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High-Pressure and High-Temperature Testing Protocol of Isolation Tools with Focus on Geothermal Wells

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1 ABSTRACT

The rise in the world population is directly proportional to the increase in energy demand; hence, in the coming future, energy production from fossil fuel and renewable sources will be utilized to meet the rising energy demand. Renewable energy needs to increase its footprint significantly to achieve the net zero goal by 2050, as agreed on in the Paris Agreement by the USA, China, India, and the European Union. In that respect, geothermal energy will be an important source, as it is the only renewable energy independent of the weather conditions and remains in operational mode 98% of the time.

Extracting the heat from the earth's interior comes with challenges; a common challenge to downhole tools used in geothermal wells is to withstand harsh downhole conditions, such as the High-Pressure, High-Temperature (HPHT), corrosive fluids, and high flows. Without technologies capable of operating in these conditions can compromise the success of a project.

One of the downhole technologies is the zonal isolation systems, for which Welltec has designed a system specifically for the UTAH FORGE (Frontier Observatory for Research in Geothermal Energy) project. The main features of this system are long-term reliability under geothermal downhole conditions and high-pressure high-temperature resistance. To test this system at HPHT conditions (350°C and 10,000 psi) a dedicated testing facility has been designed and built at the University of Oklahoma. The testing setup allows for the tools to be tested continuously for three to six weeks at low costs. This study will give an insight into the set-up build to test this tool, the HPHT conditions upon the testing, and the procedure performed.

2 INTRODUCTION

Geothermal energy has gained increasing importance in lowering CO2 emissions. In recent years, the oil and gas industry has shifted its focus toward geothermal energy and other renewable sources (Parra & Karami, 2024). For the United States, geothermal energy is important in energy generation, where geothermal sources produce 0.4% of the total energy (Sanni, 2024). The geothermal project can either be started from scratch by drilling new wells in the field, or an old and abandoned oil or gas field can be retrofitted for the geothermal application. Either way, it can benefit communities by providing green and low-cost energy (Hessinger et al., 2024).

Even though the oil and gas industry has similarities with the geothermal industry regarding how wells are drilled, completed, or produced, there are still many differences that require the geothermal industry to pay extra attention to the practices currently performed for this industry. One of the main differences between these two industries is the high-pressure and high-temperature (HPHT) conditions under which geothermal wells are drilled (Abid et al., 2022). Therefore, the downhole tool must be adequately tested at the simulated in situ pressure and temperature conditions before deployment in the geothermal well. This paper focuses on a testing protocol for a zonal isolation tool designed by Welltec for the Utah FORGE project. This paper will explain how the tool was installed and tested over four thermal cycles (6 weeks of testing) under HPHT conditions (up to 6,000 psi and 310ºC). These tests were performed in the University of Oklahoma's high-temperature facilities developed as part of the UTAH FORGE project.

3 TESTING PROTOCOL

A testing protocol was developed to meet the requirements of the Utah FORGE project, and a unique high-temperature facility was constructed at the University of Oklahoma to conduct HPHT tests on downhole tools. The testing setup consists of pumps (to apply pressure inside the tool and in the annular space), pressure and temperature transmitters, relief valves to ensure safety from overpressure, induction heating devices to increase temperature, and a casing where the isolation tool was installed for testing, this setup can increase the temperature and pressure to 350 ºC and 10,000, along with the continuous monitoring of the system. Figure 1 illustrates the schematic of the testing setup in which the isolation tool is placed, while Figure 2 presents the testing protocol used for expanding and testing the isolation tool. It is important to note that, under the conditions for which the isolation tool was designed during the HPHT test, it was required to limit leaks to no more than 0.5 GPM. A similar testing setup was developed to evaluate smaller tools under HPHT conditions; the setup followed the same concept and was successfully used to test flow valves and stimulation initiation devices (VELÁSQUEZ et al., 2024).

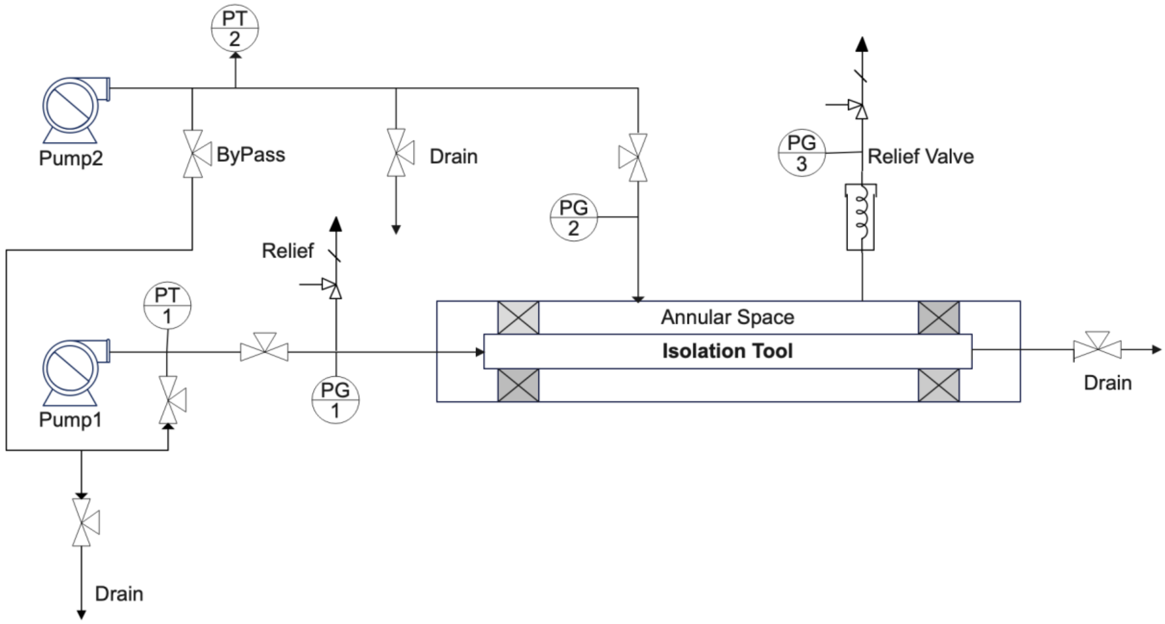

Figure 1: Schematic diagram of the long-scale testing setup (Alvarez Escobar et al., 2024)

