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Air Barriers for Waste Containment in the Subsurface

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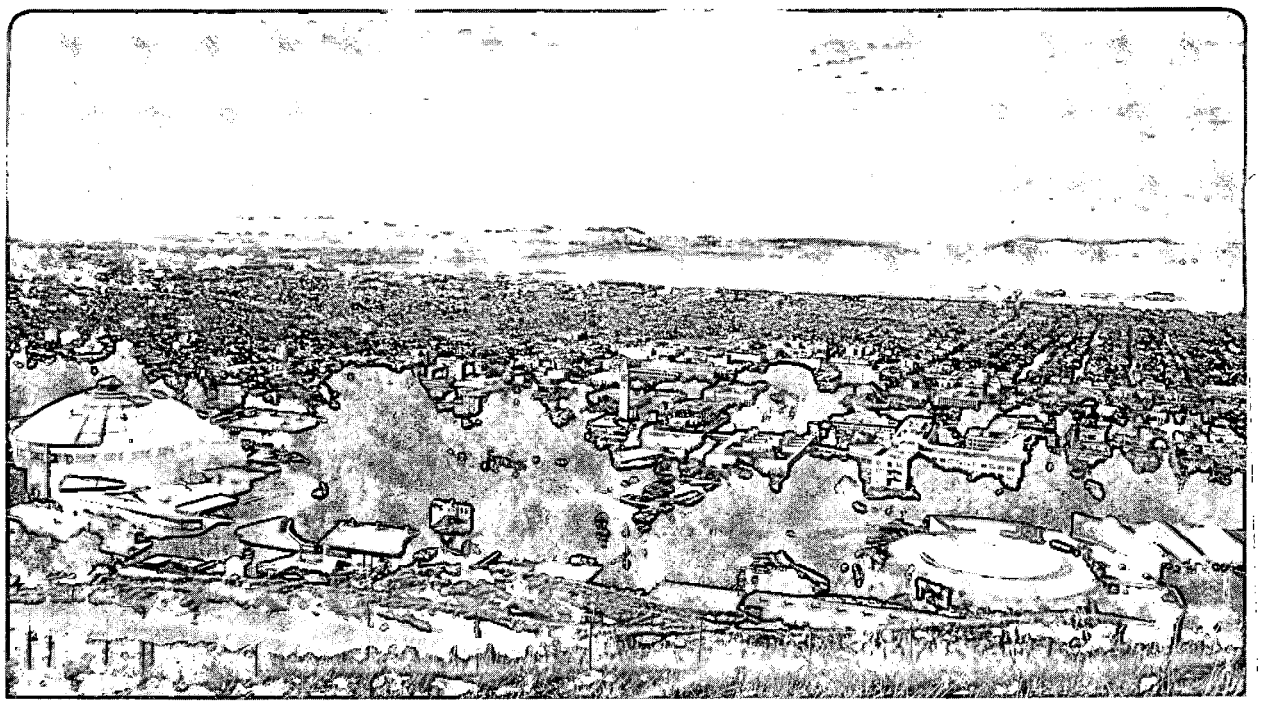

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AIR BARRIERS FOR WASTE CONTAINMENT IN THE SUBSURFACE

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AIR BARRIERS FOR WASTE CONTAINMENT IN THE SUBSURFACE

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Introduction

The increase of air saturation in a soil alters significantly its hydraulic characteristics by reducing its the relative permeability to liquids. This realization led to the concept that air injection could be used in the context of remedial strategies to create low permeability barriers to contaminated water and NAPL migration. Air offers a number of significant advantages as a barrier fluid: it is not a contaminant, already exists in the vadose zone, is abundant, easily available, free of charge, and has well-known thermodynamic properties. This report provides a brief summary of ait barrier modeling results to date.

Concept Description

The design discussed here involves a single layer of horizontal wells below the contamination in the vadoze zone. If the wells are numbered, the odd-numbered wells are used for air injection, and the even-numbered ones for gas removal. This system has a predominantly horizontal orientation of flow. This horizontal barrier is characterized by (1) a drier zone near the injection wells due to water displacement and evaporation, (2) a wetter zone near the removal wells due to recondensation, (3) a high gas pressure zone in the vicinity of injection, and (4) low gas pressure near the removal wells. In the vicinity of the injection wells, contaminated water and NAPLs cannot move downward because of a reduced NAPL relative permeability (caused by high gas saturation) and a pressure barrier to downward flow. In the vicinity of the removal wells, NAPLs and NAPL vapors cannot move downward due to a hydraulic gradient towards the wellbore.

