ABSTRACT
Injection of carbon dioxide into deep saline formations is seen as one possible technology for mitigating carbon emissions from utilities. The focus of this study is on the changes in resident brine pressure due to the injection of large volumes of carbon dioxide into the subsurface. The applicability of several semi-analytic solutions to the problem of brine pressurization is determined. The goal is to find ranges of formation parameters for which simplifying assumption are justifiable. The process involves a solution hierarchy from the most complex solution down to the basic Theis solution.

CONCEPTUAL MODEL ASSUMPTIONS
• single-phase flow (valid at distances beyond CO2 plume extent)
• radial-symmetric domain
• aquifer / sealing layer properties are homogeneous and isotropic in each aquifer / sealing layer
• horizontal layering
• constant aquifer / sealing layer thickness
• piecewise constant volumetric injection rate
• purely horizontal flow in aquifers; purely vertical flow in leaky layers
• constant head in overlying and underlying aquifer

Figure 1: Cross-section of conceptual model of single layer injection

Figure 2: Cross-sectional view of bounded domain with single-phase flow

LATERAL BOUNDARY
• assumes radial-symmetric boundary centered on the injection well
• derived by Q. Zhou of LBNL (Zhou et al., 2009)
• Laplace transformed dimensionless head is given as:

\[ \psi = \frac{p}{2 \pi H} K \left( \frac{H}{K \gamma} \right)^{1/2} \left( \frac{H}{K \gamma} \right) \]

where \( p \) is the Laplace variable, and \( \gamma \) is the dimensionless radius.

The influence of the lateral boundary is found by evaluating the Laplace transformed head gradient at the boundary radius in an infinite domain.

\[ i = \frac{Q}{2 \pi H K} \psi \]

A gradient close to zero means no influence by the lateral boundary.

Numerical experiments suggest gradients lower than \( 10^{-5} \) lead to head errors of less than 5% (Fig. 3).

Figure 3: Relative error in head at a radial distance of 0.9 \( r_i \) introduced by neglecting lateral flow boundary

HANTUSH-JACOB SOLUTION
• Two additional assumptions \((r_w=0, S'=0)\) lead to the Hantush-Jacob solution (1955)

\[ h_0 = \frac{K_s}{4 \pi H} \sqrt{\frac{Q}{2 \pi H}} \]

Numerical experiments (Fig. 4) suggest that the assumption \( S'=0 \) is valid when

\[ \left( \frac{S'H}{K'H} \right)_0 < 0.5 \]

Figure 4: Impact of neglecting storage in sealing layers \((h_0 = \text{dimensionless head including sealing layer flow, } h_{\text{dimless}} = \text{dimensionless head neglecting sealing layer flow})\)

THEIS SOLUTION
• Assuming no flow through the sealing layers leads to the Theis solution (1935)

\[ h_0 = \frac{K_s}{4 \pi H} \sqrt{\frac{Q}{2 \pi H}} \]

This assumption is valid for small leakage factors

\[ \lambda = \frac{K/H}{K/H} \]

Numerical experiments suggest a threshold of about \( 10^{-6} \)

CONCLUSIONS
• Lateral boundaries can be neglected for Laplace transformed head gradients of about 1e-10
• Storage in leaky layer can be neglected for

\[ \left( \frac{S'H}{K'H} \right)_0 < 0.5 \]

• Flow through leaky layers can be neglected for \( \lambda < 10^{-5} \)

FUTURE RESEARCH
• multiple aquifers
• comparison to numerical simulators

REFERENCES


ACKNOWLEDGEMENTS
This research was performed while the lead author held a National Research Council Research Associateship Award at US EPA-ORD, Athens, GA.

Technical support: Q. Zhou and J. Birkholzer (Lawrence Berkeley National Lab)