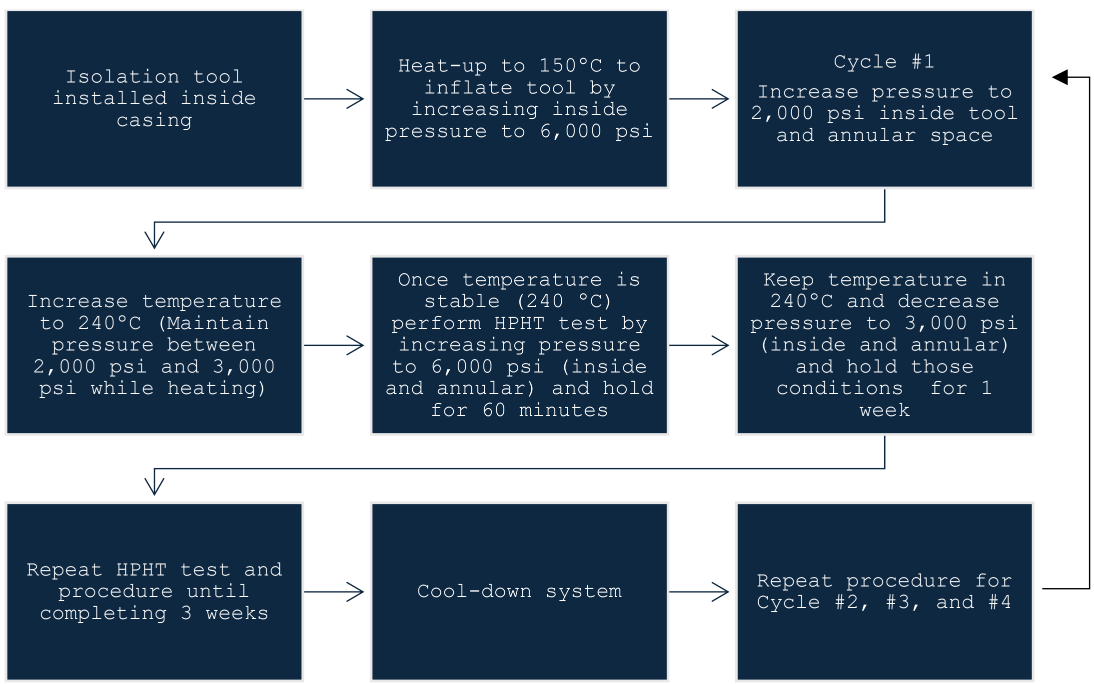

Figure 2: Long-scale testing protocol

4 THERMAL TESTING CYCLES

The isolation tool was tested in four sequences (testing cycles), during which the temperature and pressure were increased to the target conditions of 225ºC—320ºC and 6,000 psi, respectively. Figure 3 shows the positions of the temperature transmitter placed within the testing setup.

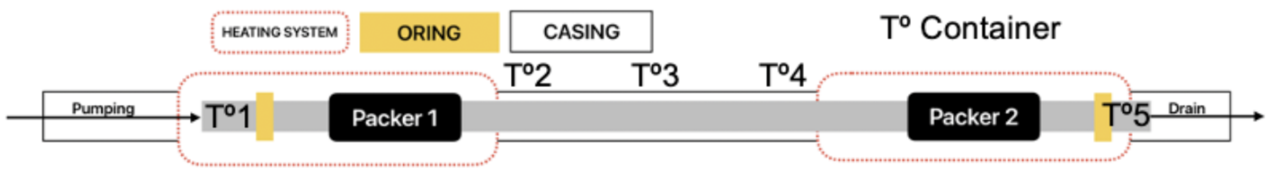

Figure 3 Thermocouples positioned along the isolation tool (Alvarez Escobar et al., 2024)

4.1 Cycle 1

The first testing cycle involved installing the isolation tool inside the casing and inflating it by heating the system to 150ºC and applying 6,000 psi pressure. Figure 4 This shows the behavior of the pressure during the tool expansion. It can be observed that the increase in pressure around the 80-minute mark slows down, which indicates that the packer has expanded. This stage represents the deployment of the packer in a well that is partially cooled or at a geothermal gradient. Thus, the inflated temperature was kept lower, and it must be noted that higher temperatures help the expansion process.

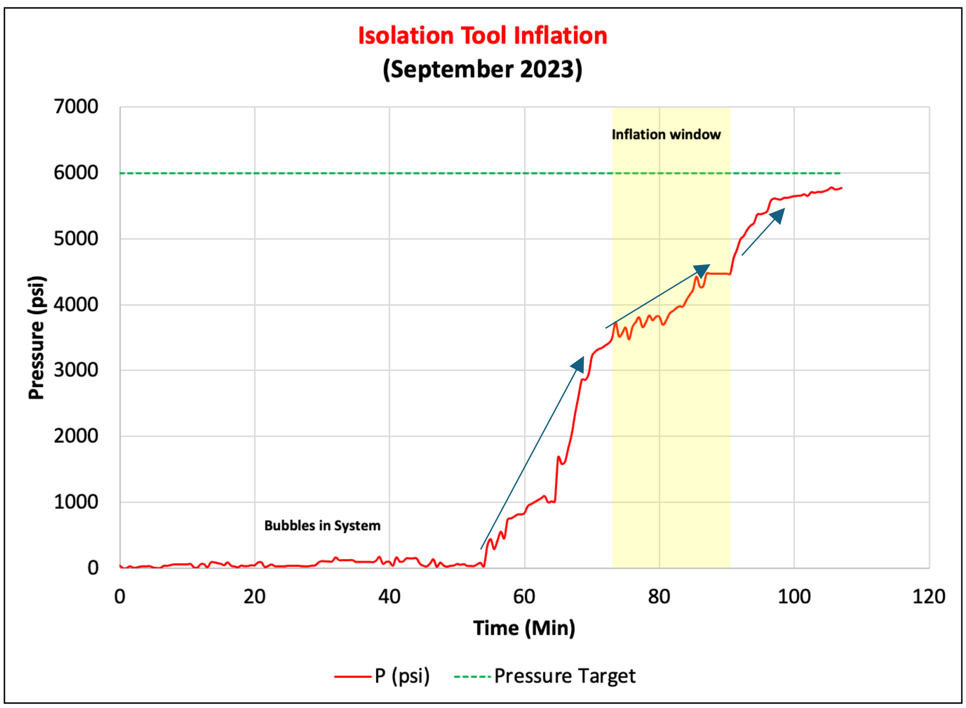

Figure 4 Isolation tool expansion

After the expansion, Cycle #1 was started by increasing the system pressure to around 2,000 psi and heating the isolation tool to the target temperature (225ºC). The result of the first testing cycle is presented in Figure 5; the yellow section shows the initial part of the test, during which some equipment problems were encountered, causing a fluctuation in the system's temperature. After overcoming those problems, two HPHT tests lasted almost 5 days.

