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Biogas Recovery from Anaerobic Digestion of Starched Food Refuse what would be proper conditions?

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Abstract

The research results showed that biodegradation of starch resulted in the decrease of pH and alkalinity in the anaerobic digester, making it hard to achieve optimal conditions for microorganism growth. It were very difficult to control suitable conditions in both batch anaerobic digestion reactor and one stage semi-continuous system as a result of low biogas recovery efficiency. However, it is possible to get highest CH_4 concentration of 56.2% and approximately 50% within 7 days in the two-stage continuous system with sludge retention time (SRT) of 60 days. When SRT reduced to 20 days, maximum CH_4 concentration in biogas was only 45.1% and maintained for 2 days. About 73.5 m^3 biogas/ton of rice remnant by wet weight, equivalent to 247 m^3 biogas/ton of rice remnant dry weight were measured from lab-scale two-stage continuous anaerobic digestion system.

Key words: *Anaerobic digestion, biogas, one-stage and two-stage continuous anaerobic digestion, starched food refuse, rice remnant.*

1. Introduction

The rapid urbanization in Vietnam leads to developing of several new urban. Ministry of Industry of Vietnam (2010) predicted that economic growth rate of Vietnam would reach 7% by the next decade. However, it seems that high economic growth will go together with unpredictable environmental issues, including municipal solid waste generation and impacts, one of the most concerned problems in Vietnam nowadays. It was reported that average amount of municipal solid waste generated from urban areas in Vietnam increased 10-16% every year (Vietnam Environmental Protection Agency, 2011).

Table 1 Municipal solid waste (MSW) generation in Vietnam during the period of 2007 - 2010

Issues	2007	2008	2009	2010
Urban population (millions people)	23.8	27.7	25.5	26.22
% of urban population to total population	28.20	28.99	29.74	30.2
Daily MSW generation (kg/person/day)	0.75	0.85	0.95	1.0
Total MSW generation (tons/day)	17,682	20,849	24,225	26,224

Source: Vietnam Environmental Protection Agency, 2011.

In Ho Chi Minh City, MSW generation ranges from 6,400 tons/day to 7,200 tons/day (Nguyen Trung Viet, 2013). In particular, domestic solid waste accounts for 60-70% of the MSW generation (the National Environment Report: Solid Waste, 2011). This causes a great challenge for MSW management.

Currently, the methods of municipal solid waste treatment are improved, but large amounts of solid waste per day are still threats to public health and the environment. The popular solid waste treatment is landfill. However, this method cannot ensure about sanitary if not comply strictly the requirements of technical standards for the construction and operation, besides this method always needs large area of land and to be difficult to reuse for other purposes afterward. Meanwhile, the composition of organic biodegradable waste of MSW in Vietnam is very high, about more than 50% (National Environment Report: Solid Waste, 2011), particularly in Ho Chi Minh, statistics data from 2008 to 2012 shows that in municipal solid waste, about5-65% is food waste (Nguyen Trung Viet, 2013). This is potential material resources to develop the recovery biogas technology and composting organic fraction of municipal solid waste.

In Vietnam, biogas recovery from anaerobic digestion technologies has been introduced and applied for years. Larger-scale farms have applied this technology to generate electricity and provide heat for cooking. In industrial enterprises, such as DAKFOCAM (Dak Lak) Cassava Starch Factory, electricity produced from biogas has been used to solve environmental issues and achieve energy recovery[i]. Biodegradable solid waste can create a large amount of methane gas, which has very high calorific value (9,000 kcal/m^3) (Le Thi Kim Oanh, 2013). In a mixture of biogas, methane energy is about 6,000 kcal/m^3. Therefore, this heat source should be fully utilized in order to save fossil fuels, reduce landfill area requirement as well as protect the environment.

There are many factors that affect to the process of biogas recovery from anaerobic digestion such as pH, alkalinity, temperature, etc. However, under the same conditions, the ability to recover biogas could be different from different types of wastes. Currently, there is no research clearly indicates the biogas recovery potential from each component of solid waste. For this reason, studies on *biogas recovery potential from anaerobic digestion of starched food refuse* would be a scientific basis to determine optimal conditions for biogas recovery from this component, and is the basis for reasonably operating biogas recovery system from solid waste which has high starch content.

This study aims to determine the operating conditions of anaerobic digestion system and evaluate biogas recovery potential from anaerobic digestion of starched food refuse from households. In order to achieve this core objective, the following sub-objectives were conducted:

- Assess the effects of types of sludge mixed to starched food refuse from household domestic solid waste to biogas recovery efficiency in one-stage batch anaerobic digestion reactor;
- Assess the effects of initial sludge mixing ratios to biogas recovery efficiency from starched food refuse in one stage semi-continuous anaerobic digestion reactor;
- Assess the effects of retention time to biogas recovery efficiency from starched food refuse in two-stage continuous anaerobic digestion system;
- Determination of biogas generation rate and time need for complete degradation of a certain amount of starched food refuse.

2. Materials and methods

2.1 Anaerobic digestion reactor

One-stage batch anaerobic digestion reactor

The experiments were carried out in batch reactors made of plastic container with a volume of 7.5 L and 40 cm in height. A two-way PVC valve with 21 mm internal diameter and 15 cm height was put on the lid for sampling and adding chemicals. Biogas collection valve has a diameter of 7 mm was attached on the body of container and connected by a plastic tube to a biogas collection bag with 2 L volume. At the bottom of the bag, it is an air-relief valve to measure biogas composition and volume of biogas generation every day. After filling incubation mixture including starched food refuse, additives (blending materials) and chemicals, the reactors were sealed by silicone glue to ensure that no air infiltrated into as will as biogas released out of the reactors. The reactors were shaken 3 times/day manually, at 9 a.m., 1 p.m. and 5 p.m. and operated at room temperature (about 33^{o}C).

