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Development of Two-Stage Anaerobic Digesters for Biogas Production from Biodegradable Waste of Phitsanulok Municipal, Thailand

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ABSTRACT

The purpose of this research is to get more efficiency from a methane producing system using municipal biodegradable waste. This research built a pilot plant in a Phitsanulok municipal slaughter house with a treating capacity of 100 kilogram per day for biodegradable wastes from Phitsanulok city. For more improved efficiency, the pilot plant built a grinding machine, conveyor, added acid tank, two-stage anaerobic digesters with pillows in each digester for promotion of methane productions. Data collection such as Temperature, pH, TDS, Con., salt by data logger and COD, BOD, TS, TSS, TVS, TKN were tested by chemical lab. Gas volume was by a gas meter and methane content by gas chromatography. The result showed that the performance of the system Anaerobic Sequencing Batch Tank (ASBT) was high. The average biodegradable loading rate was 54.45 kg/d., the organic loading Rate 3.5 kgTCOD/(m^3.d) in acid tank and 0.47 kgTCOD/(m^3.d) in two-stage anaerobic digesters. The biogas generation rate average 0.13 m^3/kgTCOD.d and methane production average was 49.1-56.0 %. From these results, the two-stage anaerobic digesters showed high efficiency of methane producing about two times of the general fresh waste biogas system could produce about 20-30 % in general. This fundamental data was showed that, it is reasonable to expand to a large scale for municipal biodegradable waste treatment and is useful for the development of high methane producing system.

Keywords: *Municipal Biodegradable Waste, Anaerobic Digestion, Biogas System, Methane, Two-Stage Anaerobic Digesters, Anaerobic Sequencing Batch Tank*

1. INTRODUCTION

Biogas is a renewable source of energy. Biogas is one of the most suitable technologies to reduce the volume of biodegradable waste (BW) the stability of a treatment process. During the past decades, efforts to enhance biogas system performance have resulted in several new designs to apply high-rate operation to various type of biodegradable waste of municipal solid waste (BWMSW). The economic feasibility of biogas production in general is low, and only limited subsidies are provided by the state. Such designs are developed based on detention of enough active biogas by separating the solid retention time (SRT) from the hydraulic retention time (HRT), which is an essential factor for the high-rate digestion of biodegradable waste and could be achieved using sequencing batch operation. In case of temperature-phased digestion technology, successful performance was reported owing to the advantages of thermophilic microorganisms with fast metabolism [1]. Anaerobic digestion process is considered as innovative and attractive technology for organic waste stabilization with significant mass and volume reduction with the generation of valuable by products such as biogas and fertilizer.

Moreover, this process is attractive method, especially in Phitsanulok Thailand, because of biodegradable waste (BW) in Phitsanulok city is composed of high fraction of organic material of more than 75% with high moisture content [2]. So far, the available technologies for anaerobic digestion of biodegradable waste (BW) are varied from solid to liquid, from batch to continuous and within a variety of feedstock. The specific features of batch process includes simple design and process control, lower investment cost, small water consumption, etc., make them attractive for developing country [3]. To maintain a stable high solids digestion process, the chemical value, pH, ammonia and moisture content should be considered as the important environmental factors affecting the efficiency [4]. In the complement process of anaerobic digestion, the hydrolysis/acidification and methanization are considered as rate-limiting steps. Since hydrolytic/acidogenic bacteria and methanogens have different growth requirements, it may not be possible to use single-phase system, especially in high-solid digestion where substrates are concentrated and Volatile Fatty Acids (VFA) are produced in high amount inhibiting the growth of biogas. Thus, separation of hydrolysis/acidogenesis and methanogenesis would possibly high the process. Growth of hydrolytic and acidogenic bacteria can be optimized in the first stage where methanogenesis can be optimized in the second stage [5].

Thus, this research was built up the biogas pilot plant to get fundamental data for improvement of hydrolysis/acidogenesis and methanogenesis processes and development of new biogas system for municipal biodegradable waste treatment.

2. MATERIAL AND METHODS

The study was performed in the pilot scale biogas system. The equipment associated with the grinding machine, Conveyor, Added Acid Tank, two-stage anaerobic digesters with built a pillow in each digester for promotion of early up flow and mix aeration, due to the advantage of thermophilic process over than mesophilic in the digester tank concerning to methane production.. The data collection such as Temperature, pH, TDS, Con.,Salt by data logger and COD, BOD, TS, TSS, TVS, TKN by chemical laboratory and gas volume by gas meter and methane content by gas chromatography, The experimental set-up is illustrated (Fig. 1).

