IATMI22-078

A Discussion on Premium Connection Qualification for CCS/CCUS Well

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Abstract. This work aims to depict the different aspects that need to be considered for the evaluation of threaded OCTG connections used in CCS (Carbon Capture and Storage) projects. The paper also shows the different stages followed by the authors to develop a methodology that could be used to conduct such evaluation.

Considering that the evaluation of threaded connections used in wells should take into loads, pressures and temperatures expected during injection and a less likely survival case, the authors have found two methods to physically evaluate the specimens and a numerical analysis to investigate extreme load cases.

Numerical methods allow a quick simulation of the exposure to the survival loads by imposing sudden changes in temperatures and combined loads and pressures. In such a way, it is possible to understand the mechanical behavior within a define perimeter and be prepared for the physical testing.

The physical evaluation, also known as Full Scale Testing, consider the two above-mentioned scenarios: injection in steady conditions and survival loads. For the steady conditions the evaluation of a connection following a test load envelope at sub-zero temperatures in the range of -25°C to -35°C covers most of the known scenarios. For the survival loads, it is necessary to demonstrate with a sudden exposure to freezing temperatures around -70°C that the connections can both maintain structural integrity and, subsequently, a sealing response under normal operation.

The methodology described by the authors combining numerical analysis and full scale testing was applied in real cases. It demonstrated its suitability for the evaluation of OCTG threaded connections under the extreme low temperatures that could be seen during the operation of the well in Carbon Capture and Storage projects. Different materials were also evaluated during the preliminary stages as well as with the final procedure demonstrating its applicability to different types of materials from carbon steels to martensitic alloys.

Considering that there is no standard in the industry capable of covering all the potential scenarios of the carbon storage well, the methodology presented herein can be used a starting point for future projects.

Keyword(s): CCS; CCUS; OCTG; premium connection; qualification

1 Introduction

In the current context of global net-zero carbon efforts, CCS/CCUS has taken the stage in the oil and gas industry being one of the methods to reduce CO2 concentration in the atmosphere, while its emission is also being reduced. The drilling industry particularly plays an important role considering its experience in oil and gas wells drilling.

OCTG industry has also been developing its optimized technologies to answer various challenges being faced in the drilling operations. Particular steel grades with specific characteristics e.g. high strength, high collapse, sour service, and corrosion resistant alloys are available for selection as well as different types of connections ranging from API and premium connections with gas sealability performance.

Gas sealability is particularly important in CCS/CCUS wells in ensuring wells' reliability to inject CO2 gas into the targeted reservoir. In answering the needs of reliability, methodologies of connections qualification are being developed considering specific scenarios in CCS/CCUS wells.

2 Development of CCS/CCUS Connection Evaluation Protocol

2.1 CCS Well Scenarios for Connection Evaluation

When a connection has to be evaluated to assess its performance in Carbon Capture & Storage (CCS) environment, the first aspect to consider is that there is no International Standard describing the steps to be followed to accomplish this goal. Therefore, it is necessary to define ad hoc procedures to cover the potential scenarios the connection may face during the different stages of the operation and, eventually, under some survival loading cases.

In a typical Carbon Capture & Storage (CCS) well, the first scenario to be considered are the steady operative conditions in which the well can operate. Depending on certain factors of the reservoir, Injection of CO2 in these conditions can happen in low temperatures such as -35°C. Main concern in this scenario is related to the operation of the connection under sub-zero temperatures. Extreme case in which the pin part of the connection suffers a thermal contraction due to the below zero temperatures while the box part remains at a higher temperature (most extreme and less likely scenario). This contraction of the pin part results in a decreased seal interference which could affect the seal performance. This is due to the fact that OCTG threaded connections are designed and tested to operate at ambient or higher temperatures, which are conditions covered by certain International Standards such as API 5C5:2017 and ISO 13679:2019. In the particular environment of a CCS well, any validation needs to assess the sealability performance of the connection considering the different tension and pressure load scenarios in addition to the below zero temperatures.

The second scenario to be evaluated occurs when the CO2 that is being stored inside the well (at a higher pressure) rapidly expands due to a failure in the sub-surface valve of the well. This expansion causes a sudden drop of the temperature of the CO2 and subsequently the entire cooling of the string. This is known in thermodynamics as the Joule–Thomson effect. According to a typical CO2 phase diagram [diagram [1], this depressurization can cool the gas down to almost –80°C (actually -78.5°C is the theoretical temperature at ambient pressure) and subsequently the entire string in the well. Under this these conditions the concern is not related to the sealability performance of the connection, due to the depressurization of the gas (i.e. no pressure applied to the seal) but to the structural performance. The most extreme case in this scenario is when the pin part is cooled down to -80°C (the pin part and suffers a thermal contraction) , while the box part remains at a higher a temperature, resulting in a temperature difference (ΔT) between the two parts. The thermal contraction causes an increase in the applied axial load to the connection (given the constrained string) thus it is necessary to validate the resulting load is within the limits the connection can structurally withstand.

