Technical Report

Development of a Smart Completion & Stimulation Solution

Award Recipient Organization: University of Utah (DOE Project DE-EE0007080)

Subrecipient Organization:

Welltec Inc.

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Abstract

Final Report for: Development of a Smart Completion & Stimulation Solution

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Multiple efforts are being conducted to meet the energy requirements in the world. However, with the imminent increment of the population around the globe, the energy sector is leaning towards renewables. Therefore, this is the reason why geothermal has become an important source of energy in the United States, with multiple studies performed to fully understand its potential. The Frontier Observatory for Research in Geothermal Energy (FORGE) is at the forefront in the studies involving the potential Geothermal energy may bring, allowing the cooperation between different parties to further develop new technologies which will be used in the geothermal sector. In this aspect, Welltec Inc. and The University of Oklahoma have partnered with FORGE, to conduct research on a unique completion and stimulation solution, based on its cutting-edge technology, which includes the Metal Expandable Packer (MEP). The Development of a Smart Completion & Stimulation Solution took place in the previous years, from literature review, small-scale experimentation and, lastly, full-scale research conducted in a unique environment with a successful implementation of the completion and stimulation solution at 6,000 psi differential pressure and up to 300 °C temperature, to simulate the challenges that will be encountered in geothermal operations. The following report comprehends a detailed insight on the project lead by Welltec Inc. and The University of Oklahoma for FORGE.

Keywords: Isolation tools, Metal Expandable Packer, Geothermal, HTHP, Annular Isolation, Well Integrity

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Final Report for: Development of a Smart Completion & Stimulation Solution

Principal Investigator: Business Development Manager – Yosafat Esquitin

1. Executive Summary

1.1 Background

Multiple tests and trials have proven that the operating limits of existing downhole zonal isolation technology based on elastomeric type seals are challenged in their temperature and material compatibility for EGS completions. The use of non-elastomeric sealing elements developed under this grant will, under the life of the well, allow:

1. Provision of true zonal isolation of geothermal reservoirs for multiple zones and cycles.
2. Enable effective stimulation and treatments of determined zones, multiple times.

To achieve this, a set of objectives were developed. The objectives took place from theoretical study and simulations to the development of manufactured prototypes, both in small and large scale, to qualify the functionality of the products for geothermal operations.

1.2 Objectives

The main objective is to develop external (MEP) and internal isolation systems, Stimulation Isolation Device (SID), capable of withstanding downhole conditions of geothermal operations. This will mitigate previous challenges experienced with the use of conventional downhole packers in the Utah FORGE wells. Additionally, a Fracture Initiation Device (FID) is designed to minimize the risk of fracture bypassing the annular isolation devices by the controlled initiation of the fracture during stimulation.

1.3 Key findings

Some key findings encountered during the time of this grant are listed as follows:

- The ability to seal in a high rugosity formation. This was addressed through a combination of metal and spring-energized thermoplastic seals.
- Findings obtained after test performed:
    1. Sealing element at elevated temperature with a downscaled 6" diameter assembly. The results provided critical information for FEA modeling and the final design of the full-scale MEP.
    2. Downscaled testing of the interface between the MEP and the rock to better understand the behavior of the MEP when set against the rock face. The stresses generated during expansion were better understood and used and to validate the geomechanical model.
- The ability to maintain seal during multiple open/close cycles of downhole tools. This was addressed by the development of non-elastomeric elastomeric sliding seals, used in the WFV and SID systems
    - We created an innovative seal design using metal spring leaves with a very small form factor and ability to generate large contact stresses.

2. Introduction

2.1 Purpose of the Report

The purpose of the report is to highlight the results obtained throughout the project, with the different conclusions and key findings after testing the Smart Completion and Stimulation Solution under the HPHT conditions of geothermal wells. A summary of these findings will be shown in detail, as well as different lists of the conferences / GDR generated out of this sub-awardee.

2.2 Scope of Work

The project was divided into three main phases:

i. Phase 1: Small-scale experiments performed together with detailed numerical modeling of the isolation systems and rock mechanics.
ii. Phase 2: Building a full-scale system prototype and testing to the required 225 °C and 6,000 psi, with a test at 300 °C to explore the system limits.
iii. Phase 3: Deployment of the isolation system and testing in a FORGE test well.

During this period, we were able to understand the behavior of the MEP system in combination with the rock (MEP to Rock interface), design and evaluate a Non-Elastomeric High Temperature (HT) seal, with the design and modeling of full-scale prototypes of MEP, Well Flow Valves (WFV) and Stimulation Isolation Device (SID). This involved the manufacturing, testing and qualification of the prototypes, which can be suitable for open hole applications between 8.5" and 9.5" and eventually be upscaled to different sizes such as 12.25" and up to 17.5" open holes and be deployed in geothermal wells with no changes to the design.