In the vadose zone air injection not only displaces water, but also causes phase changes due to its drying effect. In the vicinity of the injection point, water and volatile NAPLs vaporize. The combination of displacement and drying drastically reduces the liquid relative permeability and creates a dry zone of high capillary suction from which liquid contaminants cannot escape. These effects may be significantly enhanced by increasing the temperature of the injected air. The vaporized water and NAPLs recondense away from the injection point, but their migration is controlled by the presence of the dry zone and the hydraulic impedance to flow between the injection and removal wells. In addition to containment, air barriers may also have a significant element of remediation because the vaporized NAPLs are removed from the subsurface through the gas removal well. These vapors will need to be treated before release to the atmosphere. Unlike other techniques, air barriers do not introduce a new liquid which can mobilize contaminants, and are easy to maintain.

Numerical Simulation

The problem under study involves numerous strongly non-linear complex processes: multi-phase (aqueous, gas, NAPL) multi-component flow, dissolution and advective transport, multicomponent diffusion, phase changes (evaporation and condensation) and heat transport. T2VOC [*Falta et al.*, 1995], a member of the TOUGH2 [*Pruess*, 1991] family of codes, was used for the simulation.

The computing platform was an IBM RS/6000 370 workstation. We used a typical Hanford soil and TCE as the contaminant. The soil was considered homogeneous and isotropic with a permeability $k = 1.6\times10^{-11}\ m^2$ and porosity $\phi = 0.385$. Relative permeability and capillary pressures were given by the *Parker et al.* [1987] 3-phase relationships, with $S_m = 0.13$, $n = 1.53$, $\alpha_{gn} = 13.15$, and $\alpha_{nw} = 15.47$ [*Falta et al.*, 1995]. The watertable was located 45 m from the surface. We modeled a section of the vadoze zone 40 m deep (from the surface) and 2 m wide.

The two-dimensional domain was discretized in 1720 gridblocks (20×86 in x,z). We made two runs. The first run (3 equations per cell, 5160 simultaneous equations) represented the reference case and involved continuous leakage of TCE at a rate q_o= 1.3 *kg/day* at z = 18.3 m from the top and $x = 1\ m$. The second run (4 equations per cell, 6880 equations) included the air barrier, with two wells located at ($x = 0\ m$, $z = 20\ m$) and ($x = 2\ m$, $z = 20\ m$). Air was injected into the first well at a rate of q_a = 1000 *kg/day* and an enthalpy of H_a = 101 *kJ/kg*, and gas was withdrawn from the second well at a rate of q_g = 1000 *kg/day*. For both runs t_{max} = 720 days.

Results and Discussion

The reference case required only 16,814 CPU sec to solve. The extreme non-linearities of the air barrier run necessitated rather small timesteps and required 138,118 CPU sec to cover t_{max} using the DSLUCS conjugate gradient solver of T2VOC. The results are presented in Figures 1 through 6. We reach the following conclusions:

1. From Figure 1, it is evident that the extent of free-phase TCE contamination is significantly smaller in the presence of the air barrier. As expected, the gas removal well attracts and vaporizes free-phase TCE. Note that the maximum TCE saturation with the air barrier is 0.22 (vs. 0.20 without), and is attributed to the focusing effect of the removal well.
2. Figure 2 shows that without the air barrier the soil gas contamination by TCE vapors is far more extensive than the TCE free-phase contamination, and poses a more serious problem because the TCE vapors are re-dissolved in the water (following Henry's law). The beneficial effect of the air barrier is more dramatic here: the extent of TCE gas contamination is dramatically smaller, localized, and limited to a narrow band which ends at the gas removal well. The maximum TCE concentration in the gas with the air barrier is 0.42 kg/m^3, almost twice as high as the 0.28 kg/m^3 observed without the barrier. The focusing action of the gas removal well seems to be responsible for the higher TCE concentration.
3. The air barrier is evident in Figure 3, which presents the gas saturation in the domain. We observe the emergence and evolution of a completely dry zone (with a gas saturation of 1), which is as much as 3 m thick. Due to practically zero liquid permeability, this zone is impermeable to NAPLs and/or contaminated water. This is evidenced by the fact that this zone is completely dry despite being overlain by the TCE free product in a very permeable medium.
4. The significant element of remediation (because the vaporized NAPLs are removed through the gas removal well) in air barriers is evident in Figures 4 and 5. The amount of TCE in the various phases (NAPL, gas, aqueous) is significantly lower with the air barrier (Figure 4). In Figure 5 the TCE mass ratio (defined as the ratio of TCE mass with and without the air barrier) in the NAPL, aqueous, and gas phases shows that the presence of the air barrier reduces the TCE amount by at least an order of magnitude over the reference case.
5. Without the air barrier, significant amounts of TCE contamination advance past the z = 20 m line, i.e. the line connecting the wells (Figure 6). The amount of TCE free product below the well line is 470 kg. However, no TCE in the gas, aqueous, or NAPL phases escapes past the dry zone established by the air barrier.

