CHAPTER 3

METHODOLOGY

The purpose of this research was to find optimal leachate recirculation scheme for controlling gas production in landfill bioreactor. Therefore, three columns of bioreactor landfill were constructed. They were single pass leaching reactor, reactor with leachate recycle according to plan A (based on leachate volume and percent methane), and reactor with leachate recycle according to plan B (based on COD mass and methane volume)

The results of two recycling schemes would be discussed to assess merit of each method. Procedures for plan A are easier to practice in actual setting whereas plan B would give more accurate information, yet difficult to practice in field-scale landfill. Moreover, robustness of the system in response to change in COD mass input would also be observed in plan B practice since adjustment of input was made daily based on volume of methane produced the day before.

3.1 Examination of inputs and outputs from previous works

The aim of this step was to identify the relationship between inputs and outputs to set up the recirculation scheme.

Turajane (2001), Šan and Onay (2001), and Rachdawong (1994)'s works were examined for relationship between plots of inputs (leachate, COD mass), and the outputs (percent methane, volume of methane). The leachate addition (mL), COD mass input (mg), and volume of methane output (mL) of these works are shows in Figures 3.1, 3.2, 3.3, 3.4, 3.5, and 3.6.

3.1.1 Turajane (2001)'s work

From Figures 3.1 and 3.2, Turajane (2001) divided recirculation scheme into three phases according to different quantities of leachate recycled, 2 L/day, 5 L/day, and 10 L/day, respectively. The phases shifted with increasing in volume of leachate recirculation, resulting in an increase in COD mass inputs and methane volume outputs. Nevertheless, at the third recirculation phase, significant decrease in COD mass and volume of methane were noticed due to accelerated stabilization of solid waste in the reactor.

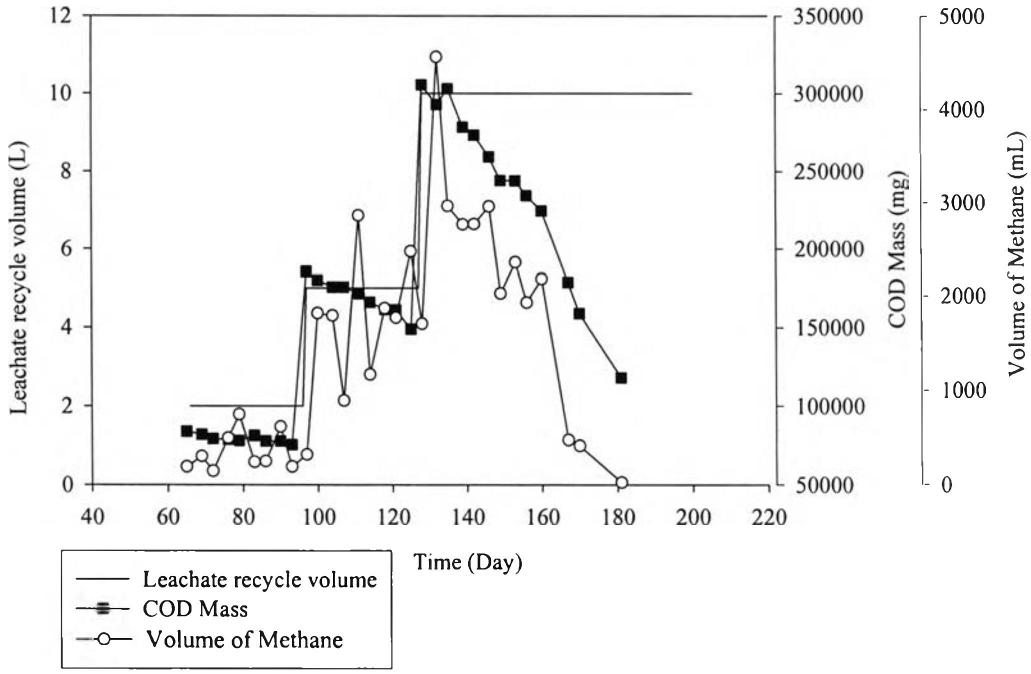

Figure 3.1 Leachate recycle volume, COD mass, and volume of methane (Turajane, 2001)