2.3 Organization of the Report

Welltec's organization is shown in the following Figure 1:

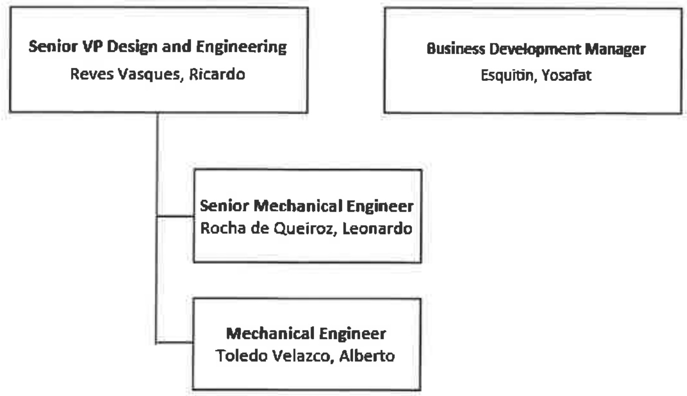

Figure 1: Welltec organization

The University of Oklahoma, which partnership with Welltec Inc., is organized as following:

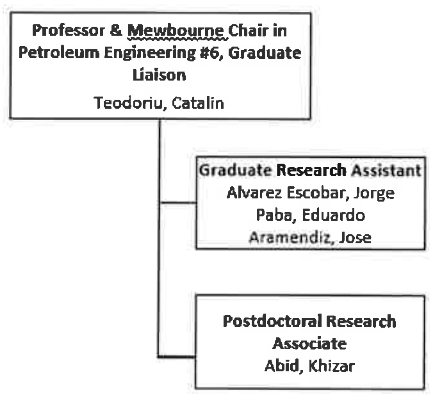

Figure 2: The University of Oklahoma organization

3. Methodology

3.1 Data Collection

Methodology: Scientific approach consisting of Gap Analysis, Specific Scope Field Tria Gap

Analysis: ✓Identify needs and risks

Specific Scope: ✓Small-Scale experiments

✓Designing and engineering

✓Modelling

✓Integration to a full-scale prototype.

✓Qualification & long-term testing

3.2 Analysis Techniques

The technical approaches / methods used to achieve the project objective(s) are the following:

- Geological and Finite Element Analysis (FEA) modeling.
- Engineering design.
- Scaled down rock and empirical testing under anticipated downhole temperature and pressure.
- Design of a unique full-scale experimental system to simulate the anticipated HPHT conditions in geothermal wells and test the manufactured tools.

3.3 Experimental Setup

The different experimental set-ups consisted of different equipment or systems, according to the objectives traced since the beginning of the project. Initially, a theoretical study was performed, with some numerical simulations and FEA. After these studies, thermoplastics and elastomers were tested under high-temperature conditions and cycles, with hardness measurements, as well as thermal properties of elastomers. These studies were conducted with a Shore D durometer and a Keithley 2400 meter with TPS-3 as shown in the following Figure 3:

Figure 3: Equipment used for sealing elements testing

After these studies were performed, small-scale experimentations followed. The tests were conducted in a geomechanical laboratory at The University of Oklahoma, in which a small-scaled packer was tested against a rock. The rock, placed in a testing chamber, was pressurized with the help of ISCO pumps, as well as confining pressure, which was applied through hydraulic jacks. Figure 4 shows the set-up used for this experimentation.

Figure 4: Set-up used to test the small-scale packers into the rock

These performed experiments comprehended the phase 1 of testing.

The phase 2 encompassed the development of a full-scale system prototype to test at the required 225 °C and 6,000 psi, with a test at 300 °C to further explore the limits of the whole system. For this reason, the downhole tools were manufactured in full-scale and sent to the laboratories at The University of Oklahoma, where the set-ups were built. Figure 5 shows the system developed at the Well Construction Technology Center facilities at The University of Oklahoma.

Figure 5: Full-scale set-up at The University of Oklahoma

The schematic of the inductions, which allowed the high-temperatures needed in the system, is shown as follows:

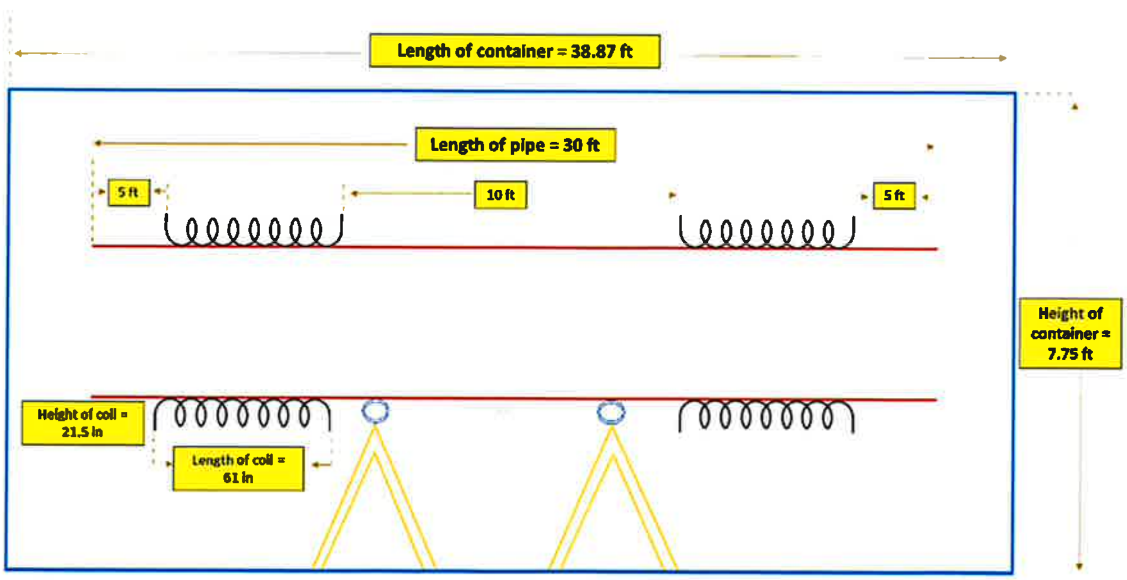

Figure 6: Schematic of induction in full-scale set-up

The system was capable of reaching the required high temperature to simulate the anticipated conditions that will be encountered in the FORGE wells. Figure 7 displays the casing used in the system, heated at 280 °C.

Figure 7: System heated at 280 deg C

The schematic of the full-scale set-up is shown in the following Figure 8:

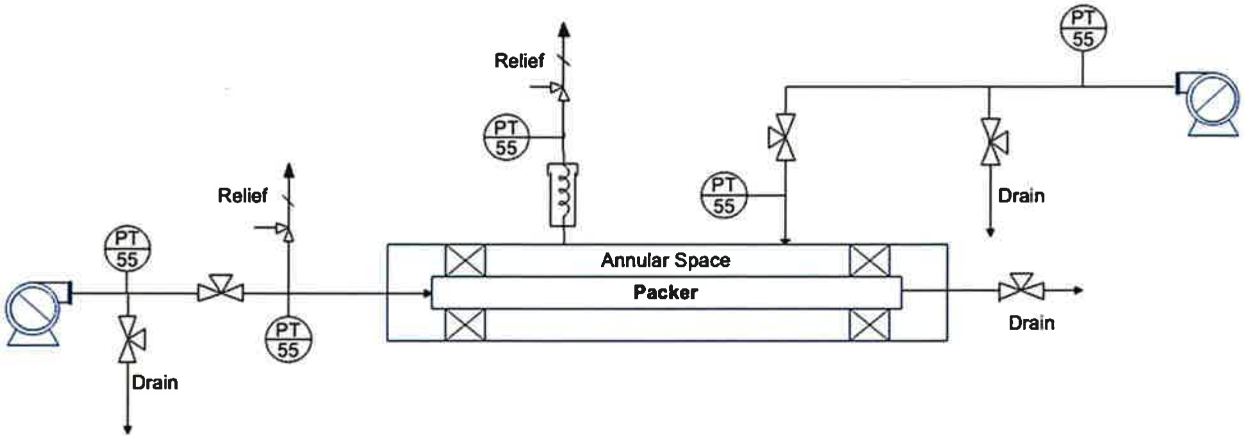

Figure 8: Schematic of full-scale set-up developed at The University of Oklahoma

The WFV was also tested in a full-scale set-up. The high temperatures were achieved using conductors, with some insulation jackets to avoid heat losses, as shown in Figure 9.

Figure 9: WFV with the conductors and isolation jackets for high temperatures

The pressurization of the system was provided by a pneumatic pump as shown in Figure 10, with the data acquisition performed in DasyLab.

