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Full Length Research Paper

Changes of hydraulic conductivity of silty clayey sand soil under the effects of municipal solid waste leachate

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Effect of municipal solid waste (MSW) on the hydraulic conductivity of soil is an important factor for designing liner systems. Leachate samples were collected within a landfill and a composting factory leachate lagoon. Soil samples from the bottom of the Esfahan, Iran, landfill were collected. Effects of the leachates on permeability of the soil samples were investigated. The results of study showed that at the highest level of leachate concentration (100%), the soil showed 20% increase in permeability (*k*) value from compost leachate and 10% reduction in landfill leachates. Compost and landfill leachates had shown contrasting impact on the soil permeability.

Key words: Hydraulic conductivity, landfills, leachate.

INTRODUCTION

Municipal solid waste (MSW) consists of everyday items we use and then throw away. This comes from our homes, schools, hospitals and businesses. Accumulated MSW in landfills decompose by a combination of physical, chemical and biological processes. Leachate is generated when water percolates through the waste in the landfill. The water can be from all forms of water that fall from the air or flow from the surrounding land into the landfill or from the waste itself. While the liquid moves into the landfill, many organic and inorganic materials are transported in the MSW leachate. As a result, various organic and inorganic compounds leach out from the solid waste (McBean et al., 1995). Containment elements, such as landfill liners and compost factory leachate lagoons, should be designed to prevent leachate from migrating to the surrounding environment (Rowe et al., 1995; Mitchell et al., 1995). Otherwise, leachate poses a serious threat to the underlying soil and aquifers (Kjeldsen, 1993).

A lined landfill site is safer and more secure for the environment in comparison with an unlined landfill site because of better engineering practices. Thus, a proper policy for long-term planning of MSW management is a crucial consideration (Li and Huang, 2009). The hydraulic conductivity (*k*) of soil liner must not increase due to chemical and biological attack from waste leachate (Bezzar and Ghomari, 2008). In fact, *k* is a measure of the resistance of the soil to flow of leachate. The *k* value for a liner system should be less than 1×10^{-7} cm/s (Daniel and Benson, 1990).

A compost factory in a landfill site is a good idea to compost out some portion of MSW to organic fertilizer, although it would produce compost leachate in the process (Bhattacharyya et al., 2006). Study of soil sensitivity to leachate in landfill site is important not only for designing a liner system, but also for assessing the potential of pollution to the surrounding environment. This study focused on the effect of leachate originating from the landfill and the compost factory on the hydraulic conductivity of the landfill soil.

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Table 1. Chemical and physical properties of the soil.

Property	The soil sample
Specific gravity	2.68
Maximum dry unit weight g/cm^3	1.98
Optimum moisture content (%)	12
Liquid limit (%)	39
Plastic limit (%)	25
Plasticity index (%)	14
Unified Soil Classification	SC-SM
Clay size fraction (<2 μm, %)	20
Permeability cm/s, 0.85 proctor compaction	5.5 E-6
EC ds/m	5.1
pH	7.6
CEC meq/100 g	8.3
AL_2O_3 (%)	6.04
MgO (%)	1.25
CaO (%)	30.56
Fe_2O_3 (%)	1.30
TiO_2 (%)	0.22
SiO_2 (%)	23.71
Na_2O (%)	1.3
K_2O (%)	0.6
SO_3 (%)	0.2
P_2O_3 (%)	0.02
Loss on ignition (%)	34.80

