CO2 Field Lab at Svelvik ridge: Site suitability

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CO_2 Field Lab at Svelvik ridge: Site suitability

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Abstract

A field laboratory for monitoring CO_2 migration has been established in the Holocene deposit of the Svelvik ridge, located at the sill of the Drammensfjord 50 km south of Oslo. Initial characterization of the site shows that the formation is very suitable for studying migration and associated leakage, particularly within the top 50 m where the sediments consist of relatively homogenous sand. In the deeper part of the deposit, the formation seems to have more structure possibly enabling monitoring of horizontal migration and more complex migration patterns.

Keywords: CO2, injection, monitoring, migration

1. Introduction

The CO_2 Field Lab project is a consortium of industry and research institutes that have had a strong involvement in CO_2 storage site management, monitoring and certification from the early stages. For both the planning and safety of any CO_2 storage operation, it is important to monitor the location and possible migration of CO_2 within and around the reservoir. The overall credibility of any storage project will ultimately rely on proper monitoring of CO_2 and understanding its behaviour.

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The EU directives on geological storage of carbon dioxide [1] and on the emissions trading scheme [2] both require the ability to detect and quantify CO_2 within and outside the storage complex. However, specific instructions on monitoring are not yet developed. Therefore, the CO_2 Field Lab project plans controlled injection of CO_2 into the aquifer in the Svelvik ridge (Fig 1). The CO_2 displacement in the subsurface and at the surface will be monitored with an extensive set of techniques to test their sensitivity to the presence of CO_2 underground with respect to saturation, the size of the plume and the detection of leakage. Moreover, through assessing monitoring technologies for detection of CO_2 migration and ultimately leakage, the project aims to provide a validated monitoring system through a protocol and certification scheme.

Fig. 1. Aerial photo looking northwards to the Svelvik ridge at the outlet of the Drammensfjord. The sill is formed by deglaciation deposits. The photo shows the sand excavation on the ridge. The laboratory location is indicated by the white rectangle (extension is approximately 300 m × 150 m).

The Svelvik ridge is located about 50 km south-west of Oslo and forms the sill of the Drammensfjord. It is a glaciofluvial-glaciomarine terminal deposit formed during the Ski stage of the Holocene deglaciation [3, 4]. The depth to the bedrock is between 300 and 400 m. The central part of the ridge is subaerially exposed with the top about 70 m above sea level. It forms a phreatic aquifer. In this part of the ridge, sand has been excavated since 1915. Clay layers onlap both flanks of the ridge below sea level. To the south the thick clay/silt layer fills the bedrock basin up to a few meters below sea level, while to the north the thinner clay/silt layer is at water depths of 100 - 120 m.

This site was chosen as a field laboratory on the assumption that the sand ridge contains more or less homogeneous, unconsolidated, highly permeable sand, which offers well constrained conditions for controlled gas injection experiments. Naturally, there had to be an extensive site characterization to assess whether the conditions would enable to achieve the objectives.

The site characterization was conducted during 2009 and 2010. A geological model was built for use in flow simulations and geophysical modelling. A shallow (20 m deep) CO_2 injection experiment is planned for during the fall of 2011 and, we hope to subsequently carry out a deep CO_2 injection experiment (100 - 300 m deep).

This paper summarizes briefly the main results of the site characterization and discusses the potential of the site as a field laboratory for CO_2 monitoring.

2. Results and discussion

2.1. Site characterization

Beginning in November 2009 and throughout 2010, a series of surveys were conducted to characterize the site. This included drilling, sampling and logging of a 333 m deep exploration well, analysis of core and flow-line samples, geophysical surveys including resistivity, seismic reflection and ground penetrating radar along two 2D lines, and hydrodynamical, geochemical and soil gas surveys.

Due to the reverse circulation method used for drilling of the exploration well, the depth reference and quality of the flow-line samples were very satisfactory. Therefore, the visual inspection of these samples provides vital information about the sub-surface. The flow-line samples and cores show that the Svelvik ridge consists, as assumed, of permeable sand down to approximately 50 m. However, below 50 m results indicate layers or lenses of considerable vertical extent that consist of variable proportions of sand, silt and clay.

Fig. 2 shows the north-south vertical seismic profile. The depth migrated seismic section shows a number of reflectors, particularly below 100 m. Note, that reflectors in the deposits seem more continuous below 200 m.

