Final Technical Report
of project 'Saline Aquifer CO2 Storage' (SACS)

Work Area 5: GEOPHYSICAL MONITORING

TASK 5.3 SENSITIVITY STUDY ON POSSIBLE CHANGES IN SEISMIC DATA DUE TO CO_2 INJECTION (SINTEF)

Work carried out in task 5.3

We have investigated the possibility of monitoring the injection of CO_2 in the Utsira formation at Sleipner from seismic data. For this, we calculated the expected seismic response of the earth before and after the injection of gas was started.
An earth model was constructed, using geological and petrophysical information about the area of interest. A structural 2-D model was obtained using interpreted horizons from a seismic line which passes close to the injection point. The depth of the top Utsira horizon was slightly adjusted to reproduce the shape of the 12 m high anticline just above the injection point. We used a combination of information from well log data in wells around the injection point and from petrophysical empirical laws to estimate the seismic parameters between the different horizons. This allowed to build a 2-D elastic model for finite-difference modeling of data from the base survey.
From reservoir modeling, we obtained a description of the geometrical and physical properties of the gas accumulations. We considered CO_2 bubbles of different thickness stored in the anticline, and CO_2 accumulations created by thin shale barriers in the Utsira formation. The density and compressibility of the CO_2 were calculated using state equations. The porosity of the Utsira formation being known, the changes of the density, and compressional- and shear-wave velocities caused by a change of pore fluid were calculated using the Gassmann equation. This allowed to build several elastic models representing different possible situations for the gas accumulations. Using these different models, the seismic response after the CO_2 injection, and the change in seismic response caused by the injection were calculated, first using a very simple convolutional model, then by a high-order 2-D finite-difference modeling.

Major results of task 5.3

In the Utsira formation, the gas has an extremely high compressibility because the temperature is just above the critical temperature. Because the rock matrix in the Utsira formation is very weak, the compressional velocity is also unusually sensitive to the compressibility of the fluid. Therefore, the presence of gas induces a dramatic drop of the compressional wave velocity even for moderate gas saturations. The Gassmann equation predicts a 34% to 37% decrease of the P-wave velocity, a 6% to 12% decrease of the density, and a 3% to 6% increase of the shear wave velocity, depending on the composition of the gas. Moreover, the transition between full-water and full-gas saturation zones is very sharp.

Hence, the top and bottom of gas accumulations are very good seismic reflectors, with negative and positive impedance contrasts, respectively. Since the thickness of gas is smaller than the dominant wavelength in the seismic signal, the reflections from the top and bottom of the gas accumulations interfere. The resulting signal is clearly detectable on seismic prestack data or on a zero-offset section, both for gas stored in the anticline and accumulated below shale barriers, even for thin gas accumulations (e.g. 3 m thick). Comparison of the data modeled with and without gas helps tracking the extension of the gas buble. Due to the excellent contrast in velocity and density between water saturated and gas saturated sands in the Utsira formation, our modeling predicts that gas accumulations thicker than 1 m cause changes in the data that are as strong as reflections from important horizons like the top Utsira. The presence of gas accumulations also causes a slight increase of the traveltime down to the base Utsira. The change induced by this push-down effect on the seismic data is also detectable, although about five times smaller than the direct effect previously mentioned.
These results suggest that a new seismic survey with the same data quality as the existing base survey would allow to locate even very thin gas accumulations (about 1 m or more) in the anticline or below shale barriers above the injection point.

TASK 5.8 FEASIBILITY STUDY OF MICROSEISMIC MONITORING (BRGM)

Objective

Evaluate cost, practicality and benefits of microseismic monitoring, as a tool to detect distribution of CO_2 in the storage reservoir.

Summary of subtasks:

1. State of the art of literature
2. State of the art of data acquisition and processing
3. Evaluation of what could be expected at Sleipner
4. Proposition of a monitoring experiment (Sleipner or Alberta?)

State of the art

- Mapping of induced microseismicity is widely used to map fractures stimulated by hydraulic fracturing in Hot Dry Rocks geothermal projects (Soultz, France, Kakkonda, Japan)
- Some examples in US show that fractures stimulated by hydraulic fracturing for EOR purpose can be mapped by microseismicity monitoring
- There are several examples of microseismicity induced by oil-production (US and North sea), gas production (Lac, France) and gas storage (France)
- One advantage of microseismicity monitoring is that it is continuous !!

Data acquisition and processing

- Observation wells are compulsory ! Distance of observation must be less than few hundreds of m (magnitudes < 0 !!)
- Downhole 3-component geophones (single or arrays of up to 48 levels) are currently used
- Clamped to casing or cemented behind the casing
- Benefits of a 2d or more observation wells
- Methods of location of hypocenters are now well developped: relative mapping (Joint Hypocenter Determination), doublets, hodograms...
- Focal mechanisms and stress tensor determination are available
- Panel of downhole seismic companies (CGG, CSMA, etc.)

What could be expected at Sleipner

- Due to high permeability of Utsira formation: low magnitudes
- Depends on initial stress state of the formation (close to rupture?)
- Stress changes as low as 0.01 MPa have promoted seismic activity in oil reservoirs or triggered earthquakes after mainshocks
- Microseismicity induced by production/injection was observed elsewhere in North Sea oil fields

Propositions for a field experiment

- Check 1st if induced microseismicity can be observed at Sleipner: an observation well is necessary
- Evaluate the cost of 3-month recording experiment with a single 3-component geophone, circa 0.15 Meuros
- If positive, plan a continuous recording with a vertical array of geophones, cost ??
- If the project is not considered at Sleipner, plan the same experiment at Alberta (IEA umbrella)?