2.1 Municipal waste collection and preparation

The substrate used was collected from fresh market in Phitsanulok Municipal, Thailand as the mixed waste. Biodegradable waste was manually sorted to remove bulky and inorganic fractions. Representative waste sample was taken for solid analysis and was characterized to contain high moisture content (75%). The shredded waste was subjected to size reduction to less than 3 mm for adding area digestion. The shredded waste was loaded into the acid tank (Fig 1).

2.2 Grinding

The grinding mechanism has diameters 0.5x0.6x0.5 m use 3 Hp 380 V 2,850 RPM, Three cutter and hole for control size waste.

2.3 Conveyor

The conveyor has diameters 0.7x4.2x2 m use motor gear 1:100, 1 Hp 380 V.

2.4 Organic Acid Tank and Added Acid Tank (First-Stage)

The organic acid tank have 2,000 litter use motor gear 1:20, 2 Hp 380 V. The organic acid tank has two pillows for mixing biodegradable waste and use electric 2 kW/24 hour.

2.5 Two-Stage Anaerobic Digesters (The last of first-stage and Main-Stage)

Two-stage anaerobic digester have double walled concrete with total volume of 10 m^3 and the designated volume for biodegradable waste is 100 kg/day, 0.5 m^3 for collection biogas per tank cover by PVC and built a pillow for rotary the liquid from the first tank to the second tank and outlet after fermentation by motor gear 1:100, 1 Hp 380 V. The top removable cover of the tank was equipped with several connector pipes, valves, screws and rubber seals, which ensure gas tightness of the reactor

Two-stage anaerobic digester tank was provided 10,000 L for capacity. The first stage was promoted on cell extraction and size reduction during flushing while the main-stage was promoted on gas production. Two-stage anaerobic digester involved two stages (Fig 2). The first stage consisted of enhanced first-stage (hydrolysis and acidification) operation with very low air flow rate application. This was viewed as beneficial to partly removed biological oxygen demand (BOD), chemical oxygen demand (COD) and other dissolved organics from the waste to reduce the size biodegradable waste load of the system and to prepare the system for methanogenic phase. The second stage (Main stage) involved start-up of biogas and methane phase.

