15th International Conference on Greenhouse Gas Control Technologies GHGT-15

5th -8th October 2020, Abu Dhabi, UAE

# How to evaluate and quantify safe $CO_2$ storage? Workflow demonstration on the Smeaheia area, offshore Norway

Ane E. Lothe[a], Per E. S. Bergmo[a], Benjamin U. Emmel[a], Alv-Arne Grimstad[a] &

Peder Eliasson[a]

*[a]SINTEF Industry, P. Box 4760 Torgarden, 7465 Trondheim, Norway*

**Abstract**

A question that is often raised in the discussion of the implementation of large-scale carbon dioxide storage in the underground, is whether the storage is safe, and the carbon dioxide will stay in place? It can be challenging to give a satisfactory answer to this question, since we know that seepage through the subsurface will take place at slow rates in most geological settings. Also, the term "safe" is unsatisfactory, since the question should be how much carbon dioxide gas can be stored over hundreds to thousands of years without uncontrolled leakage through fractures, wells or out of the structures. In this work, we aim to demonstrate a workflow for evaluation and quantification of the probability of "safe" storage operation at a site in the North Sea, offshore Norway. We propose criteria that can be used in conformance tests, to check the evolution of the storage site, in the time span between pre-injection simulations and measurement campaigns during injection.

The Smeaheia area, at the Horda Platform, offshore Norway, is a potential site for $CO_2$ storage with large aquifer sandstone reservoirs in the Middle to Upper Jurassic Sognefjord, Fensfjord and Krossfjord Formations (Fig. 1a and 1b). One of the identified risks in the pre-feasibility study for a site within the Smeaheia region was the possible effects of regional pressure depletion due to production at the nearby Troll Gas Field. Dynamic reservoir simulation studies, including the Sognefjord formation in the wider Troll Field region, indicated that the pressure at the Smeaheia site could be significantly depleted during the injection period and in the decades following cessation of $CO_2$ injection (Riis et al. 2017, Lothe et al. 2018). The pressure depletion would cause a reduction in the density of the injected $CO_2$ and a corresponding increase in the $CO_2$ volume. This in turn could cause the $CO_2$ to reach the spill point separating the injection site (the so-called ‘Alpha structure’) from the eastern part of the Smeaheia region where the sealing properties are more uncertain (Lauritsen et al. 2018).

We evaluate two main monitored parameters that could be used to determine whether the storage site is developing towards "safe" containment: 1) pore pressure, and 2) $CO_2$ saturation (see Fig. 1c). For the pore pressure, the measured Bottom Hole Pressure in the $CO_2$ injection well can be used. As described above, the pressure evolution in the Smeaheia area is affected by the depletion at the Troll Field, and the extent of the influence is controlled by the fault pattern and fault properties (Lothe et al. 2018). A conformance criterion that compares the developing bottom hole pressure during injection with the expected long-term development of the pore pressure post injection would have to be developed.

For the $CO_2$ saturation, a conformance test would have to compare the extent of the $CO_2$ plume at the time of monitoring with results from reservoir simulations on an ensemble of models where the range of possible depletion scenarios is adequately represented. This could be used to determine whether migration of the $CO_2$ plume across the spill point or out of the structure is likely on the long term. To make this comparison, new seismic data would have to be collected and interpreted. Most likely, relatively expensive 2D seismic lines or 3D datasets would have to be acquired. The selection of data density and coverage will be part of a Value of Information calculation to ensure a high probability of giving correct answers to the conformance test while minimizing the costs. If a small area can be identified where the saturation monitoring has particularly high value, it could be interesting to evaluate 1D seismic methods (low cost "pingers").

Based on the Smeaheia case study, the Bottom Hole Pressure would be the simplest and cheapest way to monitor the $CO_2$ injection. The time-dependent changes in the Bottom Hole Pressure during injection, will give valuable information about the reservoir properties, but additional information from monitoring the $CO_2$ saturation will be necessary to evaluate if $CO_2$ will reach the spill point.

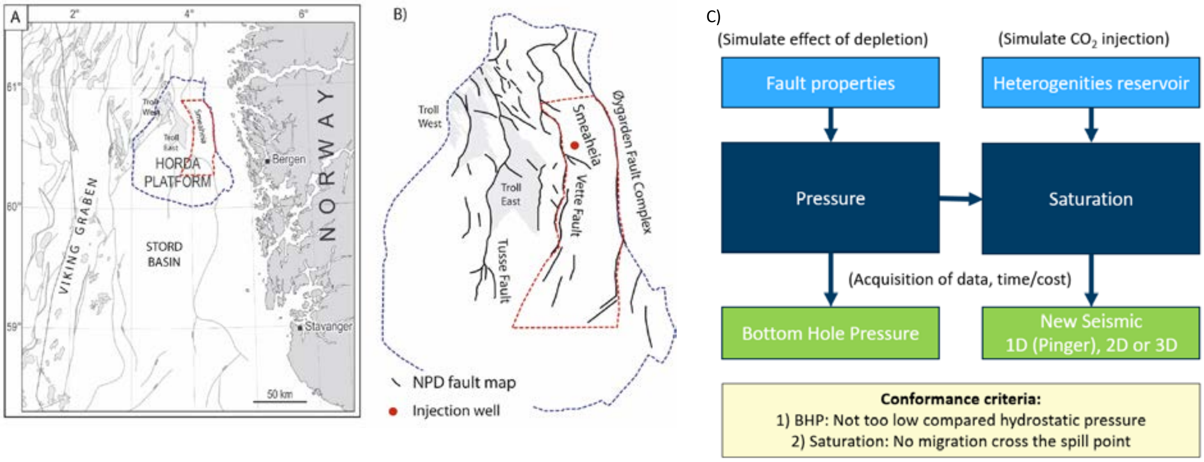


*Fig. 1 A) Study area (indicated by dashed lines) at Smeaheia offshore Norway. B) Location of simulated injection well. The pressure changes are simulated in the wider area marked with blue outline, and the $CO_2$ injection and saturation is calculated in area marked with red. C) Workflow used; for pressure the key factor is the fault properties, while for saturation it is the topography and reservoir heterogeneities (thin clay layers etc.). The $CO_2$ storage performance is checked, using bottom hole pressure (for pore pressure) and new seismic for $CO_2$ plume migration.*

Acknowledgement: The work has been performed with support from the ACT Pre-ACT project (Project No. 271497) funded by RCN (Norway), Gassnova (Norway), BEIS (UK), RVO (Netherlands), and BMWi (Germany) and co-funded by the European Commission under the Horizon 2020 programme, ACT Grant Agreement No 691712. We also acknowledge the following industry partners for their contributions: Total, Equinor, Shell, TAQA.

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*Keywords:* Pressure modelling, saturation, conformance, case study