CHAPTER 4

RESULTS AND DISCUSSION

4.1 Reactor Experiment

4.1.1 Temperature

Temperature was in the range of 26.5 - 33.0 °C throughout the experiments and was dependent on laboratory temperature fluctuations. The ambient room temperature results are presented in Figure 4.1 and in Appendix A.

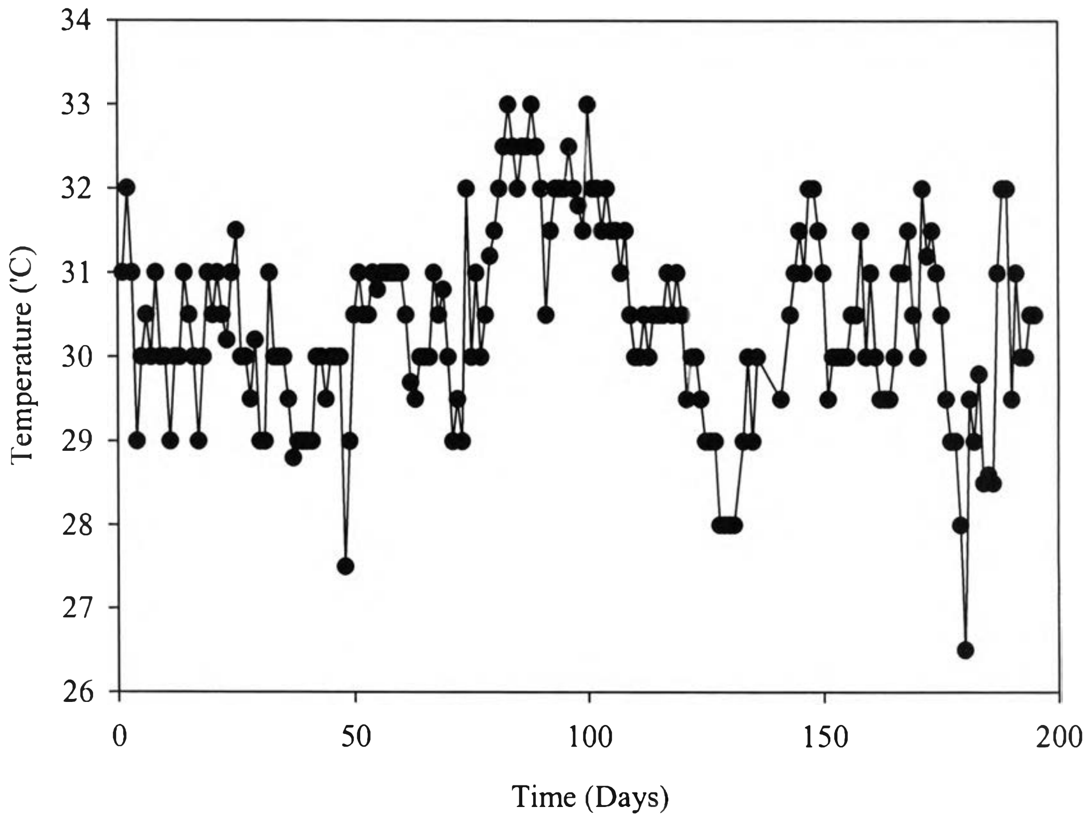

Figure 4.1 Temperature during the experiment

During the some of the experimental period, the temperature was below the optimum mesophilic range (30 - 38 °C) (Parkin, and Owen, 1982; McCarty, 1964). This has some effects on biological conversion due to the low temperature.

4.1.2 Gas Analysis

Gas Volume and percent methane from simulated landfill reactors were determined as an indication of the progress in landfill stabilization processes, and as an indicator of the rate of biological activity and organic material conversion within the landfill environment.

4.1.2.1 Gas Production

Cumulative gas volume produced in all reactors are presented in Figure 4.2, and the corresponding data are included in Appendix B, Table B-1. Daily gas volumes produced for all reactors are shown in Figure 4.3. The corresponding data are also presented in Appendix, Table B-2.

