DYNA
http://dyna.medellin.unal.edu.co/

UNIVERSIDAD
NACIONAL
DE COLOMBIA

Numerical simulation of waste landfill biodegradation: Fitting experimental data

Vladimir Buelvas-Hernandez [a,b], Juliana Lucía Moreno-Medina [b] & Marcela Mercado-Montoya [b c]

[a] *Coppe, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brasil. vladimir.buelvas@coc.ufrj.br*
[b] *Semillero In Silico – UdeA, In Silico STEM SAS, Universidad de Antioquia, Medellín, Colombia. jlucia.moreno@udea.edu.co*
[c] *In Silico STEM SAS, Medellín, Colombia. marcela.mercadom@insilicostem.com*

Received: April 11th, 2024. Received in revised form: November 12th, 2024. Accepted: November 20th, 2024.

Abstract

Landfill remains economically viable for the disposal of Municipal Solid Waste (MSW), however, experiences of failure in several Colombian and global locations, lead to soil, water, and air pollution, harming ecosystems, and biodiversity. Numerical models can help improve the design by considering biodegradation, hydraulic, thermal, and mechanical phenomena involved in landfills. This paper presents a simulation of the landfill biodegradation, calibrating parameters to make results match experimental data from previous references. COMSOL Multiphysics was used to implement McDougall's biodegradation model, tracking organic matter transformation into volatile fatty acids (VFA) and methane (CH4) production via acetogenesis. Parameters taken from previous references were recalibrated to fit data from six US landfills. The results for the concentration variation with time for organic matter, VFA and CH4 successfully follows the expected behavior and fits the experimental data. McDougall's 2007 model, successfully implemented in COMSOL, can be calibrated for data from Colombian and global landfills.

Keywords: waste landfill, biodegradation; mathematical modeling; methane generation.

Simulación numérica de la biodegradación en rellenos sanitarios: ajuste de datos experimentales

Resumen

Los rellenos sanitarios siguen siendo económicamente viables para la disposición de Residuos Sólidos Urbanos (RSU), sin embargo, experiencias de fallas en varios lugares de Colombia y el mundo, conducen a la contaminación del suelo, agua y aire, perjudicando los ecosistemas, y la biodiversidad. Los modelos numéricos pueden ayudar a mejorar el diseño considerando los fenómenos de biodegradación, hidráulicos, térmicos y mecánicos involucrados en los rellenos sanitarios. Este trabajo presenta una simulación de la biodegradación en rellenos sanitarios, calibrando los parámetros para que los resultados coincidan con los datos experimentales de la literatura técnica. Se utilizó COMSOL Multiphysics para implementar el modelo de biodegradación de McDougall, siguiendo la transformación de la materia orgánica en ácidos grasos volátiles (AGV) y la producción de metano (CH4) vía acetogénesis. Los parámetros tomados de referencias anteriores se recalibraron para ajustarlos a los datos de seis vertederos estadounidenses. Los resultados de la variación de la concentración con el tiempo para la materia orgánica, los AGV y el CH4 siguen satisfactoriamente el comportamiento esperado y se ajustan a los datos experimentales. El modelo de McDougall de 2007, implementado con éxito en COMSOL, puede calibrarse para datos de rellenos colombianos y mundiales.

Palabras clave: relleno sanitario; biodegradación; modelado matemática; generación de metano

1 Introduction

Utilizing stratified waste placement continues as an economically viable approach for the disposal of Municipal Solid Waste (MSW) in numerous countries. However, experiences of failure in several Colombian locations, including Bucaramanga (Carrasco, 2017), Cali (2001), and Bogota (1998), have underscored the need for heightened scrutiny and research on MSW management within the country.

How to cite: Buelvas-Hernandez, V., Moreno-Medina, J., and Ramírez-Meneses, M., Numerical simulation of waste landfill biodegradation: fitting experimental data. DYNA, 91(234), pp. 135-139, October - December, 2024.

