A Novel Technique to Investigate Effects of Thermal Shocks on Cement for CCS Well Integrity

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Carbon capture and storage (CCS) gains much attention as it contributes to mitigating climate change. However, during CCS, the periodic injection of pressurized CO_2 leads to strong thermal cycling and shocks in the subsurface, due to the endothermic expansion of pressurized CO_2 upon injection. Under these temperature variations, the wellbore and subsurface formations cyclically contract and expand. As a result, leakage pathways such as micro-annuli between wellbore casing and cement, and cracks in the cement can develop. They impair well integrity, and thus impede safe geological storage of CO_2. Therefore it is of significance to understand how the sealing ability of the cement sheath of CCS wells is affected by thermal cycling or shocks.

In this paper, we report a novel technique to investigate cracking in cement by thermal shocks under in-situ temperature and pressure. To this end, we use a triaxial deformation apparatus capable of mounting a cement sample in a vessel at a confining pressure of up to 70 MPa, with an axial stress up to 26 MPa. An internal furnace is used to achieve an elevated temperature in the vessel. Pore fluid lines are fitted in upper and lower axial pistons to allow water injection. In this study, we use a solid neat cement sample (Ø30×70 mm, water-to-cement ratio: 0.3) cured at 20^{o}C and ambient pressure for 28 days. During the experiments, the triaxial vessel is filled with heat-resistant oil which provides the confining pressure. The cement sample is isolated from the oil using a thin Teflon jacket. We load the sample at different in-situ states of hydrostatic stress and heat the sample assembly to various elevated temperatures (60 - 120^{o}C). We then inject cold water (20^{o}C) through the sample using two high-pressure syringe pumps at a designated flow rate for a given time. In the vessel, three linear variable differential transducers (LVDT) mounted parallel to, and span around the sample are used to calculate axial and radial strain, respectively. Two thermocouples, one mounted on the middle of the sample (outside the jacket), and another inside the upper pore fluid line, are used to measure temperature. To study the extent of cracking, how and where cracks initiate and grow in the cement under thermal shocks, we measure permeability of the sample with a differential pressure transducer measuring the difference between the up- and down-stream pore fluid line, and we use a micro-computed tomography (μ-CT) scanner to characterize the microstructure of the cement sample before and after the experiments. This technique provides valuable expedience to investigate the thermal effects on the integrity of cement under different in-situ conditions for CCS wells.

The pistons of the setup can also be readily adjusted to study how de-bonding between casing and cement, and cracks in the cement develop for composite cement samples (with analogous casing) under thermal cycling. Our overall goal by using these techniques is to develop and test novel cement designs for enhanced CCS well integrity.