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Geothermal gradients in a high-organic content landfill

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INTRODUCTION

The biodegradation processes that take place in municipal solid waste (MSW) landfills deliver not only leachate and biogas as byproducts but also heat due to the exothermic nature of the biochemical reactions that decompose organic matter [1,2]. This heat is a potentially significant source of shallow geothermal energy. Furthermore, in low-income municipalities across the world, the MSW organic load is typically much higher than that of wealthy nations.

The study of the geothermal potential available in sanitary MSW landfills is a relatively recent field of research [3–7]. Evidence indicates that, in North America and Europe, MSW landfill temperatures can be about 35°C higher than that of typical shallow soil profiles [5,6], and may rise above 65°C as a result of the anaerobic MSW biodegradation [1]. A few studies have even assessed the implementation of geothermal technology for harvesting shallow geothermal energy at landfills [8,9].

Research on geothermal energy potential and its possible recovery from high-organic content (HOC) landfills is still scarce. This may be explained due to the tropical climates where many HOC landfills exist, where no meteorological seasons take place. Nonetheless, HOC landfill geothermal energy may benefit operational, agricultural, or farming activities within and around the facility.

Based on in-situ temperature measurements and computational simulations, the present study estimates the geothermal gradients and recoverable energy potential available in a HOC MSW landfill cell after 11 years of closure.

METHODS

The Doña Juana landfill (DJL) is the main MSW engineered disposal facility in the city of Bogotá, Colombia. DJL spans across 626 hectares and is divided into 11 disposal zones. At least 61.5% of the MSW at DJL is oxidizable organic matter [10], which is significantly higher than the organic fraction in landfills of high-income countries, i.e., 12% to 30% [11]. Some official measurements of organic content at DJL have reported values as high as 74.5% [12]. The DJL has an extensive network of vibrating wire piezometers (Geokon model GK 4500), which include thermistors that allow temperature measurements. In August 2021, the DJL operator kindly measured temperatures in all their piezometers for the present project. Overall, 190 measurements were recorded with temperatures of up to 52.9°C. Additional data including landfill topography, cell age, and closure date was made available. The DJL's "Zone 8" was selected as the landfill cell for modeling. This zone (41 Ha) operated from March 2022 through September 2010. In 2021 (11 years after closure), Zone 8 showed up to 50.5°C at 23.4 m of depth inside piezometer PZ-13 (see Figure 1b).

A two-dimensional finite-element model was constructed to simulate a representative section of the DJL's Zone 8. Modeling of heat transfer in porous media was implemented in Comsol Multiphysics® assuming no unsaturated flow across the landfill volume during up to 100 years of heat production. A published heat generation function [13,14] was used, which is surprisingly independent of MSW organic content. A conservative value of DJL's organic fraction (61.5%) [10] was adopted, as well as a compacted density (1150 kg/m^3). Because direct measurements of MSW thermal properties at DJL are not available yet, these were estimated by adjusting published values [15] by proportion with respect to organic content, thus yielding thermal conductivity of 1.15 W/m.K and heat capacity of 2280 J/kg.K. In addition, permeability and porosity values were adopted from the MSW literature.

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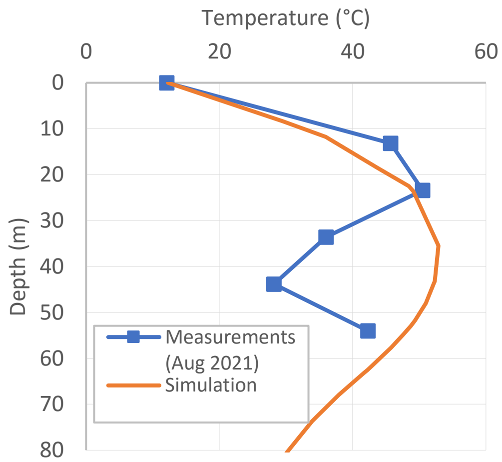
Model calibrations to fit the field-measured temperatures were undertaken by varying only the independent parameter λ (dubbed "composite climatic-operational condition factor") of the heat generation function [14]. This parameter depends on mean annual ambient temperature and rainfall, in-landfill MSW density, and annual rise of the landfill during disposal (respectively, 12.3°C, 700 mm/year, 1150 kg/m^3, and 7.82 m/year for DJL). Finally, as a first approach to estimate recoverable heat, the "volumetric method" was used assuming a typical recovery for fractured aquifers of 2.4% across the entire extraction volume. For the calculation, a extraction step of one year was adopted, and the DJL cross-section was assumed to have a thickness of 200 m.

RESULTS

The calibration of the numerical model with in-situ data yield a peak heat generation rate of about 3 W/m^3, which is between 1.3 and 15.5 higher than that of North American landfills [14]. Figure 1 displays an animation of the calculated temperature evolution during 50 years, as well as the measured and calculated geothermal gradients at piezometer PZ-13. The volumetric method predicts a peak heat recovery of 2.4 kW on year three, determined by calculation of the heat generated annually during 50 years. These results likely underestimate the actual recoverable energy at the landfill; follow-up studies, currently underway, are modeling the three-dimensional implementation of ground-source heat pump exchangers.

a)



b)

Figure 1. DJL's Zone 8 heat transfer simulation results. a) Temperature distribution and evolution through 50 and 100 years. b) Measured and calculated geothermal gradients inside PZ-13

CONCLUSIONS

This study estimates the spatial and temporal distributions of temperature, as well as the geothermal gradients, within a high-organic content landfill. The two-dimensional heat-transfer finite-element model developed for the present research is calibrated against actual temperature measurements recorded 11 years after closure of a landfill cell. Because previously published MSW heat-generation functions depend only on operational and climatic variables, future research should pursue a modified heat generation function that accounts for MSW organic content.

The present study has limitations, including: 1) the computational simulations were not three-dimensional; 2) actual MSW thermal properties evolve with time; and 3) fully coupled THBCM may be required to capture the complex behavior of a HOC landfill. Nonetheless, the authors hope that this study helps bring awareness to landfill operators and government decision-makers about the feasibility of HOC landfills as sources of shallow geothermal energy.

Data Availability Statement

The QR code was created using Adobe Express®: https://express.adobe.com/es-ES/tools/qr-code-generator. Data presented in Figure 1 are available upon scanning the provided QR code, or at: https://osf.io/u6g2d/?view_only=866da60d5d05469983242e090b7c4f3f

Contributor statement

Sara Otero Manrique: data curation, formal analysis, investigation, software, visualization, writing-original draft; Joan M. Larrahondo: conceptualization, methodology, supervision, writing-review and editing; Armando Sarmiento: conceptualization, methodology, supervision, writing-review and editing; Germán A. Bello García: resources, writing-review and editing; Carlos J. Niño Bustamante: resources, writing-review and editing

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