N.P. López-Acosta et al. (Eds.)
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doi:10.3233/STAL190360

Estimate of Heat Generation Rates in MSW Landfills Based on in-situ Temperature Monitoring

Leticia M. NOCKO[a], Keaton BOTELHO[b], Jeremy W.F. MORRIS[c], Ranjiv GUPTA[d] and John S. MCCARTNEY[e,1]
[a] *Graduate Research Assistant, Dept. of Structural Engineering, University of California San Diego*
[b] *Senior Engineer, Geosyntec Consultants*
[c] *Principal, Geosyntec Consultants*
[d] *Senior Engineer, Freeport McMoRan*
[e] *Professor and Department Chair, Dept. of Structural Engineering, University of California San Diego*

Abstract. This study focuses on heat extraction from municipal solid waste (MSW) landfills, which provide a long-term heat source that can be exploited for heating buildings. An interesting aspect of MSW is that heat is generated via anaerobic biodegradation of the waste during heat extraction. This paper provides preliminary data on heat generation in MSW obtained from an instrumented landfill cell in San Diego that incorporates an array of geothermal heat exchangers.

Keywords. Energy geotechnics, geothermal, heat exchange, landfills.

1. Introduction

The heat generated during the biodegradation of municipal solid waste (MSW) placed in landfills can elevate waste temperatures to values greater than 50°C which can be sustained for several decades. This heat can be extracted and used directly as an alternative source of thermal energy in nearby facilities [1]. Further, controlled heat extraction can also allow a landfill operator to control the temperatures within the waste and consequently optimize the methane generation, accelerate settlements, and reduce the temperature gradient across the landfill base liner, minimizing the potential for clay liner desiccation or geomembrane damage [2-8].

To design heat extraction systems in MSW landfills, the process of heat transfer within the cell can be simplified by assuming it occurs solely due to heat conduction. The form of the heat conduction equation applicable to MSW landfills that may be undergoing heat generation is given as follows:

[1] Corresponding Author, Department of Structural Engineering, University of California San Diego, 9500 Gilman Dr. La Jolla, CA 92093-0085. mccartney@ ucsd.edu.

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} + \frac{\dot{Q}}{c\rho} \tag{1}$$

where T is the temperature of the waste, t is time, x is the spatial variable, α, c and ρ are the thermal diffusivity, specific heat and density of the waste, respectively, and $\dot{Q}$ is a function used to describe the heat generated per unit time per unit volume. In the simulation of short-time heat extraction, the term $\dot{Q}/c\rho$ may be neglected, especially if the extraction occurs during the anaerobic phase of the biodegradation process when heat generation rates are significantly slower than the aerobic phase in the presence of oxygen. However, for a longer heat extraction process the heat generated within the waste must be considered. Factors such as waste composition and age, oxygen availability and climate conditions might affect the heat generation rate and, consequently, the maximum temperatures reached within the MSW cell [9, 10].

To better understand the development of temperatures within an MSW landfill and the variation of the heat generation rate as a function of time and temperature, three temperature sensors were installed in a newly-constructed landfill cell in Santee, CA, as shown in Figure 1. The thermistor string was placed on top of a lift of waste, 6m from the base liner, and had sensors placed at 16.8 m, 32.0 m and 47.2 m from the edge of the cell. A fourth thermistor was installed in the data logger to measure the air temperature during the monitoring period. After its installation, the thermistor string was covered with 150 mm of silty soil to prevent damaging by the waste components, followed by the placement of four lifts of MSW on top of the string, totalizing 24 m of waste. Additional thermistor strings and a system of geothermal heat exchanger pipes were installed in the same cell to monitor a heat extraction experiment and estimate the in situ MSW thermal properties. The effects of heat generation on the heat extraction experiment will be presented in the full paper associated with this extended abstract.

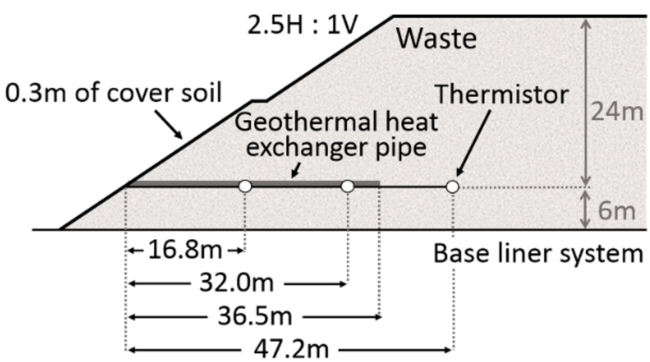

Figure 1. Cross-section showing the position of the thermistor string within the landfill.

