

Accelerated landfill waste decomposition by external leachate recirculation from an old landfill cell

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Abstract This research is focused on the management of moisture regime for a young landfill site in terms of leachate recirculation which entails the containment, collection and reinjection of leachate back into the landfill to promote in situ anaerobic biological treatment. Moreover, an innovative leachate management strategy was developed by using leachate recirculation from a mature landfill site into a young landfill site to provide accelerated waste stabilization. For this purpose, two reactors simulating young and old landfills were used in the laboratory. These reactors were loaded with shredded and compacted municipal solid waste with a typical composition determined for Istanbul Region. Both reactors were operated in a constant temperature room at 32°C to enhance the growth of anaerobic microorganisms. Moreover, water was added to the reactors in order to simulate the annual rainfall. The reactor having the properties of old landfills was used as a control reactor. The reactor which represented the characteristics of young landfill was operated under four operational stages to enhance the activity of methanogenic population and accelerate waste stabilization. Results of this study indicated that the utilization of leachate recirculation enhanced waste stabilization in the young landfill by increasing the uniformity, and providing additional substrate and nutrients. Additions of buffer solutions of KOH and Na₂CO₃ together with leachate recirculation enhanced further waste stabilization and prevented possible acid inhibition. The utilization of external leachate recycled from the old landfill having desired acclimated anaerobic microorganisms, low organic content and higher buffer capacity into a young landfill could be a promising leachate management strategy for faster and controlled waste stabilization.

Keywords Landfill; leachate recirculation; neutralization; solid waste; waste stabilization

Introduction

All over the world, the generation of municipal solid wastes has increased rapidly with increasing industrialization and urbanization. Effective management of increasing amounts of these solid wastes has become a major social and environmental concern. Landfilling is the most commonly employed disposal method worldwide since it is comparatively simple and economic. However, the most vital problem associated with landfilling is the generation and unwanted migration of landfill gas and leachate as a result of waste degradation processes. Leachate is a liquid that has percolated through the refuse mass and has extracted dissolved and suspended components (Rachdawong, 1994). Leachate characteristics change as landfill stabilization proceeds. Leachate can be characterized as young and old leachate depending upon the phase of landfill stabilization. Young leachate during the acid phase of landfill stabilization is characterized by low pH, high organic content as indicated by BOD₅, COD, TOC and total volatile acids (TVA), and abundance of mobilized ions. Old leachate mainly indicates the methane fermentation phase of landfill stabilization with reduced TVA, high pH values, reduced readily degradable organic components and the presence of humic and fulvic-like compounds (Tchobanoglous *et al.*, 1993; Quasim and Chiang, 1994). Another problem related to landfill sites is linked with the production and migration of landfill gasses. Landfill gasses including mainly carbon dioxide (CO₂) and methane (CH₄) result from the anaerobic decomposition of the solid waste. In addition, traces of other gases (N₂, O₂, CO, H₂S) and volatile organic compounds (VOCs) are found

in landfills and their production and quality depend on the microbiological system, moisture content, refuse age and composition (Pohland *et al.*, 1987; McBean *et al.*, 1995).

Two management systems, conventional waste management and bioreactor landfill operation, can be employed in landfills to reduce the potential environmental risks of leachate and gas production. Although conventional landfills consist of cells and lifts with liners, drains, gas vents, bioreactor landfills provide rapid, complete attenuation of solid waste constituents and enhance gas recovery with more controlled moisture management. Pohland (1990) defines bioreactor landfill as the modification of conventional landfill with the addition of leachate recirculation and gas management systems. Leachate recirculation management entails the containment, collection and reinjection of leachate back into the landfill to promote in situ anaerobic biological degradation of solid waste. Generally, studies demonstrated that increasing the moisture content and practicing leachate recycling had a positive effect on the waste stabilization process because of enhanced decomposition of organic matters in landfills. (Al-Yousfi and Pohland, 1998). Therefore, leachate recirculation may be used: to maximize waste disposal capacity, to increase waste biodegradation and gas production rates, to increase leachate management and treatment flexibility, to improve leachate quality and to reduce leachate treatment cost (Warzinski *et al.*, 2000). These advantages of leachate recirculation have been demonstrated by many researchers who performed numerous lysimeters and field tests (Pohland, 1975; Pohland, 1980; Doedens and Cord-Landwehr, 1989; Merrit, 1992; Otieno, 1994; Townsend *et al.*, 1996; El-Fadel, 1999; Churg *et al.*, 1998). Moreover, stabilization of the landfill may be accelerated using one of the following techniques: pH control by buffer addition, nutrient and sludge additions and shredding.