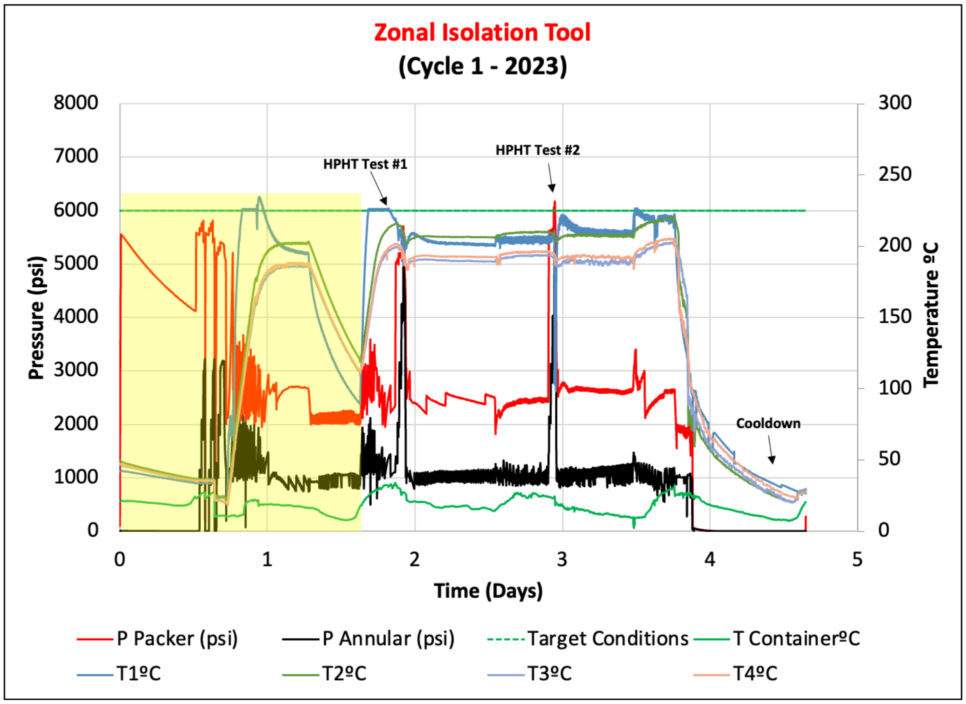

Figure 5 Testing Cycle 1 results

4.1.1 Cycle 1: HPHT test 1

The maximum leak observed in the system during this test was about 0.04 GPM, remaining below the allowable limit (0.5 GPM). Despite the low leak, the target pressure was not achieved. This test concluded that an upgrade in pump setup is required to achieve high flow rates. Figure 6 shows the inlet and annular pressure during this HPHT test.

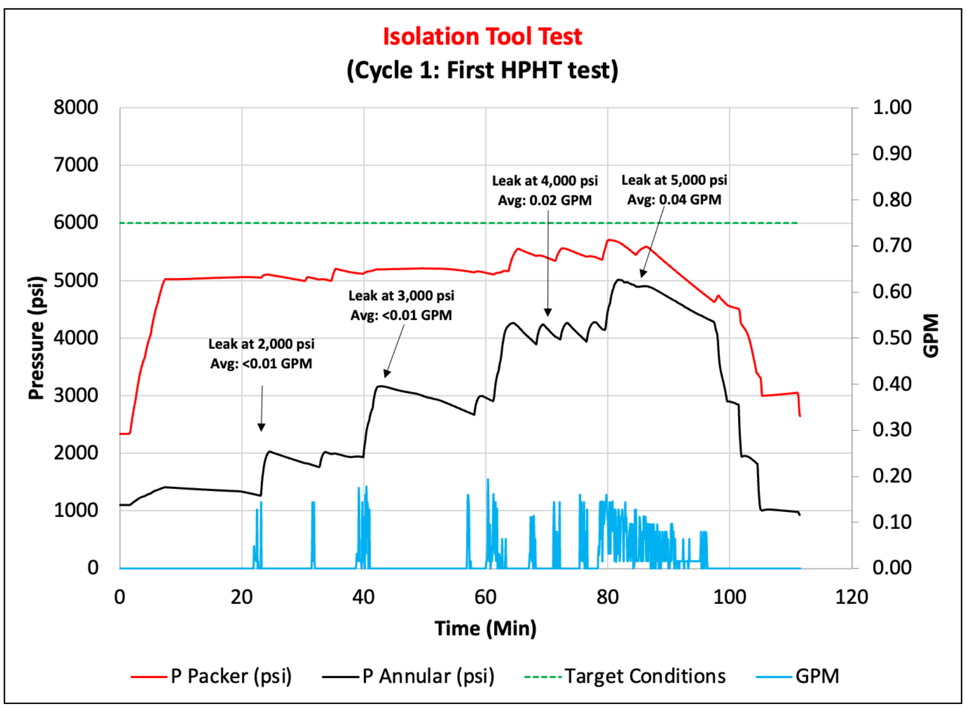

Figure 6 Result of the first HPHT test in Cycle 1

4.1.2 Cycle 1: HPHT test 2

The second HPHT test confirmed the low-pressure problem observed in the first test. Figure 7 shows the result of the second test, while Figure 8 confirms the system's leakage.

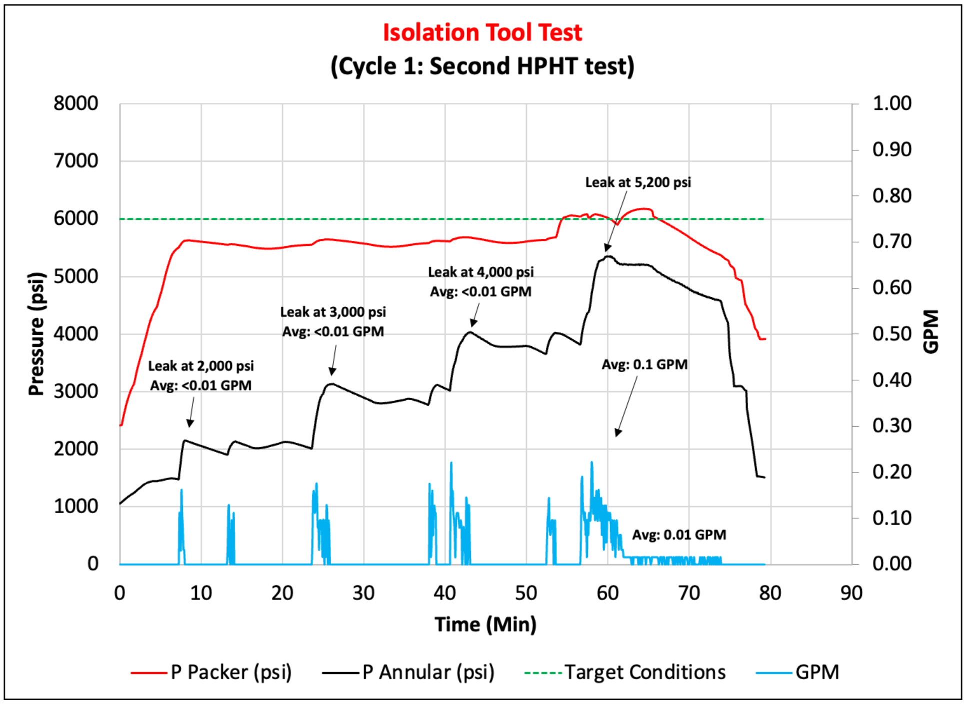

Figure 7 Result of the second HPHT test in Cycle 1

Figure 8 Steam leak from annular

4.2 Cycle 2

Modifications were made to the setup to achieve a higher injection flow rate and, therefore, increase the pressure in the system to the desired values (6,000 psi in both the annular and inside of the tool). This cycle lasted for 15 days, and 3 HPHT tests were done where the pressure of 6,000 psi was reached and held for one hour on each test. The temperature was held over 225ºC during the whole cycle period; Figure 9 presents the pressure and temperature parameters during this cycle.

