Selection of Suitable Material for Final Cover of an Engineered Landfill in Dry Zone of Sri Lanka

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ABSTRACT: Final cover system is an important component of an engineered landfill to control infiltration of precipitation to minimize leachate generation. Cover soil plays a major role in emission of landfill gases because in Sri Lankan context provision of gas recovery facility is not practiced much. As a result of anaerobic decomposition of waste, generation of methane which has a significant global warming potential, is a severe environmental problem. Therefore improvement of gas ventilation facilities inside the landfill, in order to promote aerobic decomposition, is important in designing landfill final cover. The gas exchange through final cover soil is controlled by both diffusive and advective gas transport parameters. Based on laboratory experiments, it was realized that gas transport parameters are significantly vary with the amount of moisture present in the cover material. Further, gas transport parameters can be gradually increased with the increase of air voids. When landfill cover soil compacted at 2-4% less than optimum moisture content, hydraulic conductivity is slightly higher than the Sri Lankan regulations, however, gas transport parameters are significantly higher in this region. Since, precipitation is relatively less, gas transport parameters are the governing factor in dry zone. Therefore this region can be identified as the optimum region when designing the landfill cover in dry zone of Sri Lanka.

1 INTRODUCTION

Final cover is an essential part of all municipal solid waste landfill facilities. A well designed final cover controls moisture infiltration from the surface into the closed facilities, limits the formation of leachate, prevent direct exposure of waste to the atmosphere and control gas emission and odor. Regulations have been implemented to design and construct the final cover of the landfill both in local and international context in order to achieve above requirements.

Once the solid waste is placed in a landfill and covered with a soil fill, a complex series of biological and chemical reactions is occurred within the landfill. The anaerobic degradation of organic waste in landfill which is occurred under oxygen limited condition produce mixture of gases that contain methane, carbon dioxide and various other toxic compounds. Since Sri Lanka is a middle developing country, recovery of landfill gases is not in practiced. As a result, landfill gases are emitted to atmosphere through final cover soil which creates numerous environmental problems. As infiltration of rain water in dry zone is very less, the generation of leachate in dry zone is comparatively less. Therefore, when selecting material for the final cover of landfill in dry zone, gas exchangeable parameter can be identified as the governing factor.

Landfill gas emission occurs with two mechanisms, namely diffusion and advection. The soil-gas diffusion coefficient (D_p) governs the gas transport which takes place due to soil-gas concentration gradient. Fick's law is used to calculate the gas diffusion coefficient (D_p) and it can be expressed mathematically as;

$$\frac{\partial C}{\partial t} = \frac{D_p}{\varepsilon}\frac{\partial^2 C}{\partial Z^2}$$

where C is the gas concentration, Z is the elevation difference of the sample, t is time period and ε is the soil-air content. Usually diffusion is represented as a ratio of gas diffusion coefficient of soil (D_p) with respect to gas diffusion coefficient in free air (D_o). This is termed as soil-gas diffusivity (D_p/D_o).

Since determination of the gas diffusion in laboratory is time consuming and difficult, researchers have introduced mathematical formulae to determine the gas diffusivity. Buckingham (1904) suggested that the soil gas diffusivity follows a power law function of the soil air content such that,

$$\frac{D_p}{D_o} = \varepsilon^x$$

where ε is the soil air content and x is an exponent characterizing pore connectivity-tortuosity. The proposed value for x by Buckingham is 2.This model was further modified and the proposed value for x by Marshall (1959) is 1.5. Penman (1940) further modified the model proposed by Buckingham and he proposed the relationship of gas diffusivity and soil air content as,

$$\frac{D_p}{D_o} = .66\varepsilon$$

Advection is a gas transport mechanism induced by soil-air pressure gradient. To model the advection flow a parameter called coefficient of air permeability (k_a) is used. Air permeability coefficient is computed based on Darcy's law as;

$$q = \frac{k_a A}{\eta}\left(\frac{dP}{dz}\right)$$

Here *dP/dz* represents the pressure gradient across the sample, *A* is cross sectional area of the soil sample, η is the dynamic viscosity of the air (1.86 X 10^{-5} Pa s).

In general existing predictive models for air permeability are also based on a power law function of soil air content (ε), similar to air diffusion. The generalized form of such model can be written as, $k_a = \alpha\varepsilon^X$

where α is a constant to pore connectivity and X is a power law exponent labeled as a water blocking factor for k_a which can be either 2 (Buckingham type; used by Moldrup et.al, 1998) or 1.5 (Marshall Type).

2 METHODOLOGY

2.1 *Materials*

The commonly available laterite soil in dry zone was selected as the candidate material for this research study. All soil samples were prepared under standard Proctor compaction method by varying moisture content. Moisture content was varied by 2-4% in wet and dry side of Optimum Moisture Content (OMC). After completion of each compaction test, 100 cm^3 core samples were collected from the standard Proctor compaction mould. In order to improve gas transport parameters of candidate material, different percentages of sand varying between 0-20 percent in steps of 5% on dry weight were mixed with laterite soil. The physical properties of the soil sand mixture are presented in Table 1.

