PROCEEDINGS, 50th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 10-12, 2025
SGP-TR-229

A Novel Setup Facility for Geothermal Downhole Tools Testing and Qualifying

Eduardo Andres Paba Vega[1], Jorge Andres Alvarez Escobar[1], Jose Jorge Aramendiz Pacheco[1], Khizar Abid[1], Alberto Toledo Velazco[2], Yosafat Esquitin[2], Ricardo Reves Vasques[2], Ramadan Ahmed[1] and Catalin Teodoriu[1]

[1]Mewbourne School of Petroleum and Geological Engineering, The University of Oklahoma, Norman, OK, USA

[2]Welltec Inc

eduardo.paba@ou.edu

Keywords: Utah FORGE project, Zonal isolation tools, High-Pressure, High-Temperature (HPHT) testing, Geothermal testing facility.

ABSTRACT

Unlike many renewable sources such as solar and wind, which rely on favorable weather conditions, geothermal energy is not influenced by these factors. It stands out as a unique non-conventional energy source that remains unaffected by climate change and is available in many parts of the world. Geothermal energy will play a crucial role in achieving the net zero targets set by various countries. As a result, significant focus is currently placed on advancing geothermal energy and addressing the challenges associated with its use. In that respect, this paper specifically addresses the challenges associated with the testing of downhole tools, particularly packers, which are essential for stimulation, zonal isolation, and casing protection in geothermal applications. This paper describes the upgraded setup specifically designed for High-Pressure, High-Temperature (HPHT) testing of the packer developed by our research partner for the Utah FORGE project. This setup can provide a differential pressure in the annulus and packer of up to 10,000 psi while maintaining a temperature above 350°C. Currently, no existing testing facilities offer the capability to replicate such harsh conditions for packer testing for geothermal qualification. This makes the given setup a significant advancement in geothermal technology, as it addresses a critical gap in the ability to thoroughly evaluate packers under the demanding conditions they will encounter in a real geothermal application. By providing these rigorous testing conditions, the setup ensures that packers can be thoroughly tested for their sealing capability and overall durability, which is essential for the successful implementation and operation of geothermal energy systems. This paper will show the details of the testing setup that makes this a uniquely geothermal testing facility.

1. INTRODUCTION

As several countries have moved toward net zero and pledged to attain it by 2050, geothermal energy will be an important tool for achieving this target. Geothermal energy is defined as heat from the Earth's subsurface. Due to the geothermal gradient, temperature rises due to the increase in depth. The geothermal energy resources can be classified in three categories: Low enthalpy (below 212 °F or 100 °C), medium enthalpy (between 212 °F or 100 °C and 302 °F or 150 °C), and high enthalpy (higher than 302 °F or 150 °C) (McClean and Pedersen, 2022). The working fluid gathered from the geothermal well can be used in a different applications (domestic and power generation) depending on its temperature. Geothermal wells are often compared to HPHT wells because of the drilling similarities because of the temperature and pressure conditions. The HPHT conditions are present in wells with pressures between 15,000 to 20,000 psi and temperatures between 350 °F (177 °C) to 450 °F (232 °C), whereas the ultra-HPHT is considered when the pressure is higher than 20,000 psi and the temperature higher than 450 °F (232 °C). Therefore, HPHT wells and geothermal wells share downhole tools such as packers, because the conditions are similar (Abid et al., 2022). Figure 1 depicts the range of pressures and temperatures under HPHT and ultra-HPHT conditions. Geothermal reservoirs generally exist in HPHT conditions (Baena Velasquez et al., 2024); if the temperature exceeds 763 °F (406 °C) and 4,322 psi. Such geothermal systems are considered supercritical.

