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Design and Experimental Validation of a Unique Geothermal Downhole Valve for FORGE Project

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ABSTRACT

To control climate change, greenhouse gas emissions in the atmosphere must be lowered. In that respect, many countries have set a goal of net zero emissions and are focusing on renewable energy. Amongst the non-conventional energy sources, geothermal energy is the only one unaffected by any metrological and atmospheric changes and remains in operation mode most of the time. Moreover, power generation coming from geothermal energy has been increasing in recent years as new technology has been engineered to work at the geothermal high temperature conditions and enable high production rates for power generation.

Drilling and completing in geothermal downhole conditions require the downhole tools to operate in a different work envelope compared to conventional oil and gas wells. In particular, high temperatures and combined mechanical and thermal cycles require a more detailed design and material selection.

Nonetheless, this type of renewable source has many challenges to face. On one hand, the drilling and completion costs are nearly 50% of the allocated budget. On the other hand, the downhole severe environment (high temperature and pressure) creates problems for the bottom hole assembly. This often results in unfeasible projects.

In order to improve the projects efficiency and economics, zonal control (injection or production) can enhance the well performance over a long period of time. To control the inflow/outflow in a multi-zone completion, zonal isolation requires dedicated tools capable of opening and closing repeatedly under the high-temperature conditions of the life of the well. As part of the FORGE project, the OU and Welltec teamed together and proposed a special downhole valve that uses non-elastomeric seals. This valve enables the closing and opening of the selected fracture interval and thus will enable accurate control of the fracturing process while providing full life of well inflow control.

This paper presents an experimental test on a flow valve for completion and production operations specific to the geothermal well. This flow valve was able to endure the High-Pressure, High-Temperature (HPHT) testing conditions and was able to maintain its integrity. The detailed procedure and the result of the HPHT test will be presented in this paper.

1. INTRODUCTION

The CO2 emitted by burning fossil has been a contributing factor to accelerate global warming, which has become one of the biggest challenges our planet faces. For instance, data from Crippa et al. (2022) shows that the emission of CO2 from fossil fuels in the atmosphere has increased by 5.3% from the year 2020. It was calculated that fossil CO2 emissions per person worldwide were around 4.81t in 2021 (Crippa et al, 2022). The continuous increase of CO2 levels from year to year is affecting climate change. As a result, many countries have set the goal to reduce the emission of CO2, which is one of the main greenhouse gases. It is important to shift energy production from conventional fossil fuel to renewable energy to achieve such a target (Olabi, et al. 2022, Kaven, et al. 2020)

A clean approach to mitigate the CO2 emissions from fossil fuels is geothermal energy which can be used for different applications, such as heating buildings, electricity generation, and industrial processes, helping in decarbonization (Milousi 2022). Moreover, about 98% of the time, the geothermal well remains in operational mode and is independent of the metrological condition compared to other renewable sources. (Abid, 2022, Cano, 2022). However, geothermal projects are cost-intensive, especially when it comes to drilling and completion. It is reported by DiPippo ((2016) that ~50% of the budget of geothermal projects goes toward the drilling and completion operation. Additionally, the failure of the downhole tool because of high temperature presents another challenge with respect to cost-effectiveness.

Usually, geothermal reservoirs are present in HPHT conditions and hard formations (The supercritical condition in the geothermal system is defined when the temperature and pressure are above 406C and 4,322 psi, respectively. These conditions are prevalent in seawater systems, whereas in pure water systems, the temperature and pressure are slightly lower (T > 374 °C and P > 221 bar) (Reinsch et al 2017). Currently, most of the geothermal systems in operation have a temperature range of 150-300 °C, which is used to produce electricity (Reinsch et al 2017 and Abid et al 2022).

