Tubing connection evaluation methodology and test protocol for CCS injection wells.

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\section*{Abstract}

Industries are increasingly looking to carbon capture and storage (CCS) as a key technology for advancing the energy transition. However, while CCS has strong potential as a long-term solution for decarbonization, currently there are no industry standards to qualify equipment to safely operate industrial CO\textsubscript{2} injection wells. To overcome the challenge of not having any industry guidelines to test our VAM® connections for CCS applications, through a collaboration with Oil and gas international majors actively involved in CCS projects, we devised a testing protocol that replicates operating conditions expected in CCS injection wells.

Like any oil and gas project, storage of CO\textsubscript{2} requires drilling wells and installing tubing and casing that can ensure reliable and safe operations. The pipes of the string are interconnected by threaded connections to reach reservoir depths; the oil and gas industry has developed standards, such as API RP 5C5 and ISO 13679 to test those connections to ensure sealing performance. Those standards provide guidelines to test equipment and ensure it will withstand operating conditions that are expected in the wells.

CO\textsubscript{2} storage brings different challenges to those seen in the oil and gas “standard” operations, because of the thermodynamics of CO\textsubscript{2}; these injection wells will face temperature variations through phases of depressurization, and they must ensure sealability through the life of the well. This paper will describe the testing protocol for CCS applications of Vallourec’s VAM® connections.

The main differences we found when compared to oil and gas applications are that for CO\textsubscript{2} storage the connections will be exposed to temperatures that can reach -30°C or even -60°C in regular operating conditions and down to -80°C in extreme cases of rapid depressurization; in addition, axial stresses are exerted simultaneously of several hundreds of tons, depending on the weight of the pipeline string. After being subjected to such conditions the connection performance shall remain intact. An insufficient connection design or an incomplete performance validation can lead to the loss of the tubing in the well with risks for the personnel at the surface and ecological risks of uncontrolled CO\textsubscript{2} release.

The aim of this paper is to describe the methodologies as well as the physical tests done to qualify the tubing connections for CO\textsubscript{2} storage applications that can provide a safe, reliable, gas tight, and structurally efficient solution.

The work for this study consisted of carrying out Finite Element Analysis (FEA) and defining a methodology to validate the most critical connection configuration (diameter, wall-thickness, grade).

The metal-to-metal seal can generate contact pressures from 500 MPa up to 1200 MPa, therefore an analysis has also been carried out to characterize the fretting behavior of the seal to ensure gas tightness for several decades. This type of test represents the metal-to-metal seal motions of the connection during the injection and depressurization phases in the well. Different surface treatments and different types of lubricants have been evaluated at -30°C and -60°C, and the results made it possible to launch full-scale tests.

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When a rapid depressurization occurs in the tubing the pin and the box of the connection are at different temperatures for a few seconds and therefore at different levels of thermal expansion. This can lead to the loss of the string in the well by disengagement of the connection.

The analysis of the life cycle of a North Sea CCS project highlighted a 5-phase test protocol to characterize a CO$_2$ storage well. A test was carried out to validate a 3.5” 9.20# 80ksi 13Cr VAM® connection in these 5 phases. The first phase is composed of internal and external pressure test with axial forces at ambient temperatures. The second phase is carried out in tension with thermal cycling temperatures from -15°C down to -35°C. The third phase consists of a thermal shock at -80°C. The fourth phase represents the cases of rapid depressurization in which there is a temperature difference of 60°C between the pin and the box.

Finally, the fifth phase where the loading points are identical to the first phase validated the performance in operational condition after the survival events. During all these phases permanent leak detection is monitored.

An additional analysis was carried out to characterize the sealing performance of the connection with CO$_2$ under rapid depressurization. Some wells inject CO$_2$ in supercritical phase. This CO$_2$ state is a powerful solvent which can damage the tribological conditions between the metal-to-metal seal, the surface treatment, and the lubricant. A study with full-scale test was also carried out to characterize these effects on the connection for gas tight performance.

**Keywords:** CCS; Well; CO2 Injection; Connection; seal; safe; risks