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Laboratory Determination of Water Retention Characteristics and Pore size Distribution in Simulated MSW Landfill Under Settlement

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ABSTRACT: To examine how water retention characteristics in a landfill environment change as a result of solid waste settlement and to derive the evolution of pore size distribution, a lab scale long column experiment was carried out at two different time periods while keeping all the other characteristics constant. Two columns, Column 1 and Column 2, were used in the study. The log normal distribution model was applied to model the experiment data. The Column 1 was used to obtain the water retention curve at time 0 day and the Column 2 at time 180 day. During the experiment period, landfill settlement was mainly in the primary stage of settlement. Pore size distribution was obtained by assuming that the capillary theory is applicable in the landfill environment. The results showed that water retention characteristics in solid waste landfill environment is varied with time and influenced by landfill settlement due to the changes in pore spaces. The obtained results will be taken into consideration when simulating unsaturated leachate and gas flow in municipal solid waste landfill environment.

Key words: Municipal solid waste, Landfill, Settlement, Water retention curve, Pore size distribution

INTRODUCTION

Solid waste landfill is still considered as main waste disposal option in many developing and developed countries across the world. However, the waste composition, infiltrated amount of water into landfill, oxygen concentration in landfill, temperature and recirculation of leachate, influence the landfill processes especially the biodegradation (Shalani *et al.*, 2010). Sustainable landfill management methods will mainly depend on that how biodegradation affect on landfill settlement, landfill pollution and recovery of utilizable materials which include the residual derived fuel and the compost. In this study, landfill settlement has identified as two stages, namely primary and secondary. The primary stage of settlement is mainly due to the compression of new pore space which has occurred due to the removal of leachate from waste matrix with self weight. The secondary stage of settlement is mainly due to the reduction of pore space with the combined effect of biodegradation and self weight compression.

Water retention is a basic hydro physical characteristic of soil. Despite the soil, water retention and leachate generation capacity in landfill depend on absorptive capacity of waste particles. The absorptive capacity is a function of physical properties of solid waste particles such as waste composition, density, porosity and landfill age (El-Fadel *et al.*, 1997). Many models describing the water retention characteristics in soil have been published (Brook and Corey, 1964; Van Genuchten, 1980; Fredlund and Xing, 1994; Kosugi, 1994) and these models can be identified as empirical curve fitting models and physical fundamentals based models. There are few attempts have been made to study the suction characteristics for solid waste. Unsaturated flow through solid waste was studied with laboratory column cell which is equipped with vertical line of tensiometers to measure the suction stress (Korfiatis *et al.*, 1984). Suction characteristics were studied for municipal solid waste using a modified pressure plate apparatus and measurement was compared with the Van Genuchten equation (Kazimoglu *et al.*, 2005). Water retention curves for mechanical biological pre-treated waste (Munnich, 2003) and drilled domestic waste (Stolz, 2007) were determined by using ceramic plate and applying negative pressure. The water retention curve has the vital information on deriving the unsaturated hydraulic conductivity, shear strength and volume change (Sillers *et al.*, 2001). Regardless of landfill type, pore structure of the landfill matrix governs the transportation of leachate, gas, heat and also landfill

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*Corresponding author E-mail: kandulajayakody@gmail.com settlement. However, successful attempts to model the landfill system have been constrained by the lack of understanding of the nature of moisture retention and pore size distribution in landfill. Thus knowledge of water retention dynamics and pore size distribution is necessary to understand the transient nature of gas phase, liquid phase and solid phase in the landfill and eventually for developing an accurate model to predict the landfill processes and efficient aeration and lechate management to achieve higher stabilization rate. Therefore the aims of this study are to present a method for obtaining water retention curve and evolution of the pore size distribution on the basis of water retention curve for municipal solid waste.

MATERIALS & METHODS

There are many studies and laboratory methods developed for determining water retention characteristics in many different approaches. Some of accepted techniques include one step outflow (Parker *et al.*, 1985; Van Dam *et al.*, 1992), use of capacitance and neutron probe sensors (Tomer and Anderson, 1995; Mwale *et al.*, 2005), and multi-step outflow (Van Dam *et al.*, 1994; Eching *et al.*, 1994).

