Comparative Study of Biogas Production from Cassava Pulp in a Sequencing Batch Reactor and a Continuous Stirred Tank Reactor

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Abstract. Thai cassava starch industry generates solid waste or pulp approximately of 9.5 Mt/y (with a moisture content of 70–80%). Biogas production technology has been introduced for several decades in Thailand. However, the implementation of biogas production using cassava pulp as a feedstock is still limited due to the complex lignocellulosic structure, which diminishes hydrolysis. This work investigated biogas production from cassava pulp in a 50-m³ pilot-scale sequencing batch reactor (SBR) and continuous stirred tank reactor (CSTR). Both reactors were fed with cassava pulp, under the organic loading rate (OLR) of 8 kg-COD/m³-d and the average hydraulic retention time (HRT) of 7 d. Under the batch operation, more than 60% of the starch content was utilized within the first three days. The SBR achieved methane production of 1.87 m³-CH₄/ton-pulpfresh-d and acids production of 2.19 kg-TVA/ton-pulpfresh-d while the CSTR had methane production of 0.22 m³-CH₄/ton-pulpfresh-d and acids production of 7.07 kg-TVA/ton-pulpfresh-d. The methane production was higher in the SBR because the settling process helped microorganisms remain in the system. In CSTR, acids rather than methane were produced due to the washout of methanogenic microorganisms. This work revealed that the SBR yielded higher biogas production, while the CSTR produced intermediate acids, which could be supplied to the biochemical industry.

1. Introduction
Thailand is the largest producer of cassava starch for domestic consumption and export in 2019. The cassava starch industry in Thailand had generated a large amount of cassava pulp. The approximate generation of cassava pulp is 2.5 ton per one ton of cassava starch; this is equivalent to 9.5 Mt/y of cassava pulp with 80% moisture content [1]. The pulp is rich in organic compounds composed of 47.9–75.1% of starch as the major component, followed by cellulose, hemicellulose, and lignin at 4.11–25.8%, 4.20–16.8%, and 1.2–8.2% (dry basis), respectively. It also contains fat and protein in small proportions [2-4]. However, inappropriate management of cassava pulp leads to environmental pollution [5]. To date, cassava pulp can be used as a raw material for the production of fertilizer,
mushroom growing media, animal feed, bioethanol, and biogas [1]. Biogas production from the pulp can create a positive impact on the economy and environment [6].

Anaerobic digestion (AD) is a process for transforming organic substrates into biogas through the hydrolysis, acetogenesis, acetogenesis, and methanogenesis steps [7]. There are several biogas reactor configurations such as continuous stirred tank reactor (CSTR), anaerobic contact reactor, fluidized bed reactor, anaerobic fixed film reactor, upflow anaerobic sludge blanket (UASB), and sequencing batch reactor (SBR) reactor [8-9]. Among these biogas reactors, the CSTR and SBR have been considered the most practical for most industries [9-10]. The CSTR is simpler to operate than the SBR, while the SBR is often chosen for treating complex substrates, which need a long sludge retention time [11]. The aim of this study was to investigate the performance of anaerobic digestion of cassava pulp in the CSTR and SBR to evaluate the efficiency of organic acids and biogas production.

2. Materials and methods

2.1. Substrate and inoculum

Fresh cassava pulp was sourced from a cassava starch factory in Nakhon Ratchasima province, Thailand. The characteristics of the fresh cassava pulp are presented in table 1. The pulp was mainly composed of starch (68%) and fiber, which was a combination of cellulose, lignocellulose, and lignin. The sludge from a biogas plant treating starch-wastewater was used as an inoculum.

Table 1. The characteristics of the fresh cassava pulp in this study

| Cassava pulp’s component | % Composition |
|--------------------------|---------------|
| Moisture                 | 88.00         |
| Starch                   | 61            |
| Cellulose                | 14            |
| Hemicellulose            | 13            |
| Lignin                   | 3             |
| Protein                  | 2             |
| Other                    | 7             |

2.2. Experimental setup

A 50 m³ pilot-scale reactor was fed with cassava pulp at an organic loading rate (OLR) of 8 kg-COD/m³-d and an average hydraulic retention time (HRT) of 7 d. The SBR operation consisted of five steps: feeding, mixing, reaction, settling, and supernatant withdrawal, while the CSTR reactor was operated with the fill-draw method once a day. The pumps used for feeding were controlled by a timer. Both reactors were stirred by an agitator at 100 rpm.

