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Effect of organic loading rate on reactor performance during anaerobic digestion of starch production wastewater

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Abstract

The long-term monitoring on an anaerobic digestion of cassava starch wastewater (CSW) using completely stirred tank reactor was performed for more than 260 days. The optimum operating organic loading rate (OLR) was 2.58 kg COD/m^3/d with pH, total volatile fatty acid (VFA) concentration, and VFA/alkalinity of 6.95±0.10, 618.30±37.30 mg/L as acetic acid, and 0.28±0.09, respectively. However, the reactors showed the signs of failure when operated at the final OLR of 2.96 kg COD/m^3/d. The pH significantly dropped resulting from accumulating VFA in the system. At the operating OLR of 2.58 kg COD/m^3/d, oxidation reduction potentials of the systems were in the effective range of methanogenesis stage. Total chemical oxygen demand and volatile solid removal were high as 80.85±1.37%, and 79.32±2.93%, respectively. Methane yield was reported to be 0.48±0.04 NL/gVS$_{added}$. Finally, the failure reactors were recovered, and the results could confirm the optimum operating OLR of 2.58 kg COD/m^3/d. Anaerobic co-digestion between starch wastewater and high-nutrient substrate could enhance the efficiency of the system. In addition, the biorefinery technology to produced high value bioproducts such as bioplastics and to use in biological nutrient removal process might be appropriate challenges to enhance the economic viability of the AD of CSW.

Keywords: Anaerobic digestion, Starch wastewater, Long-term monitoring, Completely stirred tank reactor

1. Introduction

In 2019, the Thailand's ministry of energy revised the Alternative Energy Development Plan (AEDP) (issued in 2015 and will be active until 2034) for increasing the renewable energy contribution to 29000 MW which will share more than 30% of the national power generation at the end of the plan. Based on this plan, biogas produced from anaerobic digestion (AD) of organic materials is predicted to take over approximately 3% of the national electricity generation at the end of 2037 [1]. In addition, at the beginning of 2020, Thai government also launched the new policy to support community-based power plant projects. A Feed-in tariff mechanism has been applied to facilitate this project and the government commits to start buying the produced electricity of 700 MW within 2020. AD is one of the promising biotechnology to convert broad spectrum of organic materials to gaseous biofuel in an absence of oxygen [2]. Many sources of industrial organic wastes could be potentially served as substrates for AD including cassava starch wastewater (CSW) [3]. Thailand is the one of the global major cassava starch exporters [4].

Unfortunately, during the production process, significant amount of wastewater (i.e. 20 tons of wastewater per ton of produced starch) can be generated with high chemical oxyden demand (COD) concentration of more than 10000 mg/L and pH in acidic range (i.e., lower than 5). Majority of this high-strength wasteswater is produced during starch sedimentation process [5]. It was reported that 32 million tons of cassava was produced in Thailand during 2015 which could potentially generate more than 0.6 billion cubicmeter of wastewater [6]. Contamination of CSW to aqua-environments could negatively affected ecosystems. Discharged wastewater could rapidly deoxygenate water bodies via large consumption of involved microorganisms regarding to it high biodegradability. Thus, the contaminated aqua ecosystems could be endangered [7]. Reversely, CSW is one of ideal substrates for AD using variety of reactor configurations. High soluble organic materials could facilitate methanogen and lead to high methane production without any limiting from hydrolysis stage. However, high organic acids in the substrate could easily push AD of cassava starch wastewater to the verge of failure. Hansupalak et al. (2016) [8] reported that more than 90% of the starch factories in Thailand changed their energy source from fossil fuels to biogas for serving the processes. In addition, by using AD of starch wastewater of the Thai starch factories could help reducing the carbon footprint by 0.9–1.0 million tons CO_{2eq}/year [8]. Based on the aforementioned statement, enhancing AD of starch wastewater has attracted many researchers. There are many digester configurations applied for AD of starch wastewater ranging from an elegant high-rate digester such as Upflow Anaerobic Sludge Blanket (UASB) to a simple low-rate reactor such as anaerobic covered lagoon [7,9]. However, only simple mono-digestion of starch wastewater alone might not satisfy economic feasibility. Anaerobic co-digestion with other appropriate organic materials could increase efficiency of AD of CSW [10]. Moreover, with respect to the Thai government policy as mentioned above, using co-digestion of multi-substrates could be awarded with higher adder of electricity cost compared with that of mono-digestion. Using intensive mixing reactor i.e., completely stirred tank reactor could be more flexible for co-digest starch wastewater with other high-solid organic waste compared to UASB. However, to the best of the authors' knowledge, the long-term monitoring of AD of starch production wastewater using CSTR as a bioreactor has not widely studied so far.

The purpose of this study is to long-term investigate the performance of AD of cassava starch wastewater using completely stirred tank reactor (CSTR) as the bioreactors. The important operating indicators are also repoted and discussed. The optimum operating OLR was confirmed by recovering failure reactors. Finally, the future directions were also discussed.

2. Materials and methods

2.1 Wastewater characteristics

The CSW was periodically collected from the cassava starch factory located at Kamphaeng Phet province, Thailand. The wastewater was stored in the refrigerated room where temperature was controlled at 4±2 °C. Before being used as the substrate in this study, CSW was left at the room temperature for couple hours. The characteristics of CSW are given in Table 1.

