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Influence of leachate recirculation on aerobic and anaerobic decomposition of solid wastes

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Abstract

In this study, the effect of leachate recirculation on aerobic and anaerobic degradation of municipal solid wastes is determined by four laboratory-scale landfill reactors. The options studied and compared with the traditional anaerobic landfill are: leachate recirculation, landfill aeration, and aeration with leachate recirculation. Leachate quality is regularly monitored by the means of pH, alkalinity, total dissolved solids, conductivity, oxidation–reduction potential, chloride, chemical oxygen demand, ammonia, and total Kjeldahl nitrogen, in addition to generated leachate quantity. Aerobic leachate recirculated landfill appears to be the most effective option in the removal of organic matter and ammonia. The main difference between aerobic recirculated and non-recirculated landfill options is determined at leachate quantity. Recirculation is more effective on anaerobic degradation of solid waste than aerobic degradation. Further studies are going on to determine the optimum operational conditions for aeration and leachate recirculation rates, also with the operational costs of aeration and recirculation.

Keywords: Solid waste; Landfill; Aerobic landfill; Leachate recirculation

1. Introduction

Solid waste generation is a growing global issue due to the large increase in solid waste production. This increase in waste quantity requires improving and expanding the solid waste management options. Landfill codisposal is the most commonly used waste management method worldwide. Physical, chemical, and biological processes occur within a conventional landfill to promote the anaerobic degradation of solid waste and result with the production of leachate and landfill gas for a very long time. According to some authors the long-term environmental impacts caused by landfill gas and leachate may last for several centuries [1,2]. Therefore, the main aim of the modern landfills is to reduce landfill emissions in terms of landfill gas and leachate such that environmental problems are not left to future generations [3]. Research in this field is currently focused on the creation of a landfill reactor that provides a reduction in landfill emissions over a relatively short time so-called bioreactor landfill. The design objectives of these landfills are to minimize leachate migration into the subsurface environment and maximize landfill gas generation rates under controlled conditions. Experimental and field-scale studies have been conducted to develop and improve landfill techniques and designs, the goal being to control the negative effects of landfill sites on the environment [4].

The bioreactor landfill provides control and process optimization, primarily through the addition of leachate. The advantages of leachate recirculation include distribution of nutrient and enzymes, pH buffering, dilution of inhibitory compounds, recycling and distribution of methanogens, liquid storage and evaporation opportunities [5]. The effectiveness of leachate recirculation has been well documented in lysimeter, test cell and full-scale studies [5–17].

The traditional method of landfill bioreactor operation involves enhancing anaerobic waste stabilization. Recently, increased interest has been focused on introducing air into the waste mass for aerobic degradation of solid wastes. Aerobic bioreactors have been promoted as a method for accelerating waste stabilization. Studies of aerobic biodegradation processes have demonstrated that the organic parts of the refuse can be degraded in a relatively short time compared with anaerobic

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degradation [18]. The concept of aerobic degradation by injecting air into a landfill presents significant alternatives in waste management both for existing and new systems. Air is typically injected into the landfill with the same devices used for extracting gas or injecting leachate, vertical and horizontal wells [19]. There has been increasing interest in aerobic landfilling during recent years, and many pilot-scale and field-scale studies have been recently undertaken [3,18,20–26].

The main purpose of the existing research is to investigate the effect of leachate recirculation on the behavior of the different options available for sanitary landfilling. In this study, the quality and the quantity of leachate from aerobic (A1 and A2) and anaerobic (AN1 and AN2) landfill reactors with (A1 and AN1) and without (A2 and AN2) leachate recirculation are determined and compared. Leachate quality is investigated by measuring pH, alkalinity, oxidation–reduction potential (ORP), total dissolved solids (TDS), conductivity, chloride (Cl^-) chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), and ammonia nitrogen (NH_3-N). The quality and quantity of leachate is observed for 250 days in aerobic reactors and for 500 days in anaerobic reactors.