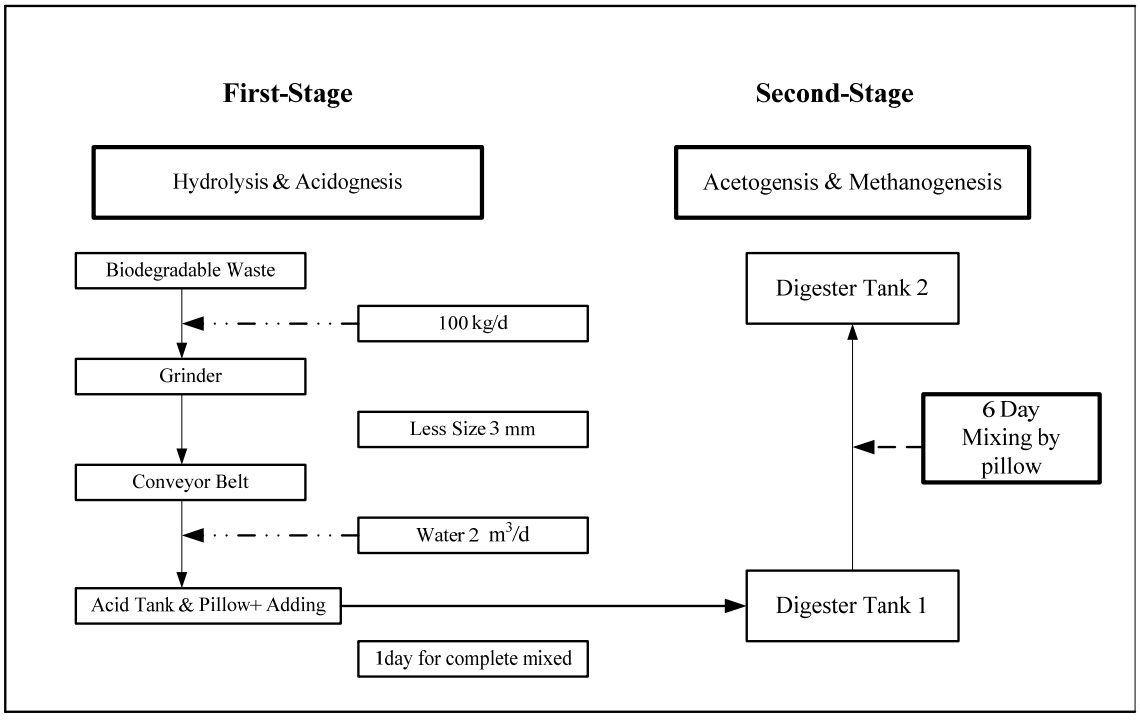
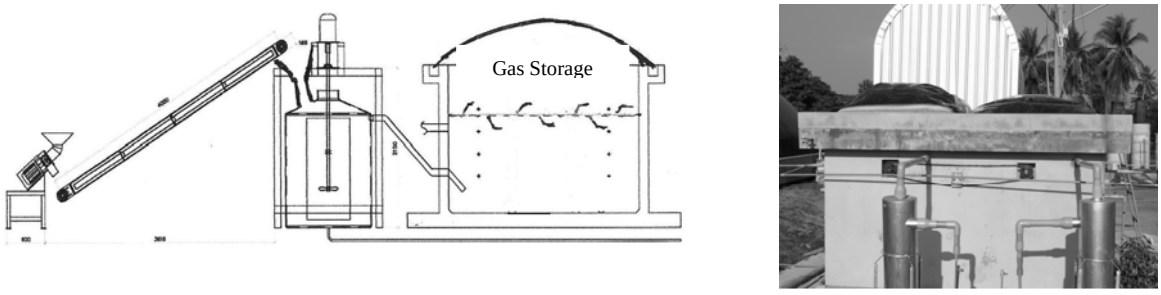


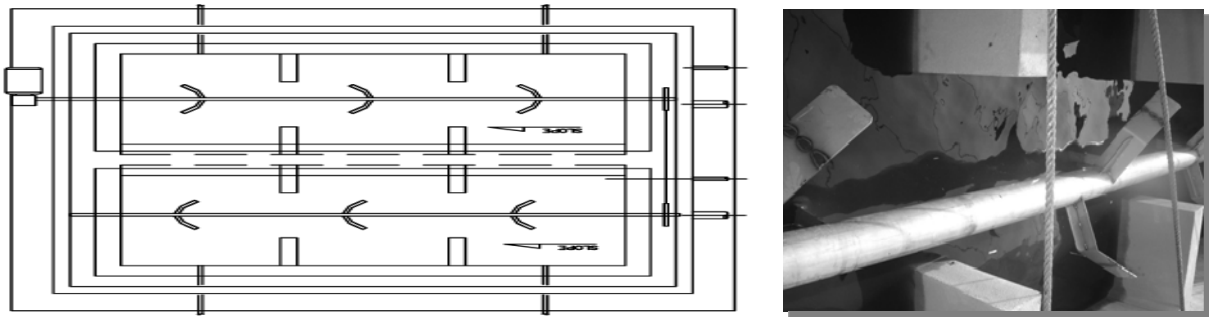
Fig. 1 Processes and flowchart of digestion

pH adjustment, inoculums addition, and mature bacteria percolation so that the inoculums can be disseminated in the system. The system was allowed undisturbed while the biogas composition was constantly monitored. Mature methanogenesis can be detected when the methane content in the biogas reached 50%, then acidified biodegradable percolation was started until the biogas production decrease and consecutive batches of biodegradable waste were fed until the biogas production leveled off at low production rate. Biodegradable waste percolation was practiced to promote biogas production and enhance methanogenic phase. Finally, after the waste was completely stabilized, aeration was applied to wash out the remaining biogas from the digester before unloading. This study was conducted in one run. Two stage digester systems were run to optimize the overall process.



Grind Conveyor belt Acid Tank & Added Two-Stage Digester Tank Gas Outlet Value

Fig. 2 Two-stage anaerobic digester and connection system



Digester Tank 1& 2 Pillow

Fig. 3 Two-stage anaerobic digester and pillow

At the Organic acid tank, 100 kg of biodegradable waste with grinded less than 3 mm was loaded in daily and mixed with acid water 20% from the added acid tank before continuously flow to the Two-stage anaerobic digester. In tank 1 and tank 2 were from top to bottom setting the temperature sensor 6 point by Temperature meter.

