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Fermentative hydrogen production potential from washing wastewater of beverage production process

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ABSTRACT

In this study, anaerobic fermentation continuous system was carried out for hydrogen production by low concentration of beverage manufacture process wastewater, the most of the food industry wastewaters are in a relative low sugar concentration. The used substrate concentration of cultivation was 10 g total sugar/L, and hydraulic retention time (HRT) was 1 h for cultivation. Then the substrate concentration of experiments was lowered to 5 g total sugar/L, and HRT 1 h after the cultivation was completed. As a result, hydrogen production rate (HPR) was 11.39 ± 1.39 L/L/d, and yield was 0.30 ± 0.06 mol H_2/mol hexose at HRT 1 h. The results showed that the hydrogen dark fermentation production in a continuous system is feasible at low concentrations for food industry wastewater. The sustainable biohydrogen production technology not only treat wastewater but also generate electricity from hydrogen via PEMFC. The SO_3^{2-} on biohydrogen production, increased with increasing of sulfate concentration can inhibit microbial growth at excess concentration. Sulfate-reducing bacteria (SRB) will cause hydrogen gas converting hydrogen sulfide become poor hydrogen production efficiency.

Introduction

According to Taiwan's Executive Yuan statistics, the food industry wastewater is 180,000 ton/per year in 2013. This high concentration of wastewater streams, if not properly treated will create problems since they are discharged in to various rivers and causes water pollution issues. Hence, solving the wastewater problems are vital issues to the environment. For waste-to-Energy, food industry wastewaters were chosen as a substrate for dark fermentation, which was equipped with the properties of clean and high efficiency bioreactor. After the Dark fermentative Hydrogen production (DFHP), the COD of wastewater could be decreased and reduce the cost of wastewater treatment. By the way the biohydrogen can replaced a part of fossil fuel and provide a clean energy for human being.

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The development of alternative and renewable sources of energy is an important issue globally. Since the current use of fossil fuels in industries and transportation vehicles lead to greenhouse gas emissions which are responsible for global climate anomalies. Biohydrogen is a clean and green energy carrier which can replace fossil fuels partially, thus improving the global warming issues [1]. Among many bioenergy production methods, a great deal of attention has been focused on anaerobic production of hydrogen rather than methane in particular because it has many advantages including no carbon dioxide emission and high energy density [2–6].

Dark fermentative hydrogen production (DFHP) has received increasing attention in recent years due to its high hydrogen production rate (HPR) [7]. For most studies in this field, continuous DFHP operation is necessary from economical and engineering points of view especially in a commercialized system. Continuous systems are always excepted to operate at a low HRT 8–4 h [8–10] for getting a high biohydrogen production event that can be operated at related low of HRT 2–0.5 h [11–13] with immobilized cell, according to the life forms of hydrogen producing bacteria (HPB) used in the reactor. Table 1 shows literature comparison chart of biohydrogen production.

In this study, these beverage manufacture process wastewater, if not properly treated will create problems since they are discharged in to various rivers and causes environmental pollution issues. Therefore, we try to use that to produce bioenergy.

Materials and methods

Feedstock and seed sludge

The beverage wastewater was employed in this study. The concentration of expired beverage wastewater was 126.58 g COD/L and a carbohydrate content of 86.9%, the concentration of manufacturing process wastewater was 3.07 g COD/L and a carbohydrate content of 86.32%. It was obtained from a beverage company located in Taiwan. Chemical composition was shown in Table 2. The seed sludge was taken from Li-Ming municipal wastewater treatment plant at Taichung city, Taiwan. The seed sludge was pretreated by heating around 95–100 °C for 1 h to remove methanogenic and unfavorable hydrogen-producing bacteria [14]. The nitrogen source was ammonium bicarbonate, other inorganic salts and trace metals were adapted from Endo et al. [15].

Table 2 – Composition analysis of organic wastewater.

Item	Expired beverage wastewater (mg/L)	Manufacturing process wastewater (mg/L)
pH	3.52	4.09
Total sugar	110,000	2648
COD	126,578	3071
NH_3–N	N.D.	0.18
S^{2-}	N.D.	N.D.
SO_3^{2-}	17.5	82.5
SO_4^{2-}	2	9

N.D. stand for not detectable.

Sivagurunathan et al., mentioned the hydrogen production performance of the reactor with HY-IM (hybrid immobilization material) (1.12 ± 0.04 mol H_2/mol hexoseutilized) was comparable to suspended cells reactor (1.07 ± 0.01 mol H_2/mol hexoseutilized), and demonstrated repeated usage of same HY-IM in the reactor with high stability [16]. Lin et al., mentioned the net energy efficiency analysis showed vinasse wastewater has the highest positive net energy gain followed by glycerin wastewater and domestic sewage as 140.39, 68.65, 51.84 kJ/g COD feedstock with the hydrogen yield (HY) of 10 mmol/g COD respectively [17]. Sivagurunathan et al., mentioned Hydrogen yield (1.65 mol-H_2/mol-$_{\text{glucose eqivalent utilized}}$) was observed at low substrate concentration of 5 g($_{\text{glucose equivalent}}$)/L [18].

Experimental setup and procedure

The continuous experiments were carried out in a continuously stirred anaerobic bioreactor (CSABR) with working volume of 300 mL for anaerobic biohydrogen production. The reactor height and inner diameter were 22.5 cm and 7.5 cm, respectively. The CSABR was made of acrylic and jacketed with water bath as show in Fig. 1. A heater was used to control the system temperature at 37 °C.

The CSABR was seeded with the heat-treated sludge, equivalent to 20% of the working volume, and filled with the

Table 1 – Literature comparison chart of bio-hydrogen production.

Substrate	HRT (h)	Influent (g COD/L)	pH	Temp. (°C)	Reactor type	Hydrogen production rate(L/L/d)	H_2 yield (mol H_2/mol hexose)	References
Dairy wastewater	24	4.7	4.56	28	ASBR	0.03	–	[27]
Molasses	16	28.2 (g VS//L)	–	55	UASB	3.97	–	[28]
Coffee drink manufacturing wastewater	4	20	5.5	35	–	4.64	0.96	[29]
Beverage wastewater	2	20	5.5	40	CSABR	44.06	1.81	[30]
Manufacturing wastewater	1	10.39	5.5	40	CSABR	11.39	0.30	This study
Beverage wastewater	1	10.13	5.5	40	CSABR	34.59	0.92	This study

ASBR = anaerobic sequencing batch reactor, UASB = up-flow anaerobic sludge blanket, CSABR = continuously stirred anaerobic bioreactor, PBR = Packed bed reactor, CSTR = continuous stirred tank reactor, AFBRs = anaerobic fluidized bed reactors.

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