2. Materials and methods

2.1. Aerobic and anaerobic landfill reactors

The laboratory-scale landfill reactors, which were constructed from 0.5 cm polypropylene and used in this study are shown in Fig. 1. Aeration pipes are used only in aerobic landfill reactors. The inner diameter and height of the reactors were 50 and 200 cm, respectively. A second layer with the diameter of 60 cm was constructed around the reactors and the blank between these two layers was filled with heat isolation material to prevent temperature redistribution between the reactors and the surrounding environment.

The lower part of the reactors consists of 15 cm gravel drainage with a perforated pipe, which has 2.5 cm diameter inserted to collect and discharge the generated leachate. Leachate collection was realized by opening the discharge valve on a daily basis at the beginning of the experiment, and at 1- or 2-week intervals for the following period. Leachate samples were collected while discharging leachate from the landfill reactors and kept at 4 °C in plastic bottles. The quantity of discharged leachate for each reactor was measured and then stored in a refrigerator to use for recirculation.

Landfill gas was collected via the perforated pipes, which were located in the center of each reactor (4 cm diameter and 170 cm height). Temperature probes were located at 60 and 120 cm depths from the top of the waste to measure temperature variation in each landfill reactor.

The solid waste added to the landfill reactors was obtained from the Odayeri Sanitary Landfill (Istanbul, Turkey). The average composition of solid wastes removed at Odayeri landfill is 44% organic, 8% paper, 6% glass, 6% metals, 5% plastic, 5% textile, 9% nylon, 8% diaper, and 9% ash and others [16]. A1, A2, AN1, and AN2 reactors were filled with 179, 174, 173, and 175 kg of fresh solid waste, respectively, with the waste representing the bulk composition of MSW determined by waste composition analysis.

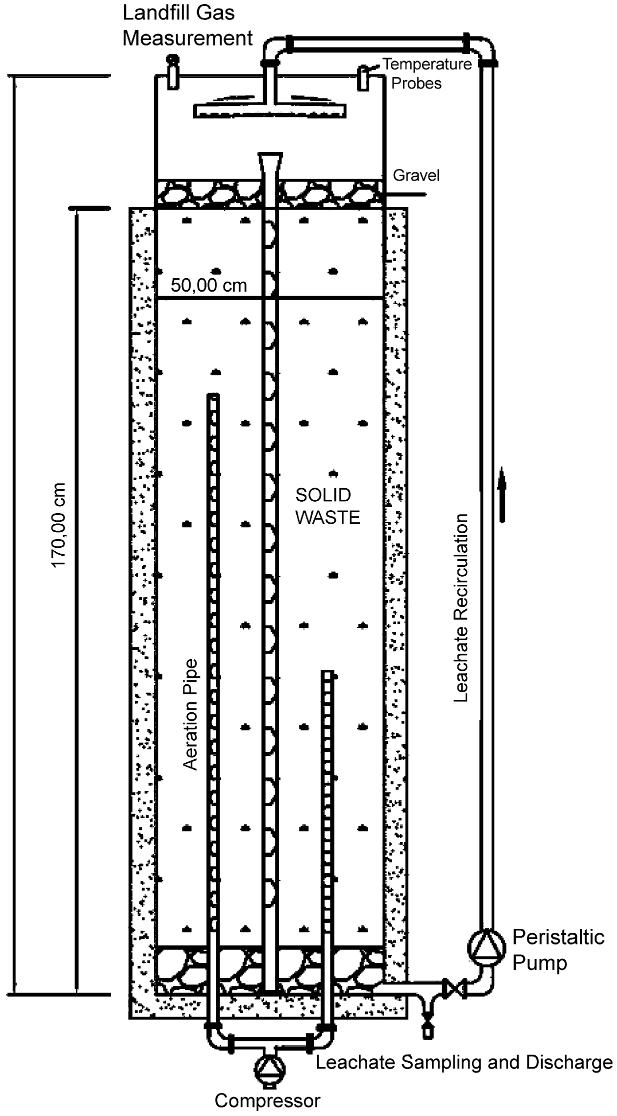

Fig. 1. Aerobic and anaerobic landfill reactors.

