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Treatment of leachate by recirculating through dumped solid waste in a sanitary landfill in Addis Ababa, Ethiopia

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ABSTRACT

In order to study the effect of leachate recirculation on the quality of leachate and as an in-situ ammonia–nitrogen removal mechanism, two polyvinyl chloride pipes compacted with a similar raw material composition and working with 4 mL/min and 8 mL/min leachate recirculation flow rate were continuously operated for nine consecutive weeks. In this laboratory scale study, wastewater quality indicator parameters including TS, BOD_5, and two selected heavy metals Pb and Cu were used. To this end, the raw material characterization data indicates that all the materials compacted in the reactor were suitable for recirculation of leachate. We found 84.32% BOD_5, 82.24% TS, 88.97% COD, 79.2% NH_4^+–N and 94% Cu removal efficiency that was operated at 4 mL/min in R_1 and 66.45% BOD_5, 75% COD, 62.98% TS, 67.47% NH_4^+–N and 79.32% Cu achieved removal efficiency at 8 mL/min in R_2. The overall study indicates that leachate recirculation can serve as an in-situ treatment of leachate, even for ammonia nitrogen removal and old landfill leachate, if the working conditions are maintained in appropriate manner.

1. Introduction

Solid waste management (SWM) is in crisis in many of the world's largest urban areas due to rapid population growth that is resulting in ever increasing quantities of domestic solid waste and decreasing space for waste disposal (World Bank, 1999). Nevertheless, landfill as a SWM approach has been neglected in many communities (Salvato et al., 2003). Associated with this approach, one of the greatest concerns is the production of landfill leachate, an aqueous effluent generated as a consequence of rainwater percolation, leaching of solid waste moisture content, water production due to biochemical process, and ground water entering into the waste mass during and/or after operation of a landfill (Warith, 2003). Its potential for degrading water, soil and receiving ecosystems is widely recognized (Nyame et al., 2012).

A new and promising trend in leachate management is treating the landfill as a bioreactor in which moisture control and/or air injection are used to enhance the creation of a solid waste environment capable of actively degrading the biodegradable organic fraction of the waste. Moisture control, usually accomplished via leachate recirculation, can be an effective method of leachate treatment (Ozkaya et al., 2004).

Since leachate consists of several common types of contaminants such as heavy metals, ammonia nitrogen, organic matter, microorganisms and solid particles, it is one of the major issues of environmental conservation. Thus, to discharge a leachate containing these contaminants into surface water bodies and groundwater will negatively impact on the receiving environment (Warith, 2002).

On the other hand, ammonia–nitrogen levels found in leachate from bioreactor landfill are much higher than those found in conventional landfill. Although recirculating leachate decreases organic matter constituents, it results in an increase in ammonia–nitrogen concentrations. An effective in-situ treatment of this pollutant would be very advantageous, potentially resulting in both environmental and economic advantages (Reinhart, 2007).

Since the potential negative impacts of leachate on a receiving environment depends on the sensitivity of the reserving

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environment and the type and amount of the pollutants embraced in it, the removal or reduction in the quantity of contaminants to environmentally acceptable levels is urgently needed to maintain the integrity of the biotic environment and minimize public health risks.

Commonly practiced leachate treatment methods, such as flocculation/precipitation, activated carbon adsorption, membrane filtration, and chemical oxidation are complicated, expensive and generally require multiple processes. Therefore, the identification and application of effective in-situ treatment technologies is urgently needed in developing countries, including Ethiopia.

To this end, this study was carried out by using lab scale landfill bioreactors containing approximately 9.4 kg of waste, in order to follow leachate output quality over a nine week period.

2. Material and methods

2.1. Materials

2.1.1. Sources of data

Primary data concerning leachate and solid waste were obtained from Addis Ababa open solid waste dumping site, Rephi, while black cotton soil was collected from the local Chebi–Weregenu sanitary landfill site. Then the leachate samples collected from Rephi open dump site were analyzed for the presence and amount of COD, BOD_5, pH, NH_4^+–N, Pb and Cu concentration at JIJE LABOGLASS analytical testing service and Addis Ababa environmental protection authority laboratories. The other variables considered in this study were analyzed at Addis Ababa Institute of Technology, School of Chemical and Bio-Engineering Department laboratory. Soil characterization was performed before and after treatment at the central laboratory of the Geological Survey of Ethiopia.

