Improvement of Waste Decomposition in Leachate Recirculation Simulated Landfill by High Water Addition

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Abstract: A considerable amount of research has been conducted to demonstrate the development of bioreactor landfills promoted by leachate recirculation [1-10]. The effectiveness of leachate recirculation has been well documented in lysimeter studies [1, 5, 11, 12], test cell studies [2, 13, 14-16] and full-scale studies [17-20]. However, the results from these investigations might not be applied appropriately to Thailand due to the difference of waste type and composition. There are still small basic information regarding to the bioreactor improvement by high water addition and a few researches have been done in Thailand. Therefore, this investigation focuses on the improvement of leachate recirculation simulated landfill by high water addition, which help to improve the landfill not only on waste decomposition that aims to overcome the inert state of a landfill in a short time but also on leachate treatment and energy conversion as well.

Keywords: Anaerobic digestion, High water addition, Leachate recirculation, Municipal solid waste

Introduction

Current municipal solid waste (MSW) landfill technology in Thailand is based on a dry concept, which minimizes the water entering the waste sealed in order to prevent the formation of leachate and landfill gases so as to reduce environmental impact. This approach tends to delay the waste decomposition due to the lack of moisture and risk for long-term environmental impacts when the waste seal becomes less effective. The bioreactor concept, in contrast to the dry landfill cell, is becoming more widely accepted because it focuses on enhancing the degradation processes and methane production.

Also it offers the potential to avoid the long-term environmental risks associated with the dry landfill cell approach.

A considerable amount of research has been conducted to demonstrate the development of bioreactor landfills promoted by leachate recirculation (Pohland, 1975; Leckie *et al.*, 1979; Pohland, 1980; Buivid *et al.*, 1981; Tittlebaum, 1982; Pohland *et al.*, 1985; Malta-Alvarez and Matinez-Viturtia, 1986; Beker, 1987; Barlaz *et al.* 1989a and 1989b). The effectiveness of leachate recirculation has been well documented in lysimeter studies (Pohland, 1975; Tittlebaum, 1982; Otieno, 1989; Pohland *et al.*, 1992), test cell studies (Leckie *et al.,* 1979*;* Wehran Engineering, P.C. and Dynatech Scientific Incorporation, 1987; Halvadakis *et al.*, 1988; Campbell, 1991; Lechner *et al.*, 1993) and full-scale studies (Natale and Anderson, 1985; Robinson and Maris, 1985; Doedens and Cord-Landwher, 1989; Watson, 1993). However, the results from these investigations might not be applied appropriately to Thailand due to the difference of waste type and composition. There is still little basic information regarding the bioreactor improvement by high water addition and same research has been done in Thailand. Therefore, this investigation focuses on the improvement of leachate recirculation simulated landfill by high water addition, which helps to improve the landfill, not only on waste decomposition that aims to overcome the inert state of a landfill in a short time, but also on leachate treatment and energy conversion as well.

Materials and Methods

1. Reactor Preparation.

The study was conducted by constructing 2 simulated landfill reactors, which were built using opaque PVC. The diameter and height in each case was 0.30 and 1.25 m., respectively. A leachate collection PVC pipe with a diameter of ½ inch was installed at the center of the bottom of the reactor and used for collecting leachate into a transparent container and leachate sampling port. The tap water addition port was installed at the top of the reactor where the leachate distribution pipe was joined as the access of the water at the equivalence volume annual precipitation. The gas sampling port, with a diameter of ½ inch PVC pipe, was installed at the top lid of the reactor, located 0.10 m away from the center, and the end of the pipe was capped by a rubber septum. The other port was joined to a silicone tube that was connected to a gas meter. All ports and lids were checked for leakage by using a soap solution before the waste loading. The simulated landfill reactors were constructed with the configuration as presented in Figure. 1.

