Center for Olie og Gas - DTU
The Danish Hydrocarbon Research and Technology Centre

CO_2 storage in Danish Oil & Gas fields

A state-of-the-art study

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1 EXECUTIVE SUMMARY

To limit global warming and the associated environmental impact, many countries are now on the mission of reducing CO_2 emissions. Carbon Capture and Storage (CCS) has been identified as a technology that is particularly suitable for decreasing the CO_2 levels during the energy transition from fossil fuels to renewables. Although the number of dedicated CCS projects is slowly increasing, the majority are still carried out in combination with Enhanced Oil Recovery (EOR). CCS has also been embraced in Denmark, where several climate and energy institutions emphasize that capturing and storing the CO_2 is essential for the mid-term achievement of the emission reduction targets and for becoming carbon neutral in the long term. Although the first feasibility CO_2 storage project, *Greensand*, was announced recently, the CCS status in Denmark is well behind its neighboring country, Norway. However, the recent North Sea agreement, which sets 2050 as the end for the Danish oil and gas production and urges the CO_2 storage in the depleted hydrocarbon fields, represents an important step towards the deployment of CCS technology.

This report provides a summary of the 'State of the Art' for CO_2 storage in existing offshore oil and gas reservoirs in the DUC fields. Further, it maps the knowledge and technology gaps that will be important to close for a dedicated CO_2 storage project to become feasible. Reusing existing oil and gas reservoirs for CO_2 storage has both benefits and drawbacks; the knowledge and technology gaps for CO_2 storage in the DUC reservoirs have been identified and defined such that the benefits are fully exploited while trying to eliminate the impact of the drawbacks.

Benefits and drawbacks

For a Danish CO_2 storage site to be competitive it has to be both cost-effective and 'safe', with low potential for future leaks. In addition, the availability of CO_2 storage in the near-term is important since several countries in the North European region have pledged to deliver on climate goals with challenging short-term deadlines.

One way for a CO_2 storage site to be cost-competitive is to reduce investment; by reusing existing infrastructure from the oil and gas developments offshore, the CAPEX investment will be reduced. At the same time, the oil and gas fields have already acquired subsurface information for the storage site and therefore no significant costs related to additional data gathering/evaluation are expected.

Further, the oil and gas reservoirs have, over geological time, proven the existence of an effective caprock seal, ensuring that the CO_2 will stay underground and not leak back to the atmosphere. The oil and gas fields have produced for decades and fluid/gas movement in the reservoirs over time has been monitored. The resulting comprehensive datasets and knowledge are key when modelling the injected CO_2 plume movement. A similar understanding for other geological CO_2 storage sites, e.g., saline aquifers, will be difficult to obtain.

In Denmark, the ambition is to be able to store CO_2 starting from 2025. If deciding to use the existing oil and gas fields for CO_2 storage, the 2025 aspiration could potentially become a reality. Moreover, the offshore location of the existing oil and gas fields could make the approval process for CO_2 storage easier as it has higher social acceptance compared to options closer to shore. There are, however, also drawbacks connected to using the old oil and gas fields for CO_2 storage. The offshore location of the reservoirs increases both the CO_2 transportation and maintenance costs compared to similar onshore/nearshore options. Additionally, the old oil and gas fields have a significant number of well penetrations which could potentially develop into leak paths.

Gaps and enablers

In the following, the gaps and enablers within the areas of storage capacity, subsurface, transport/facility, wells, monitoring, and CCUS are summarized. The identified knowledge/technology gaps are highlighted at the end of each section and categorized based on their importance for a potential DUC CO_2 storage project:

Category 1 – Very important research gap – need to be understood for DUC project demonstration
Category 2 – Important research gap
Category 3 – Important research gap – not specific to DUC fields

Category 4 – Opportunity

Storage capacity

The Danish CO_2 storage capacity has been evaluated by several European CCS research projects. A capacity of 16 and 0.8 Gt CO_2 was estimated for 11 saline aquifers and 17 oil fields, respectively. The greater storage capacity and the (expected) reactive response of chalk to CO_2 injection, guided the Danish research on CCS towards the sandstone saline aquifers and not the hydrocarbon-bearing chalk fields. There are currently no existing CCS nor CO_2-EOR projects implemented in chalk formations and the main source of knowledge for the chalk behavior in presence of CO_2 comes from CO_2-EOR laboratory investigations. The existing storage estimates should be treated with caution because they may differ depending on the methodology adopted for the calculation.

