CHAPTER IV

RESULTS

This section describes the results obtained during the lab-scale anaerobic digestion of food waste operating in thermophilic condition and mesophilic condition. The experiments were conducted in two-stage anaerobic digestion system i.e. acid phased digestion and methane phased digestion. The analysis and evaluation are described to examine the performance in laboratory-scale experiment to achieve the objectives of this study.

The biogas production at various temperatures digestion

The biogas production at various temperatures digestion

Biogas from the degradation of food waste as a renewable source of energy is presented in Figure 48. The data shown are the biogas generation from reactors incubated at mesophilic temperature (20-40°C) and thermophilic temperature (50-65°C). Maximum biogas production occurred at 55°C (38.14 L. of biogas) when compared to the other temperatures. Second best was at 50°C (37.44 L. of biogas), followed by 40°C (35.36 L. of biogas) respectively (the detail are attached in Appendix D).

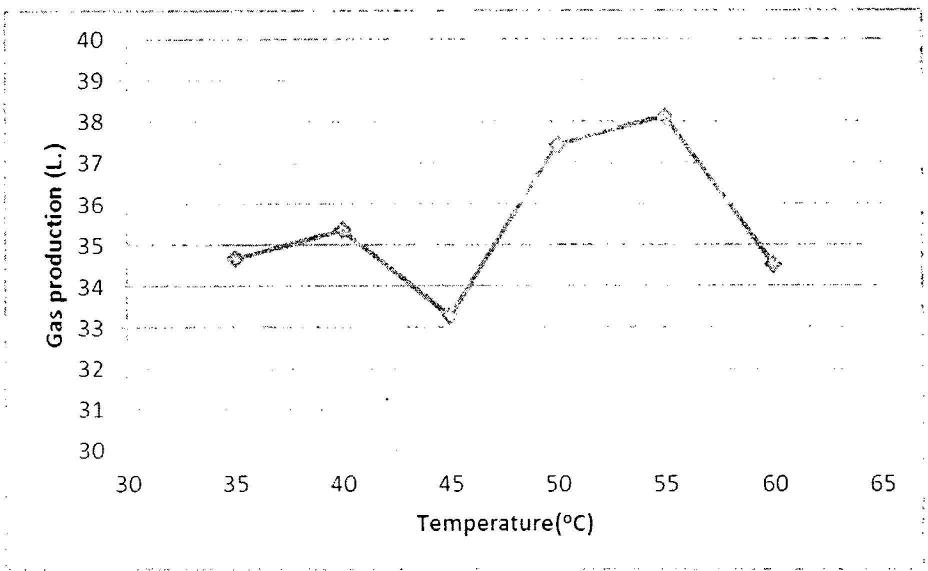

Figure 48 Biogas production (L.) at various temperatures digestion

The biogas composition at various temperatures digestion

The biogas composition of the biogas production from reactor incubated at mesophilic temperature is presented in Figure 49. The data shown that the biogas composition from reactors incubated at 40°C. Maximum methane of the biogas production was 57%. Second carbon dioxide was 35%, followed other gas was 8% respectively.