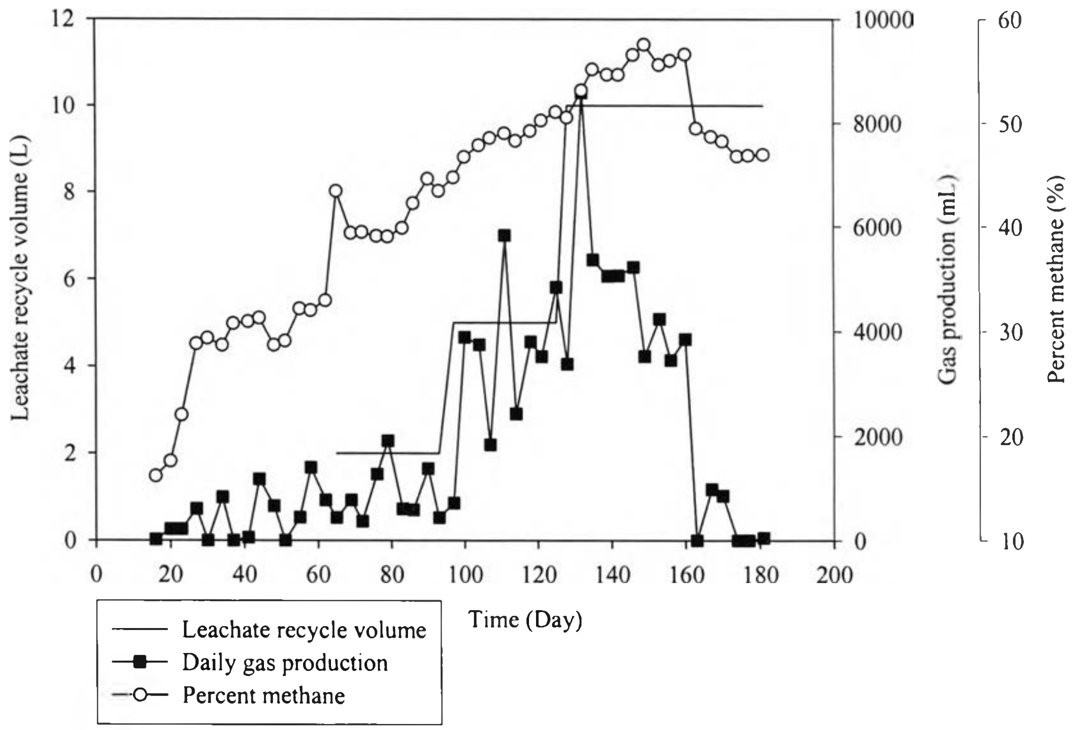

Figure 3.2 Leachate recycle volume, daily gas production, and percent methane (Turajane, 2001)

3.1.2 Šan and Onay (2001)'s work

From Figures 3.3 and 3.4, Šan and Onay divided the leachate recirculation phases into five stages. They were 142 mL/day, 285 mL/day, 571 mL/day, 857 mL/day, and 1142 mL/day, respectively. The increase in leachate recirculation volume also resulted in an increase in COD mass inputs and volume of methane outputs. Nevertheless, during day 184-190, the methane volume were greatly increased, from 338 mL to 640 mL. With this result, they shifted to their next recirculation phase, which reduced the volume of methane production to 252 mL in day 196. In addition, after day 246, COD mass and volume of methane started to reduce and maybe an indication that the reactor content was stabilized.