2.2 Inoculum

The inoculum was collected from the commercial-scale anaerobic digester treating cow manure in Lamphun province, Thailand. The collected inoculum was stored at 4±2 °C and reactivated at 32±2 °C for a week before being transferred to the prepared reactors. The characteristics of inoculum were analyzed, and the results are presented in Table 1.

Table 1 The characteristics of the collected cassava starch wastewater (CSW).

Parameter	Average concentration	
	CSW	Innoculum
pH	3.9±0.1	7.8±0.1
VFA (mg/L)	5296±292	N/A
COD_t (mg/L)	47427±6299	N/A
COD_f (mg/L)	21148±3876	N/A
TS (mg/L)	36911±5686	36911±5686
VS (mg/L)	33696±6114	33696±6114
TSS (mg/L)	N/A	785±64
VSS (mg/L)	N/A	157±23
TKN (mg/L)	758±64	N/A
TP (mg/L)	157±23	N/A

2.3 Reactor setup

Two lab-scale Completely Stirred Tank Reactors (CSTR), made of stainless steel with total volume of 9 L and effective volume of 7 L, were used in this study. The mechanical mixers (Zhengke Motor, China) were installed to perform continuously mixing at a constant rotating speed of 100 rpm. The reactors were operated in semi-continuous mode at mesophilic condition and the operating temperature was maintained at 35±2ºC using a heat exchanger. Oxidation Reduction Potential (ORP) and pH probes (Cole-Parmer, Illinois, United States) were installed at the top of the reactors to monitor and indicate the system performance. The probes were calibrated monthly to ensure the experimental data precision. Type T-thermocouples (Imari, Japan) were used to monitor the reactor temperatures. CSW was added to the reactors using the inlet port located on the reactor lids and the effluent was withdrawn from the outlet ports located at the bottom of the reactors. Gas pipes were connected on the top of reactors and collected biogas into the gas bags. The diagram of lab-scale CSTR reactor is presented in Figure1.

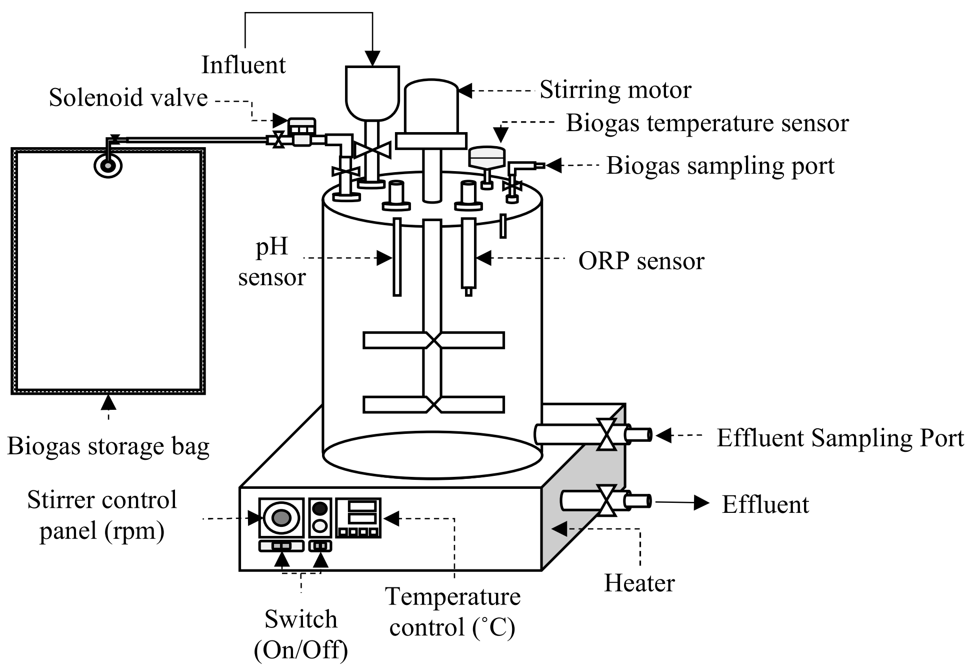

Figure 1 The CSTR reactor configuration.

2.4 Reactor startup and operation

The CSTR bioreactors were seeded with 2 L of the prepared inoculum as discussed in section 2.2 and 5 L of water was also filled to adjust the volume of the reactor contents. The reactors were started up at an initial organic loading rate (OLR) of 0.5 kg COD/m^3/d for 15 days. Following the startup period, the OLR was gradually increased to prevent shock loading and ensure the system stability. $NaHCO_3$ was intermittently added to maintain sufficient buffering capacity in the system (i.e., alkalinity of approximately between 2000 and 3000 mg/L as $CaCO_3$). The reactors operation was terminated when a sign of failure was observed (i.e., VFAs accumulation, and low methane yield). The withdrawn effluent was centrifuged and subsequently analyzed for pH, VFA, alkalinity daily, while total chemical oxygen demand COD_t, filtrated chemical oxygen demand COD_f, total solid (TS), volatile solid (VS), total suspended solid (TSS), and volatile suspended solid (VSS) were analyzed twice a week. Biogas generation rate and its composition were analyzed daily. The effect of OLR on reactor performance were determined by investigating VFA concentrations, pH, VFA/alkalinity ratio, and ORP of each operating OLR. COD and VS removals were also used as indicators reflexing reactor performance. Biogas and methane yields were also observed since they could be effective direct indicator representing AD system efficiency. Finally, the operating OLR of the failure reactors were decreased and subsequently stepwise increased again as detailing in section 4. The purpose is to confirm the optimum operating OLR since this information is an important criterion for scaling up the anaerobic system treating CSW and to examine a strategy to recover the failure reactor.