MATERIALS AND METHODS

Soil samples were collected from the bottom of MSW landfill site, Isfahan, Iran for the laboratory research and prepared in accordance with BSI (British Standard Institution 1990: 1377-1). The physical properties of the natural soil used in the tests, such as particle density and Atterberg limits were determined in accordance with BSI (1990: 1377-2), and the dry density/moisture content relationship was determined in accordance with BSI (1990: 1377-4). The soil also was characterized chemically and mineralogically. Leachates from the municipal landfill and the compost factory lagoon were used in the tests conducted in this study. The major inorganic chemical components were analyzed using the standard methods (Cleresci et al., 1989) and heavy metals were measured by an inductively coupled plasma mass spectrometer (ICPMS) (Yoshida et al., 2002; Wiszniowski et al., 2006). Soil specimens were compacted at 85% maximum dry density. The soil specimens were saturated with various leachate concentration ratios in distilled water ranging from 20 to 100% with 15 days curing time. Cation exchange capacity (CEC) of the samples was measured at pH 7 with ammonium acetate (Chapman, 1965). About 125 ml of 1 M NH_4OAc was added to the soil samples, was shaken and allowed to stand overnight. The soil samples were washed gently with NH_4OAc using a Buchner funnel filtration, followed by washing with 95% ethanol. The NH_4^+ was extracted by leaching the soil with eight separate 25 ml additions of 1 M KCl. The concentrations of NH_4^+-N were determined by an auto analyzer. Determination of pH and EC were carried out by the electrometric method, which gives a direct reading of the pH and EC values of a soil suspension in water.

In the falling-head permeability test, the soil specimen was placed inside a tube and water was allowed to flow through the specimen. The hydraulic conductivity, *k*, was calculated by the following equation:

$$k = 2.303\frac{aL}{At}\log\frac{h_1}{h_2}$$

Where *k* is the hydraulic conductivity, in centimeters per second, *h* is the head difference, in centimeters, at any time *t*, *A* is the area of the specimen, in square centimeters, *a* is the area of standpipe, in square centimeters and *L* is the length of specimen, in centimeters. The permeability apparatus had a plastic mould 10 cm wide, 20 cm high and 2 mm thick. The test apparatus consisted of the plastic mould with lids and a standpipe 10 mm in diameter and 100 cm high (Liu and Evett, 2003). During the permeability tests, prepared samples in moulds were saturated under leachate pressure for 15 days and then permeability values were determined for 48 h. At least five specimens were tested for each combination of permeability values in the permeability tests.

RESULTS AND DISCUSSION

Soil and leachate properties and effects of leachates on hydraulic conductivity of the soil

The soil was silty clayey sand (SC-SM) texture as defined by the Unified Soil Classification System. The physical and chemical results are given in Table 1. The soil

Table 2. Chemical composition of the landfill and compost leachate.

Parameter	Landfill leachate	Compost leachate
pH	7.14	4.50
E.C (ds/m)	15.74	34.2
Na^{+} (mg/l)	800	4200
Ca^{+2} (mg/l)	1800	7820
Mg^{+2} (mg/l)	39	890
K^{+} (mg/l)	185	4100
Cl^{-} (mg/l)	3400	4100
SO_4^{-2} (mg/l)	150	650
NO_3^{-} (mg/l)	39	150
Cu (mg/l)	10	12
Zn (mg/l)	120	181
Pb (mg/l)	5	6.8
Cd (mg/l)	0.9	1
Ni (mg/l)	1	1.42
Hg (mg/l)	0.7	0.9
TDS (mg/l)	17065	23558

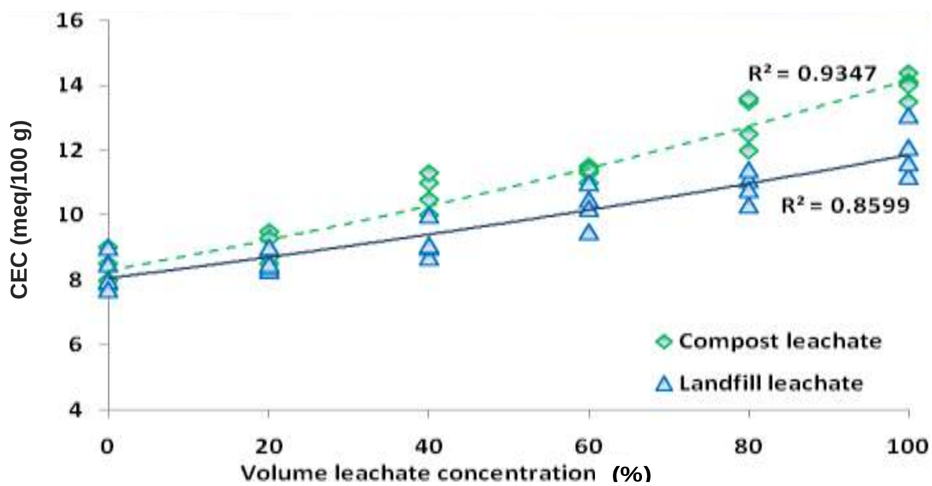

Figure 1. The soil CEC versus volume leachate concentration.

