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Computer simulation of gas generation and transport in landfills. V: Use of artificial neural network and the genetic algorithm for short- and long-term forecasting and planning

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ABSTRACT

In the first four parts of this series a three-dimensional model was developed for transport and reaction of gaseous mixtures in a landfill. An optimization technique was also utilized in order to determine a landfill's spatial distributions of the permeability, porosity, the tortuosity factors, and the total gas generation potential of the wastes, given a limited amount of experimental data. In the present paper we develop an artificial neural network (ANN) in order to make accurate short-term predictions for several important quantities in a large landfill in southern California, including the temperature, and the CH_4, CO_2, and O_2 concentration profiles. The ANN that is developed utilizes a back-propagation algorithm. The results indicate that the ANN can be successfully trained by the experimental data, and provide accurate predictions for the important quantities in the sector of the landfill where the data had been collected. Thus, an ANN may be used by landfills' operators for short-term plannings. Moreover, we showed that a novel combination of the three-dimensional model of gas generation, flow, and transport in landfills developed in Parts I, II, and IV, the optimization technique described in Part III, and the ANN developed in the present paper is a powerful approach for developing an accurate model of a landfill for long-term predictions and planning.

1. Introduction

Landfills, where municipal solid wastes (MSWs) are stored, are complex systems to model, as they contain materials in three distinct phases, namely, solid, liquid, and gas. The solid wastes are biodegraded by various micro-organisms, and eventually produce significant amounts of CO_2 and CH_4. The biodegradation process is usually exothermic, resulting in the generation of a significant amount of heat that is trapped in the landfill. The heat increases the landfill's temperature, hence creating hazardous conditions and posing danger to the community adjacent to the landfill. A vital issue in landfills operation is the existence of *hot spots*, or *enhanced oxidation zones* (EOZ), where the temperature of the landfill can exceed 130 °F. The EOZ conditions occur when significant amounts of oxygen infiltrate landfills from the perimeter wells. The infiltration of air to sections of landfills transitions waste from an anaerobic phase to an aerobic phase. Aerobic biodegradation reactions have a higher heat of reaction than the anaerobic ones. If the heat generated from aerobic biodegradation is trapped in the low permeability waste, it will gradually increase the temperature in the trapping section of the landfill. Some of the problems that arise from the elevated temperature and the development of the EOZ in a landfill include the loss of, or at least damage to, the extraction wells, underground fires, and rapid settlement of the wastes. The landfill gas (LFG) may also create the risk of underground fire, if the ratio of CH_4 and O_2 approaches its flammability limit.

At the same time, large landfills produce very significant amounts of CH_4 that can be used as a relatively clean source of energy. They also produce large amounts of CO_2 that, if released into the atmosphere, will contribute to the Greenhouse phenomenon. Thus, due to the possibility of the underground fires and the danger to the surrounding community on the one hand, and the need for proper planning for the use of the produced CH_4 on the other hand, development of a computational model for predicting the temperature and the amounts of CH_4 and other important gases, such as O_2 and CO_2, is vital to the safe operation of a landfill. Such a tool will enable the operators to identify the problematic areas in a landfill, and to take the proper precautions, in order to ensure that the emerging problems are addressed in a timely fashion.

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Conventional methods for predicting the temperature distribution and the concentrations of the various species throughout a landfill are based on the numerical simulation of the governing equations for energy and mass transfer. In four previous papers (Hashemi et al., 2002; Sanchez et al., 2006, 2007, 2010, hereafter referred to, respectively, as Parts I, II, III, and IV) we presented a comprehensive three-dimensional (3D) model that accounts for the generation and transport of the four major gaseous components of the LFG, namely, CH_4, CO_2, O_2, N_2, assuming that isothermal conditions prevail. Given that a landfill is a strongly heterogeneous large-scale porous medium, the model developed in Parts I–IV allowed for broad spatial distributions of the permeability, porosity, and tortuosity factor in a landfill and its surrounding soil (if the landfill does not have liners), as well as a large number of wells for extraction/monitoring of the LFG.

Part I studied the behavior of landfills under quasi-steady-state condition, which pertains to those that have been closed for a long time, and investigated the effect of the important parameters. Part II investigated the dynamics of a landfill under a variety of conditions such as, for example, when (a) some of the monitoring and/or extraction wells are shut down; (b) some new wells are drilled in the landfill, after it has been closed for some time, in order to collect additional gases or meet the environmental regulations, and (c) the landfill's cover is, for some reason, damaged. Part III proposed a new approach to the development of an accurate model of a landfill by addressing a key question: *Given a limited amount of data for one or several properties of a landfill, what are the optimal spatial distributions of its porosity, permeability, tortuosity factors, and the wastes' gas generation potentials that not only honor (preserve) the existing data, but also provide accurate predictions for its future behavior?* The study in Part III formulated the problem as one of optimization, and utilized a technique based on the genetic algorithm – a powerful method for obtaining the optimal solution of a constrained problem – to address the question. In addition to the LFG, landfills usually contain leachates. Water enters a landfill by different means, such as precipitation from rain, moisture that the wastes contain when they are stored in the landfill, and recirculation of leachate throughout the landfill. In Parts I–III we ignored the presence of the leachate, and included in the model only the rates of the reactions and the generation of the gases. Thus, in Part IV we developed the model further by focusing on its extension to the case in which the flow of both the leachate and the gases can be studied.