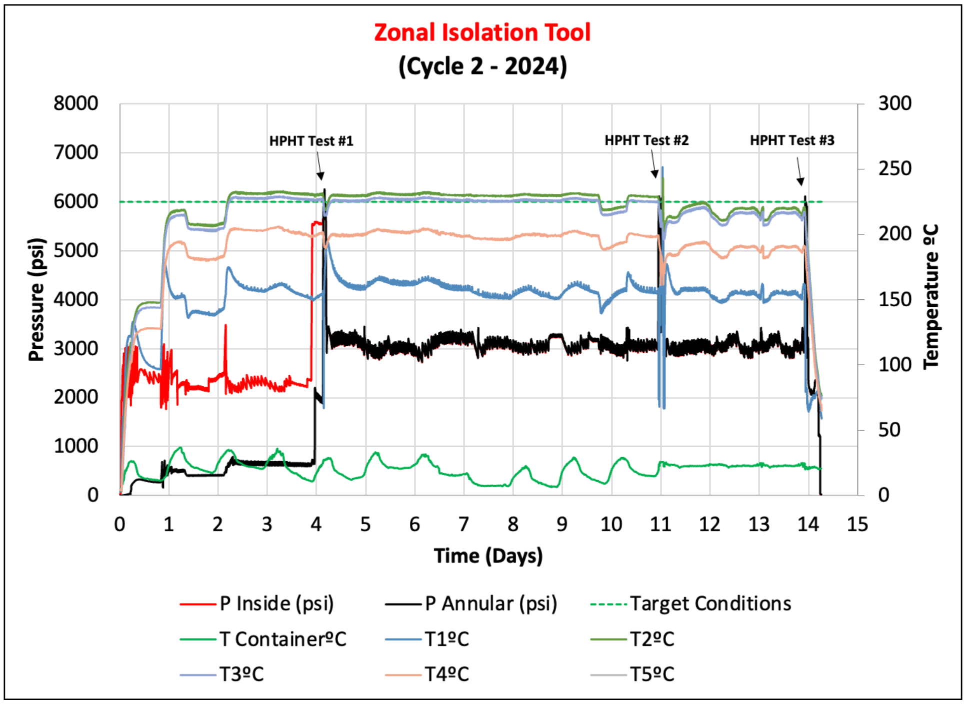

Figure 9 Testing Cycle 2 results

4.2.1 <u>Cycle 2: HPHT test 1</u>

The pressure in both the annular and inlet spaces was increased to 6,000 psi, and with the new system modifications, it was possible to hold the pressure for one hour. The average leak during this test was less than 0.2 GPM, below the acceptable leak threshold of 0.5 GPM. The pressure and leak parameters are shown in Figure 10.

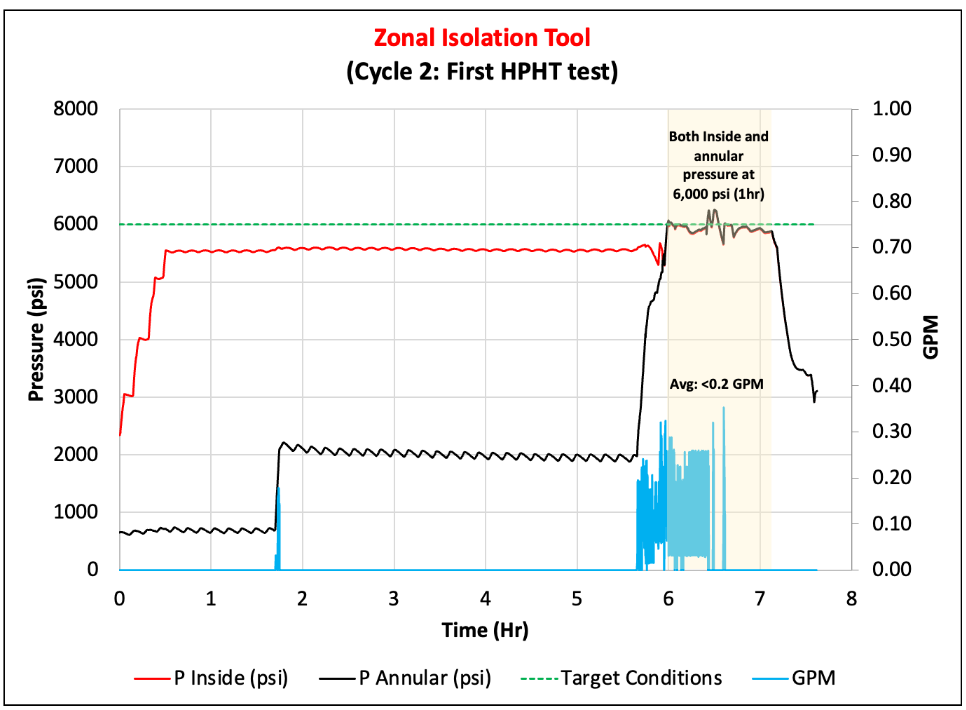

Figure 10 Result of the first HPHT test in Cycle 2

After each HPHT test, there was a baking period during which the pressure was held at 3,000 psi for both the inside and annular space, and the system's temperatures were kept around 225ºC. The baking period lasted 160 hours (6.5 days), as shown in Figure 11.

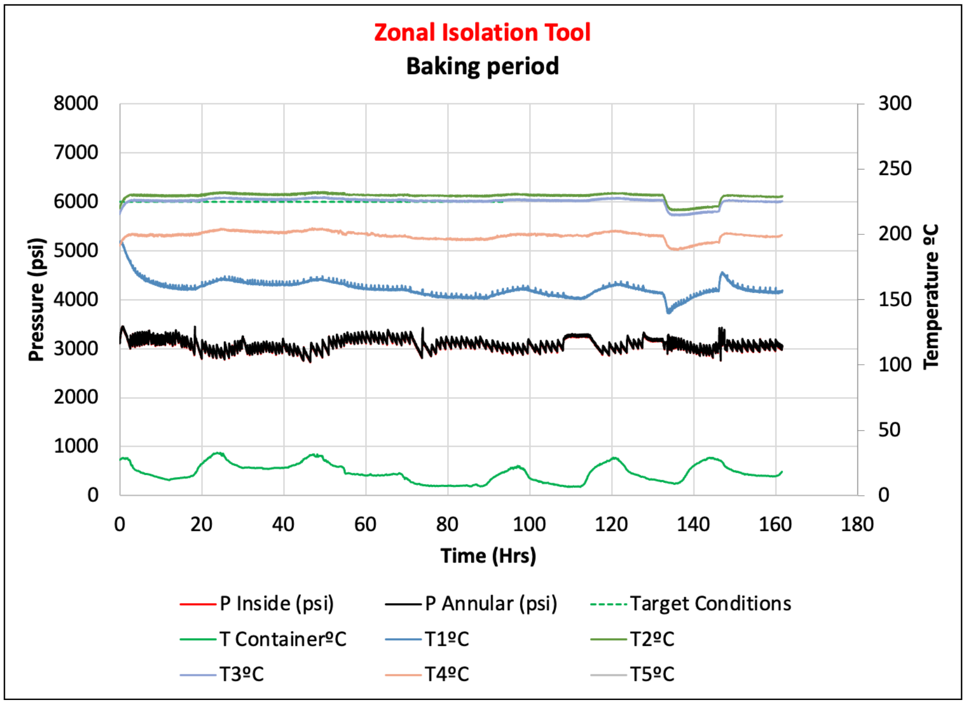

Figure 11 Result of the first HPHT test in Cycle 2

4.2.2 Cycle 2: HPHT test 2

For the second HPHT in cycle 2, the pressure could be held for 1 hour at around 5,500 psi with a leak of 0.3 GPM, below the allowed limit. Figure 12 shows the pressure conditions during this test.