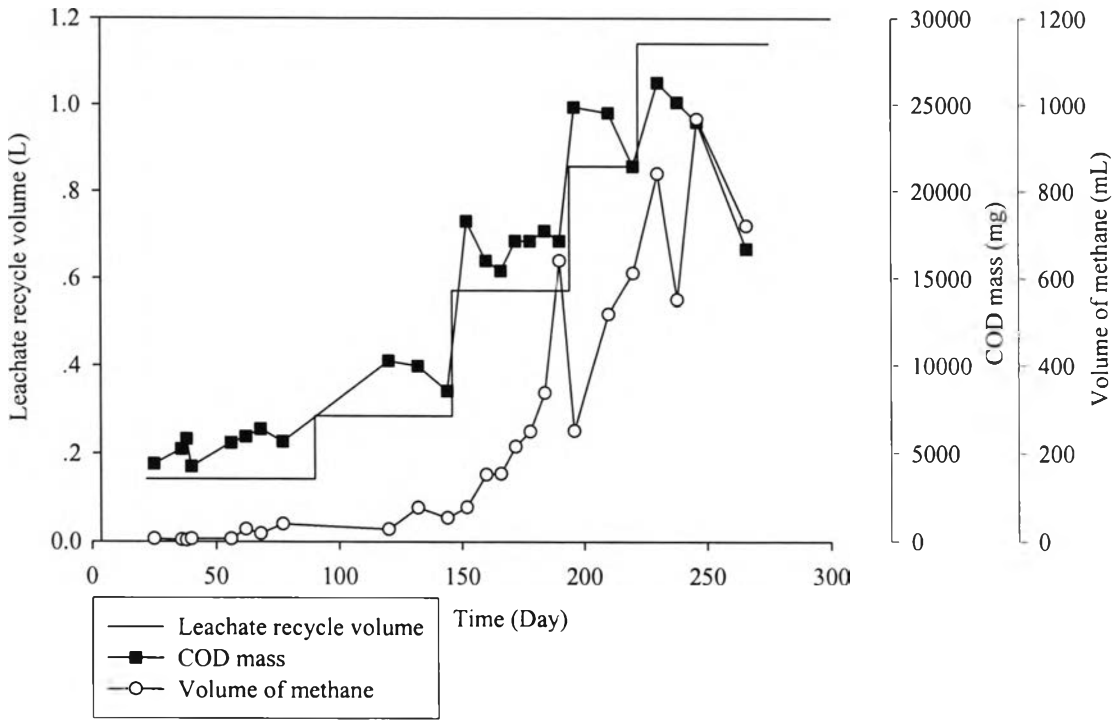

Figure 3.3 Leachate recycle volume, COD mass, and volume of methane (Šan and Onay, 2001)