In order to obtain the water retention curve for simulated landfilled solid waste, a long column drainage test was developed. Solid waste based on the generalized composition of developing countries municipal solid waste was collected from different sources. Then solid waste was shredded and filled into two plexyglass columns (Column 1, Column 2). The waste was filled manually and softly compacted by hand without using any external load. The used solid waste was identified as easily biodegradables (EB) which is mainly comprised of kitchen waste (vegetable, fish, meat, rice and other food waste), slowly biodegradables (SB) which is comprised of paper (office paper, news papers) and cardboards, hardly biodegradables (HB) which is comprised of plastics (high density and low density plastics). The columns were made up of small cylindrical units (Fig. 1), which allow separating the column into small units when analyzing the water content. Table 1 shows the initial characteristics of two columns. The only difference between the two columns is the operated time period.

After filling the waste into Column 1 and Column 2, these were allowed to drain out leachate for about 24h. Then the water was supplied to the waste matrix of Column 1 for about 48h by connecting the bottom leachate outlet pipe of the column to a Mariotte's tank. The Mariotte's tank is used to supply the water at a constant pressure head. Saturation was conducted gradually by changing the hydraulic head to ensure the complete saturation. After achieving the complete saturation, the column was disconnected from the Mariotte's tank and bottom outlet pipe was closed. Then it was placed in a water bath and water level of the water bath was maintained to keep the saturation level up to the first two small cylindrical units from the bottom. The evaporation from the top of the column was also prevented by using wet cotton. And then the gravity drainage was allowed by opening the bottom outlet pipe until the moisture content reached the field capacity. The time period required for gravity drainage was about 6-8 weeks.

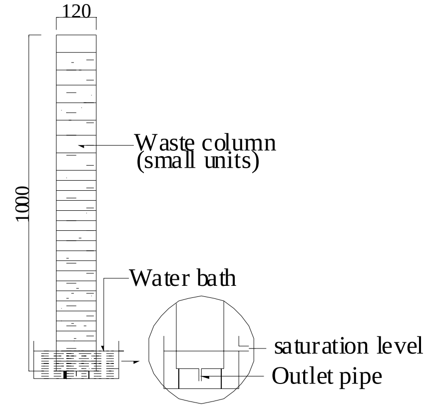

Fig. 1. Schematic diagram of the experimental column

All dimensions are in millimeters

Table 1. Initial characteristic of the experimental columns

Column No.	**1**	**2**
Composition (%)	70 EB 18 SB 12 HB	70 EB 18 SB 12 HB
Height of waste column (m)	0.86	0.86
Initial density (t-wet/m^3)	0.882	0.882
Water added (ml/week)	0	300
Operation time (days)	0	180

*EB: Easily Biodegradable, SB: Slowly Biodegradable, HB: Hardly Biodegradable

Field capacity is defined as the amount of water can be retained in waste matrix against the gravity. After the gravity drainage, gravimetric moisture content was measured for the waste in each small cylindrical unit and volumetric water content was calculated.

The Column 2 was operated as a flushing type landfill by adding 300 ml of water once a week. However the water was supplied at a slow rate by ensuring equal water distribution onto the surface. The water supply was started after 24h from the filling. Leachate quality, generation and solid waste settlement were recorded. Total settled solid waste volume was obtained by multiplying the settlement and surface area of the column.

Water retention curves obtained from the experiment were fitted by Kosugi's unimodal lognormal distribution model (Kosugi, 1994).

$$\theta = \theta_r + \left(\theta_s - \theta_r\right) Q\left[\frac{\ln\left(\psi / \psi_m\right)}{\sigma}\right] \qquad (1)$$

Where θ is the waste-moisture content (m^3/m^3) (ratio of volume of water to the total waste volume), θ_s is saturated water content (m^3/m^3), θ_r is the residual water content (m^3/m^3), Q is the complementary cumulative normal distribution function, ψ matric suction head (m), ψ_m and σ are fitting parameters. Complementary cumulative normal distribution function is defined as;

$$Q\left(x\right) = \int_x^{\infty} \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{x^2}{2}\right) dx \qquad (2)$$

Pore radius distribution function $f(r)$ was derived on the basis of capillary theory and equation (1) (Kosugi, 1996).

$$f(r) = \frac{\left(\theta_s - \theta_r\right)}{\sigma r \sqrt{2\pi}} \exp\left\{-\frac{\left[\ln\left(r / r_m\right)\right]^2}{2\sigma^2}\right\} \qquad (3)$$

Where f (1/m) is the frequency of a certain pore radius r (m), r_m (m) is the relevant pore radius of the suction head at the effective saturation equal to 0.5. Effective saturation S_e is defined as;

$$S_e = \frac{\left(\theta - \theta_S\right)}{\left(\theta_S - \theta_r\right)} \qquad (4)$$

RESULTS & DISCUSSION

Column 2 was operated as a flushing type simulated landfill for a period of 180 days. All other conditions were similar to the Column 1 (operation time is 0 day). As the experiment was conducted during the winter season, level of biodegradation was very low and there was not considerable gas generation (data are not shown). Thus the solid waste settlement was mainly in the primary settlement stage. The cumulative settlement variation is shown in the Fig.2. Observed settlement rate in Column 2 was 48%.