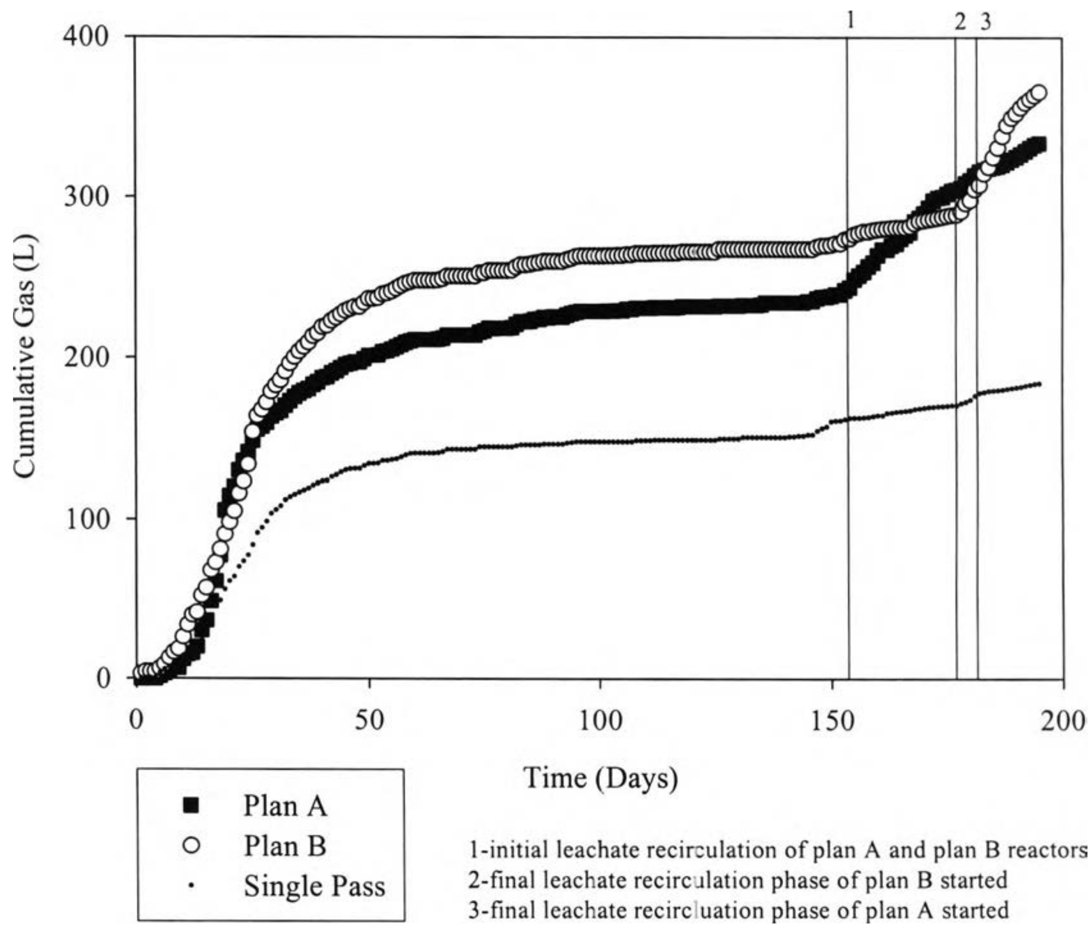

Figure 4.2 Cumulative gas production

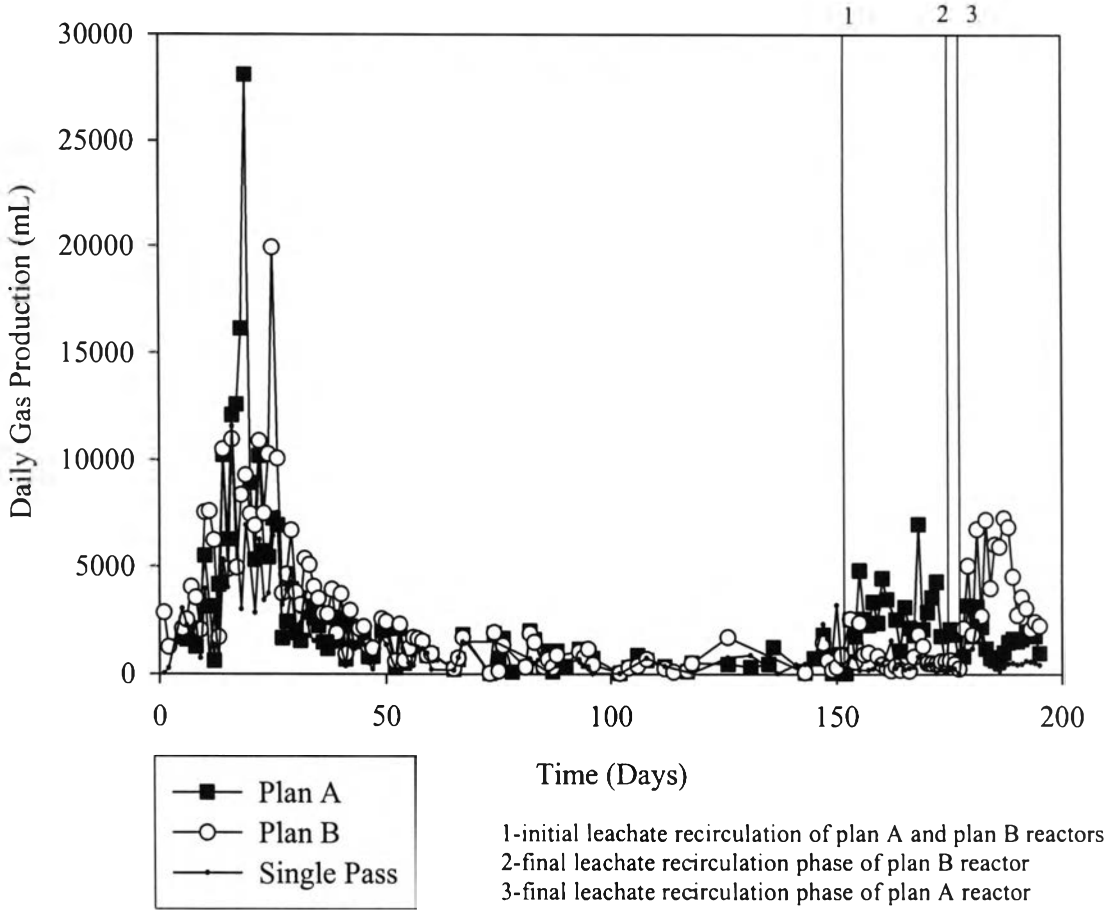

Figure 4.3 Daily gas production

The total gas production were much greater in both recycle reactors (Plan A: 333.73 L, Plan B: 365.74 L) than in the single pass reactor (184.33 L), thereby indicating that waste stabilization occurred more quickly and completely in the recycle reactors than in the single pass reactor. The greater degree of stabilization was attributed to the leachate recycle technique practiced, since the volatile organic acids, a principal substrate for methanogens, were removed by leachate wasting in the single pass column, but were contained and utilized in the recycles column. Hence, methanogens in the recycle reactor experienced an increased contact opportunity with the substrate due to leachate recirculation.

Gas production rates for the first 50 days were high due to the aerobic reaction in all reactors. Consequently, from Day 51 to Day 141, the gas production rates were stable since there was no liquid addition during that period. From Day 142, the gas production rates in all reactors were significantly increased, due to the addition of the sludge.

After the replacement of gas collection system and recycle started on Day 148, the large volume of gas production was observed in all reactors. This was likely because liquid, which was a substrate distribution medium, became more uniformly distributed and more available for microbial utilization after recirculation.

Changes in recycle phase to final phase of Plan B reactor from Day 179 reflected the gas volume produced in the Plan B reactor to be as high as 5 L/day and remained in the range of 1.8 to 7.2 liters toward Day 195. This was because the plan B was more responsive to the condition of reactor than the other recycle reactor.

The gas production rate of single pass reactor was low. The volumes of landfill gas produced did not exceed 3 L. Low volume of landfill gas generated in the single pass column was directly associated with less contact opportunity between substrate and methanogens offered by the liquid management technique, washout of essential nutrients, and less homogeneous moisture distribution.

4.1.2.2 Methane Production

Methane percentages for all reactors are presented in Figure 4.4. Corresponding data are also included in Table B-3 of Appendix B. Cumulative methane volume produced in all reactors are presented in Figure 4.5, and the corresponding data are included in Appendix B, Table B-4.

The data of methane percentages were available since Day 148 due to the availability of the GC-TCD. However, results from Day 148 were low indicating a leak in systems. As a consequence, the gas collection systems were replaced to make the system gas tight.

Since data on methane analysis was available starting on Day 148, this day was the first day of cumulative methane calculation. Dramatic changes in the methane percentages from Day 153 indicated the replacement of gas collection system were successful. This showed that methanogenic condition was established.