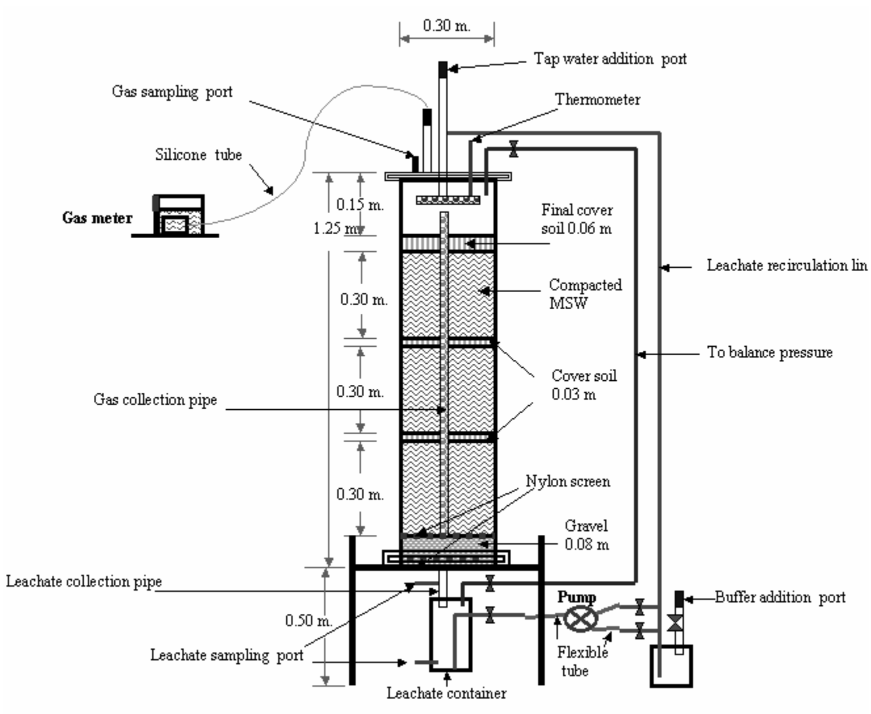


Figure 1. Simulated landfill reactor.

2. Municipal Solid Waste (MSW) Preparation.

The MSW was collected from Nongkham transfer station, Bangkok, Thailand. The bulky wastes and the portion that could be recycled were removed. Big size plastic and paper were torn then mixed by backhoe to maximize the homogeneity of wastes. About 1 000 kilograms of MSW were obtained and then sampled by the quartering method. The result of MSW composition showed that the major constituent was 50.46% garbage. The others were 16.28% paper, 13.02% trimmings from gardens and 11.39% plastic & foam and the least constituents being 0.14% leather & rubber. The moisture content of MSW was 70.28% and the C/N ratio was 21.79.

3. Solid Wastes Loading.

Before the process of solid waste loading was commenced, a circular nylon screen with 1-mm diameter holes and a 0.08-m depth layer of 1-inch diameter gravel was placed at the bottom of each reactor and then a circular nylon screen was placed on the gravel layer again as the basement, to prevent clogging of the reactor. During loading, the MSW was manually compacted and then covered with soil. Finally, a rubber gasket was placed on an acrylic flange prior to the top lid, tightened using knots, and sealed with silicone rubber to make them gas tight. Typically, the density of compacted MSW was 500-700 kg/m^3 (Tchobanoglous *et al*., 1993). This investigation, the density of compacted MSW, was operated at 600 kg/m^3 and compacted soil at 1 300 kg/m^3. The quantity of MSW and soil used in each reactor are presented in Table 1.

Table 1. The quantity of MSW and soil used in each reactor.