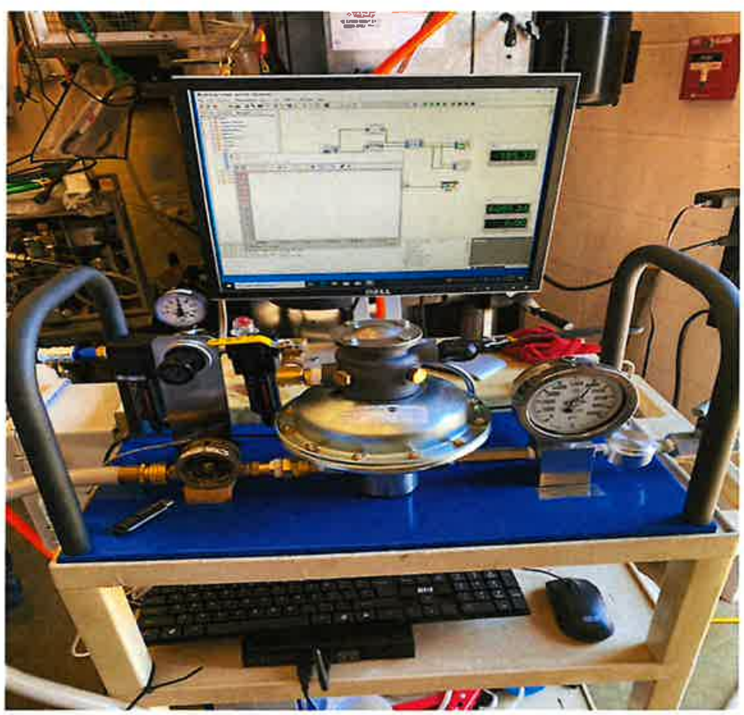

Figure 10: Pneumatic pump to pressurize the system

The WFV set-up used the same configuration as the SID (Figure 11), which was also tested with the same conductors to heat the system up to the desired high-temperature and pressurized with the same pump. However, in the case of the SID, an accumulator was implemented in the system configuration due to the small volume inside the tool. The schematic is shown as follows:

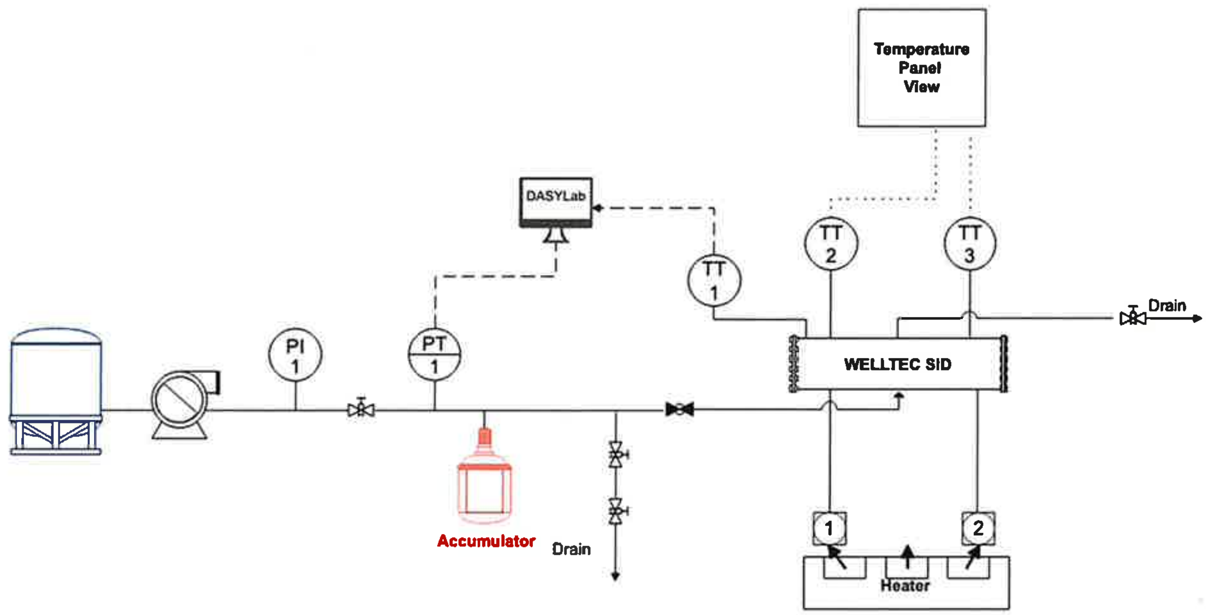

Figure 11: Schematic of SID test at The University of Oklahoma

4. Results and Discussion

4.1 Key Results

The key results throughout and after the development of this project are described as follows:

Seal design of the Stimulation Isolation tool (SID):

Initially, the design and testing of a tailored made seal assembly with no elastomeric seal component. This design had to overcome the following challenges:

i. High axial load during deployment.
ii. High radial gap due to manufacturing tolerances.
iii. Small form factor.

A seal system design by specialized seal companies was successfully tested. Based on the result of the test, a better and fine-tuned seal system mounted on a sliding sleeve system was redesigned and tested with 7,500 psi at room temperature with promising results. Two 7" sliding sleeves were manufactured with two versions of the elastomeric free seal system. Both designs were tested to 225 °C and 260 °Cand 6000 psi differential. Both designs passed the project requirements with the second version slightly superior performance (zero leak). Further testing was performed with 5 thermo-cycles to validate the design reliability. The temperature was increased to 300 C, with pressure of 4000 psi differential.

Theoretical study of thermo-cyclic resistance of the MEP:

The study addressed the following:

i. Plastic deformation (expansion) during deployment.
ii. High temperature and differential pressure.
iii. Hole rugosity.

