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Influence of Composition of Food Waste to Methane Recovery by Two-Stage Low Solid Anaerobic Digestion

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Abstract

The study was carried out to assess influences of composition of household food waste and retention time to methane gas recovery by two-stage low solid anaerobic digestion process without adjustment of pH, alkalinity, and temperature. It is found that except for food waste containing only starch or only fruit peels with essential oil, it is possible to recover about 445-775 L CH_4/gVS of household food waste mixture at the methanogenesis retention time of 60 days. However, the mixture of 30% fruit peels + 50% wasted vegetables + 10% starch food remnants + 10% other food remnants give the best methane gas recovery with 775 L CH_4/gVS. Food waste containing only fruit peels without essential oil allows achieving higher amount of methane gas at shorter the retention time compared to that of food waste containing only fruit peels with essential oil. It is possible to get 747 L CH_4/gVS of fruit peels without essential oil at the retention time of 60 days compared to only 493 CH_4/gVS of essential oil-fruit peels at the retention time of 120 days. If the food waste containing only starch food remnant or only fruit peels with essential oil, it is necessary to control retention time of the methanogenesis reactor of 120 days. It is possible to achieve 493 L CH_4/gVS of fruit peels with essential oil and 300 L CH_4.gVS of starch food waste at the retention time of 120 days and organic loading rate of 1.1 gVS/L.day and 2.6 gVS/L.day, respectively. With shorter the retention time, lower amount of methane gas can be recovered. In the case of starch food waste, it is impossible to recover biogas at the retention time of 30 days.

Key words: *Low solid anaerobic digestion, food waste, biogas.*

1. Introduction

During the past twenty years, there has been a great interest in applying the anaerobic digestion process for processing of the organic fraction of municipal solid waste (MSW) because of the opportunity to recover methane (Tchobanoglous et al., 1993). Baere (2006) has predicted application of anaerobic digestion technology will increase rapidly in Europe. By the end of 2010, capacity of more than 200 anaerobic digestion plants, using organic fraction of MSW and other biomass, from 17 countries in Europe, reached 6 millions tons/year (Baere and Mattheeuws, 2010). Anaerobic digestion as a pre-treatment prior to landfill disposal or composting offers several advantages such as minimize masses and volume, inactivation of biological and biochemical processes in order to avoid environmental problem from improper operation of landfill and energy production in term of methane gas (Nayono, 2009). In the other words, this can be considered as an alternative to reduce environmental implications caused by biodegradable organic solid waste and at the same time taking an advantage of renewable energy production from available bio-waste.

Several factors can affect the performance of the anaerobic digestion, either by process enhancement or inhibition, such as pH, temperature, input material composition, organic loading, retention time, mixing condition and inhibitory substances (Nayono, 2009; Chen, 2010; Reungsang et al., 2012; Dobre et al., 2014). Influence of temperature to performance of anaerobic digestion is well known. Mesophilic (25-45^oC) and thermophilic (45-65^oC) anaerobic digestion are commonly applied in the field (O'Reilly et al., 2009; Chen, 2010). Parkin and Owen (1986), Donoso-Bravo et al. (2009) found that almost full-scale anaerobic digesters are operated at mesophilic temperature. pH is an important factor for keeping functional anaerobic digestion. The pH for the optimal hydrolysis stage is between 5-6 (Castillo et al., 2006; Vavilin et al., 2008; Dobre et al., 2014), while the optimal pH for methanogenesis stage varies in the range of 6.5-8.0 (Converti et al., 1999; Dobre et al., 2014). The composition of raw material is essential in the biogas production as it affects to carbon and nitrogen ratio (C/N) and it may contain inhibitory substances. The composition of raw material is essential in the biogas production as it affects to carbon and nitrogen ratio (C/N) and it may contain inhibitory substances. The optimal C/N ratio is expected to be in the range of 15-25 for a single-stage anaerobic digestion process, while for two-stage process, the C/N ratio is usually in the range of 10-45 for first step and 20-30 for the second step (Dobre et al., 2014). Retention time is chosen to ensure the condition that number o the removed microorganisms with the digestate may not be greater that the number those resulted by duplication, thus the retention time must adapt to decomposition rate of the raw materials used (Dobre et al., 2014).

Everyday, Ho Chi Minh City (HCMC), Vietnam generates about 10,000-11,000 tons of municipal solid waste (MSW) (DONRE, 2013). Of which, amount of domestic solid waste generated from residential areas, commercial areas, offices, schools, canteens of enterprises and industrial zones, non-infected medical centers is about 9,000 tons/day and composition of the separated food waste from household DSW comprises about 80.1-90.0% of biodegradable food refuse (Tran Thi My Dieu et al., 2014). Though this seems to be a qualified material source to to produce energy via anaerobic digestion process, so far, it is mainly dumped in the existing sanitary landfills in HCMC.

This study was carried out to assess influences of composition of household food waste and retention time to methane gas recovery by two-stage low solid anaerobic digestion process without adjustment of pH, alkalinity, and temperature. The study promises to contribute a solution for reducing amount of solid waste to be dumped in the landfills, producing energy by environmentally-friendly way, and promoting waste reuse-recycling activity in HCMC and Vietnam.

2. Materials and methods

2.1 Lab-scale reactors

The lab-scale two-stage anaerobic digestion model consists of two reactors: reactor 1 for hydrolysis process (hydrolysis reactor) and reactor 2 for methanogenesis process (methanogenesis reactor). These reactors were made of empty paint containers which have volume of 4 L, diameter of 19 cm, and height of 25 cm with caps. Input materials are feed into the reactors via a feeding plastic pipe with a diameter of 10 mm and length of 10 cm connecting to the cap. Biogas generated is collected through the other plastic pipe with a diameter of 8 mm on the cap and connecting to a biogas collection bag. For taking sample inside of the reactor, a sampling plastic pipe with a diameter of 20 cm and length of 10 cm is installed to fix sample collection pipe. Materials are ground and fed into the reactor 1 for hydrolysis and then transferred manually into the reactor 2 for methanogenesis process.