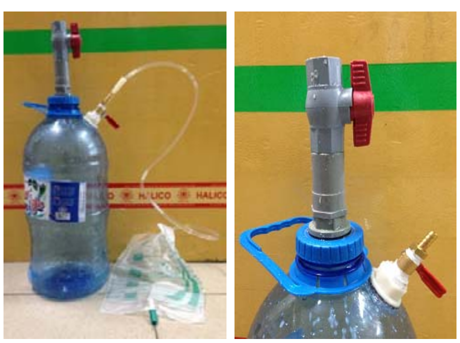

Fig 1 One-stage batch anaerobic digestion reactor.

One-stage semi-continuous anaerobic digestion reactor

The reactor was made of plastic container with a volume of 7.5 L resembling to the one stage batch anaerobic digestion reactor. However, in order to limit air enters the reactor during sampling and feeding daily, a 25 cm long plastic tube was extended inside the reactor, placed 10 cm from the bottom to ensure the tube submerged in the mixture, creating favorable conditions for anaerobic process.

Fig 2 One-stage semi-continuous anaerobic digestion reactor.

Two-stage continuous anaerobic digestion system

Two-stage continuous anaerobic digestion system consists of two tanks: a hydrolysis reactor and methanogenic reactor. Methanogenic reactor is the same as one-stage semi-continuous reactor. The hydrolysis reactor is made of plastic box with a volume of 350 ml and 15 cm height.

2.2 Assess the effects of types of sludge blended to starched food refuse to biogas recovery efficiency in one-stage batch anaerobic digestion reactor

Starched food refuse from households includes several types such as rice, noodles, bread, etc. However, in this the research, rice remnant is selected as materials use for experiments because this is the main food waste in the households. Rice is typical and main component representative to starched food refuse from household domestic solid waste.

Each type of sludge has different properties, therefore if mixed with starched food refuse and incubated in anaerobic condition, it may bring to different biogas generation rate. The purpose of this investigation is to determine suitable type of sludge to blend with starched food refuse to get better biogas recovery. Experimental conditions are summarized in Table 2. Two types of sludge selected were digested sludge from digester of pig manure from a pig breeding farm at Cu Chi District, Ho Chi Minh Cit and septic sludge from Hoa Binh Fertilizer Factory. A no sludge mixing reactor is operated simultaneously to check biogas generation of on starched food refuse.

Experimental procedure is as follows:

- Determining moisture content, OM (organic matter), VS (volatile solid), pH, alkalinity of rice remnant, digested sludge and septic sludge;
- Adding 2 kg of rice remnant into 3 reactors;
- Adding appropriate amount of sludge into the reactors as indicated in Table 2;
- Complete mixing the mixture inside the reactors;
- Determining pH, alkalinity of the initial mixtures;
- Adding $NaHCO_3$ into the mixture of the reactors until reaching optimum range of pH and alkalinity;
- Checking the reactors to ensure that they are closed, the valves and the biogas collection bags work well;
- Placing the fed reactors at room temperature;
- Sampling and determining pH, alkalinity of mixture once a day;
- Measuring biogas composition by Geotechnical Instruments once a day;
- Measuring volume of biogas produced by Wet Gas Meter once a day;
- Maintain the reactor until no biogas generated;
- Analyzing moisture, OM, pH and alkalinity of the remaining digested sludge after the decomposition process ended.

Table 2 Experiment conditions to assess the effect of the kind of sludge to the biogas recovery efficiency by the batch one-stage reactor

Parameter	Reactor		
	1	**2**	**3**
Volume of the reactor (L)	7.5	7.5	7.5
Useful volume (L)	2.5	2.5	2.5
Type of sludge	No sludge	digested sludge	Septic sludge
Amount of sludge (kg)	0	0.2	0.2
Amount of rice remnant (kg)	2	2	2
Weigh of $NaHCO_3$ (g)	24	20	10
pH of initial mixture	5.84	6.27	6.88
Alkalinity of mixture ($mgCaCO_3$/l)	125	5,000	5,500
Moisture of initial mixture (%)	60.66	80.14	66.01
Dry matter (DM) (%)	39.34	19.86	33.99
Temperature (°C)	nature (about 33°C)		

The amount of $NaHCO_3$ added to each reactor depending on its initial pH and alkalinity to control alkalinity in the range of 2,500-5,000 $mgCaCO_3$/L.

2.3 Assess the effects of initial sludge mixing ratios to biogas recovery efficiency from starched food refuse in one-stage semi-continuous anaerobic digestion reactor

The purpose of selection one-stage semi-continuous anaerobic digestion reactor is to determine the appropriate initial sludge blending ratio for microorganism adaptation and growth. It also helps to maintain pH and alkalinity in the optimal range to create suitable condition for anaerobic digestion process. By semi-continuous feeding, it may help to limit rapid reduction of pH in the incubation mixture, maintaining favorable environment for microbial growth and decomposition of the substrate while reducing pH adjustment requirement during operation.

