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Journal of Hazardous Materials B87 (2001) 259–271

Journal of Hazardous Materials

www.elsevier.com/locate/jhazmat

Impact of various leachate recirculation regimes on municipal solid waste degradation

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Received 30 August 2000; received in revised form 8 June 2001; accepted 14 June 2001

Abstract

Landfilled municipal solid waste can be treated by introducing leachate into the waste matrix. Increasing attention is being given to landfill leachate recirculation as a means for in situ leachate treatment and landfill stabilization. Landfills with leachate recirculation may be operated as municipal solid waste bioreactor treatment system rather than as a conventional waste dumping sites. In order to study the impact of various leachate recirculation regimes on municipal solid waste degradation, two landfill-simulating reactors, one with leachate recycle and one without, were constructed and placed at a constant room temperature (34°C). Both reactors were filled with a municipal solid waste mixture representing the typical solid waste composition determined for the city of Istanbul. For the purpose of this experiment, leachate recirculation volume and frequency were changed periodically. This research showed that increased frequency of leachate recirculation accelerates the stabilization rate of waste matrix. About 2 l of recirculated leachate and four times per week recirculation strategy were found to provide the highest degree of waste stabilization. Additionally, this research confirmed that leachate recirculation is a very feasible way for in situ leachate treatment.

Keywords: Landfill; Leachate; Leachate recirculation; In situ leachate treatment; Solid waste

1. Introduction

The city of Istanbul, like as most metropolitan cities, has significant problems associated with the management of solid waste. If it is assumed that the population of Istanbul will reach 17 million by 2020, the amount of solid waste generated will increase by 25%, i.e.

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PII: S0304-3894(01)00290-4

from 0.63 kg per capita per day in 1990 to 0.8 kg per capita per day in 2020 [1]. Only a small fraction of the generated waste is currently recycled, composted, or incinerated, and the unprocessed part is sent directly to two sanitary waste disposal sites. The theoretical amount of leachate produced from the landfill sites in Istanbul is 2 m^3 ha^{-1} per day for the first 5 years after encapsulation, and 5 m^3 ha^{-1} per day for the succeeding years [2]. If not managed properly, these high volumes of produced leachate pose a major threat to the environment. Therefore, landfills should be operated in a manner which minimizes environmental impacts while optimizing waste degradation.

Increasing attention is being given to leachate recirculation in municipal solid waste landfills as an effective way to enhance microbial decomposition of biodegradable solid waste. With leachate recirculation, a landfill can be used as a relatively controlled anaerobic filter to treat leachate, provide accelerated waste stabilization, and reduce the volume of leachate by maximizing evaporative losses during recirculation [3]. In order to maximize waste stabilization, leachate recirculation frequency must be carefully selected. If too much leachate is recirculated, problems such as saturation, ponding, and acidic conditions may occur. Limited data are available on the application of different leachate recirculation regimes to the waste matrix. However, it is recommended that leachate should be introduced slowly, since high flow rates may deplete buffering capacity and remove methanogens, increasing the flow rates and frequency of recirculation as gas production is established [4]. Several research studies indicated that the waste decomposition can be improved by an increase in the moisture flow, as a result of increased flushing and dilution of the inhibitory products, maintenance of favorable environmental conditions by uniform distribution of moisture, and addition of higher quantities of inoculum and nutrients [5,6].

This research was conducted in order to study the impact of various leachate recirculation regimes on waste degradation in landfills and in situ leachate treatment, and to provide data for successful operation of landfill sites in the Istanbul metropolitan area.

2. Materials and methods

2.1. Simulated landfill reactors construction

In order to study the impact of leachate recirculation volume and frequency on waste degradation in landfills and in situ leachate treatment, two reactors simulating landfills, one with leachate recycle and one without, were constructed in the laboratory using two PVC pipe columns with a length of 1 m and a diameter of 0.35 m. A leachate drainage zone, leachate collection system, leachate recirculation pumps and gas collection system were utilized to simulate landfill bioreactors. A peristatic pump was used to deliver the leachate collected in the storage container to the recycle reactor. Reactors were placed at a constant room temperature (34°C) to enhance the growth of anaerobic microorganisms [7]. The gas produced from the reactors was collected and its volume measured by using the inverted cylinder technique. The configuration of the recycle reactor, which is the same as the single pass reactor except the recirculation line, is presented in Fig. 1.