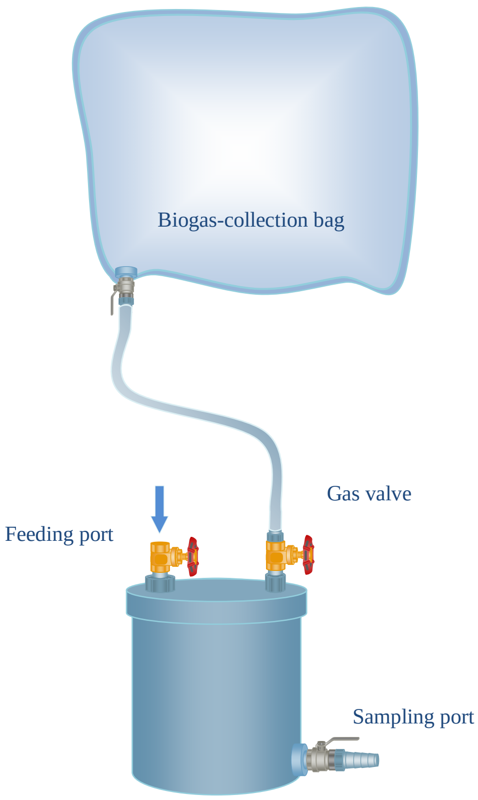

Fig. 1 Experimental reactor.

Determination of household food waste composition

Composition of household food waste was determined by taking samples from 50 households located in street 25A, Tan Quy Ward, District 7, HCMC. Samples were taken on Sunday and Monday (total 100 samples) and brought to Laboratory of Department of Environmental Technology and Management, Van Lang University for analysis. Non-biodegradable materials were separated and removed. Only biodegradable materials were used for composition analysis. Each type of material is separated, weighed and calculated its percentage (in wet weight) in total amount of food waste.

Household food waste contains different type of food refuse such as wasted vegetables, essential oil and non-essential oil fruit peels, and food remnant containing starch as wasted rice, noodles, etc. or containing protein as wasted meat, fishes, and shrimps. Therefore, food waste samples were analyzed by separated them into the following components: (1) wasted vegetables, (2) non-essential oil fruit peels (watermelon peels, mango peels, papaya peels, etc.), (3) essential oil fruit peels (orange peels, grapefruit peels, lemon peels, mandarin peels, etc.), (4) food remnant containing starch (wasted rice, noodles, etc.) and (5) other remnant food (wasted meats, fishes, etc.).

2.2 Assess influence of food waste composition to methane gas recovery efficiency

Based on the composition of household food waste determined by surveying 50 households, experiments were set up with different food waste components as follows: (1) experiment 1 (MH1) used a mixture of 30% fruit peel + 50% wasted vegetables + 10% food remnant containing starch + 10% food remnant containing wasted meat, fishes. The composition of this mixture represents the composition of food waste from households; (2) experiment 2 (MH2) used a mixture of 50% fruit peel + 30 wasted vegetables + 10% food remnant containing starch + 10% food remnant containing wasted meat, fishes; (3) experiment 3 (MH3) used only non-essential oil fruit peels (such as papaya peels, watermelon peels, etc.); (4) experiment 4 (MH4) used only wasted vegetables; (5) experiment 5 (MH5) used only essential oil fruit peels (such as orange peels, grapefruit peels, etc.); (6) experiment 6 (MH6) used only food remnant containing starch (such as wasted rice, noodles, etc.) and (7) experiment 7 (MH7) used only septic sludge.

The input materials, as set up above, were ground and fed into the reactor 1 (for hydrolysis process) two times for each experiment so that it is possible to control the retention time of the hydrolysis process of 15 days (Carneiro, 2010). pH of the mixture in the reactor 1 was in the range of 3.86-5.80. Everyday, a portion of the mixture in the reactor 1 was transferred manually to the reactor 2 (for methanogenesis process) depending on the retention time needed to control. Every two days, samples from the hydrolysis reactors (the reactor 1) were taken to measure pH and alkalinity. Organic matter (OM) and dry matter (DM) contents were measured once a week.

Unlike the hydrolysis reactors, methanogenesis reactors (reactor 2) were fed initially with 2 L of septic sludge that has moisture content of 93% took from Hoa Binh Fertilizer Factory. The reactors were mixed by shaking manually before removed a certain amount of the digested sludge out of the reactors depending on the control

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retention time and fed the same amount of the input material from the hydrolysis reactors. pH and alkalinity of the septic sludge in the methanogenesis reactors were 7.8 and 8,000 mg $CaCO_3$/L, respectively. When feeding the mixture from the hydrolysis reactors to the methanogenesis reactors, pH of the mixture in the methanogenesis reactors decreased but it was still greater than 6.2. Every two days, pH and alkalinity were measured from the withdrawn digested sludge. Organic matter (OM) and dry matter (DM) contents were measured once a week. Volume of biogas and concentration of methane gas were measured every four days before feeding the methanogenesis reactors. Experimental set up for the hydrolysis reactors and methanogenesis reactors are summarized in Table 1 and Table 2.