Fig.3.depicts the comparison between settled volume and net leachate discharge volume in Column 2. Net leachate discharge was estimated by deducting the amount of added water from the total volume of generated leachate. Almost 97% of total settled solid waste volume is caused by leachate discharge from the waste matrix. Water phase in the landfill exists in four sub phases; namely capillary water, gravitational water, hygroscopic water and water inside the waste particles (Jayakody *et al.*, 2011). In here, the hygroscopic water refers the water film adhered to the surface of waste particles and the water inside the particles is defined as the cell plasma water. The result affirms that water dissipation from the sub phases is the main cause for the primary stage of settlement.

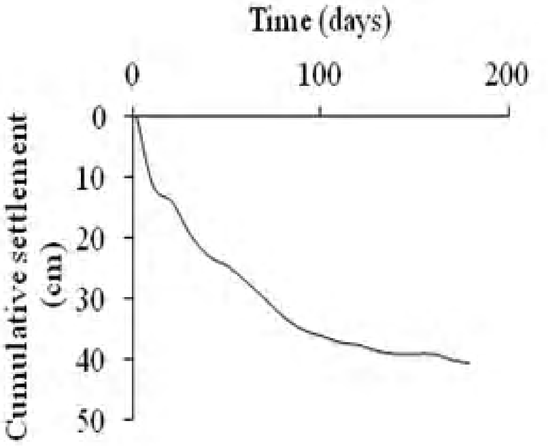

Fig. 2.Cumulative settlement variation in Column 2

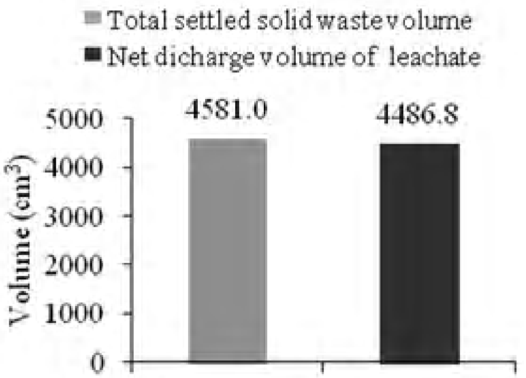

Fig. 3. Comparison of the settled solid waste volume and net leachate discharge volume in Column 2

However, the level of contribution depends on the initial moisture content, waste composition, placement density, leachate salinity, type of landfill operation etc. The volume difference between the settled volume and the net discharge volume of leachate could be resulted due to the escape of entrapped gas phase and/or restructuring of the solid waste matrix.

Water retention curve is a non linear relationship between volumetric water content and the suction head. Fig. 4 shows the observed water retention curves and fitted curves for the simulated landfilled waste at two different times (0 day and 180 days). Although, the maximum suction value of the Column 1 should be equal to the initial height of the waste matrix, during the period of gravity drainage, settlement had resulted in Column 1. Thus the effect of the settlement had caused to reduce the maximum suction value of the Column 1. This settlement could be considered as the compression due to self weight without external stress. Temporal variation in water retention characteristics was observed with the influence of primary settlement in the Column 2. The fitted water retention curves by using non linear least square optimization procedure shows the small decrease of saturated water content. The θ_S, θ_r, ψ_m and σ were allowed to change during the non linear least square optimization. For the Column 1, $\theta_S = 0.49$, $\theta_r = 0.10$, $\psi_m = 61.10$ and $\sigma = 0.14$, while for the Column 2, $\theta_S = 0.48$, $\theta_r = 0.27$, $\psi_m = 34.80$ and $\sigma = 0.02$ were achieved by curve fitting. The ψ_m and σ decide the shape of the curve to match with the experimental water retention curve. This is to say, number of pores with large and intermediate sizes is decreased with the settlement. Thus, along the landfill depth, pores with large and intermediate sizes are subjected to reduce the size. According to the fitted curves, residual water content has increased with time by suggesting the landfill pore structural development. In the secondary stage of settlement, where microbiological degradation could be predominant, the behavior of water retention curve could differ from the primary stage of settlement. In the primary stage of settlement, size of solid waste particles has not been reduced as like in the secondary settlement stage. Rearrangement of solid waste particles and changes in absorptive capacity with time cause to increase the hydroscopic water phase which shows as an increase in residual water content.