Any proposed validation needs to assess the sealability performance after the survival case in order guarantee that the sealability capacity of the connection remains unaltered.

2.2 Evaluation of the Connection in CCS Application

As it is common in the Oil and Gas industry, before any physical validation also known as Full Scale Test (FST), a numerical analysis or FEA (Finite Element Analysis) can help model and simulate the different scenarios to which the connection is going to be exposed, and even extreme cases to evaluate the connection performance to its limits.

Back to the evaluation of a connection for CCS, considering that for the first scenario previously described (steady well injection conditions), a FEA simulating the different tensions and pressure loads in addition to a cooled down pin and box are performed to understand the seal mechanism's performance in normal operation. Moreover, a more severe case is to consider is the pin at low temperature (e.g. -35°C) and the box with a higher temperature. To explore an extreme scenario, a FEA simulating a temperature difference (ΔT) between pin and box of 80°C (far greater than what is expected in the CCS well) can be conducted in order to validate the sealability performance in which the pin suffers a high geometrical contraction, and the seal interference is heavily reduced. Figure 1 shows the seal contact pressure profile for two cases with the same load scenario: i) pin and box at the same temperature (ΔT=0) and ii) pin at lower temperature with a ΔT between the two parts of 80°C.

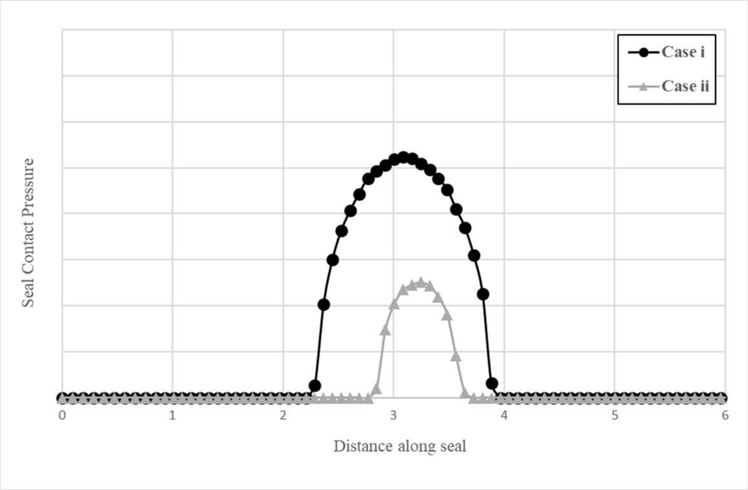

Figure 1. Seal Contact Pressure Profile.

As it can be observed, although the contact pressure is reduced due to the reduction of seal interference, the seal remains closed (no negative contact pressure) and the profile is not altered.

In the second scenario, in which there is a sudden depressurization of the CO2 and the gas is cooled down to -80°C, FEA was performed to represent different conditions:

0. Make-up
1. Maximum axial load expected in the well under normal operation
2. Thermal shock test (maximum axial load expected in the well + thermal contraction)
3. Limit load or tension to failure

Stage 0 represents the initial make-up of the connection with no load or pressure applied. Both the pin part and box part have the same temperature.

In Stage 1, the maximum tension load (expected from the well and string analysis) is applied to the connection. In Stage 2, structural performance is evaluated with a ΔT between pin and box of 80°C. This is an extreme scenario in which only the pin side is cooled down (thus it suffers a thermal contraction) and no heat is transferred from the box side which remains at a higher temperature. Given that the string is constrained, this results in an increased tensile load. It is important to highlight that a certain margin from the axial limit of the connection at this stage has to be considered in any well design applicable for CCS.

Finally, in Stage 3, axial tension load is applied until failure, essentially to demonstrate that failure will occur outside the structural limits of the connection.

In Figure 2, the four stages are represented in the theoretical Von Mises Envelope (VME) of the connection.

