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Enhancement of Anaerobic Digestion of Cellulosic Fraction in Cassava Production Wastewater by Microaeration

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Effects of microaeration on the anaerobic digestion of cassava wastewater with added cassava residue in the continuous stirred tank reactor (CSTR) system were studied. The CSTR system was operated at ambient temperature. The biogas was analysed for the production rate and compositions by a gas meter and gas chromatography (GC), respectively. In addition, the overflown liquid effluent was collected and analysed for chemical characteristics. Operating parameters were varied to achieve the optimum chemical oxygen demand (COD) loading rate, the maximum content of added cassava residue, and the optimum oxygen dosing on the degradation of the cellulosic fraction. The COD loading rate was varied from 0.604 to 2.500 kg/m^3 d to determine the optimum COD loading rate without oxygen supply. The results showed that with the optimum COD loading rate of 1.710 kg/m^3 d, the generated gas mainly composed of 74.42 % CH_4 and 18.43 % CO_2 with negligible amounts of nitrogen and oxygen. The addition of a small amount of oxygen played an important role in the methane production.

1. Introduction

Commonly, biogas is generated from organic matter decomposing under anaerobic conditions in the open, or in captive anaerobic digesters, or in the guts of large ruminant animals, or by termites and some other smaller organisms (Abbasi et al., 2012). Anaerobic digestion is presently outstanding and effective technology. It is a biological process, which helps to degrade organic matter in the absence of oxygen. The organic matter is degraded partially by the combined action of several types of microorganisms. The process stages of anaerobic digestion are hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Rapport et al., 2008). Cassava wastewater is a potential source for the biogas production via anaerobic digestion because it is acidic with high organic matter content (soluble carbohydrates and proteins) and suspended solids (lipids and non-soluble carbohydrates-starch or cellulose fibers). Besides, it also has very high COD and biochemical oxygen demand (BOD) (Food and Agriculture Organization of The United Nations, 2000). Although cassava residue can be used as a feedstock, there is lignocellulose that is composed of carbohydrate polymers (cellulose, hemicellulose) and an aromatic polymer (lignin). These structures cause high complex in the plant cell wall (Yu et al., 2014) As a result, anaerobic microorganisms may not be able to digest cassava residue by anaerobic hydrolysis.

Therefore, this research work was conducted to investigate ways to enhance anaerobic digestion of this lignocellulose by studying likelihood of supplying microaeration to enhance the hydrolysis of cassava wastewater with added cassava residue. A CSTR was used as the anaerobic digester. Investigated parameters included different characteristics of cassava wastewater, fibre content of cassava residue, and gas compositions to find the optimum conditions of experiment for hydrolysis.

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2. Materials and methods

2.1 Substrate preparation

Seed sludge, cassava wastewater, and cassava residue were collected from the biogas plant at Ubon Biogas Co., Ltd., Ubon Ratchathani, Thailand. Their characteristics were investigated and are shown in Tables 1 - 3.

2.2 CSTR operation

A CSTR was used as the anaerobic digester for cassava wastewater. The system was operated without light illumination in a PVC reactor to inhibit the activity of photosynthetic bacteria. The CSTR was operated with liquid working volume of 4 litres and had a magnetic stirrer for mixing during the anaerobic digestion. The cassava wastewater was fed to the top of the CSTR by carrying it from the feed tank through the feed pump. Oxygen was supplied to the top of the CSTR. Oxygen concentration of the system was measured by a dissolved oxygen (DO) meter. The temperature was at ambient temperature. The biogas was analysed for the production rate and composition by a gas meter and GC, respectively. Besides, the

Table 1: Characteristics of the seed sludge

Parameters	Unit	Value
Colour	-	Dark
TSS (Total suspended solids)	mg/L	8,940
TVS (Total volatile solids)	mg/L	8,880
Nitrogen content in 1 g of dried seed sludge	g/L	0.3998