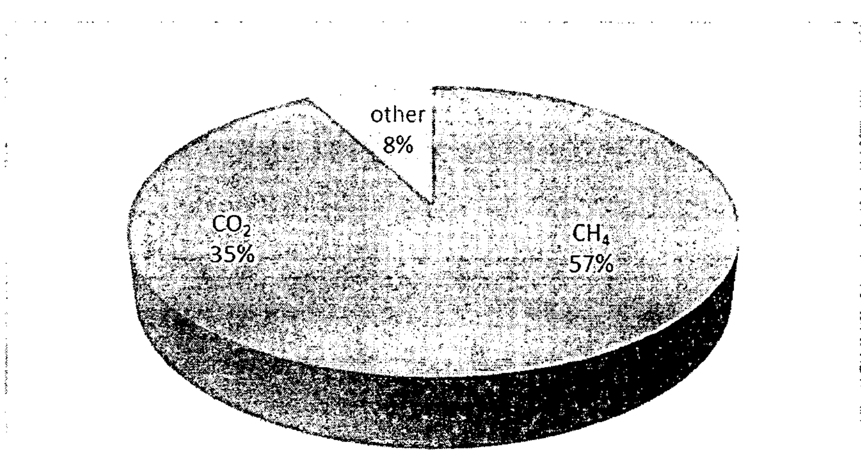

Figure 49 Biogas composition occurred at 40°C

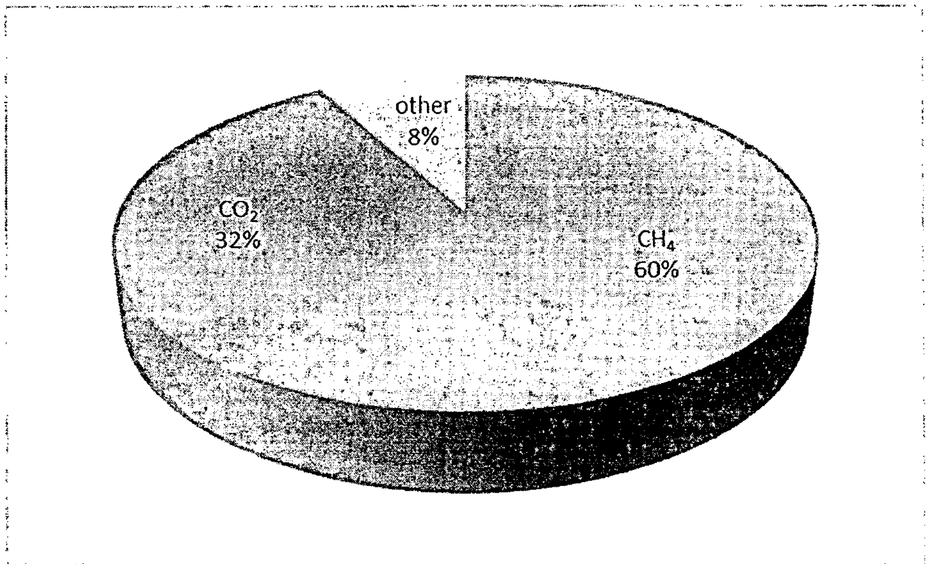

Figure 50 Biogas composition occurred at 55°C

The biogas composition of the biogas production from reactor incubated at thermophilic temperature is presented in Figure 50. The data shown that the biogas composition from reactors incubated at 55°C. Maximum methane of the biogas production was 60%. Second carbon dioxide was 32%, followed other gas was 8% respectively.

Time digestion at various temperatures digestion

The day digestion of the biogas production is presented in Figure 51. The data shown are the days digestion from reactors incubated at mesophilic temperature (20-40°C) and thermophilic temperature (50-65°C). Minimum day digestion of the biogas production occurred at 55°C (11 days) when compared to the other temperatures. Second best was at 50°C (12 days), followed by 35 and 40°C (15 days) respectively. This lower days digestion, when compared to the other temperatures, is attributed to a temperature of about 55°C is important for bacteria's growth and activity.