Table 1 Experimental conditions of the hydrolysis reactors fed with different food waste components

Parameters	The hydrolysis reactors (reactor 1)					
	MH1	MH2	MH3	MH4	MH5	MH6
Volume of the reactor (L)	4	4	4	4	4	4
Effective volume of the reactor (L)	3	3	3	3	3	3
pH	4.46	4.52	4.57	5.8	4.38	4.13
Initial moisture content of food waste (%)	86.7	88.4	91.1	91.8	82.0	62.0
Alkalinity (mg $CaCO_3$/L)	300	350	350	500	180	0
Amount of water added (ml/kg)	143	120	66	66	210	550
%TS of the input material	11.7	11.0	8.4	8.0	15.0	21.0
%VS of the input material	73.57	76.92	80.18	83.08	88.69	78.19
Retention time (days)	15	15	15	15	15	15

Table 2 Experimental conditions of the methanogenesis reactors fed with different food waste components

Parameters	The methanogenesis reactors						
	MH 1	MH 2	MH 3	MH 4	MH 5	MH 6	MH 7
Type of sludge	Septic sludge						
Volume of the reactor (L)	4	4	4	4	4	4	4
Effective volume of the reactor (L)	2	2	2	2	2	2	2
pH of sludge	7.58	7.58	7.58	7.58	7.58	7.58	7.58
Alkalinity of sludge $CaCO_3$/l	8000	8000	8000	8000	8000	8000	8000
Moisture content of sludge (%)	93	93	93	93	93	93	93
Dry matter of sludge (%)	7	7	7	7	7	7	7
pH, alkalinity, dry matter of the input materials	These values vary depending on the mixture from the hydrolysis reactors described in Table 1						
Retention time (days)	30	30	30	30	30	30	30
Temperature	Laboratory temperature (~ 33°C)						

2.3 Assess influence of retention time of the methanogenesis reactors to methane gas recovery efficiency

Experiments were operated using the same food waste composition and the same experimental conditions of the the hydrolysis and methanogenesis reactors as described above. The only difference is that retention time of the methanogenesis reactors were controlled at 30 days, 60 days, 90 days and 120 days. Therefore, amount of the input material (from the hydrolysis reactors) into and amount of the digested sludge withdrawn from the methanogenesis reactors were different for different reactors (Table 3).

Table 3 Experimental conditions with different retention time

Parameters	The methanogenesis reactors						
	MH 1	MH 2	MH 3	MH 4	MH 5	MH 6	MH 7
Type of sludge	Septic sludge						
Volume of the reactor (L)	4	4	4	4	4	4	4
Effective volume of the reactor (L)	2	2	2	2	2	2	2
pH of sludge	7.58	7.58	7.58	7.58	7.58	7.58	7.58
Alkalinity of sludge (mg $CaCO_3$/l)	8000	8000	8000	8000	8000	8000	8000
Moisture content of sludge (%)	93	93	93	93	93	93	93
DM of sludge (%)	7	7	7	7	7	7	7
Amount of material took from the hydrolysis reactors (ml)							
SRT - 30 days	66.6	66.6	66.6	66.6	66.6	66.6	66.6
SRT - 60 days	33.3	33.3	33.3	33.3	33.3	33.3	33.3
SRT - 90 days	22.2	22.2	22.2	22.2	22.2	22.2	22.2
SRT - 120 days	16.6	16.6	16.6	16.6	16.6	16.6	16.6
Temperature	Laboratory temperature (~ 33°C)						

Volume of biogas was measured by Wet Gas Meter – Shinagawa. Methane gas concentration was measured by Geotechnical Instruments.

3. Results and discussions

3.1 Composition of household food waste

Food waste from households contains wasted vegetables, fruit peels, food remnants containing starch such as rice, noodles, food remnant containing protein such as wasted meats, fishes, etc. Other components of food refuse such as bone, crap shells, and other hard shells as coconut shells, mango seeds, etc. were removed. Composition of

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household food waste based on the surveys at Tan Quy Ward, District 7, HCMC is described in Table 4.

Table 4 Composition of separated household food waste

Component	Percentage by wet weight
Fruit peels	39.16 ± 9.38
Wasted vegetables	49.24 ± 8.07
Food remnant containing starch	7.83 ± 3.31
Food remnant containing protein	3.92 ± 2.09

Fruit peels

Non-essential oil fruit peels appears in household food waste usually containing peels from several type of fruits as watermelon, papaya, banana, jackfruit, dragon, star apple, rambutan, mango, guava, apple, grape, etc. Fruit peels with essential oil in household food waste usually containing peels from orange, grapefruit, lemon, etc. 76% of household food waste samples (equivalent to 38/50 samples) contained fruit peels. Distribution frequency of percentage (by wet weight) of fruit peels in household food waste is described in Fig. 2.

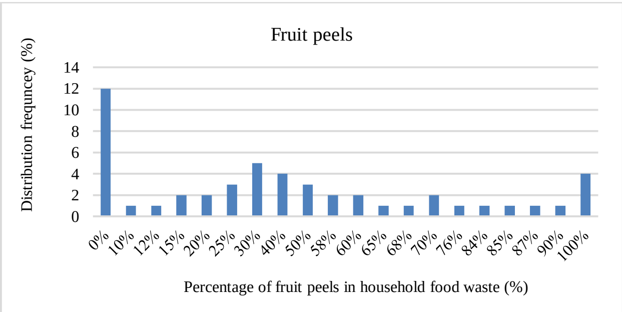

Fig. 2 Distribution frequency of percentage (by wet weight) of fruit peels in household food waste.

Figure 2 shows that percentage of fruit peels ranges from 0% to 100%. 12 of 50 samples did not contain fruit peels. Typical value of percentage of fruit peel in household food waste found from this study is 30% (which highest distribution frequency). Fruit peels with and without essential oil were separated for evaluating influence of these components to biogas recovery from anaerobic digestion process.

Wasted vegetables

Vegetable is one of important kinds of food in the meals of Vietnamese as it plays an important role in human nutrition. Vegetables can be eaten either raw or cooked. Wasted vegetables found in household food waste come from cleaning before eating or cooking or as food remnant. 6 of 50 samples didn't contain wasted vegetables. Typical value of percentage of wasted vegetable in household food waste is 50% (Fig. 3).