sample contained 20% clay size fraction. Mineralogical analysis of the soil showed the presence of calcite, quartz and montmorillonite. The concentration of ions and the electric conductivity (EC) in the leachate of the compost factory were higher in comparison with the contents of the leachate from the landfill (Table 2). The pH of leachate originated from compost factory was 4.5, while the pH of landfill leachate was 7.14. The presence of the dissolved inorganic materials in the samples caused the high EC values (Ouhadi and Goodarzi, 2002). The CEC value of the soil increased with increase in volume leachate concentration in distilled water (Figure 1). The effect of landfill leachate in increasing the CEC of the soil was less than the effect of compost factory leachate. Increase in the soil organic matter could increase the CEC (Stevenson, 1994; Asadi et al., 2011a; Asadi et al., 2011b; Moayedi et al., 2011). Although clay size fraction was 20%, a low content of Al_2O_3 (6.04%) and SC-SM texture suggests that the native soil CEC was not under influence of montmorillonite (Table 1). Since movement of the pore fluid through the soil is closely related to the CEC (Kalkan and Bayraktunan, 2007), the landfill soil potentially was more sensitive to the compost leachate flow than to the landfill leachate flow.

The levels of Na^{+}, K^{+}, Ca^{+2} and Mg^{+2} present in the leachate of the compost factory were sufficiently high that they could effectively exchange some of the cations present in the native soil during advection and diffusion. This reaction could expand the native soil double layers (Calace et al., 2001). However, these effective factors

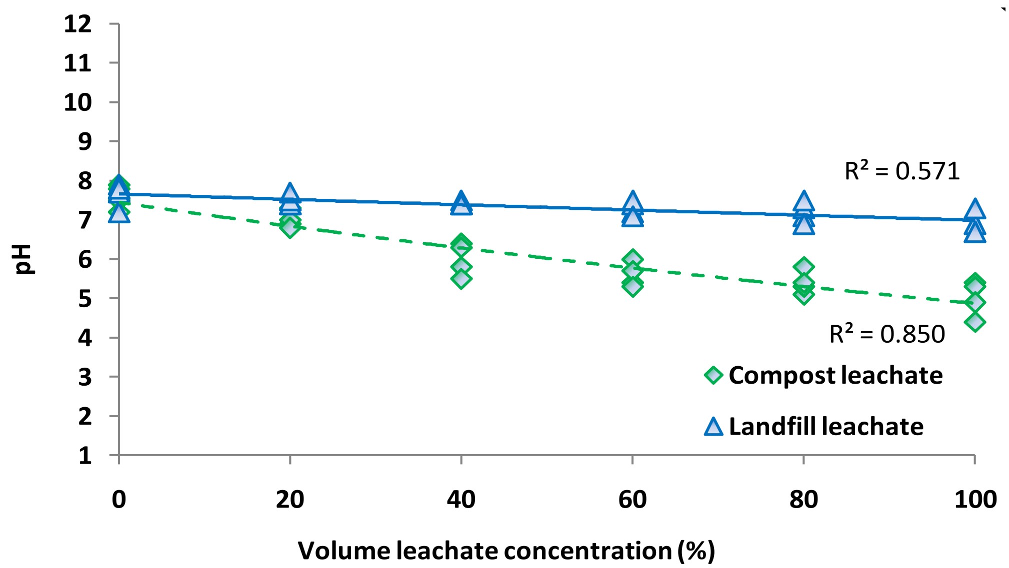

Figure 2. The soil pH versus volume leachate concentration.