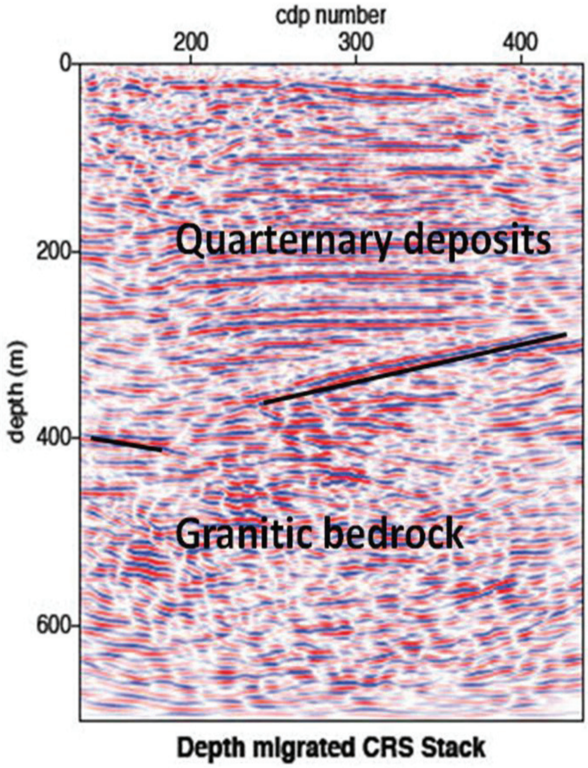

Fig. 2. Seismic profile through the central part (oriented from north (left) to south (right)) of the Field Laboratory at the Svelvik ridge. The upper boundary of the bedrock is indicated by solid black lines.

For the shallow injection the feasibility and suitability of three different areas within the CO_2 Field Lab site experiment were surveyed with ground penetrating radar and surface gas measurements. Two areas were found to be problematical, due to either hard ground conditions which make gas sampling difficult, or due to the high water level (saturation at 25-65 cm depth). The third area did not have these problems and its suitability was confirmed by ground penetrating radar measurements. The surface gas measurements were used to assess baseline conditions. Soil gas concentrations and fluxes are low with CO_2 concentrations mostly below 1.0 % and fluxes less than 8 $gm^{-2}d^{-1}$. This is consistent with the scarcity of vegetation.

2.2. Modelling of the shallow CO_2 injection

The shallow injection will be conducted at 20 m depth where the formation is interpreted to be a relatively homogeneous sand body. The objective is to study migration and surface leakage under well controlled conditions.

Using the results from the core analyses, an Eclipse reservoir model was developed with an isotropic sand with a permeability of 2 Darcy equivalent to the average value of direct permeability measurements on cores taken in the 333 m deep exploration well [5]. The modelling algorithm uses the equation of state of Span and Wagner [6]. To model the pVT properties and the phase behaviour of the CO_2/water system, the properties of CO_2 and the solubility model for CO_2 and water described in Spycher et al. [7] were used. The relative permeability and capillary curves used in the Eclipse simulations are similar to experimental data from the Utsira sand [8].

The modelling of various flow rates and durations, shows that an injection rate of 187.5 kg/d for 4 days would provide suitable conditions, in terms of plume growth, extension and migration, to perform a sensitivity study of the monitoring techniques planned for the shallow experiment.

The saturation profiles of CO_2 are shown in Fig. 3. Injection point is at 20 m depth. After approximately 55 hours injection, CO_2 arrived at the surface and a steady state occurred soon after. At this point, the escape rate can be adjusted simply by adjusting the injection rate. The maximum diameter of the exposed surface area is 7.5 m.

In this simulation 750 kg was injected. 45 % of the injected CO_2 (336 kg) escaped to the atmosphere, 46 % was dissolved and 9 % trapped as residual gas after 14 days. The escape profile is illustrated in Fig. 4. The peak escape rate of 7.5 kg/hour (lasting for about 1.4 days) corresponds to a flux of 4.1 $kgm^{-2}d^{-1}$. The escape rate falls to almost zero after the injection stops.

For the same shallow injection experiment, a different scenario including anisotropy was modelled using Tough2 simulations. In this simulation, the injection point was also 20 m below surface with a CO_2 injection rate of 173 kg/d. For this anisotropic model, the horizontal permeability was set to 20 Darcy while the vertical permeability was 2 Darcy. To obtain insight into the sensitivity of the modelling, the Sleipner [9] and Viking [10] sandstone models were applied in addition to testing both models with and without capillary entry pressures (0 and 1500 Pascal, respectively).