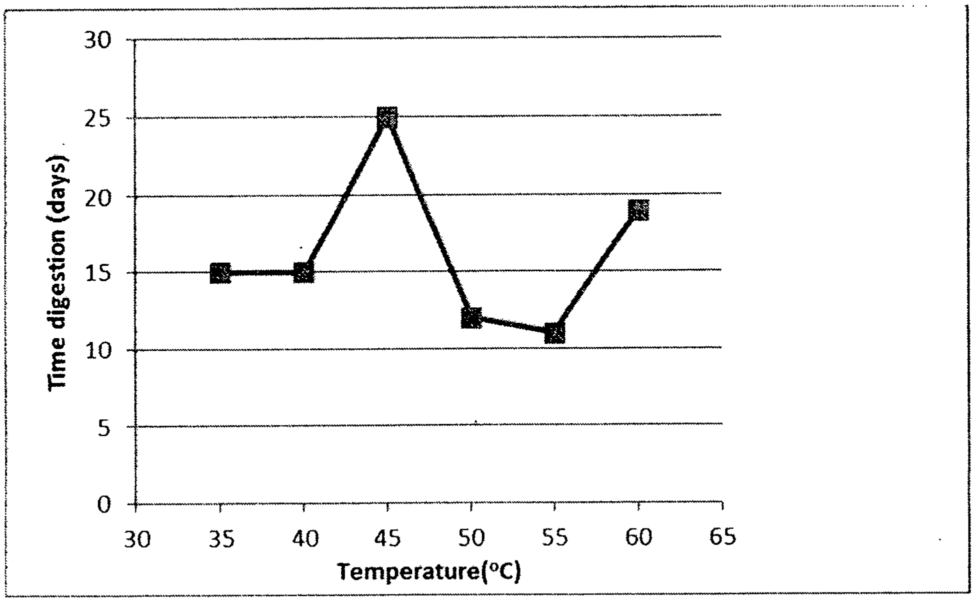

Figure 51 Time digestion (days) at various temperatures digestion

The results of the laboratory-scale experiment, maximum biogas production occurred at 55°C (38.14 L. of biogas) for a period of 11 days when compared to the other temperatures. Second best was at 50°C (37.44 L. of biogas) for a period of 12 days, followed by 40°C (35.36 L. of biogas) for a period of 15 days respectively.

Develop the temperature control system for biogas production.

In solar hot water system design, it is necessary to estimate the long-term average heating load. The hot water load or the amount of the energy required to warm water from the inlet cold water temperature to a desired temperature is dependent on several factors such as cold water inlet temperature, location, system characteristic and quality. This load also includes any heat loss from the storage tank and piping system.

Solar heating

The heating required for the bioreactor was performed using a solar collector combined with biogas energy. Water contained within the jacket of the bioreactor was 35 liters and the bioreactor volume was 70 liters. Heating this volume of water to 35-60°C for the solar collector design.

Solar collector

The solar collector consists of a galvanized steel flat plate of 4.98 m^2 dimensions. The absorber was insulated with a glass wool layer of 4 cm thickness at the bottom. All of these parts were arranged within a box of galvanized steel base and glass top.

Controller

Heating the bioreactor using solar energy can be approximated by first order dynamics. Since solar energy radiation is continuously affect the system, a closed loop controller has to be used over an open loop controller.

Two types of controllers were implemented; an on–off controller, and an analog PID controller. The on–off controller sensor was sensitive to small temperature variations. It responded to temperature error before it was switched to an on–off position. Other reasons using a PID controller are due to the sensitivity of the controller to input variation and the simplicity of the parameters design.

Design of solar collector by calculations

The bioreactor volume is 70 liters and the water contained within the water jacket is 35 liters. The flow rate of water was 15 liters /hour (force circulation) and 1°C temperature difference between the water jacket inlet and outlet. Heating this volume of water to 35-60°C for the solar collector design. Temperature of water inlet was 30°C.

Solar radiation was 18,200 kJ. / m^2/ day.

Efficiency of flat plate solar collector 0.5

$$= 18{,}200 \times 0.5 \text{ kJ./m}^2\text{ /day}$$

$$= 9{,}100 \text{ kJ./m}^2\text{ /day}$$

Heat to water

$$Q = m\, c_p\, \triangle T$$

Flow rate of water was 15 liters /hour.

Working hour of hot water was 24 hours/day.

Total hot water was 360 liters /day.

Specific gravity of water was 1 liter per 1 kilogram.