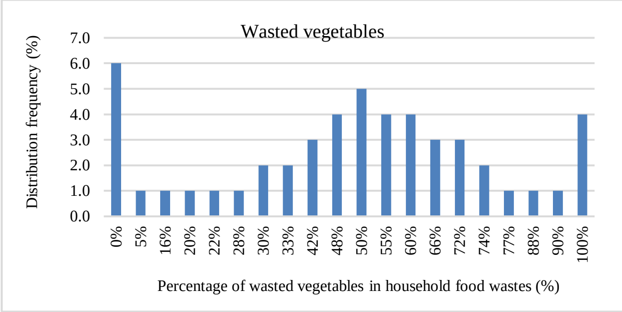

Fig. 3 Distribution frequency of percentage (by wet weight) of wasted vegetables in household food waste.

Food remnants containing starch

Starch is main kind of food of the meals. The appearance of this component in household food waste is mainly as food remnant. 22 of 50 samples didn't contain food remnant containing starch. Its percentage is only about 4-10% in household food waste, however it can influence significantly to pH value of the incubation mixture in the anaerobic digesters.

Food remnants containing protein

The remaining food remnants contain mainly wasted meats, fishes, shrimps, etc. 32 of 50 samples didn't contain this kind of food remnants. If it appears in household food waste, the highest percentage found is about 10-13%.

3.2 Influence of food waste composition to methane gas recovery efficiency

The study was carried out with six different components of food waste as described above with SRT of hydrolysis reactors (reactor 1) of 15 days and of methanogenesis reactors (reactor 2) of 30 days. Everyday, the input materials was taken from the reactor 1 and fed into the reactor 2 with amount equivalent to 1/30 total amount of the incubation mixture needed to control the SRT of the methanogenesis reactors of 30 days. Biogas generated was stored in biogas collection bag. Volume of biogas and concentration of methane gas were measure every four days at 9 a.m. in the morning. By subtracting amount of biogas generated from septic sludge, amount of biogas generated from the food waste is determined. Changing of volume of biogas generated from different experiments containing different food waste components in this case is described in Fig. 4.

It is found that with 30 days retention time in the methanogenesis reactors, all six experiments with six different components of food waste generate biogas. However, only experiment with food waste containing only starch (MH6), amount of generated biogas decrease gradually while amount of generated biogas from the others still increase and to be stable after 36 days of operation. By this time, amount of seeding sludge in the methanogenesis reactors was replaced completely by the digested sludge from the input materials. Amount of biogas generated from different food waste components with methanogenesis retention time of 30 days is described in Fig. 5.

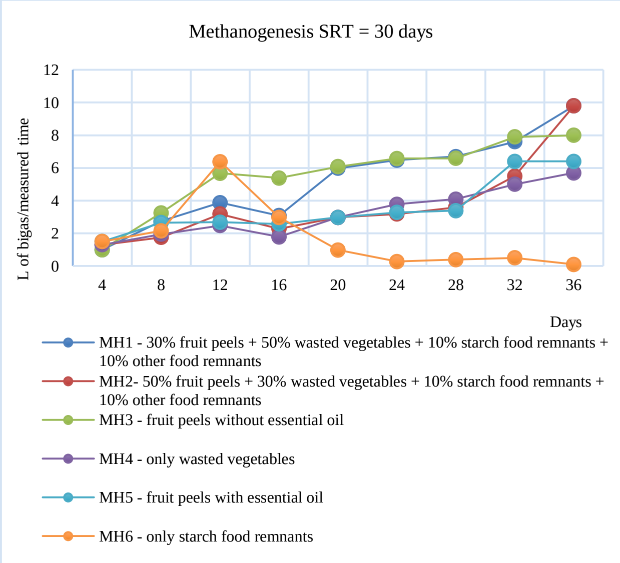

Fig. 4 Change of biogas generation/measure during operation with the case of SRT of 30 days.

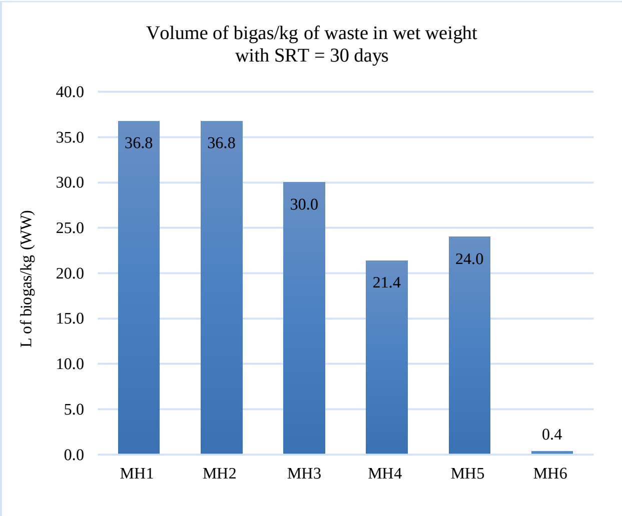

Fig. 5 Amount of biogas generated from different food waste components the case of methanogenesis SRT of 30 days.

Figure 6 shows that the highest value of methane gas concentration reaches 64.10% in average (maximum of 76.2%) from MH4 (containing only wasted vegetable), 63.34% (maximum of 74.3%) from MH2 (containing mixture of food waste) and 60.76% (maximum of 74.00%) from MH3 (containing non-essential oil fruit peels). Concentrations of methane gas in biogas generates from the other food waste components are lower, but it also reaches 60.5% (maximum of 71.5%) and 53.3% (maximum of 65.5%) from MH 1 (containing other mixture of food waste) and MH5 (containing only essential oil fruit peels), respectively. Methane gas concentration from the reactor containing only starch decrease gradually and remain only 0.5% by day 36^{th}. Thus, the two-stage anaerobic digestion process allows recovering methane gas from different food waste components with methanogenesis retention time of 30 days, except for food remnants containing only starch.

