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Oil-well cements behavior for integrity assessment of CO2 injection wells

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ABSTRACT

The Carbon Capture and Storage (CCS) is considered as a potential solution for reducing emissions from large-scale fossil-based energy and industry sources, but wider deployment hinges on resolving some important challenges. The global status of CCS reflects a remarkable and consistent growth in the past five years, resulting from private sector's response to the public demand for a transition towards a net-zero emissions future and from shifts in government policies and increased investments in various countries.

For many regions, among existing transport options, by pipeline or by ship, transport by ship seems to be a more interesting solution as it involves lower capital expenditure, lower financial risk, and more flexibility. One particular aspect of the CO2 transport by ship is its very low temperature, -53°C at 7 bar, needed to keep it in liquid state. Injecting a cold fluid in a well at much higher temperature, typically between 70°C and 200°C, raises serious challenges to ensure the well integrity, particularly its main sealing element, the cement sheath.

The injection well is a complex structure constituted by one or several metal casings and cement sheaths placed in the annular spaces between two casings and between the casing and the rock formation. The injection of CO2 at temperatures much lower than its environment can cause thermal stress changes in this complex system composed of materials of different thermal expansion coefficients and rigidity. The resulting evolution of the stress state can potentially lead to cracking and failure of the cement matrix or a debonding between the cement sheath and the casing. While the thermal stress changes can be evaluated by knowing the geometrical data and thermo-mechanical properties of different materials in the system, the risks of cement failure, casing debonding and integrity loss depend directly on the state of stress in the cement sheath, a factor generally unknown.

The integrity assessment of a CO2 injection well and the prediction of its response during different phases of a CCS project should be based on a numerical simulation of the well. This analysis, and particularly the evaluation of the initial stress state in the cement sheath, needs an appropriate constitutive law for the deep well cement paste covering its evolution from

the early-age to the hardened state. This work is dedicated to the development of a thermo-poro-visco-elastoplastic constitutive law for the cement-based materials using a multi-technique approach based on macro-scale laboratory experiments, microstructure characterization and micromechanical modelling. This constitutive law is implemented in an open-source finite element simulation platform and can be used for the integrity assessment of CO2 injection wells.