Measurement of gas transport parameters for final cover soil at Maharagama landfill in Sri Lanka

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Abstract

To make a proper evaluation and better understanding of gas component movement inside a landfill site, and investigation of the different parameters related to gas flow is important. In this study, air permeability (k_a) and gas diffusivity (D_p/D_o; where D_o is the gas diffusion coefficient in free air) were measured as a function of soil air content (ε) in final cover soil at Maharagama landfill in Sri Lanka. The k_a and D_p were measured at different gravimetric water content in some samples and another set of samples were treated under different pF conditions (pF= log (-φ) where φ is the soil water matric potential in cm H_2O). Results showed that greater variation of k_a with ε in both experimental conditions. The k_a rapidly increased with ε at relatively higher gravimetric water condition and then less variation near field water content and finally at drier condition the ka increased again with ε significantly. D_p/D_o exhibited exponential variation with ε. Based on measured data, predictive models for D_p and k_a were tested and pore connectivity parameter (α) and water blockage parameter (X) were calculated accordingly.

Key Words

Air permeability, gas diffusion coefficient, predictive models, pore connectivity, water blockage

Introduction

Gas generation and transport phenomenon are very important to understand in landfills to improve environmental aspects, landfill gas recovery or air supply for a better aeration inside the site. Moreover, when landfill gas is released into the atmosphere or migrates beyond landfill boundaries, it threatens the environment as well (Kallel *et al.,* 2004). In recent years, landfills have been identified in greenhouse warming scenarios as significant sources of atmospheric methane (CH_4). In addition, it is well known that toxic gases such as hydrogen sulphide (H_2S) and volatile organic chemicals (VOC) are emitted from the landfill sites (Song *et al.,* 2007). All these gases are emitted to the environment through the final cover soil layer, therefore better understanding of transport, fate and emission of gases through such a final cover layer plays vital role as mentioned in many studies (Moon *et al.,* 2008; Kallel *et al.,* 2004). Moreover, open dumpsites are being gradually replaced by sanitary landfills where negative impacts to the environment are less compared to open dump site in developing countries (Chiemchaisri *et al.,* 2007).

The gas exchange through the final cover soils is controlled by advective and diffusive gas transport. Air permeability governs the advective gas transport induced by soil-air pressure gradient, while gas diffusion coefficient is governed by soil-gas concentration gradient. Generally, landfill final cover soils are highly compacted to prevent precipitation infiltration. Weeks *et al.* (1992) have reported bulk density (ρ_b) ranging from 1.57- 1.74 (g cm^{-3}) for differently-textured landfill cover soils. Further in this study, the field investigation showed that the in situ bulk density reached 1.90 (g cm^{-3}). Soil compaction has a major impact on gas transport characteristics. Hamamoto *et al.* (2009) showed that soil compaction simultaneously caused reduced water blockage effects and reduction of larger-pore spaces. It is a widely accepted fact that the soil physical and chemical properties of soil and soil texture are also vital for gas transport phenomena. Therefore selection of construction material for final cover soils is needed to be considered in engineering applications.

In this study, the main objective was to measure the gas transport parameters and to test with some acceptable models in landfill final cover soil at Maharagama in Sri Lanka where municipal solid wastes were dumped and final soil cover was applied.

Methods

Materials and Method

A waste landfill site located at Maharagama in Sri Lanka was selected as a sampling site in this study. The

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final cover soil at the sampling site is highly compacted, exhibiting dry bulk density (ρ_b) of around 1.90 (g cm^{-3}) and a total porosity (ϕ) of 0.35. Further, some data used in this study was from Saitama landfill. Undisturbed soil samples were taken from the final cover soil and the soil sample was sieved through 2 mm mesh to eliminate effects of gravel and coarse sand size fractions (75.0-2.0 mm) on gas transport and obtain homogeneous physical properties. The composition and physical properties of the soil samples are shown in Table 1.

Table 1. Composition and physical properties of Maharagama and Saitama landfill cover soils.

Landfill site	Particle size fraction (%)				Soil texture	Particle density	Bulk density	Total porosity	pH	EC
	Gravel (> 4.75 mm)	Sand (4.75-0.075 mm)	Silt (0.075-0.005mm)	Clay (<0.005mm)		ρ_s (g cm^{-3})	ρ_b (g cm^{-3})	ϕ		mS m^{-1}
Maharagama	10	40	35	15	Silty Sand	2.77	≈ 1.90	≈ 0.35	5.4	32
Saitama	36	42	13	9	Silty Sand	2.66	≈ 1.85	≈ 0.29	5.6	27

Compaction tests were performed for soil samples at different water content using (ASTM D 698-07). Water contents of soil samples were adjusted by adding water to air-dried soil samples. In the compaction tests, the soil samples were repacked into large soil cores (i.d. 15 cm, length 12 cm) at a compaction level (600 kN m^{-2}) (Figure 1). The falling height (H) and weight of rammer (M) for compaction levels was 30.5 cm, and 2.5 kg, respectively and 56 blows were applied per layer (3 layers). The results of the compaction tests are shown in Figure 1.

