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Effect of In-situ Aeration on Leachate Qualities under Uncompacted Municipal Solid Waste Disposal Conditions

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Abstract

This research was carried out to investigate the effect of in-situ aeration on leachate qualities in simulated lysimeters containing uncompacted municipal solid wastes representing typical municipal solid waste disposal conditions in Thailand. The study was performed by applying different aeration conditions to the lysimeters and leachate volume and its chemical characteristics were monitored over 6 months. The air supply conditions varied from natural ventilation to active aeration at rates of 0.18 and 0.36 l/min. The generated leachate was compared to the control lysimeter representing typical anaerobic disposal conditions. The lysimeters operated at a high airflow rate of 0.36 l/min and natural ventilation had their leachate qualities in terms of organic (BOD, COD) and nitrogen (TKN) well stabilized by more than 90% within 30 days. Under low aerated conditions (0.18 l/min), organic stabilization in leachate required more than 100 days whereas TKN removals were also highly fluctuated. Based on the results from this study, waste disposal operation under natural aeration through a ventilation pipe installed into the uncompacted waste layer would be sufficient to reduce organic and nitrogen pollutants in leachate to the same level as the highly aerobic landfill condition.

Keywords : Landfill aeration; Leachate generation; Leachate quality; Waste stabilization

Introduction

Direct land disposal of fresh municipal solid wastes (MSW) is practiced in most developing countries. Conventional landfills are mostly designed so that the disposed wastes are kept isolated from the outside environment causing a dry anaerobic environment, which is unfavorable for microbial decomposition. Therefore, waste stabilization processes take a long time, and products from land disposal of MSW such as gas and leachate are continuously generated, demanding long-term monitoring and pollution control [1]. To mitigate these problems, new operating techniques were developed in an attempt to accelerate the waste stabilization process and reduce pollutant discharge such as the use of the bioreactor concept through leachate recirculation and storage [2, 3] or the development of the aerobic condition in the waste matrix [4].

The aeration concept has been introduced for waste stabilization and reduction of environmental impacts. The introduction of air could accelerate the microbial degradation process and reduce pollutant emissions both in terms of gaseous and leachate forms. Aerobic conditions in waste disposal areas can be promoted either through passive or active aeration methods. In Japan, naturally aerated landfills so-called "semi-aerobic landfills" have been developed by Fukuoka University where leachate and gas are continuously removed from the waste mass using leachate collection and gas venting systems allowing ambient air flows into the waste body [5]. Meanwhile, the active aeration method using a mechanical air-pressurized system is popularly implemented in

European countries [6]. In-situ aeration through pipes applied in a shallow landfill provided a widespread distribution of air into the waste body [7]. The air intrusion into the waste body leads to the subsequent improvement of waste stabilization and leachate qualities due to the enhancement of aerobic microbial activities within the waste cell [8]. Under aerobic conditions, organic matter present in wastes is subjected to biodegradation by aerobic microorganisms to carbon dioxide and water. Enhancement of organic carbon mineralization under aerobic treatment compared to that of anaerobic treatment has been confirmed [9]. Development of aerobic conditions in landfills resulted in rapid reduction of organic pollutants and reduction of methane emission [10]. In this regard, it was reported that aerobic treatment led to lower emissions due to the increased sorption capacity of aerated wastes than a lower overall pollutant potential [9]. Leachate qualities were found to be significantly improved under semi-aerobic and aerobic conditions in the landfills when compared to conventional anaerobic landfills [11, 12]. Ma et al. [13] reported the effects of aeration on the improvement of leachate qualities reaching 97% of Chemical Oxygen Demand (COD) and 88% of ammonium nitrogen (NH_4^+) removals. Liu et al. [14] also reported the beneficial effects of providing micro-aeration and leachate recirculation on the acceleration of landfill stabilization through promoting hydrolytic activities.