Experimental procedure is as follows:

- Determining initial moisture, OM, pH and alkalinity rice remnant and septic sludge;
- Balancing for septic sludge into the reactor;
- Adding appropriate amount of rice remnant into the reactors;
- Check the reactors to ensure that they are closed, the valves and the air bags works well;
- Remove 0.15 kg of the mixture from the reactor before adding 0.15 kg of rice remnant every day. Stop adding rice remnant after 20 days;
- Place the reactor at room temperature;
- Measuring biogas composition by Geotechnical Instruments once a day;
- Measuring volume of biogas produced by Wet Gas Meter once a day;
- Maintain the reactor until no biogas generated;
- Analyzing moisture, OM, pH and alkalinity of the remaining digested sludge after the decomposition process ended.

Table 3 Experiment conditions to assess effects of initial sludge mixing ratios to biogas recovery efficiency from starched food refuse in one-stage semi-continuous anaerobic digestion reactor

Parameter	Reactor		
	1	2	3
Volume of the reactor (L)	7.5	7.5	7.5
Useful volume (L)	3.2	3.2	3.2
Total amount of rice remnant to be fed (kg)	3	3	3
Amount of septic sludge (kg)	0.9	1.5	3.0
Percentage of initial septic sludge amount compared to amount of rice remnant (%)	30	50	100
SRT (days)	20	20	20
Amount of rice remnant filled into the reactor (kg/day)	0.15	0.15	0.15
Amount of the mixture removed from the reactor (kg/day)	0.15	0.15	0.15
Temperature (°C)	Nature (about 33°C)		

2.4 Assess the effects of retention time to biogas recovery efficiency from starched food refuse in two-stage continuous anaerobic digestion system

The two-stage continuous anaerobic digestion reactor seems promising possibility to maintain stable pH and alkalinity of the system. Therefore, this research selected two-stage continuously system and changed sludge retention time (SRT) intervals to determine the appropriate time for microorganism acclimatization and growth. Selecting sludge retention time of 20 days and 60 days to evaluate the effects of SRT to biogas recovery efficiency. Experimental conditions are summarized in Table 4.

Experimental procedure is as follows:

- Determining initial moisture, OM, pH and alkalinity rice remnant and septic sludge;
- Balancing for septic sludge into the reactor;
- Adding appropriate amount of rice remnant into the reactor;
- Check the reactors to ensure that they are closed, the valves and the air bags works well;
- For the system with SRT = 20 days, removed 150 g of the mixture from methanogenic reactor every day, took

150 g of the mixture from hydrolysis reactor and added into the methanogenic reactor, and then feed 150 g of the new mixture into the hydrolysis reactor every day;
- For the system with SRT = 60 days, removed 50 g of the mixture from methanogenic reactor every day, took 50 g of the mixture from hydrolysis reactor and added into the methanogenic reactor, then fed 50 g of the new mixture into hydrolysis reactor every day;
- Place the reactor at room temperature;
- Measuring biogas composition by Geotechnical Instruments once a day;
- Measuring volume of biogas produced by Wet Gas Meter once a day;
- Maintain the reactor until no biogas generated;
- Analyzing moisture, OM, pH and alkalinity of the remaining digested sludge after the decomposition process ended.

Table 4 Experiment conditions to assess the effects of retention time to biogas recovery efficiency from starched food refuse in two-stage continuous anaerobic digestion system

Parameter	Reactor			
	1		2	
	Hydrolysis reactor	Methanogenic reactor	Hydrolysis reactor	Methanogenic reactor
Volume (L)	7.5	7.5	0.35	7.5
Useful volume (L)	1.0	3.2	0.3	3.2
Amount of septic sludge (kg)	0.9	3.0	0.3	3.0
SRT (days)	6	20	6	60
Sludge taken from hydrolysis reactor (kg/day)	0.15	-	0.05	-
Sludge filled into methanogenic reactor (kg/day)	-	0.15	-	0.05
Temperature (°C)	Nature (33°C)			

2.5 Determination of biogas generation rate and time need for complete degradation of a certain amount of starched food refuse

The study aims to determine the time needed for complete degradation of 100 g of rice remnant, then evaluate decomposition rate of starch from this material. The experiment was carried out with the conditions shown in Table 5.

Table 5 Experiment conditions to determine biogas generation rate and time need for complete degradation of a certain amount of starched food refuse

Parameter	Reactor	
	1	2
Volume of the reactor (L)	7.5	7.5
Useful volume (L)	3.2	3.1
Amount of rice remnant (kg)	0	0.1
Amount of septic sludge (kg)	3.0	2.9
pH of septic sludge	8.47	8.47
Alkalinity of septic sludge (mgCaCO$_3$/l)	7,750	7,750
pH of the mixture	4.38	4.38
Alkalinity of the mixture (mgCaCO$_3$/l)	250	250
Moisture of the mixture (%)	91.87	92.65
Dry matter of the mixture (%)	8.13	7.35
Organic matter (% by dry weight)	54.68	57.89
Temperature (°C)	Nature (about 33°C)	

Experimental procedure is as follows:

- Determining initial moisture, OM, pH and alkalinity rice and septic sludge;
- Balancing for septic sludge into the reactor;
- Adding appropriate amount of rice remnant into the reactors;
- Check the reactors to ensure that they are closed, the valves and the air bags works well;
- Place the reactor at room temperature;
- Measuring biogas composition by Geotechnical Instruments once a day;
- Measuring volume of biogas produced by Wet Gas Meter once a day;
- Maintain the reactor until no biogas generated;
- Record, drawing to compare CH_4 concentration and volume of generated biogas of both 2 reactors during the decomposition process;
- Analyzing moisture, OM, pH and alkalinity of the remaining digested sludge after the decomposition process ended.

