Using pressure recovery at a depleted gas field to understand saline aquifer connectivity

Michelle Bentham[1] Gareth Williams[2] Hayley Vosper[1] David Noy[1] John Williams[1], Andrew Chadwick[1] and Karen Kirk[1]

[1]British Geological Survey, Environmental Science Centre, Keyworth, Nottingham, NG12 5GG, UK
[2]British Geological Survey, The Lyell Centre, Research Avenue South, Edinburgh, EH14 4AP, UK

Abstract

A key uncertainty facing Carbon Capture and Storage (CCS) in saline aquifers is long term injectivity, which is primarily a function of the connected aquifer pore-volume within which formation brine can be displaced as the CO_2 is injected. Protracted injection testing to interrogate and prove the far-field connected pore-volume would increase the lead-in times for commissioning of storage sites and would significantly increase appraisal costs. Here we aim to use natural gas production and subsequent reservoir recharge data to gain an understanding of the dynamic behaviour of a UK saline aquifer, and its suitability for large-scale injection.

The Bunter Sandstone in the Southern North Sea is the target storage reservoir for the proposed White Rose Project. The storage site comprises a gently folded anticlinal structure known as Endurance (previously termed 5/42), and has recently been characterised for CCS by the drilling of an appraisal well by National Grid Carbon (NGC), which proved the suitability of the site for storage (Furnival et al. 2014). Well testing indicated an average reservoir permeability is 270 mD, and that no barriers or baffles to flow present within at least 1.3 km of the well, the radius being constrained by the duration of the test. The capacities provided by the UK STORage Evaluation Database (Bentham et al. 2014) indicate that much larger volumes of CO_2 could be stored in the Endurance structure. If the site were to be developed as a storage hub following successful implementation of the White Rose Project, greater confidence in the long term injectivity of the aquifer is required.

Gas fields in the Bunter were produced by depletion drive, whereby gas is lifted to the surface by reservoir formation pressure, maintained by connected aquifer waters encroaching into the gas reservoir as the pressure drops due to gas production. The invading aquifer water drives gas to the producing wells, improving recovery. This drive mechanism is indicative of hydraulic communication within the aquifer the degree to which water influxes into the reservoir depending on the size of the adjoining aquifer and the degree of communication between the aquifer and the gas reservoir. If a gas reservoir is hydraulically connected to a larger aquifer, post-production reservoir pressures will increase and recover as water floods back into the depleted gas field.

The Esmond gas complex comprises the Esmond, Forbes and Gordon fields, all with Bunter Sandstone reservoirs. Gas production at the Esmond Field began in 1985 with 8866 x 10^9 m^3 of gas

(at STP) produced by cessation of production in 1996. Measurements at field abandonment shows a significant reduction in reservoir pressure. In 2008 the field was considered for natural gas storage, and re-entered by a new appraisal well which indicated that the field had largely re-pressurised. Although the gas storage plans were subsequently abandoned, the pressure measurement provides a unique and rare post-production dataset indicating connectivity of the reservoir to a significant aquifer volume.

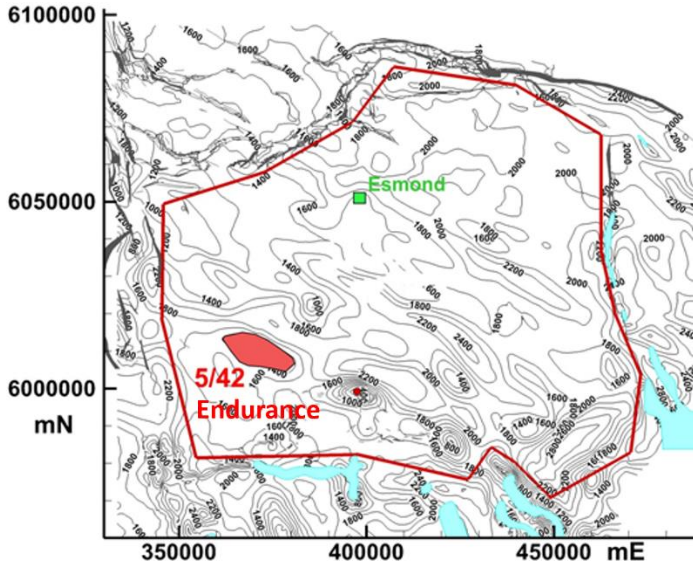

Figure 1 Map showing the depth (m) to the top of the Bunter Sandstone Formation. The Location of the Esmond Gas Field and the Endurance Structure (proposed as the storage site for the White Rose Project) are shown. The blue polygons denote subcrop of the Zechstein Group.