Despite the obvious advantages of providing semi-aerobic and aerobic conditions in MSW disposal sites, the effect of aeration either provided through active or passive aeration operation on the waste matrix is still unclear. Some previous attempts have been performed using intermittent aeration operation [12, 15] pre-aeration [16], or aeration during leachate recirculation [17]. In a previous review of landfill aeration research [18], optimum aeration rates were found to vary widely ranging from 0.00006-4.51 l/min/kg dry mass depending on aeration mode (continuous or intermittent), waste characteristics (fresh or old) and disposal condition (low or high waste densities) and operating conditions such as temperature and leachate recirculation practice. Meanwhile, clear operation guidelines to achieve appropriate aerobic conditions in MSW disposal sites under different waste disposal and climatic conditions have not been developed especially those disposed as uncompacted waste under high moisture conditions which is the predominated condition of MSW in Thailand. In this study, the effect of in-situ aeration on leachate characteristics was experimentally investigated to determine appropriate conditions for reducing leachate pollution from MSW disposal sites in Thailand.

Materials and Methods

Experimental set-up

Laboratory-scale lysimeters were made of acrylic with 0.3 m diameter and 1.5 m height (Figure 1). They were filled with MSW obtained from a local authority in Thailand to an initial height of 1.0 m and covered with a sand layer of 0.3 m. Major waste components were 63.5% food waste, 4.9% paper, 14.4% plastic, and 10.2% glass (Table 1), representing typical MSW composition received at solid waste disposal sites in Thailand. Four lysimeters were operated under different conditions. The first lysimeter was operated under anaerobic conditions as the control experiment. Another two lysimeters were operated at different aeration rates of 0.18 and 0.36 l/min supplied by an air blower. The other lysimeter was operated under passive aeration (natural ventilation) through a vertical pipe (1 in. diameter). The amount of MSW placed in each lysimeter was 25.7 kg wet weight (or 7.7 kg dry mass) except for that of natural aeration in which 23.9 kg of wet wastes (or 7.2 kg dry mass) were added due to lower active lysimeter volume from vertical aeration pipe placement. The initial waste densities in all lysimeters were set equally at 385 kg/m^3. The aeration rates in aerated lysimeters were set equivalent to 0.023 and 0.046 l/min/kg dry mass of solid waste which were reported as optimum conditions in previous landfill aeration studies [19-20]. In those researches, aeration rates of 0.027-0.043 l/min/kg dry mass were reported as appropriate conditions for fresh waste disposed under low compaction densities (350-384 kg/m^3).

Table 1 presents the physical composition and chemical characteristics of solid wastes used in this study. The chemical analyses of solid wastes were performed according to the procedures provided by the Soil and Plant Analysis Council [21]. During the lysimeter operation, waste temperature and settlement were also monitored weekly.

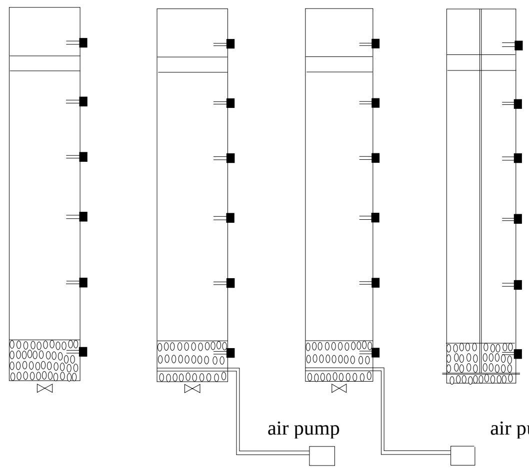

Figure 1 Experimental lysimeters with different aeration set-up

Table 1 Composition and chemical characteristics of MSW

Composition	Percentage (wet wt.)
Food wastes	63.55
Paper/Newsprint/cardboard	4.86
Plastics	14.44
Rubber	0.32
Textile	2.07
Wood	0.84
Glass	10.21
Metals	1.60
Others	2.11
Chemical characteristics	**Percentage**
Moisture	69.92 (wet wt.)
Volatile solids (VS)	93.45 (dry wt.)
Carbon (as TOC)	56.20 (dry wt.)
Nitrogen (as TKN)	3.34 (dry wt.)

Lysimeter operation, sampling, and analyses

The lysimeters were operated and monitored for 6 months. The temperature inside the lysimeters was measured at four different levels along the waste height, i.e. 0.2, 0.4 m, 0.6, and 0.8 m. from the bottom of lysimeters using thermometers. During the experimental period, waste layer height, leachate volume, and chemical characteristics were monitored regularly. The determining parameters included pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), nitrite (NO_2^-), and nitrate (NO_3^-). All water quality analyses were performed according to Standard Methods for the Examination of Water and Wastewater [22].