3. Results and discussions

3.1 Assess the effects of types of sludge blended to starched food refuse to biogas recovery efficiency in one-stage batch anaerobic digestion reactor

This study aiming at assessment of effects of digested sludge septic sludge mixed to rice remnant to biogas production from one-stage batch anaerobic reactor under initial optimum conditions of pH, alkalinity and temperature. pH and alkalinity were measured every day and chemical was added to adjust pH during operation. Rice remnant was taken from Educational Management School in Ho Chi Minh City (No. 7, Nguyen Binh Khiem Street, District 1). Characteristics of materials used in the experiment are presented in Table 6.

Table 6 Characteristics of rice remnant and sludge used

Parameters	Rice remnant	Digested sludge	Septic sludge
pH	5.34	8.06	7.97
Alkalinity (mgCaCO$_3$/L)	125	1,200	8,500
Moisture (%)	60.66	99.61	83.67
VS (%)	-	72.66	-
DM (%)	39.34	0.39	16.33
OM (%)	87.84	-	59.00

By measuring composition of biogas generated from the reactors during operation, it is found that CH_4 gas of biogas generated from the reactor 1 (contained only rice remnant) and the reactor 2 (contained the mixture of rice remnant and digested sludge) remained at less than 1% for almost 20 days. While the reactor 3 (contained the mixture of rice remnant and septic sludge, CH_4 started to increase from day 6 and kept constant at about 6% during day 10 to

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day 17. It is attributed to low pH and alkalinity (pH = 5.34 and alkalinity = 125 mgCaCO$_3$/L) in the reactor contained only rice remnant. For reactor 2 and 3, though being mixed with digested and septic sludge to have high alkalinity and pH at the starting, the pH and alkalinity of the mixtures were decreased rapidly during operation and reached below the optimal range for the anaerobic digestion. This explains why biogas generated has very low percentage of CH$_4$ very low. It is important to maintain pH and alkalinity in the anaerobic digester around 7,0 (Kythreotou et al., 2014) and 3,000-5,000 mg CaCO$_3$/L, respectively to create favorable condition for methanogenic bacteria growth (Metcalf and Eddy, 2003).

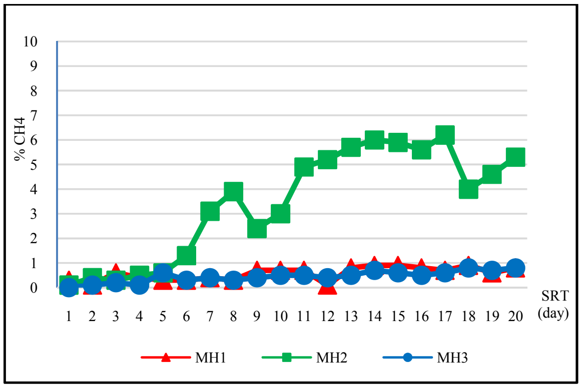

Fig. 4 Concentration of CH$_4$ (%) in biogas generated from 3 batch anaerobic digestion reactors.

Figure 5 shows that the pH of the 3 reactors fluctuates during the first 10 days. Reactor has initial pH of 5.84 and decreased steadily during operation and from day 12, pH maintained at 4.5. The reactor 2 contained mixture of rice remnant and digested had initial pH of 6.27, but it decreased rapidly only after 1 day of operation. Though chemical was added in day 3 to increase pH to 6.26, but it still could not maintain pH of the mixture. pH decreased rapidly after that and remained in the range of 4.05 to 4.67 during the next 17 days. For the reactor 3, though initial pH of the mixture of rice remnant and septic sludge was 6.88, after 1 day of operation, pH also decreased sharply to 3.99. Similar to the reactor 2, adding chemical to adjust pH was unable to control optimum pH condition in the reactor. pH decreased rapidly and maintained in the range of 4.15 to 5.57.

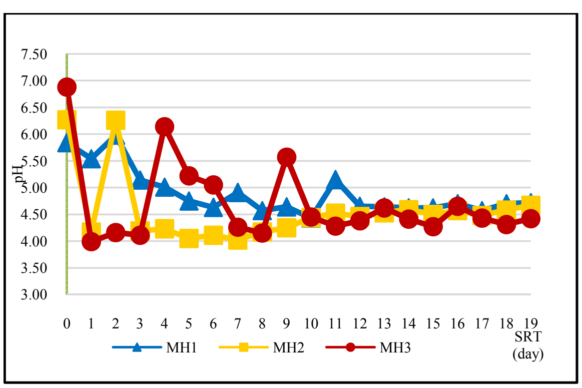

Fig. 5 Change of pH in 3 batch reactors.

Decomposition of starch from rice remnant creates acid condition and reduces pH. In all 3 reactors, pH was lower than 5.0 even chemical was added for pH adjustment. It is attributed to very low CH$_4$ percentage in the biogas generation from these reactors. In addition, addition of chemical could increase TDS significantly and affect to metabolism of anaerobic microorganisms.