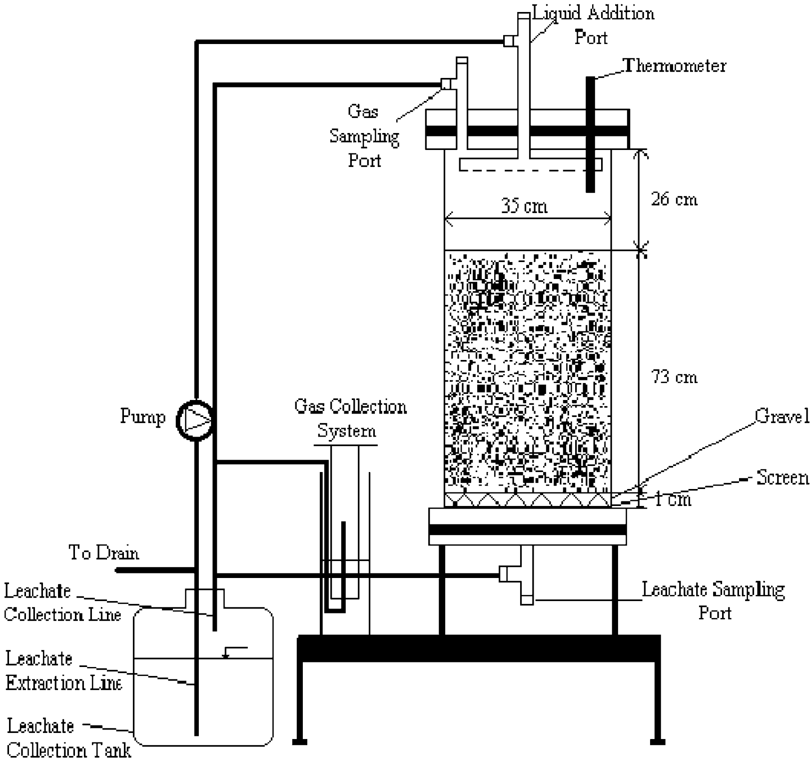

Fig. 1. Lab-scale simulated landfill reactor with leachate recycle.

2.2. *Simulated landfill reactors loading*

Simulated landfill reactors were filled with 13 kg of shredded and compacted synthetic solid waste. The composition of solid waste used in the experiments is given in Table 1. The waste composition was chosen to emulate the average values of typical municipal

Table 1
Synthetic solid waste composition

Composition	Percentage
Food	76
Paper	12
Plastics	4
Textiles	4
Yard waste	3
Metal	1
Total	100

Table 2
Operational phases employed throughout the experimental study to the recycle reactor

Phase	Days	Volume added (ml)		Frequency	
		Leachate	Water	Recirculation (per week)	Water addition (per week)
I	0–22	–	1000	–	Periodically
II	22–90	1000	–	1	–
III	90–146	2000	500[a]	1	1
IV	146–194	2000	500	2	1
V	194–222	2000	500	3	1
VI	222–249	2000	500	4	1
VII	249–275	2000[b]	500	4	1

[a] Commenced on day 125.
[b] Buffered to neutral pH.

solid waste compositions for five zones in the city of Istanbul. These zones were selected to represent the different socio-economical levels and type of fuel used for heating. The average in-place density of solid waste in each reactor was 178 kg m^{-3}. After sealing, the reactors were purged with nitrogen to displace oxygen from the system and to immediately establish anaerobic conditions.

2.3. Simulated landfill reactors operation

The experimental study was divided into seven operational phases (Table 2). Preliminary analysis of waste samples indicated that the solid waste had approximately 80% moisture. Throughout phase I, 1 l of tap water was periodically added to each reactor in order to reach field capacity. The volume of recirculated leachate and the frequency of leachate recirculation to the recycle reactor were periodically changed to determine the impact of various leachate recirculation regimes on solid waste degradation, as well as to observe its effects on waste stabilization and leachate treatment. The maximum volume of the recirculated leachate did not exceed 2 l in order to avoid flooding of the reactor. Recirculation frequency was gradually increased from one to four times per week.