Results and Discussion

Waste characteristics in lysimeter

Figure 2 shows waste subsidence in the lysimeters during 6 months of operation. The control lysimeter had about 10% settlement, significantly lower than the other aerobic lysimeters (25-35%). Comparatively, the lysimeters with active aeration had higher waste subsidence than passively aerated lysimeters, especially after about 100 days of operation. The higher settlement rate observed in the aerobic lysimeters could relate to faster biodegradation of organic wastes under aerobic conditions. Figure 3 shows the average temperature of solid waste in the lysimeters. While the temperatures were found to fluctuate with time, it was noticed that higher average temperatures were temporally detected in aerated lysimeters compared to the control lysimeters, especially during the first 100 days of operation. This temperature rise indicated the heat released from the aerobic decomposition of organic wastes. It was also noted that higher temperature was detected at the bottom part of the lysimeters where aeration was introduced. This observation suggests that aerobic conditions prevailed in the aerated lysimeters. The temperatures in the lysimeter supplied with a higher aeration rate (0.36 l/min) were found relatively stable than the others, especially during the early stage of operation. Meanwhile, the lower aerated lysimeter (0.18 l/min) had its temperature highly fluctuated possibly due to the occurrence of facultative or semi-aerobic conditions with temporal temperature rise observed twice during the experimental period, i.e. after the first week and towards 100 days of operation. These results also suggested that a more uniform distribution of supplied air took place in the lysimeter operated at a higher aeration rate of 0.36 l/min. These temperature-rise incidents were followed by high waste subsidence observed in the lysimeter so they are expected to be associated with the waste degradation. Under natural ventilation conditions, the highest temperature was observed during the start-up period and it declined to the same level as the other lysimeters and mostly became stable afterward whereas the waste subsidence suggested its conditions were between the control (anaerobic) and active aeration conditions.

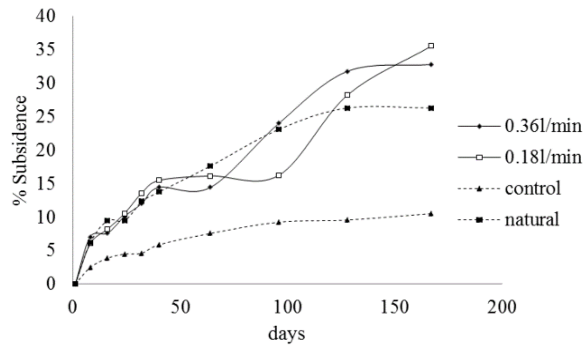

Figure 2 Waste subsidence in the lysimeters

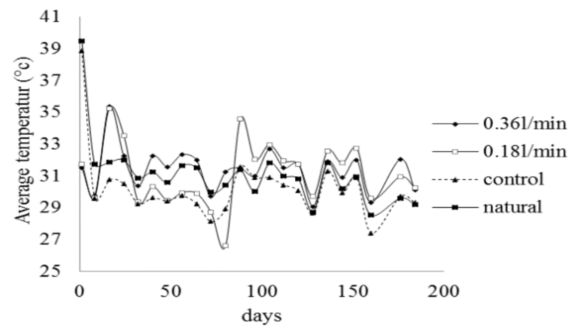

Figure 3 Variation of temperatures of waste in the lysimeters

Leachate quantity and qualities

During the lysimeter operation, the amount of leachate formed and drained from the lysimeters was recorded. The total cumulative volume of leachate from the control lysimeter was found to be approximately 2 liters whereas the highest detected volume was 8 liters from the naturally ventilated lysimeter as shown in Figure 4. The two aerated lysimeters have about the same volume of leachate at about 6.5 liters but it was found that the lysimeter with a higher aeration rate produced leachate faster than the other during the early stage of operation. The amount of leachate produced primarily comes from the original moisture content in waste as well as that produced from organic waste degradation. The reduction of organic matter in solid waste during its degradation also reduced water holding capacity of landfilled waste whereas a greater ventilation rate resulted in lower water content of landfilled waste due to the water evaporation effect [23]. Comparing aerated and naturally ventilated lysimeters, a higher volume of leachate was observed in naturally ventilated lysimeter as most of the moisture loss occurred only through leachate formation in the lysimeter whereas those aerated lysimeters had their moisture loss occurred through leachate formation as well as evaporation of water.