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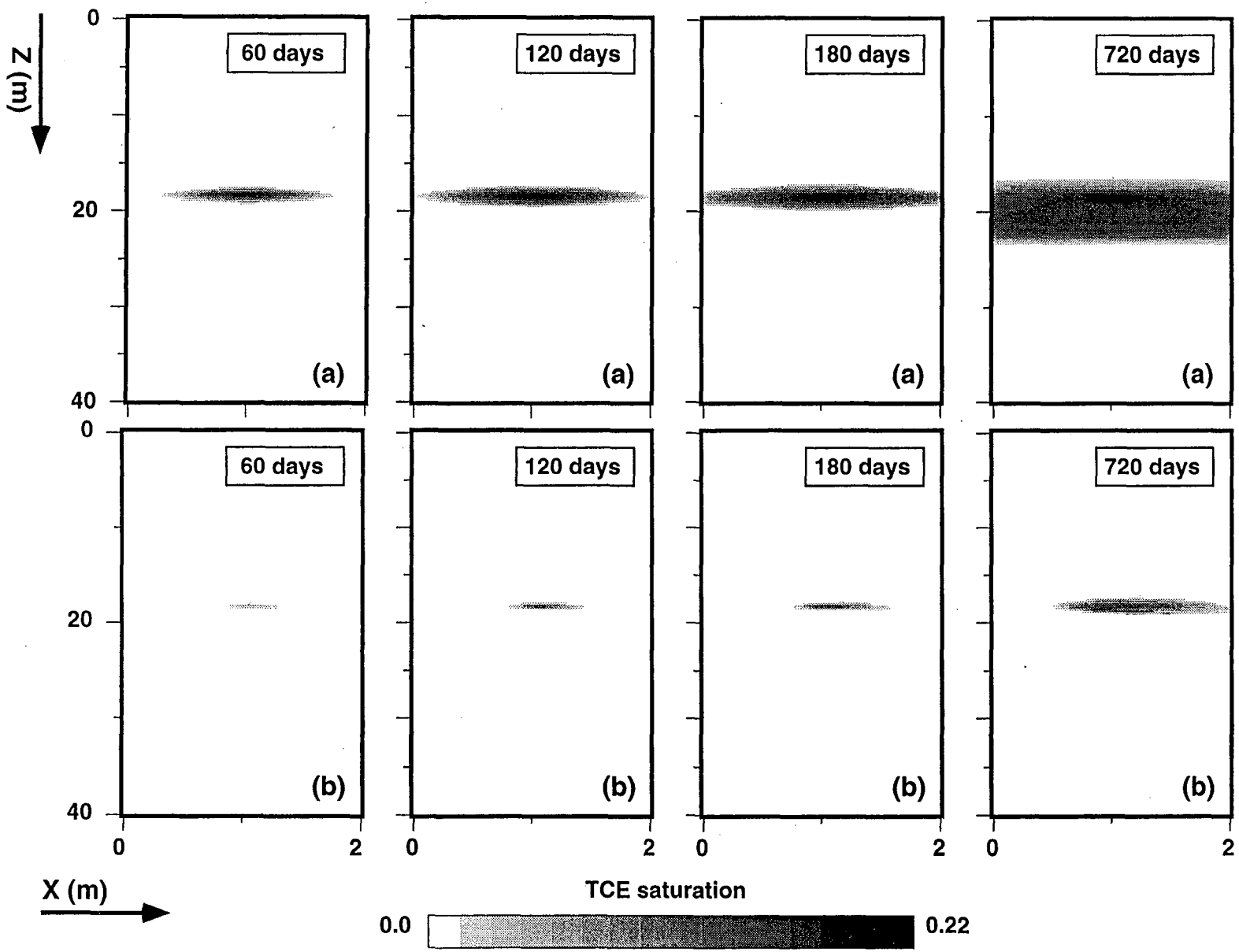

Figure 1. TCE saturation in the soil (a) without and (b) with the air barrier.