In phase VII, recirculation with leachate buffering was practiced as an attempt to enhance the activity of the methanogenic population and accelerate the rate of landfill stabilization. Throughout the experimental study, water was added to the single pass reactor at a constant rate of 500 ml per week in order to simulate the 20 cm per year annual infiltration. On the other hand, water addition to the recycle reactor commenced on day 125 (phase III).

2.4. Analytical methods

Leachate collected from both reactors were analyzed for pH, oxidation–reduction potential (ORP), chemical oxygen demand (COD), ammonia-nitrogen in accordance with the procedures given in [8]. Gas production and the gas composition were monitored. Gas production was measured daily by observing the displacement of confining solution at every gas collection unit. The gas composition (CH_4 and CO_2) analysis was performed utilizing a HP 5890A gas chromatograph equipped with an 8 ft HEYSEP Q 80/100 19093A packed column using nitrogen as a carrier gas.

3. Results and discussion

3.1. pH

The pH values of the leachate collected at the bottom of each reactor are given in Fig. 2. After the initial adjustment, phase was completed and the anaerobic decomposition of waste proceeded, initially high pH values decreased as low as 5.2 on day 52 (phase II). The pH of both the recycle and single pass reactors showed a similar trend throughout the first five phases of the experiment, with an average pH value of 5.5. However, after day 222 of phase VI, when the leachate recirculation frequency was increased to four times per week, a slight increase in pH of the leachate from the recycle reactor was observed. The pH increase from 5.5 on day 221 to nearly 6.0 on day 247 was accompanied with an increase in methane production indicating the onset of anaerobic stabilization in the recycle reactor. However, the pH of the recycle reactor was still not favorable for the development of an active methanogenic population. Therefore, in phase VII, an attempt was made to increase the pH of the leachate from the recycle reactor from 6.0 to 7.0 and speed up the stabilization process, and establish the active methanogenic population. 1N KOH was mixed with the collected leachate and the mixture was recycled back to the recycle reactor four times per week. This resulted in a sudden increase in the pH of the recycle reactor from 5.92 on day 250 to 7.3 on day 257. The pH of the single pass reactor remained constant at a pH value of about 5.5 which was not suitable for the establishment of the methanogenic conditions.

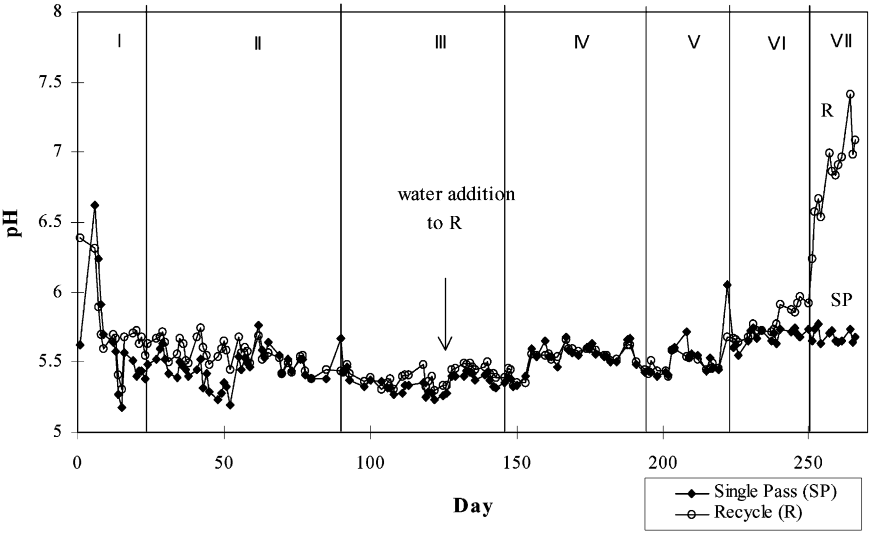

Fig. 2. pH of leachate from the single pass and recycle reactors.

