Geophysical response to gaseous and supercritical CO_2 flowing through a fractured Draupne shale core

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Abstract

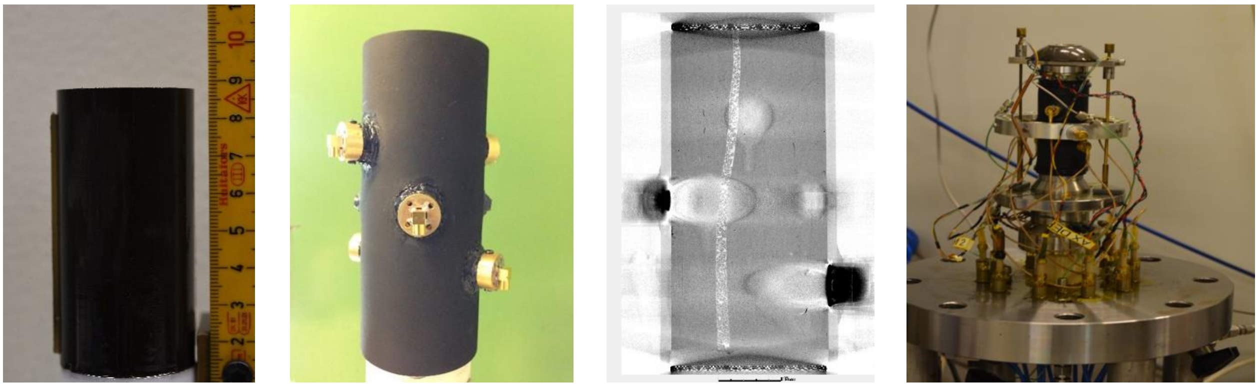
In Geological CO_2 Storage (GCS) it is essential to monitor the fate of injected CO_2 and the physical performance of storage sites including reservoir, caprock, and overburden. In this context, geophysical monitoring plays a key role by acquiring and analysing field-scale data such as seismic, CSEM (controlled source electromagnetic) and gravity. Many research and industrial GCS projects throughout the world (e.g. Sleipner, Snøhvit, Weyburn, Illinois Basin Decatur, Otway, Ketzin, etc.) have already proven to a certain degree that geophysical data can detect and quantify injected CO_2 and its behaviour (distribution of pressure and saturation). However, there are still some uncertainties originating from both known and unknown factors, which are resulting in some challenges. One of the challenges is to be able to accurately detect and monitor CO_2 migration through fractures and faults, if any. Such an ability with high confidence is critical for monitoring and assessment of caprock integrity and overburden management. For this purpose, we need to understand how geophysical data respond to the fluid changes (and also pressure) within fractured reservoirs and faulted zones. While this can be achieved in many different ways (e.g. theoretically, numerically), laboratory experiment is a good candidate to start with, where we can control most of the related parameters (e.g. pressure, injection rate, fracture size, CO_2 state (gas, liquid, supercritical etc.)). The objective of this study is to enhance our understanding of the impact of CO_2 flow in fractures on geophysical data.

In this study, we measure simultaneously acoustical signals and electrical resistance, while gaseous and supercritical CO_2 is injected through a cylindrical shale core (ca. 74 mm long and 38 mm in diameter) with a single natural fracture oriented along its longitudinal axis (Figure 1A). In an attempt to keep the fracture open and permeable for at least the initial phase of the experiment, the fracture is filled with quartz grains. The core used is from the Upper Jurassic organic-rich shale of the Draupne Formation in Lupin well (18/6-3S) in the central North Sea (Zadeh et al. 2017). The Draupne Formation is categorized as marine black shale, which is the main source rock in the North Sea as well as seal for the Middle Jurassic sandstone reservoirs in the area. Furthermore, it is the primary caprock for the Smeaheia CO_2 storage site which is currently the proposed full-scale CCS project in Norway.

The experimental setup consists of a hydrostatic pressure vessel and several pressure controllers, enabling separate control of confining pressure and CO_2/brine pressure at sample inlet and outlet. For the geophysical measurements, a recently-developed sample sleeve equipped with radial piezo elements is used. Together with the piezo elements enclosed in the top and bottom end caps, this enables not only simultaneously vertical acoustical velocity and electrical resistivity measurements,

but also measurements along multiple directions (axial and radial) and multiple levels (top, middle, bottom) along a core sample (shown in Figure 1B). Therefore, this apparatus provides core-scale heterogeneity parameters as well as acoustic and electrical resistivity anisotropy of the studied cores. More details can be found in Soldal et al. (2015).

During the flow tests, we inject gaseous CO_2 (with 3 MPa back pressure) and supercritical CO_2 (with 9 MPa back pressure) into the brine-filled fracture. For each state, CO_2 drainage and imbibition cycles are performed, in which brine and CO_2 are displaced, respectively. All the tests are performed at 40°C. The experiments are conducted at different confining pressures levels ranging from 6 MPa to 24 MPa. In addition to acoustic velocity and electrical resistivity measurements, the change in sample dimensions is recorded using LVDTs throughout the tests. Fracture permeabilities for gaseous CO_2, supercritical CO_2, and brine are also measured. Figures 1(C) and (D) show, respectively, a CT image of the Draupne shale core when put inside the sensor-equipped membrane, and the whole system mounted on the isotropic cell.



(A) (B) (C) (D)

Figure 1. (A) Draupne marine black shale core with an axially-oriented natural fracture; (B) acoustical and electrical sensors with multiple directions and levels attached to a membrane (each yellow part houses both P-acoustical and electrical sensors; axial sensors not shown); (C) CT image of Draupne shale core when put inside the sensor-equipped membrane shown in (B) (vertical band is the natural fracture filled with coarse quart grains, resulting in ca. 1.2 mm fracture-width before pressurized); (D) the whole system mounted on the isotropic cell.

The experiment setup and results can tell us how the seismic and CSEM data respond to gaseous and supercritical CO_2 migrating or passing through an open fracture and, when upscaled, even through a fault (or faulted zone) as well as give us an idea of what type of fracture opening/permeability is needed to be visible on the geophysical data. In addition, we can learn how different geophysical data should be applied or analysed (e.g. separately or combined) in order to maximize extracted information and quality. Finally, since the Draupne shale core was used, the experimental findings from the current study would provide direct insights into the geophysical monitoring of the Smeaheia CO_2 storage site.

Acknowledgement

The study is sponsored jointly by 1) FME centre SUCCESS for CO2 storage (193825/S60) and 2) KPN PROTECT (233736), both funded by the Research Council of Norway (RCN). Also, the core material for this study has been provided by partners in PL360 with funding from CLIMIT (Project 223122) and Statoil.

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