Definition and characterization of CO\textsubscript{2} storage complexes in depleted gas fields for the Aramis project, offshore Netherlands

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Abstract

The L4-A and K6-C depleted natural gas fields located 80 to 100 km offshore Netherlands have been identified by TotalEnergies as suitable and safe sites for CO\textsubscript{2} storage in the frame of the Aramis project. In both sites, the reservoir where CO\textsubscript{2} will be injected is overlaid by two caprocks with excellent sealing properties. Natural gas has been stored in these traps for hundreds of millions of years before production started. No subsurface or well-related integrity issues have been observed during production.

As per EU CCS directive 2009/31/EC, the “storage complex” is described as “the storage site and surrounding geological domain which can have an effect on overall storage integrity and security; that is, secondary containment formations.” The storage complex is commonly depicted as the ensemble of the geological formations (Reservoirs and caprocks) where the CO\textsubscript{2} will be stored in an area geographically defined (storage license). This paper addresses the work carried out in order to define and qualify L4-A and K6-C as adequate CO\textsubscript{2} stores, and the lessons learned throughout this process for addressing future reservoir conversion in Aramis project.

L4-A gas field was discovered in 1974 with the vertical exploration well L4-1. In the period 1979–1986, 6 production wells were drilled. Gas production started in 1983 and continues today.

The K6-C gas field was discovered in 1986 by the vertical exploration well K6-3 that was converted into a production well (K6-C1). Well K6-C2 horizontal production well was drilled in 1992, and production started the same year. Selected gas producer wells from both fields will be converted into CO\textsubscript{2} injectors.

The L4-A and K6-C storage complexes are fault-bounded blocks including the geological formations of Permian age: the Lower Slochteren storage formation, the Silverpit Formation caprock, and the Zechstein Formation caprock. The base of the storage complex is the Hercynian Unconformity (base Lower Slochteren reservoir) and top is the Top of the Zechstein Formation. The K6-C storage complex will also include the Westphalian C & D units, as they also were found gas bearing and in connection with the Lower Slochteren. CO\textsubscript{2} will be injected in the Lower Slochteren Formation reservoir which consists mainly of Saxonian age aeolian and fluvial sandstones.

The geological containment of K6-C and L4-A was fully assessed by a dedicated geosciences team focusing on caprocks and overburden characterization and description of faults. Well correlations, seismic interpretations and lithological descriptions allowed to characterize the Silverpit Fm and Zechstein formations caprocks and the overburden at the storage sites scale in term of thickness and sealing efficiency. A detailed structural analysis was conducted on faults affecting the caprocks to assess the risk of vertical CO\textsubscript{2} migration outside the CO\textsubscript{2} storage complexes. For lateral fault seal evaluation of K6-C and L4-A, integration of seismic interpretation, structural analysis

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and production data was key to understand dynamic behaviour of the L4-A and K6-C fields. This allowed to assess the risk of CO₂ lateral migration out of the CO₂ storage complex.

A 3D geological model was built including the storage complex and the overburden up to seabed in order to perform geomechanical analysis and assess the impact of gas production followed by CO₂ injection on the caprocks and faults. Findings of the structural analysis and geomechanical studies were included in the final Containment Risk Assessment. Working on mature depleted gas field one could think that geological and geophysical characterization of the CO₂ storage complexes should be easy and based on abundant data from existing wells, legacy seismic, production history and reservoir models. However, those datasets were acquired during the field life mainly to optimize gas production from the reservoir. This paper demonstrates that CO₂ storage poses new challenges for geologists and geophysicists. First is the scarcity of data in the shallower section of the wells to characterize the caprocks and overburden petrophysical and mechanical properties. Regional geological understanding of the shallower terrains is needed to conclude on storage scale containment.

Then the impact of CO₂ injection on the storage formation, on the caprocks, overburden and the faults has to be evaluated. This can be done through a thorough structural analysis and a 3D geomechanical model including the storage complex and the overburden up to seabed. A new type of study workflow was created as this type of model is not required for conventional hydrocarbon fields development.

Finally, proper definition and characterization of the CO₂ storage complex and overlaying terrains is key to design the monitoring plan. While in conventional oil and gas projects monitoring is mainly used for conformance, in CCS projects monitoring main objectives are to confirm the CO₂ containment within the CO₂ storage complex. The present study provided necessary inputs for the 4D seismic and passive seismic feasibilities as part of the monitoring plan. This work paves the way for other CO₂ storage developments. Study workflow will be continuously improved and could be replicated to define and characterize future CO₂ storages for the Aramis project. It could also be adapted to other CO₂ storages in aquifers of depleted hydrocarbon fields.

**Keywords:** CCS; Offshore; Depleted gas fields; CO₂ storage; Geosciences; Containment; Caprocks; Faults