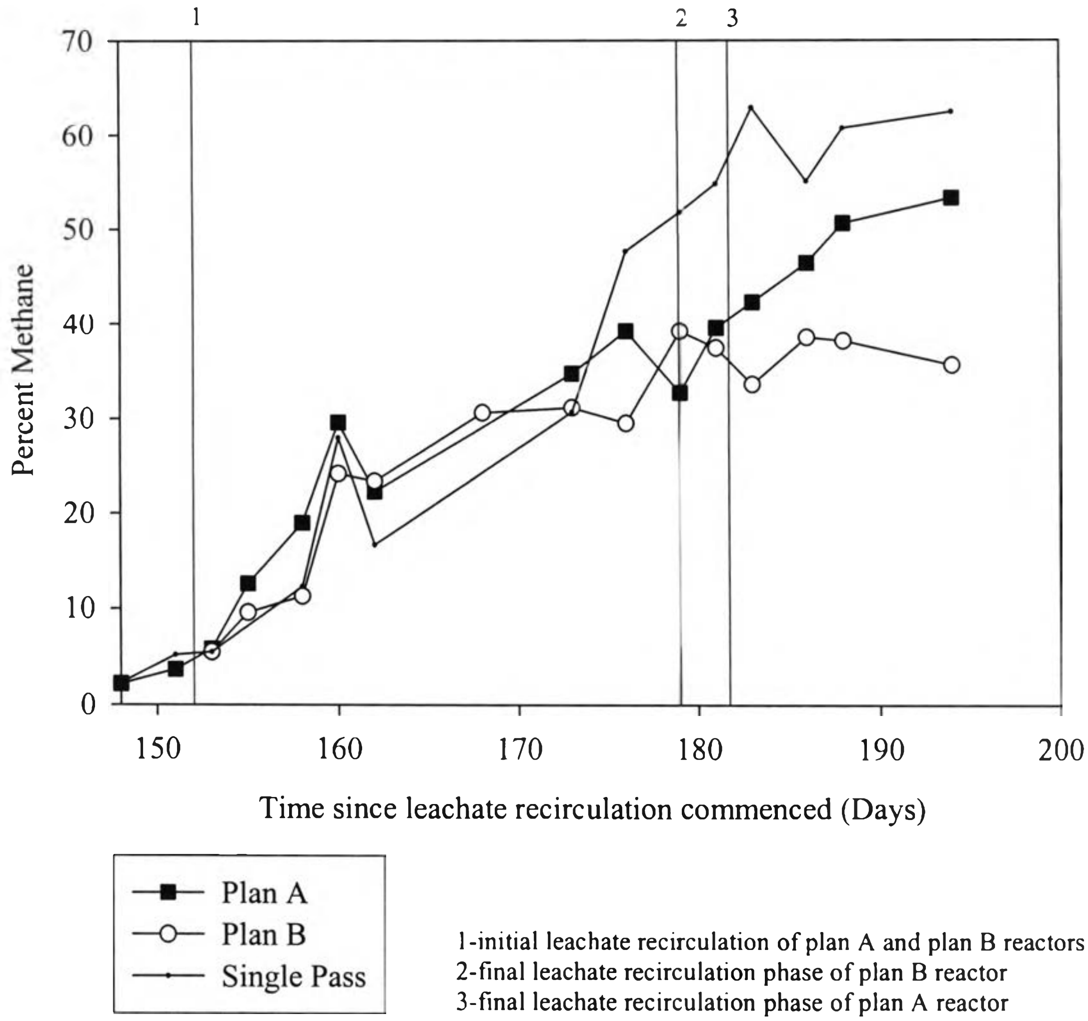

Figure 4.4 Methane percentages

Results of methane percentages of the single pass reactor were the highest compared to the other two reactors. The lower m ethane percentages in Plan A and Plan B reactors mainly attributed to the intrusion of atmospheric air during the drainage of leachate to recirculated back to reactors. Since the amount of leachate drained out were high as 4.5 L/Day for Plan A reactor and in range of 3 to 8.5 L/Day for Plan B reactor. This showed some degree of methanogenic inhibition due to the recycling of leachate.

Cumulative methane production of plan B reactor showed the highest volume of methane compared to other two reactors, indicating the flexibility of this leachate management scheme. From Day 148, the last operation phase of plan B showed the efficiency of methane production. The daily methane production of plan B reactor dramatically increased, as showed in Figure 4.5, due to the quick response to the inputs of the day before.

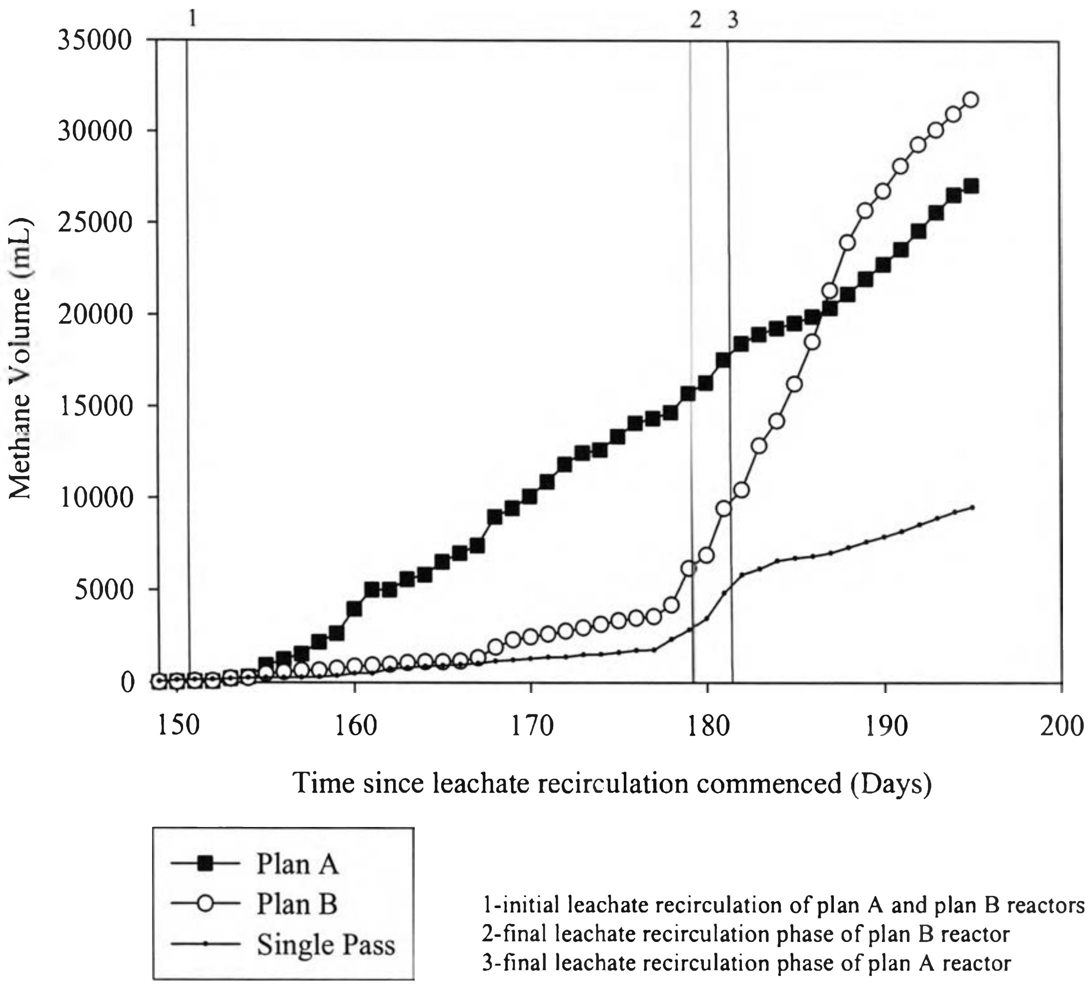

Figure 4.5 Cumulative methane production

4.1.3 Leachate Analyses

Leachate parameters analyzed and presented herein were utilized for investigation of the progression of landfill stabilization processes, especially the degree or age of waste stabilization taking place in the simulated landfill reactors.

4.1.3.1 pH

The pH of an anaerobic system is a function of the existing buffer system and component species ionization. The predominant pH is dependent upon interaction between volatile organic acids, alkalinity, and partial pressure of evolving carbon dioxide gas. In the Acid Formation phase of landfill stabilization pH values are normally low due to the presence of volatile organic acids and their buffering effects on system pH. When the available VOA are converted to methane and carbon dioxide during the Methane Fermentation phase, pH usually rises to values characteristics of the bicarbonate buffering system, and may continue to rise with excess ammonia generation. The pH of leachate from all reactors are presented in Figure 4.6. Corresponding data are also included in Appendix C, Table C-1.