Flow rate of water was 360 liters / kilogram.

specific heat of water was 4.2 kJ/kg °C.

$$Q = (360\ \text{kg})\ (4.2\ \text{kJ/kg °C})\ (60 - 30)\ \text{°C} = 45{,}360\ \text{kJ}$$

$$\text{Size of flat plate solar collector} = 45{,}360\ \text{kJ} / 9{,}100\ (\text{kJ/m}^2) = 4.98\ \text{m}^2$$

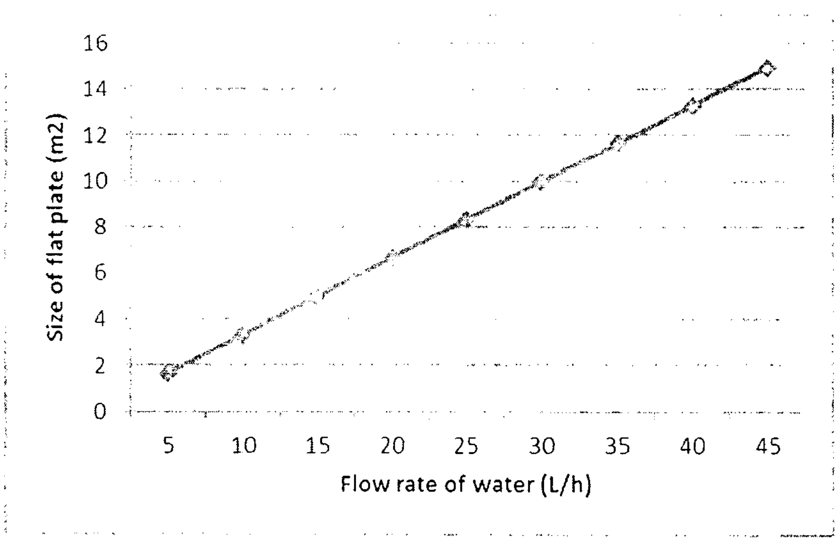

Figure 52 The size of flat plate (m^2) at flow rate water (L/h)

When increase the size of the biogas system need to increase the flow rate of water. Therefore, in order to temperature constant need to increase the size of flat plate. In Figure 52, the data shown are the size of flat plate from flow rate water in 24 hours operation by the calculation.

The water contained within the water jacket was 35 liters.

The flow rate of water was 15 liters /hour (0.004 L / second)

The time of water flows out = 35 /15

= 2.4 hours.