Table 2: Characteristics of the cassava wastewater

Parameters	Unit	Value
Total COD (Total chemical oxygen demand)	mg/L	10,557
Settled COD (Settled chemical oxygen demand)	mg/L	10,417
Soluble COD (Soluble chemical oxygen demand)	mg/L	9,408
Total nitrogen	mg/L	266.67
Total phosphorous	mg/L	80
COD : N : P	-	100 : 2.5 : 0.8
Ammonium	mg/L	2.00
Nitrate	mg/L	46.67
Nitrite	mg/L	1.07
pH	-	4.34

Table 3: Characteristics of the cassava residue

Parameters	Unit	Value
TS (Total solids)	(g/g of dried TS)	0.994
TVS (Total volatile solids)	(g/g of dried TS)	0.976
Ash	(g/g of dried TS)	0.018
COD (Chemical oxygen demand)	(g/g of dried TS)	0.806
Total nitrogen	(g/g of dried TS)	0.031
Total phosphorous	(g/g of dried TS)	0.004
COD : N : P	-	100 : 3.8 : 0.5
Moisture	%	11.63
Carbon	%	37.07
Hydrogen	%	5.89
Nitrogen	%	0.20
Sulphur	%	0.07
Oxygen	%	56.77
Extractives	%	9.34
Hemicellulose	%	23.41
Starch	%	41.05
Lignin	%	5.63
Cellulose	%	18.95
Ash	%	1.62

overflown liquid effluent was collected and analysed for chemical characteristics .Experiments were carried out as follows:

The cassava wastewater was digested in the anaerobic digestion without oxygen supply. The COD loading rate was varied from 0.604 to 2.500 kg/m^3 d corresponding to the feed flow rate and hydraulic retention time (HRT) to determine the optimum COD loading rate. Contents of cassava residue were varied and mixed with the cassava wastewater at the feed tank. The cassava wastewater with added cassava residue was fed to the CSTR and digested without microaeration under the optimum COD loading rate. Contents of cassava residue were varied from 250 to 1,500 ppm to determine the optimum content of added cassava residue for methane production. Oxygen was supplied to the CSTR for 5 min every 2 h, while the cassava wastewater with the optimum content of added cassava residue was digested under the total optimum COD loading rate. The oxygen supply rate was varied from 1.5 to 6.0 mL O_2/L_R d to determine the optimum value for the anaerobic hydrolysis of the cellulosic fraction.

2.3 Measurement and analytical methods

The gas composition of the produced gas was determined by the GC (AutoSystem GC, Perkin-Elmer) equipped with a thermal conductivity detector (TCD). The volume of the produced gas in the reactor was recorded daily using the water replacement method by a gas counter (Ritter, TGO5/5).The COD value was determined by the closed reflux, colorimetric method and spectrophotometer (HACH, DR 2700). The amount of volatile fatty acid in mg as acetic acid per liter was determined by the distillation-titration method (Eaton et al., 2005). The samples obtained from the steam distillation were also taken for the determination of organic acid compositions by using another gas chromatograph (PR 2100, Perichrom) equipped with a flame ionization detector (FID). In addition, DO value was determined by a DO meter (DO-5512SD).

3. Results and discussion

3.1 Anaerobic digestion of cassava wastewater without microaeration

Effects of the COD loading rate were investigated for methane production in the CSTR system without temperature and pH control. The COD removal was increased from 22.04 to 34.53 % by increasing the COD loading rate from 0.604 to 1.710 kg/m^3 d. In addition, the COD removal was decreased from 34.53 to 31.75 % with further increase in the COD loading rate from 1.710 to 2.500 kg/m^3 d. The maximum COD removal was 34.53 % at the COD loading rate of 1.710 kg/m^3 d. It may be explained that the increase in the COD loading rate resulted in the increase in the organic compounds available for microorganisms to degrade, which is consistence with the increase in the COD removal. On the other hand, when the COD loading rate was too high, like 2.500 kg/m^3 d, there is high volatile fatty acid accumulation, which unavoidably resulted in the system toxicity; hence, the decrease in the COD removal. The gas production rate showed the similar trend to the COD removal. This is the maximum gas production rate 265.50 mL/d at the COD loading rate of 1.710 kg/m^3 d. In other words, the optimum COD loading rate of 1.710 kg/m^3 d resulted in the maximum COD removal and gas production rate.