Material loading	Volume/lift (liter)	Density/lift (kg/m^3)	Weight/ lift (kg)	Total Weight/ reactor (kg)	Total Volume/ reactor (liter)
MSW	21.20	600	12.72	38.15	63.60
Gravel	5.65				5.65
Bottom layer soil	2.12	1 300	2.76	2.76	2.12
Medium layer soil	2.12	1 300	2.76	2.76	2.12
Top layer soil	4.24	1 300	5.51	5.51	4.24
Head space	10.60				10.60
Total				49.17	88.33

4. Experimental Design and Operation.

In this study, two reactors with leachate recirculation were employed. One reactor was operated as a control reactor –RC (without high water addition) while the other served as experimental reactor –R1 (with high water addition). This study was divided into two steps, the first step was a comparison of the results between the operation with and without high water addition. Started from day 73 to day 105, the water was added into R1 with the amount 37.5 l, which was 6.25 times or 84% higher than RC. To operate the simulated landfill reactors as bioreactor, the leachate was recirculated along with sodium bicarbonate ($NaHCO_3$) addition on day 203, when the leachate concentrations from both reactors showed steady values. The recirculation rate commenced at 5% waste volume and then the recirculation rate was increased, however, it was difficult to recirculate with the same rate between two reactors because of the variation of leachate quantity from the reactors. This step was carried out until the waste was stabilized (day 330). The second step was to study the loading capacity of landfill leachate in order to investigate the performance of the reactors and to improve the operating of landfills. The leachate from fresh waste was introduced into the reactors and increased organic loading rate (OLR) stepped at 3, 4 and 5 kg/m^3-day from day 330 to day 360. The operated data at the first step and the second step are presented in Table 2 and Table 3, respectively.

Table 2. The operated data for the leachate recirculation simulated landfill reactor with (R1) and without (RC) high water addition from day 203 to day 304.

	Operation		Day 203	Day 231	Day 251	Day 258	Day 281	Day 304
RC	Leachate COD	(kg/m^3)	22.33	11.77	18.68	12.91	5.23	4.62
	Flow	(m^3/d)	0.003	0.003	0.005	0.005	0.008	0.007
		(% waste vol.)	(5%)	(5%)	(8%)	(7%)	(12%)	(11%)
	COD Loading	(kg COD/d)	0.071	0.038	0.093	0.058	0.042	0.032
	OLR	($kgCOD/m^3$-d)	1.117	0.589	1.459	0.908	0.654	0.505
	HRT	(day)	20.0	20.0	12.8	14.2	8.0	9.1
R1	Leachate COD	(kg/m^3)	1.19	4.91	17.4	15.6	1.06	0.96
	Flow	(m^3/d)	0.003	0.006	0.007	0.010	0.008	0.008
		(% waste vol.)	(5%)	(10%)	(11%)	(15%)	(12.5%)	(12.5%)
	COD Loading	(kg COD/d)	0.004	0.031	0.122	0.148	0.008	0.008
	OLR	($kgCOD/m^3$-d)	0.059	0.491	1.903	2.316	0.133	0.12
	HRT	(day)	20.0	10.0	9.1	6.7	8.0	8.0

Table 3. The operated data for the 2 simulated landfill reactors from day 330 to day 351.

Leachate		Day 330	Day 339	Day 344	Day 351
Leachate COD	(kg/m^3)	5.00	31.81	25.21	25.21
Flow	(m^3/d)	0.006	0.006	0.010	0.013
	(% waste vol.)	(10%)	(9.5%)	(16%)	(20%)
COD Loading	(kg COD/d)	0.032	0.194	0.257	0.320
OLR	($kgCOD/m^3$-d)	0.500	3.032	4.018	5.003
HRT	(day)	10.0	10.5	6.3	5.0

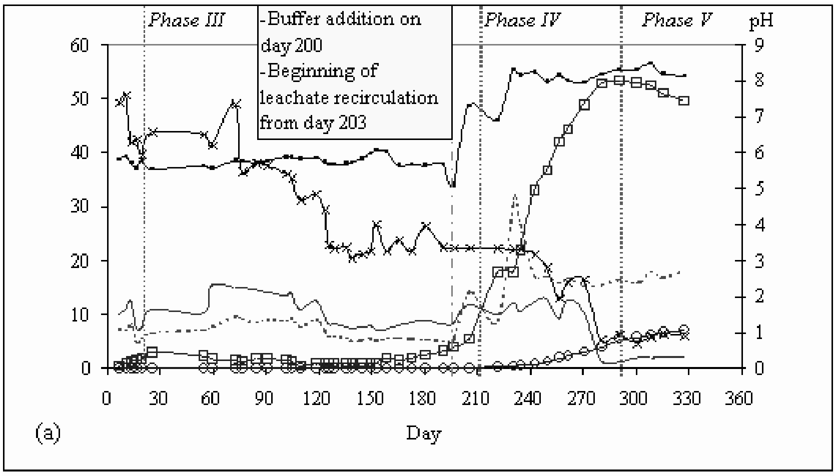
5. Laboratory Analysis.