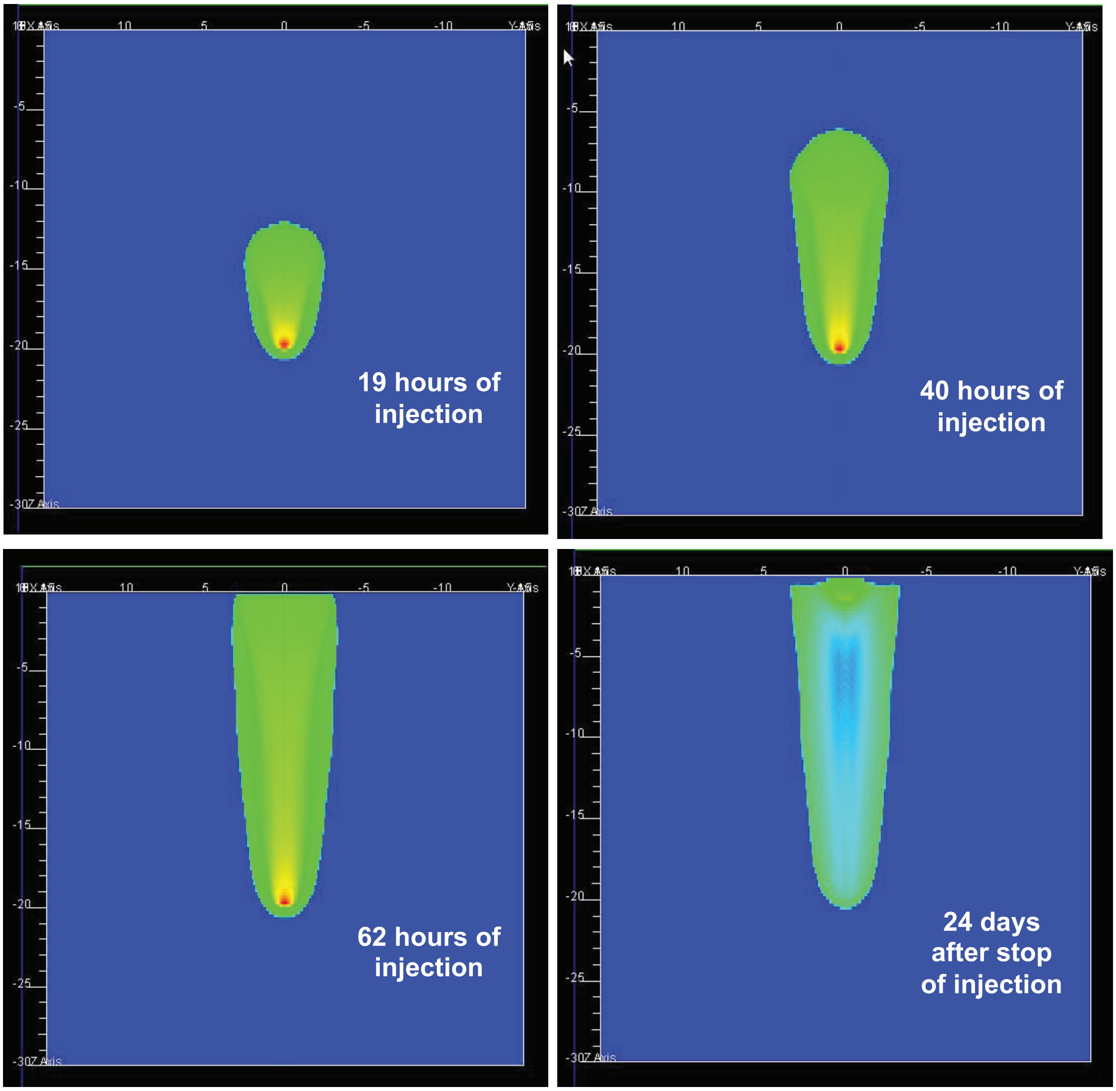

Fig. 3. The vertical saturation profile of the CO_2 plume in a shallow injection scenario simulated with Eclipse. The sand is assumed to be isotropic sand body (2 Darcy permeability).750 kg of CO_2 is injected totally The injection point is 20 m below surface and the total thickness of the sand body is 30 m. The colour bar indicates CO_2 saturation. The saturation varies form; dark blue = 0 % to red = 76 %. The total horizontal extension in the images is 30 m.

The Tough2 simulation shows that injection of 200 - 500 kg CO_2 is needed for it to reach the surface. The model with capillary entry pressure significantly increases the quantity of CO_2 needed for it to reach the surface and results in a more laterally extended plume (Fig. 5).