Chu et al. (2008) found that two-stage anaerobic digestion of food waste can recover biogas containing 70-80% methane gas, while Nguyen Thi Kieu Hanh (2015) found that it is possible to recover biogas containing 58.7% methane gas from biodegradable organic materials of an agricultural product whole sale market in HCMC, Vietnam by the same process.

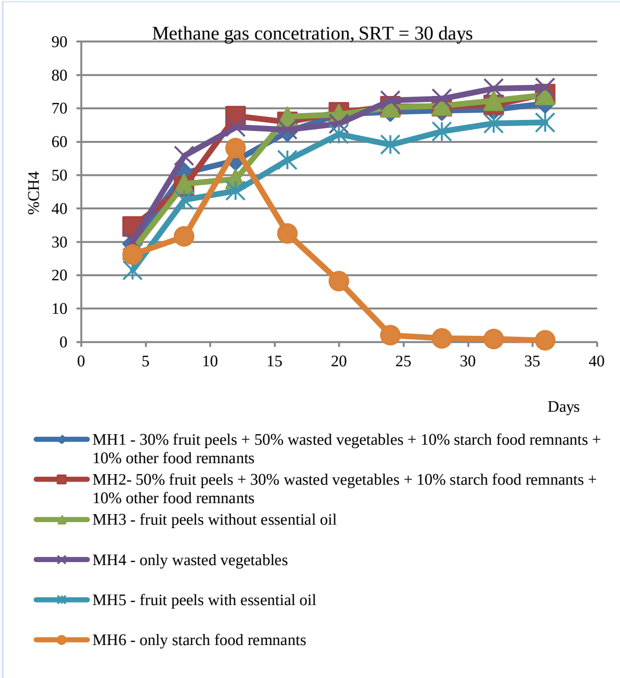

Fig. 6 Influence of food waste component to methane gas concentration in the biogas in the case of methanogenesis SRT of 30 days.

After hydrolysis process in the reactor 1, dry matter contents of the food waste mixture were changed. Hence the dry matter contents of the inputs to the methanogenesis reactors differed from different initial food waste components. The highest biogas volume per kilogram of dry matter of food waste come from the mixture of food waste of MH1 and MH2. Amount of biogas generated from fruit peels with essential oil (MH3) is higher from fruit peels without essential oil (MH5). At organic loading rate of 2.7-4.6 g VS/L.day, it is possible to generate biogas from all food waste components as tested in this study, except for food waste containing only starch. Efficiencies of biogas and methane gas recovered from different food waste components in the case of hydrolysis retention time of 15 days and methanogenesis retention time of 30 days are summarized in Table 5.

Table 5 Biogas and methane gas recovery from different food waste components with hydrolysis retention time of 15 days and methanogenesis retention time of 30 days

Parameters	MH1	MH2	MH3	MH4	MH5	MH6
TS (%)	9.25	8.89	7.85	6.02	8.24	18.79
VS (%TS)	0.74	0.74	0.73	0.68	0.81	0.82
Organic loading of the reactor 2 (gVS/L.day)	4.6	4.4	3.8	2.7	4.5	10.3
At 33°C						
m^3 biogas/ton (WW)	36.8	36.8	30.0	21.4	24.0	0.4
m^3 biogas/ton VS	537	561	524	523	359	2
L biogas/gVS	0.537	0.561	0.524	0.523	0.359	0.002
% CH_4	71.5	74.3	74.0	76.2	65.8	0.5

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Parameters	MH1	MH2	MH3	MH4	MH5	MH6
m^3 CH_4/ton VS	384	417	388	399	236	0
L CH_4/g VS	0.384	0.417	0.388	0.399	0.236	0.000
At 25ºC						
m^3 biogas/ton (WW)	35.8	35.8	29.2	20.8	23.4	0.4
m^3 biogas/ton VS	523	547	510	510	350	2
L biogas/gVS	0.523	0.547	0.510	0.510	0.350	0.002
% CH_4	69.6	72.4	72.1	74.2	64.1	0.5
m^3 CH_4/ton VS	374	406	377	388	230	0
L CH_4/g VS	0.374	0.406	0.377	0.388	0.230	0.000

The mixture of food waste containing 50% fruit peels + 30% wasted vegetables + 10% starch food remnants + 10% other food remnants (MH1) allows to receive highest amount of methane gas, equivalent to 406 L CH_4/kg VS of waste. The other food waste components generates lower amount of methane gas. It is possible to achieve 377 L CH_4/kg VS of waste generated from MH3 containing only fruit peels without essential oil, while from MH5 containing only fruit peels with essential oil can generate only 230 L CH_4/kg VS of waste. Food waste containing only starch could not generate methane gas if methanogenesis retention time was controlled at 30 days. Verena and Schnitzhofer (2012) found that it is possible to recover 302 L CH_4/kg VS of food waste at organic loading rate of 4.9 g VS/L.day, while Chu (2008) achieved 464 L CH_4/kg VS of food waste.

pH of the inputs from hydrolysis reactors varies and causes variation in pH values of the mixtures in the methanogenesis reactors. However pH values were always greater than 6,5, except for the methanogenesis reactor fed with starch food remnants (MH6). pH value of MH6 reduced from 7.58 at the beginning to only 4.73 after 12 days of operation. This inhibits methanigenic bacteria growth and therefore no biogas generates from this reactor from that day onwards.