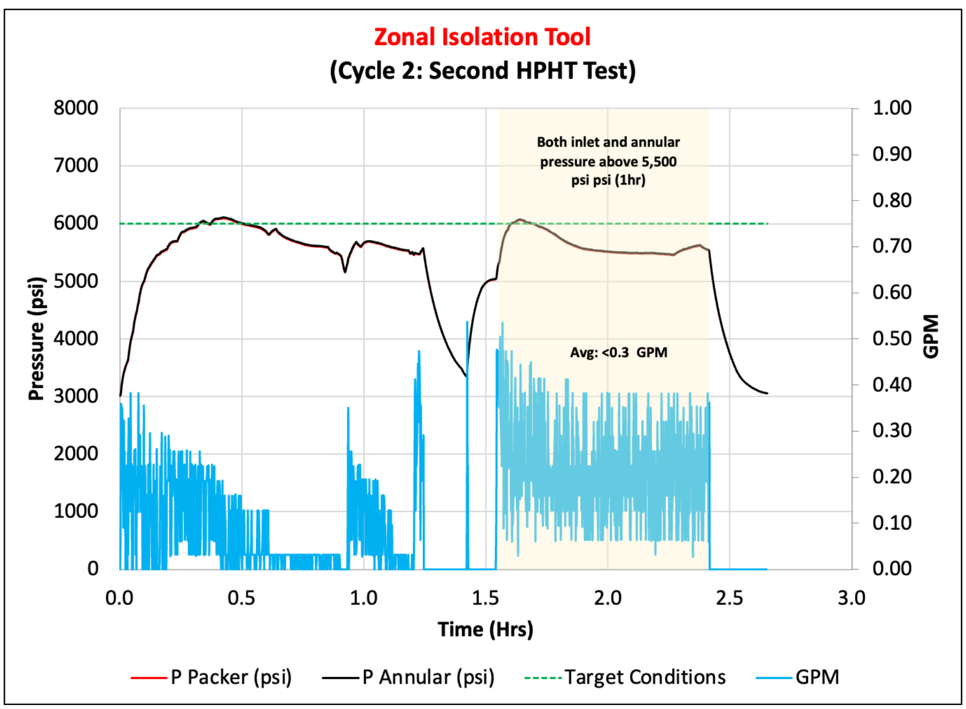

Figure 12 Result of the second HPHT test in Cycle 2

4.2.3 Cycle 2: HPHT test 3

The third and last HPHT test of cycle two was performed without issues; the pressure was increased to 6,000 psi in the annular and inside the tool. The result of this test is presented in Figure 13.

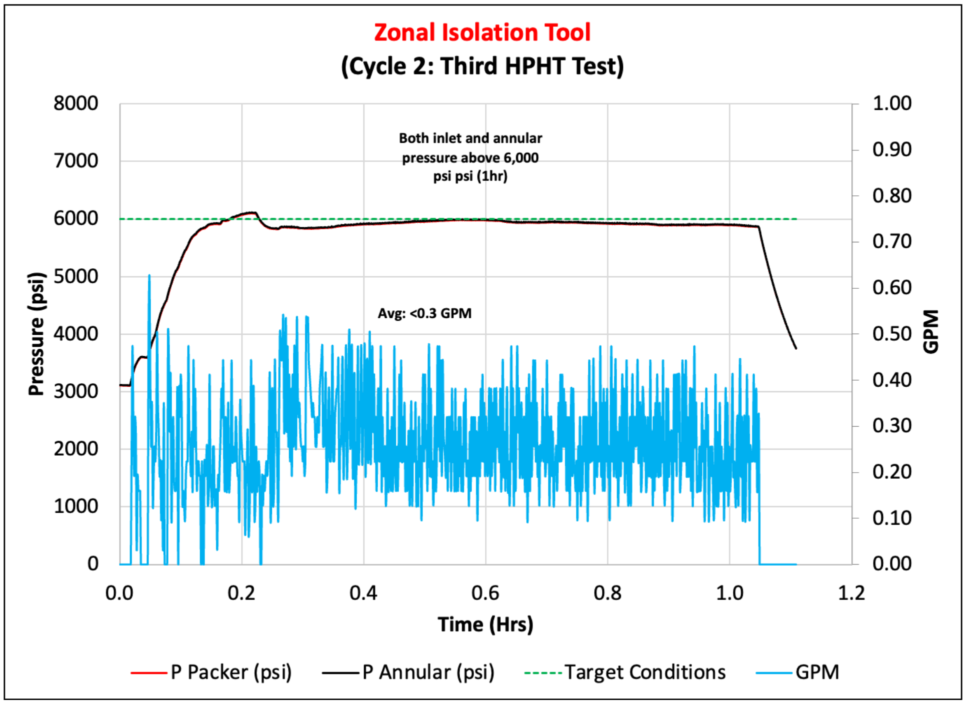

Figure 13 Result of the third HPHT test in Cycle 2

Once the third test was finished, the system was allowed to cool while the pressure was held over 2,000 psi to prevent steam from damaging the tool.

4.3 Cycle 3

The tool was tested for 21 days for the third cycle, during which four HPHT cycles were performed. During this period, a tornado struck the area where the test was being conducted, and the data was lost, as shown in Figure 14. The heating was turned off to prevent damage to the unit and protect the personnel involved in the 24-hour testing.