During 20 days of operation, alkalinity varied widely for reactor 2 and reactor 3. Sometimes, the alkalinity was in the optimum range but several day alkalinity was very low, even reached 0 when pH < 4.3. The reactor 1 had initial alkalinity of about 5,000 mg CaCO$_3$/L and decreased gradually during operation.

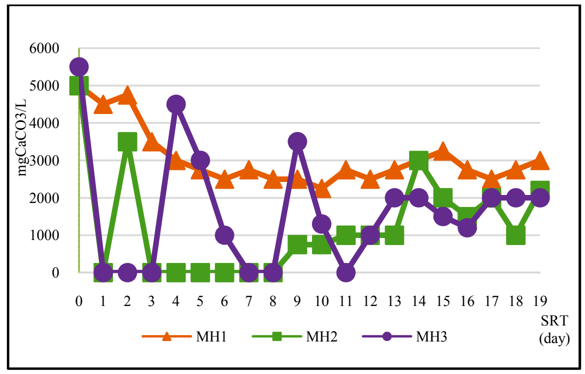

Fig. 6 Change of alkalinity in 3 batch reactors.

After 20 days of operation of these 3 reactors, it is possible to conclude that the one-stage batch reactor is not suitable for operating the anaerobic degradation of starched food refuse, especially rice remnant. Septic sludge seems to be a better material to be used as additives for the incubation mixture.

3.2 Assess the effects of initial sludge mixing ratios to biogas recovery efficiency from starched food refuse in one-stage semi-continuous anaerobic digestion reactor

The experiment was conducted by using septic sludge as additive. The purpose of this experiment is to determine the suitable ratio of septic sludge used for mixing with rice remnant to maintain optimal pH and alkalinity condition in anaerobic digestion reactors. One-stage semi-continuous model was used to overcome obstacle of accumulation of volatile fatty acid of the batch system. Characteristics of materials used in this experiment are presented in Table 7.

Table 7 Characteristics of rice remnant and septic sludge used

Parameters	Rice remnant	Septic sludge
pH	4.89	8.13
Alkalinity (mgCaCO$_3$/L)	500	7,250
Moisture (%)	63.20	86.56
DM (%)	36.80	13.44
OM (%)	83.39	45.07

Fig. 7 showed that the reactor contained 50% septic sludge (by wet weight) reached highest CH$_4$ concentration. After 3 days of operation, CH$_4$ concentration in biogas generated reached 12.1%. However, after that it reduced steadily (from 11.4% at 4th day to 0.4% at the last day). For other two reactors, which were controlled to have 30% (reactor

1) and 100% (reactor 3) of septic sludge of the total mixture, CH_4 was still very low. After 1 day, CH_4 concentration was 5.8% and 2.8% from the reactor 1 and reactor 3, respectively and then it decreased gradually in next days. It could be explained with the same reason as mentioned above experiment. It seems that the feeding rates were still high leading to overloading of the system.

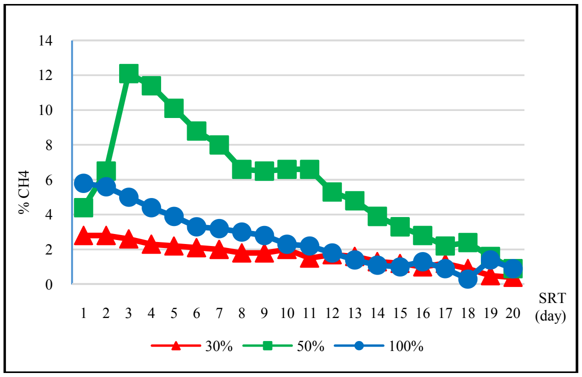

Fig. 7 Concentration of CH_4 (%) in biogas generated from 3 one-stage semi-continuous anaerobic digestion reactors.

Figure 8 shows the change of pH in 3 one-stage semi-continuous anaerobic digestion reactors during 20 days of operation. Septic sludge with slightly high pH (about > 8) was selected to be a buffer to maintain pH of the mixture during digestion. However, when starch from rice remnant degraded, pH of the 3 reactors were decreased rapidly. Three reactors had pH varied from 4 to 5 during operating (from day 1 to ay 17) and increased lightly at the end of period (from day 18), but only reached approximately 5. This causes very low CH_4 generation and indicates that sludge retention time (SRT) was still short or the systems were overloaded.

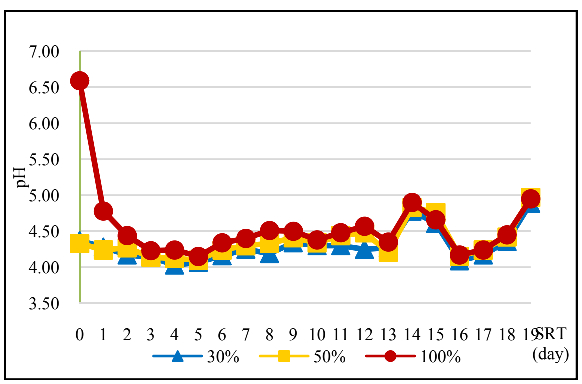

Fig. 8 Change of pH in 3 one-stage semi-continuous anaerobic digestion reactors.

Corresponding to pH reduction, alkalinity also decreased. It shows that if controlled SRT of 20 days, it is impossible to maintain optimal pH and alkalinity even in semi-continuous anaerobic digestion reactors as a result of very low CH_4 generation. Starch from rice remnant fed daily is hydrolyzed with a higher speed compared to the consumption rate of methanenogenic microorganism. This leads to accumulation of volatile fatty acid stored and causes pH and alkalinity reduction. Nevertheless, after changing from one-stage batch reactor to one-stage semi-continuous reactor, higher CH_4 concentration was achieved in the biogas generated (about 12% compared to 6% in the batch reactor).