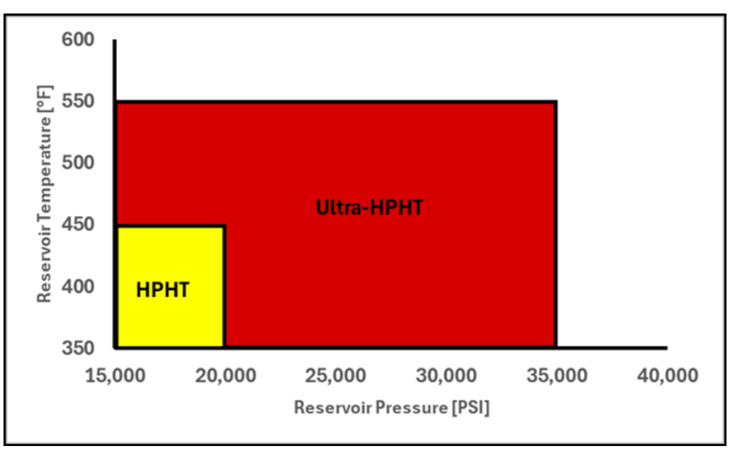

Figure 1. Range of pressures and temperatures under HPHT and ultra-HPHT conditions. (Modified from Doane et al., 2013)

Drilling and completion of geothermal wells are crucial phase in the development of a geothermal project (Barbier, 2022). In this context, packers are fundamental elements in geothermal applications. They are usually made of one or several elastomeric and metallic sealing elements, which are inflated or expanded to provide the isolation of the annulus of the wellbore, casing or tubing. Packers are essential for stimulation, zonal isolation, and casing protection. The challenges for the application of the packers in geothermal wells include the proper selection of materials and the reliability to withstand harsh environments, particularly under HPHT conditions. For the assessment of packers, the international standards ISO 14310:2008 and API Specification (Spec) 11D1, provided by the International Organization for Standardization (ISO) and the American Petroleum Institute (API), outlines the information about the packer selection, manufacture, use, testing, and minimum criteria to meet for supplier or manufacturer, in order to declare conformity with the requirements of the standards (International Organization for Standardization [ISO], 2008). There are seven standard validation grades, each with a set of requirements to satisfy the needs of the user application. The validation grades range from V0 to V6, whereas the rigorousness of validation testing decreases as the grade number increases. The setup described in this paper has been used for validation grade V6, meaning that the validation procedure was established by the supplier or manufacturer.

2. HPHT VALIDATION TESTS

Ali et al. (2023) validated an open-hole metal expandable packer that was deployed in a geologically complex field, characterized by various shallow horizon targets, isolated blocks, compartments, faults, and fractures. Because of the complexity and importance of the isolation tool, a testing and qualification process was performed before the deployment to confirm that the metal expandable packer could overcome any potential challenges. The packer was tested and qualified to ISO 14310 V3 and ISO 14310 V0, in five test phases summarized in Table 1.

Table 1. Test stages during packer qualification.

Phase	Test
1	Expansion with 5000 psi at 90 °C
2	Axial Loading with 0 – 5000 psi at 150 °C with −100 – 400 klbs
3	Axial Loading with 0 – 5000 psi at 25 °C with −100 – 400 klbs
4	Axial Loading with 1000 – 5000 psi at 150 °C with −170 – 360 klbs
5	Axial Loading with 1000 – 5000 psi at 25 °C with −80 – 300 klbs

The packer passed all the axial load tests with differential pressures up to 5000 psi at 150 °C and 25 °C. Because of the acceptance criteria of ISO 14310 V3 and ISO 14310 V0, the hold period for passing the tests is 15 minutes after stabilization.

Roy et al. (2022) designed a geothermal packer, which aligns with the design of a conventional HPHT packer, with a triple stack of elements and multiple layers of anti-extrusion rings surrounding them. The elements feature a composite structure consisting of an elastomeric core, insulated by a material with ultra-low thermal conductivity, and sealed within a flexible skin made of a grain boundary-engineered nano-metallic material. The components of the packer that will be exposed to direct contact with fluids are constructed from nanocrystalline CRA alloy(s) in order to improve strength, thermal stability, and corrosion resistance. Due to the packer design, it is rated as 15K psi for differential pressure and 750 °F (400 °C) for external environment temperature, limiting that the temperature of the elastomer does not surpass 400 °F (204 °C) due to the insulation. It is important to mention that assembled packer was pending qualification by the date of publication, while the subcomponents testing was undergoing. The test equipment for the verification and validation is given in Table 2.

Table 2. Test equipment for validation from Roy et al., 2022.