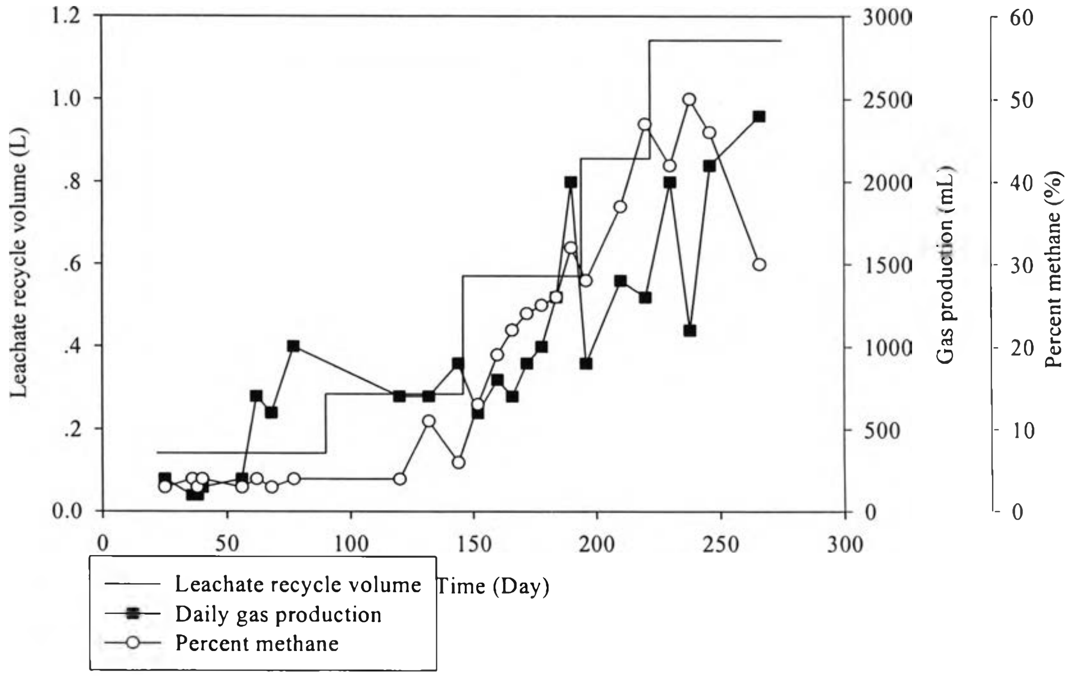

Figure 3.4 Leachate recycle volume, daily gas production, and percent methane (Šan and Onay, 2001)

3.1.3 Rachdawong (1994)'s work

From Figures 3.5 and 3.6, Rachdawong recycled leachate into recycle reactor intermittedly. Strong relationship between the amount of leachate recycled and the COD mass input was noticed. The leachate recirculation frequency and COD mass input showed great impact on the volume of methane in the off-gas. High frequency in recirculation from day 277 to 312 was accompanied by rise in methane volume from an average of 800 mL to approximately 2800 mL.

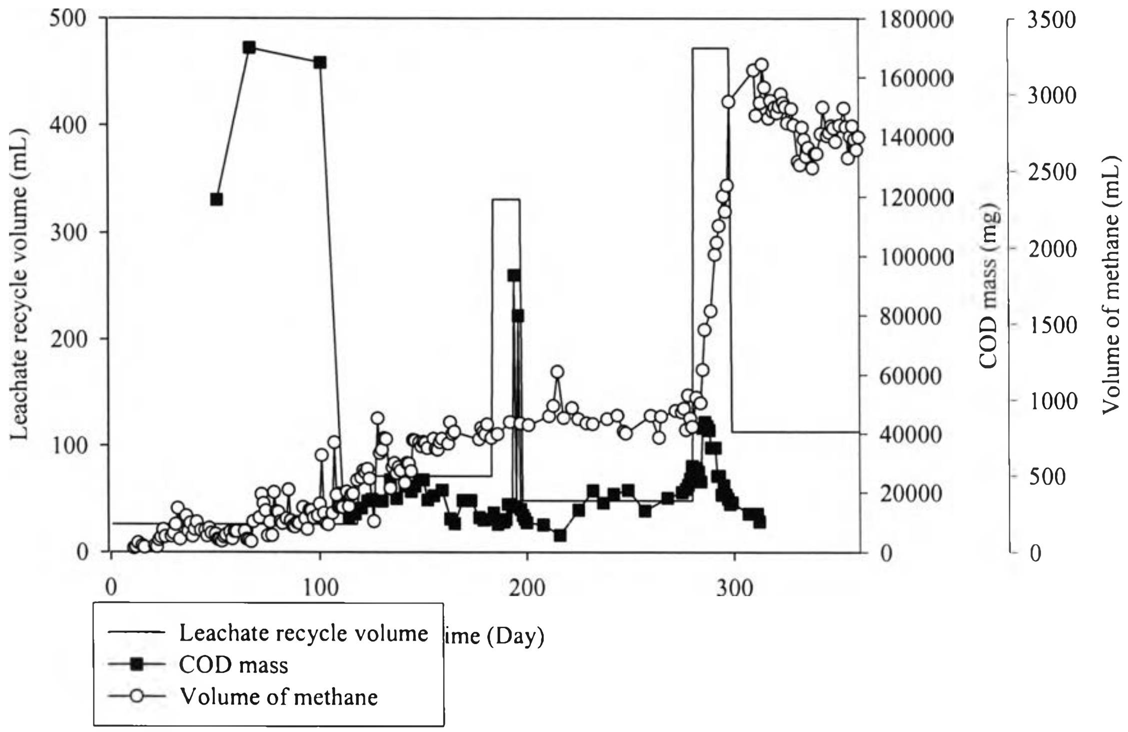

Figure 3.5 Leachate recycle volume, COD mass, and volume of methane (Rachdawong, 1994)