Because of the harsh environment of geothermal wells, different problems are encountered during drilling and completion operations. In that respect, the first challenge is the wear on the bit as it has to drill through some of the hardest formations, such as igneous and metamorphic rocks. Imaizumi et al. (2019) reported that during the drilling of five geothermal wells in Japan, five different PDC bits were designed to drill the formation with UCS values ranging from 7832 to 53,229 psi . While to achieve the drilling data in real-time and improve the ROP, a downhole motor and MWD should be used (Pastored et al. 2019). Nonetheless, both Downhole motors and MWD have temperature restrictions that can be overcome by using the appropriate additives in the mud systems and some changes in the circulating circuit that can treat the mud when it is returned from the high temperatures (above 350°C) reservoir (Saito 1995). Other problems in geothermal wells, such as tight holes, dogleg, ledges, swelling, and abrasive formations, can be controlled using a reaming tool, which allows the enlargement of the hole around 15-20% and can work in the temperature of 215°C (Schlumberger 2021). On the other hand, the packer used in conventional oil and gas wells have limited use in geothermal environments for zonal isolation due to their lack of long-term resistance under elevated temperature conditions. In that respect, Welltec as part of the Utah FORGE project, has designed a packer that uses a metal-to-metal seal and is able to work in geothermal conditions (Abid, 2022). However, not much work has been conducted on the flow valve applicability in the HPHT condition. Therefore, this study presents the results of the HPHT experiment test that was performed on the flow valve designed by Welltec to be used in Utah FORGE. The target temperatures were 225, 260 and 320°C. Meanwhile, the target pressure was about 6,000 psi.

2. MATERIALS AND METHODS

2.1 Flow Valve

A flow valve supplied by Welltec was tested at Well Construction Technologies Center (WCTC) facilities in Norman, Oklahoma. The given tool was designed to be used for completion and production operations in the geothermal wells of the Utah FORGE. Figure (1) shows the schematic for the flow valve.

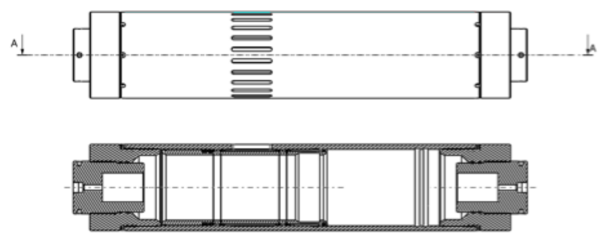

Figure 1: Schematic of the specimen used for the testing.

The metallurgical construction of the flow valve consisted of S13Cr110, which is considered suitable for geothermal systems. For testing purposes, some measurements of the flow valves were taken, including total length, ODs, length of endcaps, and thread. Two ports were added to supply the fluid in the flow valve (inlet and outlet). While on both sides of the endcap, O-rings and backup rings were installed for sealing. Figure 2 shows different parts of the flow valve.

Figure 2: Flow Valve connected to the pressure system

2.2 Testing Setup

To supply high pressure to the flow valve for the testing, a pneumatic pump model S-216-JB-101 with a max outlet pressure of 10,000 psi was connected to the inlet port. For the heating, three conductors/thermocouples that had the capability to work independently were installed on the body of the flow valve. A heating unit was used to control the temperature of the conductors. For safety purposes, the relief valve was installed at the outlet port to remove the pressure from the system. DASYLab software was used to record and collect the data from the experiment. Figures 3 and 4 show the experimental setup. Moreover, to avoid heat loss during the experiment, the flow valve was covered with an insulation jacket (Figure 5)