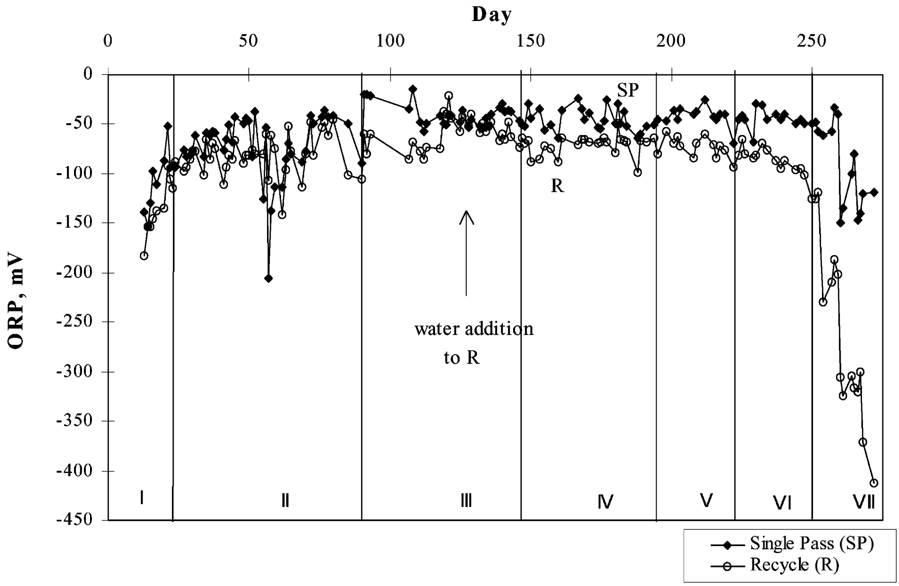

Fig. 3. ORP of leachate from the single pass and recycle reactors.

3.2. Oxidation–reduction potential (ORP)

The ORP values of the leachate collected at the bottom of each reactor are given in Fig. 3. The initial purging of the reactors with nitrogen gas resulted in very low ORP values. After reaching the field capacity on day 48, the ORP values increased to −50 mV in the single pass reactor and −70 mV in the recycle reactor, indicating the prevalence of anaerobic environmental conditions. The increase in the recirculated leachate volume from 1 to 2 l during phase III did not affect the ORP values. However, the ORP values of the recycle reactor began to be more negative on day 150 (phase IV) as a direct result of the increased leachate recirculation frequency from one to two times per week. Furthermore, a slight drop in ORP values was observed throughout phases V and VI, when leachate recirculation frequency was changed from two to three and from three to four times per week, respectively. The increase in leachate recirculation frequency resulted in faster waste stabilization, i.e. decrease in ORP. In phase VII, the ORP values decreased from −125 to approximately −415 mV due to the positive effect of the pH neutralization of leachate.

On the other hand, the ORP values of the leachate from the single pass reactor remained less negative during the experimental period and reached to about −150 mV at the end of the study.

3.3. COD

The COD concentrations of the leachate collected at the bottom of the single pass and recycle reactors are given in Fig. 4. Due to the rapid release and hydrolysis of organics from

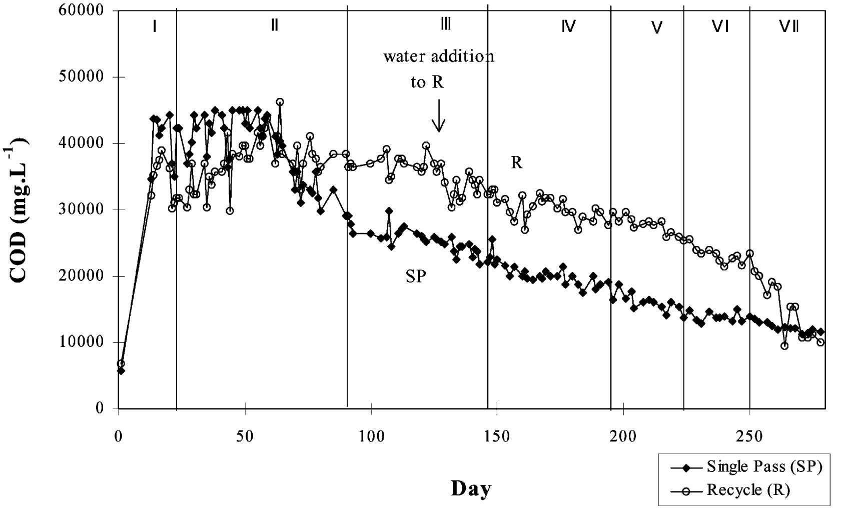

Fig. 4. COD concentrations for the single pass and recycle reactors.