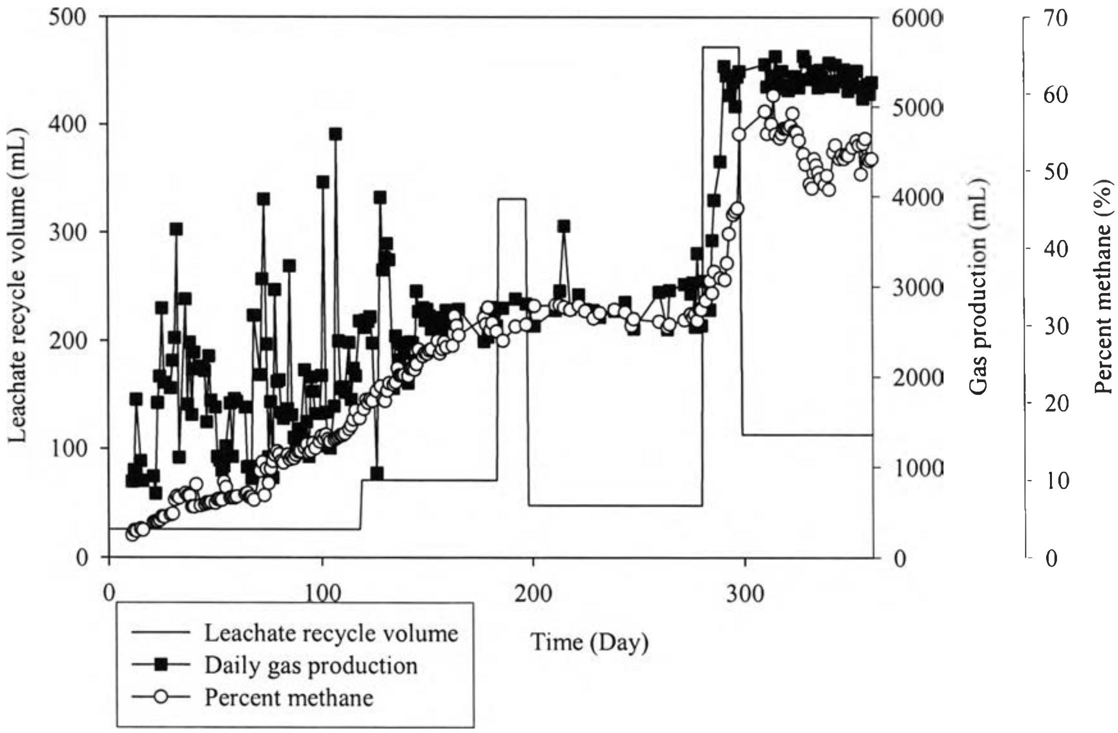

Figure 3.6 Leachate recycle volume, daily gas production, and percent methane (Rachdawong, 1994)

The relationship between inputs and outputs from Turajane (2001) and Šan and Onay (2001) was alike in almost all parameters. While significant fluctuating parameters from Rachdawong (1994) can be noticed. Turajane (2001) used food waste while Šan and Onay (2001) used municipal solid waste. Since the refuse used in this study was food waste, the leachate addition phases would be conducted in four phases as in Turajane is study.

3.2 Leachate Recirculation Phase Shift Conditions.

The aim of this step was to find the feasible condition for enhancing methane production by measuring cumulative gas production and percent methane.

The phase shift conditions from previous works were reviewed to formulate the leachate recirculation plan for this study. The Leachate recirculation phase shift conditions of Turajane (2001), Šan and Onay (2001), and Rachdawong (1994) are show in Table 3.1.