Item Name	Description
Pressure Vessel	AUTOCLAVE CRA: 16 ksi Maximum Working Pressure (MWP)

Temperature Controller	PID, ITC-106, −100 to 2300 °F
Ceramic Heater Band	TEMPCO, max temperature 900 °F
Pressure Gauge	Additel GP15K, 0.05 Accuracy FS%; Data Logging
Pump	Haskel, Max Pressure: 50,000 psi (Hydrostatic – Liquid)
Air Compressor	California Air Tools, 5510SE

Stair and Makowiecki (2016) detail a validation method for a HPHT packer used in cementing applications, while challenging the current industry standards for packer validation. The philosophy behind this validation method is that the packer is run in hole (RIH) prior to testing in the lab. They claim that testing a packer that has previously been deployed and set in a real well environment accurately reflects its performance under actual field operating condition. This is because the standard test does not consider the operating conditions in a cementing application, including high RIH speeds, high circulation rates, and suspended debris in the fluid. These conditions can cause issues, for example pre-set of the packer or debris stuck in the annular space between the elastomer elements and casing.

The test procedure followed by Stair and Makowiecki was to RIH the packer inside a 13 3/8-in. 72-lb/ft casing with 2,800 ft of 9 5/8-in. 47-lb/ft casing hanging below the packer. The casing string was RIH to total depth (TD), subsequently the packer was reciprocated for a total distance of 7,500 ft at speeds up to 5 ft/sec, aiming to simulate running casing. During the operation, a water-based drilling mud (14 ppg) was utilized. The next step for the validation was to circulate 3,000 bbl of mud at a rate equal to 17 bbl/min for 3 hours with the packer located in the assembly for a further setting and pressure test. Following this, the process continued with the packer setting, which was performed in 8 stages of 5 minutes each, reaching a pressure over 3,400 psi before confirming that the packer and slips are set. Finally, after heating for 4 hours in a test chamber while reaching 300 °F (149 °C) the packer underwent the pressure test. The summary of the pressure test is illustrated in Table 3.

Table 3. Pressure test procedure after Stair and Makowiecki (2016).

Phase	Time	Description
1	4 hours	Heating at 300 °F (149 °C)
2	-	Pressurize mandrel with water to 5,000 psi - 6,000 psi
3	16 minutes	Pressurize the annulus above the element with N_2 to 11,500 psi
4	-	Depressurize to 0 psi at different rates
5	16 minutes	Pressurize the annulus below the element with N_2 to 11,500 psi
6	8 hours	Hold pressure at 11,500 psi
7	-	Depressurize to 0 psi at different rates

From the above studies, it can be noticed that none of the test setups is designed specifically for geothermal testing. The University of Oklahoma (OU) developed an innovative setup tailored for geothermal downhole tool testing and qualification, with a particular focus on packers. This setup addresses the existing limitations in the HPHT setups and the international standard guidelines for packer testing and qualification, offering a reliable method to demonstrate that the packer will operate in geothermal conditions. The detail of the setup is given in the following section.

3. SETUP DESCRIPTION

The OU testing setup consists of a packer placed inside a casing, surrounded by induction coils controlled by a power induction unit. To simulate the high-pressure conditions of the geothermal wells, two pneumatic pumps are utilized to increase the differential pressure between the packer and the annular space. The heating of the testing system was conducted with the help of the induction unit, which replicates the high-temperature geothermal environment. This setup is the first of its kind to be used continuously for three weeks across four different cycles. The equipment and function are described in the following sections:

3.1 Heating System

The principle of induction heating is to provide contactless, fast, and efficient heating of conductive materials. An induction unit is used to supply an alternating voltage to an induction heating coil. The coil generates an alternating magnetic field, in which the pipe (and packer) is placed. The heating of the element is done by means of two physical phenomena: eddy currents and magnetic hysteresis [Brown et al., 1947, Lucia et al., 2013]. Eddy currents oppose the magnetic field applied to the pipe, and they produce the heating by the Joule effect, whereas magnetic hysteresis (delay in the magnetization-demagnetization of the pipe) creates energy losses that are converted into heat. To remove heat from the coils and avoid overheating, a mix of water and glycol flows through the coils to remove the excess of heat and maintain an optimal operational temperature. Subsequently, the heated water goes through an industrial chiller to cool down and repeat the cycle. Figure 2 represents a schematic of the testing setup inside the container. Whereas Figure 3 shows the heating setup used in the testing system.