the solid waste into the leachate in phase I, the COD concentrations from the single pass and recycle reactors increased from 5,000 to 45,000 mg l^{-1} and 39,000 mg l^{-1}, respectively. The decomposition process in the recycle reactor continued throughout phase II as a result of different operating moisture regimes, and may be related to the difference in moisture available in the two reactors. The increase in volume of the recirculated leachate from 1 to 2 l did not affect the COD concentrations in the beginning of phase III. However, the addition of water to the recycle reactor on day 125 caused a decrease in the COD concentration and an increase in methane concentrations. The change in the recirculation frequency in phases IV–VI resulted in faster decomposition of the solid waste in accordance with the progression of microbially-mediated stabilization processes. Decreases in COD occurred along with corresponding increases in gas production. The highest methane concentration was observed during phase VI when the recirculation frequency was changed from three to four times per week. The decrease in COD concentration from 26,000 mg l^{-1} on day 222 to 21,500 mg l^{-1} on day 240 was accompanied by an increase in methane concentration from 47% on day 218 to 51% on day 234. Buffering the leachate prior to its recirculation accelerated the waste decomposition even more.

On the other hand, the reduction of the organic strength of leachate from the single pass reactor was not only a result of the waste stabilization process, but also of the dilution and washout mechanism that dominated in the single pass reactor as validated by other indicator parameters.

3.4. Ammonia-nitrogen

The ammonia-nitrogen concentrations for the single pass and recycle reactors are given in Fig. 5. Initial concentrations of ammonia-nitrogen in both reactors were found to be similar,

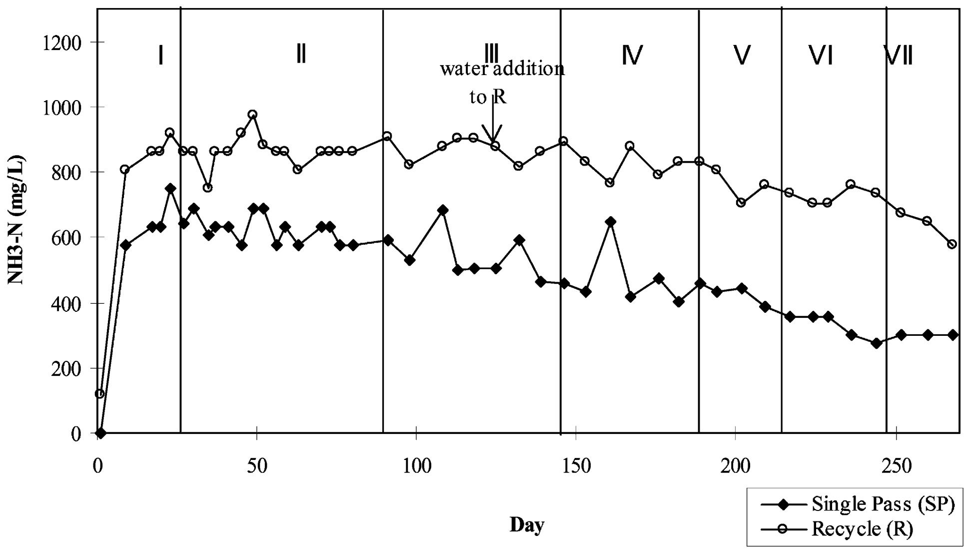

Fig. 5. Ammonia-nitrogen concentrations from the single pass and recycle reactors.

indicating uniformity in waste composition in both reactors. As a result of decomposition of organic matter containing nitrogen, initial concentrations increased from 0 and 115 mg l^{-1} NH_3-N to a maximum of 747 and 976 mg l^{-1} NH_3-N for the single pass and the recycle reactors, respectively. The recirculation practice in the recycle reactor reintroduced ammonia to the system, keeping its value almost constant throughout the first four phases of the study. With an increase in recirculation frequency in phases V, VI and VII, ammonia-nitrogen concentrations decreased slightly. Ammonia concentration behavior was attributed directly to the nature of the leachate recirculation management strategy, whereby available nutrients are contained and recirculated within the column, providing an increased opportunity for their accumulation and/or removal through biological assimilation. The ammonia concentrations observed for recycle reactor was approximately 800 mg l^{-1}, a level which has been shown to exert no adverse effect upon anaerobic processes [9].