The following tasks to address the challenges were performed:

1. Developed a MEP design with dual seal system – metal membrane and spring-loaded PTFE. The system was tested successfully. Differential pressure tests under the ISO14310 were performed in Q4 2022.
2. Design and manufacture seal and test system to enable testing with expansion, temperature, and pressure.
3. Five coupons with different sealing material were tested at high temperatures (275 °C) for material degradation evaluation. The tests were performed at OU. The coupons showed different hardness variances depending on their composition. One of the materials showed to have the less impact.
4. Testing of a downscaled seal design inside a test pipe was performed with 6" scaled down models. The tests were performed with differential pressure test at ambient and heated temperatures.
5. The downsized design of the MEP for the rock tests were manufactured and tested in the rock block, tests were successful to seal and create a hydraulic fracture on the rock block without propagating it beyond the MEP seals.

Numerical study of pressure build-up around the MEP during the hydraulic fracturing process:

The following challenges were experienced:

i. Downsizing the system while keeping similar stresses.
ii. Manufacturing to scale the downsized equipment and components.
iii. Creating geomechanical model to accurately reflect the MEP to rock interface.

The following tasks were completed to overcome those challenges:

a. A hybrid model using FLAC3D was created to simulate the interaction between the MEP and the rock.
b. Built a small-scale model adjusted for block size of existing rocks to validate the numerical input parameters that will be used for the geomechanical model.
c. Run elastic-plastic models for the MEP material to fully simulate its expansion.

Experimental study on the SID, FID, Sleeve Valve and MEP:

Once the theoretical and numerical study was performed, the experimental study took place. The following challenges were experienced with ongoing development to resolve them:

i. To test the Stimulation Initiation Device (SID), an accumulator was used due to the small volume inside. However, target conditions were achieved with and without it.

ii. When testing the MEP, there were difficulties in achieving target conditions. This was due to lack of enough air supply for pumps. A bigger compressor was attached to provide higher air supply and achieve target conditions.

The following tasks were completed:

a. The test on rock for the FID was performed in two patterns.
b. The Stimulation Initiation Device was successfully tested at 6,000 psi and 260 °C.
c. Two different sleeve valves, from different manufacturing material, were successfully tested under 6,000 psi and 260 °C conditions.
d. Three cycles of testing (three interrupted weeks per cycle) were performed on the MEP (long-scale), achieving conditions of 6,000 psi for pressure and 225 °C for temperature.
e. Ongoing long-term high temperature test on the new MEP design.

Figure 12 to 14 display the plots of the three cycles performed on the packer at HPHT, which were successfully completed.

