Full-scale Surface Experiment of Cemented-in Casing Connections Designed for Thermal Stress Mitigation

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ABSTRACT

Common failure mechanisms in high-temperature geothermal wells are casing collapse and tensile joint rupture. For medium- to high-enthalpy geothermal wells, thermal cycling has the potential to severely deteriorate the integrity of the cemented annulus. Additionally, for higher enthalpy wells, yielding of casings becomes a structural concern. A recently innovated patented solution, flexible couplings, aim to reduce thermal strains by allowing displacement from thermally expanding casing segments at ~12 m intervals (API Range 3 casings). In the GeConnect project, a full-scale surface experiment composed of a 9⅝″ casing equipped with a flexible coupling cemented into a 13⅜″ casing is constructed and installed on a well pad of an existing high-temperature geothermal well in Iceland. The aim is to investigate effects of thermal cycling on well integrity and to test the function of cemented-in flexible couplings. Along with testing the flexible coupling, cement sheath integrity and the cement-casing boundary behavior will be evaluated at moderate to high temperatures. Structural models are used to analyze casing-cement interactions and to evaluate prospects and potential improvements of well integrity by using flexible couplings on experimental up to field scale.

1. INTRODUCTION

The cost of geothermal wells for co-generation of electricity and district heating system is typically 20-50% of the total investment cost of the energy production (Pálsson, 2017) (Pálsson, 2017). Frequent failure mechanisms for high-temperature geothermal are casing collapse and mechanical overload of the casing string in the well due to constrained thermal expansion (Lohne, et al., 2017) (Thorbjornsson, et al., 2019). In addition, for medium enthalpy geothermal wells, it is stated that temperature and pressure cycles above 100°C during construction, operation and shut-in phases have the potential to severely deteriorate the integrity of the cemented annulus (Heege, et al., 2017). The goal in the GeConnect project is to test new technology that aims at increasing the reliability of the downhole construction of geothermal wells beyond the state of the art, i.e. flexible couplings (Figure 1), that were developed in EU Horizon 2020 projects GeoWell (grant agreement No 654497) and DEEPEGS (grant agreement No 690771).

Figure 1. *The flexible coupling is designed to allow thermal expansion of casings at 12 m intervals. The figure shows one of the prototypes (for 9 5/8" casing) of the FC that was built and tested in the Horizon 2020 project GeoWell.*

Together with the new flexible couplings, cement sheath integrity and the cement-metal interface is evaluated with the ~12 m long surface test setup simulating the downhole structure. Steam from a geothermal well is used to induce thermal cycling loads at moderate (~100°C) to high temperatures (~300°C). The resulting strains and displacements will be monitored throughout the test and compared to numerical model results.

2. THE CONCEPT

GeConnect is based on work done in the EU Horizon 2020 funded projects GeoWell and DEEPEGS. Full-scale prototypes of the flexible coupling have already been laboratory tested in GeoWell at ambient temperatures (Ragnarsson, et al., 2018). In the full-scale test defined in GeConnect, a 9⅝″ prototype will be tested in real geothermal environment by using steam directly form a high-temperature geothermal well. The concept of the project is to validate the function of flexible couplings in cemented conditions at elevated temperatures and to monitor the casing-cement bond integrity by monitoring strain/displacement of the inner casing.

Figure 2. *GeConnect project structure. Work packages of the project.*

The project is set up with five work packages that aside from project management, coordination and dissemination has three technical work packages (Figure 2). The market needs for flexible couplings will be analyzed for medium- to high-enthalpy geothermal wells. Surface demonstration is the main focus in the project where a test setup of cemented-in casing with flexible coupling will be thermally cycled. The concept will be validated in a surface experiment in real geothermal environment along with analyzing the integrity of cemented annulus and the casing using flexible couplings. After successfully tested in the framework of the EC funded projects IMAGE (Reinsch, et al., 2015) and GeoWell (Reinsch, et al., 2019), fiber optic distributed strain sensing technology together with conventional acoustic sensors will be used to validate the performance of the flexible coupling. Possible implications and risks associated with using the new flexible couplings will be assessed through structural modeling of the surface test, upscaling to field-scale and by performing a quantitative risk assessment analysis. Structural analysis will be used to evaluate the performance of flexible couplings and demonstrate the benefits to well integrity of reducing thermal axial stress and strain in casings by introducing the new flexible coupling.

GeConnect addresses the need for better understanding of the impact of cement/casing interaction, and its reaction when casing is moving axially. Key geothermal partners are onboard the project, highlighting the industrial need for more reliable solution in traditional geothermal fields, and to provide a solution to harvest energy from deep geothermal resources in Europe and worldwide.