2.5 Analytical methods

pH was measured using a pH meter (Mettler Toledo, Ohio, United States). COD_t, COD_f, TS, VS, TSS, VSS, total kjeldahl nitrogen (TKN), total alkalinity and total phosphorus (TP) were analyzed following the standard methods [11]. Total volatile fatty acid (VFA) and alkalinity were analyzed using titration method as described by Anderson and Yang (1992) [12]. Biogas production was quantified using gas meters (China Coal, China). Biogas compositions were analyzed using a GFM406 portable multi-channel handheld gas analyzer (Gas Data Limited, Coventry, United Kingdom). All parameters were analyzed in duplicated except biogas production.

2.6 Statistical analysis

The significance of the experimental data was determined using analysis of variance (ANOVA) with a confidence level of 95% followed by a post-hoc Tukey's test using IBM SPSS statistical software version 25 (SPSS, Chicago, IL).

3. Results and discussion

3.1 CSTR reactor performance

3.1.1 Characteristics of the substrate

The characteristics of the collected starch wastewater were analyzed as mentioned in section 2.1. From Table 1, pH of CSW was quite low (i.e., below 4) which correlated with high VFA and negligible alkalinity. Thus, basic chemical such as $NaHCO_3$ should be periodically added to increase alkalinity and subsequently, to prevent system failure. The ratio of VFA and COD_f is high i.e., 0.25 which could potentially lead to system overloading and endanger the sensitive methanogens. Thus, starting up at low OLR (i.e., 0.5 kg COD/m^3-d) might be an appropriate strategy to prevent VFA accumulation in the systems. In addition, COD_t/TKN/TP of this substrate is 100.0:1.7:0.3 which fell in the recommended range for highly loaded anaerobic digestion [13]. Based on the aforementioned characteristics of the substrate and to simulate the real situation, nutrients were not added in this study. The characteristics of the CSW used in this study and those reported by the other researchers are compared in Table 2.

Table 2 Comparison of the characteristics of the cassava starch wastewater from different sources.

Parameters	Present study	[14]	[15]	[16]	[17]
COD_t	47427	6792	32000	10496	16000
TS	36911	-	12180	-	-
VS	33696	-	-	-	-
TKN	785	200	-	524	350
TP	157	-	-	94	-
pH	3.93	4.4	3.4	4.5-4.9	5.5

Analogous to the others, pH of the collected starch wastewater is in acidic range. However, COD_t of the substrate in this study shows the highest concentration. The difference might be from raw substrates and starch production processes.

3.1.2 pH, VFA, and VFA/Alkalinity

Typically, pH is one of key indicators for justifying performance of anaerobic reactor. An appropriate pH for AD was between 6.80 and 7.20 as recommended by Khanal (2008) [13]. In this study, pHs of the reactor contents at the operating OLRs of 1.08, 1.34, 1.65, and 2.58 kg COD/m^3/d were 7.10±0.02, 7.12±0.01, 7.10±0.01, 6.95±0.10, respectively. However, when OLR was increased to 2.96 kg COD/m^3/d, pH dropped to 6.57±0.11 which was lower than the proper pH for AD and reactors showed a sign of failure. Reactor overloading might play a key role in this phenomenon thus the reactor recovery for confirming the optimum OLR was performed as presented in section 3.1.4.

VFA is the organic acids with carbon less than 5 atoms produced during acidogenesis stage of AD. VFA is finally converted to methane during methanogenesis stage. However, VFA accumulation is one of the main indicators reflecting unhealthy AD process. Experimental pH and VFA observed in this study are presented in Figure 2.