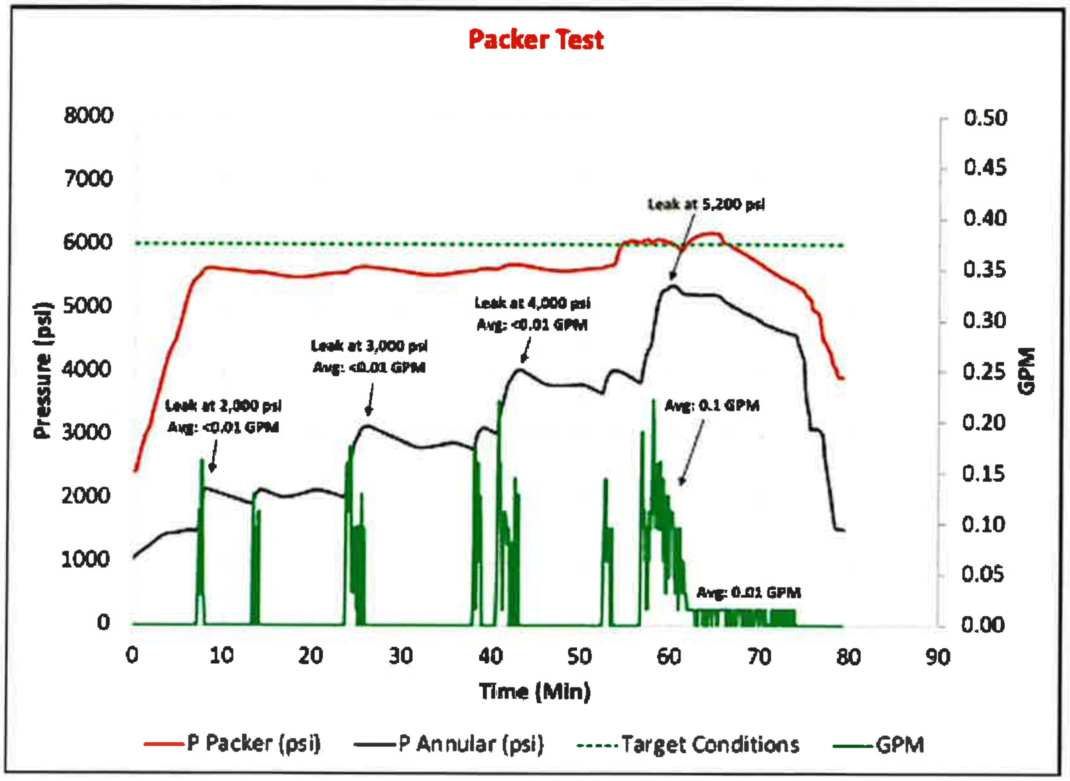

Figure 12: Plot of first HPHT cycle on full-scale system

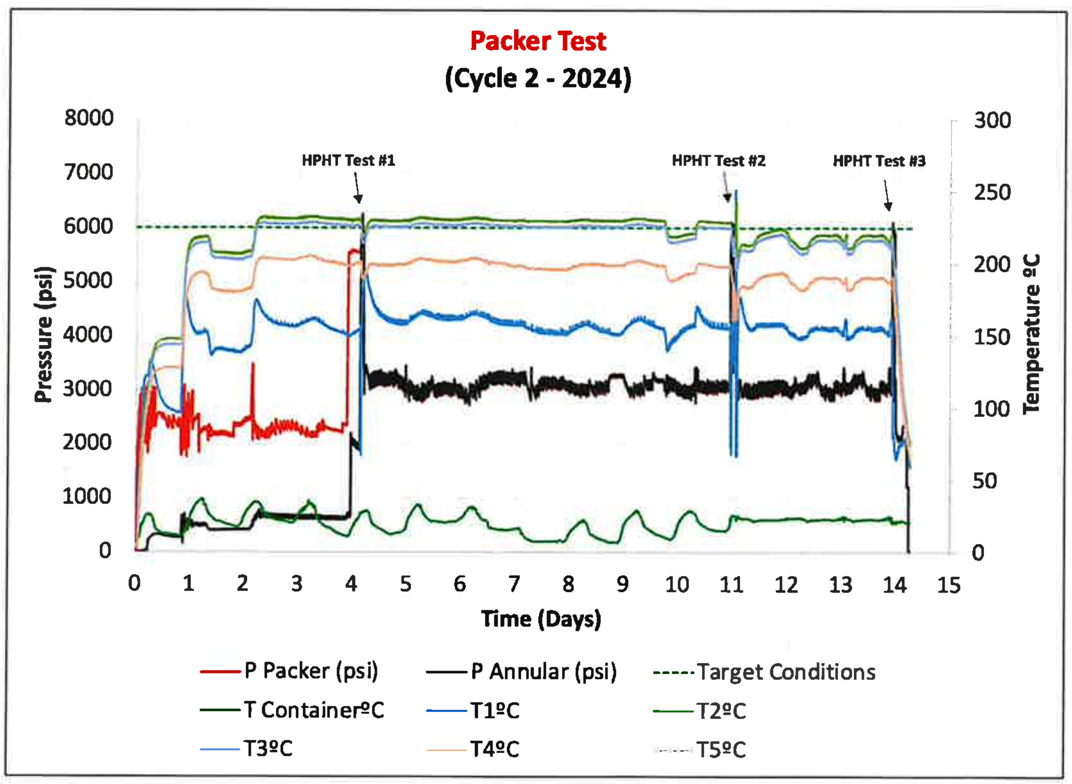

Figure 13: Plot of the second HPHT cycle on the full-scale system

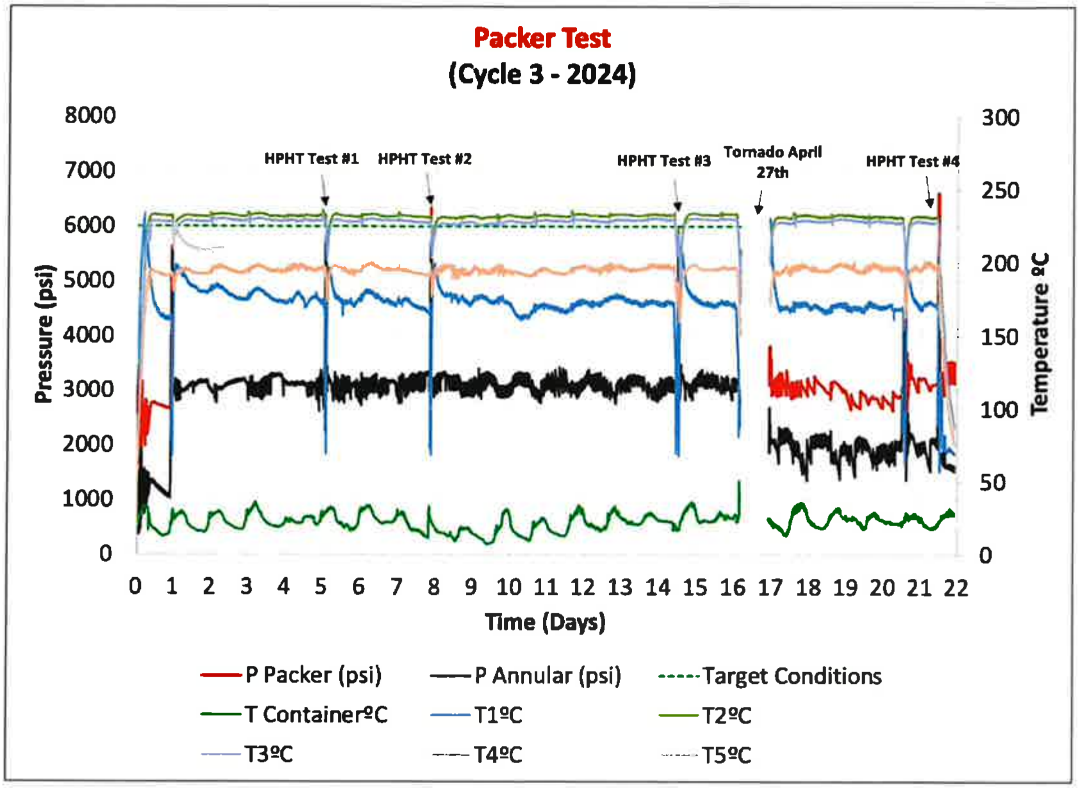

Figure 14: Plot of the third HPHT cycle on the full-scale system

After successfully testing the system three times, a fourth test, which was intended to explore the system limits was performed. The results are shown in Figure 15

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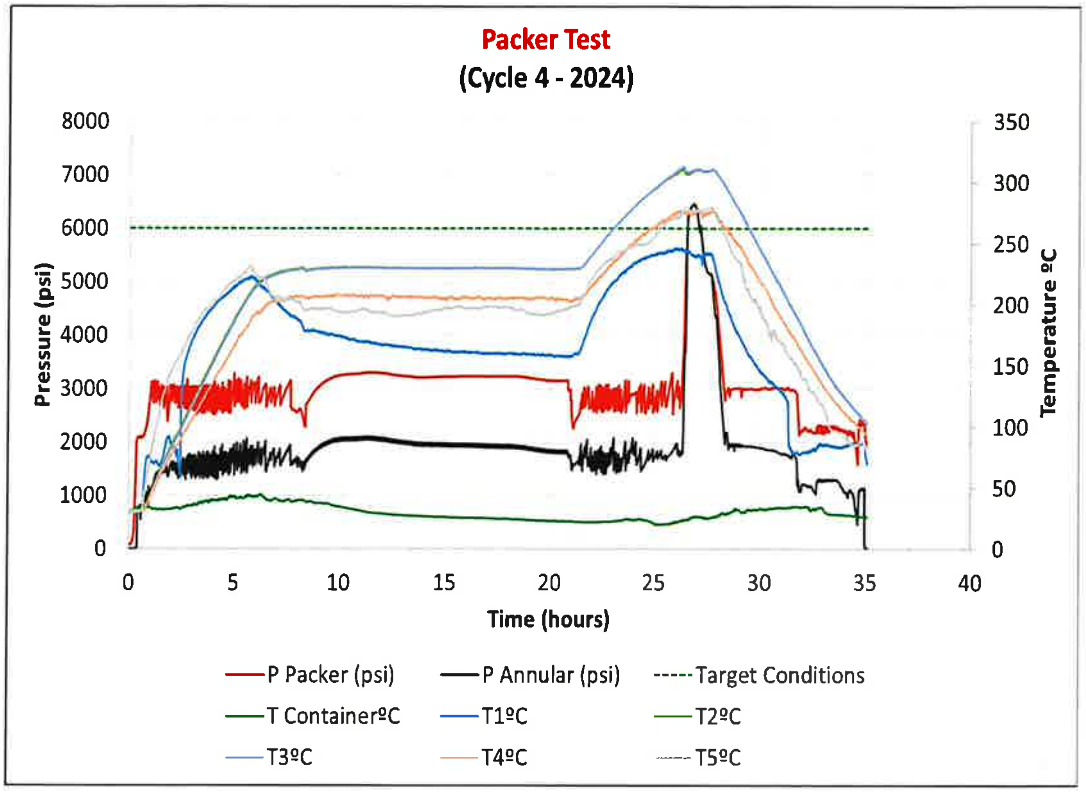

Figure 15: Plot of the successful fourth HPHT cycle on the full-scale system

As noticed in Figure above, not only the target conditions were achieved, but also the system proved to withstand 300 ºC.

4.2 Implications of Findings for Utah FORGE and EGS Technologies

At the end of the project, the Smart Stimulation System developed within this grant was fully tested to the expected conditions, demonstrated its functionality, with the following specific impacts on geothermal applications:

1. Enable a lower completion to provide effective zonal isolation during stimulation.
2. Allow effective multiple zone stimulations that will enable the implementation of Enhanced Geothermal Systems (EGS) in any size of well, in multiple locations, from district heating to power generation. It is non-intrusive to the existing well designs.
3. The testing setup it is the first of its kind focusing on long term safety and reliability evaluation of downhole tools under geothermal downhole conditions.

