Introduction

Carbon capture and storage (CCS) is an indispensable component of global efforts to mitigate carbon dioxide (CO2) emissions from anthropogenic sources. The world first CO_2 storage project in North Sea has been operating safely since 1996. The annual injection rate is 1 million-ton CO_2 through a deviated injection well (perforation length: 38m). This project is endowed with a thick (180-300m), high porosity (35-40%) and high permeability (1-3 darcy) sand layer. The Decatur CO_2 storage project is a unique one, the daily injection rate in IBDP (Illinois Basin Decatur Project) phase was 1,000-ton (Jan 2011-Jan 2014) and then increased to 3,000-ton in Industrial CCS phase (July 2016 - until now). The injection interval is 76 feet (23.16m) for IBDP and 208 feet (63.39m) for Industrial CCS. The target reservoir is the Mount Simon Sandstone with an average porosity of 13% (from wireline log data) but the lower unit of the Mount Simon Sandstone for CO_2 injection in IBDP phase has an average porosity of 22% and an average permeability of 200 mD (100 -1,000 milidarcy).

The Canadian Quest project is the first one focused on the CO_2 storage performance in storage complex (one sandstone reservoir, multi seals). The target reservoir is a 40 m thick Basal Cambrian Sandstone with the highest quality sands in the bottom 30m perforated for injection. The high-quality injection interval has an average of 17% porosity and 1,000 mD permeability across the Storage Complex. Due to the reservoir thickness there are three injection wells for about 1 million-ton CO_2 injection annually in the Quest project. It is interesting to learn how the operators made their decisions on the injection strategy, such as the number of injection wells, the perforation interval and the annual injection rate, based on the limited information of reservoir property estimated from seismic survey and appraisal well drilling.

The first Japanese offshore CO_2 storage demonstration project has gained some experience in the CO_2 injection interval design. Fig.1 shows the injection well designs for Moebetsu sandstone formation (left) and for Utsira sand formation (right). The injection interval of Moebetsu formation was completed with the perforated liner covered by screen and length was up to 1,194 m for 100k-ton CO_2 injection annually. Compared to the perforated interval of Utsira sand the interval was much longer for Moebetsu formation. The time-lapse seismic survey results indicated the CO_2 was injected into the high permeability layers within the shallow depth and the actually used injection interval was about 30% of whole injection interval.

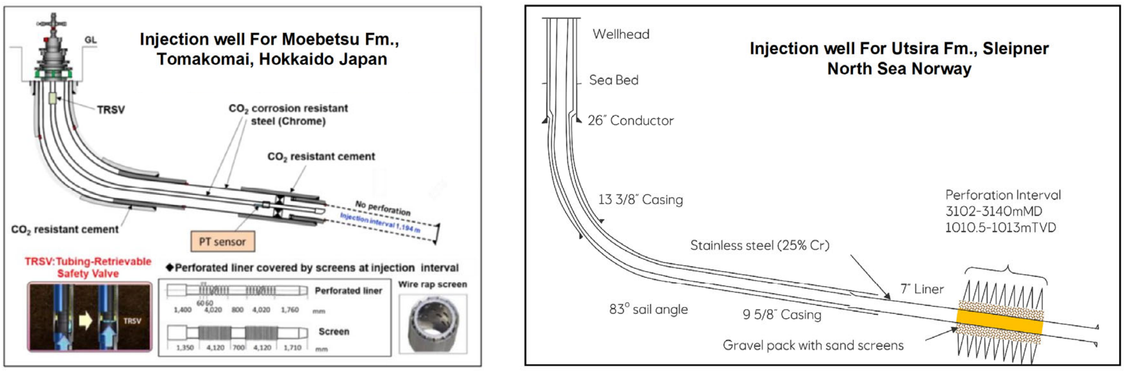

Fig.1 Well design and Injection interval in Moebetsu sandstone (Tanase et al., 2024) and Utsira sand formations (Ringrose and Osaether, 2020).