Heat losses rate of hot water

$Q = m^{o}\, c_p\, \triangle T$

$= (0.004\ kg/s)\ (4.2\ kJ/kg\ ^{o}C)\ (1\ ^{o}C)$

$= 0.0168\ kJ/s$

$= 16.8\ watt$

$Q_{loss} = (2.4\ h) \times (16.8\ watt)$

$= 145{,}152\ watt$

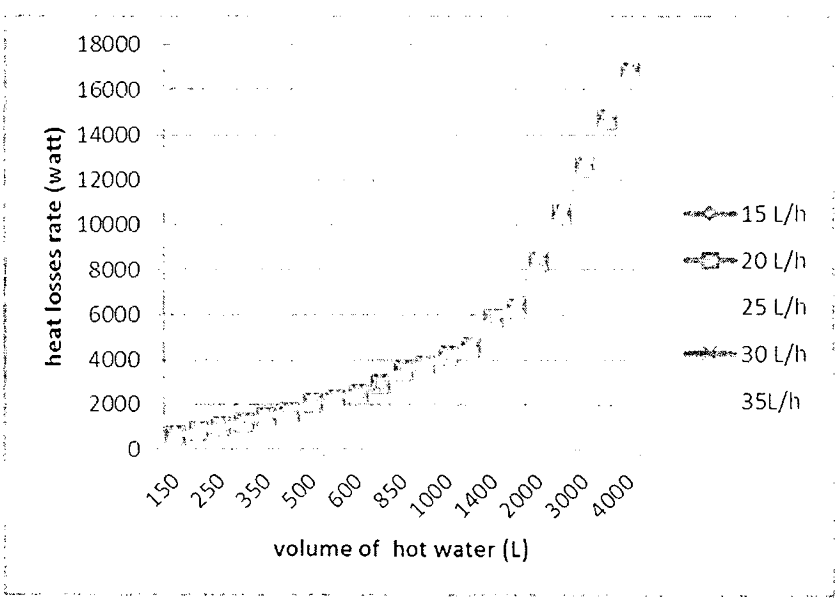

Figure 53 The heat losses rate (watt) at volume of hot water

When increase the size of the system need to increase the volume of hot water. Therefore the heat losses rate increase. In Figure 53, the data shown are the heat losses rate from volume of hot water by the calculation.

If the temperature of hot water was reaction at 60 °C and the system needed to be mixing at the temperature of 40 °C then the 30 °C water was used to mix of 70 L by the calculate was shown.

Q_{hot}	=	Q_{cool}
Energy balance $M \cdot c_p \triangle T$	=	$X \cdot c_p \triangle T$
(35L) (4.2 kJ/kg °C) (60-40)	=	X (4.2 kJ/kg °C) (40-30)
2940	=	42X
X	=	70 L

If the temperature of hot water was reaction at 60 °C and the system needed to be mixing at the temperature of 55 °C then the 30 °C water was used to mix of 7 L by the calculate was shown.

Q_{hot}	=	Q_{cool}
Energy balance $M \cdot c_p \triangle T$	=	$X \cdot c_p \triangle T$
(35L) (4.2 kJ/kg °C) (60-55)	=	X (4.2 kJ/kg °C) (55-30)
735	=	105X
X	=	7 L

specific heat of biogas was 1.6 kJ/kg °C.

If the temperature of hot water was reaction at 35 °C and the system needed to be mixing at the temperature of 40 °C then the biogas burn of water to mix of 91.88 kJ by the calculate was shown.

Q_{hot}	=	Q_{cool}
Energy balance $M \cdot c_p \triangle T$	=	$X \cdot c_p \triangle T$
(35L) (4.2 kJ/kg °C) (40-35)	=	X (1.6 kJ/ kg °C) (40-35)
735	=	8X
X	=	91.88 kJ

If the temperature of hot water was reaction at 55 °C and the system needed to be mixing at the temperature of 40 °C then the biogas burn of water to mix of 91.88 kJ by the calculate was shown.

Q_{hot}	=	Q_{cool}
Energy balance $M \cdot c_p \triangle T$	=	$X \cdot c_p \triangle T$
(35L) (4.2 kJ/kg °C) (55-35)	=	X (1.6 kJ/ kg °C) (55-35)
2,940	=	32X
X	=	91.88 kJ

Analysis the economic parameter

Economics analysis in this research will be study temperature control system for biogas production cost that the economics analysis consist of evaluation expenses side the other yearly both biogas production system and find out payback period in case.

Assumption and parameter for evaluation economic analysis consist of;

1. The capital cost of building the system.
   1.1 Biogas system 8,000 Bath.
   1.2 Hot water system 90,000 Bath. (data: September 2014)
2. Discount rate 7.5%.
3. Total hour of operating system 8,400 hour/year.
4. Maintenance cost 5% of the system.
5. The cost of electricity 3.5 Baht/kWh.
6. Ruins value of the system 10% of the capital cost of building the system.
7. In term of payback period analysis the reward net per year will be compared the cost of maintenance.