Gap 9: Evaluation of CO_2 storage capacity in the DUC reservoirs – Category 2

Subsurface

The structural trapping provided by the caprock is the first barrier for CO_2 containment. CO_2 may interact with the caprock and alter its porosity, permeability, and capillary entry pressure. Although no studies on the interaction of the caprocks overlying DUC reservoirs with CO_2 could be found, experiments have been performed with core material from Fjerritslev and Børglum formations. These studies proved that these shales have excellent sealing properties and are not degraded in presence of CO_2.

The existing literature suggests that 95% of the CO_2 injected may be immobilized by capillary trapping. However, the residual CO_2 saturation and the relative permeabilities are formation-dependent and these should be assessed for the specific case of chalk. The wettability and the presence of residual oil are also expected to have a great influence on the capillary trapping and should be considered for obtaining an accurate estimate of the potential of this trapping mechanism in chalk.

The injected CO_2 can also partially dissolve in the formation water. The total CO_2 dissolved depends on the in-situ conditions (e.g., brine chemistry, temperature, and pressure) and the mixing within the porous medium. The development of convective fingers driven by the density difference between saturated and non-saturated CO_2 formation water is an efficient mixing mechanism and can increase the amount of CO_2 dissolved in the formation water. However, the low permeability and fast geochemical reactions in carbonate formations are reported to hinder the development of these instabilities, thereby reducing the mixing and CO_2 dissolution in the brine.

The CO_2 dissolution in the formation water decreases the pH, which induces chalk dissolution. Increasing research points out that the calcite reactivity cannot be extrapolated to chalk. This means that the kinetics of calcite dissolution/precipitations cannot be used to describe the behavior of chalk. Besides this, the geochemical reaction kinetics in depleted oil fields will be most likely affected by the presence of oil coating the mineral surface. The dissolution/precipitation reactions in chalk formations are not only important to assess mineral or solution trapping but they also have an impact on the porosity, permeability, and mechanical properties; these factors will eventually affect the migration of the CO_2 plume and the integrity of the storage site.

The existing studies on the effect of CO_2 on the mechanical properties of chalk are conflicting, i.e., some studies report increased deformation and weakening whereas others do not. In general, reservoir samples seem less affected than outcrop ones but the observations are highly dependent on the experimental conditions. The chemical effects (e.g., dissolution) leading to weakening become more relevant at non-equilibrium conditions. At the field scale, these conditions will most likely occur near the wellbore; thus, chalk weakening may become especially relevant for borehole stability and injectivity.

Injectivity issues are commonly reported in CCS projects. These issues may be even more relevant for the low permeability DUC fields. Several chemical effects (e.g., salt precipitation, rock dissolution, fines migration, asphaltene deposition, bioclogging, etc.) and mechanical effects (chalk weakening, compaction) are expected to impact the injectivity of the DUC reservoirs. The relevance of all these phenomena needs to be individually assessed and their effect should be coupled comprehensively so that the injectivity can be predicted and solutions and mitigation measures are proposed beforehand.

Gap 7: Injectivity impairment upon CO_2 injection – Category 1

Gap 8: Storage site safety – Category 2

Transport/Facility

Given the offshore location of the DUC fields, the CO_2 can be transported either by pipeline or ship. When CO_2 is transported by pipeline, flow assurance becomes a central topic and a good understanding of the CO_2 (with impurities) phase behavior is required. For the Nordic region, however, ship transport has been identified as the cheapest option and many firms have put effort into retrofitting and designing dedicated carriers for CO_2 transport. By ship, CO_2 is transported liquefied at conditions well below the temperatures and pressures required for injection. Additional heating and pumping equipment will then be needed to condition the CO_2 stream. Thus, the chosen transport solution not only governs the CO_2 delivery conditions but also sets requirements for the platform in terms of surface facilities. Additionally, it will also impact the injection mode, e.g., continuous vs. intermittent, and the performance/lifetime of the wells. Thus, the discharge and injection of the CO_2 offshore without the use or with minimum facility modifications deserves further consideration. The use of minimum conditioning equipment is more relevant for dedicated CO_2 projects as CO_2-EOR applications have completely different surface facility requirements with other associated knowledge gaps, e.g., flow assurance. A holistic approach needs to be adopted when assessing the CCS chain so that to ensure a sustainable balance between the economy and technical aspects.