Landfill is a porous medium which consists of series of inter connected pores. These are randomly distributed between the maximum and minimum value. Capillary and statistical theories are used to derive the pore size distribution (PSD) from the water retention curve (Kosugi, 1994). In this study, the equation 3 is used to derive the PSD. Fig.5. shows the derived PSD at two different times. The parameters obtained from the fitted water retention curve were used for deriving the PSD for a wide suction range and also values beyond the experimental range. The applied suction range for deriving the PSD was within the range of pF 0 to pF 4. The mode of the pore radius distribution has a little increment with time. This might be caused by worm burrows (D'Haene et al, 2008) or uneven shrinkage of solid waste particles. Especially the larval stages and pupa of some insects like flies live in waste layers and make burrows. The results show that the effective pore volume $(\theta_s - \theta_r)$ decreased during the primary stage of landfill settlement. This is mainly due to increased residual pore storage.

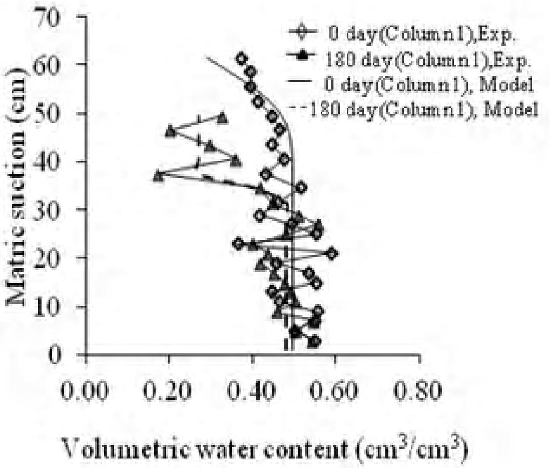

Fig. 4. Measured and modelled water retention curves

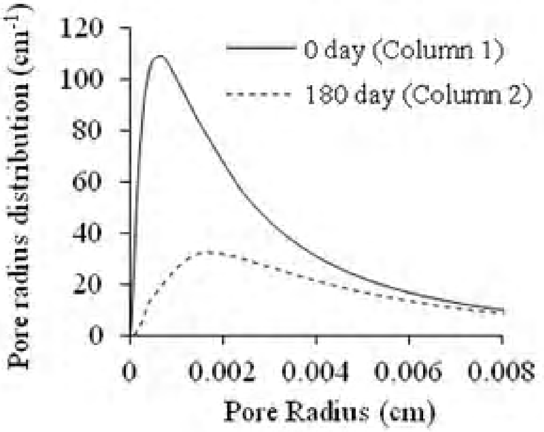

Fig. 5. Derived pore size distribution of simulated landfill

CONCLUSION

This study was conducted to present a laboratory method to obtain water retention characteristics for solid waste also to characterize and compare the influence of primary stage of landfill settlement on the water retention characteristics in landfill and to derive the pore size distribution from the water retention curve. It is possible to use the presented method to obtain water retention characteristics for solid waste. The primary stage of settlement was mainly due to the physical changes in the waste matrix occurred with the dissipation of water. However microbial biodegradation of solid waste is the governing process of secondary stage of settlement (El-Fadel and Khoury 2000). The water retention characteristic has varied from landfilled waste in primary stage of settlement compared to the initial stage (day 0). As log normal water retention model is based on capillary theory, it has a strong relationship to pore size distribution.

Although, there was no or very low level of biodegradation in experimental columns, the microbial decomposition produces particles with different sizes and different characteristics. Hence author's intention is that microbiological degradation of solid waste creates secondary particles (humus like materials) and consequently a secondary pore system which will cause to change the water retention characteristics compared to water retention characteristics of the primary stage of settlement. In conclusion, water retention characteristics in solid waste landfill environment is varied with time and influenced by landfill settlement due to the changes in pore spaces and this must be taken into consideration in municipal solid waste landfill modeling, aeration and leachate recirculation. Further study is required to test effects of changing absorptive properties of the solid waste with time and on water retention characteristics and to verify the applicability of experimental method over a boarder range of solid waste compositions than evaluated in this study.

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