4. Allow for the individual stimulation and production thereby mitigating geological uncertainties
5. Enable the controlled initiation of fractures in an uncemented well segmented by annular barriers, leading to an important breakthrough in the industry for the feasibility of EGS.

4.3 Limitations/Lessons Learned

Some of the challenges encountered were related with the schedule and had impact in the original project plans. These are described as follows:

1. Availability of many materials such as casing, part for the heating unit, etc. has been a major hurdle. We researched alternative vendors and selected the best quotes to be on time and budget. For example, a new delivery date of components for the testing in August 2022 versus the original scheduled date of May 2022, delaying testing by 3 months, necessitating a request to extend the delivery of the milestones for Y1 to Q1Y2.
2. The hiring of students by OU was delayed by the extended period negotiating the terms and conditions. However, this did not affect the deliverables as the OU team was in place by August 2022.

Regarding the technical aspect, some limitations and challenges which lead to learned lessons were encountered and are described as following:

1. Challenges performing TIG welding of the springs of the scaled down version of the seal element with 0.4mm cross-section were encountered during manufacturing.
2. Due to the challenges obtaining acceptable compression levels of springs with relatively small cross-section, it was replaced by a small-sized O-ring in the scaled down MEP.
3. Damages occurred to the non-elastomeric sealing system during assembly.
4. Downscale assembly was affected by hardening during machining.
5. Compressed timeline of testing coupons resolved by shortening the test cycles.

6. When the MEP test started, the pressure target in both annular space and packer was difficult to achieve due to the air supply in the system. A higher air compressor was required.

5. Conclusions and Recommendations

5.1 Summary of Conclusions

- Successful testing of scaled down system and seal materials.
- After test of the packer in rock with the FID, it was confirmed that the FID system is not required. FID test conducted did not create a fracture on the rock block.
- Sliding sleeve tests (WFV) were completed. The target conditions were reached.
- SID tests were completed. The target conditions were reached.
- Extended tests in the MEP have been performed, with operational targets confirming its suitability to Forge operation. Target conditions were reached in three cycles of testing.
- A fourth test to explore system limits was performed, successfully reaching 300 °C and 6,000 psi.
- Ongoing test on the enhanced MEP design with dual seal system.

5.2 Recommendations for Future Work

Even though the technology has not been able to be trialed at FORGE. We have manufactured the components to assemble four MEP's and two WFV for future deployments.

6. Tables

A. Uploaded GDR Datasets/Reports List

Table 1: Summary of GDR datasets

No.	*Name*
1	Devices Suitable for Sectional Isolation Along Both Cased and Open-hole Wellbores - Geomechanical Packer Formation Model Interaction
2	Devices Suitable for Sectional Isolation Along Both Cased and Open-hole Wellbores - Pipe Preparation Report
3	Devices Suitable for Sectional Isolation Along Both Cased and Open-hole Wellbores - Large-scale Test Setup
4	Devices Suitable for Sectional Isolation Along Both Cased and Open-hole Wellbores - Materials Testing Report

Multiple reports have been uploaded to GDR.

B. Conferences List

Table 2: Summary of work presented in conferences

No.	*Name*	*Conference*
1	GRC Paper 222 – Ultra High Temperature Isolation System for EGS Stimulation	*GRC*
2	GRC Paper 266 – Lower Completion Systems for Effective Stimulation of Sedimentary Rocks	*GRC*
3	A discussion about the new methodology to test downhole tools for geothermal well applications	*DGMK Spring Conference*
4	GRC Paper 1526046 - Laboratory Testing of a Novel Packer Instrumentation for EGS Applications	*GRC*

5	GRC Paper 1517742 - High Temperature testing of downhole nonmetallic materials used for sealing annular space	*GRC*
6	Design and Experimental Validation of a Unique Geothermal Downhole Valve for FORGE Project	*Stanford Geothermal Workshop*
7	GRC Paper 1776904 – Zonal Isolation Concept for FORGE Geothermal Wells	*GRC*
8	GRC Poster 1776919 - Testing a novel high-temperature stimulation initiation device for FORGE wells	*GRC*
9	A Novel Setup Facility for Geothermal Downhole Tools Testing and Qualifying	*Stanford Geothermal Workshop*
10	High-Pressure and High-Temperature Testing Protocol of Isolation Tools with Focus on Geothermal Wells	*Stanford Geothermal Workshop*
11	Testing a Novel High-Temperature Stimulation Isolation Device for FORGE Wells – GRC Poster 2024	*GRC*

7. References

Appendices

- 1-2410 Welltec Inc - Yosafat Esquitin Year 1
- 1-2410 Welltec Inc - Yosafat Esquitin Year 2
- 1-2410 Welltec Inc - Yosafat Esquitin Year 3

A. *Data Tables*

Find in Appendices

B. *Additional Figures*

Find in Appendices

C. Supplementary Documents

Additional information can be provided upon mutual agreement.