Table 3.1 Leachate recirculation phase shift conditions from Turajane (2001), Šan and Onay (2001), and Rachdawong (1994)

Phase	Day	Length (Day)	Avg %CH_4	Range %CH_4	Leachate Recycled (mL/day)	Avg COD mass (mg/day)	Avg volume of methane (mL/day)	COD mass / Volume of CH_4
Turajane (2001)								
1	1-65	65	28.9	16.2-43.4	0	82927	191	434.2
2	66-96	31	40.9	39.0-44.6	2000	78271	372	210.4
3	97-127	31	48.4	44.7-51.1	5000	159415	1660	102.1
4	128-200	73	52.3	46.8-57.6	10000	239510	2084	114.9
San and Onay (2001)								
1	1-21	21	-	-	0	-	-	
2	22-90	69	3.5	3.0-4.0	142	5422	13	417.1
3	91-146	56	7.0	4.0-11.0	285	9595	53	181.0
4	147-194	48	23.0	13.0-32.0	571	16966	261	65.0
5	195-222	28	37.3	28.0-47.0	857	23596	460	51.3
6	223-275	53	42.0	30.0-50.0	1142	23011	769	29.9
Rachdawong (1994)								
1	1-118	118	10.3	2.9-18.9	26	82985	291	285.2
2	119-183	65	25.2	19.1-32.3	71	17523	662	26.5
3	184-197	14	29.3	28.0-30.1	331	24271	805	30.2
4	198-280	83	31.4	29.7-32.6	48	16992	858	19.8
5	281-298	18	40.1	33.2-54.8	472	29331	1710	17.2
6	299-360	62	52.8	47.6-59.8	113	13056	2955	4.4

From Table 3.1, the leachate recirculation phase shift conditions both for plan A and plan B was set up as showed in Tables 3.2 and 3.3, correspondingly.

The great difference in leachate volume recycled and COD mass from Turajane (2001) and Šan and Onay (2001) works are noticed. The reasons of this should be the initial amounts of refuse (Turajane, 2001, 35 kg; Šan and Onay, 2001, 13 kg) and types of the refuse (Turajane, 2001: food waste, Šan and Onay, 2001: municipal solid waste).

Leachate recycle operation plan A (recycling based on leachate volume and percent methane)

The experimental study was divided into four operational phases. The volume of recirculated leachate to the reactor would be changed according to degree of waste stabilization and gas production. The four operational phases are shown in the Table 3.2. Volume of leachate recycle were changed in stair step manner according to data from Turajane (2001).

Table 3.2 Leachate recirculation phase shift conditions for plan A

Phase	Range %CH4	Leachate Recycle Volume
1	0-15	-
2	16-19	5 % of initial moisture in system
3	20-29	7 % of initial moisture in system
4	30-40	15 % of initial moisture in system
5	≥40	25 % of initial moisture in system

Leachate recycle operation plan B (recycling based on COD mass and methane volume)

From Table 3.1, the leachate recirculation phase shift condition for plan B is setting up as showed in Tables 3.3

The operation of this reactor was divided into 4 phases as shown in Table 3.3. The amount of the recycled leachate volume would correspond to the recycled COD mass and volume of methane gas, which will be calculated and adjusted periodically.

Table 3.3 Leachate recirculation phases shift condition for plan B

Phase	Range %CH4	COD mass / Volume of methane ratio
1	0-15	-
2	16-19	450
3	20-29	300
4	30-40	200
5	≥40	100

3.3 Configurations of the Simulated Landfill Reactors

The three simulated landfill reactors were constructed using a PVC pipe. Each reactor has a diameter of 0.40 m and a height of 0.70 m. The columns were assembled with two 0.5 m outer diameter PVC flanges at both ends to provide support for top and bottom lids.

The reactors equipped with three ports. One port was use for leachate drainage and sampling while the other two inlet/outlet ports are placed at the top lid to collect gas samples and to add liquid using a distribution system made of PVC. Landfill gas produced in the reactors was collected and measured by an inverted glass cylinder method. This technique utilized one 1-L glass cylinder placed invertly in one 2-L glass cylinder which was filled with confining solution.(20% Na_2SO_4 in 5%H_2SO_4)

(Sawyer, McCarty, and Parkin, 1994). The design and operation feature of the simulated landfill reactor in this experiment is shown in Figure 3.7.