2.2. Aeration and leachate recirculation

The aeration was achieved by a compressor that was connected to the aeration pipes at the bottom of aerobic reactors. Air was introduced at the bottom of the waste and passed through the waste in an upward direction by the help of the perforated aeration pipes with 60 and 120 cm length in each aerobic reactor [27].

There is a wide range of aeration rates used in pilot and full-scale aerobic landfill studies in the literatures [2,21,25–31]. Cossu et al. [2], set up lab-scale tests to investigate different options for reducing long-term landfill emissions and they used an aeration rate of 0.22 L/(min kg) waste in their aerated landfill test. Smith et al. [21], used a 53.500 m^3 test cell to determine the potential of converting anaerobic process to more rapid aerobic process with an aeration rate of 0.0002 L/(min kg) of waste, assuming the specific weight of the solid waste landfilled to be 500 kg/m^3. Borglin et al. [25], used 200 L reactors with 30 kg of solid waste to determine the differences between aerobic and anaerobic biotreatment of municipal solid waste and they used aeration rates of 0.06 L/(min kg) waste in their study. Boni et al. [26], in their column study used an aeration rate of 0.03 L/(min kg) waste during 90 days. Keener et al. [28,29], summarized the operating conditions and experimental results of a large number of pilot aerobic bioconversion studies. The preferred aeration rate ranged from 0.35 to 0.97 L/(min kg). Bernreuter and Stessel [30], have recommended an aeration rate of 0.5 L/(min kg) of waste. Ishigaki et al. [31] used an aeration rate of 0.8 L/(min kg) waste in their 577 L volume reactor filled with 250 kg of synthesized waste in order to obtain detailed information on the stabilization of aerobic landfill.

Although a wide range of aeration rates for solid waste have been reported in the literature the general consensus is that an airflow that provides an outlet CO_2 concentration of about 15% is sufficient for the aerobic decomposition of solid wastes [32]. In this study, CH_4, CO_2 and O_2 concentrations within the effluent gas were measured to determine whether the quantity of the air was sufficient for aerobic decomposition of the solid waste. Gas monitoring analysis was carried out using a LMS-XI Model Landfill Gas Monitoring Device (Gas Data Limited, data not shown). Totally, 5400 m^3 air is added to each aerobic landfill reactor (during 250 days) and the aeration rates were equal to 0.084 and 0.086 L/(min kg) waste, respectively, for A1 and A2 reactors [27].

Leachate was recirculated using a peristaltic pump located at the top of the recirculated reactors. The recirculated leachate quantity was low at the beginning of the study. After reaching to methanogenic phase, the recirculated leachate quantity is increased in AN1 reactor. Temperature and leachate generation rates are used to determine the leachate recirculation rate in A1 reactor. In total, 29.4 L of leachate (29.4 L/(250 days 0.334 m^3 waste) = 0.35 L/(day m^3 waste)) was recirculated within the A1 landfill reactor, while this quantity was 35 L (35 L/(500 days 0.334 m^3) = 0.21 L/(day m^3 waste)) in AN1 reactor.

2.3. Leachate characteristics

Leachate samples collected from the A1, A2, AN1, and AN2 landfill reactors were analyzed to determine pH, alkalinity, oxidation–reduction potential (ORP), total dissolved solids (TDS), conductivity, chloride (Cl^-) chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), and ammonia nitrogen (NH_3-N) values. All analyses were realized according to the relevant methods described in the Standard Methods of APHA [33].

3. Results and discussion

3.1. Leachate quantity

The control of leachate quantity and quality is the basis for long-term landfill operation and leachate treatment. To secure long-term dewatering of landfills and reduce treatment costs it is necessary to control leachate quantity and quality. Leachate recirculation is a potential solution for on-site control and treatment.