Universidad Nacional de Colombia.
Revista DYNA, 91(234), pp. 135-139, October - December, 2024, ISSN 0012-7353
DOI: https://doi.org/10.15446/dyna.v91n234.113404

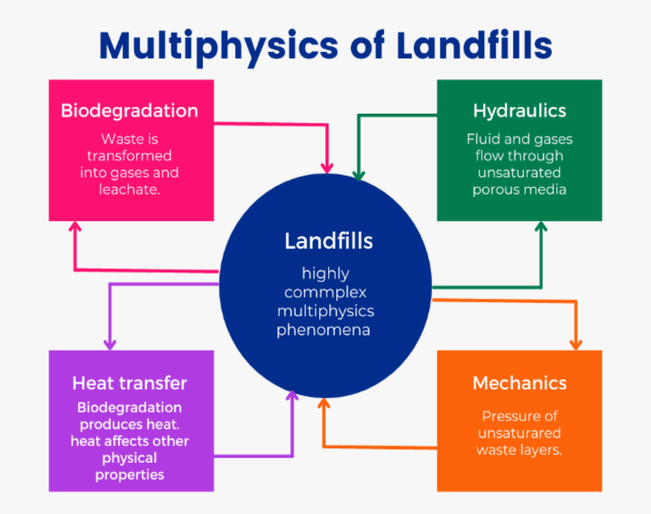

Figure 1. The Multiphysics phenomena influencing landfill design.
Source: Own

One of the primary challenges in MSW landfill management revolves around the accurate estimation of settlement, given that landfills naturally undergo settling processes over time. The final settlement can amount around to 30% of the initial landfill height according to [1]. The intricate interplay of waste biodegradation significantly influences this settling phenomenon. As waste materials biodegrade, they generate byproducts such as gas and leachate, initiating a cascade of complex processes that involve biochemical, mechanical (settlement, stresses, etc.), hydraulic (flow, pressure), and thermal phenomena (temperature rise). Fig. 1 illustrates the multiphysics phenomena intricately interwoven in landfill design and performance [2].

Introducing a Multiphysics simulation of biodegradation in landfill waste is crucial for understanding the long-term behavior of municipal solid waste (MSW) and its environmental impact. Landfill settlement estimation and the complex processes involved are of significant concern in landfill management. To address these challenges, innovative models have been developed, such as hydro-mechanical [3-8], bio-mechanical [3-11], hydro-bio-mechanical [3-8,11], hydro-thermal [12,13], gas generation [3-5,9,11], and hydro-bio-thermal models [13-15].

The degradation model encompasses various stages, from organic matter coming from solid degradable fraction (SDF) transforming into volatile fatty acids (VFA) through hydrolysis and acidogenesis to the formation of methanogenic biomass (MB), which leads to methane (CH4) and carbon dioxide (CO2) production, Fig. 2 [2]. Methane generation is an environmental concern that further emphasizes the study of biodegradation in landfills [8].

Different methods, such as one-state, two-state, and multi-state, can be used to classify anaerobic biodegradation models based on the number of chemical and bacterial reaction paths. The two-state method is the most widely used and relies on variables such as Solid Degradable Fraction (SDF), VFA, and MB.

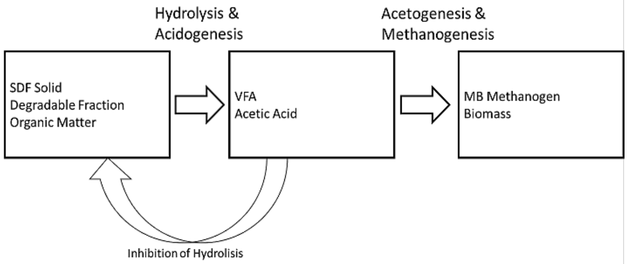

Figure 2. Biodegradation process.
Source: Own

Several mathematical models have been proposed to describe the depletion rate of SDF in MSW. A mathematical model proposed by McDougall [3] based on a chemical equation has served as a foundation for subsequent studies. [16] proposed a bio-thermal (BT) model validated through six laboratory experiments conducted by [5] and [17]. As a result of calibrating the model, the author applied it to a typical full-scale landfill cell geometry to examine the long-term spatial and temporal variation over time. A laboratory test performed by [18] achieved similar results using a biodegradation model based on McDougall of approach.

Estimating MSW properties for numerical modeling requires empirical measurements. Studies by [5] and [17] conducted laboratory tests to characterize biodegradation potential and measure key byproducts such as VFA and MB. These studies provide valuable insights into the behavior of MSW under different conditions.

A series of laboratory tests were performed and carried out to characterize anaerobic biodegradation potential of fresh MSW, using two large-scale Consolidating Anaerobic Reactors (CARs). The CARs contained waste material of the same composition as that used in BMP tests in other laboratory test performance by the authors. Two levels of constant vertical overburden pressures were applied on the top of the waste sample during the entire course of the experiment (CAR1: 150 kPa and CAR2: 50 kPa) to simulate representative overburden stresses experienced in landfills [5].