2.6 Data Collection and Methods

Before and after running the experiment, grinded biodegradable waste was sampling for analysis of moisture content (MC), total solids (TS), and volatile solids (VS). The biochemical methane potential (BMP) test was conducted based on the method established [1]. The various parameters digestion performance were pH, dissolve oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD) and bacteria counter (BC) based on the analytical procedures in Standard Methods [6]. And the biogas composition was measured by using gas chromatography (Shimudzu, Model G14B).

3 RESULTS AND DISCUSSION

3.1 Particle Size Reduction and conveyor

The grinder machine can grinds biodegradable waste 100 kg/hr and use 0.1 kW/100 kg by electricity. The biodegradable size was less than 3mm. The conveyor could carry biodegradable waste 100 kg/5 min and use 0.05 kW/100 kg by electricity (Fig. 4 a-b).

a) Biodegradable waste b) Particle size less than 3 mm

Fig. 4 Biodegradable waste and particle size after grinding

3.2 Organic Acid Tank and Added Acid Tank

The early stage in organic acid tank, adjusted the pH of material to 6.5 by added acid tank at the upper part of the tank to ensure for anaerobic condition.

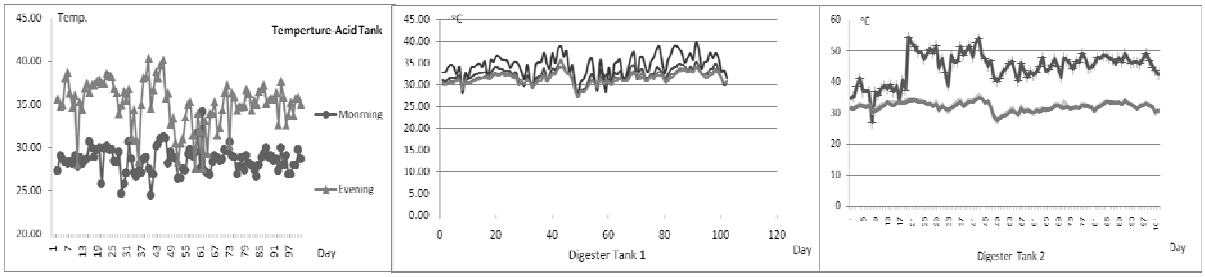
3.3 Two-Stage Anaerobic Digesters results

The average value of various parameters in a day and weekly are as follows (Table 1).

Table 1 Average value of various Parameters during digestion process

Daily				**Weekly**			
Parameter	Acid	Tank 1	Tank 2	Parameter	Acid	Tank 1	Tank 2
Tem.(^{0}C)	34.8	34.6	38.9	TS(mg/l)	3635	2287	1656
pH	6.05	7.14	7.17	TSS(mg/l)	1312	328	201
TDS(mg/l)	1781.3	1526	1485	TVS(mg/l)	1541	937	898
Con	3.79	3.48	3.38	TKN(mg/l)	243.83	251.26	230.51
SALT	1.76	1.52	1.50	BOD(mg/l)	1519	1421	702
				COD(mg/l)	3225	2312	1147

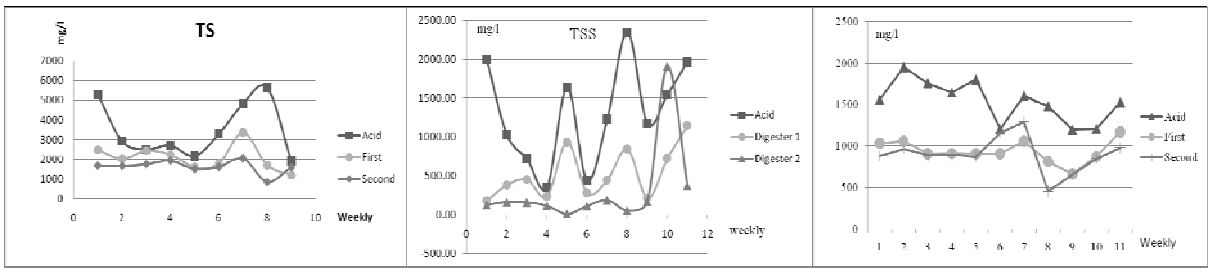
The temperature data was showed that, at the first stage in organic acid tank the temperature was low in daytime but high variation (Fig 5a) due to pre-stage of digestion and ambient temperature in each day during measurement. In the Tank 1 the temperature was higher than organic acid tank and stable approximately 37 ^{0}C that means digestion process of hydrolysis and acidogensis was started or mesophilic stage (Fig 5b). In the tank 2 the temperature was high about (50 ^{0}C) due to high rate of digestion by anaerobic bacteria methane gas was produce in this stage or so called therophilic and methanogenic phase(Fig 5c).