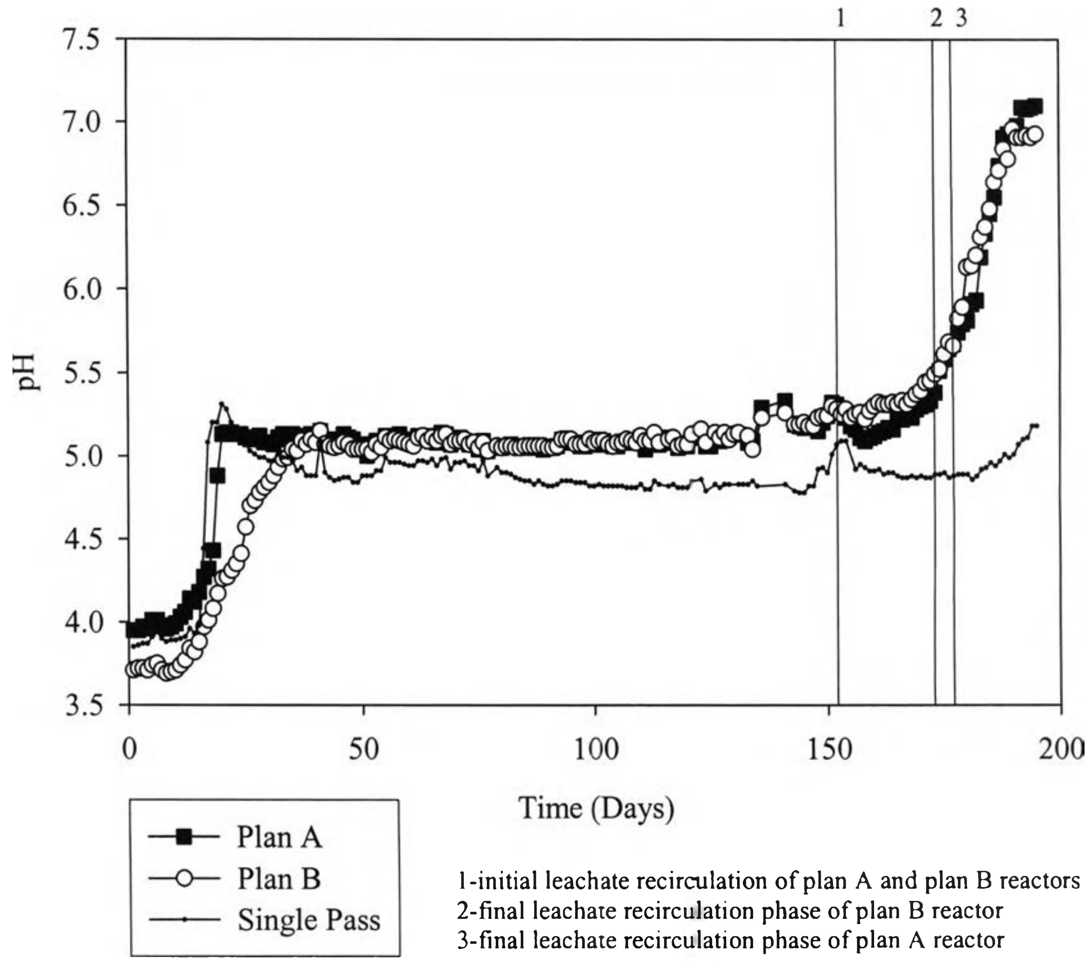

Figure 4.6 pH of leachate

Leachate pH of all reactors during the first 50 days exhibited the similar increase from 3.95, 3.71, and 3.85 to 5.07, 5.04, and 4.88 for Plan A reactor, Plan B reactor, and single pass reactor, respectively. Consequently, leachate pH were stable during Day 51 to Day 142. This showed the methanogenic did not establish in all reactors. Therefore, sludge supernatant was applied to all reactors to enhance the organic waste stabilization. This resulted the slightly increase in pH values of leachate in all reactors.

Since Day 153, the recirculation were commenced in both recycle reactors. Since the pH for both recycle columns was still not favorable for the development of a viable methanogenic population, an attempt then was made to increase the pH of recycled leachate to 7. This resulted in a rapid increase in pH of leachate collected. The pH during the final phase of recirculation was beneficial for development of microbial population responsible for waste stabilization as supported by an abrupt increase in methane percentages and gas generation rates from both recycle reactors. This also emphasized the importance of maintaining pH near neutrality in enhancing waste transformation in anaerobic waste treatment processes.

In contrast to both recycle columns, the pH of the single pass reactor was relatively steady at about 5.

4.1.3.2 Chemical Oxygen Demand (COD)

Leachate chemical oxygen demand (COD) was measured as an indicator of organic strength. The COD data of leachate from all reactors are presented in Figure 4.7, and the corresponding data are included in Table C-2 of Appendix C.

The leachate COD values in all reactors were fluctuating. However, in single pass reactor, leachate COD values from Day 43 to Day 58 were significantly decreased from 54,134 to 20,886 mg/L. Moreover, the leachate COD values in single pass reactor remained lower than those other reactors throughout the experiment. This was the effect from leachate drained out during Day 0, Day 32, Day 53, and Day 74 about 16 L. This indicated the leachate was discarded and the organic constituents contained did not undergo extensive transformations. Consequently, the COD strength of single pass reactor were stable during the last period from Day 58 (20,886 mg/L) to Day 189 (14,739 mg/L).

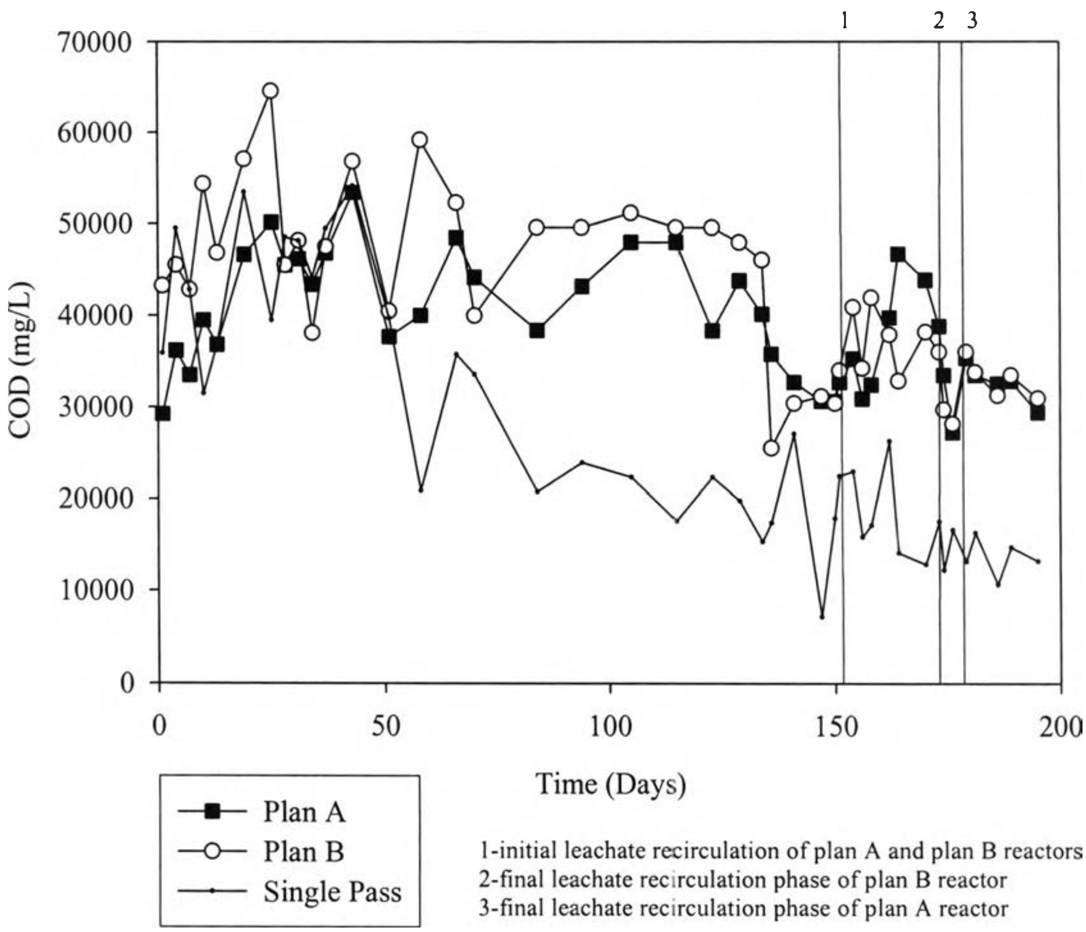

Figure 4.7 Chemical oxygen demand of leachate

Results of COD leachate analysis before starting recirculation from both recycle reactors were similar suggested that the waste used and leachate management to both reactors was similar.