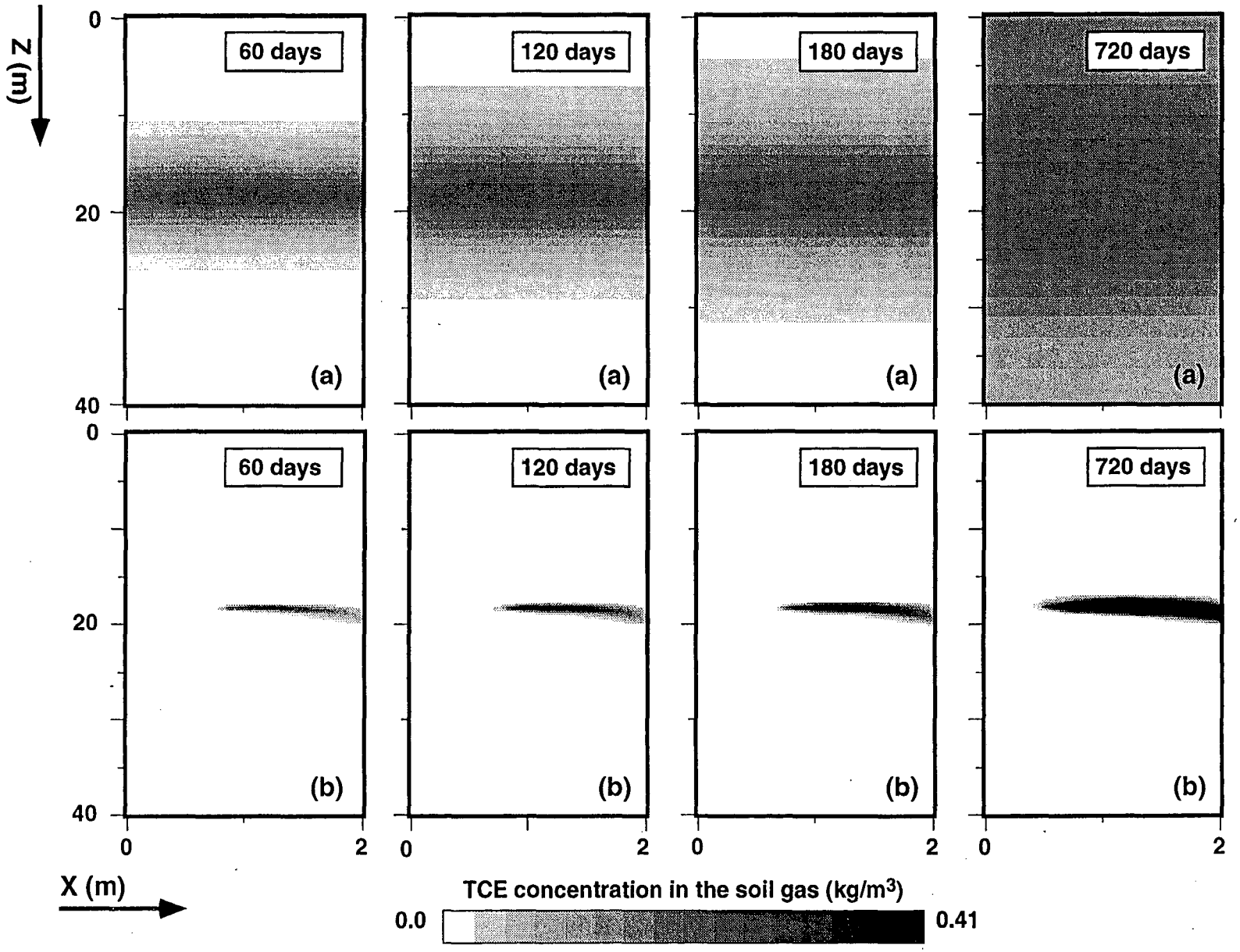

Figure 2. TCE concentration in the soil gas (a) without and (b) with the air barrier.