3.3 Assess the effects of retention time to biogas recovery efficiency from starched food refuse in two-stage continuous anaerobic digestion system

Two two-stage continuous anaerobic digestion reactors were operated with SRT of 20 days and 60 days to evaluate effects of SRT on biogas recovery efficiency SRT of hydrolysis reactor was controlled for 6 days for both cases. Characteristics of materials used in this experiment are summarized in Table 8.

Table 8 Characteristics of rice remnant and septic sludge used

Parameters	Rice remnant	Septic sludge
pH	4.38	8.01
Alkalinity (mgCaCO$_3$/L)	250	5,500
Moisture (%)	70.20	91.87
DM (%)	29.80	8.17
OM (%)	83.28	54.68

CH_4 concentration generated from the methane reactors are showed on Fig. 9. For the system 1 with SRT of methane reactor of 20 days, CH_4 concentration reached about 45.0% at day 5. However, it did not last long. At day 7, CH_4 concentration reduced to 29.9% and remained only 7.8% from day 9. For system 2 with SRT of methane reactor of 60 days, after 6 days of operation, concentration of CH_4 in biogas achieved around 50% and maintained at this level for 7 days. From day 14, CH_4 concentration went down (under 40%). From day 16, CH_4 remained at 27.2% and decreased continuously to lower 20% from day 19.

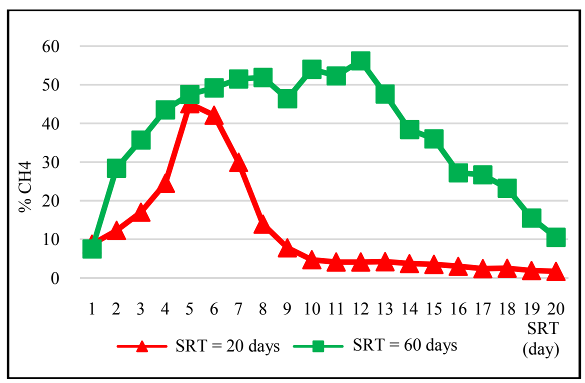

Fig. 9 Concentration of CH_4 (%) in biogas generated from two-stage continuous anaerobic digestion reactors with different SRT.

Although CH_4 concentration could not be maintained in many days, two-stage continuous system proves that it is possible to recover high CH_4 concentration in biogas generated. The highest CH_4 concentration reached 56.2% from the system with SRT of methane reactor of 60 days and 45.1% from the system with SRT of 20 days. Besides, the days in which CH_4 concentration of biogas higher than 20% was last longer, 4 days for the system with SRT of 20 days and 17 days for the system with SRT of 60 days.

Amounts of biogas generation from these 2 systems are presented in Fig. 10. Maximum amount of biogas generated from system 1 with SRT of 20 days was 2.9 L/day, at day 5. During the first 5 days, amount of biogas

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generated increased rapidly. However it reduced from day 6 to day 10 and maintained around 0.5 L/day after that until day 20. In the case of system with SRT of methane reactor of 60 days, maximum amount of biogas generated reached 3.35 L/day at day 14. Amount of biogas generated kept increasing within 14 days and started decreasing from day 15 afterward. There is a clear different between biogas generation line from these two systems (Fig. 10). It seems that the system with SRT of methane gas of 60 days created better conditions for anaerobic digestion and helped to achieve better biogas generation rate.

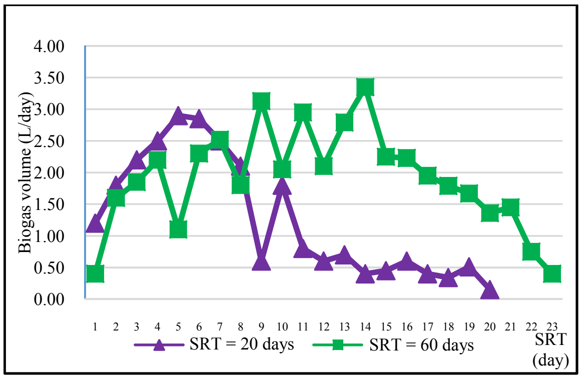

Fig. 10 Amount of biogas generation from two-stage continuous anaerobic digestion reactors with different SRT.

After 20 days of operation, system 1 with SRT of methane reactor of 20 days had total amount of biogas generated was 24.47 L, while it was 41.39 L from the system 2 with SRT of methane reactor of 60 days, about 1.67 times higher than that of system 1.

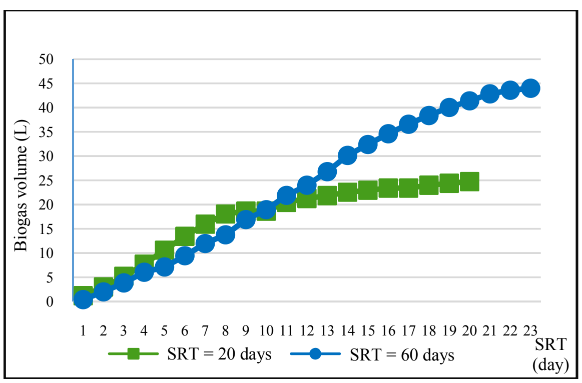

Fig. 11 Accumulated amount of biogas generation from two-stage continuous anaerobic digestion reactors with different SRT.