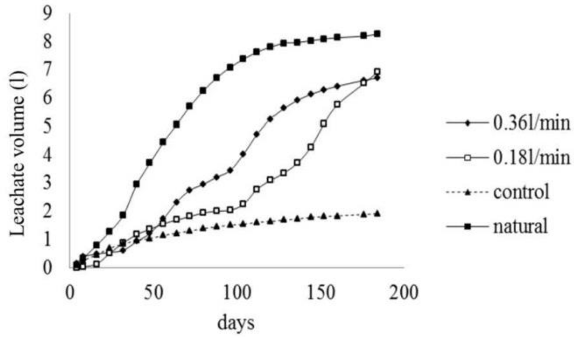

Figure 4 Cumulative leachate volume produced during lysimeter operation

Figures 5a) to 5e) show the chemical characteristics of leachate from the lysimeters in terms of pH, BOD, COD, TKN, and oxidized nitrogen. Leachate from the control lysimeter was found to be acidic and contained higher organic and nitrogen concentrations. Meanwhile, other aerobic lysimeters produce more stabilized leachate, being alkaline while containing low BOD, COD, and TKN concentrations after 30 days of operation and became stable mostly during the whole experimental period. The oxidized nitrogen was also detected in leachate from those aerobic lysimeters but at much lower concentrations when compared to TKN. These results indicate that aerobic condition in the lysimeters has significantly improved leachate qualities and simultaneous nitrification and denitrification reactions possibly took place in the lysimeters according to the following reactions assuming organic matter available for denitrification reaction was in the form of acetic acid.

- Nitrification reaction:
$NH_3 + 2O_2 \rightarrow H^+ + NO_3^- + H_2O$

- Denitrification reaction:
$5CH_3COOH + 8NO_3^- \rightarrow 4N_2 + 10CO_2 + 6H_2O + 8OH^-$

Among the aerated lysimeters, the lysimeter with the highest aeration rate (0.36 l/min) had the lowest organic pollutant leaching out during its operation. Meanwhile, the lysimeter with natural ventilation conditions also yielded good and stable leachate qualities which suggested that the air supply was sufficiently provided for its leachate stabilization. Under lower aeration conditions (0.18 l/min), the qualities of leachate fluctuated and it took longer time up to more than 100 days to be stabilized. However, this stabilization period (100 days) is similar to that reported for leachate stabilization in the semi-aerobic recirculation process [24] but comparatively shorter than that of large-scale simulated semi-aerobic landfills reported at 48 weeks [25]. These results also suggested that air supply into un-compacted waste under natural ventilation conditions was similar to that of a higher aeration rate of 0.36 l/min whereas there was no uniform distribution of air at a lower aeration rate of 0.18 l/min for leachate stabilization.

The pollutants load from produced leachate was determined from the leachate amount and pollutant concentrations at the end of the lysimeter operation. Comparing among the lysimeters, it was found that the lysimeter operated at a higher aeration rate (0.36 l/min) yielded the lowest pollutant load as it had their organic and nitrogen pollutants well stabilized whereas its leachate amount was similar to that observed in lower aerated condition and lower than of natural ventilation lysimeter. However, pollutant load from natural ventilation conditions was also not very much higher due to a similar degree of leachate stabilization achieved though a larger volume of leachate of about 20% was observed. Meanwhile, the control lysimeter had the highest pollutant load due to high pollutant concentrations contained in leachate even though it produced a lesser amount of leachate.