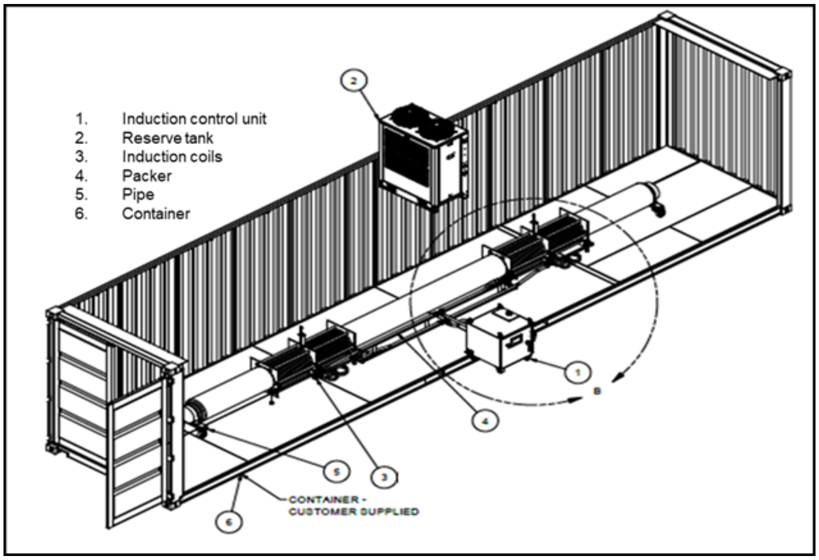

Figure 2. Test equipment schematic.

Figure 3. Induction unit (left) and coil system (right)

3.2 Pressure System

The other part of the setup is located in the operational container, where the test engineer operates the system and analyzes results in real time using DASYLab software, which collects data from the pressure and temperature gauges of the system. The operational container accommodates two pneumatic pumps, the data recording system, and a Closed-Circuit Television (CCTV) to monitor the test area. Two air compressors are used to power the pneumatic pumps located in the operational container. The pumps transport water to the packer and the annular space through stainless steel tubing lines which are positioned outside the containers. Figure 4 presents the pumps in the operational container.

Figure 4. Pumping unit configuration.

3.3 Test Methodology

Figure 5 summarizes the steps taken during the validation test, including multiple cycles if necessary.

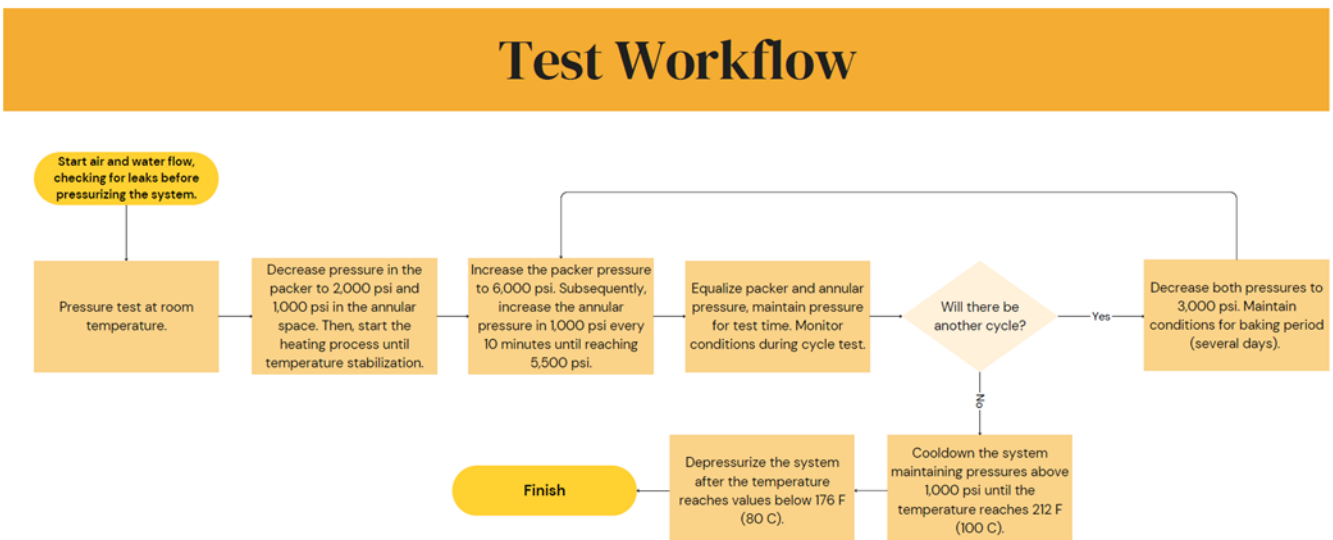

Figure 5. Workflow overview of the test procedure.