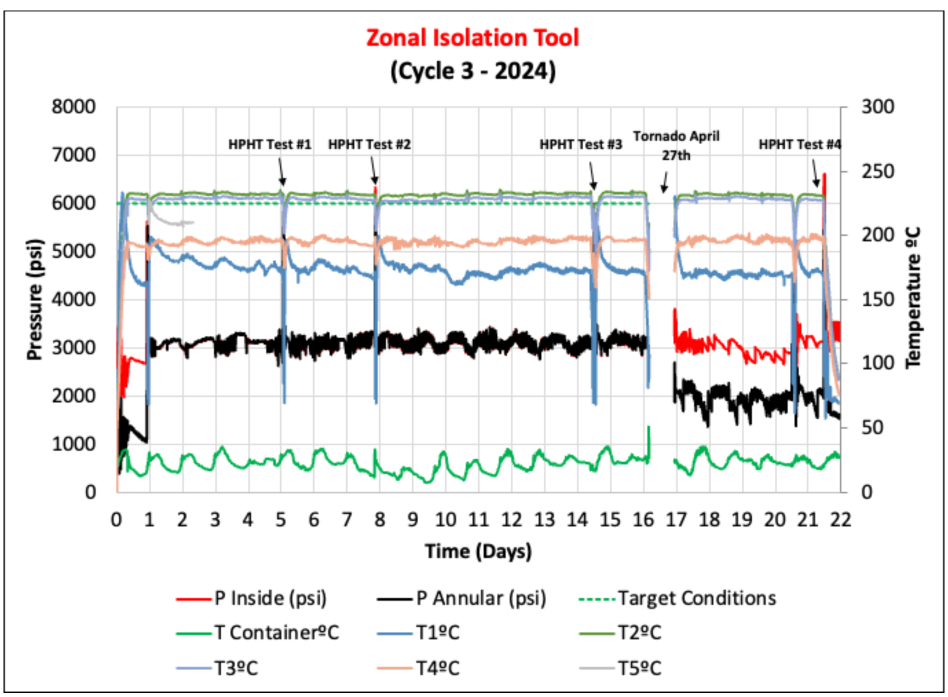

Figure 14 Testing Cycle 3 results

4.3.1 Cycle 3: HPHT test 1

The isolation tool was allowed to be baked for 5 days before performing the first HPHT test in the third cycle; during this test, it can be observed in Figure 15 that the pressure could not be increased to 6,000 psi as done in the previous cycles. The maximum pressure achieved was 5,850 psi, and the average leak rate was around 0.5 GPM, which is the maximum allowed leak for the design of this isolation tool, which means that the thermal cycles have started to affect the sealing capability of the tool. It must be noted that no changes were made to the setup from cycle 2 to cycle 3. After finishing HPHT test 1, the tool was baked for 3 days before performing the second HPHT test.

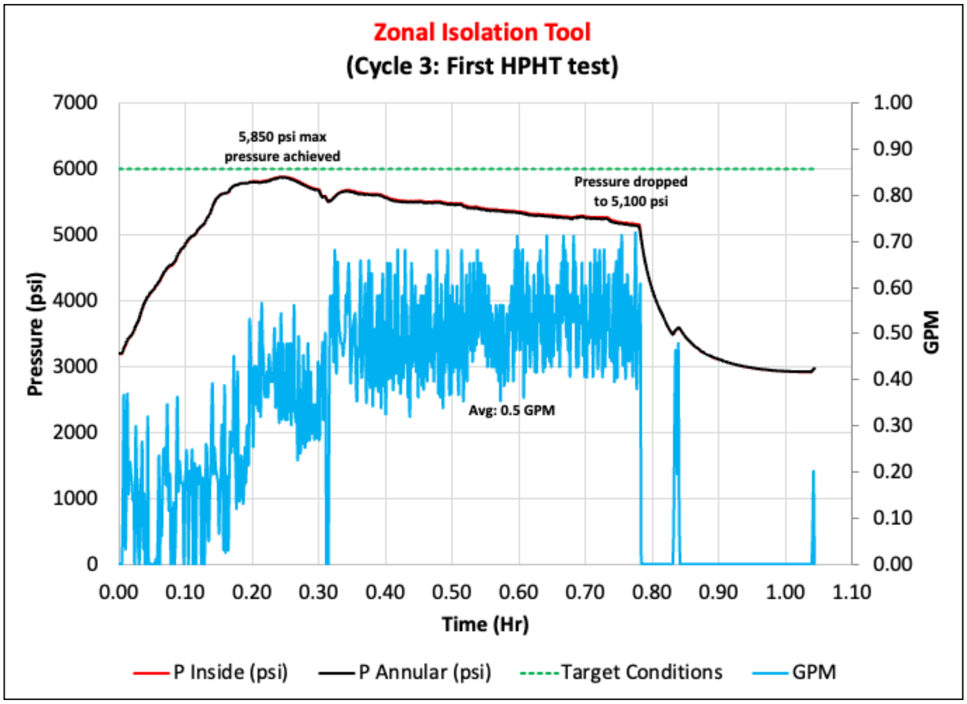

Figure 15 Result of the first HPHT test in Cycle 3

4.3.2 Cycle 3: HPHT test 2

As in the previous test, the maximum pressure achieved for the second HPHT test was around 5,900 psi. During this second test, a 2,000 differential pressure was applied to the tool to increase the inside pressure above 6,000 psi and observe whether the system could maintain the pressure. As can be observed in Figure 16, once the pressures were equalized, the pressure dropped to values around 5,500 psi (both inlet and annular pressure), and during this period, the average leak was also around 0.5 GPM, which means it is impossible to increase the pump rate due to the tool's maximum allowed leakage (0.5 GPM). Once the second test was finished, the tool was allowed to bake for 7 days to check if, with a more extended baking period, different results could be attained in the subsequent tests.

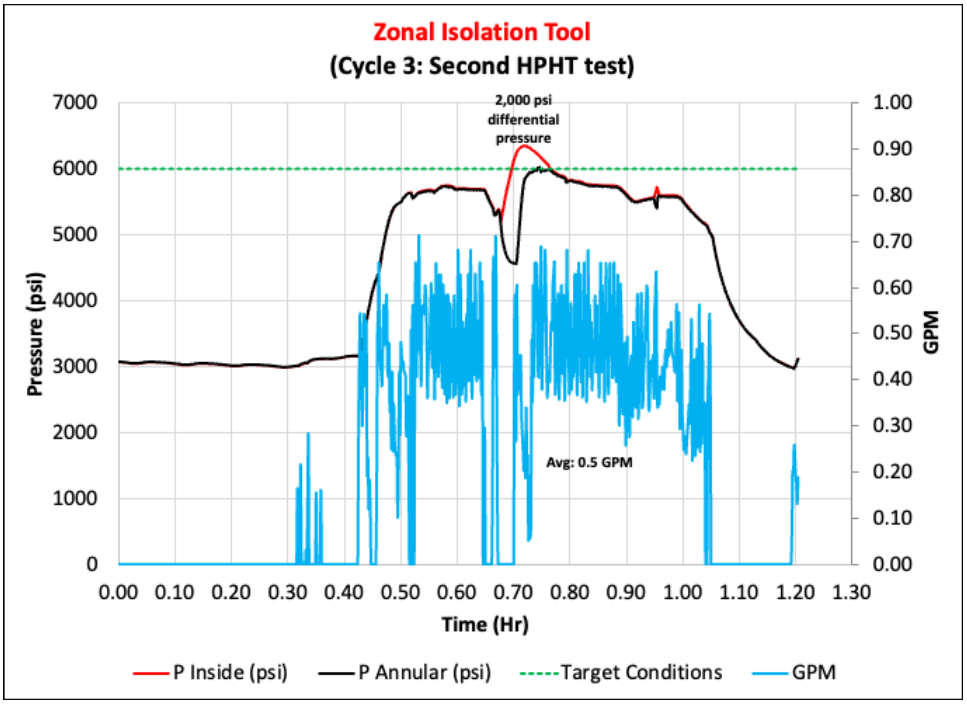

Figure 16 Result of the second HPHT test in Cycle 3

4.3.3 Cycle 3: HPHT test 3

Figure 17 shows that the tool achieved 6,000 psi for the third HPHT test. However, the pressure was held for only 15 minutes, after which it slowly started to drop to around 5,200 psi. The average leak was around the maximum allowable limit, 0.5 GPM. The tool was baked for 8 days before performing the fourth and last HPHT test of cycle 3.