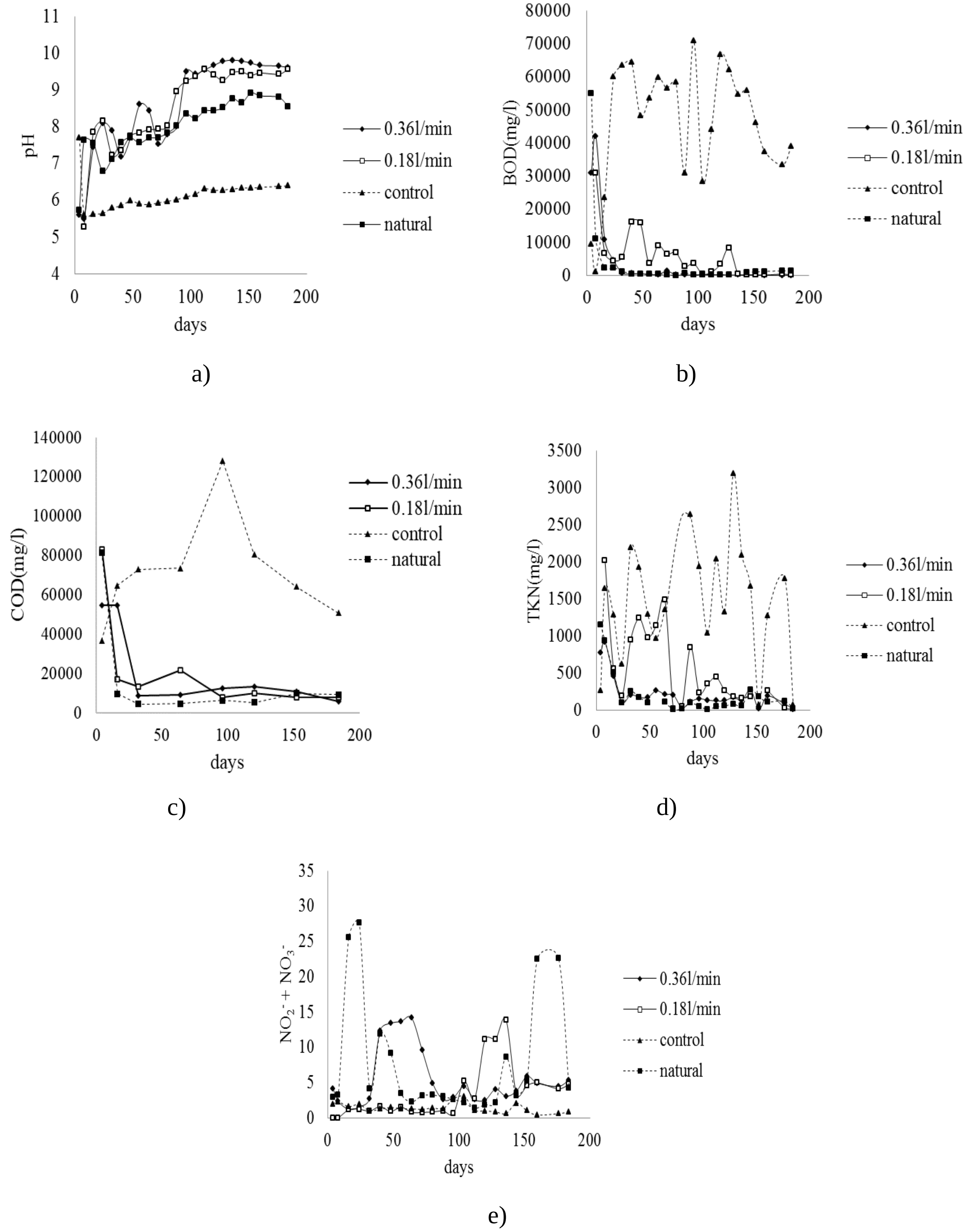

Figure 5 Variations of leachate characteristics a) pH, b) BOD, c) COD, d) TKN, e) NO_X of the lysimeters

Conclusions

The effect of aeration on improved leachate qualities from uncompacted solid waste disposal was confirmed in lysimeter experiments. The lysimeters operated at a higher air flow rate (0.36 l/min) and natural ventilation had their leachate qualities in terms of BOD and COD well stabilized by more than 90% within 30 days whereas those in low airflow condition (0.18 l/min) required more than 100 days. Meanwhile, organic substances in leachate were not stabilized during the whole experimental period under anaerobic conditions. TKN removals of more than 90% were also achieved in the lysimeters with 0.36 l/min air flow rate and natural ventilation after 30 days whereas their removals fluctuated under low air flow rate and anaerobic conditions. The majority of nitrified nitrogen was denitrified in the lysimeters resulting in low oxidized nitrogen in the leachate. The supply of sufficient air through active aeration at a higher rate (0.36 l/min) or natural ventilation significantly improved and accelerated organic waste degradation and leachate stabilization from the traditional anaerobic conditions. This in-situ aeration utilizing ventilation pipes installed into the uncompacted waste layer could help reduce leachate pollution from solid waste disposal sites in Thailand, similar to that of aerated landfills.

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