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Bio-hydrogen production from food waste and sewage sludge in the presence of aged refuse excavated from refuse landfill

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ABSTRACT

In this work, the aged refuse (AR) excavated from a typical refuse landfill with over 10 years of placement was used for the enhancement of bio-hydrogen production from food wastes. Firstly, the food wastes taken from a university dining hall were inoculated with sewage sludge (SL) pre-treated by 15 min heating at 80 °C. It was found that below 0.4% of hydrogen concentration could be detected in the biogas produced due to its severe acidification properties. However, the addition of AR (50% in weight) can considerably increase the hydrogen concentration in the biogas to over 26.6% with pH ascending from 4.36 to 5.81, in comparison with 4–6% using activated carbon as additive with pH descending from 4.43 to 3.91. Meanwhile, it was also found that the hydrogen content in the biogas decreased drastically to 3.3% when the AR was sterilized by heating at 160 °C for 2 h and then used as additive for bio-hydrogen production from food wastes, indicating that the AR may chiefly function as a microbial inoculum instead of a porous material like activated carbon. Statistical analysis showed that the ultimate hydrogen production potential (H_p), hydrogen production rate (R_{max}) and lag-phase time (λ) were found to be 193.85 mL/gVS, 94.35 mL/(h gVS), 15.28 h, respectively, in the presence of 50% AR, and the optimal mixing ratios were 100:50 (wet weight) for food wastes to AR and 100:30 (dry weight) for food wastes to sewage SL, respectively.

1. Introduction

Hydrogen is a promising energy source due to its clean product and high-energy yield (122 kJ/g). Electrolysis of water, steam reforming of hydrocarbons and auto-thermal processes are well-known methods for hydrogen gas production, but cost-intensive due to high-energy requirements. Environmental friendly anaerobic bio-hydrogen fermentation from organic wastes has gained increasing concern due to energy generation while reducing the wastes.

The major problems in bio-hydrogen production from wastes are the low hydrogen generation rates and yields. Several factors must be considered for maximizing hydrogen production in the fermentation process, such as avoiding the loss of hydrogen to hydrogen-consuming anaerobes, e.g., methanogens.

Heat-shock treatment has been widely used [1–3] to select for spore formers, such as Clostridia, with temperatures ranging from 80 to 104 °C and exposure times between 15 and 120 min. Sewage sludge (SL) was treated with HCl (pH = 3–4) for 24 h followed by neutralization before inoculated into a fixed bed reactor containing a sucrose medium [4]. Besides, BESA (100 mmol) was used to kill the methanogenic bacteria in SL after pasteurization at 121 °C for 30 min in order to isolate pure strains of Clostridium for hydrogen production [5]. The sewage SL was also purged with compressed air for 1 h to inactivate acetoclastic methanogens. However, a lower hydrogen production rate compared to heat-shock-treated seed was obtained [6].

Other factors such as inoculum, substrate, temperature, nitrogen sparging, and initial start up have all been examined by various researchers in an effort to optimize hydrogen production [7–9].

The quantity of food wastes amounts to 65,000 t/d in China, accounting for 15.3% of municipal solid wastes [10], which are the main source of decay, odor and leachate in collection and transportation due to its high-volatile solids (VS; 85–95%) and moisture content (75–85%). Landfill treatment of food wastes creates various problems such as putrid smells and leachate polluting underground waters, while incineration is restricted due to its low calorific value and cost of fuel supplements for operation. Thermophilic composting of food wastes obtains compost or biofertilizer. However, its market seems quite constrained due to high-moisture content and odor problem. Direct use of food wastes as a feedstuff for livestock breeding can cause potential sanitary threats. At present, the dark fermentation

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of food wastes with sewage SL for the biogas production is attracting considerable attention as the present trend about waste management is recycling and/or the recovery of waste as new materials or energy.

Anaerobic acidification of food waste produces various volatile fatty acids (VFA), hydrogen, and other intermediates. Not only hydrogen gas itself is a beneficial energy source, but also VFA can be further digested for methane production. Therefore, the harvest of hydrogen from food waste at the acidification stage of anaerobic treatment, leaving the remaining acidification products such as acetate and butyrate for further methane production, is a great challenge from the viewpoint of energy.