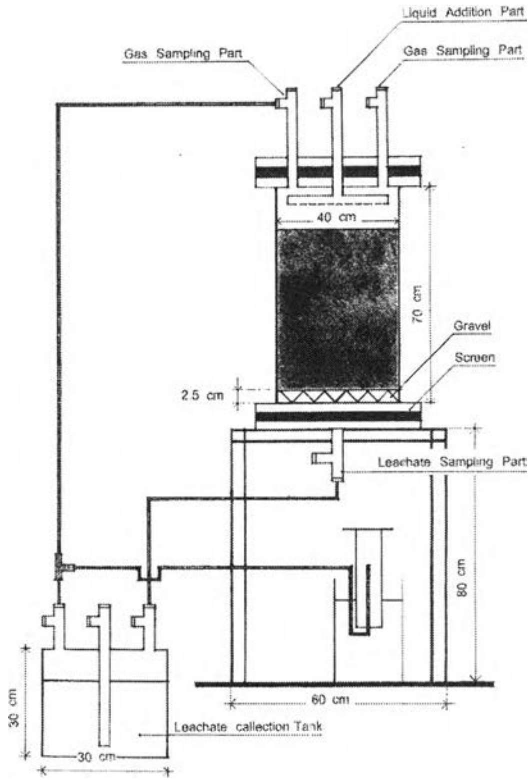

Figure 3.7 Configuration of the Simulated Landfill Reactor

3.4 Simulated Landfill Reactor Loading

Each reactor was loaded with 20 kg of synthetically prepared, shredded and compacted solid waste mixture and 1 L of anaerobic digested sludge obtained from wastewater treatment plant. The synthetic solid waste mixture representing typical solid waste composition of Sri-Mum-Muan Market and consisted of 80% vegetables and 20% fruit by weight. Shredded synthetic refuse of composition presented in Table 3.4 was mixed prior to loading. Preliminary analysis of waste samples was performed to assess solid waste moisture and volatile solid content.

Before the process of solid waste loading on August 7, 2003, a 2 cm diameter gravel were placed at the bottom of each reactor. A circular nylon screen with 1 mm diameter holes was placed underneath and on the gravel layer. The average in-place density of solid waste in each reactor was 461 kg/m^3.

Table 3.4 Synthetic Solid Waste Composition

Type	Total wet weight (kg)	Percent(by weight)
Chinese White Cabbage	2.5	12.5
Morning Glory	2.3	11.5
Eggplant	6.3	31.5
Kale	2	10
Cow Pea	2.5	12.5
Water Mimosa	0.6	3
Cabbage	0.6	3
Chinese Cabbage	0.4	2
Bitter Cucumber	0.5	2.5
Banana	1	5
Orange	1.3	6.5
Total	**20**	**100**

3.5 Simulated Landfill Operation

3.5.1 Moisture Application and Management

Preliminary analyses indicated that the synthetic solid waste had approximately 90% of moisture content. On the first day of the operation, the liquid collected at the bottom was recycled to the top of each reactor. This leachate application procedure was repeated for three days until the amount of liquid introduced each day was equal or less than the amount of liquid collected on the next day. This indicated field capacity was reached and that day was defined as day 0.

The moisture applications for each reactor were different due to purposes of each reactor. However, there was no moisture addition to both recycle reactors from August 14, 2003 (Day 0) to October 16, 2003 (Day 63), since the volume of moisture content in reactor was determined sufficient to initiate microbial activities. During October 16, 2003 (Day 63) to October 24, 2004 (Day 71), 2.5 L of deionized (DI) water was added to each reactor to make up the volume of moisture that was taken for sampling purposes. From Day 148 to Day 151, 1,000 mL of leachate were recirculated to both Plan A and plan B reactors daily.

3.5.1.1 Single Pass Reactor

The application rate of moisture is 850 mL/week, corresponding to an equivalent rainfall infiltration of 12 inch per year, during all the research period.

3.5.1.2 Leachate Recycle Operation Plan A (Recycling based on leachate volume and percent methane)

The leachate recirculation volume of plan A reactor during the experiment is showed in Table 3.5.