2. Results and analysis

The waste temperature was monitored for 13 months and its evolution is presented in Figure 2, along with the air temperature for the period. The maximum temperature measured was approximately 51°C for all three sensors and was observed in less than one year, confirming the potential for heat extraction in a short-term after the waste placement. After reaching those maximum values, the temperatures remained stable for the rest of the monitoring period. The gap in data observed in the figure was the result of technical issues with the datalogger battery, but the trend in the data is clear.

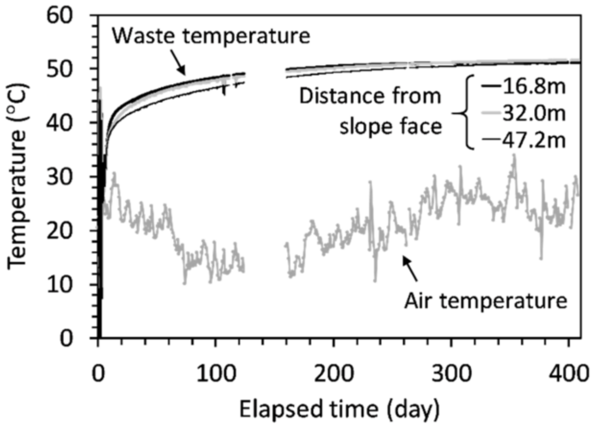

Figure 2. Temperature time series obtained for a 13-month monitoring period following waste placement.

The accumulated heat generated per unit volume of MSW was calculated based on the gain of temperature in time and using the average waste volumetric heat capacity of 0.84 MJ/m^3°C. Since the waste at the sensors' locations was not affected by daily variations in temperature, it was assumed that no heat was lost to the environment, so all the heat generated in those locations was used to increase the temperature of the waste. The results obtained for the sensor positioned 32.0 m from the cell edge are shown in Figure 3(a), and the line trend is similar to the temperature evolution behavior, presenting a faster increase in the first months after waste placement and tending to a stable maximum value. A nearly stable value of accumulated heat generated suggests a low heat generation rate, enough only to balance eventual heat losses and keep the temperatures nearly constant. Since the results of the temperature evolution with time, and consequently heat generated, were similar for all sensors, the analysis for sensors 16.8 m and 47.2 m are not shown for brevity.

The heat generation rate was calculated as the variation of the heat generated per unit time and its variation in time is presented in Figure 3(b) for the first 50 days of monitoring, to highlight the interval in which it is highly variable. The values of heat generation rate observed after this period tend to stabilize around 0.5 W/m^3, which is within the range of values estimated in literature [11, 12]. The peak values observed in the first 10 days of monitoring likely correspond to the aerobic stage of the biodegradation. However, this stage generally corresponds to 20 to 30% of the total increase in temperature in the landfill, while the remaining occurs due to anaerobic biodegradation [9]. Since the gain in temperature observed in the first 10 days corresponds to nearly 50% of the total increase in temperature, it is possible that the biodegradation of the monitored waste is already partially anaerobic at this point. The variation of the heat generation rate as a function of the temperature is presented in Figure 3(c) and it shows that the peak in heat generation rate occurs around 35 °C, which is also the temperature of peak methanogenic mesophilic bacterial activity [4, 13].