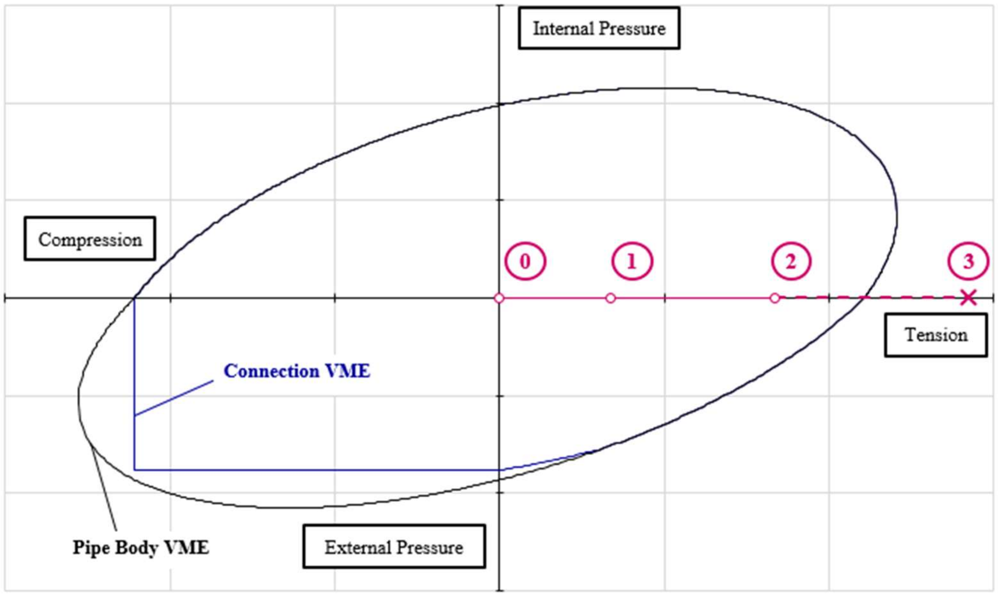

Figure 2. The four stages represented in the VME.

From a technical standpoint, it is always mandatory to verify that, in the unlikely scenario of a sudden decompression, the additional loads generated by the contraction of the string fall within the structural capacity of the connection.

As it can be seen if Figure 3, the Von Mises stress results from the FEA show that failure occurs outside the Service Envelope of the connection (Stage 3), specifically

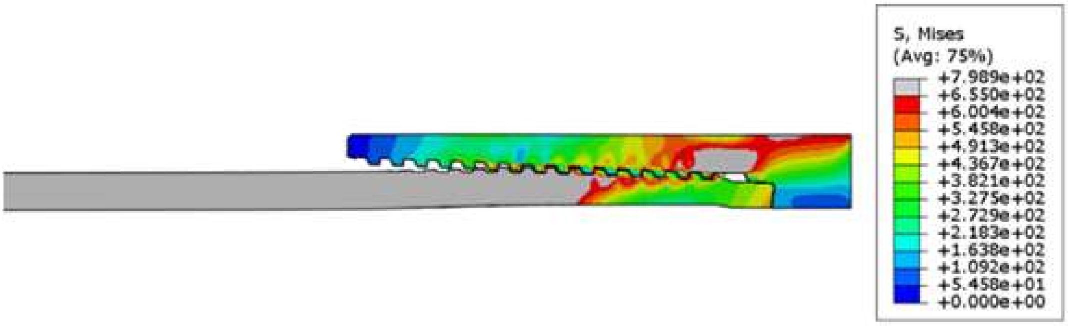

Figure 3. The FEA results for Stage 3 of the analysis.

2.3 *Proposed Full Scale Test (FST) Program*

The concept of the Full Scale Test (FST) is to physically validate the performance of the connection. As described in Figure 4, in the case of CCS applications, the idea is to use the FST program to evaluate the structural and sealability performance of the connection at ambient and low temperatures, before and after a Thermal Shock Test (which simulates the survival case previously described). As in any OCTG product validation, before the sealability test, a Make-up & Break-out Test for the connection is required.

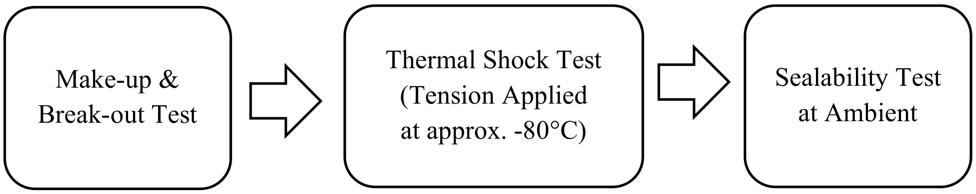

Figure 4. Proposed FST Program.

Thermal Shock Test consists on applying the expected maximum pure tension in the CCS well and rapidly cool down the temperature of the tested sample. Given that the -80°C temperature is a theoretical limit and, in terms of the heat transfer, there is a certain inefficiency in the system, a temperature around this limit in the range of -80°C/-70°C may be considered for this part of the test using CO2. The idea of this step of test is to validate both structural performance of the connection, in the scenario that the CO2 inside the CCS well expands rapidly in the case of a blow-out with CO2 being released to the atmosphere. After the hold time is finished, the sample is brought back to ambient temperature and tension is unloaded.

Final step of the FST program is to perform a sealability test at ambient temperature in a known working condition validating the performance of the connection after the survival case scenario.

Any proposed sealability scheme should be based in an OCTG normally used standard, such as API Recommended Practice 5C5 in order to compare results with already validated connections.

References

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