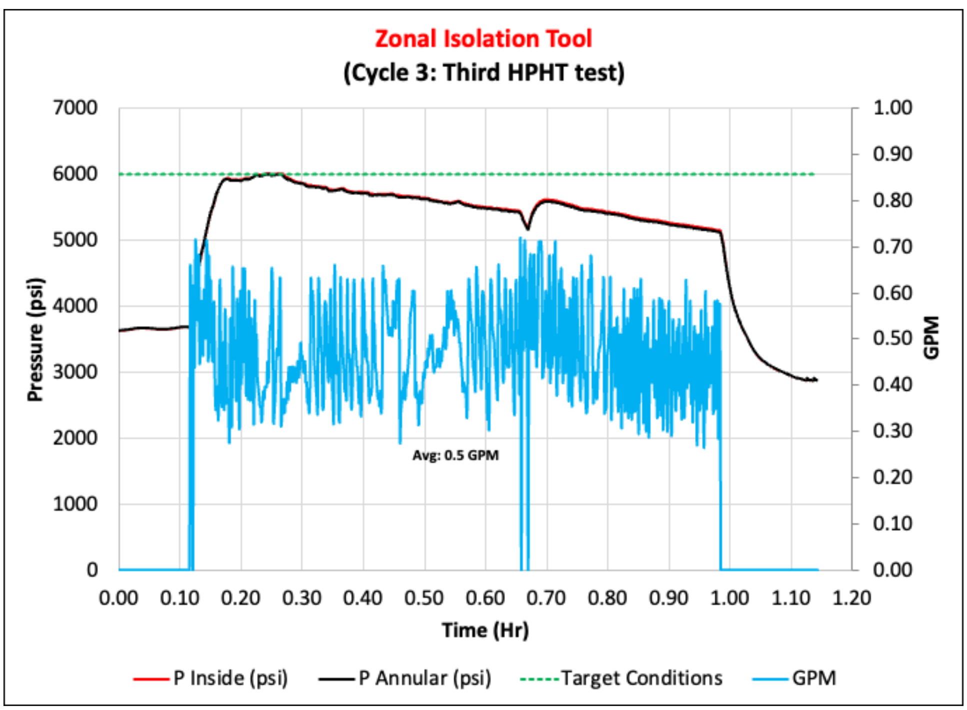

Figure 17 Result of the third HPHT test in Cycle 3

4.3.4 Cycle 3: HPHT test 4

Figure 18 shows the pressure and temperature conditions during the fourth HPHT test of cycle 3. The tool was tested for one hour during this test, but the inlet and the annular pressure were not equalized in the first half hour. Therefore, it was observed that the differential pressure of only 1000 psi was maintained, and once the pressures were equalized, the pressure dropped to below 5,000 psi. After finishing this test, the tool was cooled down, and the results were analyzed to decide the best options for the next cycle.

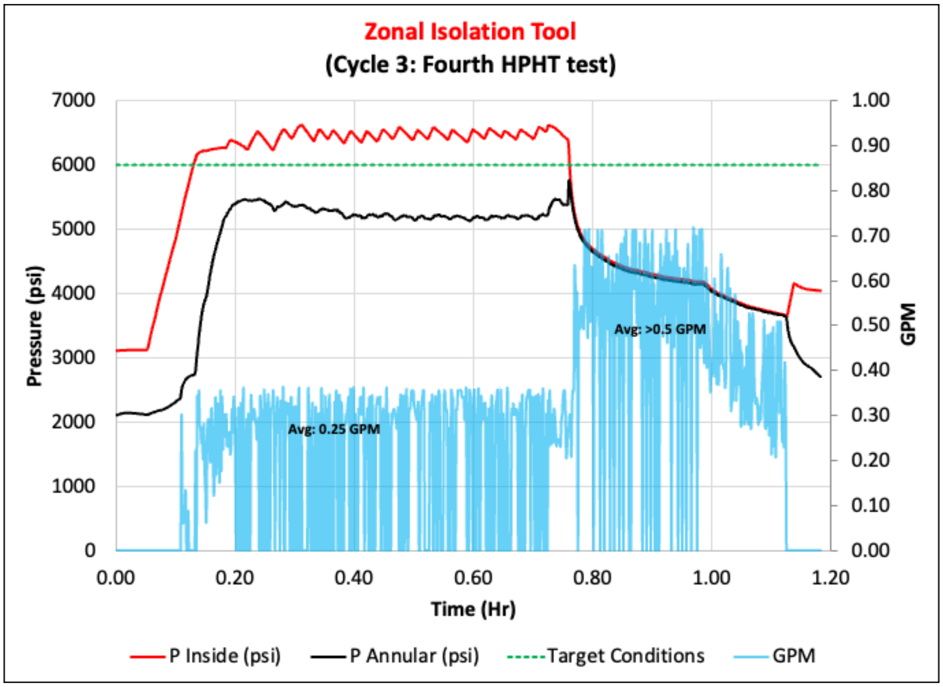

Figure 18 Result of the fourth HPHT test in Cycle 3

4.4 Cycle 4

To evaluate a higher temperature impact on the system during the HPHT test, the temperature was raised to 310ºC for this cycle. Figure 19 shows the pressure and temperature conditions during this cycle, with a temperature increase of 310°C noted during the HPHT test.