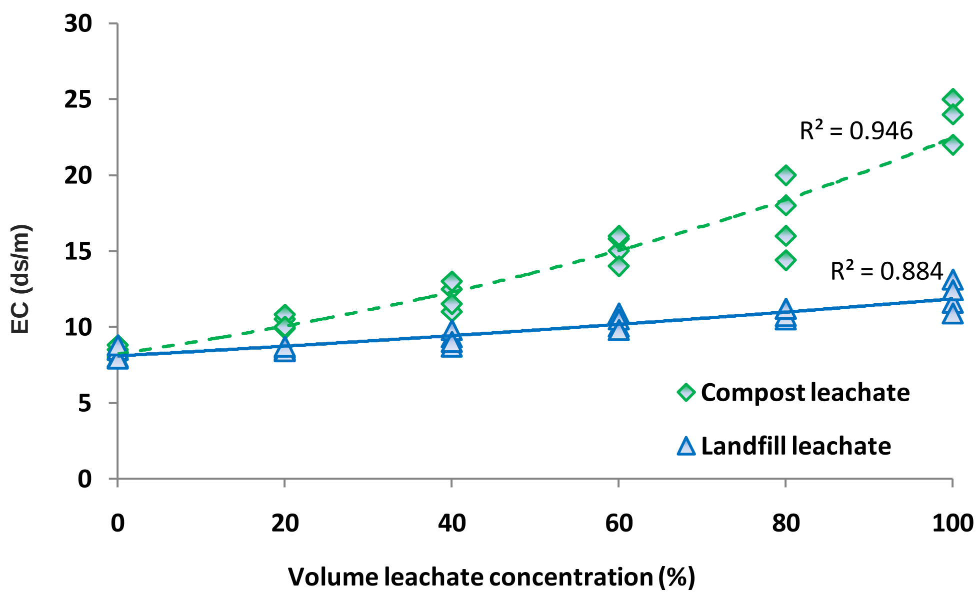

Figure 3. The soil electrical conductivity versus volume leachate concentration.

were in addition to potential gradient for transmitting a liquid in a porous medium. The sensitivity of soil to environment is hinged not only to the local environment but is also influenced by naturally inherited mineral structure, initial CEC and length of time (Fang and Daniels, 2006). The decrease in the soil pH caused by adding compost leachate was greater in comparison to that caused by adding landfill leachate (Figure 2). The pH is an important indicator of the leachate as a pure fluid of the soil. During the biological decomposition process and increase in the leachate age in the landfill, the production of acids decreased (Ouhadi and Goodarzi, 2002). In essence, decreasing the soil pH can cause changes in the soil-water structure, the soil-water adsorption and movement of the pore fluid. Low pH conditions favor the soil particles to aggregate and increase in soil permeability and reduce the soil inter-particle repulsion, while high pH conditions can make contrary effects (Fang and Daniels, 2006). A significant increase in EC of the soil by the compost factory leachate was observed (Figure 3). This result can be explained as an increase in EC of pore fluid because of an increase in leachate