[17] run out laboratory tests to investigate the biochemical and physical characteristics of MSW under leachate recirculation-enhanced conditions. Waste samples were extracted from different waste landfills around USA, with duration ranging approximately 850 to 1500 days (namely, Michigan MI – 1,100 days, Texas TX – 1,500, Arizona AZ – 885, and California CA – 850 days).

Correlations of Methane generation potential (L0) and a percentage of biodegradable waste prior to degradation, parameter B0, were obtained. In the same way, correlations of methane generation rate (r_{CH4}), L_0 and maximum soluble chemical oxygen demand in leachate were developed.

The articles by [19] and [4] present mathematical models for predicting the biodegradation of organic matter in landfills. [19] model considered factors like moisture content, temperature, and pH levels, accurately predicting degradation rates. [4] focused on biochemical processes, including hydrolysis, acidogenesis, acetogenesis, and methanogenesis, validating the model with empirical data and using it to predict waste degradation rates and methane production.

Understanding biodegradation processes and modeling them is crucial for landfill management and reducing greenhouse gas emissions. The processes can provide valuable insights and optimization strategies.

This paper presents the modeling and simulation of landfill biodegradation using the mechanistic biodegradation model [3], widely used in technical literature. The analysis is based on model parameter values reported in the literature [5,17,20,21]. In addition, the basis is laid for future comparison with laboratory measurements to corroborate the theory and calibrate the model parameters.

2 Methodology

2.1 Mathematical Model

The most used model for biodegradation in landfills is that of [3], which was implemented in this study by means of COMSOL Multiphysics software. According to the McDougall model, the three main mechanisms involved in biodegradation (Fig 1) can be simplified by eq. (1).

$$\underbrace{\overbrace{C_6H_{10}O_5}^{SDF}}_{162\,g} + \underbrace{H_2O}_{18g} \rightarrow \overbrace{CH_3COOH}^{VFA} + 8H_2 + 4CO_2 \rightarrow \overbrace{\underbrace{3CO_2}_{132g} + \underbrace{3CH_4}_{48g}}^{MB} \qquad (1)$$

The Solid Degradable Fraction (SDF), Volatile Fatty Acids (VFA) and Methanogenic Biomass (MB) are represented chemically in eq. (1) by cellulose, acetic acid, and carbon dioxide plus methane, respectively. The VFA accumulation rate r_g in gVFA m-3aqueous day-1, is expressed mathematically by eq. (2). where kVFA is the production inhibition rate constant, c is the concentration of VFA in the aqueous phase in gVFA m-3aqueous, S is the solid degradable fraction at any instant of time, SO is the initial solid degradable fraction (SDF) b is the maximum VFA growth rate (gVFA m-3aqueous day-1), n is the structural transformation parameter, $\theta_e = \frac{\theta - \theta_r}{\theta_s - \theta_r}$ is the effective volumetric moisture content, and θ, θ_r and θ_s are respectively the volumetric, residual and saturation moisture contents.

$$r_g = \theta_E b\left[1 - \left[\frac{S_O - S}{S_O}\right]^n\right] * e^{-k_{VFA}(c))} \qquad (2)$$

The MB production/growth rate (r_j) represents methanogenic substrate depletion and methanogen growth, which are described by Monod kinetics according to eq. (3). Where k0 is the specific growth rate (day-1), m is the concentration of MB in aqueous phase (g[VFA] m-3[aqueous]) and kMC is the half-saturation constant (g[VFA] m-3[aqueous]).

$$r_j = \frac{k_0 c}{(k_{MC} + c)} m \qquad (3)$$

The terms $r_h = \frac{r_j}{Y}$, and $r_k = k_2 m$ depict the VFA consumption rate and the MB decay/death rate respectively. VFA consumption rate is associated to the MB growth rate r_j through a substrate yield coefficient Y. The methanogenic decay rate is related to k2, the MB decay rate constant (day-1). Finally, it is possible to set up a system of ordinary differential equations to describe the accumulation rates of SDF (S), VFA (c) and MB (m) by equations Eq. 4 to 6 respectively.

$$\frac{\partial S}{\partial t} = -\theta \frac{162}{60} r_g \qquad (4)$$

$$\frac{\partial c}{\partial t} = \left[r_g - r_h\right] \qquad (5)$$

$$\frac{\partial m}{\partial t} = \left[r_j - r_k\right] \qquad (6)$$

The model was proved with different combinations of parameters and initial conditions as shown in Table 1, as reported in [20,21], which refers to measurements in different landfills in the USA. The parameters were further optimized for better adjustment of the simulation with the field data.