On the other hand, food wastes are suitable for bio-hydrogen production, especially its co-fermentation with sewage SL as it contains rich easily hydrolysable carbohydrate. However, the chief challenge to bio-hydrogen production from the food wastes is the prompt acidification caused by the accumulation of volatile fatty acid (VFA). The shift of predominant metabolic flow from hydrogen- and acid-forming pathway to solvent-forming pathway [11] may be delayed by control of dilution rates. However, little information can be traced in the literature concerning the effects of addition of porous materials on the bio-hydrogen production from food waste.

The refuse in landfills becomes aged or stabilized after 8–10 years of placement, and the resultant partly or fully stabilized refuse thus obtained in this work is referred to as aged refuse (AR). The AR contains a wide spectrum and large quantity of microorganisms which have been proved to have a strong decomposition capability for both biodegradable and refractory organic matter present in some wastewaters [12].

Hence, the objective of this work was to investigate the effects of the addition of AR on hydrogen production by anaerobic co-fermentation of food waste and sewage SL.

2. Materials and methods

2.1. Feedstock

Food wastes, collected from a dining hall at Tongji University, were smashed after manual separation of plastic scoops, cups and wooden chopsticks, etc., before use as the substrate for bio-hydrogen production, as shown in Table 1.

2.2. Aged refuse

The AR was excavated from a 10-year-old closed landfill compartment in the Shanghai Laogang Landfill. The larger inorganic substances, such as stones, glass, bottles, etc., were manually separated and removed. The air-dried AR was screened by a conventional mechanical screener and a granule size of less than 2 mm was employed in this work.

For further basic characteristics analysis, the AR was broken into small pieces by hammer. At least 5 kg AR was sampled and the characteristics of the AR such as water content, organic content, cationic exchange capacity (CEC), pH, TP, TN, specific surface area, and total number of bacteria were measured in triplicate (Table 2).

Table 1
Characteristics of food waste

Moisture (%)	TS (%)	VS (%)	C(%)[a]	N (%)[a]	P (%)[a]	K (%)[a]	Ca (%)[a]	Na (%)[a]
85.3	14.7	88.8	41.72	1.96	0.25	1.42	1.06	1.17

[a] Weight in dry basis.

Table 2
Characteristics of aged refuse

Parameter	Value
Moisture content (%)	32.0
Organic content (g/kg)	102.5
pH	7.81
TN (%)	0.41
TP (%)	1.02
CEC (meq/100 g)	65.4
Specific surface area (m^2/g)	5.46
Total bacteria (cfu/g)	9×10^6
Degree of porosity (%)	44
Specific gravity (g/cm^3)	1.89

Table 3
Feed schedule of two groups of tests

Item	Bottle	Aged refuse (g)	Food waste (g)	Sewage sludge (g)
Exploratory test	5% AR+SL	1	20	4.9
	15% AR+SL	3	20	4.9
	25% AR+SL	5	20	4.9
	50% AR+SL	10	20	4.9
	Sludge	–	–	4.9
	GAC+SL	3	20	4.9
	PAC+SL	3	20	4.9
Pasteurization test	1#	10 (×)	20 (√)	4.9 (√)
	2#	10 (×)	20 (√)	4.9 (×)
	3#	10 (×)	20 (×)	4.9 (√)
	4#	10 (√)	20 (√)	4.9 (√)
	5#	10 (×)	20 (√)	–
	6#	10 (×)	–	4.9 (√)

'√': high-temperature sterilization treatment (HTS); '×': not HTS treated; '–': not added.

2.3. Sewage SL

The sewage SL was taken from an anaerobic digester in a wastewater treatment plant. The moisture content, VS, pH, alkalinity, and volatile suspended solid (VSS) concentrations of the SL were 82%, 36%, 7.18, 687 mg/L $CaCO_3$, 15.7 g/L, respectively.

2.4. Experimental scenarios

The exploratory and pasteurization tests were conducted in 13 serum bottles (250 mL), 7 for the former and 6 for the latter, respectively. Moisture content was adjusted to 90% and the proportion of SL to food waste was 30:100 (dry basis), while in the pasteurization test, Bottle 5# had no SL (Table 3). Twenty g of fresh food wastes were carefully put into each serum bottle except Bottle 6#.

2.4.1. Exploratory test

Granule activated carbon (GAC), powder activated carbon (PAC) were added individually as porous materials with a mixing ratio of 15:100 (wet weight) to food waste on weight basis. The mixing ratios of AR and food waste were 5:100, 15:100, 25:100, and 50:100 in weight, respectively (Table 3). $NaHCO_3$ was employed to adjust total carbohydrate/alkalinity ratio to 1.0. Subsequently, each bottle was flushed with N_2 gas for 2 min and sealed tightly