Ammonia concentrations in the leachate from the single pass reactor displayed evidence of washout, although concentrations were maintained above 500 mg l^{-1} at all times during the experimental period, thereby indicating availability for establishing a viable microbial population.

3.5. Gas production

The cumulative gas production for the recycle and single pass reactors is given in Fig. 6. The overall volume of gas produced was much larger in the recycle reactor than in the single pass reactor. While the recycle reactor produced 269 l of gas, the single pass reactor produced only 70 l of gas. The increase in volume of the recycled leachate from 1 to 2 l in phase III did not affect the daily gas production. However, water addition on day 125

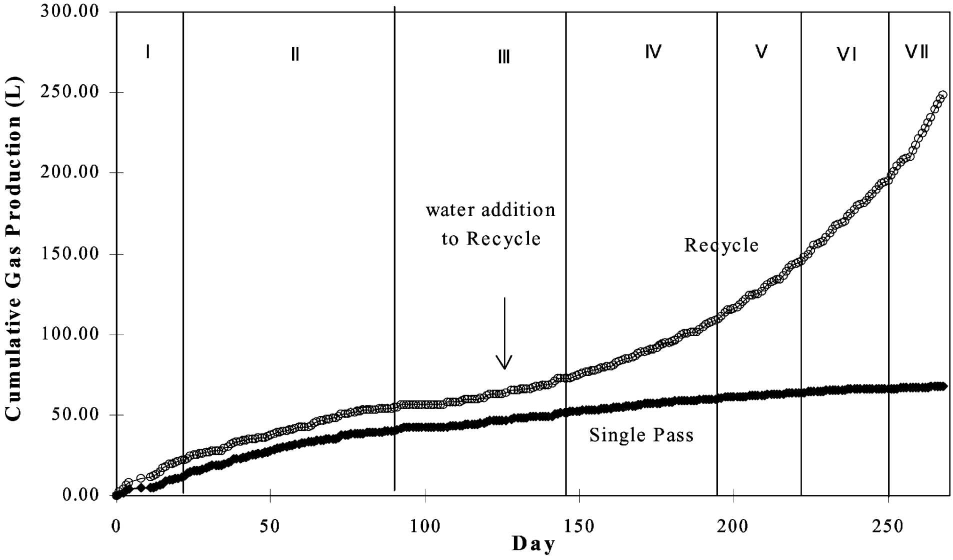

Fig. 6. Cumulative gas production for the single pass and recycle reactors.

affected the amount of gas generated from the reactor. Furthermore, increases in leachate recirculation frequency had proven to directly impact the gas generation potential. Increased gas production was directly related to the higher degree of stabilization in the recycle reactor and may be attributed to the leachate recirculation strategy employed. Buffering of leachate prior to its recirculation during phase VII resulted in establishing environmental conditions favored by methanogens which accelerated waste degradation and resulted in a further increase of gas production that reached its peak during this phase.

The single pass reactor exhibited a rather unpredictable pattern of gas production. The low gas production volumes were directly related to the washout of the substrate and essential nutrients, thus limiting the microbial activity and waste stabilization.

3.6. Gas composition

The gas compositions for the single pass and recycle reactors are given in Figs. 7 and 8, respectively. As shown in Fig. 8, the change in the recirculated leachate volume from 1 to 2 l during the phase III did not affect the methane concentration in the recycle reactor. The increase in the leachate recirculation frequency from one to two times per week in phase IV resulted in a slight increase in the methane and carbon dioxide concentrations in the recycle reactor. The increase in the methane concentration indicated an established methanogenic activity. Further increases in the leachate recirculation frequency in phases V and VI resulted in high methane concentrations. The increase in recirculation frequency had a positive effect on the methanogenic population, enhancing their growth and activity due to the increase in moisture content. An increase to four times recirculation frequency in phase VII caused