Gap 1: Optimal technical/cost balance between transport and injection pressure/temperature/ CO_2 purity conditions – Category 3

Wells

One of the perceived benefits of re-using depleted oil fields is the availability of wells for injecting the CO_2. To benefit from this availability, the selection of the wells for injection could be made based on their remaining sacrificial lifetime. On the other hand, wells can also represent leakage pathways. Sub-optimal cementation or cement degradation induced by the interactions with the CO_2 are the main concerns. Despite conflicting research, several studies concluded that Portland cement is suitable for CO_2 applications and can even self-heal in case of microannulus or fractures. However, before CO_2 injection, the integrity of both injection and abandoned wells needs to be assessed. The output from the integrity study should then be integrated within a risk assessment tool so that the risk associated with each well can be quantified. This tool would eventually assist in choosing the most suitable wells to perform the injection and would reveal if any wells require additional monitoring.

Gap 2: Barrier cement behavior over time when exposed to CO_2 under DUC conditions (including interaction with casing and formation) – Category 2

Gap 3: Extent of the sacrificial lifetime of existing production casing when exposed to CO_2 - Category 1

Gap 4: Quantify the likelihood for a potential leak to surface through well penetrations – Category 1

Gap 5: Utilization of CO_2 injection to initiate the abandonment of the old oil and gas wells – Category 4

Monitoring

CCS projects need to firmly secure that the CO_2 does not leak back to the atmosphere. 4D seismic and time-lapse gravity are currently used for monitoring several storage sites. However, the development of chemical and biological sensors together with the increasing use of machine learning in designing the monitoring and interpreting the data are all expected to decrease the costs.

Gap 6: Development of a cost-effective, simple, and reliable monitoring method – Category 3

Gap 10: Cost-effective method to demonstrate the feasibility of CO_2 storage project – pilot testing – Category 4

CCUS

Injecting CO_2 in oil and gas fields can also lead to additional oil production; besides offsetting some of the storage costs with the revenues from the oil production it also increases the reservoir storage capacity. Moreover, CO_2, while stored permanently, can be used as a medium to extract thermal energy from deep reservoirs in a closed loop and turn it into electrical power. Other possible uses include the use of CO_2 as an offshore energy storage buffer and the production of synthetic fuels and other high-value products.

Gap 11: CO_2 used for offshore energy production – Category 4

The available storage capacity of the DUC oil and gas reservoirs, although lower compared to that of saline aquifers, can facilitate the geological sequestration of CO_2 over decades. The existing data on the reservoir characterization and infrastructure carry benefits such as reduced costs, faster implementation of the storage process, and a basic understanding of the CO_2 dynamics. The injectivity issues reported at many storage sites can be partially counteracted by the great availability of wells; these wells can be used for CO_2 injection until they reach the end of their lifetime. Although laboratory experiments on outcrop samples have raised concerns regarding the suitability of chalk as a CO_2 storage site, other studies showed that DUC reservoir chalk samples preserve their integrity and mechanical properties after being exposed to CO_2/CO_2 saturated brine injection. These latter studies may promote further research to help to remove the stigma of unsafety when it comes to CO_2 storage in chalk. Thus, the main knowledge gaps concern the validation of the chalk behavior in presence of CO_2 and the integration of a simple CO_2 transport/injection/storage value chain that reuses the existing wells and relies on minimum use of offshore facilities and affordable monitoring methods. By focusing on these gaps, a cost-effective (both initial low CAPEX and low OPEX over time), safe CO_2 injection with early start could be facilitated.

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