a) Organic Acid Tank b) Digester Tank 1 c) Digester Tank 2

Fig. 5 Changing of Temperature in two-stage anaerobic digesters; a) organic acid tank; b) digester tank 1; c) digester tank 2

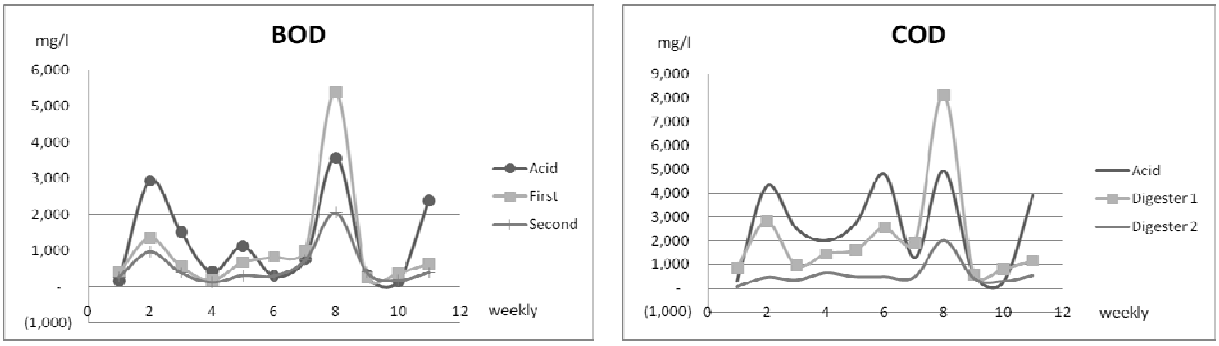
Changing of solid substrate was shown (Fig 6a-c). In term of total solids (TS) and total solid suspend (TSS) was decreased in the first two weeks and in the organic acid tank (A01) the solid substrate have the highest value than the digester tank 1 (B12, B14, B16) and then the digester tank 2 (B22, B24, B26) but total volatile solids (TVS) was changing in opposite ways, the TVS was increased from the first two week before slow down. This values shown digestion rate in each tank during the process



a) TS b) TSS c) TVS

Fig. 6 Changing of solid substrate in the process a) TS; b) TSS; c) TVS

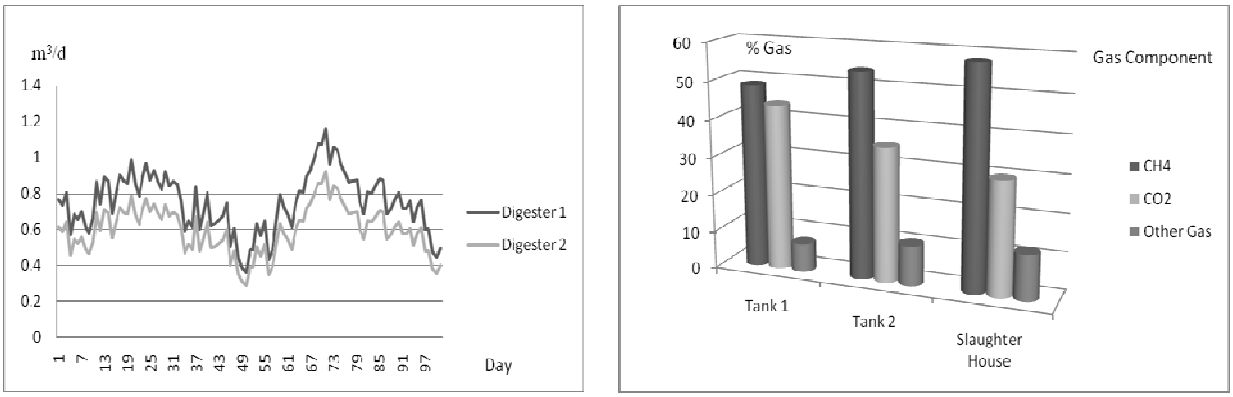
Changing of BOD and COD was shown (Fig 7a-b). The BOD and COD in the organic acid tank (A01) were increased in the first 4 weeks before slow down rapidly in after. That means in the first 4 weeks anaerobic bacteria was increased due to contain of total solid in the substrate. Thus, the BOD and COD in organic acid tank was showed the highest value, the value in digester tank 1 (B12, B14, B16) was higher than digester tank 2 (B22, B24, B26). Then, After 4 weeks when digestion was complete in the organic acid tank the BOD and COD were decreased rapidly while BOD and COD in the digester tank 1 (B12, B14, B16) and digester tank 2 (B22, B24, B26) were decreased from the first step because of some solid particle had earlier extracted and easily for digestion (hydrolysis phase) that why BOD and COD in the digester tank 1 (B12, B14, B16) and digester tank 2 (B22, B24, B26) were decreased from the first step (Fig 7).