Gradual increases in COD for both recycle reactors during the period from Day 148 to Day 170 reflected the effects of leachate recirculation. Chemical oxygen demand in the leachate from both recycle reactors during the last phase of recirculation showed the effect of the high rate of leachate recirculation, which was displayed in terms of decline in COD concentrations from 46,726 and 41,984 to 29,491 and 31,027 mg/L for Plan A and Plan B reactors, respectively. Furthermore, the importance of maintaining pH in the range beneficial to methanogens for biological organic wastes conversion was also emphasized.

4.1.3.3 Oxidation-Reduction Potential

Oxidation-reduction potential (ORP) was measured to indicate the oxidizing or reducing conditions prevailing in the simulated landfill columns. Measured ORP values are presented in Figure 4.8. In addition, supporting data are included in Table C-3 of Appendix C.

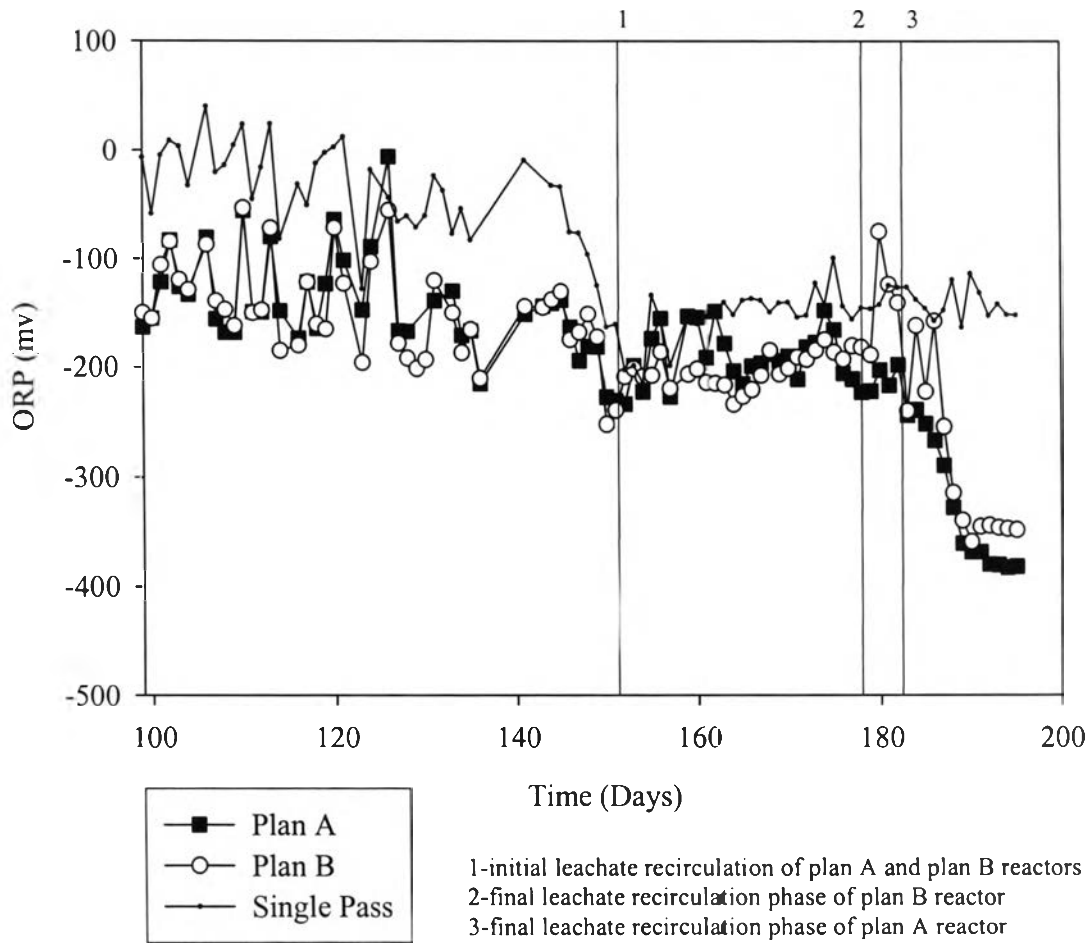

Figure 4.8 Oxidation-reduction potential of leachate

The Oxidation-reduction potential started on Day 99 due to the available of the instrument. The Oxidation-reduction potential of both recycle reactors were lower than those of the single pass reactor in the period of Day 100 to Day 150. This reflected the volume of leachate that leached from single pass reactor since the leachate discarded and the organic constituents contained were not enough for anaerobic bacteria. In addition, in single pass reactor 850 mL of DI water was added weekly to make up the rainfall. This may affect the ORP values in single pass reactor.

From Day 142, the Oxidation-reduction potential in all reactors began to be more negative since the sludge supernatant was applied. In the period of Day 180 to Day 195, ORP values of both recycle reactors were significantly negative due to the last phase of leachate recirculation that supplied the sufficient amount of volatile organic acids to methanogenics. Whereas, the ORP values of the single pass reactor were still less negative throughout the observation period.

4.1.3.4 Ammonia Nitrogen

Ammonia nitrogen is a readily available form for microbial utilization of nitrogen, and is produced from decomposition of organic materials containing nitrogen. Ammonium ion was predominantly present within the pH ranges observed in the experiment. This form of ammonia was known to be less toxic than ammonia gas producing at higher pH. Measurement of ammonia was performed to assess nutrient availability in all reactors. The results of analyses are expresses in mg/L of nitrogen and are presented in Figure 4.9, with corresponding data included in Table C-4 of Appendix C.

The ammonia nitrogen in both recycle reactors were found to be similar in concentrations, suggesting uniformity in refuse composition, and similar leachate recirculation scheme. The ammonia nitrogen in the single pass reactor was low as a consequence of washout.