Table 1.
Parameter values for different landfill data cases

Parameter	CAR1	CAR2	MI	TX	AZ	AC
Initial volumetric moisture content (%)	56.3	64.3	27.0	49.0	38.0	42.0
Volumetric residual moisture content (%)	11.0	11.0	7.7	15.0	12.0	16.0
Percentage of degradable solids (%)	55.0	55.0	30.2	11.7	24.0	9.0
Degradable solids density (kg m^{-3})	745.0	745.0	882.0	1044.0	955.0	1338.0
Inert solids phase density (kg m^{-3})	1735.0	1735.0	895.0	1727.0	1716.0	1660.0
Initial SDF concentration (kg m^{-3})	240.6	196.6	93.4	70.1	111.6	57.4
Initial VFA concentration (g$_{[VFA]}$ m$^{-3}_{[aqueous]}$)	300.0	300.0	0.0	0.0	8500.0	0.0
Initial MB concentration (g$_{[VFA]}$ m$^{-3}_{[aqueous]}$)	1000.0	1000.0	300.0	100.0	1200.0	10.0
Maximum hydrolysis rate (g$_{[VFA]}$ m$^{-3}_{[aqueous]}$ day^{-1})	18000.0	24000.0	9000.0	2000.0	5200.0	2000.0
Product inhibition factor (m^{3}g^{-1}) kVFA	1 × 10^{-4}	1 × 10^{-5}	8.5 × 10^{-4}	4.2 × 10^{-4}	1.2 × 10^{-4}	6.3 × 10^{-3}
Structural transformation parameter (-) n	0.06	0.06	1.00	0.70	1.00	0.70
Maximum specific growth rate for MB k(day^{-1})	0.047	0.047	0.128	0.150	0.070	0.70
Methanogen death rate (day^{-1})	0.0040	0.0040	0.0050	0.0005	0.0040	0.0005
Half saturation constant kMC(g m^{-3} aq.)	4000	4000	1000	1500	3500	700
Cell to substrate yield coefficient	0.08	0.08	0.30	0.40	0.40	0.30

Source: taken from [20]

3 Results and Discussion

Fig 2 illustrates the biodegradation process, wherein degradable waste undergoes hydrolysis, acidogenesis/acetogenesis, and methanogenesis to transform SDF material into VFA and MB. Over time, Figs. 3 to 5 display the concentrations of SDF, VFA, and MB. A comparison between field data and model results from six experiments conducted across various waste landfills is available for analysis.

As shown in Fig. 3, a non-linear drop in SDF is presented as the initial fraction consumed by chemical processes under anaerobic conditions. The comparison between field data and model results for MI, TX, AZ and CA samples shows a very similar behavior of SDF over time, suggesting the model parameters are well calibrated. The experimental results are not available for CAR 1 and CAR2, but the simulated results are like the other samples in trend. In the case of CAR2, the results suggest additional parameter refinement could be done to improve the results, as other references suggest the decay time of SDF is shorter for this sample [16].

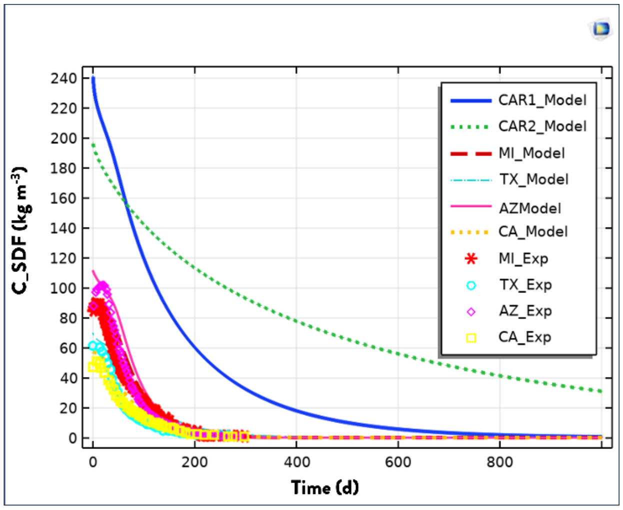

Figure 3. Concentration of Solid Degradable Fraction (C_SDF) as a function of time.
Source: Own

