components (per liter) was used to ensure a proper level of alkalinity: 200 g of NH_4HCO_3, 100 g of KH_2PO_4, 10 g of $MgSO_4 \bullet 7H_2O$, 1.0 g of NaCl, 1.0 g of $Na_2MoO_4 \bullet 2H_2O$, 1.0 g of $CaCl_2 \bullet 2H_2O$, 1.5 g of $MnSO_4 \bullet 7H_2O$, and 0.278 g of $FeCl_2$. A nutrient stock solution with a volume of 0.5 mL was added to the batch bottles. Each reactor was inoculated with 4 g of pre-treated anaerobic sludge as inoculum; therefore, the initial inoculum concentration in the reactor was 26.7 g/L of TS. The chemical oxygen demand (COD) was quantified at the beginning of the test. During the experiments, the biogas produced was measured at regular interval times. After the biogas production ceased (2.1 d), the pH, biogas composition (H_2, CH_4 and CO_2), total and dissolved COD, total solids, volatile solids, sulfate, lactate and volatile fatty acid (acetic and propionic acids) concentrations were quantified.

2.4. *Kinetic analysis*

To evaluate the cumulative hydrogen production in response to the different conditions, a kinetic analysis was conducted using the modified Gompertz Equation (1) as described by [23]. The experiments were conducted in triplicate.

$$H(t) = H_{max} * \exp\left[-\exp\left(\frac{2.71828 * R_{max}(\lambda - t)}{H_{max}} + 1\right)\right] \qquad (1)$$

Here, H(t) (mL) represents the total amount of hydrogen produced at time *t* (h); H_{max} (ml) represents the maximal amount of hydrogen produced; R_{max} (mL/h) is the maximum hydrogen production rate, and λ (h) represents the lag time.

Table 1 – Characterization of the OFUSW used in this study.

Parameter	Value
Moisture, %	79.12 ± 0.19
TS Wet basis, %w/w	20.88 ± 0.24
VS Wet basis, %w/w	19.48 ± 0.22
Density, g/L	805.04 ± 0.20
NH_3–N, g/L	0.65 ± 0.15
COD_{total}, g/L	140.55 ± 11.78
pH	4.6–5.0

Average of five tests ± standard deviation.