a) BOD b) COD

Fig. 7 Changing of the BOD and COD during the process; a) BOD; b) COD

The gas volume and gas component were showed (Fig 8a-b), the gas volume (biogas) in digester tank 1 was higher than digester tank 2. This results means that gas producing in the system was rapidly from the first step after running experiment. The effected from grinded particle size and up flow rate effected by the pillow are considerable. The gas producing was increased from the first step up to the maximum on 25 days then decreasing to 45 days, that means maximum digestion of this system is on 25 days about 1.34 cubic gas per day while in the general biogas plant from first step (fresh waste) to maximum of gas production is about 45 days with average of 0.60 cubic gas per day. The gas components special methane content was showed that the digester tank 2 was higher (56%) than the digester tank 1 (49.1%). (Fig 8b) This high methane content was showed the efficiency methane producing of the system due to mixing gas to bacteria in the liquid by the pillow while methane content in general biogas plant is less than 30% (Fig 8 b).



a) GAS Volume b) Components GAS

Fig. 8 Gas production and Gas components; a) Gas Volume; b); Gas Components

3.4 Energy Balance

The energy consumption was from this system (Grinder, Conveyor, Acid tank and Two Stage Digester).

Table 2 Energy Balance from Plant

Input Energy (kW)					Energy Producing (kW)		
Grinder	Conveyor	Acid Tank	Two Stage Digester	Sum	First Tank	Second Tank	Sum
0.1	0.05	0.8	1.2	2.15	1.48	1.20	2.68

Note: 1 m^3 Biogas = 2 kW (Generator Engine)

The result shown that under this system to produce energy of 2.68 kW (6.0 m^3 .Biogas), its need energy input about 2.15 kW (Table 2).

4 CONCLUSIONS

Two stage anaerobic digesters system has showed the emphasized results for municipal biodegradable waste treatment. The result shown that system designed with contained of grinding machine for reduction of the particle size less than 3 mm before fermentation and added acid tank about 20% to the substrates before loading to digester tank and also built up of the pillows in both digester tanks are effected to the digestion rate in the tank. Because small particle size increasing the surface areas to water and bacteria were for hydrolysis promotion. The environmental in the tank also important for high efficiency rate of digestion. So that in this research was aims to promote the advantage of thermophilic phase than mesophilic phase, the result was showed high temperature about 50-65^{o}C in the digester tank 2 (thermophilic phase) and about 35^{o}C in the digester tank 1 (mesophilic phase). All over mention process caused the high content methane when compared to the other system. The system can removed the TS and TVS as same as removed BOD and COD in short period. The gas production also from the first step to the maximum about 25 days are short period and purified methane gas content about 49.1% - 56% by built up the pillow was suitable for this system. The system was able to produce gas volume a little bit higher or almost the same with another system [7]. Energy balance was under this system to produce energy of 2.68 kW (1.334 m^3 of biogas per day). It need to input energy about 2.15 kW. But purify of methane content in this system are important for both reasons, up-scale for municipal waste treatment in industrial scale and for renewable energy purposes.

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