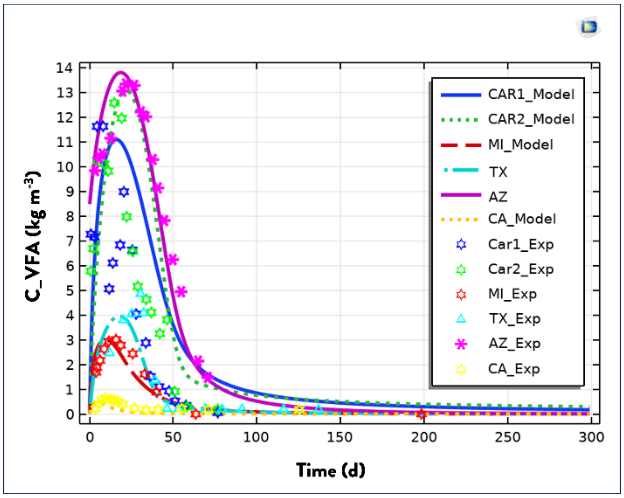

Figure 4. Concentration of Volatile Fatty Acids (C_VFA) as a function of time.
Source: Own

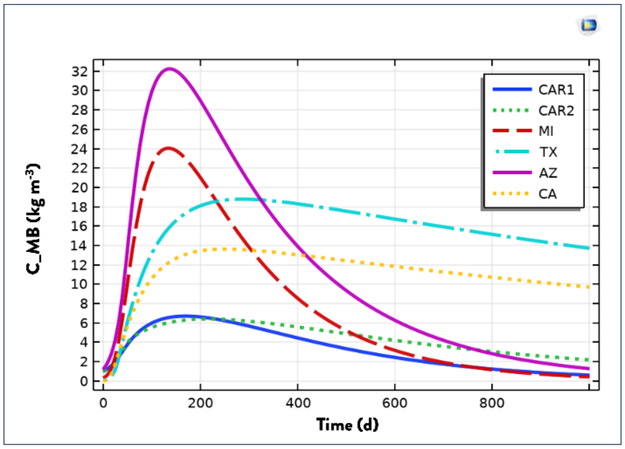

Figure 5. Concentration of Methanogenic Biomass (C_MB) as a function of time.
Source: Own

Fig. 3 presents only simulated results available for CAR1 and CAR2 samples. For MI, TX, AZ, and CA samples, the comparison of experimental and simulated results is available.

The VFA behavior over time is shown in Fig. 4. Fig. 4 presents all the samples (CAR1, CAR2, MI, TX, AZ, and CA), the comparison of experimental and simulated results is available. The comparison between field and simulated data shows a good agreement for all the samples. As SDF is consumed, the maximum VFA peaks after 25 to 50 days, then decays exponentially leading to MB generation. For all the samples, 150 to 200 days are required to consume all the VFA.

On the other hand, Methane production/consumption occurs slower (Fig. 5), reaching a peak after 150 days just when the VFA has been depleted, controlled by the specific decay rate (k2). For all the samples (CAR1, CAR2, MI, TX, AZ, and CA), only simulated results are available.

The numerical results spanning 1000 days of simulation, as depicted in Figs. 3-5, align closely with the anticipated outcomes based on the chemical processes inherent to the waste site. Moreover, the model accurately reproduces curve trends, with peak values closely resembling those reported by the authors [20,21].

4 Conclusion

The mathematical model proposed by McDougall in 2007 has been successfully implemented in COMSOL. Its validation was achieved through comparison with biochemical data collected from six laboratory experiments conducted on samples sourced from real MSW landfills in both the United States and the United Kingdom. In summary, the model delineates the biodegradation process within a bioreactor landfill, comprising three phases transitioning from SDF to MB via intermediate VFA stages. Graphical representations underscore the correlation between the consumption of the VFA phase and the subsequent increase in the MB phase, offering insights into the dynamics of the system.

Upon calibration of the model, we have successfully determined biodegradation parameters. These parameters exhibit strong agreement with laboratory experimental data, particularly concerning variations in biochemical parameters such as volatile fatty acids and degradable solids within the waste samples. This alignment underscores the model's reliability in capturing the intricate dynamics of the biodegradation process. These refined parameters serve as a foundation for executing coupled Multiphysics models in subsequent analyses.