The gas composition was mainly methane and carbon dioxide. The methane composition and methane production rate were increased from 61.77 to 74.42 % and 45.87 to 197.61 mL/d, respectively, with the increase in the COD loading rate from 0.604 to 1.710 kg/m^3 d. However, when the COD loading rate was increased from 1.710 to 2.500 kg/m^3 d, the methane composition was decreased from 74.42 to 47.73 % and the methane production rate was down from 197.61 to 85.76 mL/d, while the hydrogen composition was increased to 34.85 %. The results indicated that the lower COD loading rate was suitable for the methane production because the lower COD loading rate had lower volatile fatty acid accumulation than the higher COD loading rate. The lower volatile fatty acid accumulation can be clearly observed from the pH value. The pH value was in the range of 6.52 - 7.02 when the COD loading rate was in the range of 0.604 to 1.710 kg/m^3 d. The pH value is an important factor in the anaerobic digestion by most anaerobic microorganism including methane-forming microorganism, which performs well in the pH range of 6.8 - 7.2. The pH value lower than 6 is too toxic for the methanogens activities (Chandra et al., 2012). On the contrary, the hydrogen-forming microorganism performs well in the pH range of 4.5 - 5.5 (Yu et al., 2002). The COD loading rate of 2.500 kg/m^3 d corresponding to the pH value of 5.26 and the rate of 1.710 kg/m^3 d had the pH value of 7.02. This explained the observed phenomena described above with the variuos COD loading rates. Both specific methane production rate and methane yield showed similar trend. The maximum specific methane production rate of 49.40 mL CH_4/L d (or 4.90 mL CH_4/ g MLVSS d) and the maximum methane yield of 44.13 mL CH_4/g COD removed (or 28.89 mL CH_4/g COD applied) was observed at the COD loading rate of 1.710 kg/m^3 d.

The total VFA concentration increased with the increase in the COD loading rate and attained the maximum value of 1,087.13 mg/L as acetic acid at the COD loading rate of 2.500 kg/m^3 d (pH 5.26), whereas the methane production rate decreased with the increase in the COD loading rate. The results indicated that, when the organic compounds increased, they were converted to soluble organic acids, resulting in the decrease in the pH value from 7.02 to 5.26. The decrease in the pH value was toxic to the microorganisms, which was why lower efficiency of methane production was observed. The composition of total VFA consisted of acetic acid (HAc), propionic acid (HPr), butyric acid (HBu), and valeric acid (HVa). The highest of all organic acids was observed at the COD loading rate of 2.500 kg/m^3 d. Under the optimum COD loading rate of 1.710 kg/m^3 d, the concentration of acetic acid was the highest (352.12 mg/L).

3.2 Anaerobic digestion of cassava wastewater with cassava residue without microaeration

Contents of cassava residue were varied and mixed with the cassava wastewater under the optimum COD loading rate of 1.710 kg/m^3 d. The effects of cassava residue were investigated. The COD removal was increased from 34.53 to 39.58 % by increasing the cassava residue concentration from 0 to 1,000 ppm. In addition, the COD removal was decreased from 39.58 to 37.24 % with further increase in the cassava residue concentration from 1,000 to 1,500 ppm. The maximum COD removal was 39.58 % at the cassava residue concentration of 1,000 ppm. It may be explained that the increase in the cassava residue concentration resulted in the increase in the organic compounds available for microorganisms to degrade consistence with increase the COD removal. The gas production rate showed the similar trend to the COD removal. That was the maximum gas production rate was 510.25 mL/d at the cassava residue concentration of 1,000 ppm.

