

One-dimensional transient solution for landfill gas pressure in landfills

Haijie He^{*}, Ji-wu Lan, He Li, Tao Wu, Peng-cheng Ma

MOE Key laboratory of Soft Soils and Geoenvironmental Engineering, Department of Civil Engineering, Zhejiang University, Hangzhou 310058, China

^{*}E-mail: he_haijie@zju.edu.cn

Abstract: The paper summarizes depth-based changing rules of the gas permeation coefficient, establishes a one-dimensional gas pressure distribution model with consideration of depth-based changes of the permeation coefficient, and analyzes gas extraction pressure values required by different waste landfill thickness. Results show that the gas extraction negative pressure of -1kPa satisfied gas collection requirements of landfills with thicknesses of 10m, 15m and 20m. The gas extraction negative pressure of -1kPa satisfied gas collection requirements of landfills with thicknesses of 10m, 15m and 20m. On the landfill with waste thickness of 30m, landfill gas within the scope from the pile top to the 27m height under the ground could not be collected effectively, the maximum gas pressure of about 0.65kPa appeared at the 12m height under the ground.

1. Introduction

Municipal solid waste is mainly disposed by means of sanitary landfill, burning and composting. Sanitary landfill is deemed as the most economical way for dealing with municipal solid waste which can deal with huge amount of solid waste [1-3]. Moreover, it's convenient to manage this cost-effective and affordable method. A lot of landfill gas will be generated through degradation of organic matters at waste landfills [4-6]. Landfill gas consists of 50%–60% methane. Methane is a primary greenhouse gas contributing to global warming, with landfills estimated as being the third largest source of methane emissions in the United States [7].

Townsend, et al. proposes a one-dimensional steady gas migration model of horizontal gas collection layers at a landfill, analyzes gas collection effects of a gas extraction layer under a geo-membrane on the landfill top[8]. Young, et al. analyzed effects of combination forms of gas extraction wells and well diameters on gas migration in waste. It was suggested that a gas extraction well with a small diameter could be adopted on landfill covering layers, and a gas extraction well with large diameter could be adopted in landfill bodies [9]. Chen, et al. researched gas migration in gas passive collection wells of a landfill, finding that the affecting radius of the passive gas collection well would not exceed 20m in general [10]. In above models, estimated values are taken as gas permeation coefficients, and it is believed that the waste is a homogeneous material and the gas permeation coefficient is the same at different positions of the landfill. However, the gas-phase permeation coefficient decreased gradually and significantly with the depth, and gas migration in the solid waste shows obvious anisotropic characteristics.

This paper establishes a one-dimensional gas pressure distribution model with consideration of depth-based changes of the permeation coefficient, and analyzes gas extraction pressure values required by different waste landfill thickness as well as corresponding time spent to reach a steady running state,



so as to provide reference for collection of landfill gas at landfills.

2. The change of landfill gas permeation coefficient

Estimated air permeability decreased significantly with increasing waste depth, the lower permeability encountered in the deeper layers was primarily attributed to the lower porosity of the waste caused by higher overburden pressures and higher moisture content of waste in deeper layers of the landfill than in shallow layers. According to the air injection test, getting the change of landfill gas permeability with depth.

$$k_g = e^{-\frac{z+110.3}{4.5}} \quad (1)$$

Where z = depth; k_g = vertical intrinsic permeability of the fill material.

3. Development of governing equation

In order to establish the landfill gas migration control equation, this paper makes the following assumptions:

- (1) LFG behaves as an ideal gas with uniform molecular weight and dynamic viscosity[8];
- (2) LFG transport can be described by a Darcy's law type relationship with the gravitational effects neglected;

According to the fluid mass conservation equation of porous media

$$\frac{\partial}{\partial t}(\rho_g \theta_g) + \nabla \cdot (\rho_g v_g) = Q_g \quad (2)$$

Where t = time; ρ_g = landfill gas density; θ_g = gas content of the fill material (volume of gas per bulk volume); v_g = The movement speed of the landfill gas; Q_g = LFG generation rate.

Darcy's law for the gas phase is

$$v_g = -\frac{k_g}{u} \frac{\partial P}{\partial z} \quad (3)$$

Where t = time; u = dynamic viscosity of LFG; k_g = vertical intrinsic permeability of the fill material; P = gas pressure.

The ideal gas equation is

$$P = \frac{m}{V} \frac{1}{M} RT = \frac{\rho_g}{M} RT \quad (4)$$

Where V = Landfill gas volume; m = Landfill gas weight; R = universal gas constant; T = absolute temperature; M = molecular weight of LFG.