3. THE FLEXIBLE COUPLING

The flexible coupling, a patent solution (Thorbjörnsson, 2017), has been in development from the year 2015. It was introduced in the GeoWell project where the idea was developed to a full-scale prototype (Figure 3). Several prototypes were built and tested at ambient temperatures (Figure 4). Its function and structural limits was evaluated. The prototype in casing size of 9⅝″ was tested pressure tight up to 110 bar (with pressurized water) and has a load capacity of 300 tons (Thorbjornsson, et al., 2019). Its sliding function was confirmed both in straight position and with bending loads.

The connection was further developed in the DEEPEGS project and has been incorporated in well designs for the Krafla Magma Testbed (KMT) that aims towards better understanding of magmatic systems by establishing the first magma observatory (Eichelberger, et al., 2018) (Hólmgeirsson, et al., 2018).

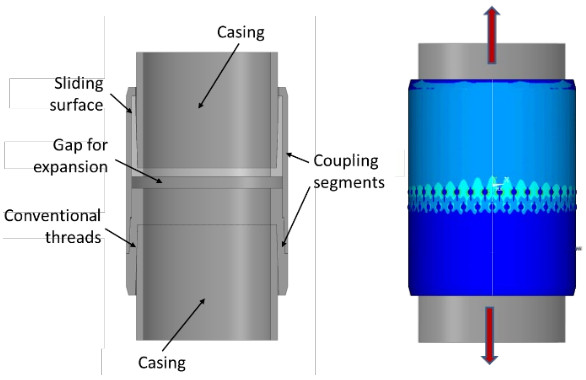

Figure 3. *Flexible couplings for casings are designed to mitigate thermal stresses by allowing intermittent expansion (displacement) of casing segments into the connection at 12 m intervals. It was designed by using finite-element modeling and developed further by full-scale testing.*

The objective of the flexible coupling is to lower thermal stresses in production casings of geothermal wells, increasing reliability and reducing risk of casing failures. Testing its performance in operational conditions at elevated temperatures in the GeConnect project will further establish confidence in its function for use in production casings of future geothermal wells.

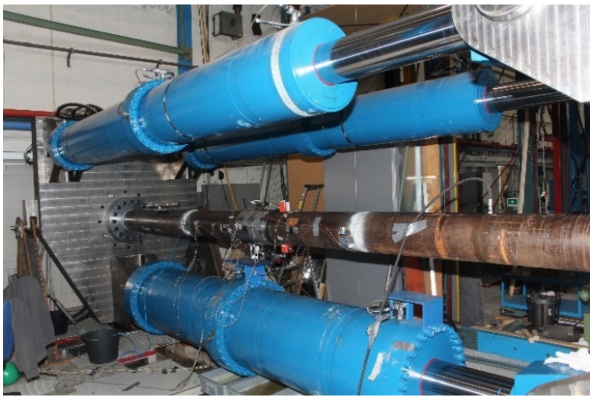

Figure 4. *The function and structural capacity of prototypes of the flexible coupling has been tested at ambient temperatures at SINTEF and later after modifications it was tested at NORCE (former IRIS) in the GeoWell project (picture taken during testing at SINTEF facilities in Trondheim, Norway).*

4. SURFACE EXPERIMENT (AT 100-280°C)

The integrity of cemented annulus and the casing using flexible couplings will be tested in a full-scale surface experiment (Figure 5). Steam from a geothermal well will be feed through the test setup and the structural response will be documented by various monitoring equipment, including temperature and pressure sensors, acoustic sensing, strain gauges and fiber optic distributed sensing.

Approximately 12 m casing segment (9⅝″) is cemented into a larger diameter casing (13⅜″), simulating annular clearance of a typical well. The inner casing will be fitted with a flexible coupling, where approximately one casing segment (API 5CT standard range 3) or about 12 m has the capability to expand axially into the flexible coupling during the test.

The test segment is designed to according to standards for high pressure equipment, high pressures (40-60 bar-g) at saturated steam conditions are expected. For the experiment to work properly as intended, it is essential to fix the displacements of the end plates. Thermal expansion of the test piece itself is constrained by beams over its whole length, simulating constrained casing-cement-formation system. The test segment will be assembled, cemented and placed at a convenient well pad for performing the surface experiment.