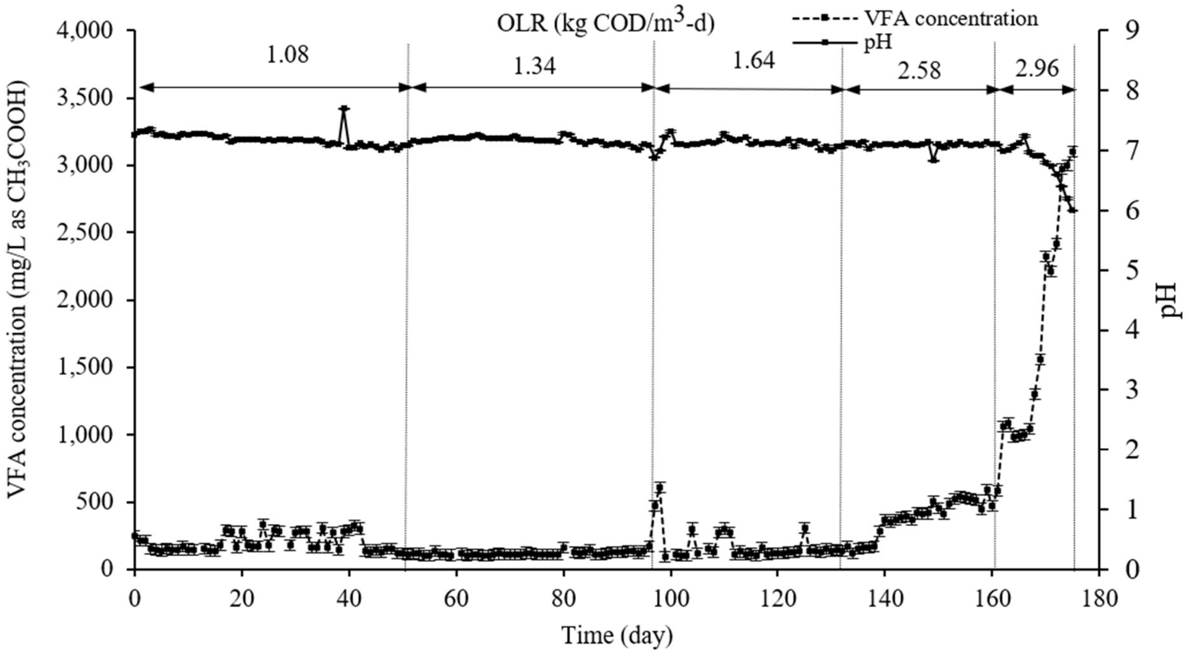

Figure 2 VFA concentration, and pH of the reactor content.

VFA at OLRs of 1.08, 1.34, 1.64, 2.58, and 2.96 kg COD/m^3/d were 183.26±12.08, 123.70±2.32, 140.96±7.69, 618.30±37.30 and 2,201.37±258.69 mg/L as CH_3COOH, respectively. Typically, total VFA concentration in AD system should not exceed 2000 mg/L as CH_3COOH [13]. However, based on the low pH (i.e. 6.57) at the OLR of 2.96 kg COD/m^3/d, VFA could be turned to be unionized from and could negatively affect methanogen and lead to digester failure. Khanal (2008) [13] mentioned that unionized VFA could inhibit methanogens even at low concentrations of 30–60 mg/L compared to more than 10000 mg/L of acetic acid and butyric acid, and more than 6000 mg/L of propionic acid, respectively at neutral pH. Alkalinity was well controlled between 2200–3500 mg/L as $CaCO_3$ which was in the recommended range (i.e. 1500–3000 mg/L as $CaCO_3$) [13] by adding $NaHCO_3$. Low VFA/alkalinity ratios i.e., 0.06±0.02, 0.04±0.01, 0.05±0.61, 0.18±0.03could be observed at OLR 1.08, 1.34, and 1.64 kg COD/m^3/d, respectively. However, when OLR was elevated to 2.58 kg COD/m^3/d, VFA/alkalinity ratio was sharply increased to 0.28±0.09. Finally, when OLR reached plateau at 2.96 kg COD/m^3/d, VFA/alkalinity ratio was 0.87±0.46 which is significantly higher than those of the previous operating OLRs and could clearly indicate reactor failure [13]. In addition, the microorganisms in the reactor contents were washed out when OLR was increased as showed in Figure 3 and might be one of the issues causing organic acid accumulation.

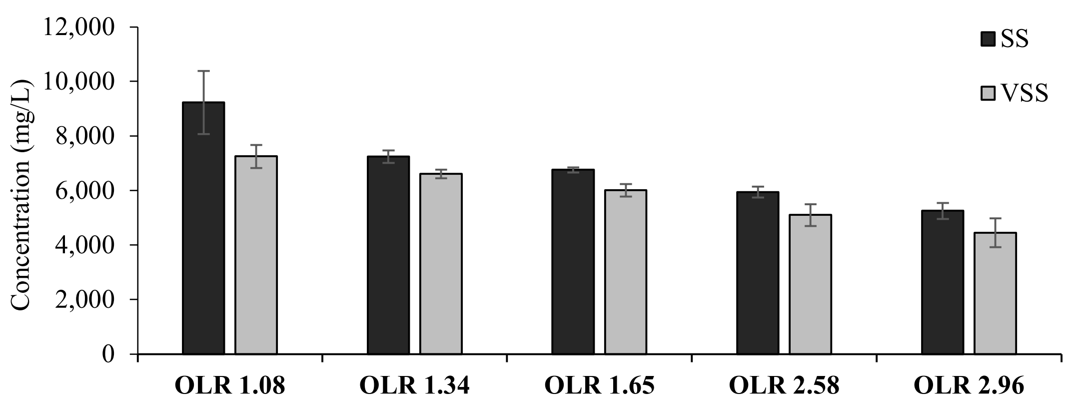

Figure 3 SS and VSS concentration of the reactor contents at each of organic loading rate.