θ_g doesn't change over time, so

$$\frac{\partial P}{\partial t} = \frac{1}{u\theta_g} \frac{\partial k_g}{\partial z} P \frac{\partial P}{\partial z} + \frac{k_g}{u\theta_g} \frac{\partial}{\partial z} \left(P \frac{\partial P}{\partial z} \right) + \frac{Q_g RT}{M\theta_g} \quad (5)$$

4. Landfill gas pressure under different condition

Table 1. Input Values of Basic Parameters

Parameter	Unit	Value
θ_g		0.5
u	Pa · s	1.37×10^{-5} [6]
R	J/(mol · K)	8.31 [6]
T	K	298 [6]
M	kg/mol	0.03 [6]
Q_g	kg/(m ³ · s)	4.4×10^{-7} [8]

Table 1 lists the values used for the parameters. Take the parameter in table 1 to solve equation (5), the

distribution of the gas pressure can be found.

Figure 1 shows the gas pressure distribution on the landfill bottom under the gas extraction pressure of -1kPa and different waste thicknesses. Comparison results of gas pressure distribution curves under different waste thicknesses show that the gas extraction negative pressure of -1kPa satisfied gas collection requirements of landfills with thicknesses of 10m, 15m and 20m. After 0.2h of continuous gas extraction at the landfills with thicknesses of 10m, 15m and 20m under the -1kPa gas extraction negative pressure, pressure values at different depths of the site were negative, and newly generated landfill gas on the landfill could be collected effectively. On the landfill with waste thickness of 30m, the permeation coefficients on the pile bottom areas were small due to stacking of upper waste. Hence, negative pressures of the bottom gas collection system could not be effectively transmitted to the upper areas, and the newly generated landfill gas could not be collected effectively. Gas extraction of -1kPa was continuously conducted on the pile bottom, but pressures of landfill gas within the scope from the pile top to the 24m height under the ground still increased continuously. Pressure values of landfill gas within the scope from the pile top to the 27m height under the ground exceeded the average atmospheric pressure, so gas within the interval could not be collected effectively. The maximum gas pressure of about 0.65kPa appeared at the 12m height under the ground. The landfill gas with the smaller pile thickness would spend less time to reach a steady state. Under a large waste landfill thickness, the negative pressure of landfill gas collection system on the bottom or a collection pipeline shall be added in the middle part of pile, so that newly generated landfill gas could be collected continuously and effectively.