Alvarez et al. (2024) presented the testing of the isolation tool, which was conducted using the setup described in the previous section. Additionally, the paper shows the results of one of the cycles performed on the isolation tool, where it was heated to 437 °F (225 °C) with a differential pressure of 6,000 psi. A flow valve presented by Baena Velasquez et al. (2024) was also tested in the same facilities and under similar conditions. Figure 6 depicts the pressure and temperature ratings of the setup.

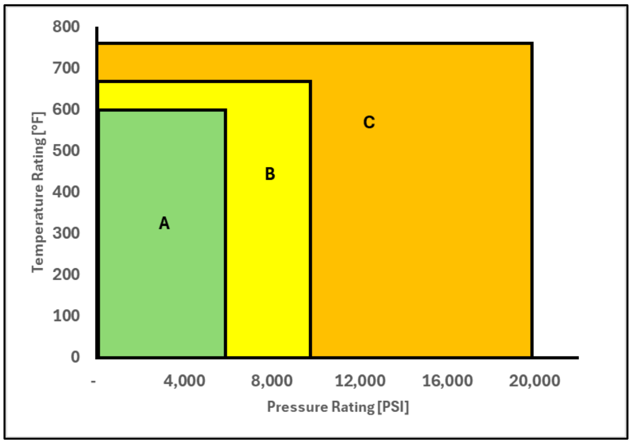

Figure 6. Temperature and pressure ratings for the setup. A) Isolation tool ratings during the test. B) Current ratings of the setup. C) Future work ratings for the setup.

4. SETUP EVOLUTION

Initial setup used during the first long-term test cycle, two pneumatic pumps were utilized to circulate water through separate 1/4" lines to the packer and annular space. However, due to the separation of these lines, it was challenging to balance the pressures in the annular space and the packer as required by the test. Figure 7 shows the original schematic for the setup.

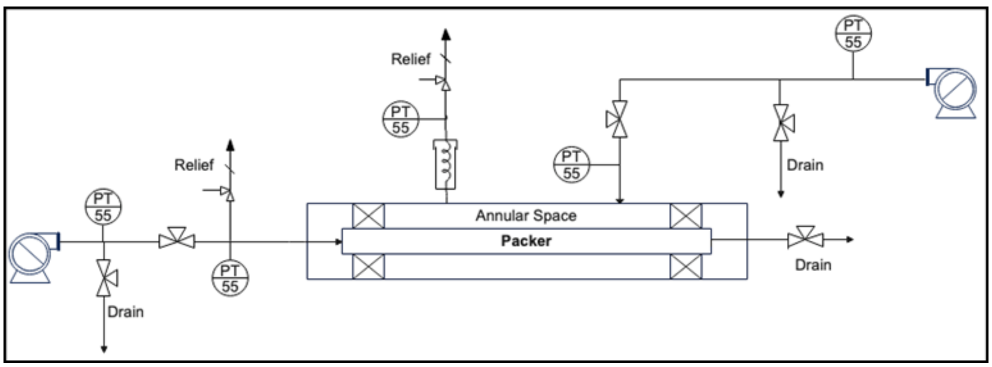

Figure 7. Original setup schematic.

For the second long-scale test cycle, the setup was modified by adding a 1/4" line to facilitate pressure equalization between the packer and the annular space. This modification allowed both pumps to be used interchangeably for either the packer or the annular space. Figure 8 shows the schematic of the setup used during the second and third cycles of the long test.