Figure 12 illustrated change of pH in 2 two-stage continuous anaerobic digestion systems. At the beginning, pH of methane reactors of both systems was around 8.0. After the first 5 days, pH of methane reactor of the system 1 reduced 6.0 and maintained in the range of 4.5 to 6.0 till the end of period. This explains why biogas generation rate from this system decreased from day 5 afterward. In the case of system 2, pH maintained greater than 6.5) for 10 days and after that it also reduced to lower than 6.0. pH was not adjusted during operation of these systems. The reduction of pH to lower than 6.0 impacted significantly to performance and quality of biogas generated.

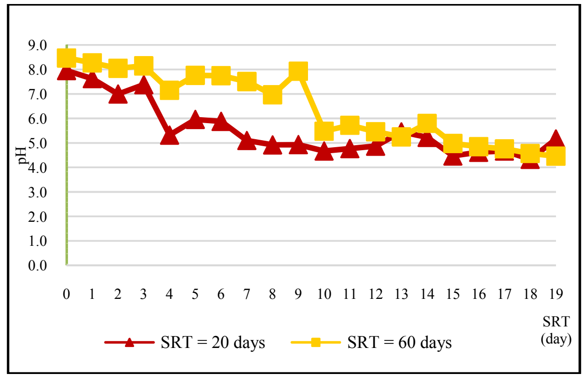

Fig. 12 pH of two-stage continuous anaerobic digestion reactors with different SRT.

Alkalinity of these systems also decreased during operation (Fig. 13). However, alkalinity always greater than 2,000 mgCaCO$_3$/L.

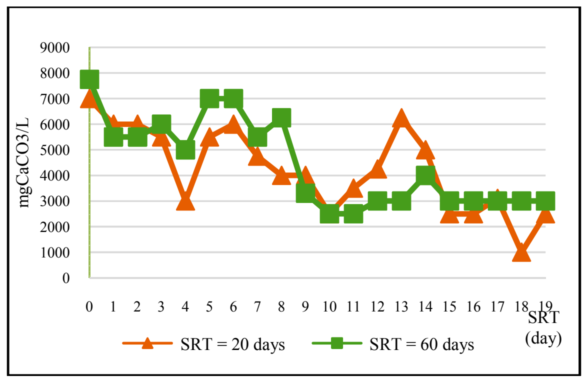

Fig. 13 Alkalinity of two-stage continuous anaerobic digestion reactors with different SRT.

It is possible to conclude that CH_4 concentration in biogas generated from two-stage continuous anaerobic digestion system is much higher than that of the one-stage batch and one-stage semi-continuous systems. It is attributed to the separated operation of hydrolysis and methanogenic fermentation step. When organic substances were fed into hydrolysis reactor, anaerobic and facultative anaerobic bacteria created hydrolaza enzyme to digest and convert carbohydrate in rice remnant into simple compounds. Therefore, when entering methane reactor, methanogenic fermentation process can occur faster. In addition, when SRT of methane reactor is controlled longer (60 days compared to 20 days), organic loading rate in this system is lower, anaerobic microorganism have sufficient time to convert them into methane gas.

3.4 Determination of biogas generation rate and time need for complete degradation of a certain amount of starched food refuse

Time needed for complete digestion of different substances will be different. Many substances have short bio-degradation time (from 3 months to 5 years) while the others needed longer time for complete bio-degradation (≥

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15 years) (Tchobanoglous et al., 1993). In order to determine the time need for complete biodegradation of starched food refuse based on rice remnant in anaerobic condition was done by measuring volume of biogas and concentration of CH_4 generated from the system until no biogas produced. Reactor 1 was fed with only septic sludge (3 kg) and reactor was fed with the mixture of rice remnant (0.1 kg) and septic sludge (2.9 kg). Characteristics of materials used in this experiment are presented in Table 9.

Table 9 Characteristics of rice remnant and septic sludge used

Parameters	Units	Starchy leftover	Septic sludge
pH	-	4.38	8.47
Alkalinity	mgCaCO$_3$/l	250	7,750
Moisture	%	70.20	91.87
DM	%	29.80	8.13
OM	%	83.28	54.68

Amounts of biogas generated from these two reactors are presented in Fig. 14. Experimental results showed that after 20 days of operation, the reactors finished generating biogas and complete digestion of 100 g rice remnant.

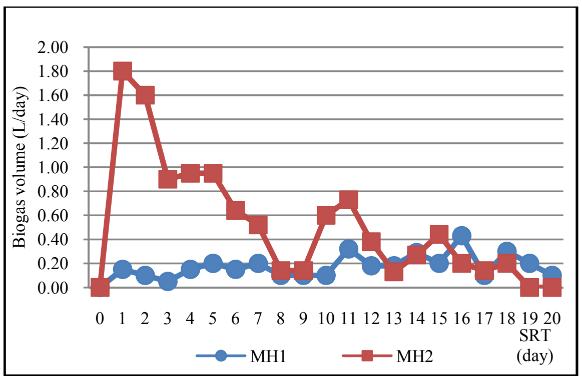

Fig. 14 Amount of biogas generated from the reactor 1 contained only septic sludge and the reactor 2 contained the mixture of septic sludge (2.9 kg) and rice remnant (0.1 kg).