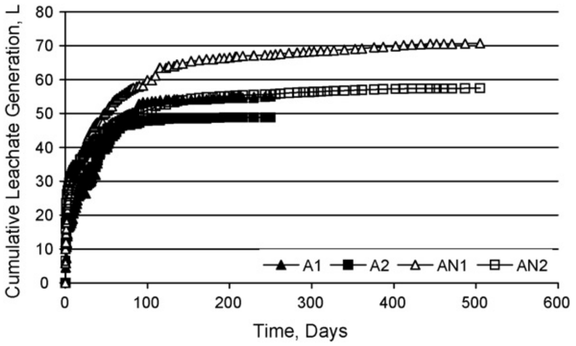

Fig. 2. Cumulative leachate generation in aerobic and anaerobic landfill reactors.

Cumulative leachate production from the reactors is shown in Fig. 2. The leachate generated from the A1, A2, AN1, and AN2 reactors is 55.1, 48.8, 70.7 and 57.5 L, respectively, while the recirculated leachate quantity is 29.4 L in the A1 reactor and 35 L in AN1 reactor. The recirculated leachate is 53.3% and 49.5% of the generated leachate in A1 and AN1 reactors, respectively. All of the leachate generated from the aerobic and anaerobic dry cells is discharged, while the discharged quantity in the A1 reactor is 55.1 − 29.4 = 25.7 L, and 70.7 − 35 = 35.7 L in AN1 reactor. Thus, the quantity of leachate generated from A1 reactor decreased by 47.3%, 28%, and 55.3% when compared with A2, AN1 and AN2 reactors, respectively. Similarly, the quantity of leachate decreased by 26.8% and 37.9% in AN1 reactor when compared with A2 and AN2 reactors, respectively.

The decrease in leachate quantity in the A1 reactor is caused by the evaporative effects of the waste temperature and the effects of air-drying of the waste. Also leachate recirculation has shown to provide the opportunity for leachate volume reduction [5].

3.2. Leachate quality

3.2.1. pH, alkalinity, and oxidation–reduction potential

The pH curves (Fig. 3) show that, pH values were in the range of 4–6 in the first 30 days of degradation in all reactors. After

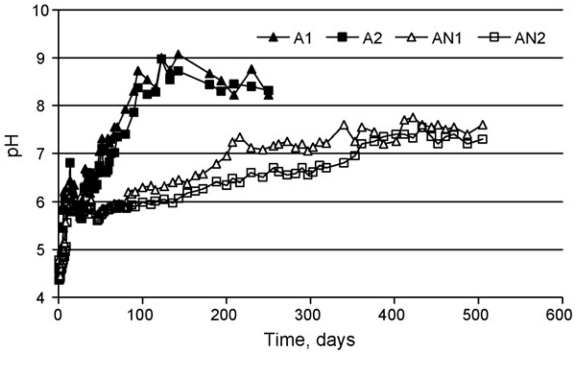

Fig. 3. The change of pH in aerobic and anaerobic landfill reactors.

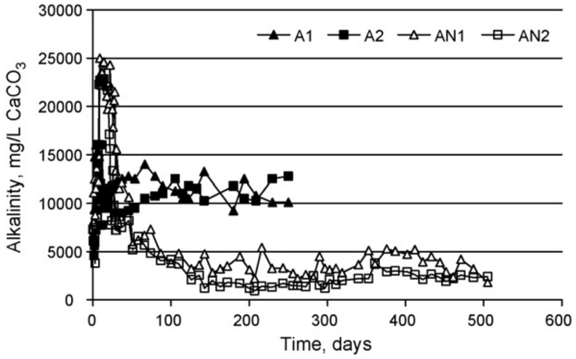

Fig. 4. The change of alkalinity in aerobic and anaerobic landfill reactors.