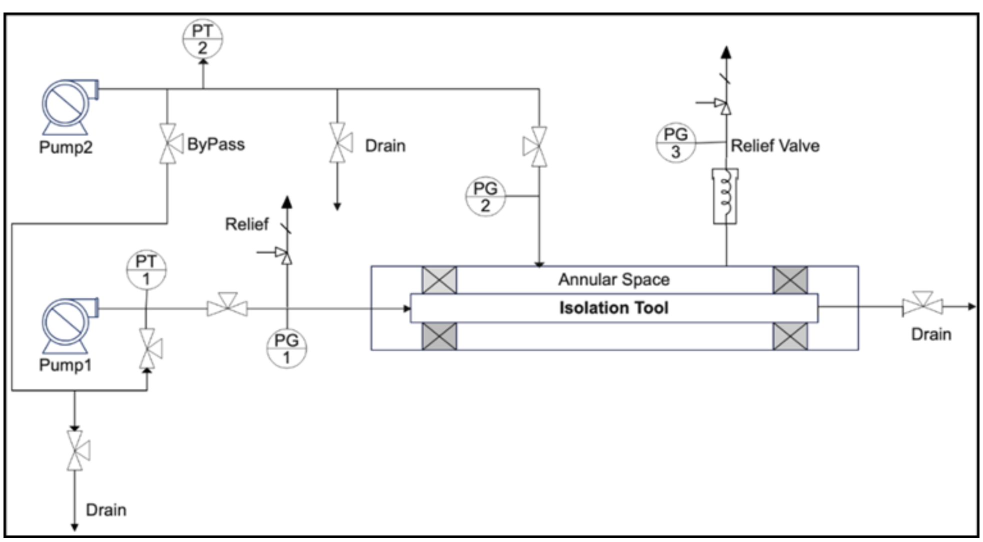

Figure 8. Schematic of the updated setup.

During the first three long-scale test cycles, the pumps were mounted separately on different tables, and the drainage process was conducted using a separate panel as shown in Figure 9.

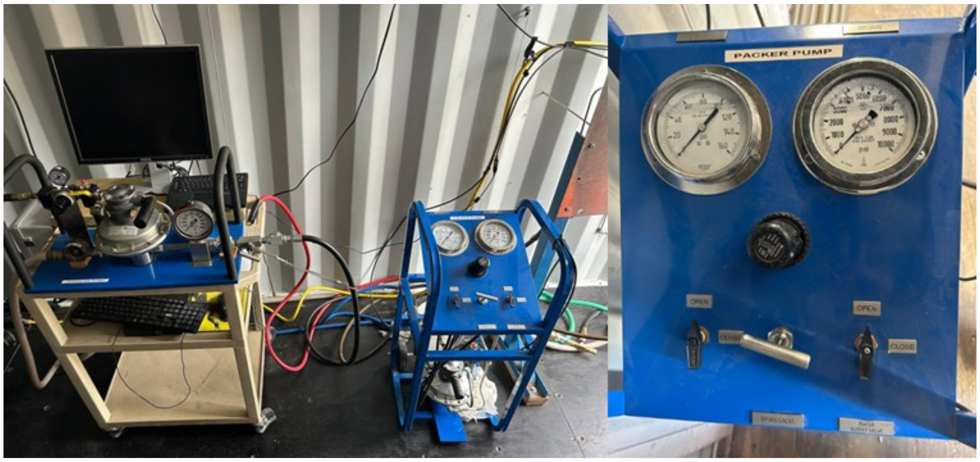

Figure 9. Pump arrangement used in the first three test cycles.

For the fourth long-scale test cycle, a new board was introduced to facilitate valve manipulation during the tests. This allowed better control of the air flowing to the pumps, the flow to the lines, and the water rate. Figure 10 illustrates the updated pump arrangement and new board.