The pressure history was matched to the production and aquifer recharge data from Esmond to infer the regional-scale flow properties and hydraulic capacity of the surrounding Bunter Sandstone aquifer. A suite of 1D axisymmetric numerical flow models was used to test a range of parameters including aquifer permeability, hydraulic connectivity and volumetric capacity. A more detailed 3D model was then built to refine the preferred solution, calibrated by seismic reflection and well datasets from the area, and also incorporating the peripheral pressure effects of production from the nearby Forbes field. The history-matching required a connected aquifer of 18.5 km radius with a bulk mean permeability of between 50 and 60 mD (Figure 2), dependant on model sensitivities.

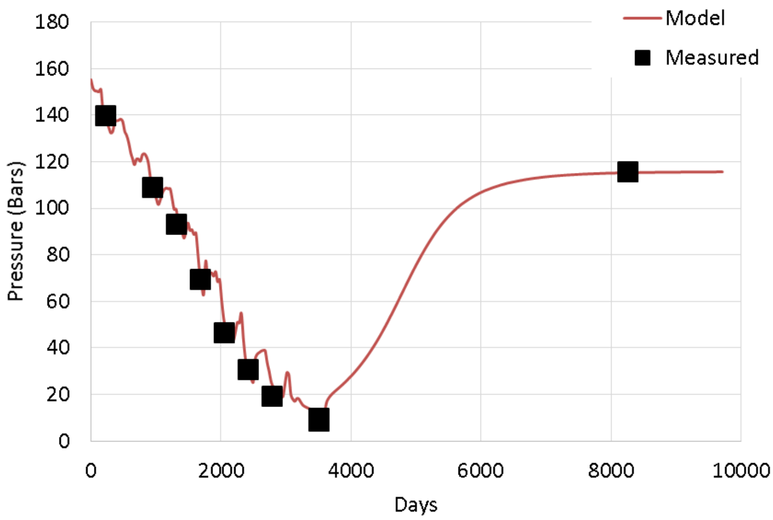

Figure 2 Best fit 3D flow model of pressure recovery following gas extraction at the Esmond field. The model aquifer has a radial extent of 18.5 km and bulk formation permeability of 56 mD.

After establishing the dynamically-calibrated conceptual model for the Esmond-Forbes area, we carried out a comparative qualitative assessments of the Bunter Sandstone at the Esmond and Endurance areas using well and 3D seismic reflection data. The purpose was to examine the data for potential flow barriers (faults, salt walls, changes in cementation, facies changes and intrusive dykes), that might have an impact on the connected pore volume of the Bunter Sandstone and the inferred injectivity.

Qualitative examination of 3D seismic data around the Esmond gas field supports the dynamic modelling results that the reservoir is connected to an aquifer volume with a radius of at least 18.5 km. Comparison of 3D seismic data at Esmond and Endurance indicate that the Endurance structure is likely to be more favorable due to its lack of seismically resolvable flow barriers. This provides a degree of confidence that the Bunter Sandstone saline aquifer surrounding the Endurance structure has a sufficiently well-connected pore-volume to allow the injection of CO_2 for the White Rose project duration and beyond.

Acknowledgements

The Authors thank The Crown Estate for the inception and funding of this work, especially Tom Mallows and Ward Goldthorpe for insightful comments. We also acknowledge Schlumberger (Graham Milne) who provided seismic data for analysis.

References

Bentham M, Mallows T, Lowndes J, Green A (2014) CO_2 Storage Evaluation Database (CO_2 Stored). The UK’s online storage atlas. Energy procedia, 63, 5103–5113. www.co2stored.co.uk

Furnival S, Wright S, Dingwall S, Bailey P, Brown A, Morrison D, De Silva R (2014) Subsurface Characterisation of a Saline Aquifer Cited for Commercial Scale CO_2 Disposal. Energy procedia, 63, 4926–4936.