Development of Storage Coefficients for Carbon Dioxide Storage in Deep Saline Formations

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Background to the Study

The IEA Greenhouse Gas R&D Programme commissioned the Energy and Environmental Research Centre, from the University of North Dakota, to undertake a study to develop storage coefficients for CO2 storage in deep saline formations. The project was co-sponsored by the US Department of Energy. The aim was to define a series of storage coefficients, which can be applied to regional calculations to provide more realistic estimates.

Storage Resource Classification

The study considered 4 existing CO2 storage resource classification schemes:

- The CSLF Techno-Economic Resource-Reserve Pyramid;
- The US DOE classification scheme;
- The probabilistic assessment methodology being developed by the USGS;
- The CO2CRC classification system.

The CSLF and US DOE classification schemes, with elements of the CO2CRC scheme, were considered as the most appropriate basis for development of storage capacity coefficients. In relation to the storage coefficients developed by the study, the key definitions are:

- Theoretical Storage Resource – The upper limit of storage resource, includes pore volume that can be used to store CO2 in separate phase, dissolved phase, and mineral phase.

Effective Storage Resource – Estimated resource after technical constraints have been applied. It is the pore volume in known storage sites into which it is technically feasible to inject and store CO2.

DoE and CSLF Methodologies

The basic equation for the US DOE approach is:

\[ G_{CO2} = A \times h \times \phi \times \rho_{CO2} \times E \]

Where, the mass of stored CO2 (GCO2) is based on investigational area (A), formation thickness (h), porosity (\(\phi\)), CO2 density (\(\rho_{CO2}\)), and the application of a storage coefficient (E).

The CSLF main equation is:

\[ V_{CO2,T} = V_{trap} \times \phi \times (1 - S_{swirr}) = A \times h \times \phi \times (1 - S_{swirr}) \]

Where the theoretical volume of stored CO2 (\(V_{CO2,T}\)) is based on a geometric volume of a trap, (\(V_{trap}\)) the area (A), average thickness (h), porosity (\(\phi\)) and the irreducible water saturation (\(S_{swirr}\)). The capacity coefficient (\(C_C\)) which incorporates the cumulative effects of trap heterogeneity, CO2 buoyancy, and sweep efficiency, is then multiplied by \(E\) to derive an effective storage capacity.

The two storage coefficients can be related by the following equation, provided that the same assumptions concerning storage conditions are applied:

\[ E = C_C \times (1 - S_{swirr}) \]

Coefficients for Effective Storage Capacity

Methodology

Depleted oil and gas reservoirs are generally well characterised from exploration/production data and have proven capacity to retain buoyant fluids over geological timescales. These storage resources can be readily assessed using mass balance considerations rather than through coefficients and so the study focussed on deep saline formations (DSF).

A literature review of actual CO2 storage projects showed that these are of insufficient numbers to adequately represent all possible DSF scenarios, therefore, a simulation approach was adopted.

To construct the models, the Average Global Database was constructed by using hydrocarbon reservoir properties as a proxy for DSF characteristics (due to the general paucity of data available for DSF). This was compiled through use of existing US databases and an extensive literature review for other regions and contains details of over 20,000 reservoirs.

Calculation of Storage Coefficients

Heterogeneous models were developed for the various lithologies, depositional environments and structures, to derive ranges of storage capacity coefficients. Statistical distributions from the AGD were employed for key input parameters including porosity and permeability. The issue of scale was considered in detail, in particular whether calculation of coefficients and storage resource at localised scales can be applied to entire formations. Site-specific storage coefficients were developed from 195 simulations using heterogeneous models, before attempting to extrapolate these results to the formation level. The resulting values for storage coefficient, \(E\), ranged from 4% to 17% with an 80% confidence interval. Structural setting was found the exert the largest influence of any parameter on the results, with storage coefficients for effective resource exceeding 25% in some cases.

General Formation Properties for the AGD

<table>
<thead>
<tr>
<th>Percentile Value</th>
<th>Depth, m</th>
<th>Salinity, ppm</th>
<th>Temp Grad, °C/m</th>
<th>Reservoir Thickness, m</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>905</td>
<td>8,300</td>
<td>0.020</td>
<td>3.4</td>
</tr>
<tr>
<td>50</td>
<td>2,100</td>
<td>97,000</td>
<td>0.025</td>
<td>26</td>
</tr>
<tr>
<td>90</td>
<td>3,800</td>
<td>175,000</td>
<td>0.033</td>
<td>190</td>
</tr>
</tbody>
</table>

The site-specific results were then extrapolated to the formation scale.

The modelling work showed the relative influence of various parameters on the efficiency of storage, and allowed the derivation of probabilistic ranges of storage coefficients for calculation of effective storage resource at both site-specific and formation levels, the overall mean value for all lithologies being 2.6% at the formation level.

Conclusions and Recommendations

The study has successfully built upon earlier work by CSLF and US DOE, confirming the similarities of the two methodologies and more importantly, establishing an ease of comparison of storage coefficients employed and resources calculated for deep saline formations.