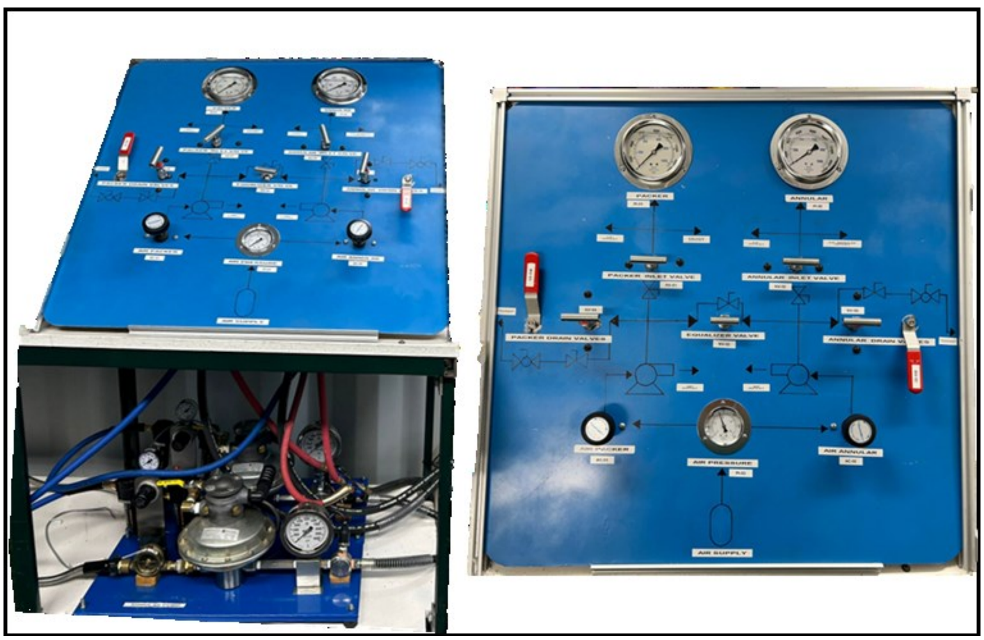

Figure 10. New valve and pump configuration.

In addition to the board design, another improvement for the setup was the installation of a new 3/8" flow line to the annular space in addition to the 1/4" line that was already installed. This modification increases the flow to the annular space, helping achieve the target differential pressure. Figure 11 presents the latest schematic of the setup.

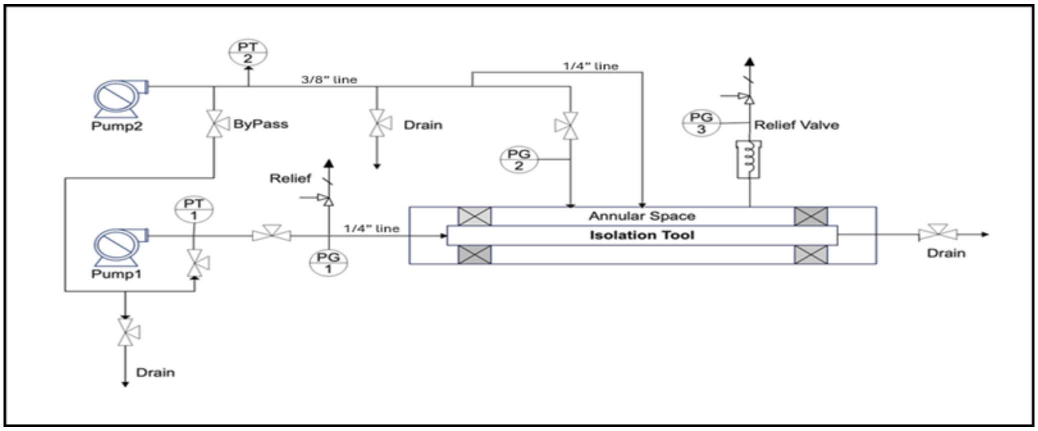

Figure 11. Latest schematic of the setup.

5. DISCUSSIONS

Even though some of the qualification tests performed on packers are modified tests when compared to the industry standards, some of them fall short regarding the testing time; this is because the minimum requirement for these tests is just a 15-minute hold period and only one cycle. Considering that thermal cycles should be considered in geothermal wells, four different long-term cycles were successfully performed on the same packer continuously for 6 weeks using the setup previously described in this paper. The setup allows for testing temperatures in the range of 660 °F (350 °C) and differential pressures up to 10,000 psi in the annulus and packer. These conditions exceed those of the downhole tools in the Utah FORGE project, making this the first setup to perform such tests. Furthermore, the industry standards do not fully embrace the harsh geothermal conditions to which a packer is exposed and thus creating the need for a new standard for geothermal downhole tools (Abid et al., 2022).

6. FUTURE WORK

Future improvements are being considered for the setup, including performing tests involving axial forces and a pressure range between 15,000 to 20,000 psi while maintaining temperatures around 750 °F (400 °C).