The methane composition and methane production rate were increased from 74.42 to 80.09 % and 197.61 to 408.68 mL/d, respectively, with the increase in the cassava residue concentration from 0 to 1,000 ppm. However, when the cassava residue concentration was increased from 1,000 to 1,500 ppm, the methane composition was decreased from 80.09 to 71.24 % and the methane production rate was down from 408.68 to 288.02 mL/d, while the hydrogen composition was increased to 11.34 %. The results indicated that the lower cassava residue concentration was suitable for the methane production because the lower cassava residue concentration had lower volatile fatty acid accumulation than the higher cassava residue concentration. The maximum specific methane production rate of 102.17 mL CH_4/L d (or 9.22 mL CH_4/g MLVSS d) and the maximum methane yield of 89.75 mL CH_4/g COD removed (or 54.22 mL CH_4/g COD applied) was observed at the cassava residue concentration of 1,000 ppm.

In addition, with the cassava residue concentration of 1,000 ppm, the system provided the maximum hydrolysis efficiency corresponding to the highest cassava residue degradation in term of the highest percentage of cellulose (38.84 %), hemicellulose (23.09 %), and starch degradation (27.25 %). Hence, the concentration of cassava residue of 1,000 ppm was considered to be an optimum concentration for methane production under CSTR anaerobic digestion without temperature and pH control.

3.3 Anaerobic digestion of cassava wastewater with cassava residue with microaeration

The enhancement of anaerobic digestion of added cassava residue in the cassava wastewater was investigated by supplying oxygen under the total optimum COD loading rate of 1.884 kg/m^3 d. Effects of oxygen supply rate on the COD removal and gas production rate are shown in Figure 1a. The COD removal and gas production rate were increased with increasing the oxygen supply rate and then decreased when further increasing the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d. The maximum of both COD removal (79.24 %) and gas production rate (1,188.50 mL/d) were found with the oxygen supply rate of 3.0 mL O_2/L_R d. The main components of produced gas were methane and carbon dioxide. Both methane composition and methane production (Figure 1b-d) had a similar trend to the COD removal result. Interestingly, when the oxygen supply rate increased from 1.5 to 3.0 mL O_2/L_R d, the methane production increased. However, the oxygen supply rate increased beyond 3.0 mL O_2/L_R d, the methane production performance sharply decreased and the dissolved oxygen and oxygen gas composition increased (Figure 1e). It may be explained that the lower amount of oxygen supply could enhance the anaerobic hydrolysis by increasing the microbial activity (especially facultative bacteria being organisms that can switch between aerobic and anaerobic types of metabolism) resulting in the higher population and more secreted enzyme corresponding to a higher hydrolysis efficiency (Figure 1f). However, further increase in the oxygen supply rate from 3.0 to 6.0 mL O_2/L_R d, resulting the lower methane production because acetogenic and methanogenic bacteria are anaerobes, which are either inhibited or killed by oxygen resulting in the inhibition of both acetogenesis and methanogenesis step (Botheju and Bakke, 2011). In addition, at the oxygen supply rate of 3.0 mL O_2/L_R d, the system provided the maximum hydrolysis efficiency corresponding to the highest cassava residue degradation in terms of the highest percentage of cellulose (62.57 %), hemicellulose (37.24 %), and starch degradation (44.85 %). Therefore, the oxygen supply rate of 3.0 mL O_2/L_R d was considered to be an optimum oxygen supply rate for methane production under CSTR anaerobic digestion without temperature and pH control. The results

