Time-lapse geophysical monitoring of a subsurface CO_2 bubble in the Utsira Sand, Sleipner, northern North Sea

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CO_2 separated from natural gas produced at the Sleipner field in the northern North Sea is currently being injected into the Utsira Sand, a subsurface saline aquifer within the thick Cenozoic post-rift succession. The operation commenced in 1996, and is expected to last for 20 years, injecting at a depth of 1012 m, at an average injection rate of about 1 $MTyr^{-1}$. The international SACS (Saline Aquifer CO_2 Storage) project, accompanies the ongoing injection. A project aim is to monitor the injected CO_2 by geophysical methods and to develop a robust and repeatable monitoring and verification methodology for future CO_2 sequestration operations.

Time-lapse seismic data acquired in 1999, after 2.3 MT of CO_2 injection, show an exceptionally clear image of the CO_2 bubble, characterised by very high reflection amplitudes. The outer envelope of the amplitude anomaly roughly defines an elliptical cylinder, ~ 230 m high, with a major axis of ~ 1500 m oriented NNE and a minor axis of ~ 600 m. Reflections from within the bubble are interpreted as accumulations of CO_2 beneath thin intra-reservoir shale horizons. Complex internal structure of the amplitude anomaly is interpreted as evidence of ‘chimneys’ of CO_2 migrating through high permeability ‘holes’ in the shale layers. Anomalous amplitudes at the top of the reservoir are of limited extent, indicating that by 1999 CO_2 had only just reached this level. Two small anomalies provide evidence of limited migration into a thin sandy unit in the lowermost caprock succession.

Modelling the gravity change due to the 1999 CO_2 bubble indicates that it is currently marginally detectable using a modern sea-bed gravity meter. This detectability will improve as the injection continues. Scenarios for future CO_2 migration are also examined and offer the possibility of designing a time-lapse gravimetric monitoring system.

In addition to monitoring subsurface distribution and migration, both gravity and seismic methods offer the potential to provide independent verification of the amount of CO_2 sequestered; the former by Gauss’s Law, the latter by a quantitative analysis of the velocity ‘pushdown’ using the Gassman equations. This is likely to prove an essential requirement of subsurface sequestration, in the likely future environment of internationally regulated carbon trading.