The reactor performance of AD of starch wastewater were reported by many researchers. Rajbhandari and Annachhatre (2004) [7] observed the performance of anaerobic ponds treating starch wastewater in Thailand. The system could be operated effectively with OLR up to approximately 1.10 kg $COD/m^3/d$. In addition, the high-rate AD processes were also applied to treat starch wastewater such as anaerobic packed-bed reactor [14] and UASB reactor [18] with the OLRs of 4, and 10 kg $COD/m^3/d$, respectively. Similar to this study, when OLR was increased, VFA accumulation occurred and significantly pushed VFA concentration up and signaling the reactor failure. It should be noticed that the optimum OLR for AD of starch wastewater strongly depending on a reactor configuration. However, acid accumulation is the common cause of failure for this specific wastewater. The high biodegradability of starch-rich wastewater could facilitate hydrolysis and acidogenesis and subsequently, lead to acid accumulation and low pH. Thus, the methanogen could be suppressed [13].

3.1.3 Oxidation Reduction Potential (ORP)

ORP is the redox condition measurement of the system and could be potentially indicated AD performance. The ORP level could also determine the stages of AD [19]. Typically, ORP of methanogenesis stage is below –300mV [20]. ORP of the reactor contents in this study are illustrated in Figure 4.

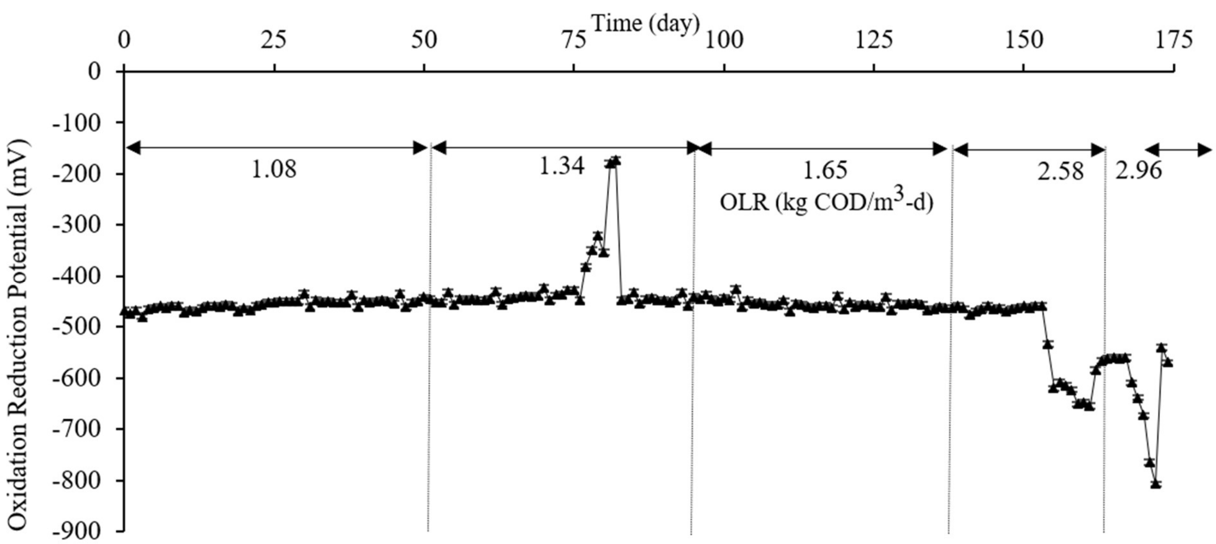

Figure 4 ORP of the reactor contents.

ORPs of the reactor contents during OLR of 1.08, 1.10, 1.34, 1.65, 2.58, and 2.96 kg $COD/m^3/d$ were 449.33±2.10, –414.07±8.32, –456.07±1.96, –527.20±15.02, and –620.50±15.20 mV, respectively. Similar to this study, the effect of increasing OLR on ORP was also presented by Vongvichiankul et al. (2017) [19] using screw anaerobic digester to treat synthesis food waste and leachate. The results showed that the increasing OLR, the decreasing trend of ORP were observed. Lu et al. (2015) [18] also observed ORP of AD of starch wastewater. The authors reported that ORP of the effluent was around -300 mV which is higher than the results obtain in this study. However, the ORPs from both studies are in a range of methanogenesis stage (i.e. lower than –300 mV) [20]. In addition, the results from this study agreed with Nguyen et al. (2019) [21]. The authors presented that ORP value was decreased when OLR was increased resulting from VFA accumulation, pH drops, and low microorganism concentration (presented in VSS) in the reactor at the high of OLR.

3.1.4 COD and VS removal efficiency

Organic matter, represented in COD and VS, removal is a key indicator to determine an efficiency of AD process. COD_t and VS removal efficiencies of each OLR were presented in Figure 5.