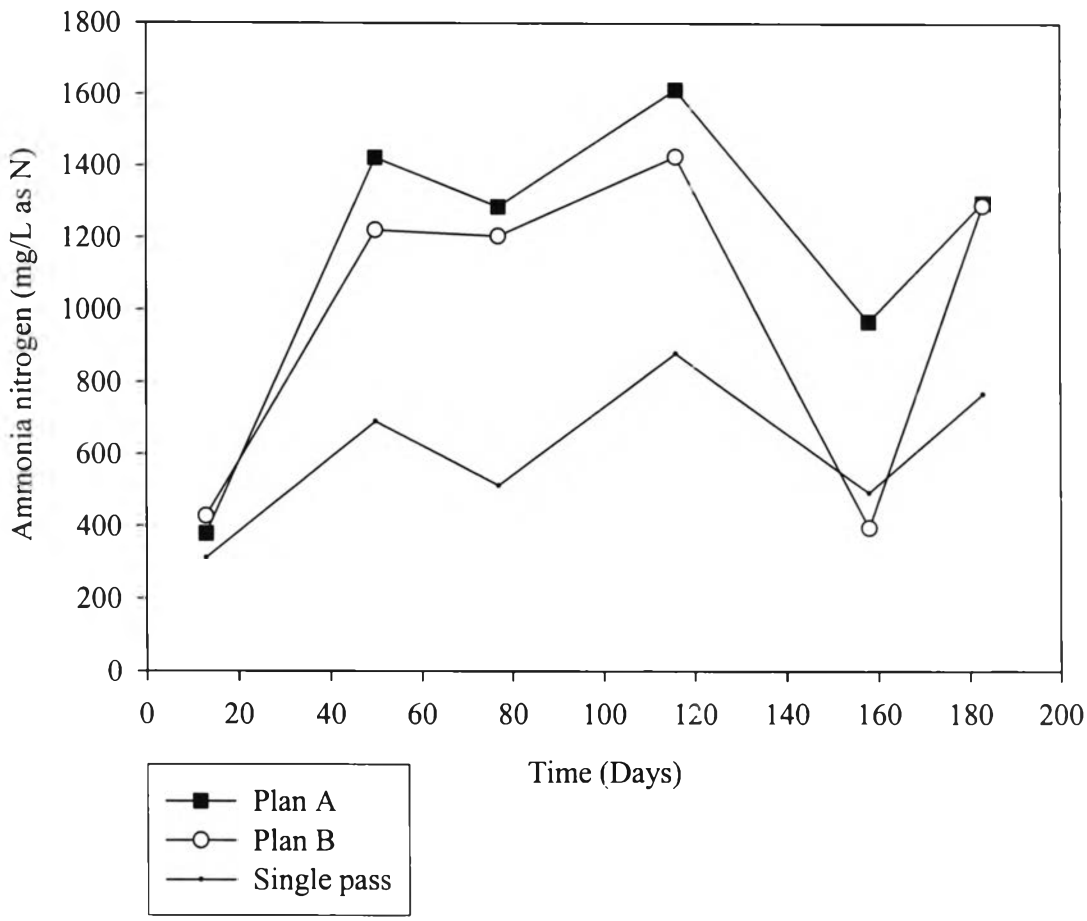

Figure 4.9 Ammonia nitrogen of leachate

4.1.3.5 Orthophosphate

Orthophosphate was measured an as indication of phosphorus availability to anaerobic microbial utilization. Orthophosphate data from the single pass and recycle reactors are expressed in mg/L of phosphorus and are presented in Figure 4.10 with supporting data given in Table C-5 of Appendix C.

Orthophosphate in single pass reactor was observed to decrease with time. This behavior was in conformity with an extensive use of phosphorus during the Methane Formation phase by methanogens and its possible precipitation. In both recycle reactors, after leachate recycle were commenced, orthophosphate were significantly increased. However, the phosphorus concentrations throughout the course of experiments were sufficient for sustenance of microbial population development in all reactor systems.

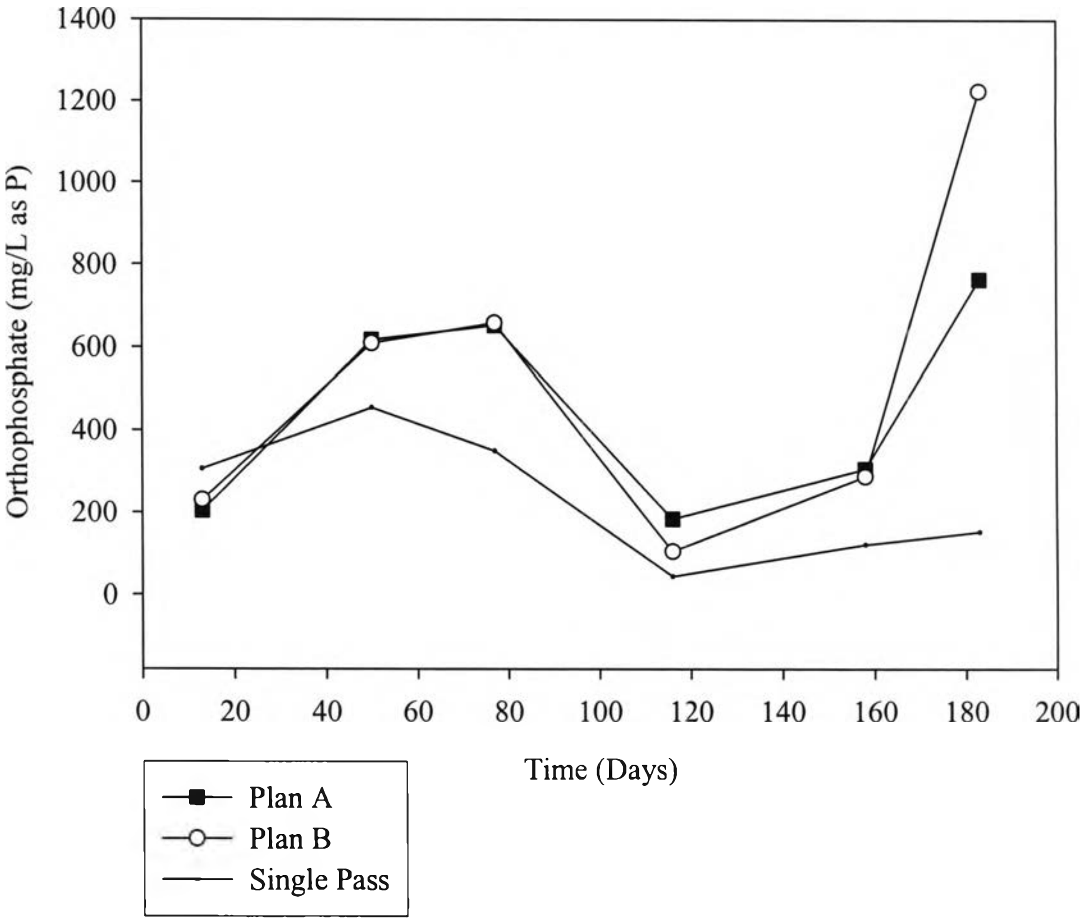

Figure 4.10 Orthophosphate of leachate

4.2 Comparison of Leachate Recirculation between Plan A Reactor and Plan B Reactor

In theory, the plan B operation would have more controllable performance in landfill stabilization, since the mass balance for input (food) and output (gas) principle was used in Plan B. However, in practicality, the plan A operation is easier to operate in the field scale landfill because it is easier to measure input (leachate recirculation volume) and output (gas production volume or percent methane). Therefore, the comparison between results of Plan A and Plan B in terms of gas quality (methane percentages) and quantity (daily and cumulative gas production) were done to find out the relationship between these two operations. The analytical result would have tremendous benefits for instance; increase the landfill stabilization performance and gas production, and measures in full scale landfill.

4.2.1 Daily Methane Production

The volume of moisture present in both recycle reactors had effects on bacteria in the system, since most physical and biochemical reactions occur in liquid phase or at the interface between phases. Liquid also serves as a transport medium for microorganisms and substrate, providing contact opportunity for reactions to proceed. Sufficient moisture content is critical for rapid stabilization within landfills. Data and computation for moisture available are presented in Table D-1 of Appendix D.

Computations for the moisture present were based on volume of liquid originally present, the introduced liquid, and the liquid lost from the systems. The volume of leachate recycle for plan A reactor was in Table 3.2 and plan B reactor in Table 3.3. Plan A and plan B reactors initially contained 18,540 and 18508 mL of liquid. By the end of the experiment, Plan A and Plan B reactor had 22,296 and 21,199 mL of liquid, respectively.

The volume of leachate recycle, daily methane production, and COD loading for Plan A and Plan B reactors are presented in Figures 4.11 and 4.12, respectively. Corresponding data included in Table D-2 of Appendix D.

Leachate recycle volume and daily methane production of plan B reactor had direct relationship since the amount of leachate recycled are adjusted according to the daily volume of methane production of the day before. This scheme of leachate recycle showed larger amount of methane gas production compared to plan A reactor in the final stage of leachate recirculation as showed in Figure 4.5.