After compaction tests, two 100 cm^3 core samples (i.d. 5.1 cm, length 4.1 cm) were taken inside each repacked large core. After each 100 cm^3 core sample was water-saturated, the core samples were drained at different matric suctions and the gas diffusion coefficient (D_p) and air permeability (k_a) were measured. The D_p was measured on the repacked 100 cm^3 soil cores with a diffusion chamber method. Oxygen was used as tracer gas and measured as a function of time in the diffusion chamber. In this study, the gas diffusion coefficient of oxygen in free air (D_0) at 20 °C was used as 0.20 (cm^2 s^{-1}). The k_a was measured by flowing air through a repacked 100 cm^3 soil core. The k_a was calculated from the Darcy's equation based on the pressure difference across the core and the viscosity of the air (1.86×10^{-5} Pa s).

Models applied

Power-law type models for D_p/D_0 and k_a can be written in general form (Hamamoto *et al.,* 2009; Moldrup *et al.,* 1998) as,

$$\frac{D_p}{D_0} = \alpha_p \varepsilon^{X_p} \qquad [1]$$

$$\frac{k_a}{k_{a,100}} = \left(\frac{\varepsilon}{\varepsilon_{100}}\right)^{\eta} \qquad [2]$$

where α_p is pore connectivity parameters for D_p/D_0, and X_p is water blockage parameters for D_p/D_0. The $k_{a,100}$ and ε_{100} are reference point values, where first term is for k_a at pF 2 and latter was ε at pF 2, while η represents the combined effects of tortuosity and connectivity of air-filled pores. Kawamoto *et al.* (2006) found that $\eta = 1+3/b$, where b is the slope of soil-water characteristic curve in log-log coordinate system.

Results

Compaction curve for the investigated landfill cover soil

The results of the compaction tests of standard method for investigated soil are shown in Figure 1. The bulk density (ρ_b) ranged from 1.88-1.93 (g cm^{-3}) for the soil. The optimum moisture content was around 0.14 % for soil and the correspondent maximum dry bulk density was 1.93 g cm^{-3}. The field water content was 10.50 %. From the Table 1, it is clear that the physical and chemical properties are different (mainly different clay, silt and gravel contents) in the both soils.

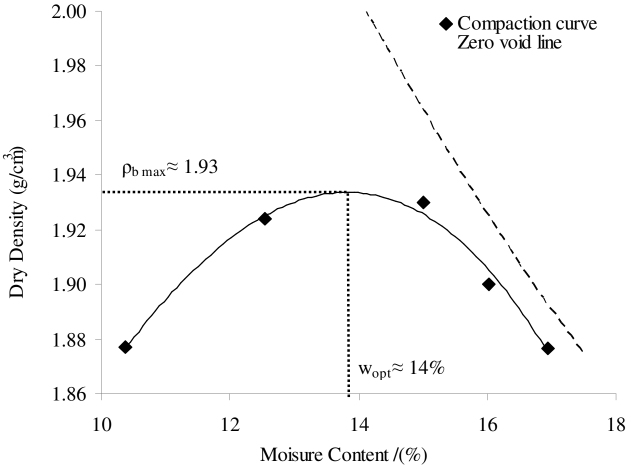

Figure 1. Compaction curve for the investigated Sri Lankan Soil.

Soil water retention curve and equivalent pore radius distribution function for soil