7. CONCLUSIONS

From this paper, it can be concluded that the OU testing setup is more than capable of replicating the HPHT conditions in a geothermal well by delivering a differential pressure between the packer and the annulus of up to 10,000 psi while maintaining a temperature above 660 °F (350 °C). This setup also factors in thermal cycles and testing for at least 6 weeks continuously, making it a unique geothermal testing and qualifying facility. The constant evolution of the setup improves the quality of the test, which is observed in the last update to the setup, which allowed better manipulation of the valves used during the test. This advancement allowed better control of the differential pressure.

ACKNOWLEDGMENT

We would like to thank the University of Oklahoma for providing the facilities at the Well Construction Technology Center and our research partner, Welltec Inc., which designed the isolation tool used in the setup and for all the help and support during the elaboration of this paper.

REFERENCES

G. H. Brown, C. N. Hoyler, and R. A. Bierwirth, Theory and Application of Radio-Frequency Heating. New York,: Van Nostrand, 1947.

Oscar Lucia, Pascal Maussion, Enrique J. Dede, Jose Burdio. Induction Heating Technology and Its Applications: Past Developments, Current Technology, and Future Challenges. IEEE Transactions on Industrial Electronics, Institute of Electrical and Electronics Engineers, 2013, vol. 61 (n°5), pp. 2509-2520. ff10.1109/TIE.2013.2281162ff. ffhal-01107267v2

Ali, Syed Muhammad, Nwosu, Emmanuel Onyema, Farsi, Nasser, and Kevin Wood. "Successful Deployment of Metal Expandable Annular Sealing Systems in High Extended Reach Wells." Paper presented at the Middle East Oil, Gas and Geosciences Show, Manama, Bahrain, February 2023. doi: https://doi.org/10.2118/213756-MS

Roy, Ting, Ben Naceur, Kamel, Singh, Manjinder, Markel, Daniel, Harp, Leonard, Ardic, Hifzi, Wilkinson, Christian, and Indranil Roy. "Design of a 750 °F, 15 K packer for Enhanced Geothermal Systems, Supercritical CO2 - Sequestration and SAGD: Energy Transition Through Technology Synthesis." Paper presented at the Offshore Technology Conference, Houston, Texas, USA, May 2022. doi: https://doi.org/10.4043/31895-MS

Stair, Todd , and Gary Makowiecki. "Improved Validation Method for Annular Casing Packers." Paper presented at the SPE/IADC Middle East Drilling Technology Conference and Exhibition, Abu Dhabi, UAE, January 2016. doi: https://doi.org/10.2118/178212-MS

Abid, K., Sharma, A., & Teodoriu, C. (n.d.). Do We Need a New Standard for Geothermal Downhole Tools?

Barbier, E. (2002). Geothermal energy technology and current status: an overview. In Renewable and Sustainable Energy Reviews (Vol. 6). www.elsevier.com/locate/rser

McClean, A., & Pedersen, O. W. (2022). Who Owns the Heat? The Scope for Geothermal Heat to Contribute to Net Zero. Journal of Environmental Law, 34(2), 343–351. https://doi.org/10.1093/jel/eqab038

Abid, K., Sharma, A., Ahmed, S., Srivastava, S., Toledo Velazco, A., & Teodoriu, C. (2022). A Review on Geothermal Energy and HPHT Packers for Geothermal Applications. In Energies (Vol. 15, Issue 19). MDPI. https://doi.org/10.3390/en15197357

Alvarez Escobar, Jorge & Velazco, Alberto & Abid, Khizar & Esquitin, Yosafat & Vasques, Ricardo & Queiroz, Leonardo & Teodoriu, Catalin. (2024). Zonal Isolation Concept For FORGE Geothermal Wells.

International Organization for Standardization. (2008). ISO 14310:2008 - Petroleum and natural gas industries-Downhole equipment-Packers and bridge plugs (2nd ed.). https://www.iso.org/obp/ui/en/#iso:std:iso:14310:ed-2:v1:en

Doane, J., Deng, G., Collins, S., Anderson, G., & Shyu, G.-D. (2013). IPTC 16852 Pushing the Boundary of Ultra-HPHT Completion Technology: The First 20,000 psi, 470°F Permanent Production Packer for As-Rolled Casing. http://onepetro.org/IPTCONF/proceedings-pdf/12IPTC/All-12IPTC/IPTC-16852-MS/1558983/iptc-16852-ms.pdf