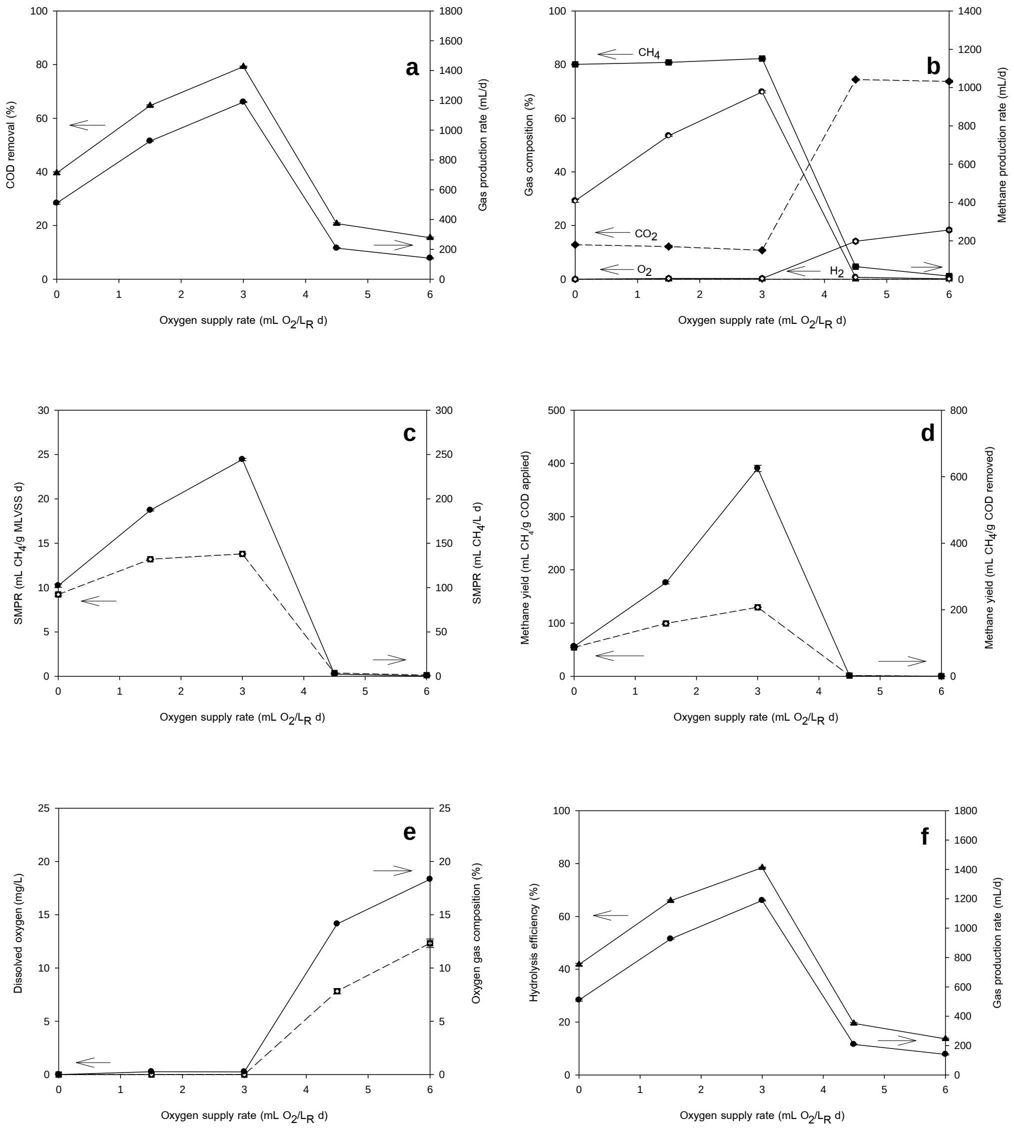

Figure 1: Effects of oxygen supply rate on (a) COD removal and gas production rate, (b) gas composition and methane production rate, (c) SMPR (Specific methane production rate), (d) methane yield, (e) dissolved oxygen and oxygen gas composition, and (f) hydrolysis efficiency

were achieved in this research work demonstrating the microaeration resulting in the enhancement of anaerobic hydrolysis and methane production efficiency that were also observed previously by Diaz et al. (2011), Lim et al. (2013), Xu et al. (2014), and Zhu et al. (2009).

4. Conclusions

The enhancement of methane production with microaeration from adding cassava residue in the cassava wastewater was investigated under the anaerobic digestion in the CSTR at the total COD loading rate of 1.884 kg/m^3 d without temperature and pH control. The oxygen supply rate of 3.0 mL O_2/L_R d was considered to be an optimum oxygen supply rate for facultative anaerobes via aerobic respiration under anaerobic hydrolysis that provided the maximum COD removal, methane gas production, hydrolysis efficiency , and percentage of cassava residue degradation.

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