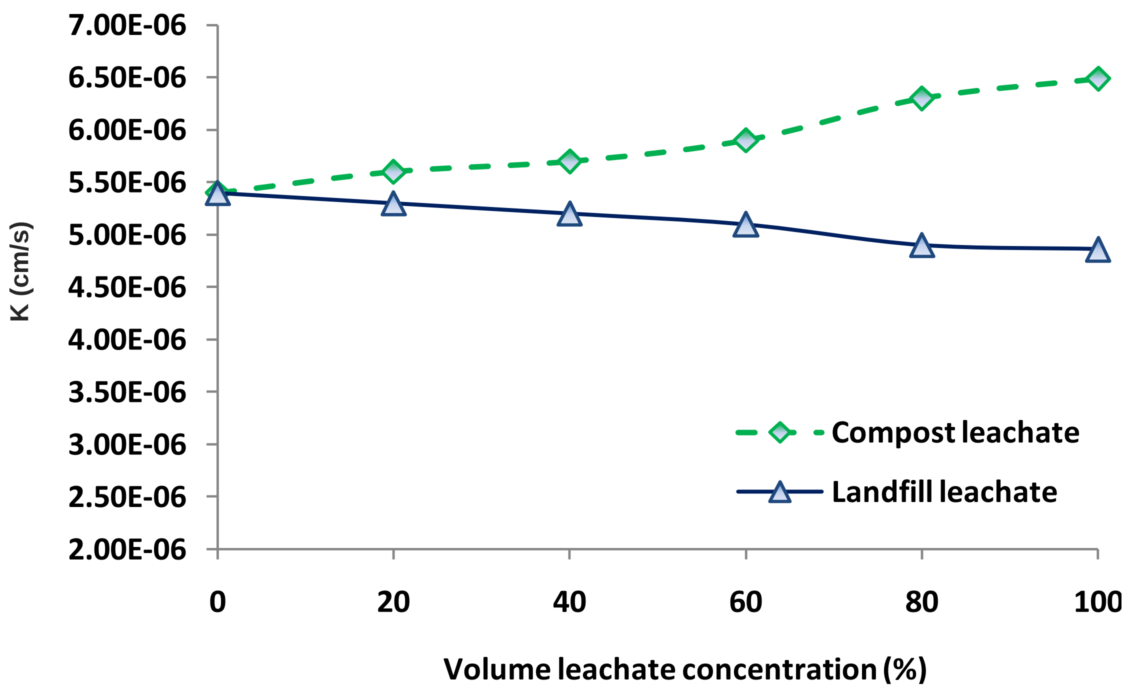

Figure 4. The soil permeability versus volume leachate concentration.

constituent acting as charge carrier (Ouhadi and Goodarzi, 2002). Electrical potentials of the soil may also give rise to movement of leachate and may cause change in the soil porosity (Fang and Daniels, 2006). At the highest level of leachate concentration (100%), the soil showed 20% increase in *k* value from compost leachate and 10% reduction in landfill leachates (Figure 4).

Adding high concentrations of cations Ca^{+2} (7.82 g/l) and Mg^{+2} (0.89 g/l) from compost leachate changed the soil from dispersive to flocculative structure (Fang and Daniels, 2006). This effect could be explained by double-layer contraction and increase in pore space (Mitchell and Madsen, 1987; Yanful et al., 1990; Ruhl and Daniel, 1997; Asadi et al., 2009; Asadi et al., 2010). Mineralogical analysis of the soil showed the presence of montmorillonite. Reactivities of montmorillonite are more than those of soils containing less reactive clay minerals, such as kaolinite or illite (Broderick and Daniel, 1990; Stern and Shackelford, 1998). Generally, *k* decreases with increasing CEC (Kalkan and Bayraktutan, 2007), but the amount and the kind of exchangeable cations present on the soil surfaces and the excess negative charge of crystal lattices, which these cations neutralize, are more considerable (Hartman et al., 1998; Yilmaz, 2006). Several researchers noted that the *k* for a liner system must be less than or equal to 1×10^{-7} cm/s (Daniel and Benson, 1990; Daniel, 1993; Sharma and Lewis, 1994; Jang and Hong, 2003). In addition, Day and Daniel (1985) found that the field-measured *k* values are much higher than the laboratory-determined values.

The leachate compost lagoon is unlined; the *k* of the soil increased because of the effect of compost leachate, and the *k* value does not satisfy the hydraulic conductivity requirement. Thus, in the near future, several environmental problems are expected to occur from the potential source of contamination.

The small decreased in *k* due to landfill leachate could be attributed to a slight consolidation of the soil sample and small reduction of the void ratio during the test (King et al., 1993).

Conclusions

The compost factory leachate had higher electric conductivity, was richer in cations and was more acidic, in comparison with the landfill leachate. The effect of landfill leachate in increasing the CEC of the soil was less than the effect of compost factory leachate. Compost and landfill leachates had shown contrasting impact on the soil permeability. At the highest level of leachate concentration (100%), the soil showed 20% increase in *k* value from compost leachate and 10% reduction in landfill leachates.

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