In this study, the importance of moisture regime for a young landfill site in terms of leachate recirculation management was investigated to reduce the time required for waste stabilization, improved leachate quality and enhanced rate of gas production. Moreover, an innovative leachate management strategy was developed by using leachate recirculation from an anaerobically digested, mature landfill site into a young landfill site to provide accelerated waste stabilization.

Materials and methods

Configuration of the simulated landfill reactors

Two 96-litre PVC reactors simulating young and old landfills were used in this study. The reactors were operated in a constant temperature room at 32°C to enhance the growth of anaerobic microorganisms. The design and operational features of the reactor simulating young landfill with leachate recycling is presented in Figure 1. Each reactor had a diameter of 0.35 m and a length of 1 m. The reactors were equipped with three ports: one port was used for leachate drainage and sampling while the other two ports were used at the top lid to collect gas samples and to add liquid. A leachate distribution system made of PVC sheet was used at the center of the top lid to provide uniform leachate distribution onto the waste matrix. All connections to the reactors were sealed with silicone to prevent any leak. A thermometer was placed 10 cm radially apart from the liquid addition port at the top lid to determine the daily temperature changes in the reactors. An ISMATEC S460 MINI pump was used to recycle leachate collected in the plastic container to the young landfill reactor. The gas produced from the reactors was measured by using liquid displacement technique. A 2-L cylinder was inverted in a vessel and filled with confining solution (20% NaSO₄ and 5% H₂SO₄ by weight) to minimize the dissolution of CO₂ and CH₄ in the liquid. The volume of daily displaced liquid in the cylinders was recorded as the daily gas production.

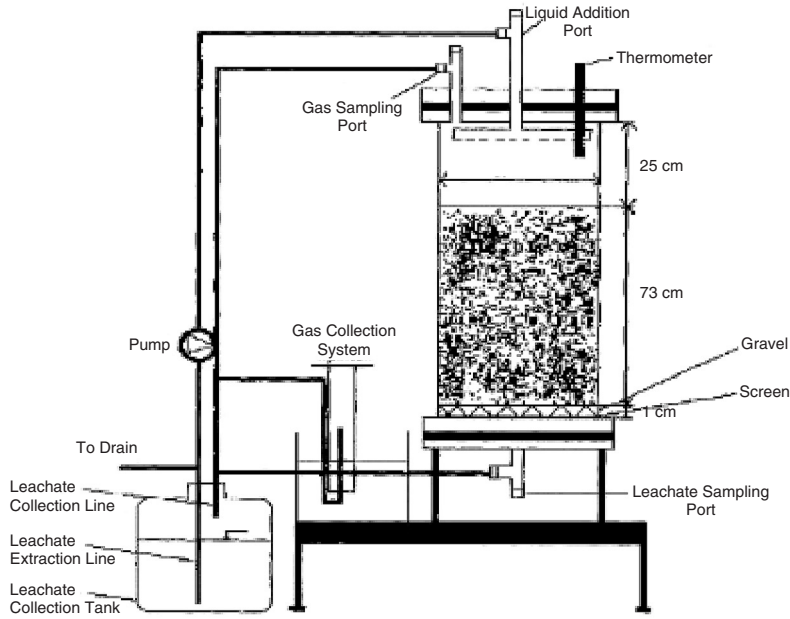


Figure 1 The design and operational features of the reactor simulating young landfill with leachate recycling

The characteristics of waste matrix in the simulated landfill reactors

Each reactor was loaded with shredded and compacted solid waste mixture of approximately 13 kg. One litre of anaerobic digested sludge obtained from the Tekel Raki (alcoholic beverage) factory in Beykoz-Istanbul was also added to initiate solid waste stabilization. Shredded solid waste in the reactors were prepared synthetically to assure accelerated stabilization and maximize the homogeneity of the refuse. The synthetic solid waste mixture was representative of the typical solid waste composition observed for the Istanbul Region (Table 1). Preliminary analyses of waste samples and digested sludge indicated that solid waste had approximately 80% moisture content and volatile solid content of the anaerobic sludge was 88%.