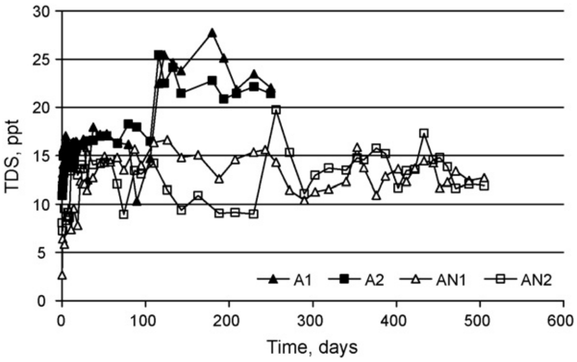

Fig. 6. The change of TDS in aerobic and anaerobic landfill reactors.

day 30, pH values began to increase and reached to 8 after day 100 in aerobic reactors. After that, no considerable change was observed in pH of leachate from aerobic landfill reactors and measured between 8 and 9. At day 100, the pH values were 6.3 and 6.0 in AN1 and AN2 reactors, respectively. On day 250, when aerobic landfilling operation is finished, pH of the leachate from AN1 and AN2 reactors were 7.2 and 6.7, respectively. These results show that when aerobic degradation of solid wastes completed, the AN1 reactor reaches to optimal pH values for anaerobic degradation, indicating the rapid degradation of solid wastes in aerobic conditions. These results are in accordance with the data stated by Cossu et al. [2], Ishigaki et al. [31], and Nakasaki et al. [34].

Farquhar and Rovers [35] suggested that a system would need an alkalinity of at least 2000 mg/L to maintain an optimum methanogenesis. In this regard, both aerobic and anaerobic landfill reactors show a good pH buffer capacity as reflected by the high total alkalinity as shown in Fig. 4. It can be seen from Fig. 4 that there is adequate alkalinity in all stages of both aerobic and anaerobic degradation in reactors.

The redox potential within a landfill determines the mechanism of waste degradation. Generally, high redox potential (aerobic conditions) causes accelerated degradation of waste [36]. It has been suggested in the literature [7,35,37] that there is an optimum oxidation–reduction potential (ORP) requirement for methanogenesis, which generally ranges from −100 to −300 mV. The results of ORP are plotted in Fig. 5.

ORP tests are very sensitive to sample storage time. The reading may rise fairly rapidly and become a lot more positive when it is tested only hours after sampling. Thus, ORP tests are done immediately at the time of sampling [38]. At the beginning of the operation, all reactors have the same ORP values. After the consumption of the available oxygen in anaerobic reactors, ORP values began to decrease indicating the degradation is shifting from acidogenic phase to methanogenic phase. After day 180, ORP decreased below −200 mV in AN1 reactor, while AN2 reactor reached to this value after 300 days. Oppositely, ORP is increased in both A1 and A2 reactors and reached 200 mV values after 115 and 140 days, respectively.

3.2.2. Total dissolved solids and conductivity

Based on a statistical evaluation, Kylefors and Lagerkvist [39] reported that total solids (TS) concentration is expected to decrease as the leachate moves from acidogenic to methanogenic. Yuen [38], reported the same results for total solids, but indicated that the dissolved solids concentrations do not change in large quantities as total solids.

Fig. 6 gives the TDS measurement results of aerobic and anaerobic landfill reactors. TDS concentrations varied between 10 and 15 ppt except the beginning period in anaerobic reactors. TDS concentrations were higher in AN1 reactor during the first 250 days, as a result of leachate recirculation. TDS concentrations were higher than anaerobic reactors in aerobic reactors during all the periods of the study. TDS concentrations reached to 20–25 ppt after 100 days and continue at this level until 250 days.

Fig. 7 shows the measurement of conductivity serving as another concentration indicator. The trend in conductivity is the same as TDS for both aerobic and anaerobic landfill reactors.