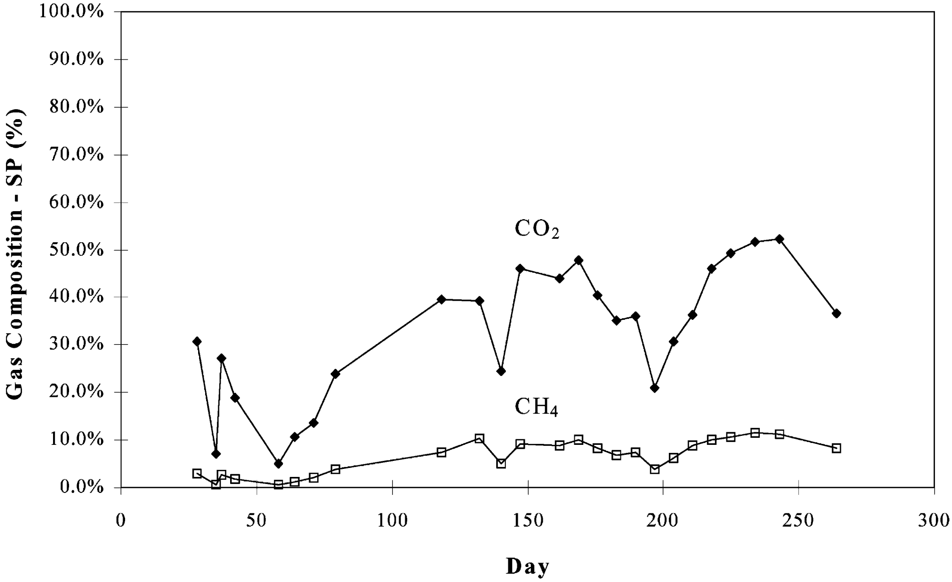

Fig. 7. Gas composition for the single pass reactor.

short-term operational problems. Leachate recirculated to the recycle reactor between day 260 and 270 was retained in the reactor. At the same time pH values decreased from 7.5 to 7, and COD concentrations increased from 9,000 to 17,000 mg l^{-1}. Based on these two parameters, it was assumed that acidic conditions occurred in the recycle reactor slowing

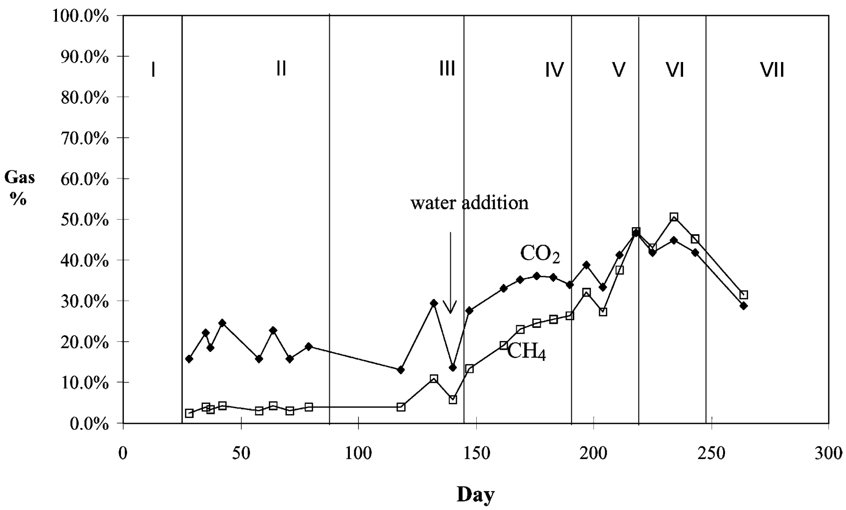

Fig. 8. Gas composition for the recycle reactor.

down the activity of methanogens decreasing methane and carbon dioxide concentrations from 51 to 45% on day 234 and 31 to 29% on day 264, respectively. However, the reactor recovered very rapidly, as seen from the COD values that on day 270 decreased to the same value as before day 260.

The single pass reactor exhibited a rather steady pattern of methane production with a gradual increase in carbon dioxide concentration. The average observed methane concentration was 10% throughout the study. Low methane concentrations were considered to be another proof of washout, indicating the inability of the system to develop an active methanogenic population and enhance waste stabilization.