While the model developed in Parts I–IV is suitable for long-term planning for the operation of a landfill, it is too costly, in terms of the necessary computations, for short-term predictions. A typical landfill operator would like to be able to predict, for example, how the short-term trends (over a few months) in the spatial distribution of the temperature of a landfill develop, particularly in the areas near the extraction/monitoring wells, so that plans can be drawn for taking suitable actions, if need be. Such short-term predictions would be computationally too costly to be made by the model developed in Parts I–IV. Instead, one needs faster predictive methods. One purpose of the present paper is to describe one such method, and use it for making short-term predictions for a large landfill in southern California. The method that we develop is based on the use of artificial neural networks (ANNs).

Generally speaking, the ANNs consist of a class of computational tools that attempt to mimic the nature. They have been developed based on the way that the human brain performs operations and computations, using millions of individual neurons that are highly interconnected with one another. Information, in the form of electrical pulses, from the output of other neurons is received by the cell at the connections that are known as synapses. The synapses connect to the cell inputs – the dendrites – with a single output of the neuron appearing at the axon. An electrical pulse is then sent down the axon when the total input stimuli from all of the dendrites exceed a certain threshold. An ANN is composed and operates in a similar manner. It consists of individual models of the network, often in the form of distinct connection strengths associated with the synapses that it contains. The connections in an ANN are called the *weights*. The neurons are referred to as the *nodes*, when associated with an ANN. We will come back to the elements of the ANNs shortly.

One uses a set of data to train an ANN and familiarize it with the trends in the data for the quantities of interest. The ANN is then used to perform a particular function, namely, computing by adjusting the weights between its elements. Typical ANNs are trained such that a particular input will produce a specific target output. To be effective, the ANNs must be accurate function approximators and excellent at recognizing patterns in the data. Even simple ANNs might be able to fit any practical function, if they are properly trained. But, as we describe in this paper, the use of an accurate ANN offers another advantage to modelling of landfills, namely, that it can broaden the range of the data that we need for determining the optimal spatial distributions of the important parameters of a landfill, as described in Part III.

Over the past two decades the ANNs have been recognized as universal approximators, and have been widely used for forecasting analyses (see, for example, Fausett, 1994; Hagan et al., 1996; Gurney, 1997) in engineering. Applications of the ANNs to the problems in the landfill industry, as well as identifying problems in groundwater flow that might somehow be linked to a landfill, have been made only very recently. Coppola et al. (2003) used successfully an ANN to predict the hydraulic head using synthetic data and numerical simulations. They utilized the data for a period of 5 years in order to train the ANN and predict the liquid head in a limestone aquifer. The inputs to the ANN included pumping rates and the climate conditions. Hamed et al. (2004) used an ANN to predict the biochemical oxygen demand and the concentration of suspended solids in the effluent of a plant for wastewater treatment. Shamim et al. (2004) used an ANN to predict groundwater contamination in a region of Pakistan, by predicting the concentrations of iron, copper, and lead in the groundwater. Almasri and Kaluarachchi (2005) utilized an ANN to forecast the nitrate concentration in the Sumas-Blaine aquifer in Washington state. The results were in agreement with the actual field data.

Karaca and Özkaya (2007) utilized an ANN to study the effect of the meteorological and leachate characteristics on the predictions of the daily amount of leachate at a major landfill in Turkey. The input parameters to their ANN were the leachate's pH, temperature, and conductivity, the air temperature, cloudiness, pressure, relative humidity, and precipitation. Their study indicated that the ANN was able to accurately predict the daily quantity of the leachate in the landfill. Özkaya et al. (2007) used an ANN to study another landfill in Turkey. The input data included the pH, alkalinity, the concentration of the sulfate, the conductivity, the wastes' temperature, and the refuse age. Data collected over 34 months were used to validate the ability of the ANN for predicting some of the properties of interest in the landfill. Scozzari (2008) used an ANN to determine the surface biogas flux in the municipal solid wastes landfills, with the input parameters being the meteorological parameters. The predictions provided by the ANN for the biogas flux were accurate. Singh and Datta (2007) used an ANN to identify the unknown sources of groundwater pollution in terms of the magnitude, location, and the time of leakage of the pollutants. The ANNs have also used for predicting and addressing many issues concerning modelling of oil and gas reservoirs, based on some limited data (see, for example, Al-Kaabi and Lee, 1993; Mohaghegh, 2009a,b).