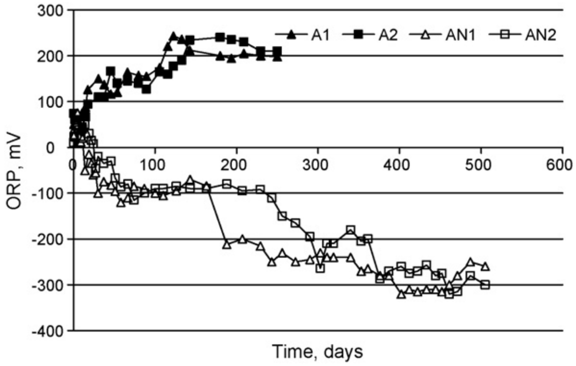

Fig. 5. The change of ORP in aerobic and anaerobic landfill reactors.

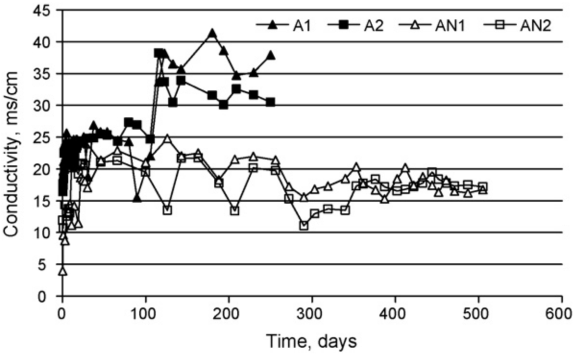

Fig. 7. The change of conductivity in aerobic and anaerobic landfill reactors.

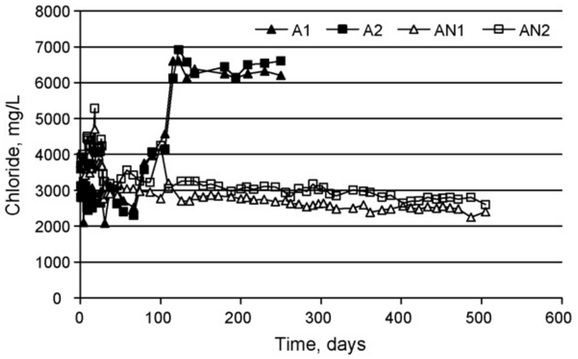

Fig. 8. The change of Cl^- concentrations in aerobic and anaerobic landfill reactors.

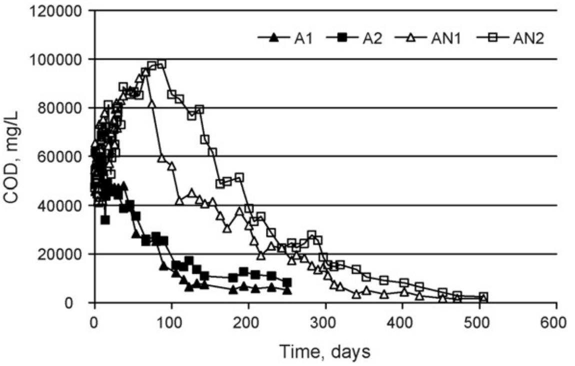

Fig. 9. COD concentrations in aerobic and anaerobic landfill reactors.

3.2.3. Chloride

Chloride is a non-degradable conservative parameter and the change of its concentration is commonly used to assess the variation of leachate dilution. Ehrig and Scheelhaase [40] suggested that there is no observable difference in chloride concentration between acidogenic and methanogenic phases. A similar observation by Andreottola and Cannas [41] revealed that in non-recirculation landfills, chloride concentration is expected to decrease very slowly with landfill age due to washout by infiltrating water.

Fig. 8 shows variation in Cl^- concentrations in the aerobic and anaerobic landfill reactors. Compared with conductivity in Fig. 7, there is a close correlation between the two parameters observed at all reactors. This reflects that chloride played a significant role in the conductivity measurement. The comparison also provides a good indication regarding the reliability of both parameters.