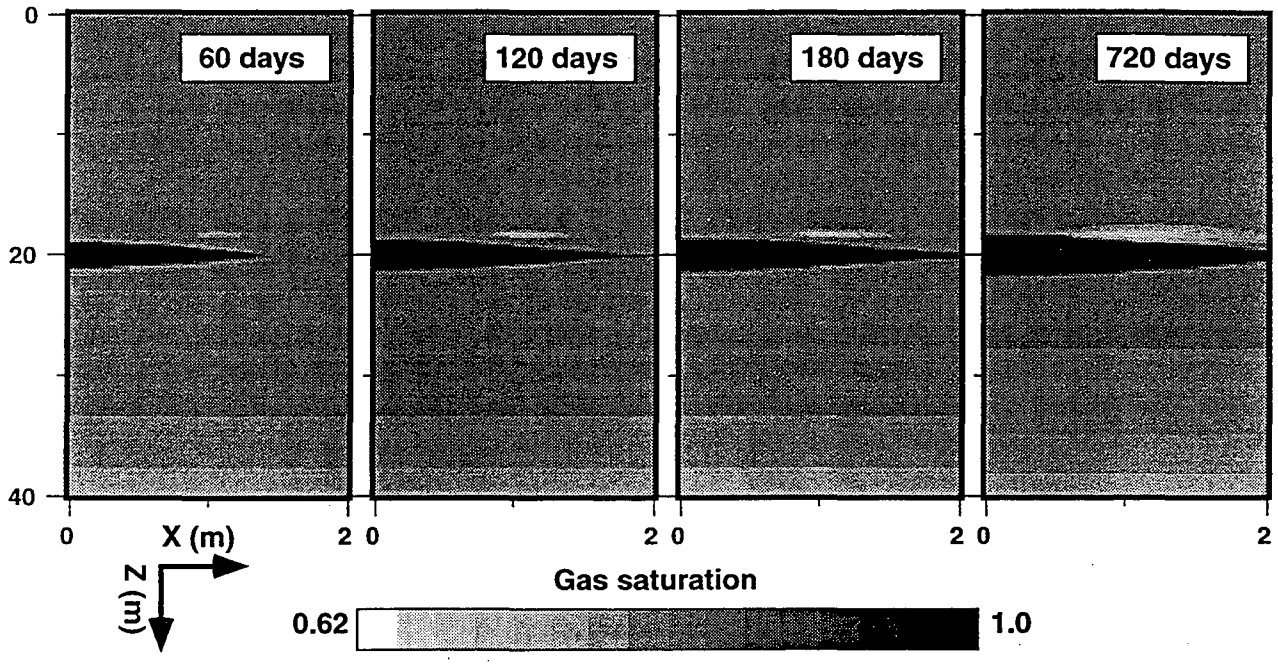

Figure 3. Gas saturation in the soil with an operating air barrier.