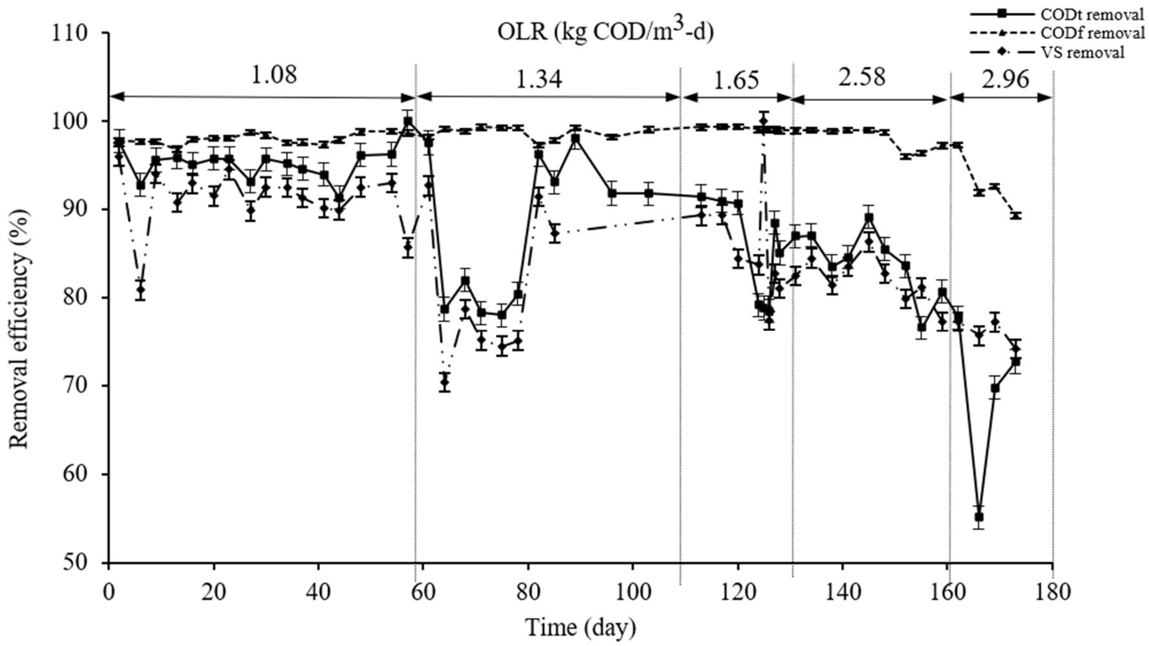

Figure 5 COD_t, COD_f and VS removal efficiencies.

COD_t removal efficiencies were high when the reactors were operated at low OLR (i.e., 94.15±0.52%, and 87.26±3.19% at OLR of 1.08 and 1.34 kg $COD/m^3/d$, respectively). These parameters started dropping to 84.40±1.39%, and 80.85±1.37% when OLR was increased to 1.65 and 2.58 kg $COD/m^3/d$, respectively. At the maximum OLR of 2.96 kg $COD/m^3/d$, COD_t removal efficiency was significantly decreased (at $\alpha = 0.05$) to 67.32±3.66%. VS removal efficiencies also showed the same trend with those of COD_t. VS removal efficiencies at OLR 1.08, 1.34, 1.65, 2.58, and 2.96 kg $COD/m^3/d$ were 91.78±0.52, 83.15±3.01, 80.74±0.70, 79.32±2.93, and 76.22±2.56, respectively. A high COD removal efficiency of AD of starch wastewater was reported by many researchers. Lu et al. (2015) [18] reported the maximum COD_t removal efficiency of 98.7% when UASB was used as the anaerobic bioreactor. The modified UASB system with the bio-electrochemical system could also degrade COD up to 80% [22]. The anaerobic batch experiment of tapioca starch wastewater was also studied by Elaiyaraju and Partha (2012) [23]. The high COD removal efficiency of more than 90% was obtained within 20 days of the experiments. Typically, a low COD removal efficiency could also effectively reflex a sign of failure. Analogous to this study, the increasing OLR from 6 to 8 kg $COD/m^3/d$ resulted the sharp drop of COD removal efficiency from 92% to 36% during AD of starch wastewater using UASB [18]. In addition, Jiraprasertwong et al. (2019) [9] studied the three-stage UASB for hydrogen and methane production from cassava wastewater. The results indicated that the increasing of OLR from 5 to 15 kg $COD/m^3/d$ could suppress COD removal efficiency for more than half (i.e., from approximately 85% to 40%). Thus, the low COD removal efficiency could potentially be from reactor overloading and might lead to end-product inhibition and imbalance of the involved microorganisms [24].

3.1.5 Biogas production and methane yield

Table 3 illustrates the results of biogas production and biogas yield. Biogas production rate showed an increasing trend during the reactor operation at the OLRs between 1.08 and 2.58 kg $COD/m^3/d$ with the production rate between 4.7±0.42 and 9.67±0.71 NL/d.

Table 3 Biogas production, biogas yield and biogas composition in each OLR.

Organic loading rate ($kgCOD/m^3$-d)	Biogas production (L/d)	Biogas composition (%)	Biogas yield (NL/gVS_{added})	Methane yield (NL/gVS_{added})
1.08	4.7±0.4	58.6±4.6	0.88±0.08	0.52±0.07^a
1.34	6.2±0.6	55.0±1.7	0.88±0.08	0.49±0.05^a
1.65	7.3±0.6	58.8±0.8	0.93±0.08	0.55±0.05^a
2.58	9.7±0.7	61.1±1.0	0.79±0.06	0.48±0.04^a
2.90	8.4±1.1	46.0±14.3	0.62±0.08	0.30±0.11^b

Remarks: the results shown as Mean ± SD, Different superscripts in the same column indicate differences (p< 0.05).