Table 1 – Physical properties of the soil sand mixtures

Property	**Sand Content (%)**				
	0	**5**	**10**	**15**	**20**
Specific Gravity	2.67	-	2.68	-	2.69
Liquid Limit (%)	56	-	40	-	37
Plastic Limit (%)	30	-	27	-	25
Maximum Dry Unit Weight (kN/m^3)	16.25	16.83	17.05	17.20	17.23
OMC (%)	23.0	21.5	19.4	18.5	17.0
Air content at OMC (%)	2.0	2.5	3.0	3.2	3.5

2.2 *Determination of gas transport parameters*

The D_p was measured with the diffusion chamber method proposed by Curie (1960). Initially, the chamber was flushed with nitrogen in order to remove the oxygen inside the chamber and closed it. Then soil sample was fixed to the apparatus and top of the soil sample is exposed to the atmosphere. Once the chamber was opened, atmospheric air is diffused to the chamber through the soil sample. Oxygen was used as the tracer gas. Change of oxygen concentration was measured as a function of time using the oxygen sensor connected to the diffusion chamber, and then D_p was calculated. In this study, the gas diffusion coefficient of oxygen in free air (D_o) at 20 ˚C was taken as 0.20 cm^2/s.

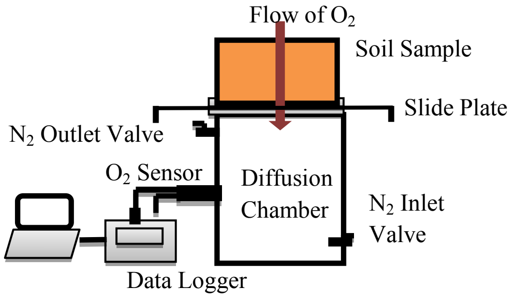

Fig. Gas diffusion chamber

k_a was measured in the laboratory by flowing air at a given inlet pressure through soil samples. Using the pressure gauge atmospheric air pressure and air pressure at the top of the sample was measured. Then k_a was calculated from Darcy's law based on the pressure difference across the soil sample.

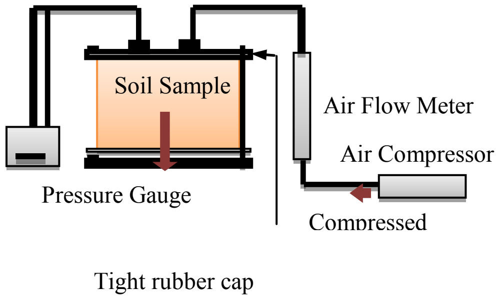

Fig. 2 Air permeability setup

3 RESULTS AND DISCUSSION

3.1 *Effect of soil- air content on soil-gas diffusivity*

Fig. 3 illustrates the variation of soil-gas diffusivity (D_p/D_o) with air content (ε).

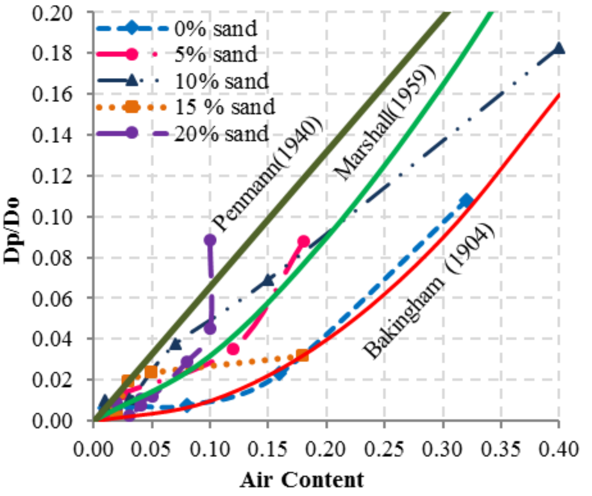

Fig. 3 Variation of D_p/D_o with ε

It can be seen that D_p/D_o exponentially increases with the ε irrespective of sand content. However, when sand content of cover material increases, D_p/D_o significantly increases even at low ε. This implies that, D_p/D_o is strongly affected by soil structure. Further, test results are compared with Buckingham, Marshall and Penman models as shown in Fig. 4. According to Wickramarachchi et.al (2010) soil of final cover system in Maharagama landfill site, which was consist of well compacted laterite soil followed Buckingham model well. In dry, sieved and repacked porous media, Moldrrup et.al (2000) found that gas diffusivity was best described by Marshal (1959) Model. It can be seen that measured data of unamended soil is well agreed with the Buckingham model where as amended soil with sand is in between Marshall and Penman model when $\varepsilon < 0.15$.