Simulated landfill reactors operation

Two reactors, one simulating the characteristics of an old landfill (OL) and the other of a young landfill (YL) were used in the laboratory. The reactor simulating the OL was operated and maintained under methanogenic conditions until the end of the experiments. Moreover, this reactor was used as the control reactor throughout the study. As indicated in Table 2, the reactor simulating the YL was under acidogenic conditions and operated under four different stages to provide faster transition from acidogenic to methanogenic phase. The operational stages were classified according to the frequency of weekly leachate recirculation as presented in Table 3.

Leachate recirculations were made from the container of the reactors in which leachate was collected. The change in the characteristics of the recirculated leachate as related to the

Table 1 Synthetic solid waste composition (San and Onay, 2001)

| Composition | Food | Paper | Plastics | Textiles | Yard waste | Metal | Total |
|----------------|------|-------|----------|----------|------------|-------|-------|
| Percentage (%) | 76 | 12 | 4 | 4 | 3 | 1 | 100 |

Table 2 The initial leachate characteristics in the reactors before the leachate recirculation

| Reactor | pH | ORP (mV) | COD (mg/L) | Alkalinity (mg/L as CaCO ₃) | Chloride (mg/L) | PO ₄ -P (mg/L) |
|----------------|------|----------|------------|---|-----------------|---------------------------|
| Young landfill | 5.61 | -137 | 10,020 | 2,493 | 410 | 171 |
| Old landfill | 7.78 | -174 | 1,159 | 4,038 | 371 | 56 |

Table 3 Operational stages of the reactor simulating young landfill

| Stages | Days | Moisture addition (mL) | | Frequency | | Other additions |
|--------|---------|------------------------|-------|-----------|--------|---|
| | | Leachate | Water | Leachate | Water | |
| I | 0–103 | 1,000 | 500 | 1/week | 1/week | Between day 56 and 84, 200 mL 1 N KOH |
| II | 103–138 | 1,000 | 500 | 2/week | 1/week | Recycle from OL to YL ¹ |
| III | 138–170 | 1,000 | 500 | 3/week | 1/week | Between day 142 and 156, 100 mg/L Na ₂ CO ₃ |
| IV | 170–245 | 1,000 | 500 | 1/week | 1/week | |

¹OL: old landfill YL: young landfill

Table 4 Recirculated leachate characteristics

| Container | Stages | pH | ORP (mV) | COD (mg/L) | Alkalinity (mg/L as CaCO ₃) | Chloride (mg/L) | PO ₄ -P (mg/L) |
|----------------|--------|------|----------|------------|---|-----------------|---------------------------|
| Young landfill | I | 5.79 | -135 | 26,536 | 2,592 | 482 | 285 |
| Old landfill | II | 7.76 | -234 | 721 | 4,829 | 446 | 30 |
| Young landfill | III–IV | 6.91 | -284 | 11,109 | 2,700 | 315 | 81 |

operational stages is presented in Table 4. The first operational stage was started by the weekly recirculation of one litre leachate and weekly water addition of 500 mL, (corresponding to an equivalent of 20 cm/year rainfall). A buffer solution of 1N KOH was weekly employed from day 56 to 84 for the acceleration of waste stabilization and prevention of possible acid inhibition on the methanogens. However, towards the end of the stage, the addition of 1N KOH was stopped because of the accumulation of potassium which reached a moderately inhibitory level of 3,000 mg/L in the reactor. A total of 970 mL 1N KOH was introduced into the reactor during this stage. In the second stage of operation, recirculation frequency in the reactor was increased from once to twice a week. One was from the OL reactor under methanogenic conditions (Table 4) and the other was through internal recirculation. The aim of the external recycle of one litre-leachate was to introduce desirable microbial population and nutrients into the YL reactor and establish accelerated waste stabilization. After the introduction of methanogenic population into the YL reactor, the internal recirculation frequency was increased to three times per week and a buffer solution of sodium carbonate (Na₂CO₃) was added throughout the third stage for leachate neutralization. The objective of sodium cation selection as buffer solution was to reduce the toxicity of potassium cation because of the antagonistic effects of sodium and potassium cations (Barnes and Fitzgerald, 1987). The buffer addition was practiced by the neutralization of recirculated leachate to pH 7–7.5 by using a 100 g/L Na₂CO₃ solution. In the last stage, the recirculation frequency was readjusted to once a week due to the establishment of the desired anaerobic conditions in the YL reactor.