3.7. Degree of stabilization

One of the objectives of this study was to determine the effect of leachate recirculation on waste stabilization. As waste stabilization is directly related to the amount of methane produced, the amount of methane generated per kilogram of organic matter stabilized is taken to be an indicator of waste stabilization degree. Methane concentrations and the total volume of gas produced in both reactors were used to determine the total volume of methane produced during the experimental study. About 3.2 and 78 l of CH_4 were generated from the single pass and the recycle reactor, respectively.

In order to determine the stabilization degree, the maximum mass of COD released was calculated by multiplying the maximum released COD and the available moisture in the reactor for that day [10]. It was found out that the maximum mass of COD release is equal to 324 and 313 g for the single pass and the recycle reactor, respectively. Using these calculated values and observed total volume of methane produced, it can be easily shown that while 3.5% of COD removed from the single pass reactor was converted to methane, in the recycle reactor 71% of COD removed was converted to methane. These values strongly support the fact that the washout was the prevailing mechanism existing in the single pass reactor, and not the actual stabilization process. On the other hand, it was proved that the waste stabilization process in the recycle reactor was accelerated as a result of the leachate recirculation technique employed.

4. Summary and conclusions

The objective of this study was to study the impacts of various leachate recirculation regimes on waste degradation, as well as on landfill stabilization and in situ leachate treatment. Based upon experimental results obtained during the investigation, the following conclusions are drawn:

1. The reactor system designed and operated to simulate landfill environment, as controlled anaerobic bioreactor with leachate recirculation, provided accelerated stabilization of waste matrix and in situ leachate treatment. The leachate recirculation management strategy enhanced waste stabilization in terms of the extent of stabilization obtained, as reflected in the higher volume of gas produced, gas composition (i.e. increased methane gas concentrations) and other leachate indicator parameters.

2. The degree of waste stabilization and efficiency of COD removal were dependent on the operational phases. The change in recirculation frequency positively effected the stabilization process and leachate treatment efficiency. The four times per week recirculation strategy with pH control provided the highest degree of stabilization as reflected by the leachate and gas parameters monitored.
3. Recycling of leachate promoted the development of internal mechanisms responsible for waste stabilization and leachate treatment. Reintroduction of necessary nutrients such as phosphorus and nitrogen, enhanced the growth of microbial population and effected the extend of stabilization.
4. Leachate recirculation with pH control further enhanced landfill stabilization and treatment efficiency. Buffering the leachate prior to its recirculation is an important operational parameter for the maintenance of the desired pH values in the system.

This research showed that landfill leachate management with leachate recirculation is a promising and challenging strategy. Leachate recirculation is a feasible way for in situ leachate treatment decreasing the cost of further external treatment. The four times per week recirculation strategy provides the highest degree of waste stabilization. However, it should be noted that practicing the four times per week recirculation in full-scale may cause some operational problems, such as flooding or clogging, especially in areas with increased precipitation. A combination of different operational regimes may be the best way to achieve the optimum waste stabilization. The four times per week recirculation frequency may be employed right after landfilling of solid waste to raise its moisture content to field capacity and establish a viable microbial population and therefore shorten the time necessary to initiate the decomposition process. However, landfill operators should be aware of the possibility of organic overload and accumulation of volatile organic acids that may inhibit the development of a viable methanogenic population. To avoid possible adverse effects, leachate pH adjustment prior to its recirculation is recommended. After significant methane concentrations are reached, recirculation frequency may be lowered to one or two times per week. Taking into consideration the season and the climate, recirculation frequency may be changed, so that four times per week recirculation via spraying would be appropriate in summer months when maximum leachate loss due to the evaporation may be achieved. On the other hand, in fall and winter months, one or two times per week recirculation would be appropriate to prevent possible flooding, surface ponding, or freezing conditions.

The leachate recirculation management strategy may be employed in modern landfills in Turkey by making the necessary modifications in the existing landfills, and taking the necessary safety precautions. The data obtained from this study are results of bench-scale laboratory work with constant operational conditions. To confirm the results obtained, a full-scale study is recommended.

Acknowledgements

The authors acknowledge the financial support provided by Boğaziçi University Resarch Fund for the realization of this research project BU-99 Y03.

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