The injection interval is a complex function of formation thickness and depth, reservoir property (porosity, permeability), and injection rate. In reservoir engineering, net thickness is the thickness of reservoir-quality rock (usually sand), while gross thickness is the total thickness of a reservoir interval. The net-to-gross ratio is an indicator of the reservoir continuity and heterogeneity. The reservoir sand can have significant variations in porosity and permeability due to its heterogeneity. Reservoir engineers use production index correlated to permeability-thickness but CO_2 storage operators care more for injection index which is the two-phase flow in target reservoirs. Generally, the permeability dominates flow regime and the permeability-thickness affects flow rate. To achieve the higher injection index CO_2 must be injected into the full perforated interval at an appropriate rate fitting well the reservoir sand property. In this study we used a medical X-ray CT scanner to visualize the CO_2 image in a porous sandstone and to identify the appropriate injection rate when injection CO_2 in different rates under same pressure and temperature conditions.

CO_2 injection experiment results

A cylindrical sandstone sample (ϕ3.5 cm x 7 cm) was used for supercritical CO_2 injection (confining pressure: 12 MPa, pore pressure: 10 MPa and temperature: 40°C) . We started with a very low injection rate of 0.1 ml/min into the sample (permeability: 100 mD). Then the rate was increased to 0.5 ml/min, 1 ml/min, 2 ml/min, 5 ml/min and 10 ml/min. CO_2 distributions (warm colors in Fig.2) were revealed by the X-ray CT images during the injection. From the six injections we identified 5 ml/min as the appropriate rate for this sandstone. The CO_2 injection test was repeated with the rate of 5 ml/min to verify our choice. CO_2 distribution (Fig.2 right) after 20 min was almost same as the 5 ml/min case (Fig.2 left). It is important to note the appropriate injection rate also overcame the buoyance of injected CO_2.

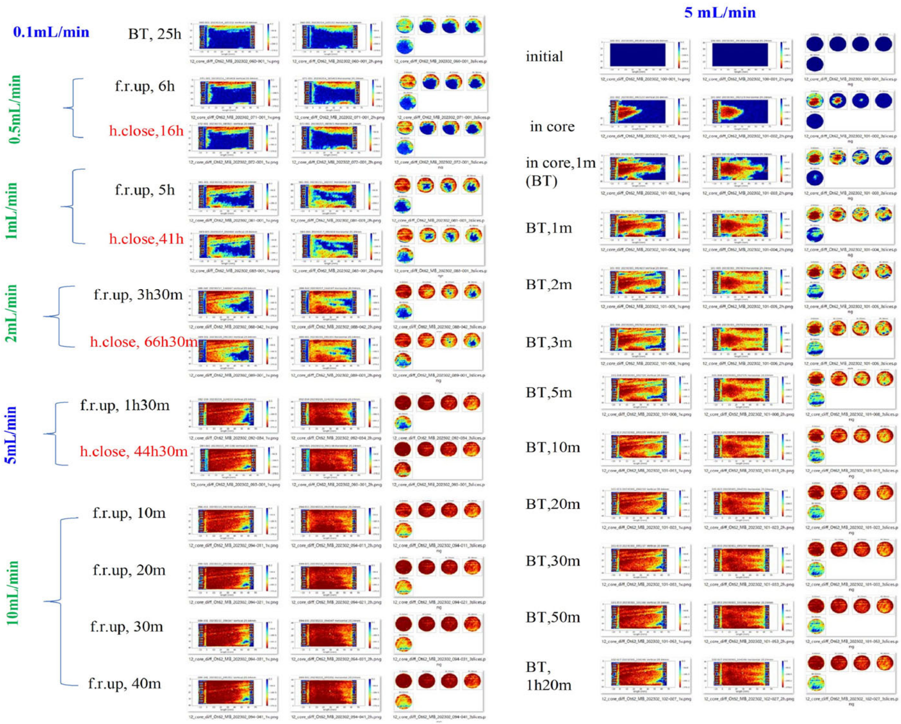

Fig.2 CO_2 distributions in two injection tests

Conclusions

Our study successfully demonstrated the appropriate injection rate for the high-performance CO_2 storage. Low injection rate into a thick and high permeability the CO_2 buoyance significantly reduces the sweep efficiency. Well completion and injection interval designs in complex and heterogeneous reservoirs are of fundamental importance to operators.

Acknowledgements

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Reference

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