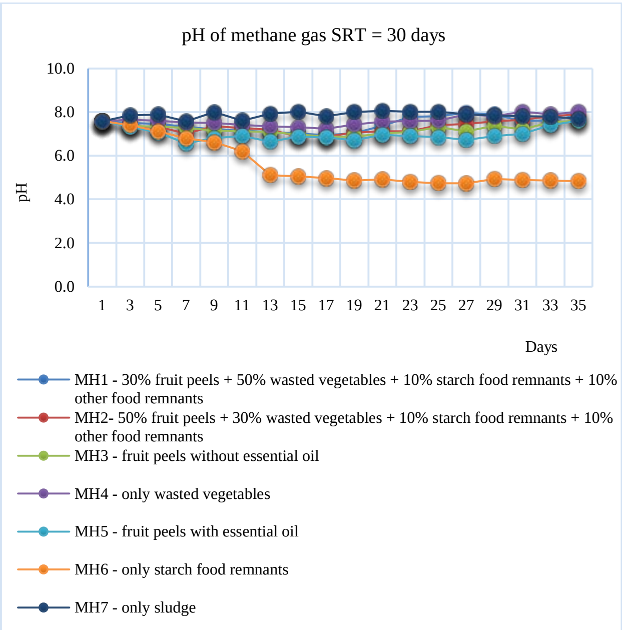

Fig. 7 Varying of pH values in the methanogenesis reactors received different food waste components with methanogenesis SRT of 30 days.

Alkalinity of the mixtures in the methanogenesis reactors vary in the range of 5,766-7,125 mg $CaCO_3$/L except for the reactor of MH6 (containing only starch food remnants). Alkalinity of the reactor of MH6 decreases from 8,000 mg $CaCO_3$/L (alkalinity from the seeded septic sludge) to 2,700 mg $CaCO_3$/L during replacing the sludge by the input material from the hydrolysis reactor.

3.3 Influence of retention time of the methanogenesis reactors to methane gas recovery efficiency

Experiment MH1 - 30% fruit peels + 50% wasted vegetables + 10% starch food remnants + 10% other food remnants

Experimental results show that by controlling retention time of the methanogenesis process (reactor 2) of 60 days, it is possible to achieve highest biogas generation with 72 L biogas/kg waste (by wet weight, with TS = 9.25%). This is about 1.9 times higher than the case of STR of 30 days and about 1.7 times higher than the case of SRT of 90 days and 120 days. Maximum methane gas concentration reached 73.7% at pH of 7.37 ± 0,19 and alkalinity 6,227 mg $CaCO_3$/L. Influence of the methanogenesis retention time to biogas and methane gas recovery from the mixture of food waste containing 30% fruit peels + 50% wasted vegetables + 10% starch food remnants + 10% other food remnants (MH1) is summarized in Table 6.

Table 6 Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing 30% fruit peels + 50% wasted vegetables + 10% starch food remnants + 10% other food remnants (MH1)

Parameters	MH 1-1	MH 1-2	MH 1-3	MH 1-4
SRT of the reactor 2 (days)	30	60	90	120
Amount of the input from the reactor 1 (ml)	66.66	33.33	22.22	16.66
TS of the input (%)	9.25			
Organic loading (gVS/L.day)	4.6	2.3	1.5	1.1
At 33ºC				
m^3 biogas/ton (WW)	36.8	72.0	41.6	42.0
m^3 biogas/ton VS	537	1051	607	613
L biogas/g VS	0.537	1.051	0.607	0.613
% CH_4	71.5	73.7	72.0	72.6
m^3CH_4/ton VS	384	775	437	445
L CH_4/gVS	0.384	0.775	0.437	0.445
pH in average	7.45	7.37	7.47	7.52
Alkalinity (mg$CaCO_3$/L)	6811	6227	6316	6311
At 25ºC				
m^3 biogas/ton (WW)	35.8	70.1	40.5	40.9
m^3 biogas/ton VS	523	1024	591	597
L biogas/g VS	0.523	1.024	0.591	0.597
% CH_4	69.6	71.8	70.1	70.7
m^3CH_4/ton VS	374	755	426	433
L CH_4/gVS	0.374	0.755	0.426	0.433
pH in average	7.26	7.18	7.27	7.32
Alkalinity (mg$CaCO_3$/L)	6633	6064	6151	6146

Experiment MH2 - 50% fruit peels + 30% wasted vegetables + 10% starch food remnants + 10% other food remnants

Experimental results show that by controlling retention time of the methanogenesis process (reactor 2) of 60 days, it is possible to achieve highest biogas generation with 40.5 L biogas/kg waste (by wet weight, with TS = 8.89%). Compared to STR of 30 days, 90 days and 120 days, amount of biogas recovered was only 36.8, 29.0 and 31.0 L biogas/kg waste (by wet weight), respectively. About 460 L CH_4/kg VS can be recovered at the organic loading rate of 2.2 g VSS/L.day and the methanogenesis SRT of 60 days. Maximum methane gas concentration reached 74.4% at pH of 7.36 ± 0,11 and alkalinity 6,472 mg $CaCO_3$/L. Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from the mixture of food waste containing 50% fruit peels + 30% wasted vegetables + 10% starch food remnants + 10% other food remnants (MH2) is summarized in Table 7.

