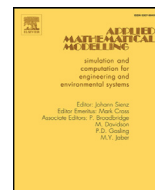




Contents lists available at ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Dynamics of spatial heterogeneity in a landfill with interacting phase densities – a stochastic analysis

Amit K. Chattopadhyay^{a,*}, Prasanta K. Dey^b, Sadhan K. Ghosh^c^a Nonlinearity and Complexity Research Group, Aston University, Birmingham B4 7ET, England^b Aston Business School, Aston University, Birmingham B4 7ET, England^c Mechanical Engineering Department, Centre for Quality Management System, Jadavpur University, Kolkata 700 032, India

ARTICLE INFO

Article history:

Received 9 September 2015

Revised 31 May 2016

Accepted 24 August 2016

Available online xxx

Keywords:

Stochastic

Landfill

Probability density function

Hydrolysed mass

Acetogenic mass

Methanogenic mass

ABSTRACT

A landfill represents a complex and dynamically evolving structure that can be stochastically perturbed by exogenous factors. Both thermodynamic (equilibrium) and time varying (non-steady state) properties of a landfill are affected by spatially heterogeneous and nonlinear sub-processes that combine with constraining initial and boundary conditions arising from the associated surroundings. While multiple approaches have been made to model landfill statistics by incorporating spatially dependent parameters on the one hand (data based approach) and continuum dynamical mass-balance equations on the other (equation based modelling), practically no attempt has been made to amalgamate these two approaches while also incorporating inherent stochastically induced fluctuations affecting the process overall. In this article, we will implement a minimalist scheme of modelling the time evolution of a realistic three dimensional landfill through a reaction–diffusion based approach, focusing on the coupled interactions of four key variables – solid mass density, hydrolysed mass density, acetogenic mass density and methanogenic mass density, that themselves are stochastically affected by fluctuations, coupled with diffusive relaxation of the individual densities, in ambient surroundings. Our results indicate that close to the linearly stable limit, the large time steady state properties, arising out of a series of complex coupled interactions between the stochastically driven variables, are scarcely affected by the biochemical growth–decay statistics. Our results clearly show that an equilibrium landfill structure is primarily determined by the solid and hydrolysed mass densities only rendering the other variables as statistically “irrelevant” in this (large time) asymptotic limit. The other major implication of incorporation of stochasticity in the landfill evolution dynamics is in the hugely reduced production times of the plants that are now approximately 20–30 years instead of the previous deterministic model predictions of 50 years and above. The predictions from this stochastic model are in conformity with available experimental observations.

© 2016 Elsevier Inc. All rights reserved.

* Corresponding author.

E-mail address: a.k.chattopadhyay@aston.ac.uk, akchaste@yahoo.com (A.K. Chattopadhyay).URL: <http://www.aston.ac.uk/eas/staff/a-z/amit-k-chattopadhyay/> (A.K. Chattopadhyay)

1. Introduction

Municipal waste management (MSW) has traditionally been a supply chain based facility primarily focused on ascertaining the most cost effective way of disposing household waste, including bio-waste. The concept of a modern landfill though stems from the idea of not only cost optimising bulk bio-waste disposal, but also to recycle the bio-disposables to convert chemical energy to industrially usable electric energy. From a supply chain perspective, this constitutes a feedback architecture where the disposable waste produces usable energy that is then fed back to the system itself for self-sustenance of the energy production process while simultaneously trafficking the extra energy generated for industrial usage [1]. Such operational management of power production from disposable bio-waste fundamentally relies on the engineering novelty that could ensure maximum energy production at minimum bio-filler consumption while also maximising the profit generated by appropriate disbursement of the energy through the associated supply chain network [2]. The success of such an “alternative energy” based industry then is inherently determined by the accuracy at which the following two factors can be probabilistically evaluated - the start time of the production process and the end time line up to which bulk production can be ensured from a plant.