Sampling and analytical methods

The collected leachate and gas samples were monitored on a regular basis to understand the degree of waste stabilization in the reactors. Leachate samples collected at the bottom of

the YL and OL reactors were analyzed for chemical oxygen demand (COD), pH, oxidation-reduction potential (ORP), alkalinity, phosphate and chloride. All analyses were performed according to *Standard Methods for the Examination of Water and Wastewaters* (1992). The volume of gas produced was determined daily by observing the displacement of the confining solution in the gas collection units. The concentrations of methane and carbon dioxide in the biogas were determined by using a gas chromatograph (GC), Shimadzu.9A equipped with a thermal conductivity detector (TCD) and a 2-m mesh Propac Q column.

Results and discussion

The experimental results of YL reactor are provided since the OL reactor was used as control. Gas volume and chemical oxygen demand are monitored as the main indicators of the progression of landfill stabilization process and results are presented in Figure 2. Daily gas production was determined by measuring the volume of daily displaced liquid in the cylinders. The initial gas production rate of the YL reactor was low (500 mL) due to the prevailing acidogenic conditions and the initial COD concentration was high (10,000 mg/L). A slight decrease in gas production rate and a sharp increase in COD values was observed when acidic conditions became more intense after the commencement of leachate recirculation having high organic content (26,000 mg/L). The COD values in the reactor rose from 10,000 mg/L to about 20,855 mg/L at the end of this stage. The addition of 1N KOH buffer solution did not provide a decrease in leachate COD due to the high organic content of the recirculated leachate. However, buffer addition helped the initiation of organic material conversion which was confirmed by the accelerated gas generation rate from 200 mL to 1000 mL. Stopping the addition of 1N KOH on day 84 caused decrease in gas production until the introduction of leachate from the old landfill. During the second stage, COD values in the YL reactor decreased from about 19,206 mg/L on day 106 to 11,109 mg/L on day 138 and with the daily gas production rates of 800–1,000 mL due to the leachate recirculation from the OL reactor. This decrease in COD concentrations and increase in the daily gas volume can be explained by the dilution effect of leachate recirculation from OL reactor and introduction of methanogens into the reactor helping the onset of methanogenic conditions. During the third stage, increase in the frequency of recirculated leachate from twice a week to three times a week did not affect the conversion rate of organics which was observed through constant COD concentrations and gas production rates. After the addition of Na_2CO_3 with three times a week leachate recirculation, the conversion of organics to methane and carbon dioxide was accelerated rapidly due to the prevention of the accumulation of volatile organic acids by pH neutralization. This rapid decrease continued until the middle of the fourth stage. After day 200, significant decreases in COD concentrations were not observed indicating the existence of microbially refractory organics. On the other hand, the gas production rate reached to its highest value of

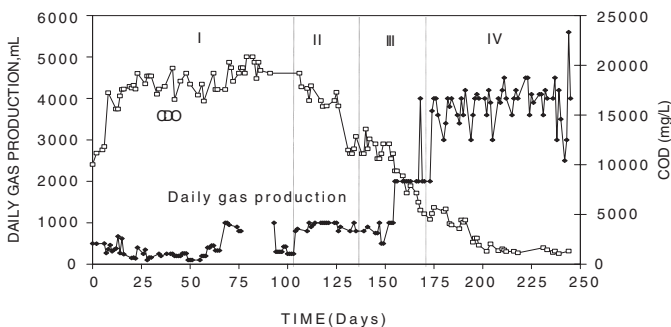


Figure 2 Daily gas production and leachate COD concentrations from the reactor simulating YL cell

approximately 5,000 mL in the fourth stage. Recirculation of leachate intensified microbial activity by reintroducing the nutrients, homogenizing the environment and allowing better contact between microorganisms and substrate. As a result, conversion of volatile organic acids to methane and stabilization of waste were enhanced, as confirmed by the increase in gas production and the decrease in leachate COD concentrations.