Integrating thermal dynamics, mechanical settlement, and hydraulic processes is essential for advancing the present waste backfill model. Thermal dynamics account for temperature's impact on biodegradation, while considering mechanical settlement ensures structural stability and deformation analysis. Hydraulic processes govern fluid flow, gas migration, and leachate transport. By incorporating these physics, we develop a comprehensive model that predicts temperature variations, structural integrity, and fluid dynamics within landfill systems, enhancing our management strategies.

Acknowledgements

We extend our sincere thanks to Semillero In Silico UdeA for their invaluable support in promoting sustainability through STEM disciplines. Vladimir would like to greatly acknowledge the financial supports by ¨Pasaporte a la ciencia¨-ICETEX-Colfuturo.

Bibliography

[1] Krase, V., Bente, S., Kowalsky, U., and Dinkler, D., Modelling the stress-deformation behaviour of municipal solid waste, Geotechnique, 61(8), pp. 665–675, 2011. DOI: https://doi.org/10.1680/geot.8.P.140.

[2] Hubert, J., Liu, X. F. and Collin, F., Numerical modeling of the long term behavior of Municipal Solid Waste in a bioreactor landfill, Comput Geotech, 72, pp. 152–170, 2016. DOI: https://doi.org/10.1016/j.compgeo.2015.10.007

[3] McDougall, J., A hydro-bio-mechanical model for settlement and other behaviour in landfilled waste. Comput Geotech, 34(4), pp. 229–246, 2007. DOI: https://doi.org/10.1016/j.compgeo.2007.02.004.

[4] White, J., Robinson, J., and Ren, Q., Modelling the biochemical degradation of solid waste in landfills, Waste Management, 24(3), pp. 227–240, 2004. DOI: https://doi.org/10.1016/j.wasman.2003.11.009.

[5] Ivanova, L.K., Richards, D.J., and Smallman, D.J., Assessment of the anaerobic biodegradation potential of MSW, Proceedings of Institution of Civil Engineers: Waste and Resource Management, 161(4), pp. 167–180, 2008. DOI: https://doi.org/10.1680/warm.2008.161.4.167.

[6] Hettiarachchi, H., Meegoda, J., and Hettiaratchi, P., Effects of gas and moisture on modeling of bioreactor landfill settlement, Waste Management, 29(3), pp. 1018–1025, 2009. DOI: https://doi.org/10.1016/j.wasman.2008.08.018.

[7] Chen, Y., Xu, X., and Zhan, L., Analysis of solid-liquid-gas interactions in landfilled municipal solid waste by a bio-hydro-mechanical coupled model. Sci China Technol Sci, 55(1), pp. 81–89, 2012. DOI: https://doi.org/10.1007/s11431-011-4667-7.

[8] Staub, M.J., Gourc, J.-P., Drut, N., Stoltz, G., and Mansour, A.A., Large-scale bioreactor pilots for monitoring the long-term hydromechanics of MSW. J Hazard Toxic Radioact Waste, 17(4), pp. 285–294, 2013. DOI: https://doi.org/10.1061/(ASCE)HZ.2153-5515.0000160.

[9] Machado, S.L., Carvalho, M.F. and Vilar, O.M., Constitutive model for municipal solid waste. Journal of Geotechnical and Geoenvironmental Engineering, 128(11), pp. 940–951, 2002. DOI: https://doi.org/10.1061/(ASCE)1090-0241(2002)128:11(940).

[10] Babu, G.L.S., Reddy, K.R., Chouskey, S.K., and Kulkarni, H.S., Prediction of long-term municipal solid waste landfill settlement using constitutive model. Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, 14(2), pp. 139–150, 2010. DOI: https://doi.org/10.1061/(ASCE)HZ.1944-8376.0000024.

[11] Liu, X., Shi, J., Qian, X., Hu, Y., and Peng, G., One-dimensional model for municipal solid waste (MSW) settlement considering coupled mechanical-hydraulic-gaseous effect and concise calculation. Waste Management, 31(12), pp. 2473–2483, 2011. DOI: https://doi.org/10.1016/j.wasman.2011.07.013.

