Motivation

Spreading and migration of contaminants in the unsaturated zone may occur as liquid or gas. Vapor (gas) plumes may accumulate in subsurface parts of buildings or sink towards the groundwater table.

- Does migration of vapors from a liquid spill in the unsaturated zone pose a potential threat to underlying aquifers?
- How does a contaminant vapor plume migrate in the unsaturated zone and how is it influenced by the component’s properties?
- Do physical processes (e.g., adsorption) retard migration in porous media and how does water saturation affect the behavior?

Vapor Migration

Column experiments to quantify density-driven vapor migration of carbon disulfide (CS$_2$) in dry porous media.

Darcy’s law and Rayleigh number for vapor transport [4]:
\[ q = -\frac{\mu}{\rho} \nabla (P + pgz) ; \text{Ra}_{\text{gas}} = \frac{g kl (\rho_s - \rho_v)}{\mu D_{\text{eff}}} \]

Migration is dependent on molecular mass and vapor pressure of contaminant.

Vapor migration experiment:
- 1-D column experiments (L = 4 m)
- Boundary conditions
  - Glass beads: $K_{\text{base}} = 1.5 \times 10^{-9} \text{m}^2$
  - $K_{\text{base}} = 2.6 \times 10^{-10} \text{m}^2$
- Injection of heavy NAPL vapor (CS$_2$) in middle of column
- Top-bottom: constant pressure ($p_{\text{base}}$)
- Concentration measurement over time

Numerical simulation to understand physical principles for migration:
  - 1-D 2p2cni model
  - Initial hydrostatic pressure distribution
  - Model including boundary set-up (tubing)

Preliminary results of investigation:
  - Description of density-driven vapor migration
  - Observed acceleration as an effect of boundary conditions.
  - Physical principles of migration process are understood
  - Transport dependent on permeability and total mass of contaminant
  - Migration behavior reproduced in 1-D numerical simulations

Vapor Retardation

Column experiments to quantify retardation of CS$_2$ vapor in unsaturated zone and its dependency on porous media and water saturation.

Retardation of vapor in moist porous media [1, 2]:
\[ R = 1 + \frac{\theta_v}{\theta_s} + \frac{f_h K_{\text{out}}}{\theta_s K_H} + \frac{K_{\text{eff}} A_{\text{L}}}{\theta_s} \]

Vapor retardation experiments:
- 1-D column experiments (L = 2 m)
- Upwards flow of CS$_2$ vapor and conservative tracer (Helium)
- Breakthrough curves at outflow to evaluate retardation

Outlook

Vapor migration: additional experiment runs to delineate effect of boundary conditions and validate model.

Vapor retardation: description of retardation as function of porous medium and water saturation variation based on set of column experiments

References


Simulations are performed using the open-source simulator DuMu² and Shell’s Dynamo/MoReS.