Collection rates of the output landfill (methane) gas and associated collection efficiency are pivotal in quantifying the quality of a production plant and in future planning deliverables based on such production. Results at real methane production sites (methanogenic phase) have shown that the production rate and volume could drastically change depending on the nature and quality of clay covers, geosynthetic clay liners and geomembrane composite covers with the CH_4 [3] emission rates varying from 2.2 to 10,000 $\text{mg/m}^2/\text{d}$. Aside of the core landfill engineering, alternative (methane) production methods in the form of microbial oxidation have been proposed as a cost efficient measure [4]. Numerical models, focusing on the methane production rate with respect to the height dependence of landfill sites have supported such observations [5–8] with additional information such as 99% of the methane gas flow at the bottom being oxidised across the 0.8 m soil compost column with bulk oxidation of methane occurring within the top 0.2 m. The aspects of municipal solid waste management [9,10] have been areas of recent research interest, especially focusing on landfilling impacts [11] and systems analytics [10,12] based perspectives. Such statistical studies have made extensive use of linear programming algorithms [12,13] in analyzing multi-phase mixing of leachates. In a recent work [14], landfill gas generation data from residual municipal solid waste (RMSW) have been utilised to estimate the anaerobic gas generation rate constants. Without having been explicitly mentioned in this article [14], the numbers obtained ($0.0347\text{--}0.0803\text{ y}^{-1}$) seem clearly to indicate the importance of incorporation of stochasticity in the landfill gas related mathematical models, albeit the model applied specifically to aerobically stabilised MSW. Order of magnitude estimates made in the context of the United Kingdom landfill data also agree with such numbers [15]. The methane production time lines of real plants as indicated by numbers in this article estimate time periods between 12.5 and 33 years [14] that are obtained by inverting these rate constants¹. An accurate estimation of methane production time lines from landfill sites have evaded estimations from available deterministic theoretical models [16–21] in which these numbers come grossly overestimated by up to 150% further confirming the need for improved theoretical models.

In all these aforementioned studies, explicit incorporation of stochasticity in the otherwise deterministic dynamics could prove useful in analyzing the production process as a function of time. This is where stochastic mathematical modelling of the degradation rates of landfilled waste and consequent emergence of the hydro-carbon gases (e.g. methane) from the facility assumes importance. While traditional models [16–22] have been successfully able to predict the correct deterministic core of the processes defining a landfill facility, very few of these have made any explicit allusion to stochastic modelling. While some attempts [17–19,21] have been made to analyze the four phased biosolid \rightarrow hydrolysed leachate \rightarrow acetogenic compounds \rightarrow biogas (methane) production process, the incorporation of an explicit stochastic uncertainty could emphasise the role of phase heterogeneity in the mathematical model. The descriptions in these models clearly indicate the understanding for the need of such additional contributions in the model but related attempts were restricted only to the “mean field” probabilistic model.

The premise of this article is to bridge this information gap between realistic stochastic fluctuations of variables as seen in actual landfill sites and assumed deterministic approximation of the same in theoretical modelling as have been done. The target is to ensure that not only qualitative facts concerning the landfill dynamics are correctly accounted for but also accurate quantitative estimates of decay times of gas production facilities be estimated from the theoretical model. This is the objective of this article and would be studied using well established reaction–diffusion formalism as detailed below.

The article is organised as follows. After the derivation and description of the core stochastic model in the following Section 2, the temporal dynamics will be analysed in details in Section 3 where the focus will be on autocorrelation functions, the squared terms of which will clone the stochastic temporal dynamics. This then will be followed by Section 4 where a summary of the main results will be drawn.

2. Materials and methods

This is a paper on theoretical modelling of a stochastically forced dynamical process. As indicated already, this is a non-reductionist scheme geared towards optimised management of resources related to a waste management site, primarily

¹ Production time periods are roughly equal to the inverse of the gas generation rate constants.

Download English Version:

<https://daneshyari.com/en/article/5471367>

Download Persian Version:

<https://daneshyari.com/article/5471367>

[Daneshyari.com](https://daneshyari.com)