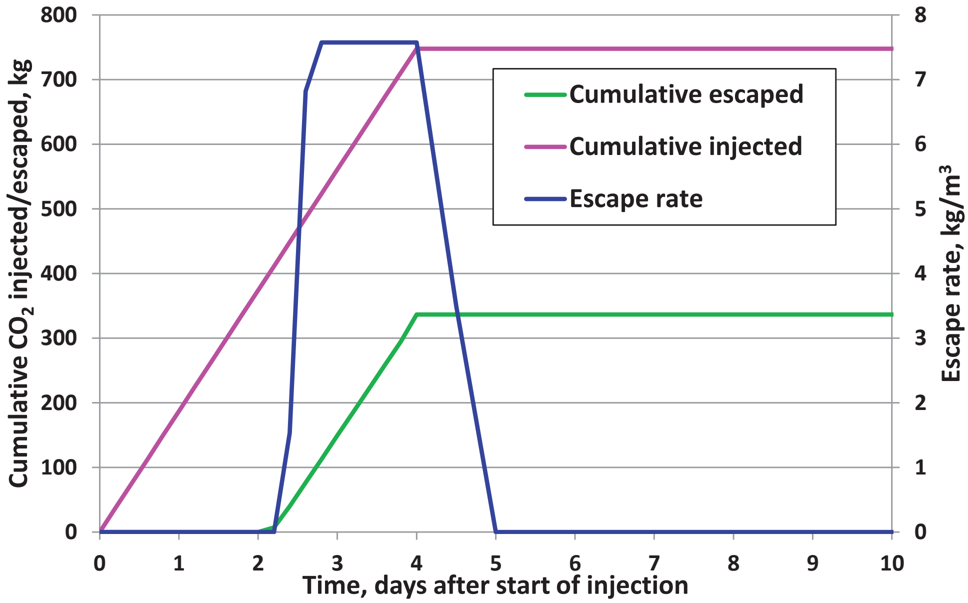

Fig. 4. Escape profiles with cumulative injection and escape volume (left axis) and escape (leakage) rate (right axis) for the CO_2 from the shallow injection scenario (Eclipse model). Injection stops after 4 days.

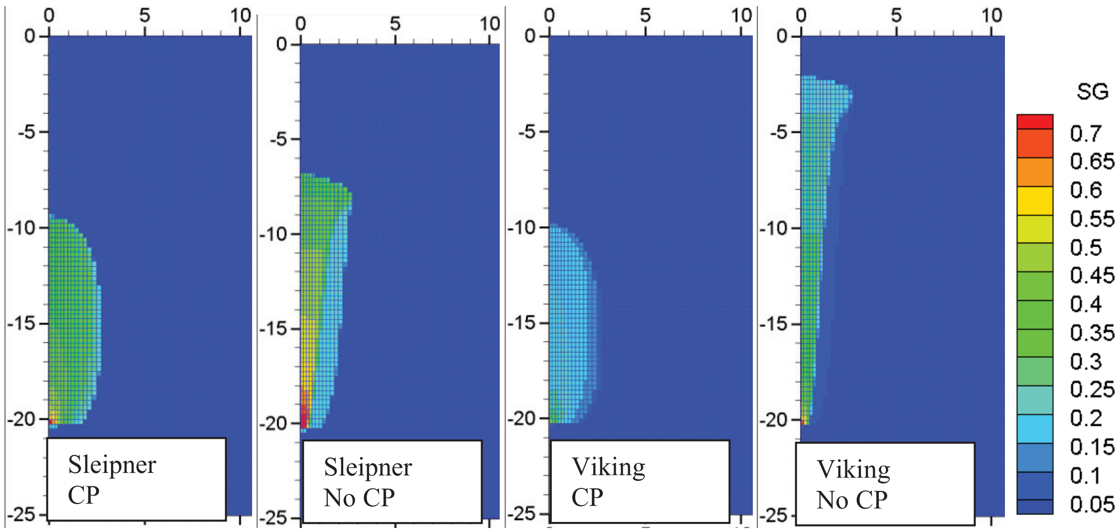

Fig. 5. Sleipner versus Viking relative permeability models, with capillary pressure (CP) and without capillary pressure (No CP) in terms gas saturation (SG) after 1 day of injection (Tough2 model). Vertical axis is depth in metres and horizontal axis is the (right half) horizontal extension in metres. Injection point is 20 m below the surface.

Summarizing, the plume development in both modelling scenarios consists of three phases. First, and only for a short time, the injection creates a CO_2 sphere around the injection point, whose radius depends highly on the injection rate, intrinsic permeability, anisotropy factor, and relative permeability. This sphere contains the minimum required gaseous saturation that allows CO_2 mobility. As injection continues, the CO_2 sphere stops growing and starts moving upward, saturating the overlying porous medium with CO_2, until it reaches the surface. Finally, almost immediately after breaking through the surface, the CO_2 flux attains a steady state, where the leakage rate is equal to the injection rate.

3. Conclusion

A field laboratory for monitoring CO_2 migration and leakage has been established at the Svelvik ridge (Norway). The characterization and associated modelling have shown that the site is very suitable for studying both migration and leakage at shallow depths. The shallow aquifer (down to approximately 50 m) consists of a relatively homogeneous sand body. Moreover, the site offers the opportunity to study migration signatures in more complex structures at semi-shallow depths (50-200 m) possibly with associated surface seepage. The deeper strata (below approximately 200 m) are most probably impermeable to CO_2 migration to the surface. However, these beds may be suitable for studying horizontal migration. By further confirmation of the site suitability, the established field laboratory may persist beyond the scope of the CO_2 Field Lab project.

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