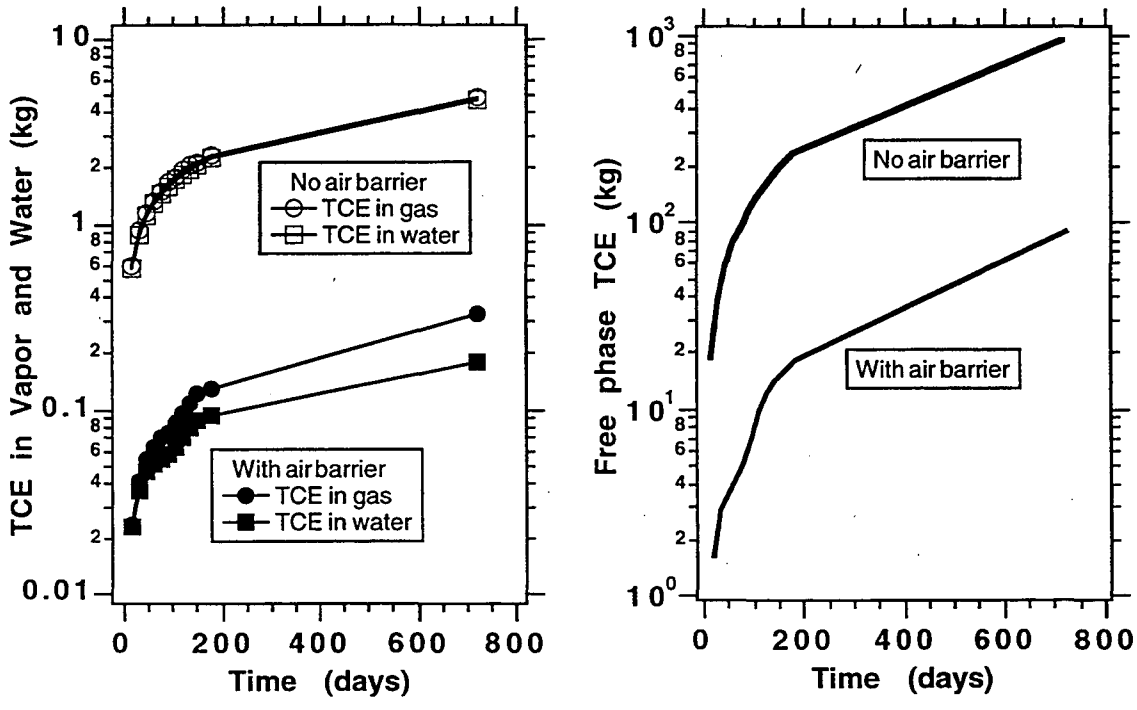

Figure 4. The amount of TCE in the vapor, liquid, and NAPL phases with and without the air barrier.

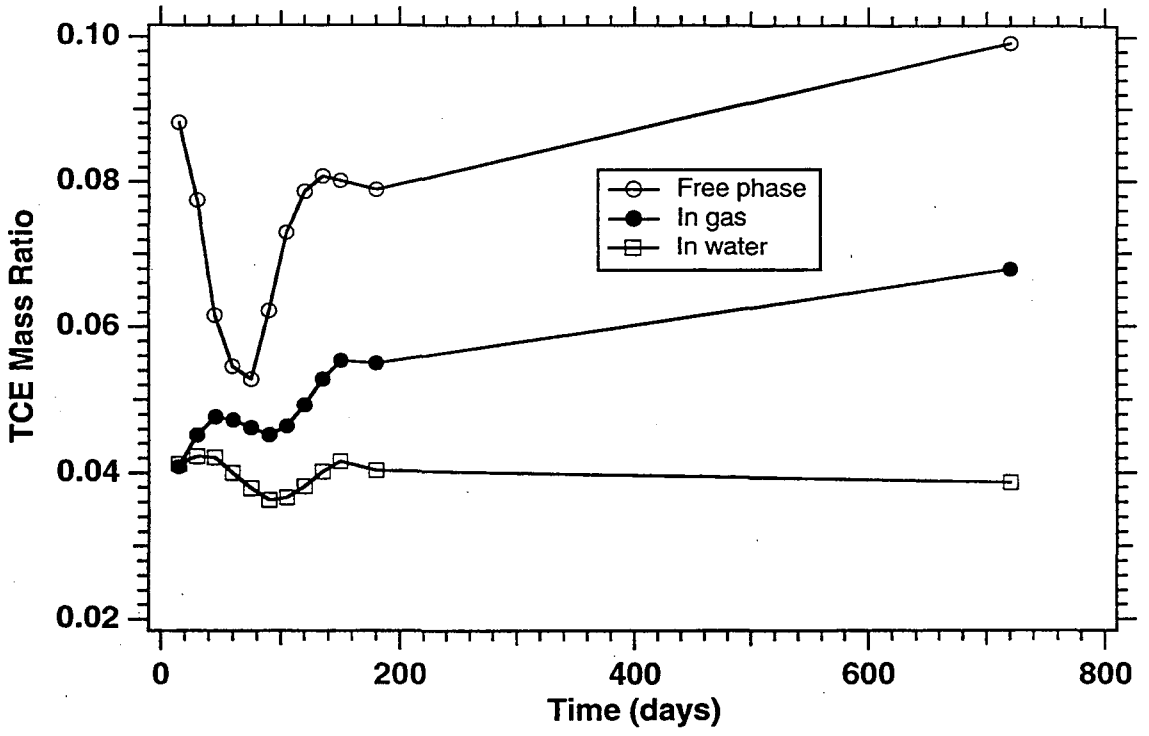

Figure 5. TCE mass ratio for the gas, aqueous, and NAPL phases.