However, it was unstable and significantly dropped to 8.39±1.07 L/d when OLR was finally increased to OLR of 2.96 kg COD/m^3/d. Methane contents varied between 55.0±1.74 and 61.1±1.03 % when the reactor was operated at OLR of 1.08–2.58 kg COD/m^3-d. However, the methane content was significantly decreased to 46.0±14.32 % at the end of experiment (i.e., OLR of 2.96 kg COD/m^3/d). As mentioned in section 3.1.2, the VFA accumulation and low pH of the reactor contents at the high operating OLR could negatively affect methanogens and leaded to low biogas production. Methane yields during OLRs of 1.08, and 1.34 kg COD/m3/d were 0.52±0.07, 0.49±0.05 NL/gVS$_{added}$, respectively. Methane yield reached the plateau at the OLR of 1.65 kg COD/m^3/d with the maximum value of 0.55±0.05 NL/gVS$_{added}$. When the operating ORL was increased to 2.58 kg COD/m^3/d, the methane yield dropped to 0.48±0.04 NL/gVS$_{added}$. However, it was still not significantly different from those of the previous OLRs. When the operating OLR was increased to 2.96 kg COD/m^3/d, methane yield was significantly decreased to the minimum value of 0.30±0.11 kg COD/m^3/d which indicated the system failure. The comparison of methane productions from starch production wastewater between previous studies and this study are presented in table 4.

Table 4 Comparison of methane productions from starch production wastewater.

Studies	Conditions	Methane yield (NL/gVS$_{added}$)
This study	-CSTR reactor -Controlled temperature at 35 °C -Organic loading rate 2.58 kg COD/m^3/d -VS loading rate 1.78 kg VS/m^3/d -Organic Load = 17.48 g COD/d -VS Load = 12.47 g VS/d	0.48
Cremonez et al. (2020) [25]	-Two stage anaerobic digestion -Controlled temperature at 35 °C -HRT of acidogenic reactor 5 days -HRT of methanogenic reactor 20 days -VS load of methanogenic reactor 4.45 g/L	0.25
Antwi et al. (2017) [26]	-UASB reactor -Controlled temperature at 35 °C - OLR 3.65 kg COD/m^3/d - Organic load 26.25 g COD/L	0.47

The methane yields in this study were ranged between 0.48 and 0.55 NL/gVS$_{added}$ that similar the study of Antwi et al. (2017) [26]. Moreover, CSTR has some advantages compared to UASB system including but are not limited to handling high-solid waste stream, easier operation, and cheaper construction system.

3.1.6 Operating OLR confirmation

From the previous section, the optimum operating OLR for AD of starch wastewater was 2.58 kg COD/m^3/d before reactor failure occurred when the OLR was increased to 2.96 kg COD/m^3/d. Subsequently, the confirmation test (i.e. between day 193 and 263) was performed to ensure the optimum operating OLR since this parameter is the key to success to obtain the maximized benefit of AD system [13] and must be considered as the design and operating criteria for scaling up AD system. Firstly, the OLR was suddenly decreased to 1.14 kg COD/m^3/d and the reactors were operated for 5 days. Then the OLR was increased to 1.53 kg COD/m^3/d and the reactors were maintained at this condition for 2 weeks. After that, the reactors were operated at the OLR of 1.94 kg COD/m^3/d for 10 days. Finally, the OLR was increased to the OLR of 2.58 kg COD/m^3/d. The reactor performances of the operating OLR confirmation are presented in Figure 6. The operating parameters and reactor performance of the operating OLR confirmation period are showed in Table 5.