2.1.2. Sample analysis

The targeted physical and chemical pollutants (pH, TS, TDS, TSS, BOD_5, COD, TOC, alkalinity, NH_4^+–N, Pb and Cu) of the leachate during characterization and throughout the experiment were analyzed each week in accordance with standard methods for examination of water and wastewater (APHA, 2000).

2.2. Methods

2.2.1. Experimental setup of the study

For the removal of organic constituents, dissolved solids, and selected heavy metals the reactors and the landfill cell were prepared in the following manner:

2.2.1.1. Reactor preparation. The reactors were made by loading locally available polyvinyl chloride pipe (PVC) with 9.42 kg of unshredded solid waste. A 0.05 m layer of gravel with a nominal diameter ranging from 12 to 20 mm was placed at the bottom of the bioreactor and then a circular nylon screen was placed on the gravel layer as the basement to prevent clogging of the reactor. A 0.15 m deep layer of locally available black cotton was placed on both the top of the gravel and waste layers as a cover and further to provide even distribution of the recirculated leachate. Finally, the bioreactor cell cover was placed on top and the whole unit was sealed.

2.2.1.2. Solid waste loading. During loading of the manually compacted municipal solid waste (MSW), the waste was properly mixed and then covered with soil in order to minimize the problem of channeling. Furthermore, according to Tchobanoglous et al. (1993), typical MSW is compacted to a density of 500–700 kg/m^3. In this study, the MSW was compacted to a density of 600 kg/m^3 and soil to a density of 1300 kg/m^3.

Since the size of the reactors and the raw materials they contain is critical in the loading activity, with some engineering modification both in its operation and size, the Gawalpanchi et al. (2007) and Jirapure and Khedikar (2011), setups were used as a benchmark.

2.2.1.3. Municipal solid waste preparation. For the preparation of the solid waste fed to the reactors, the amount of waste from each composition was taken from Rephi open dump site based on the solid waste composition data obtained from Addis Ababa solid waste reuse and disposal project office. In the sorting activity, special wastes were discarded and the remaining material was sorted proportionally to obtain the required 9.4 kg of solid waste in the bioreactors, for each reactor. In order to assess leachate recirculation as in-situ treatment of ammonia which is a greater problem of bioreactor landfill than conventional landfills, oxygen was introduced to the overall set up mentioned above for nitrification denitrification process using an oxygen cylinder. Moreover, varied amounts of oxygen were introduced throughout the experiment based on the concentration of ammonia nitrogen concentration during each consecutive week, based on the following equations.

Nitrification equations

$$NH_4^+ + 1.5\,O_2 \rightarrow 2H^+ + 2H_2O + NO_2^-$$

$$NO_2^- + 0.5\,O_2 \rightarrow NO_3^-$$

$$NH_4^+ + 1.83\,O_2 + 1.98\,HCO_3^- \rightarrow 0.021\,C_5H_7O_2N + 0.98\,NO_3^- + 1.041\,H_2O + 1.88\,H_2CO_3^-$$

$$NH_4^+ + 1.9\,O_2 + 2HCO_3^- \rightarrow 1.9\,CO_2 + 2.9\,H_2O + 0.1\,CH_2$$ (Bitton, 2005; Wang et al., 2009)

From the above equations, it was calculated that for every kilogram of ammonia oxidized to nitrate, the following occurs:

- 4.18 Kg of oxygen are consumed

Oxygen requirement (kg/L) = Y kg/L of $NH_4^+ \times$ 4.18 kg of O_2 / 1 kg of NH_4^+

- 7.14 kg of alkalinity as calcium carbonate (as $CaCO_3$) is consumed

Alkalinity as $CaCO_3$ (kg/L) = Y kg/L of $NH_4^+ \times$ 7.14 kg alkalinity as $CaCO_3$ / 1 kg of NH_4^+

Y = concentration of NH_4^+ in the leachate

At standard temperature and pressure, density of oxygen is equal to 1.43 g/L (1430 mg/L). Since the rotameter measures the volumetric flow rate of a material the density serves as a conversion factor to change the mass flow rate to volumetric flow rate as follows:

Density = mass flow rate/volumetric flow rate

Mass flow rate of oxygen = $[O_2]$ required in kg/L × flow rate of leachate

Therefore, volumetric flow rate of oxygen from each cylinder = mass flow rate of oxygen / density of oxygen.

2.2.2. Effect of flow rate on the performance of leachate recirculation

A flow rate of 4 mL/min and 2.77 mL/min that were used by Sharma and Rout (2010) and Reinhart (2007) respectively were used as a basis, due to lack of standardized flow rate range for