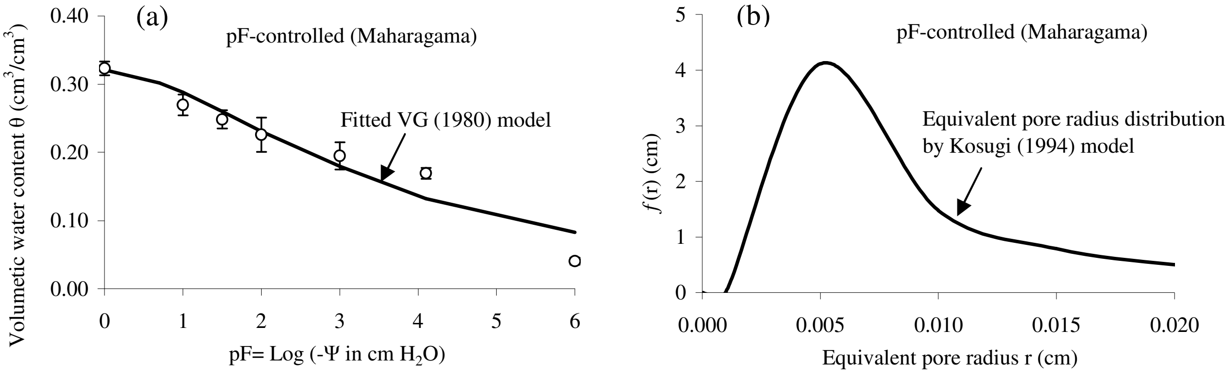

Figure 2. (a) Soil water retention curve; (b) equivalent pore radius distribution function

The soil-water retention curve and equivalent pore radius for soil are shown in Figures 2(a) and 2(b) respectively. In Figure 2(a) solid line shows the fitted van Genuchten (1980) model and open circles denote the experimental data in Maharagama landfill data with standard deviation. The next figure shows the equivalent pore radius distribution curve by Kosugi (1994) model.

Gas transport parameter variation and model fitting

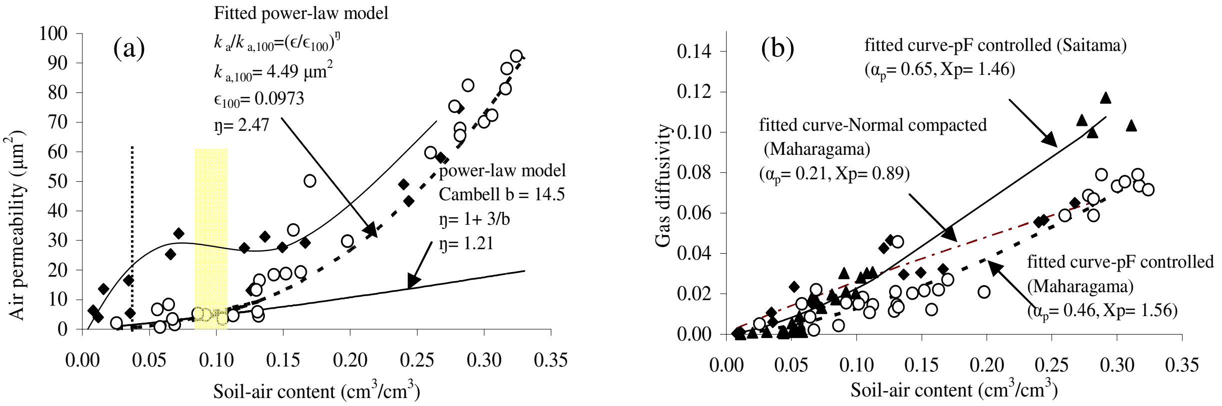

Figure 3. (a) air permeability and (b) gas diffusivity variation with soil air content.

Figure 3(a) shows the air permeability variation of soil. Solid line was drawn to show the tendency of k_a with ε over the gravimetric water content from 10.0 to 17.0%. The open circles denoted the pF controlled samples of Maharagama soil while closed squares denote the normal compacted samples. The closed rectangles show the pF controlled Saitama samples. The shaded area is to illustrate the soil air content relevant to field water content and dotted line is the optimum water content respectively. For the pF controlled samples power law model (Moldrup *et al.*, 1998) fitted well. The relevant values and fitting parameters are shown in Figure 3(a). In addition to that power law model (Kawamoto *et al.,* 2006) was fitted but it underestimated the experimental values. In the case of normal compacted samples the air permeability variation was significant at wetter condition and drier condition and at around field water content it was not so significant. For this kind of variation one reason may be the changes of structure formation as suggested by Poulsen *et al.* (2008). Other possible reason could be the packing effects of two different procedures. Figure 3(b) shows the gas diffusivity with ε. Eq.1 was fitted with data and fitting parameters are shown in the figure. For the comparison Japanese soil with fitting curve is shown. In generally gas diffusion is increased with ϵ and power law model and is well fitted with measured data.

Conclusion

Air permeability and gas diffusivity were measured as a function of soil air content in different water content. In normal compaction sample k_a was initially increased with ε and then around ε correspondent to field water content, its variation was not so significant. Finally k_a was increased significantly with drier conditions. This scenarios may suggest the structure formation with water content. In the case of pF controlled samples, k_a was increased exponentially. Gas diffusivity was increased with ε and power law modal was fitted well. In comparison the two soils were nearly close in dry bulk densities and the fitting parameters were also approximately equal.

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