A MATHEMATICAL MODEL FOR REMOVING VOLATILE 
SUBSURFACE HYDROCARBONS BY MISCIBLE 
DISPLACEMENT

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Abstract. A mathematical model is developed for analyzing the forced venting method of controlling 
hazardous vapors escaping from underground spills. Equations for predicting concentration profiles are 
derived from the fundamental laws governing the isothermal flow and dispersion of two-component, 
miscible, compressible fluids in a porous medium. The resulting equations are solved numerically by finite 
difference methods to predict concentration profiles for a two-dimensional venting process. Concentration 
profiles were found to be more sensitive to the dispersion coefficient than to porosity or permeability for 
the flow rates examined. A comparison of the model profiles with laboratory measurements indicated that 
realistic predictions are feasible.

Nomenclature

\[ D_{AB} \] binary diffusion coefficient,
\[ g \] gravity constant,
\[ h \] height of tank,
\[ K_{l,t} \] dispersion coefficient for the medium,
\[ k \] permeability,
\[ L \] length of tank,
\[ \bar{M} \] average molecular weight,
\[ M \] molecular weight,
\[ m \] transformed pressure variable,
\[ u \] total mass flux,
\[ N_{Pe} \] Peeler number,
\[ p \] pressure,
\[ R \] perfect gas constant,
\[ N_{Re} \] Reynolds number,
\[ F_g \] ratio of gravitational forces to viscous forces,
\[ T \] temperature,
\[ v_x \] velocity in the x-direction,
\[ v_y \] velocity in the y-direction,
\[ v_z \] velocity in the z-direction,
\[ \beta \] Schmidt Number/(Peclet Number)^2,
\[ \mu \] viscosity,
\[ \phi \] porosity of the medium,
\[ \chi_i \] mole fraction of component i,
\[ \omega \] mass fraction,
1. Introduction

Large quantities of gasoline and other volatile hydrocarbons are stored in underground facilities. Some leakage is inevitable and may be tolerable when quantities are small and confined to remote area. However, considerable amounts are often spilled in populated areas. The volatile hydrocarbons vaporize in the soil creating a toxic or explosive threat as they penetrate the foundations of neighboring buildings. Only recently has this been recognized as a widespread environmental problem.

The size and movement of the contaminated zone depend upon the nature of the soil, position of the water table and the quantity and type of hydrocarbon. As a result, effective cleanup and containment measures will vary considerably for each individual spill. Vreeken (1984) gives a discussion of the physical behavior of hydrocarbon transport in soils, along with proposed cleanup measures.

One method, which has received recent attention and is the focus of this investigation, is forced venting or aeration. This can be an effective *in situ* method when low viscosity hydrocarbons are spilled in a dry porous soil such as coarse sand. This method provides a way of controlling the immediate vapor threat and providing oxygen to the soil while removing a significant amount of the contaminant. In a typical application, pipes are sunk in the vicinity of the spill and an air/vapor flow in the soil is established by pumping. In the past, empirical methods have been used to determine the venting geometry, pumping capacity and duration. Large, complex venting arrangements may always do the job, but the additional time and effort required to set up a complex arrangement, when a simpler method would do, is costly and prolongs a hazardous situation.

Although forced venting has been used in actual spill situations, little information is available in the general literature to provide guidance for those who are faced with a venting problem but do not have direct experience to draw upon. A large scale laboratory study of venting was recently completed by Texas Research Institute, Inc. (TRI) (Wootan and Voynick, 1984). The results indicate that venting is a viable way of removing hazardous vapors. However, there are obvious problems in trying to design a venting system for field applications based upon data collected under ideal conditions.