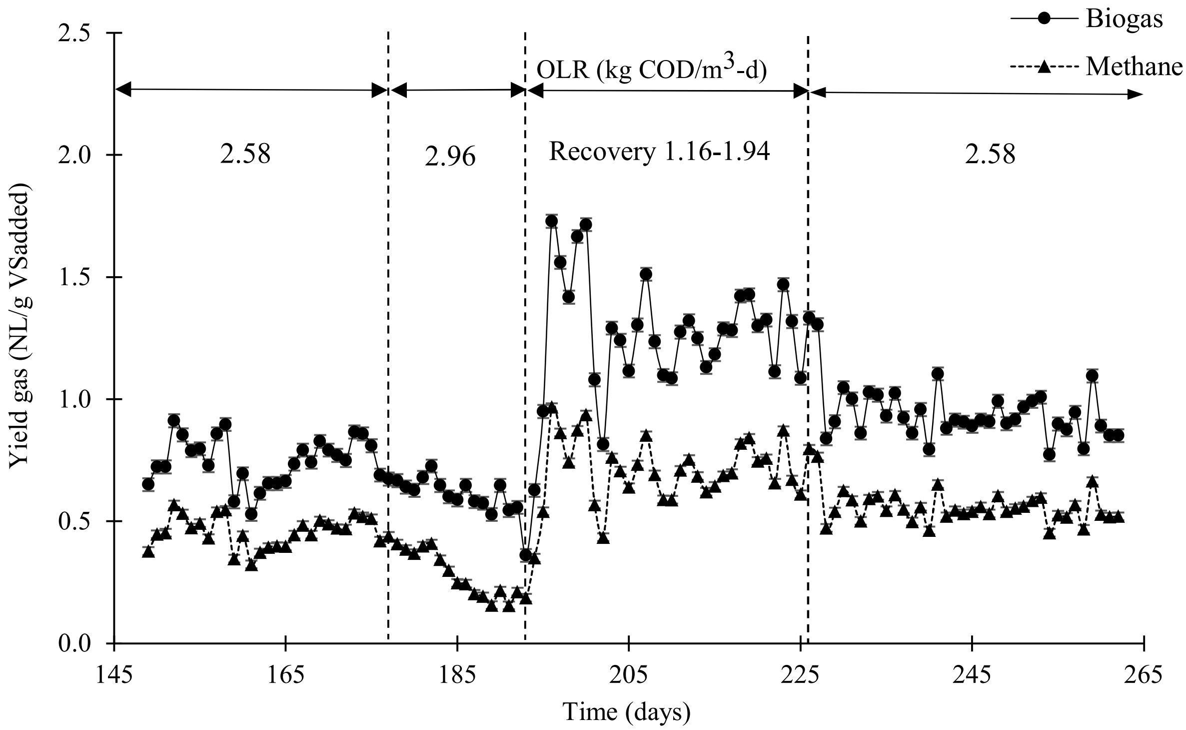

Figure 6 Biogas, and methane yields during OLR confirmation period.

Table 5 The operating parameters and reactor performance during the operating OLR confirmation period at the OLR of 2.58 kg COD/m^3-d

Parameters	Value
COD_t removal (%)	79.80±1.35
COD_f removal (%)	98.02±2.26
VS removal (%)	77.20±0.88
Biogas production (NL/d)	10.15±0.94
Methane production) NLCH_4/d)	6.06±0.60
Biogas yield (NL/gVS_{added})	0.92±0.10
Methane yield (NL CH_4/gVS_{added})	0.55±0.06

3.1.7 Biogas and methane yield during OLR confirmation period

The average methane yield during the operating OLR confirmation period was 0.55±0.06 NL/gVS_{added} which is significantly higher (at $\alpha = 0.05$) than that of the operating period (i.e., between day 133 and day 162) of 0.49±0.01 NL/gVS_{added} when operated at the OLR of 2.58 kg COD/m^3/d. Thus, it could be clearly concluded that in this study, the optimum operating OLR was 2.58 kg COD/m^3/d. ORP, an indirect indicator for determining AD system performance, was also determined. It was found that during the operating OLR confirmation period at OLR of 2.58 kg COD/m^3/d, the ORP was between –351 and –429 which was in the appropriate range of methane production [20]. However, when the operating OLR was increased to 2.94 kg COD/m^3/d, ORP significantly dropped to between –701 and –792 mV which indicated the reactor failure. In addition, this phenomenon followed the same trend as when the reactors were in the normal operating period. Moreover, it is worth to notice that the reactors could be recovered by stop feeding for a week. Then the reactors could be re-operated at the OLR of 1.00 kg COD/m^3/d and moreover, the operating OLR could be increased at the interval of 30% until reaching the designated OLR. The failure occurred in this study might be from the organic overloading of the reactor, thus, the microorganisms might be only temporary suppressed. When the feeding was discontinued, the reactor could be easily recovered. Moreover, the significantly higher of methane yield during the operating OLR confirmation period might be from the more active acclimated microorganisms in the system which already adapted to the high organic load compared to the those of the operating period.

3.2 Future direction

Anaerobic biorefinery is an appropriate technology to produce multiple products to optimize the benefit from the substrate utilization and minimize waste generation with AD as a centerpiece [27]. The products of anaerobic biorefinery process are based on the condition of investors. The products could be high volume but low value products (i.e. heat, electricity, and conventional biofuels) to enhance energy security or high value but low volume products (i.e. bio-chemicals) to enhance a benefit of AD systems [28]. The characteristics of CSW (i.e., high organic compounds and low pH) could effectively facilitate acidogenesis microorganisms to produce the mixture of VFAs. The produced acid could be used as an alternative carbon source for biological nutrient removal to replace expensive chemical such as methanol [28,29]. Moreover, individual VFA also has many applications. Acetic acid and butyric acids could be used to produce biodegradable plastic such as polyhydroxyalkanoates (PHA), polyhydroxybutyrate (PHB), and polylactate (PLA). By alternately producing VFA instead of methane, these bioplastics are environment-friendly products and could potentially mitigate the global waste issues. Anaerobic co-digestion between carbon-rich substrate such as CSW (i.e. COD/TKN of more than 60 in this study) and other nutrient-rich substrates (i.e. high-solid animal manures) to balance carbon to nitrogen ratio is one of the effective strategies to optimize the benefit from AD process [31,32]. By using this technology, the effective mixing regime could enhance performance of a system. Thus, the proper digester configuration i.e., CSTR might be required to achieve the goal of the system. Information obtained from this study could be used as guideline to design and operate the digester for maximizing the benefit of an AD system.

4. Conclusion

Anaerobic digestion of starch wastewater using CSTR reactor could be effective strategy to simultaneously produce bioenergy and address environmental problems. The optimized OLR obtained from this study was 2.58 kg COD/m^3/d with stable reactor performance. The system performance indicators (i.e., VFA, VFA/alkalinity, and biogas production among others) are in the recommended ranges for an anaerobic bioprocess. Methane yield was 0.48±0.04 NL/gVS$_{added}$. The information synthesized from this study could be used as criteria to design and operate anaerobic co-digestion of CSW and other co-substrate to enhance the mixing intensity and subsequently, system efficiency.

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6. References

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