Cumulative gas production was also calculated by summing all of the observed daily gas production within the experimental period. The cumulative gas produced in the YL reactor was about 354 L (Figure 3). Methane and carbon dioxide are the principal gases produced during the decomposition of the organic fraction of the solid waste. As indicated in Figure 4, the initial methane concentration in the generated gas was about 12%. This low percentage was due to the prevailing acidogenic conditions in the reactor. An increase in the methane concentration as a result of the activity of methanogens was observed during the third stage due to the increase in leachate recirculation frequency from two to three times per week together with the buffer addition. After the onset of methanogenic conditions in the reactor, methane percentage reached to 71%. Cumulative methane productions were calculated by using daily gas production and gas composition data. Cumulative volumes of methane and carbon dioxide produced in the YL reactor were 145 L and 101 L, respectively (Figure 3).

The change in leachate pH and alkalinity are given in Figure 5. The initial pH value of the young landfill reactor was measured as 5.61 and a slight increase was observed during the first 20 days by the introduction of one litre leachate recirculation. The initial alkalinity in the reactor was 2,493 mg/L as CaCO_3 . After day 20, the pH values and alkalinity decreased because acidogenic conditions in the reactor became more intense by the recirculation of leachate having high organic content and low pH values. To overcome this difficulty and increase the pH and alkalinity of leachate, an attempt was made by weekly addition of 1N KOH together with leachate recirculation. pH values rose from 5.62 on day 56 to 6.04 on day 84 and the alkalinity of the system increased to 3,100 mg/L as CaCO_3 towards the end of the first stage of the YL reactor. However, the addition of 1N KOH was

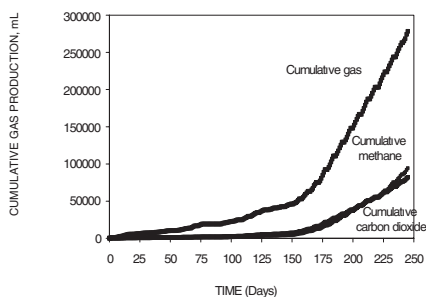


Figure 3 Cumulative gas production

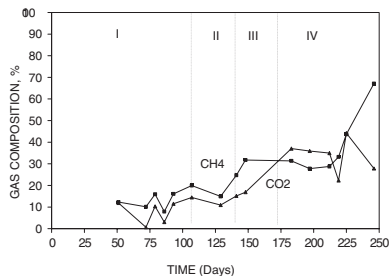


Figure 4 Gas composition

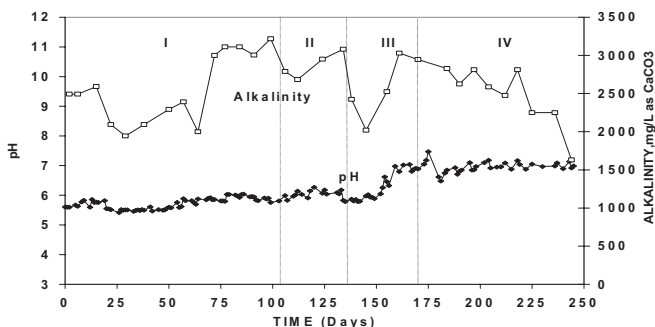


Figure 5 Leachate pH and alkalinity concentrations from the young landfill reactor

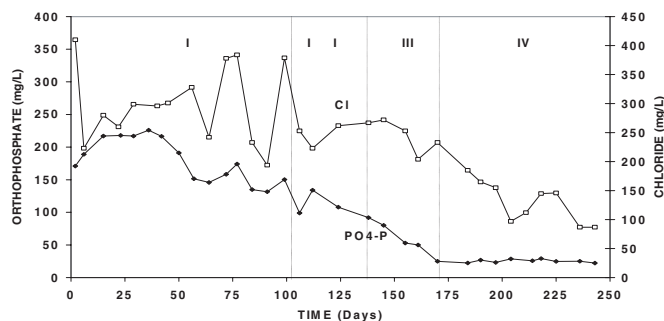


Figure 6 Leachate orthophosphate and chloride concentrations from the young landfill reactor

stopped on day 84 because potassium cation reached to the inhibitory level of 3,000 mg/L in the reactor.