The reactor was started by filling 20 m³ of the inoculum into a tank (at a total solid of 30 g/L). Then, the biogas effluent was added to the reactor until the working volume of 37 m³ was reached. Cassava pulp was used as a sole carbon source with the basal medium supplemented. During the start-up of the SBR, the OLR was initially set at 0.57 kg-COD/m³-d and then increased. The study began after the OLR of 8 kg-COD/m³-d

2.3. Analytical methods

The total solid (TS), volatile solid (VS), suspended solids (SS), alkalinity, and TVA were determined according to the AOAC standard methods [12]. The effluent pH of each reactor was measured daily by using a pH meter (Mettler-Toledo, s220). Starch content was measured by the enzymatic method [13]. The chemical composition including cellulose, hemicellulose, and lignin was determined by a two-step acid hydrolysis according to the standard NREL analysis method using Fibretherm (Gerhardt GmbH co) [14]. Gas composition was measured by a gas detector (Geotech, biogas 5000). Analytical samplings were conducted in triplicate for each sample on a daily basis throughout the experimental period. The efficiency of biogas, methane, and organic acids production was determined as
productivity, which was defined as the fraction between the products and the starch within the inlet feed. The equation for productivity is as follows:

\[ \text{Productivity} = \frac{P}{S \times t} \times 100\% \]

where \( P \) is the products, which can either be the volume of biogas (m\(^3\)), methane (m\(^3\)), or organic acids (kg-TVA), \( S \) is the quantity of substrate, which could be either the fresh pulp or the VS in the inlet feed (ton), and \( t \) is the time for substrate digestion (d).

3. Results and discussion
To increase the microbial concentration in the biogas system, the pilot-scale reactor was sequentially operated during the start-up period of approximately 4 months. The OLR was gradually stepped up from 0.53 to 8.0 kg-COD/\( m^3\cdot d\). Under the batch operation within the pilot-scale reactor, the starch was degraded by 60% within 3 days, while the fiber content (cellulose, hemicellulose, and lignin) remained almost constant. This suggests that the starch within cassava pulp was a major substrate for biogas production.

In this study, the use of a single-stage SBR means that organic acid and methane production occurred in the same reactor. The maximum acids concentration in the reactor was found to be 693 mg/L at the pH values of 6.60–7.03, which stayed within a range of the optimum conditions of the methanogenic microorganisms. The maximum methane production of 29.94 m\(^3\) was achieved in the SBR. In contrast, the CSTR behaved as an organic acid-producing unit. The maximum acids concentration in the CSTR was 2,606 mg/L. While the lowest pH measured was 6.39, the level of which is inhibitory to the methanogenic activity. The maximum methane production was 0.08 m\(^3\), which was substantially lower compared to the SBR. When comparing the performance between the two reactors, it was found that the organic acids productivity in the CSTR (7.07 kg-TVA/ton-pulp\(_{\text{fresh-pulp}}\)\( \cdot d\)) was considerably higher than the SBR, at the value of 2.19 kg-TVA/ton-pulp\(_{\text{fresh-pulp}}\)\( \cdot d\), as shown in figure 1. However, the SBR was shown to exhibit superior performance to the CSTR in terms of biogas production due to better solid and microbial accumulation through the sludge settling process before the supernatant withdrawal. The maximum SS of 36.73 g/L was obtained for the SBR, which was higher than that for the CSTR (25.73 g/L). As a result, the methanogens had a higher tendency to be retained in the SBR than in the CSTR.

![Figure 1. Productivity as a ratio of biogas, methane, and organic acids production to the cassava pulp inlet for an SBR and a CSTR.](image)
The reduction of the SS for the CSTR was not only due to the microbial washout, but also to the washout of the substrate. In the CSTR, the acids productivity determined from the VS within the pulp, as shown in figure 2, was 72.52 kg-TVA/ton-VS-d, which was substantially higher than that determined in the SBR, which was 18.57 kg-TVA/ton-VS-d.

![Figure 2. Productivity as a ratio of biogas, methane, and organic acids production to the VS of the inlet pulp for an SBR and a CSTR.](image)

4. Conclusion
This study investigated biogas production in a 50-m³ pilot-scale sequencing batch reactor (SBR) and continuous stirred tank reactor (CSTR). Both reactors were fed with cassava pulp under the organic loading rate (OLR) of 8 kg-COD/m³-d and the average hydraulic retention time (HRT) of 7 d. Over 60% of the starch content was utilized within the first three days. The methane production was higher in the SBR because the settling process helps retain the microorganisms in the system. In contrast, the acids were the major products from the CSTR rather than methane due to the washout of methanogens caused by a continuous process. The SBR achieved methane production of 1.87 m³-CH₄/ton-pulpfresh-d and acids production of 2.19 kg-TVA/ton-pulpfresh-d while the CSTR had methane production of 0.22 m³-CH₄/ton-pulpfresh-d and acids production of 7.07 kg-TVA/ton-pulpfresh-d. The microbial population needs to be investigated further to determine the relationship between microbial kinetic and reactor behavior. This work revealed that the SBR produced higher biogas yields, while the major products obtained from the CSTR were intermediate acids, which could be supplied to the biochemical industry.

5. References
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