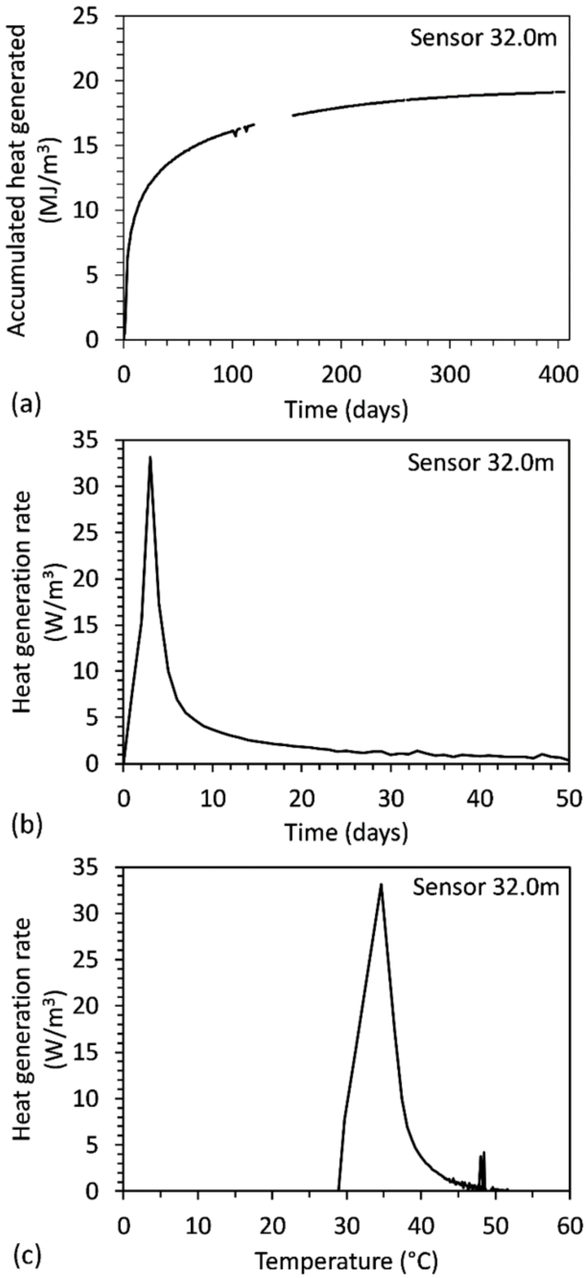

Figure 3. Estimates of heat generation at the location 32.0 m from the slope face: (a) Accumulated heat generated; (b) Heat generation rate as function of time; (c) Heat generation rate as function of temperature.

3. Conclusions

A clear correlation between the peak heat generation rate of the waste and temperature is observed in this study, with a peak heat generation rate at a waste temperature of approximately 35 °C. However, some of this heat may have been generated due to the presence of oxygen during the aerobic stage of biodegradation, and some may have been generated in the subsequent anaerobic stage of biodegradation. Further analysis of temperature recovery after a heat extraction experiment carried out during the anaerobic stage of biodegradation presented in a full paper following this extended abstract will help distinguish between the heat generation in these two stages. Numerical simulations of Equation (1) will be shown using the temperature-dependent heat-generation data to show the impacts on thermal energy extraction from MSW.

Acknowledgements

Funding from the Technical Advisory Committee of Geosyntec Consultants is greatly appreciated. The generous support of Republic Services, Inc. in providing the test site and assisting with planning and installation of the heat exchanger system is gratefully acknowledged, along with the help of Gabe Gonzales and Jamie C. Harris in construction and Jesus C. Torres in the implementation planning. The scholarship received by the first author from the Brazilian Federal Agency for Support and Evaluation of Graduate Education - CAPES (Process no. 99999.002164/2015-09) is highly appreciated.

References

[1] Emmi, G., Zarrella, A., Zuanetti, A., De Carli, M. (2016). "Use of municipal solid waste landfill as heat source of heat pump." *Energy Procedia*, 101, 352-359.

[2] Coccia, C.J.R., Gupta, R., Morris, J., McCartney, 580 J.S. (2013). Municipal solid waste landfills as geothermal heat sources". *Renewable and Sustainable Energy Reviews*. 19, 463-474.

[3] Farquhar, G.J., Rovers, F.A. (1973). "Gas production during refuse decomposition." *Water, Air, and Soil Pollution*. 2(4), 483-495.

[4] Rees, J.F. (1980). "Optimisation of methane production and refuse decomposition in landfills by temperature control." *Journal of Chemical Technology and Biotechnology*. 30(1), 458-465.

[5] Southen, J, Rowe, R.K. (2005). "Laboratory investigation of geosynthetic clay liner desiccation in a composite liner subjected to thermal gradients." *J. of Geotech. and Geoenv. Eng*. 131(7), 925–35

[6] Jafari, N.H., Stark, T.D., Rowe, K. (2014). "Service life of HDPE geomembranes subjected to elevated temperatures." *Journal of Hazardous, Toxic and Radioactive Waste*. 18(1), 16-26.

[7] Lamothe, D, Edgers, L. (1994). "The effects of environmental parameters on the laboratory compression of refuse." *Proc. 17th Int. Madison Waste Conf.* Madison, WI. 592–604.

[8] Bareither, C.A., Breitmeyer, R.J, Benson, C.H., Barlaz, M.A., Edils, T.B. (2012). "Deer track bioreactor experiment: field-scale evaluation of municipal solid waste bioreactor performance. *Journal of Geotechnical and Geoenvironmental Engineering.* 138(6), 658-670.

[9] Yeşiller, N., Hanson, J.L., Liu, W.L. (2005). "Heat generation in municipal solid waste landfills." *Journal of Geotechnical and Geoenvironmental Engineering*. 131(11), 1330-1344.

[10] Young, A. (1992). *Application of computer modelling to landfill processes*. DoE Report No. CWM 039A/92. Department of Environment (UK).

[11] Hanson, J.L., Liu, W.L., Yeşiller, N. (2008). "Analytical and numerical methodology for modeling temperatures in landfills". *Proc. GeoCongress 200*. GSP 177.

[12] Yoshida, H., Rowe, R.K. (2003). "Consideration of landfill liner temperature". *Proc. Sardinia 2003: 9th Int. Waste Mgmt. and Landfill Symp*. 9 p.

[13] Pfeffer, J.T. (1974). "Temperature effects on anaerobic fermentation of domestic refuse." *Biotechnology and Bioengineering*. 16(6), 771-787.