Table 3.5 Leachate recycle operation of plan A reactor

Phase	Range of percent methane	Percent of initial moisture in system	Leachate recycle volume (mL)	Day
1	0-29.6	5	900	152-165
2	29.6	7	1200	166-171
3	29.6-39.26	15	2700	172-180
4	42.29-53.29	25	4500	181-195

3.5.1.3 Leachate Recycle Operation Plan B (Recycling based on COD mass and methane volume)

The leachate recycle operation of plan B reactor is presented in Table 3.6. From Day 152, Plan B reactor began recirculation using by the COD mass and methane volume ratio at 450, to Day 174. The leachate recirculation ratio for Plan B reactor was changed to 300 at Day 175 and Day 176. The ratio of leachate recirculation for Plan B was changed to 200 at Day 177 and Day 178. During the last operating period, Day 179 to Day 193, the recirculation ratio applied to Plan B reactor was 100.

The pH of recycled leachate was neutralized with 5N NaOH to bring the pH up to 7 prior to leachate introduction back to the reactor.

Table 3.6 Leachate recycle operation of plan B reactor

Phase	Range of percent methane	COD mass / methane volume (mg/mL)	Average daily methane production (mL)	Day
1	0-31.17	450	153.74	152-174
2	31.17	300	199.49	175
3	29.54-31.17	200	109.29	176-177
4	33.63-38.60	100	1441.80	178-195

3.6 Sludge Seeding Procedure

To initiate and enhance the rate of solid waste degradation and stabilization with methane production in each reactor system, each reactor was seeded with 1L of anaerobic digester sludge obtained from the Utility Business Alliance Co., Ltd. The seed sludge supernatant characteristics are presented in Table 3.7. This seeding procedure was initiated on the refuse loading day.

Table 3.7 Analysis of the digested sludge supernatant added to simulated landfill reactors during loading

Parameter	Analysis
Alkalinity (mg/L as $CaCO_3$)	1550
pH	7.73
Total Solids (mg/L)	1000
Total Volatile Solids (mg/L)	126

However, all reactors received anaerobic sludge four more times on Day 125, Day 142, Day 143, and Day 146 for 2000 mL, 600 mL, 600m L, and 1000 mL respectively. The characteristics of seed sludge supernatant are presented in Table 3.8. The anaerobic digester sludge seeded during operation collected from Bangkok Wastewater Treatment Plant, Dindaeng.

Table 3.8 Analysis of the digested sludge supernatant added to simulated landfill reactors during operation

Parameter	Analysis
Alkalinity (mg/L as $CaCO_3$)	720
COD (mg/L)	41600
ORP	-276.5
pH	7.43
Total Solids (mg/L)	31654
Total Volatile Solids (mg/L)	126

3.7 Sampling and Analytical Protocols

Leachate and gas in simulated landfill were produced everyday as organic waste degradation progressed under anaerobic conditions. The quality and quantity of gas and leachate varied as different phases of stabilization occurred. Therefore, to identify the phases of stabilization, monitoring for changes in parameters is required.

Leachate samples were collected from all reactors and were analyzed for Chemical Oxygen Demand (COD), pH, Oxidation-reduction Potential (ORP), orthophosphate, and ammonia nitrogen.

The daily temperature, daily gas production rate, percent methane were also observed. Detail of frequency and method of analyses are listed in Table 3.9.

Table 3.9 Method and Frequency of Simulated Landfill Leachate and Gas Parameters Analyses

Parameter	Procedure	Frequency
pH	pH Meter	Every day
ORP	ORP Meter	Every day
Gas Production	Inverted Glass Cylinder Method	Every day
COD	Standard Methods for water and wastewater Examination#4500-COD (Colormatric Method)	Every 2 days
Percent Methane	Gas chromatography	Every 3 days
Alkalinity	Standard Methods for water and wastewater Examination#2320 (Titration Method)	Every 2 weeks
Ammonia Nitrogen	Standard Methods for water and wastewater Examination#4500-NH_3	Every month
Orthophosphate	Standard Methods for water and wastewater Examination#4500-P (Vanadomolybophoric Acid Method)	Every month

Methane Percentage was determined using gas chromatograph (Agilent Technology 6890N Network GC system) equipped with thermal conductivity detector.