There is no considerable change in Cl^- concentrations of leachate generated from AN1 and AN2 reactors. The results obtained from the last measurements were 2400 and 2600 mg/L for AN1 and AN2 reactors, respectively.

At the beginning of the landfilling operation, Cl^- concentrations were 3000 and 2800 mg/L for the A1 and A2 reactors, respectively. After 80 days of operation, Cl^- concentrations began to rise rapidly and reached values of 6100 and 6900 mg/L after 120 days for the A1 and A2 reactors, respectively. After this rapid increase, no considerable change was observed during the rest of the study. Cl^- concentrations within the A1 and A2 reactors were determined to be 6200 and 6600 mg/L, respectively, after 250 days.

It is interesting that the pH (Fig. 3) and Cl^- concentrations began to increase simultaneously in the A1 and A2 reactors. This situation can be explained by the findings of Manning and Robinson [42]. As a result of the increase in pH, the dissolution of chloride increases and thus the chloride concentration in the leachate increase.

3.2.4. COD

Fig. 9 shows the variation of COD in leachate from aerobic and anaerobic reactors. The initial COD concentrations were around 40,000 mg/L for all reactors. COD concentrations increased to maximum values of 68,500, 63,500, 94,000, and 98,000 mg/L for A1, A2, AN1, and AN2 reactors after 10, 8, 65, and 85 days of operation, respectively. After reaching to maximum values, COD concentrations began to decrease rapidly, and the concentrations on days 120 and 250 were determined as 6500–5000, 17,000–8000, 45,000–17,200, and 76,500–24,500, for A1, A2, AN1, and AN2 reactors, respectively. The last concentrations determined in AN1 and AN2 reactors on day 500 were 1600 and 2400 mg/L, respectively.

Cossu et al. [2], found in their column study that the COD values of leachate from aerobic dry and wet reactors were lower than from an anaerobic reactor. They found that after 120 days of operation the COD value of the anaerobic landfill reactor was approximately 20000 mg/L, while equivalent values were 3000 and 800 mg/L in the aerobic dry and wet reactors, respectively.

The results of the present study are similar to those of Cossu et al. [2] and clearly show that, aeration and leachate recirculation has a positive effect on the rate of solid waste degradation in landfills.

The ratio of measured COD to the maximum COD determined in each reactor is given in Fig. 10. It can be seen from the figure that, COD removal is realized more rapidly than others in A1 reactor. COD removals on day 250 are determined as 93%, 87%, 82%, and 75% for A1, A2, AN1, and AN2 reactors, respectively. Results indicate the positive effects of leachate recirculation on aerobic and anaerobic degradation of municipal solid wastes clearly.

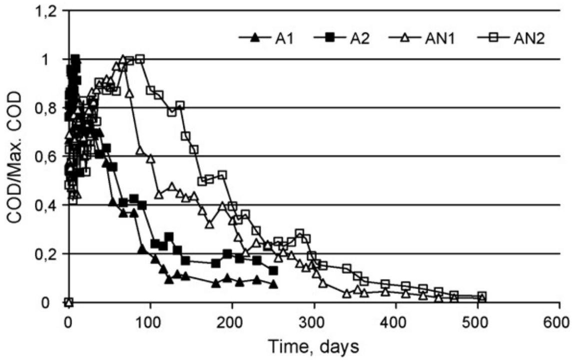

Fig. 10. COD/max. COD in aerobic and anaerobic landfill reactors.

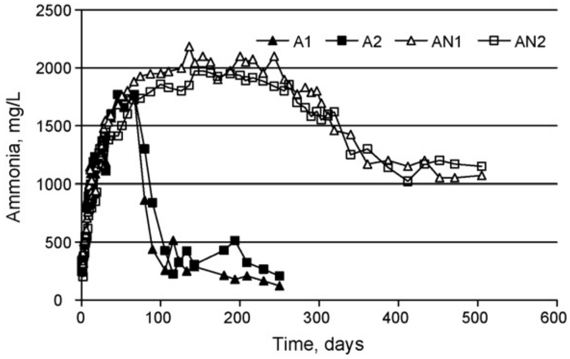

Fig. 11. Ammonia concentrations in aerobic and anaerobic landfill reactors.