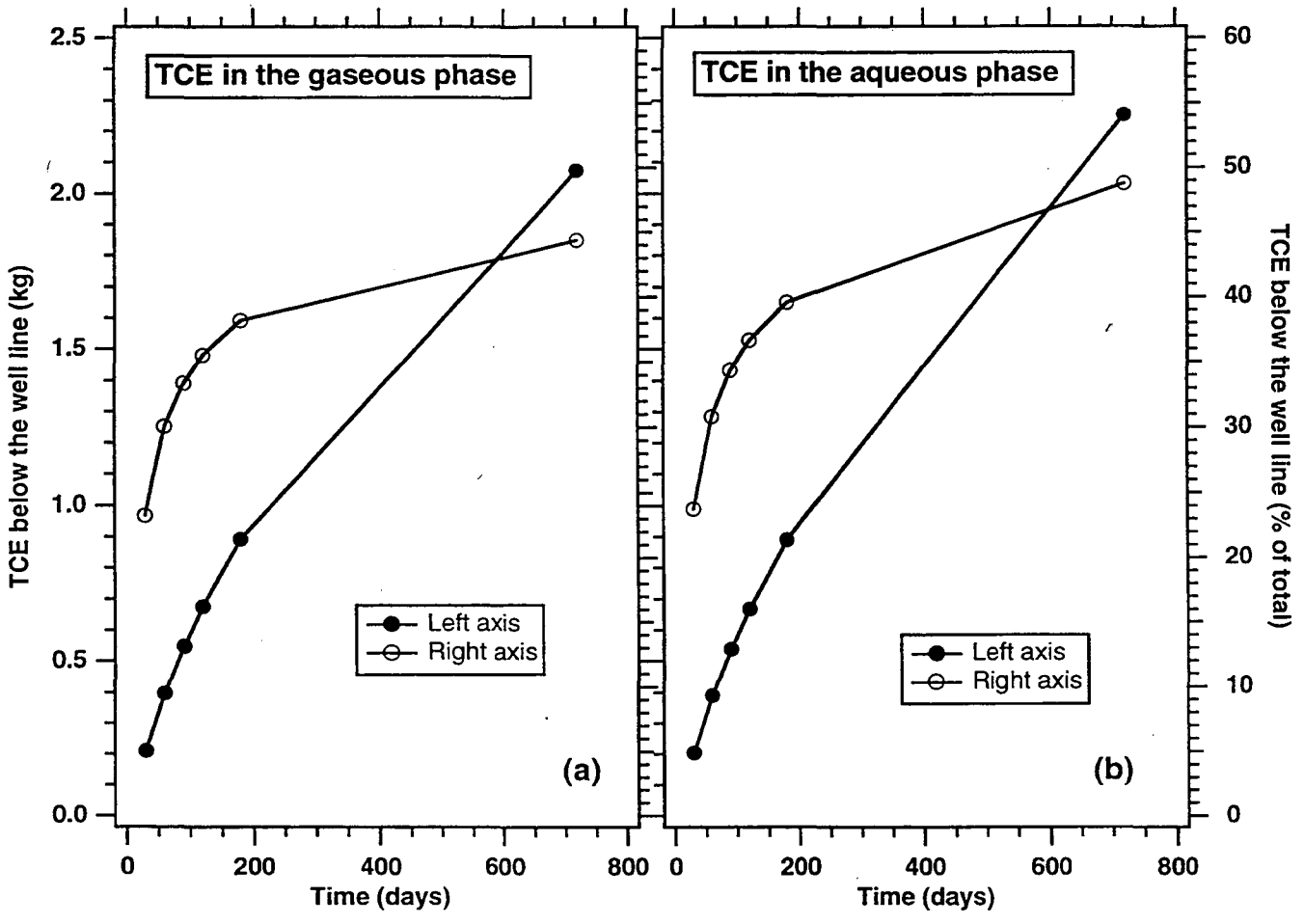

Figure 6. TCE mass below the level of the air wells without an air barrier. With an air barrier, no TCE advances below the well line.

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