Capital cost of building the system (biogas); yearly calculate

C_C = Capital cost of building the system (CRF, i, n)

$C_{C\text{-biogas}}$ = Capital cost of building the system $\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

= $8{,}000\left[\frac{7.5\%(1+7.5\%)^5}{(1+7.5\%)^5-1}\right]$

= 1,976 Baht /year

Investment cost of building the system (solar hot water); yearly calculate

$C_{C\text{-hot water}}$ = Cost of the system $\left[\frac{i(1+i)^n}{(1+i)^n-1}\right]$

= $90{,}000\left[\frac{7.5\%(1+7.5\%)^5}{(1+7.5\%)^5-1}\right]$

= 22,230 Baht /year

Ruins value of the system (biogas); yearly calculate

C_S = Ruins value of the system (SFF, i, n)

$C_{S\text{-biogas}}$ = Ruins value of the system $\left[\frac{i}{(i+1)^n-1}\right]$

= $8{,}000\left[\frac{7.5\%}{(7.5\%+1)^5-1}\right]$

= 1,376 Baht /year

Ruins value of the system (solar hot water); yearly calculate

$C_{S\text{- hot water}}$ = Ruins value of the system $\left[\frac{i}{(i+1)^n-1}\right]$

= $90{,}000\left[\frac{7.5\%}{(7.5\%+1)^5-1}\right]$

= 15,480 Baht /year

Maintenance (biogas) per year

$C_{M\text{-biogas}}$ = 5% 0f capital cost of building the system

= 8,000 x 5%

= 400 Baht /year

Maintenance (solar hot water); per year

$C_{M\text{-hot water}}$ = 5% 0f capital cost of building the system

= 90,000 x 5%

= 4,500 Baht /year

Expenses cost fuel per year

C_F = (Cost of fuel x Rate of fuel consumption)

x (Hour operating per year)

= 0 Baht /year

Expenses cost electricity per year

C_E = (Power electric value per unit x Power electric for using)

x (Hour operating per year)

= 3.5 Baht/unit x o.4 kW x 8,400 hour/year

= 11,760 Baht /year

Yearly total expenses cost

C_T = $C_{C\text{-biogas}} + C_{C\text{-hot water}} + C_{M\text{-biogas}} + C_{M\text{-hot water}} + C_F + C_E$

$- C_{S\text{-biogas}} - C_{S\text{- hot water}}$

= 1,976 + 22,230 + 400 + 4,500 + 0 + 11,760

-1,376 - 15,480

$= 24{,}010$ Baht /year

Total expenses cost per rate of system production

$$\text{Total expenses cost per rate of system production} = \frac{\text{Yearly total expenses cost}}{\text{Rate of system production yearly}}$$

$$= \frac{24{,}010 \text{ Baht /year}}{3.47 \text{ L/day} \times 350 \text{ days}}$$

$$= \frac{24{,}010 \text{ Baht /year}}{1{,}214.50 \text{ L/year}}$$

$$= 19.77 \text{ Baht / L}$$

Expenses cost operating yearly

$$C_O = C_F + C_{M\text{-biogas}} + C_{M\text{-hot water}} + C_E$$

$$= 0 + 400 + 4{,}500 + 11{,}760$$

$$= 16{,}660 \text{ Baht /year}$$

Expenses cost operating per rate of system production

$$\text{Expenses cost operating per rate of system production} = \frac{\text{Yearly expense cost operating}}{\text{Rate of system production yearly}}$$

$$= \frac{16{,}660 \text{ Baht /year}}{1{,}214.50 \text{ L/year}}$$

$$= 13.72 \text{ Baht / L}$$

Payback period

$$\text{Payback period} = \frac{\text{Capital cost of building the system}}{\text{Reward net per year}}$$

$$= \frac{8{,}000 + 90{,}000 \text{ Baht}}{400{+}4{,}500{+}11{,}760 \text{ Baht/year}}$$

$$= 5.88 \text{ year}$$

Payback period (free the hot water system)

$$= \frac{8{,}000 \text{ Baht}}{400{+}11{,}760 \text{ Baht/year}}$$

$$= 0.66 \text{ year}$$

Payback period of temperature control system for biogas production system was 5.88 year. Consideration total expenses cost per rate of system production and expense cost operating per rate of system production. The evaluation economic analysis of temperature control system for biogas production system was long time payback period because of the hot water system is very expensive. If free the hot water system, Payback period of biogas production system was 0.66 year.