Gas volume in the reactor was measured by a gas meter and then gas composition was analyzed by gas chromatography (Shimadzu model GC 9A) using a Porapak Q column (2m, 80/100 mesh) and a Thermal Conductivity Detector (TCD). The leachate volume collected at the bottom of each reactor was quantified and sampled. Leachate quality was analyzed for pH, Alkalinity, TVA and COD by standard methods [21].

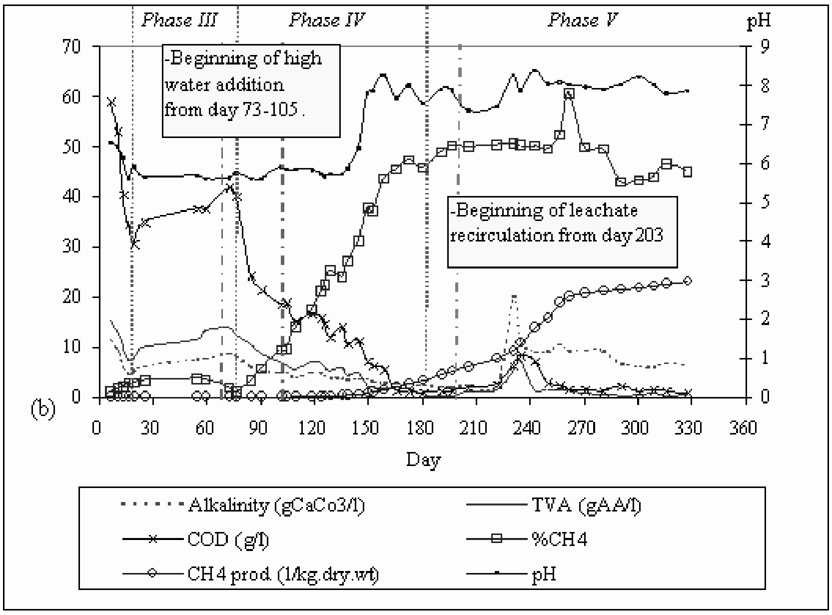
Results and Discussion

1. Leachate Recirculation with High Water Addition.

RC provided accumulative methane production of 17.04 l/kg.dry.wt with the rate of 0.143 l/kg.dry.wt-d and reached the stabilization phase on day 290 (Figure 2a) whereas R1 , with higher performance, provided accumulative methane production of 54.87 l/kg.dry.wt with the rate of 0.584 l/kg.dry.wt-d and reached the stabilization phase since day 180 (Figure 2b). It is suggested that the high water quantity added to the reactor helped to flush inhibitory substances and provided the sufficient natural buffer capacity to overcome the acid phase and lead to methanogenesis phase, resulting in the waste decomposition of R1 entering into the methanogenesis phase earlier than RC. In addition, the high water addition in R1 helped to promote the proper conditions for methanogens, hence rapid access to the methanogenesis phase occurred. These results concured with the observations of Kinman *et al.* (1987) that a high rate of infiltration or water addition accelerates waste decomposition rates but not the ultimate methane yield and Kasali *et al.* (1990) who found that water addition helped to improve the acidogenesis phase. At stabilization phase of R1, considering the substrates for methanogens such as COD and TVA concentration in the leachate, it was found that the exhaustion of these substrates occurred on day 180 (the remaining COD was 0.88 g/l and TVA was 37.5 gAA/l), which is before the leachate recirculation commenced. This indicated the effects of leachate recirculation that promoted high methane production despite waste decomposition reaching the stabilization phase. It suggested that the available nutrients and substrates were carried into the system by leachate recirculation. Moreover, the greater degree of stabilization of R1 than RC was attributed to the different decomposition phase when the leachate recirculation was started. Leachate recirculation into R1 was started on day 203, which commenced after the waste reached the stabilization phase (day 180), whereas leachate recirculation into RC was started on day 203, which commenced before the waste reached the stabilization phase (day 290). It is noticed that, when starting to recirculate, the COD value from RC remained high whereas that from R1 showed low value. The result revealed that when starting to recirculate leachate after the waste reached the stabilization phase, the simulated landfill reactor could produce more methane than before the waste reached the stabilization phase.