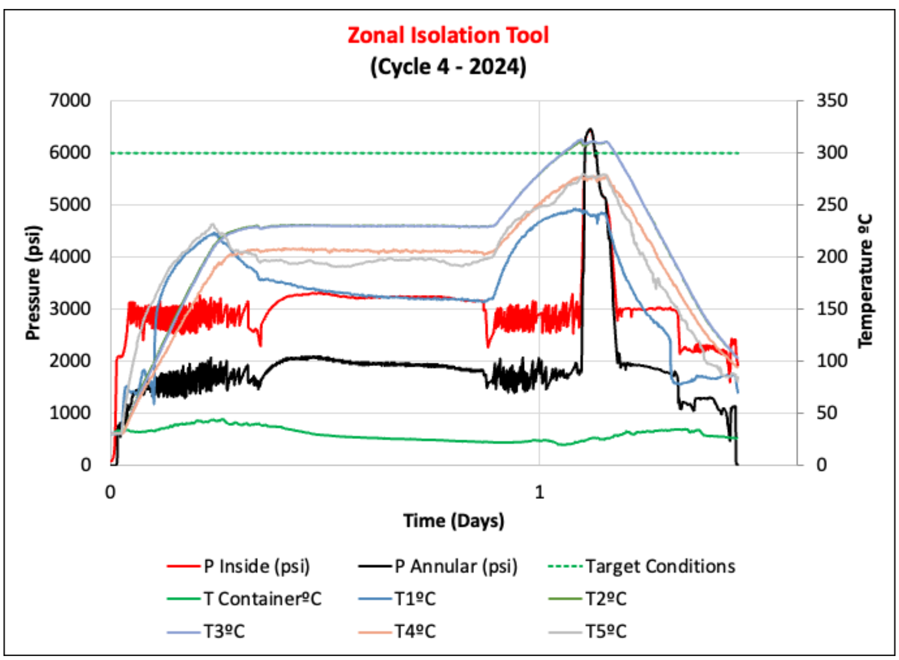

Figure 19 Testing Cycle 4 results

4.4.1 Cycle 4: HPHT test 1

The tool exhibited better sealing during this cycle than in previous thermal cycles. Once the target pressure was reached, the pressure was maintained in the system without pumping, as shown in Figure 20. A small, constant drop in pressure was noted, which triggered the pumps to operate after 1 hour of testing. Afterward, the pumps were turned off to assess the pressure drop at the new temperature of 310ºC.

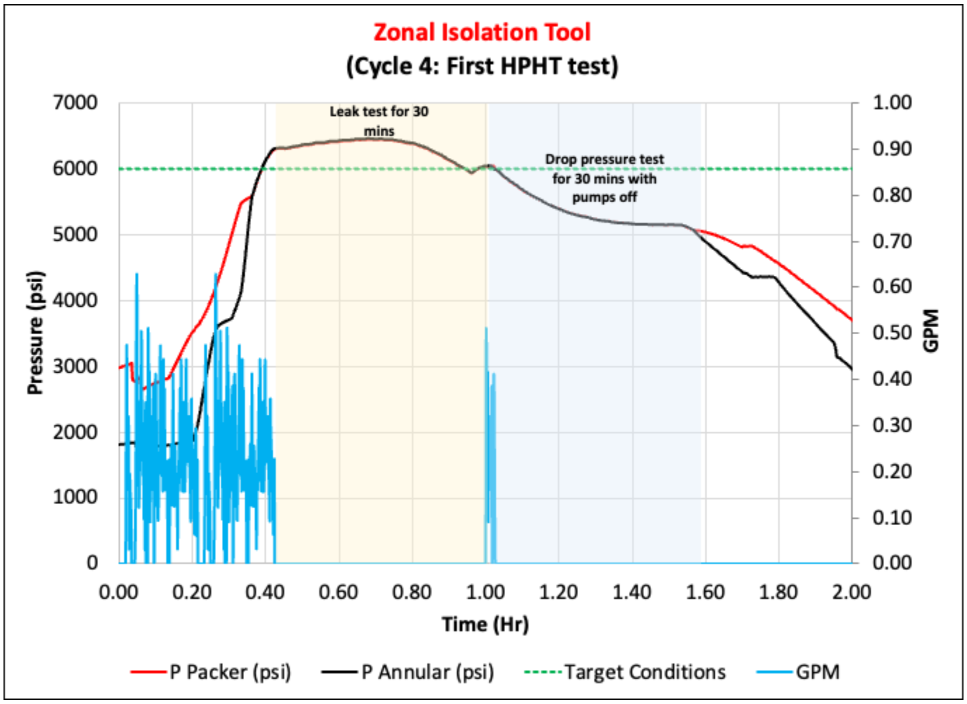

Figure 20 Result of the first HPHT test in Cycle 4

5 DISCUSSIONS

The results illustrate that the isolation tool was well-designed to satisfy the Utah FORGE project conditions. Although some issues arose during testing, they were more related to the setup than the isolation tool itself. During Cycle #1, problems concerning pumping capacity were resolved for the subsequent cycles. Additionally, some problems related to the heating unit used to increase the temperature in the isolation tool that was installed inside the casing were overcome successfully to ensure that the test conditions were properly maintained. Finally, during the tests, difficulties appeared due to weather conditions, including a tornado in April 2024 that impacted the facilities where the testing was taking place. Even with all these problems, thermal cycles were performed successfully; this can be observed in Table 1, which presents the number of cycles conducted, the maximum temperature and pressure achieved during each cycle, and the duration for which the maximum temperature was held. Three HPHT tests were conducted over 14 days during Cycle #2, where a pressure of 6,000 psi was maintained without any issues, and the leakage rate remained below the acceptable threshold of 0.5 GPM. For Cycle #3, after two thermal cycles were performed on the tool, some problems arose concerning the maintenance of pressure in the system at 6,000 psi, which may indicate the thermal cyclic effects on the isolation tool. In Cycle #4, when the temperature was raised to a higher value, the tool exhibited better-sealing properties than any cycle previously conducted. Because the packer incorporates a metal-to-metal seal that can slightly deform at elevated temperatures, this enhances contact between the sealing element and the casing wall. The pressure was held at 6,000 psi without requiring pumps, and the pressure drop was slower than in the other cycles. It is important to note that the pipe used for testing was neither surface corrected nor polished like those used in other packer tests industry.

Table 1 Cycles performed

Cycle #	Max. Temperature (ºC)	Max. Pressure (psi)	Pressure Held?	# HPHT test	Time period (days)
Cycle 1	225	5,200	Yes	2	5
Cycle 2	225	6,000	Yes	3	14
Cycle 3	225	6,000	No	4	21
Cycle 4	310	6,000	Yes	1	2

6 CONCLUSIONS

The conclusions made from the given study are as follows:

- From Cycle #1, it could be observed that once pressure above 5,000 psi was reached in the annular space, the pump flow rate was insufficient to maintain the system's pressure. The maximum flow rate achieved from the pump was 0.2 GPM. Therefore, bigger pumps were required to increase the pressure in the system.
- From the Cycle #2 test, it can be concluded that the pressure in the packer and annular space was maintained while being exposed to a temperature above 220°C. This proves that the packer's isolation mechanism maintained its integrity during the heating period, which was further validated by the outcome of the HPHT tests.
- After three heating cycles, the packer started to slightly lose its sealing capacity. During Cycle #2, the system maintained the pressure at 6,000 psi with a leakage rate lower than 0.3 GPM. However, during Cycle #3, even with a leakage rate equal to 0.5 GPM, the system could not reach or maintain 6,000 psi, which can be due to its exposure to the multiple cycles of the baking period and the limited pumping capacity of the testing setup.
- In the fourth testing cycle, the system temperature was successfully increased to 310°C, while the pressure inside the packer was raised again to 6,000 psi. The packer maintained this pressure for 30 minutes without requiring any pump assistance. Moreover, no leakage of steam or liquid was observed during the testing period, demonstrating the system integrity under HPHT conditions.
- The system was heated to the desired temperature and cooled four times, completing four thermal testing cycles on this zonal isolation tool. To our knowledge, no other isolation tool has been tested for so long.

7 ACKNOWLEDGMENTS

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