However, the COD mass over methane volume ratio of plan B during the experiment was adjusted from proposal in Table 3.3 due to changing in the reactor conditions. The COD mass over methane volume ratio of plan B reactor actually used is presented in Figure 4.13 and Table 3.6. The experimental results showed the effect of this ratio to the daily methane gas production. Comparing the early phase with the last phase, daily methane production was significantly different, 109.29 to 199.49 mL at phase 1-3 with 1,441.80 mL at the last phase.

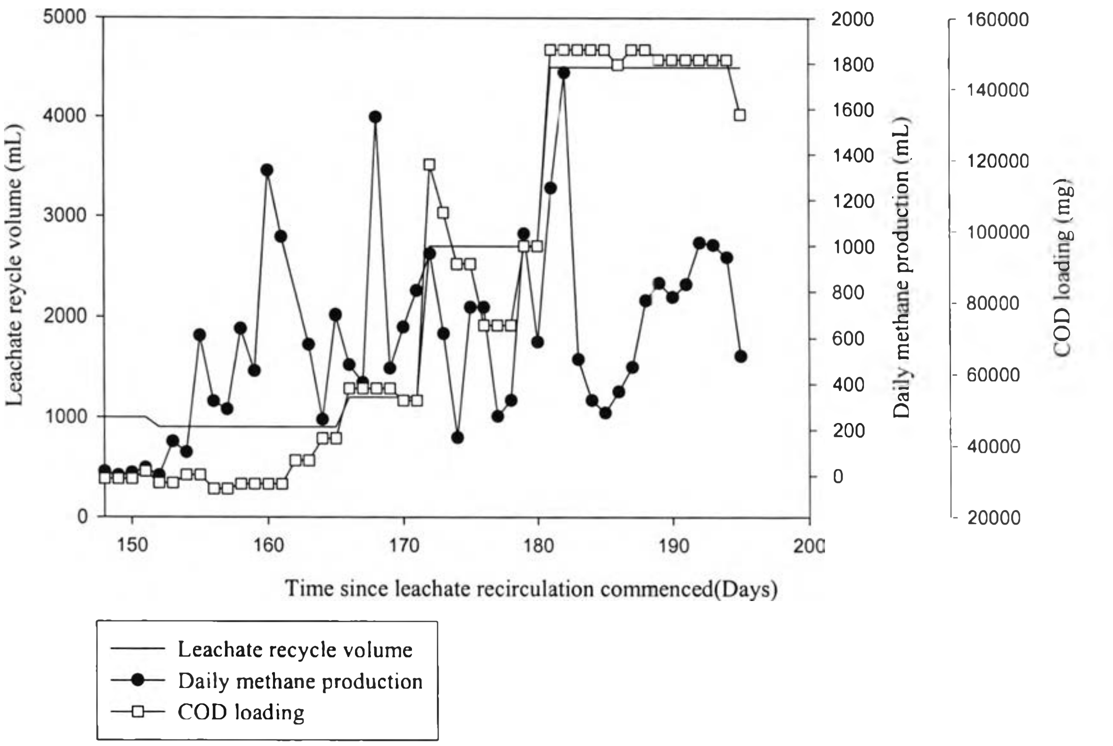

Figure 4.11 Leachate recycle volume, daily methane production, and COD loading of Plan A Reactor

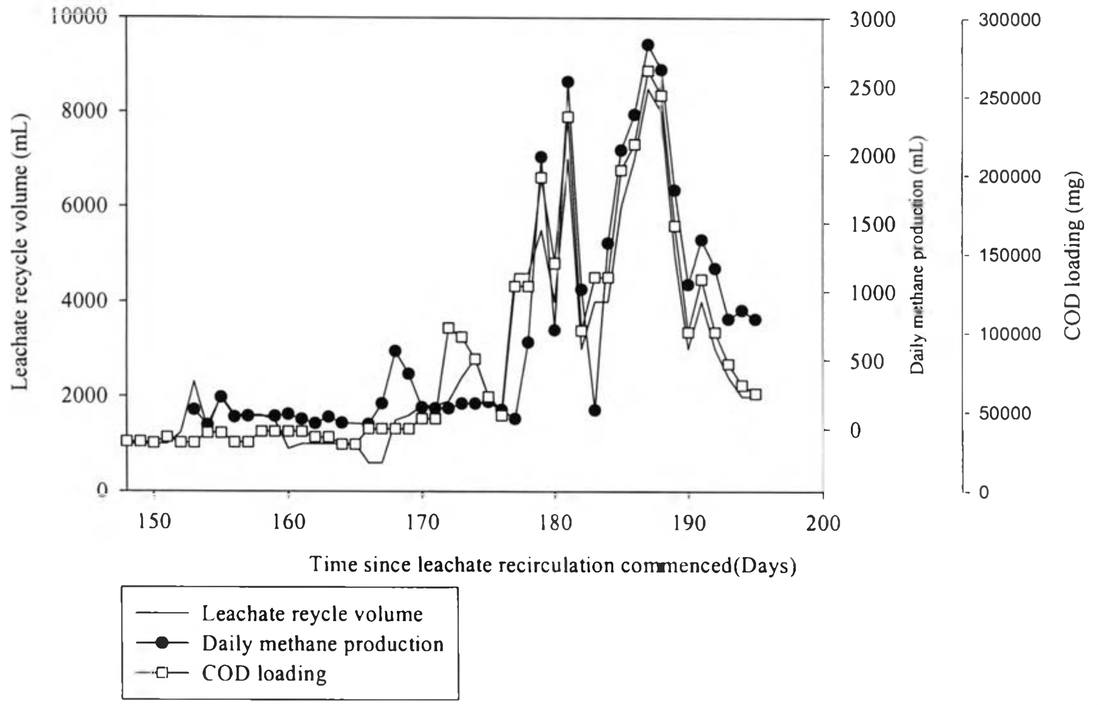

Figure 4.12 Leachate recycle volume, daily methane production, and COD loading of Plan B Reactor

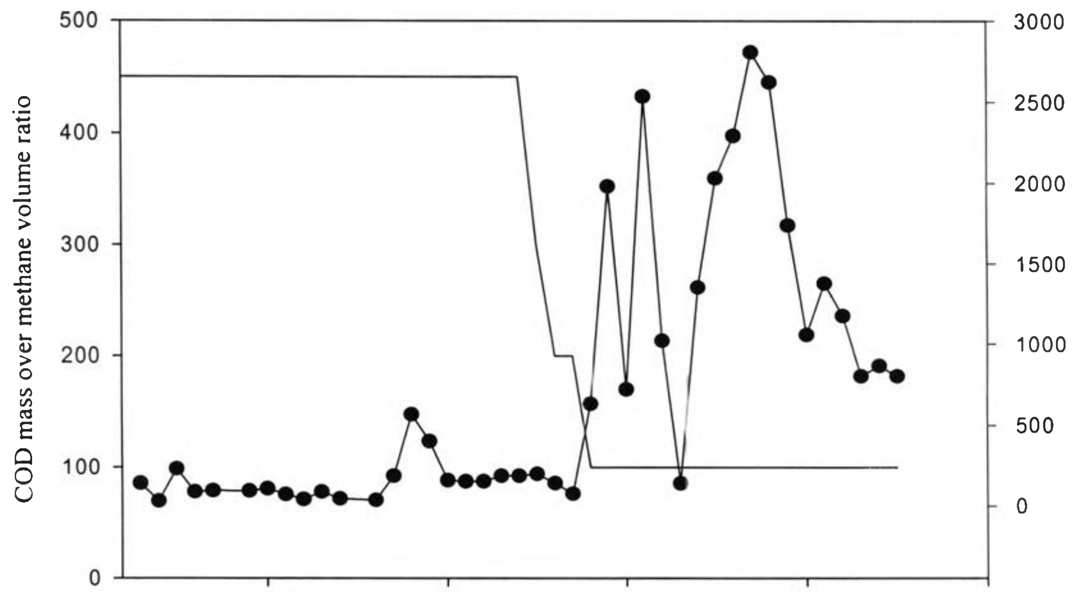

Figure 4.13 COD mass over methane volume ratio of plan B reactor

4.2.2 Leachate Recycle

The volume of leachate recycle and the COD leachate recycle loading for Plan A and Plan B reactors are presented in Figure 4.14 and 4.15, respectively.