Amount of biogas generated from the reactor 1 was very low, lower than 0.5 L/day. During the first 10 days, amount of biogas was always under 0.2 L/day. From day 10 to day 18, it slightly increased and reached maximum of 0.43 L/day at day 16. In the case of the reactor 2, maximum amount of biogas generated reach 1.8 L/day right after 1 day of operation and it tended to decrease until day 8. However from day 8 to day 13, amount of biogas generated went up to 0.73 L/day, after that it remained lower than 0.40 L/day. Fig. 14 shows significant difference in biogas generation rate between 2 reactors. In first 13 days, amount of biogas generated from the reactor 2 was considerable higher than that of the reactor 1.

Total accumulated amount of biogas generated from these two reactors are presented in Fig. 15. The reactor 1 produced 3.50 L of biogas in total, while it was 10.73 L from the reactor 2. Thus, biogas generated from anaerobic digestion of septic sludge is 1.17 m^3 biogas/ton of wet septic sludge, equivalent to 14.35 m^3/ton of dry septic sludge. Complete anaerobic digestion of rice remnant can produce 73.5 m^3 biogas/ton of wet rice remnant, equivalent to 246.6 m^3 biogas/ton of dry rice remnant.

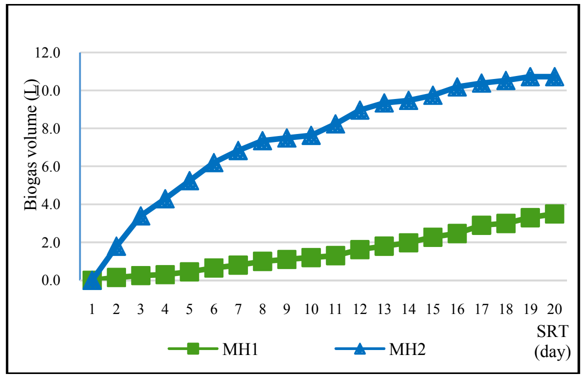

Fig. 15 Accumulated amount of biogas generated from the reactor 1 contained only septic sludge and the reactor 2 contained the mixture of septic sludge (2.9 kg) and rice remnant (0.1 kg).

It is obviously that septic sludge also contributes to biogas production from anaerobic digester but at low biogas generation rate. In the reactor 1, CH_4 concentration in biogas generated was stable and the maximum value was only 3.8% at day 7. In the case of the reactor 2, CH_4 concentration increased greatly and went to 25.6% right after one day of operation. The maximum CH_4 concentration was 31.6% at day 5. From day 12 to the end of process, CH_4 concentration decreased significantly. As shown in Fig. 16, there is a significant different CH_4 concentration in biogas generated from the reactor without and with rice remnant. It means that under favorable conditions, anaerobic microorganisms can digest starch from rice remnant very well to generate biogas with high CH_4 concentration. Septic sludge itself can only supply microorganism community and added very low amount of biogas and CH_4 produced.

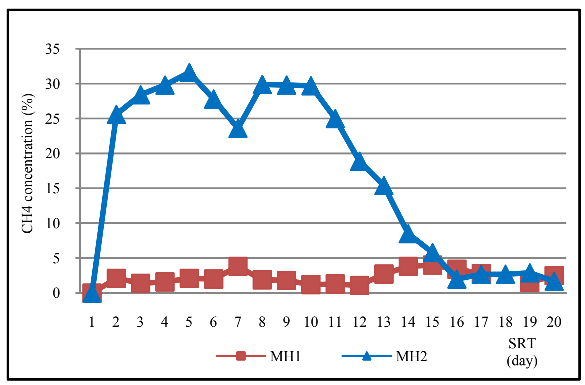

Fig. 16 Concentration of CH_4 in biogas generated from the reactor 1 contained only septic sludge and the reactor 2 contained the mixture of septic sludge (2.9 kg) and rice remnant (0.1 kg).

4. Conclusions and recommendations

4.1 Conclusions

From the experimental results, it is possible to draw the following conclusions:

- Anaerobic digestion of rice remnant, a kind of starched food refuse, causes significant reduction of pH and alkalinity in digester and hardly control by adding chemical.
- Septic sludge can be used as an additive to supply microorganism for the system. By supplying 50% amount of the mixture in the anaerobic digesters with septic sludge at the beginning, it can help to increase CH_4 concentration in biogas generated.
- Two-stage continuous anaerobic digestion system generates biogas with much higher CH_4 concentration compared to that of one-stage batch or one-stage semi-continuous system.
- Two-stage continuous anaerobic digestion system with SRT of hydrolysis reactor of 6 days and of methane reactor of 60 days achieved maximum CH_4 concentration in biogas of 56.2% for 7 days. If reduced SRT of methane reactor to 20 days, maximum CH_4 concentration of generate biogas was only 45.1% and maintained at around 40% for only 2 days.
- Biogas generated from anaerobic digestion of septic sludge is 1.17 m^3 biogas/ton of wet septic sludge, equivalent to 14.35 m^3/ton of dry septic sludge. While complete anaerobic digestion of rice remnant can produce 73.5 m^3 biogas/ton of wet rice remnant, equivalent to 246.6 m^3 biogas/ton of dry rice remnant.

4.2 Recommendations

Due to limited time for conducting experiments, the optimum SRT of the anaerobic digestion of starched food refuse which could help to maintain pH and alkalinity in the system without chemical adding requirement, have still not been found yet. It is recommended for other experiments to find it.

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