[12] Garg, A., and Achari, G., A comprehensive numerical model simulating gas, heat, and moisture transport in sanitary landfills and methane oxidation in final covers. Environmental Modeling & Assessment, 15(5), pp. 397–410, 2010. DOI: https://doi.org/10.1007/s10666-009-9217-3

[13] Gholamifard, S., Eymard, R., and Duquennoi, C., Modeling anaerobic bioreactor landfills in methanogenic phase: long term and short term behaviors. Water Res, 42(20), pp. 5061–5071, 2008. DOI: https://doi.org/10.1016/j.watres.2008.09.040

[14] Gawande, N.A., Reinhart, D.R., and Yeh, G.-T., Modeling microbiological and chemical processes in municipal solid waste bioreactor, Part I: development of a three-phase numerical model BIOKEMOD-3P. Waste Management, 30(2), pp. 202–210, 2010. DOI: https://doi.org/10.1016/j.wasman.2009.09.009

[15] Hanson, J.L., Yeşiller, N., Onnen, M.T., Liu, W.L., Oettle, N.K., and Marinos, J.A., Development of numerical model for predicting heat generation and temperatures in MSW landfills. Waste Management, 33(10), pp. 1993–2000, 2013. DOI: https://doi.org/10.1016/j.wasman.2013.04.003

[16] Kumar, G., Reddy, K.R., and McDougall, J., Numerical modeling of coupled biochemical and thermal behavior of municipal solid waste in landfills. Comput Geotech, 128, art. 103836, 2020. DOI: https://doi.org/10.1016/j.compgeo.2020.103836

[17] Fei, X., and Zekkos, D., Coupled experimental assessment of physico-biochemical characteristics of municipal solid waste undergoing enhanced biodegradation. Géotechnique, 68(12), pp. 1031–1043, 2018. DOI: https://doi.org/10.1680/jgeot.16.P.253

[18] Datta, S., and Zekkos, D., The influence of waste composition on biogas generation model parameters. Environmental Geotechnics, 10(7), pp. 443-454, 2021. DOI: https://doi.org/10.1680/jenge.20.00058

[19] Haarstrick, A., Hempel, D.C., Ostermann, L., Ahrens, H., and Dinkler, D., Modelling of the biodegradation of organic matter in municipal landfills. Waste Management & Research: the Journal for a Sustainable Circular Economy, 19(4), pp. 320–331, 2001. DOI: https://doi.org/10.1177/0734242X0101900409.

[20] Datta, S., Zekkos, D., Fei, X., and Mcdougall, J., Waste-composition-dependent 'HBM' model parameters based on degradation experiments, Environmental Geotechnics, 8(2), pp. 124-133, 2018. DOI: https://doi.org/10.1680/jenge.18.00014

[21] Kumar, G., Reddy, K.R., and McDougall, J., Numerical modeling of coupled biochemical and thermal behavior of municipal solid waste in landfills, Comput Geotech, 128, 2020. DOI: https://doi.org/10.1016/j.compgeo.2020.103836.

V. Buelvas-Hernandez received the BSc. Eng in Civil Engineering in 2001 from the Universidad Nacional de Colombia. Medellin campus, Colombia, had an MSc. in Geotechnical Engineering in 2008 from the Universidad Polytechnical de Catalunya, Spain, and currently he is pursuing his PhD. in Geotechnical Engineering from the Universidade Federal do Rio de Janeiro, Brazil. Mr. Buelvas has been working as a consultor and professor in some universities of. His research interests include simulation, modeling, and behavior of soil mechanic.
ORCID: 0009-0006-2556-9473

J.L. Moreno-Medina, is an undergraduate student in Bioengineering at the University of Antioquia, Colombia. She has been a member of the research incubator In Silico UdeA since 2022, where she has participated in projects involving Multiphysics Simulation related to areas such as landfills, geothermal energy, and hyperthermia in breast cancer treatments.
ORCID: 0009-0008-6924-9695

M. Mercado-Montoya, is the co-founder and CEO of In Silico STEM SAS and Semillero In Silico UdeA. Is a BSc. Eng. in Bioengineer and MSc. in Engineering from UdeA. She possesses extensive expertise in numerical modeling and simulation applied to sustainable physical innovations. Marcela has served as a consultant on simulation projects across various industries including biomedical, energy, chemical, and civil engineering, among others. Additionally, she has contributed to academia as a university lecturer in the same field.
ORCID: 0000-0002-1453-4690