Plan A leachate recycle scheme was set up in a stair step manner. The volume of leachate recycle were 900 mL at first phase, 1,200 mL at second phase, 2,700 mL at third phase, and 4,500 mL at the final phase. While plan B leachate recycle scheme was set up to adjust to the system response of the previous days, therefore, the leachate recycle were varied from 1,000 mL to 8,500 mL.

The COD leachate recycle loading showed the amount of COD mass that recycled back to the reactors each day. Comparing COD leachate recycle loading between plan A and plan B reactors, plan A showed more stable in COD loading each day while plan B showed more fluctuating in COD loading values. This is because the COD leachate recycle loading depends on the volume and COD of leachate recirculation.

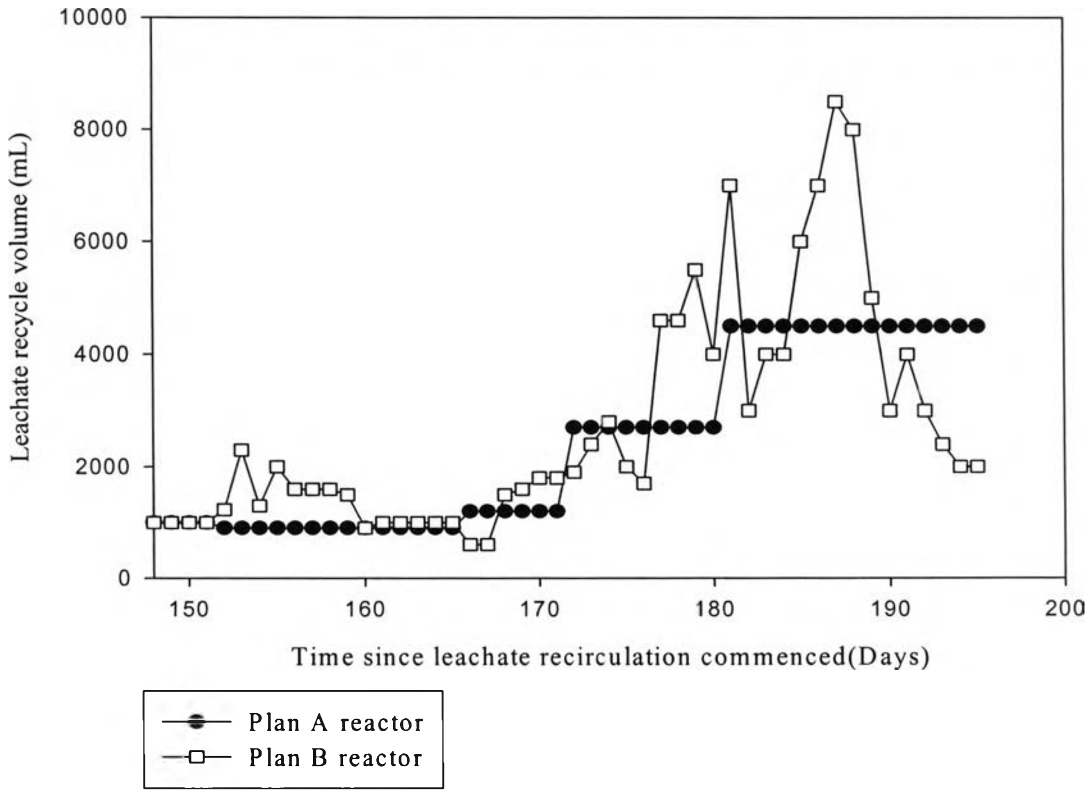

Figure 4.14 Leachate recycle volume

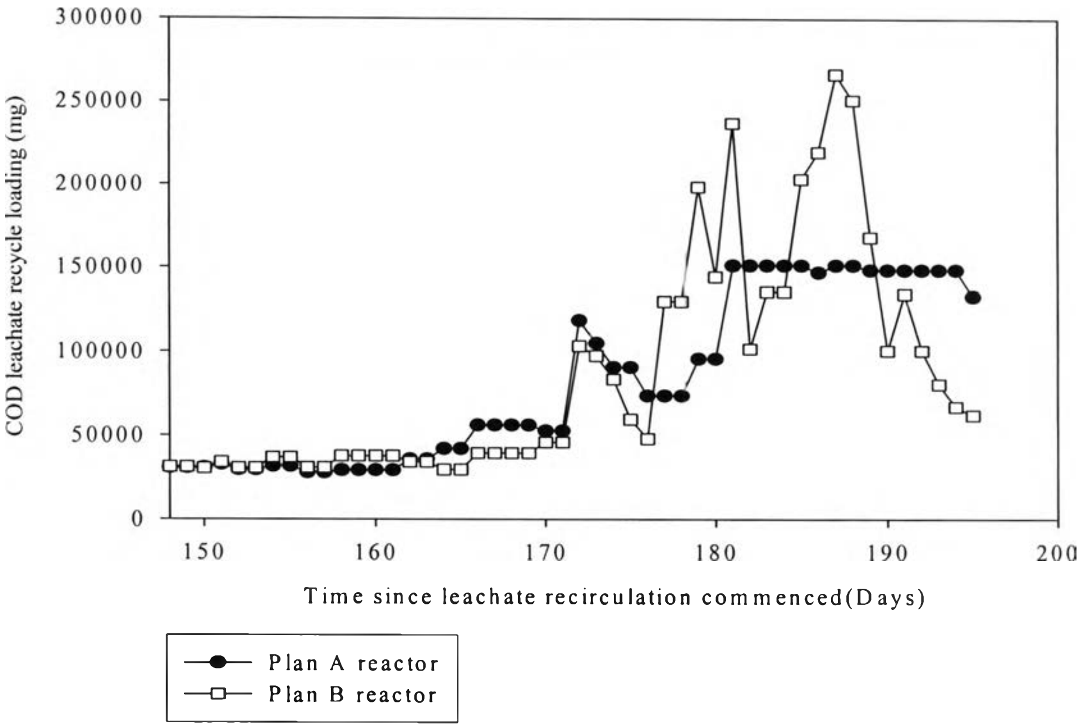

Figure 4.15 COD leachate recycle loading

4.2.3 Discussions

Comparing percent methane result of plan A and plan B reactors from Figure 4.4, the normalized methane percentage of plan B reactor was lower than plan A reactor. However, this did not mean that the plan B leachate recycle scheme inhibited the methane gas production. As the cumulative methane production from Figure 4.5 showed that more methane gas was produced from the plan B reactor.

The reason might be that the microorganisms in plan B reactor received more appropriate amount of leachate. This showed that plan B scheme was more robust to the situation of simulated landfill by adjusting leachate recycle volume accordingly.

Both plan A and plan reactors showed comparable efficiency in COD reduction. Since plan B reactor showed more efficiency in methane gas production, it is recommended that in landfill for biogas production purpose plan B should be used to manage its leachate. On the other hand, since the COD reduction efficiency of plan A and plan B reactors is comparable, plan A leachate recirculation scheme is recommended to landfill for leachate COD reduction purpose.