(a)



(b)

Figure 2. Generalize phase and the changes in leachate, methane composition and production with time of the leachate recirculation simulated landfill reactor with (R1) (b) and without (RC)(a) high water addition.

2. Leachate Recirculation with Increase in Organic Loading Rate.

When the stabilization phase occurred (from day 330 to day 351), in order to study the loading capacity of landfill leachate, the increase in OLR was observed. The COD removal and methane composition and methane production rate from the reactors are presented in Table 4 and Table 5, respectively.

Table 4. The COD removal of the leachate recirculation simulated landfill reactor with (R1) and without (RC) high water addition from day 330 to day 356.

Day	OLR (kg/m^3-d)	HRT (Day)	COD Removal (%) RC	COD Removal (%) R1
344	3	5	67.45	73.67
351	4	7	81.2	85.01
356	5	5	91.02	91.22

Table 5. Methane production rate and composition of the leachate recirculation simulated landfill reactor with (R1) and without (RC) high water addition from day 330 to day 356.

Day	OLR (kg/m^3-d)	HRT (Day)	CH_4 Production Rate (l/kg.dry.wt-d)		CH_4 Composition (%)	
			RC	R1	RC	R1
339	0.5	9	0.04	0.1	52.08	45.49
344	3	5	0.18	0.2	54.53	56.65
349	4	5	0.42	1.2	57.7	64.01
356	5	5	0.69	1.56	62.23	65.01

The results showed that after the waste reached the stabilization phase, trends of COD removal, methane composition and methane production rate from the reactors were higher when the OLR was increased. The COD removal from the reactors at maximum level of OLR (5 kgCOD/m3-d) was 91.02% and 91.22% from RC and R1, respectively, which shows no significant difference. The highest methane production rate and methane composition attained at OLR 5 kgCOD/m^3-d were 0.69 l/kg.dry.wt-d and 62.23%, and 1.56 l/kg.dry.wt-d and 65.01% from RC and R1, respectively. This also emphasized the importance of leachate recirculation after the waste reached the stabilization phase, which could turn out to be the load receptor for enhancing methane production rate and reducing leachate strength in an anaerobic system.

Conclusion

The simulated landfill reactors were treated as bioreactors with leachate recirculation and high water addition condition to provide an understanding of MSW decomposition characteristics and to enhance methane production. Key interest findings were as follows :

1) R1 – The reactor with high water addition provided earlier onset of the methanogenesis phase and higher total methane production than RC –the reactor without high water addition. R1 entered into the methanogenesis phase on day 80 and the total methane production was 54.87 l/kg.dry.wt, whereas RC entered into the methanogenesis phase on day

210 and the total methane production was 17.04 l/kg.dry.wt. High water addition helped increase flushing of inhibitory substances and reducing leachate strength, resulting in the proper condition for methanogens, and therefore accelerated the methanogenesis phase.

2) Increasing the OLR showed the possibility to produce higher methane composition, methane production rate and COD removal. The optimum level of OLR of leachate recirculation, after the waste reached the stabilization phase, in this study was 5 $KgCOD/m^3$-d.

3) From this study, it is suggested that when the waste reached the stabilization phase, both with and without high water addition the landfill reactor could turn out to be the load receptor.

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