Table 7 Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing 50% fruit peels + 30% wasted vegetables + 10% starch food remnants + 10% other food remnants (MH2)

Parameters	MH 2-1	MH 2-2	MH 2-3	MH 2-4
SRT of the reactor 2 (days)	30	60	90	120
Amount of the input from the reactor 1 (ml)	66.66	33.33	22.22	16.66
TS of the input (%)	8.98			
Organic loading (gVS/L.day)	4.4	2.2	1.5	1.1
At 33^{o}C				
m^3 biogas/ton (WW)	36.8	40.5	29.3	30.0
m^3 biogas/ton VS	561	618	447	458
L biogas/g VS	0.561	0.618	0.447	0.458
$\%CH_4$	74.3	74.4	60.5	70.8
m^3CH_4/ton VS	417	460	271	324
L CH_4/gVS	0.417	0.460	0.271	0.324
pH in average	7.32	7.36	7.03	7.17
Alkalinity (mg$CaCO_3$/L)	7125	6472	6083	6794
At 25^{o}C				
m^3 biogas/ton (WW)	35.8	39.4	28.5	29.2
m^3 biogas/ton VS	546	602	435	446
L biogas/g VS	0.546	0.602	0.435	0.446
$\%CH_4$	72.4	72.5	58.9	68.9
m^3CH_4/ton VS	406	448	264	316
L CH_4/gVS	0.406	0.448	0.264	0.316
pH in average	7.1	7.2	6.8	7.0
Alkalinity (mg$CaCO_3$/L)	6939	6303	5924	6616

Experiment MH3 - only fruit peels without essential oil

Experimental results show that by controlling retention time of the methanogenesis process (reactor 2) of 60 days, it is possible to achieve highest biogas generation with 58.5 L biogas/kg waste (by wet weight, with TS = 7.85%). Compared to STR of 30 days, 90 days and 120 days, amount of biogas recovered was only 36.8, 33.8 and 21.0 L biogas/kg waste (by wet weight), respectively. About 747 L CH_4/kg VS can be recovered at the organic loading rate of 1.9 g VSS/L.day and the methanogenesis SRT of 60 days. Maximum methane gas concentration reached 73.2% at pH of 7.31 ± 0,10 and alkalinity 5,704 mg $CaCO_3$/L. Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only fruit peels without essential oil (MH3) is summarized in Table 8.

Table 8 Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only fruit peels without essential oil (MH3)

Parameters	MH 3-1	MH 3-2	MH 3-3	MH 3-4
SRT of the reactor 2 (days)	30	60	90	120
Amount of the input from the reactor 1 (ml)	66.66	33.33	22.22	16.66
TS of the input (%)	7.85			
Organic loading (gVS/L.day)	3.8	1.9	1.3	1.0
At 33^{o}C				
m^3 biogas/ton (WW)	30.0	58.5	33.8	21.0
m^3 biogas/ton VS	524	1021	590	514
L biogas/g VS	0.524	1.021	0.590	0.514
$\%CH_4$	74.0	73.2	68.5	42.4
m^3CH_4/ton VS	388	747	404	218
L CH_4/gVS	0.388	0.747	0.404	0.218
pH in average	7.21	7.31	7.16	7.24
Alkalinity (mg$CaCO_3$/L)	5766	5704	5752	6011
At 25^{o}C				
m^3 biogas/ton (WW)	29.2	57.0	32.9	20.5
m^3 biogas/ton VS	510	994	575	501
L biogas/g VS	0.510	0.994	0.575	0.501
$\%CH_4$	72.1	71.3	66.7	41.3
m^3CH_4/ton VS	378	727	393	212
L CH_4/gVS	0.378	0.727	0.393	0.212
pH in average	7.0	7.1	7.0	7.1
Alkalinity (mg$CaCO_3$/L)	5615	5555	5602	5854

Experiment MH4 - only wasted vegetables

Experimental results show that by controlling retention time of the methanogenesis process (reactor 2) of 60 days, it is possible to achieve highest biogas generation with 445 L CH_4/kg VS at organic loading 1.4 gVS/L.day. Maximum methane gas concentration reached 71.3% at pH of 7.42 ± 0,11 and alkalinity 6,233 mg $CaCO_3$/L. Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only wasted vegetable (MH4) is summarized in Table 9.

Table 9 Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only wasted vegetables (MH4)

Parameters	MH 4-1	MH 4-2	MH 4-3	MH 4-4
SRT of the reactor 2 (days)	30	60	90	120
Amount of the input from the reactor 1 (ml)	66.66	33.33	22.22	16.66
TS of the input (%)	6.02			
Organic loading (gVS/L.day)	2.7	1.4	0.9	0.7

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Parameters	MH 4-1	MH 4-2	MH 4-3	MH 4-4
At 33ºC				
m^3 biogas/ton (WW)	21.4	25.5	27.0	21.0
m^3 biogas/ton VS	523	624	660	514
L biogas/g VS	0.523	0.624	0.660	0.514
$\%CH_4$	76.2	71.3	60.8	42.4
m^3CH_4/ton VS	399	445	401	218
L CH_4/gVS	0.399	0.445	0.401	0.218
pH in average	7.6	7.42	7.57	7.55
Alkalinity ($mgCaCO_3$/L)	6638	6233	6350	6605
At 25ºC				
m^3 biogas/ton (WW)	20.8	24.8	26.3	20.5
m^3 biogas/ton VS	509	608	643	501
L biogas/g VS	0.509	0.608	0.643	0.501
$\%CH_4$	74.2	69.4	59.2	41.3
m^3CH_4/ton VS	389	433	391	212
L CH_4/gVS	0.389	0.433	0.391	0.212
pH in average	7.4	7.2	7.4	7.4
Alkalinity ($mgCaCO_3$/L)	6464	6070	6184	6432

Experiment MH5 - only fruit peels with essential oil

Difference to experiments of MH1, MH2, MH3, MH4, this experimental results show that by controlling retention time of the methanogenesis process (reactor 2) of 120 days, it is possible to achieve highest biogas generation with 493 L CH_4/kg VS at organic loading of 1.1 g VS/L.day. The longer of the retention time and the lower of methane gas production is attributed to the presence of essential oil in fruit peels. These fruit peels contain organic oil consisting of several hundred aromatic compounds which may influence to microorganisms, hence the digestion performance. Maximum methane gas concentration reached 68.7% at pH of 7.33 ± 0,12 and alkalinity 6,027 mg $CaCO_3$/L. Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only fruit peels with essential oil (MH5) is summarized in Table 10.

