MONITORING PRESSURE IN ZONES OVERLYING STORAGE RESERVOIRS

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ABOVE-ZONE MONITORING

Monitoring the long-term integrity of CO₂ storage reservoirs will be a critical aspect of the deployment of the technology at a meaningful scale. In addition, due to the large extent of most CCS operations, the monitoring techniques should be cost-effective and easy to implement. One such method is the use of observation wells open to a permeable monitoring zone overlying the target storage reservoir. Once equipped with downhole pressure gauges, reservoir pressure can be continuously monitored for any unexpected change which may indicate a fluid leak out of the storage reservoir (see figure below). This idea was proposed in the context of natural gas storage by Donald L. Katz (1968) and evaluated for the purpose of monitoring stored CO₂ by Benson and Trout (2006).

Faults and leaky wells are the most probable pathways for leakage out of the target storage reservoir. As CO₂ is injected, however, the resident formation fluid will be displaced laterally within the storage reservoir as well as vertically through the cap rock. This study focuses on the vertical fluid migration across the cap rock and the associated pressure changes in the monitoring reservoir over a wide range of formation parameters.

ANALYTICAL APPROACH

By simplifying the geological model, analytical solutions developed and published by Neuman and Witherspoon (1969) may be used to quickly predict pressure changes in both the storage and monitoring zones:

\[
\frac{\partial P}{\partial t} = \frac{1}{r^2} \frac{\partial}{\partial r} \left( r^2 \frac{\partial P}{\partial r} \right) - \frac{1}{r^2} \frac{\partial}{\partial \theta} \left( r^2 \frac{\partial P}{\partial \theta} \right) - \frac{1}{r^2} \frac{\partial}{\partial z} \left( r^2 \frac{\partial P}{\partial z} \right) + \frac{1}{r^2} \frac{\partial}{\partial \phi} \left( r^2 \phi \frac{\partial P}{\partial \phi} \right) + \frac{1}{r^2} \frac{\partial}{\partial \chi} \left( r^2 \chi \frac{\partial P}{\partial \chi} \right)
\]

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\]

DEVELOPING THE DETECTION FACTOR

Analytical solutions allow many geologic environments, injection rates, and injection durations to be quickly evaluated. Table 2 presents the ranges over which critical input parameters were varied in order to capture both the spectrum of potential CO₂ storage sites and the variability of resulting pressure changes in the monitoring zone. Every combination of the parameters was simulated by solving Equation 2 (a–d). In total, 6075 geologic environments were evaluated at each injection rate and duration, resulting in over 50,000 data points.

To aid in the analysis of the data, it is desirable to find a single parameter that can be used to quickly compare the different cases. This parameter was constructed to reflect the anticipated magnitude of the pressure signal transmitted to the monitoring zone and thus, the possibility of detecting a pressure change with a downhole gauge. The Detection Factor (DF), as it came to be known, was developed using the following relationships to the critical reservoir and injection input parameters:

\[
DF = sf \left( \frac{Q}{t} \right) \left( \frac{1}{s} \right) \frac{1}{k} \frac{1}{S} \frac{1}{h_i} \frac{1}{h_s}
\]

Values of DF vary from 10³ to 10⁷ for the given parameter ranges, so a shift factor (sf = 10⁻³) may be applied in order to reduce the exponent range from 0 to 20. Thus, the detection factor for a particular geological setting can be conveyed on a reasonable scale through the exponent value and quickly compared to other potential storage reservoirs.

Based on this set of desired relationships between the computational inputs and the value of DF, the functional form of the parameter was constructed to be dimensionless:

\[
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\]

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DECIPHERING THE DATA

• The pressure change in the monitoring zone, Pₜ₀, and DF are computed for each combination of reservoir and injection parameters.
• Over 50,000 data points are calculated covering all permutations of values listed in Table 2.
• Pₜ₀ plotted as a function of DF; regression performed in order to test strength of correlation.
• Instabilities in numerical integration generate some erroneous pressure values that were ignored in the statistical analysis.
• Data coherence and high residual indicates strong relationship between Pₜ₀ and DF.
• Pressure changes attributable to fluid migration are estimated to be detectable in the range of 10⁵ – 10⁶ Pa.
• Regression analysis shows that for DF > 10⁵, there is a >95% probability that measurable pressure changes will be detected in the monitoring zone.
• DF < 10⁵ implies undetectable pressure change in monitoring zone due to fluid migration through cap rock.
• Pressure changes inconsistent with expectations imply fluid leakage via another mechanism (i.e. fault, wellbore).

FINDINGS

• DF allows quick determination as to whether or not a measurable pressure change will be expected over the course of CO₂ injection in a particular geologic setting.
• Project planners can use DF to compare candidate storage sites and determine whether or not the above-zone pressure monitoring technique will be applicable.
• DF can be determined from reservoir data that can either be estimated or acquired directly from well logs, core samples, and formation fluid samples.
• DF provides valuable insight when diagnosing unexpected pressure transients in the monitoring zone, creating a more effective monitoring approach.
• Frequency histogram of DF values shows the peak of the distribution in the marginal range (10² – 10³) which implies that pressure changes are expected in most cases.
• High-resolution downhole gauges may shrink the marginal zone or shift the peak of the distribution out of the marginal range.

FUTURE FOCUS

Further development of the Detection Factor will focus on these aspects:
1) Systematic analysis of the sensitivity to individual inputs in order to refine DF parameter.
2) Compute DF values for various CCS projects in order to build a database of actual field values.
3) Compare calculated results with data from field projects using the above-zone pressure monitoring technique.
4) Refinement of the numerical integration method in order to reduce the number of erroneous data points.
5) Recreating selected injection scenarios in a numerical simulator to compare results with those of the analytical calculations.
6) Analyzing additional leakage scenarios, such as faults and wellbores, to determine whether or not the risk of leakage can be quantified with additional factors, like DF.

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