3.2.5. *Ammonia and TKN*

The evolution of ammonia and TKN concentrations in aerobic and anaerobic landfill reactors are given in Figs. 11 and 12, respectively. The highest ammonia concentrations were measured to be 1700, 1800, 2100, and 1950 mg/L for A1, A2, AN1, and AN2 reactors, respectively. Ammonia concentrations were 120 and 200 mg/L for A1 and A2 reactors, and 1900 and 1800 mg/L for AN1 and AN2 reactors on day 250. Differences between aerobic and anaerobic reactors show the nitrification effect.

Landfill leachate treatment generally focuses on the removal of organic nitrogenous and carbonaceous matter and ammonia nitrogen. Most of the nitrogen in solid waste bioreactors is in the form of ammonia and is produced from the degradation of proteins and amino acids [43]. Several researchers have identified ammonia as the most significant long-term component of leachate [1,44], as there is no mechanism for its degradation in anaerobic landfills. Ehrig and Scheelhaase [40] proposed that in general there should be no apparent increase or decrease in the concentration of all nitrogen groups during the anaerobic degradation of solid waste. Kruempelbeck and Ehrig [1], reported that there was no significant change in ammonia concentrations over a 30-year period in conventional landfill leachate, and that the average value over this time was 500 mg/L.

The most of the nitrogen in aerobic and anaerobic landfill reactors is in the ammonia forms following the degradation of protein and amino acids [45,46]. Thus, the same evolution for TKN concentrations is observed during the study. According to Figs. 11 and 12, it can be seen clearly that ammonia can be in situ treated by aerobic landfilling and leachate recirculation.

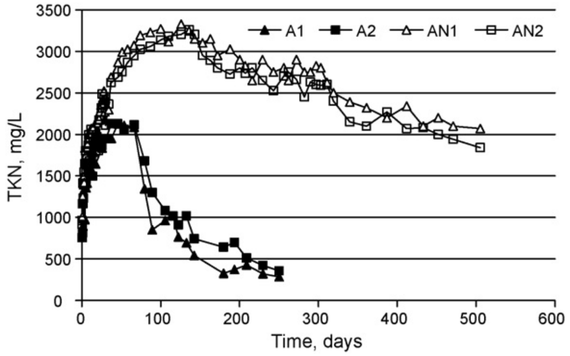

Fig. 12. TKN concentrations in aerobic and anaerobic landfill reactors.

4. Conclusions

A comparison of the emissions from four laboratory-scale landfill reactors, operating under different conditions indicates the following results:

- The addition of air strips moisture from the landfill and provides advantages for drying out landfill and minimizing leachate production. Also, leachate recirculation decreases the amount of the discharged leachate in both aerobic and anaerobic landfills.
- Aerobic landfill with leachate recirculation shows the lowest emissions for leachate, with low concentrations of COD, ammonia and TKN.
- Higher pH values cause the dissolution of some chemicals that do not degrade or transform under anaerobic conditions. Thus, the conductivity, TDS, and chloride concentrations are higher in anaerobic landfills.
- Aeration of the waste mass produces a rapid and marked oxidation of organic matter and nitrogen when compared with traditional anaerobic and anaerobic bioreactor landfill operations.
- The main difference between the recirculated and non-recirculated aerobic landfill operations is determined in leachate quantity. Leachate quality does not show considerable changes in both aerobic landfill operations.
- The positive effect of leachate recirculation is more clearly in anaerobic landfill operation than aerobic landfills.
- Lab-scale tests show that the aerobic landfill concept reduces long-term landfill emissions. Further studies are going on in order to determine the optimum operational conditions for leachate recirculation and aeration in landfills.

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