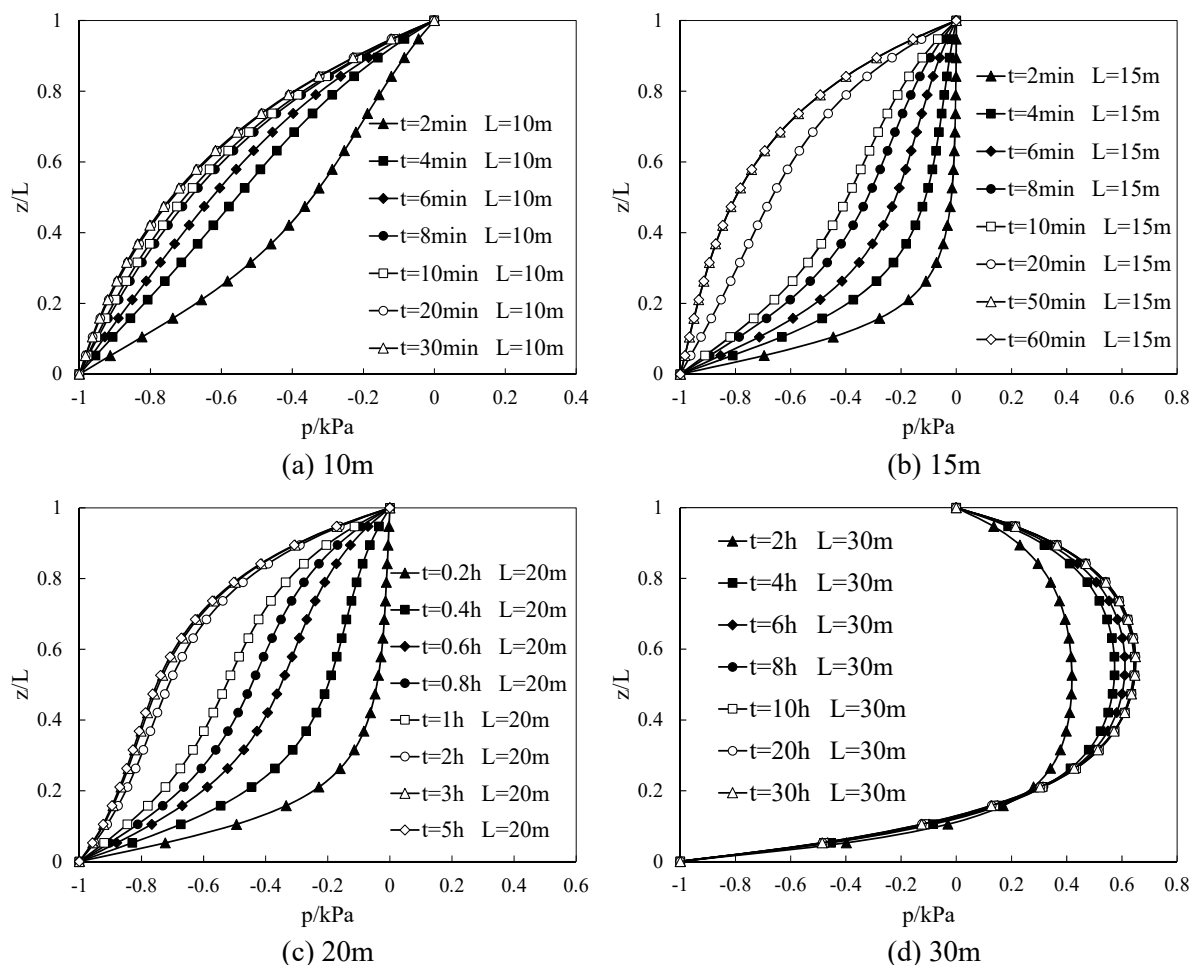


Figure 1. The gas pressure distribution under different waste thicknesses

5. Summary

The gas extraction negative pressure of -1kPa satisfied gas collection requirements of landfills with thicknesses of 10m, 15m and 20m. On the landfill with waste thickness of 30m, landfill gas within the scope from the pile top to the 27m height under the ground could not be collected effectively, the maximum gas pressure of about 0.65kPa appeared at the 12m height under the ground.

Acknowledgements

The authors are very grateful for the support of the National Natural Science Foundation of China (Grant No. 41502276).

References

- [1] Chen Z.Z., Gong H.J., Zhang M.Q., Wu W.L., Y. Liu, Feng J. (2011). Impact of using high-density polyethylene geomembrane layer as landfill intermediate cover on landfill gas extraction. *Waste Management*, **31**(5), 1059-1064.
- [2] Stoltz G., Gourc J., Oxarango L.(2010). Liquid and gas permeabilities of unsaturated municipal solid waste under compression, *Journal of Contaminant Hydrology*, **118**(1), 27-42.
- [3] Larson J., Kumar S., Gale S.A. (2012). A field study to estimate the vertical gas diffusivity and permeability of compacted MSW using a barometric pumping analytical model, *Waste Management and Research*, **30**(3), 276-284.
- [4] Wise W.R., Townsend T.G.(2011). One-Dimensional Gas Flow Models for Municipal Solid Waste Landfills: Cylindrical and Spherical Symmetries, *Journal of Environment Engineering*, **137**(6), 514-516.
- [5] Yu L., Batlle F., Carrera J., Lloret A.(2009). Gas flow to a vertical gas extraction well in deformable MSW landfills, *Journal of Hazardous materials*, **168**(2), 1404-1416.
- [6] Li Y.C., Zheng J., Chen Y.M., Guo R.Y.(2013). One-Dimensional Transient Analytical Solution for Gas Pressure in Municipal Solid Waste Landfills, *Journal of Environment Engineering*, **139**(12), 1441-1445.
- [7] Li Y.C., Cleall P.J., Ma X.F., Zhan T.L.T., Chen Y.M.(2012). Gas Pressure Model for Layered Municipal Solid Waste Landfills, *Journal of Environment Engineering*, **138**(7), 752-760.
- [8] Townsend T.G., Wise W.R., Jain P.(2005). One-dimensional gas flow model for horizontal gas collection systems at municipal solid waste landfills, *Journal of Environment Engineering*, **131**(12), 1716-1723.
- [9] Young A., Gay N.J.(1995). Interactions between gas extraction wells, *Waste Management and Research*, **13**(1), 3-12.
- [10] Chen Y.C., Chen K.S., Wu C.H., Numerical simulation of gas flow around a passive vent in a sanitary landfill, *Journal of Hazardous materials*, **100**(1), 39-52.