3.2 *Effect of soil-air content on air permeability*

Fig. 4 illustrates the variation of air permeability (k_a) of soil with different percentages of sand as a function of air content (ε).. In order to verify the results two graphs of $k_a = 250\varepsilon^{1.5}$ and $k_a = 20\varepsilon^{1.5}$, existing predictive models for air permeability, are also shown in the graph based on a power law function of soil air content (ε), similar to air diffusion. It can be noted that k_a value has been significantly increased in the dry side of optimum(air content > 0.15) of soil compaction where as there is no any improvement of k_a value in wet side of optimum of soil compaction irrespective of sand content. Further, when sand content of the cover soil increases, k_a also increases.

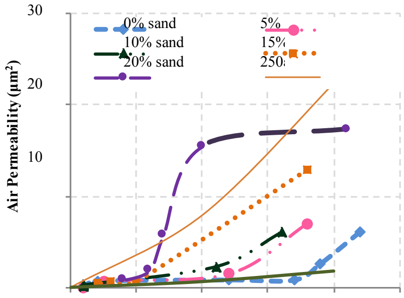

Fig. 4 Variation of k_a with ε

3.3 *Relationship between gas transport parameters and saturated hydraulic conductivity*

Based on the above study, it was realized that gas transport parameters of cover material is significantly improved when the cover soil compacted in dry side of OMC. However, according to Central Environmental Authority (CEA) guidelines, landfill cover materials should be satisfied the hydraulic conductivity requirements, i.e. hydraulic conductivity should be less than 1 x 10^{-7} m/s. Therefore a relationship has been developed between gas transport parameters and hydraulic conductivity, in order to select the most suitable landfill cover material for dry zone. Variation of soil-gas diffusivity and hydraulic conductivity over moisture content is shown in Fig. 5, whereas variation of air permeability and hydraulic conductivity over moisture content is shown in Fig. 6. Further, effect of addition of sand on gas transport parameters and hydraulic conductivity is presented.

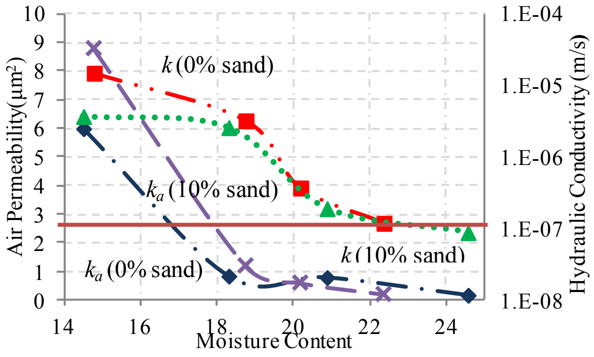

Fig. 5- Variation of D_p/D_o and k with moisture content

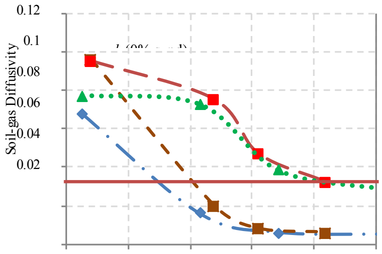

Fig. 6- Variation of ka and k with MC

4 CONCLUSIONS

Based on the results, it can be identified that both k_a and D_p/D_o are increased with soil-air content. In other words, k_a and D_p/D_o are significantly increased in dry side of OMC of compaction irrespective of sand content in the cover material. According to Sri Lankan regulations, hydraulic conductivity of final cover material should be less than 1 x 10^{-7} m/s and this requirement was satisfied only unamended soil compacted at OMC and wet side of OMC. However gas transport parameters both air permeability and soil-gas diffusivity were significantly less at OMC and at wet side of OMC. Therefore, if CEA guidelines are followed in designing landfill final cover system highly compacted soil layer should be adapted. It can be expected anaerobic condition in the landfill and as a result, methane can be generated. Therefore it is very important to provide appropriate gas ventilation facilities such as vent pipes or active ventilation systems in order to extract the landfill gases.

Due to lack of financial capabilities of most local authorities in Sri Lanka, mostly cover systems are constructed without provision of gas ventilation facilities. Therefore, enhancement of gas transport inside the landfill is more beneficial than provision of a highly compacted cover with lesser gas transport properties, especially in dry zone where precipitation limited to few months of the year. Based on the laboratory experiments carried out in this research study, it is recommended to compact the final cover material at 2-4% less than the OMC, since gas transport parameters are significantly high in this region. However, it was noted that hydraulic conductivity is slightly higher than that of Sri Lankan regulations for final landfill cover material. By considering both hydraulic characteristics and gas transport parameters of the material, for an economical design of the landfill final cover system in dry zone, it is recommended to utilize laterite soil available in dry zone amended with sand and compacted at 2-4% less than OMC . Based on the findings of this research study, it can be concluded that it is necessary to amend the regulations on landfill final cover by considering climatic conditions of the different zones (dry zone, wet zone etc.).

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