Therefore, a slight decrease in pH values and alkalinity was observed until the beginning of the second stage. The recirculation of leachate from OL reactor with low organic content and high pH values provided relatively constant pH values of 6.00 and constant alkalinity in the YL reactor. A sharp decrease in alkalinity was observed at the beginning of the third stage although recirculation frequency increased to three times a week. Alkalinity declined to 2,020 mg/L as CaCO_3 on day 145. Along with the addition of Na_2CO_3 buffer solution, a sharp increase in pH values and alkalinity was observed. pH values rose from 5.80 to 6.98 on day 159 and alkalinity increased 2,946 mg/L as CaCO_3 . After the onset of the desired conditions, pH and alkalinity remained constant until the end of the study.

Leachate orthophosphate concentrations were monitored as one of the major nutrients required in anaerobic degradation (Figure 6). The initial concentration of orthophosphate in the YL reactor was 171 mg/L and increased to approximately 226 mg/L due to the leachate recirculation with higher orthophosphate concentrations. However, orthophosphate concentrations started to decrease as a result of the enhancement of the utilization of orthophosphate by microorganisms and the dilution caused by water additions. Leachate phosphate concentration reached to 25 mg/L at the beginning of the fourth stage. The orthophosphate concentrations remained approximately constant during that period.

Chloride was monitored as a conservative tracer in order to estimate the dilution and evaporation effects throughout the experiments. Chloride concentrations for the YL reactor are given in Figure 6. Leachate chloride concentrations in the YL reactor initially decreased and increased slowly with some fluctuations throughout the first phase due to the recirculation of leachate with higher chloride concentrations from the container. Chloride concentration of the reactor stayed constant between days 103–170. After day 170, leachate chloride concentration decreased slowly due to the dilution effect of water.

Conclusions

In this study, the importance of moisture content for YL sites in terms of leachate recirculation regimes was investigated to reduce the time required for waste stabilization, improve leachate quality and enhance the rate of gas production. In accordance with this objective, the following conclusions could be obtained from the experiments.

Leachate recirculation served to facilitate degradation, conversion and immobilization of refuse constituents. This was confirmed by leachate COD concentration and gas production rate as the main indicators of waste stabilization. COD concentration in the YL reactor decreased from 20,000 mg/L to 1,000 mg/L with corresponding cumulative gas production of approximately 354 L. Conversion of volatile organic acids to methane gas and stabilization of solid waste were provided by the more uniform environment created by the

increased contact of leachate with the solid matrix and reintroduced nutrients and inoculum. The frequency of leachate recirculation has proved to be an important factor for a high degree of organic release and its removal. Although every attempt to increase the frequency of recirculation was followed by positive changes in monitored parameters, the best results as confirmed by gas and leachate indicator parameters were obtained through leachate recirculation with buffer addition. Combination of leachate buffering with three times recirculation per week provided a high degree of waste stabilization.

Leachate recirculation from an OL having low organic content and high buffer capacity and desired acclimated anaerobic microorganisms to the YL reactor was shown to accelerate the waste stabilization. During utilization of leachate recirculation from OL reactor, COD values in the YL reactor declined from about 19,206 mg/L to 11,109 mg/L and gas production reached 41 L. This decrease in COD concentrations and increase in daily gas volume was provided by the dilution of high organic content in the reactor and introduction of methanogens helping the onset of methanogenic conditions.

This study showed that leachate recirculation is a feasible way for the accelerated stabilization of waste matrix in YLs. Moreover, the utilization of leachate recirculation from mature landfill sites having desired acclimated anaerobic microorganisms, low organic content and higher buffer capacity into a YL is a promising landfill operation alternative for faster and controlled waste stabilization.

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