Table 10 Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only fruit peels with essential oil (MH5)

Parameters	MH 5-1	MH 5-2	MH 5-3	MH 5-4
SRT of the reactor 2 (days)	30	60	90	120
Amount of the input from the reactor 1 (ml)	66.66	33.33	22.22	16.66
TS of the input (%)	8.24			
Organic loading (gVS/L.day)	4.5	2.2	1.5	1.1
At 33ºC				
m^3 biogas/ton (WW)	24.0	45.0	24.8	48.0
m^3 biogas/ton VS	359	673	371	718
L biogas/g VS	0.359	0.673	0.371	0.718
$\%CH_4$	65.8	67.4	65.6	68.7
m^3CH_4/ton VS	236	454	243	493
L CH_4/gVS	0.236	0.454	0.243	0.493
pH in average	6.97	7.16	7.25	7.33
Alkalinity ($mgCaCO_3$/L)	4772	5222	5250	6027
At 25ºC				
m^3 biogas/ton (WW)	23.4	43.8	24.2	46.7
m^3 biogas/ton VS	350	655	361	699
L biogas/g VS	0.350	0.655	0.361	0.699
$\%CH_4$	64.1	65.6	63.9	66.9
m^3CH_4/ton VS	230	442	237	480
L CH_4/gVS	0.230	0.442	0.237	0.480
pH in average	6.8	7.0	7.1	7.1
Alkalinity ($mgCaCO_3$/L)	4647	5085	5113	5869

Experiment MH6 - only starch food waste

It is found from this case that by controlling retention time of the methanogenesis process (reactor 2) of 120 days, it is possible to achieve highest biogas generation even with the food waste containing only starch. 300 L CH_4/kg VS can be recovered at organic loading of 2.6 g VS/L.day and the methanogenesis retention time of 120 days. Maximum methane gas concentration reached 71.7% at pH of 7.17 ± 0,10 and alkalinity 5,444 mg $CaCO_3$/L, without pH and alkalinity adjustment. Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only starch (MH6) is summarized in Table 11.

Table 11 Influence of the methanogenesis retention time to biogas and methane gas recovery efficiency from food waste containing only starch (MH6)

Parameters	MH 6-1	MH 6-2	MH 6-3	MH 6-4
SRT of the reactor 2 (days)	30	60	90	120
Amount of the input from the reactor 1 (ml)	66.66	33.33	22.22	16.66
TS of the input (%)	18.79			
Organic loading (gVS/L.day)	10.3	5.1	3.4	2.6
At 33ºC				
m^3 biogas/ton (WW)	0.4	63.0	40.5	64.5
m^3 biogas/ton VS	2	409	263	418
L biogas/g VS	0.002	0.409	0.263	0.418
$\%CH_4$	0.5	67.8	72.9	71.7
m^3CH_4/ton VS	0	277	191	300
L CH_4/gVS	0.000	0.277	0.191	0.300
pH in average	5.57	7.04	7.15	7.17
Alkalinity ($mgCaCO_3$/L)	4116	4877	5188	5444
At 25ºC				
m^3 biogas/ton (WW)	0.4	61.4	39.4	62.8
m^3 biogas/ton VS	2	398	256	407
L biogas/g VS	0.002	0.398	0.256	0.407
$\%CH_4$	0.4	66.0	70.9	69.8
m^3CH_4/ton VS	0	270	186	292
L CH_4/gVS	0.000	0.270	0.186	0.292
pH in average	5.4	6.9	7.0	7.0
Alkalinity ($mgCaCO_3$/L)	4008	4749	5052	5302

4. Conclusions and recommendations

4.1 Conclusions

The experimental results allow drawing the following conclusions:

- Household food waste contain different types of biodegradable materials in term of cellulose (such as wasted vegetable, fruit peels), starch (such as food remnants as rice, noodles, etc.), protein (such as wasted meat, fishes), essential oil from fruit peels, etc. Wasted vegetables and fruit peels are main components in household food waste. They account for 49.24 ± 8.07 (wasted vegetables) and 39.16 ± 9.38 (fruit peels) percent by wet weight in household food waste composition. The presence of different food waste component may affect to performance of anaerobic digestion process and methane gas recovery efficiency.

- If the food waste containing only starch food remnant or only fruit peels with essential oil, it is necessary to control retention time of the methanogenesis reactor of 120 days. It is possible to achieve 493 L CH_4/gVS of fruit peels with essential oil and 300 L CH_4.gVS of starch food waste at the retention time of 120 days and organic loading rate of 1.1 gVS/L.day and 2.6 gVS/L.day, respectively. With shorter the retention time, lower amount of methane gas can be recovered. In the case of starch food waste, it is impossible to recover biogas at the retention time of 30 days.

- Food waste containing only fruit peels without essential oil allows achieving higher amount of methane gas at shorter the retention time compared to that of food waste containing only fruit peels with essential oil. It is possible to get 747 L CH_4/gVS of fruit peels without essential oil at the retention time of 60 days compared to only 493 CH_4/gVS of fruit peels with essential oil at the retention time of 120 days.

- Except for food waste containing only starch or only fruit peels with essential oil, it is possible to recover about 445-775 L CH_4/gVS of household food waste mixture at the methanogenesis retention time of 60 days. However, the mixture of 30% fruit peels + 50% wasted vegetables + 10% starch food remnants + 10% other food remnants give the best methane gas recovery with 775 L CH_4/gVS.

4.2 Recommendations

This study was conducted with fix hydrolysis retention time of 15 days. It is necessary to determine optimum hydrolysis retention time without influence to methane gas recovery. Besides, evaluation of possibility to reuse digested sludge is also needed to be considered.

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