GAS MIGRATION AND VENT DESIGN AT LANDFILL SITES

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Abstract. A finite element model has been developed to simulate the migration of gases in soil from a buried source such as a landfill. Using quadratic elements, the diffusion convection equation coupled with the mass conservation equation of a binary mixture of gases is solved under a combination of Dirichlet, Neumann and flux type of boundary conditions. The model is compared with an analytical solution and a set of field measurements. The model is used to display the influence of seasons on the migration of gases. The effectiveness of venting trenches in containing such migrations is examined and a method for the determination of trench depth is presented.

1. Introduction

For reasons of economy and simplicity, sanitary landfills are still a major means of solid waste disposal in many countries [3, 6]. Current trends suggest the continuation of this method of disposal in the foreseeable future. Anaerobic decomposition of refuse in landfills generates CH4 and CO2 [5, 9]. The problem of CH4 migration from landfills and subsequent explosions in underground structures has received increasing attention during recent years. The problem is intensified in areas where, for a significant part of the year, the ground surface remains covered with ice and snow, thereby increasing the migration to greater distances. Apart from the danger of explosions, another problem of no lesser importance arising from such migration is the deterioration of crops and plant life.

To control and contain migrating gases, reliable estimates of the extent of gas migration are necessary. These are difficult to acquire because only limited field data are available. Vents of various types have been used at landfill sites with varying degrees of success. These have been designed and positioned without the benefit of a strong field data base or a methodology to anticipate migration patterns and vent effectiveness.

This paper presents a finite element model developed to investigate migration patterns of gases in soil from a buried source, specifically a sanitary landfill under a variety of boundary conditions. The performance of the model is evaluated in an actual field situation.

The finite element model developed may be employed to simulate a wide range of field conditions. Two examples are presented in the paper.

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(i) The effect on migration of freezing and thawing of the soil surface, a time varying boundary condition, and
(ii) The effect of a vent system on the migration of gases.

In addition a demonstration of the use of the model in the design of vents is presented.

2. Theory

2.1. Governing Equations

Gases are transported from a buried source by two mechanisms:

(i) convection due to a pressure gradient, and
(ii) diffusion due to a concentration gradient.

The migration under such conditions is mathematically represented by the mass conservation equation of the diffusing species [1]

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x_i} \left( D_{ij}^p \frac{\partial c}{\partial x_j} \right) - V'_i \frac{\partial c}{\partial x_i}$$

(1)

in which $c = c(x, t) = \rho_a/\rho_{so} = \text{non-dimensional concentration of } \alpha \text{ species } \rho_a = \text{mass density of } \alpha \text{ species}; \rho_{so} = \text{value of } \rho_a \text{ at the source}; x_i = \text{cartesian frame of reference}; D_{ij}^p = \text{tensor of diffusion coefficients (} \alpha \text{ species diffusing into } \beta \text{ species) in soil}; \text{ and } V'_i = \text{volume-averaged velocity}.$

The volume-averaged velocity rather than the mass-averaged velocity is used because the fluid system is inhomogeneous. The relationship between the two velocities is given by

$$V'_i = V_i^* + D_{ij}^p \frac{\partial \rho}{\partial x_j}$$

(2)

in which $V_i^* = \text{mass-averaged velocity and } \rho = \text{mass density of the fluid mixture.}$ The mass-averaged velocity is obtained from the mass conservation of the gas mixture and Darcy's Law:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho V_i^*) = 0$$

(3)

$$V_i^* = -\frac{k_{ij}}{n \mu} \frac{\partial p}{\partial x_j}$$

(4)

in which $k_{ij} = \text{tensor of intrinsic permeability}; n = \text{porosity of soil}; \mu = \text{absolute viscosity of mixture of gases}; \text{ and } p = \text{scalar pressure field}.$

* See Appendix for complete symbol descriptions.