In the first thermal cycles, the flow of steam will be tempered such that conditions within the casing will be at saturation temperature at near atmospheric pressure. The test piece will be allowed to cool down to original temperature. At a later stage, the back-pressure of the casing will be controlled by a control valve, increasing the pressure and temperature to wellhead conditions of the selected well. A productive well with pressure of 40-60 bar-g will be selected to simulate downhole conditions of 250-280°C. By this the wellbore warm-up during initiation of flow will be simulated. Once the test piece has reached near steady-state conditions it will be quenched by pumping cold water through it. This will simulate worst conditions in a hot well that is killed by water. The flexible coupling is designed to mitigate the axial stresses that the contraction would normally produce using conventional connections. This is due to lower strain forming in the casing as it heats up initially.

One of the outcomes of the test is to analyze when and at what temperature the controlled micro-annuli will occur, i.e. the debonding of the casing-cement interface. This information is then used to predict the performance of the flexible casing on field scale and to determine a potential transition bonding zone over the length of the casing segment.

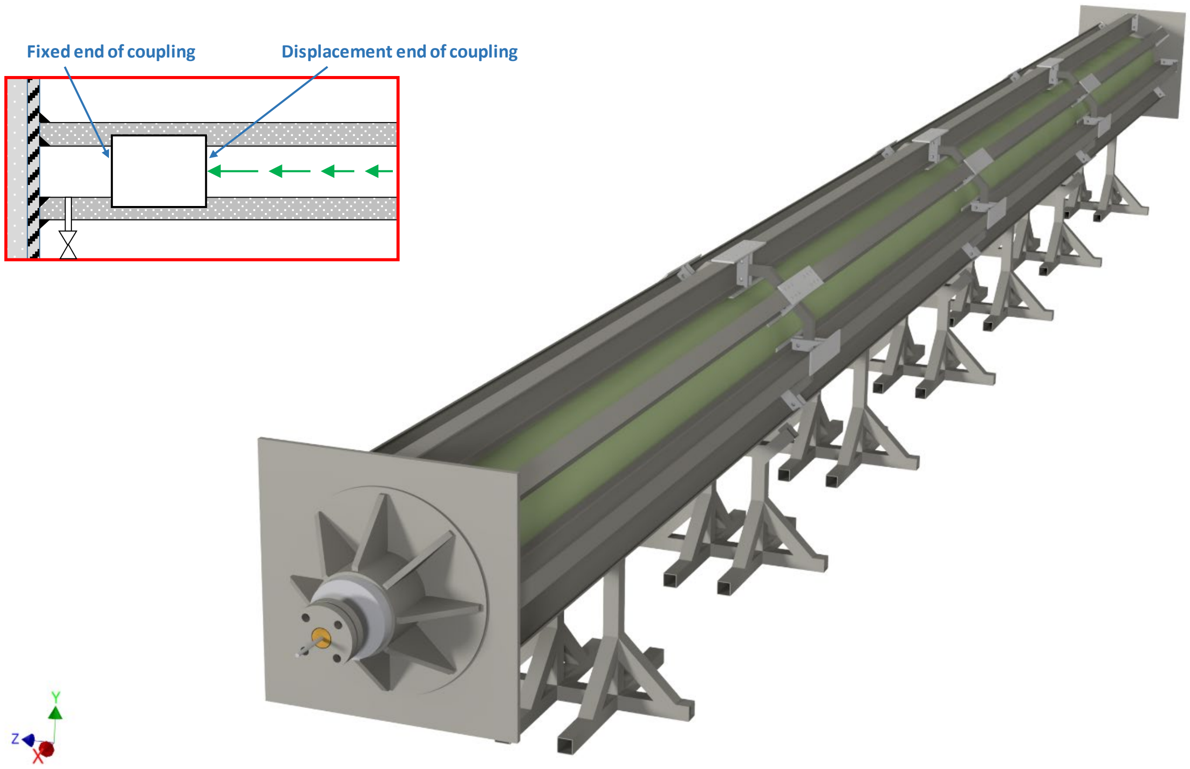

Figure 5. *Test setup, a 9⅝" casing with flexible coupling is cemented into a 13⅜" casing. The test setup is designed to keep ends in fixed position during warm up, thereby simulating downhole conditions. As high-temperature steam is feed through the casing, the internal casing expands thermally. Displacements into the flexible coupling, strain along the casing, temperature and pressure are recorded.*

5. CONCLUSION

The objective of the GeConnect project was described in the paper. Loads from constrained thermal expansion, that occur in the production casing of a geothermal well, is simulated by cementing in a typical casing size of 9⅝″ into a 13⅜″ casing by feeding hot steam through the test piece. The inner casing includes a full-scale prototype of a flexible coupling of which function will be tested in the experiment. The test setup will be built and ready for the experiment by fall 2019.

6. ACKNOWLEDGEMENT

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