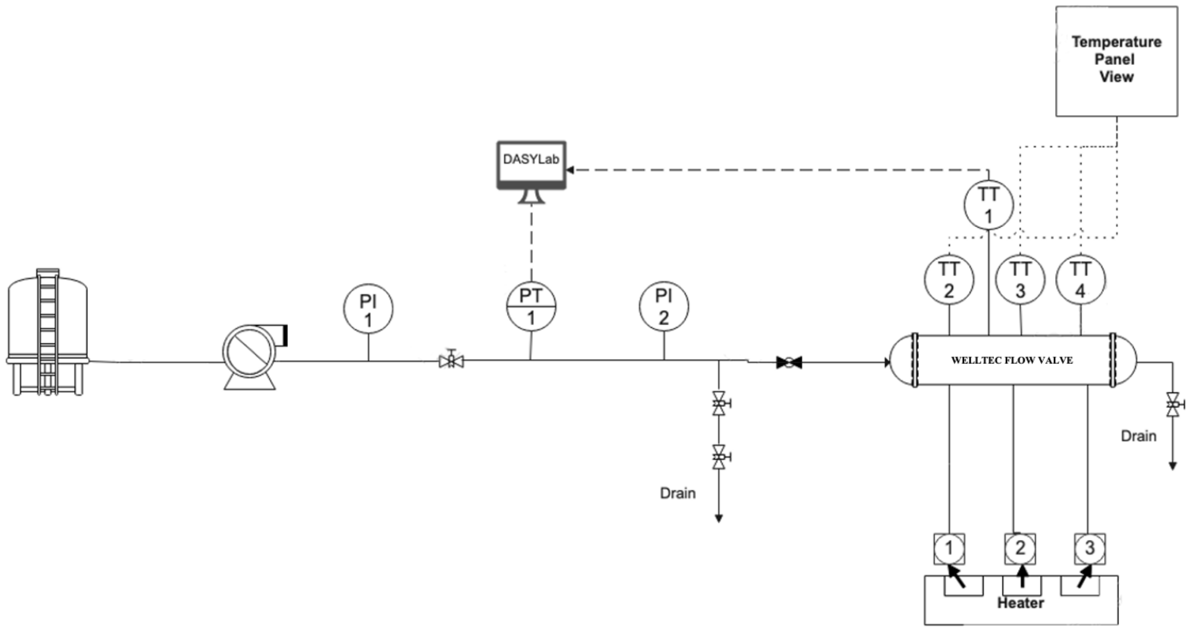

Figure 3: Schematic of the flow valve testing setup

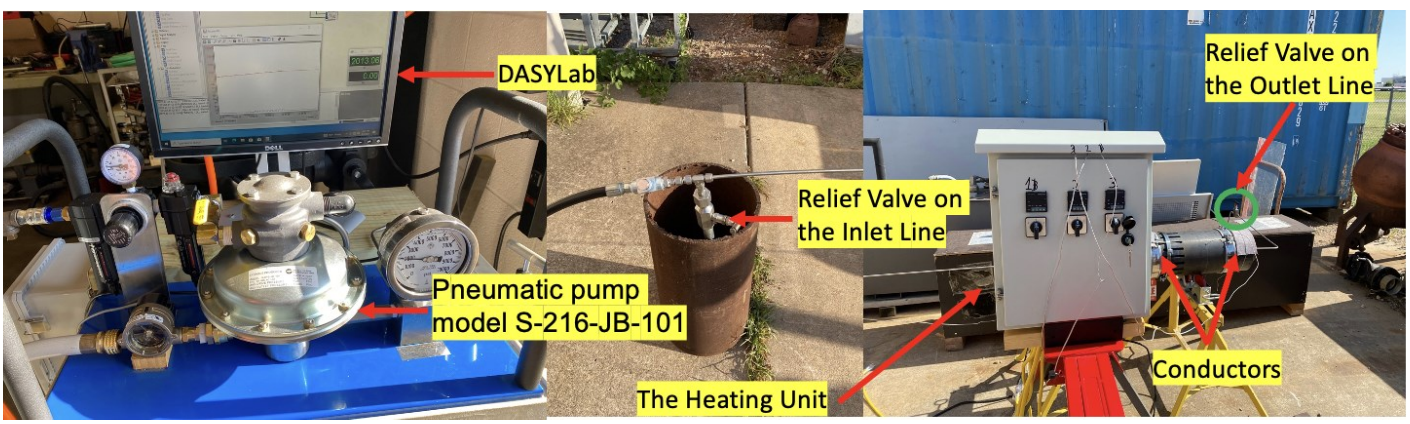

Figure 4. Experimental setup

Figure 5 Insulation Jacket

2.3 Methodology

The steps taken for the tests are as follows and are shown in Figure 6:

1. Pressurize the valve up to 1,000 psi at room temperature.
2. Turn the heating unit on and heat the specimen to 225 ℃.
3. Keep the pressure under 2,000 psi by bleeding off the pressure from the flow valve until the desired temperature is achieved.
4. When the target temperature is reached, increase the pressure in 1,000 psi steps until the target pressure of 6,000 psi is attained.
5. Maintain the HPHT conditions (6,000 psi and 225 ℃) for half an hour.
6. Increase the temperature to 260 ℃. and maintain the HPHT conditions (6,000 and 260 ℃) for the next 30 minutes.
7. Cool down the whole system.
8. Test finished.

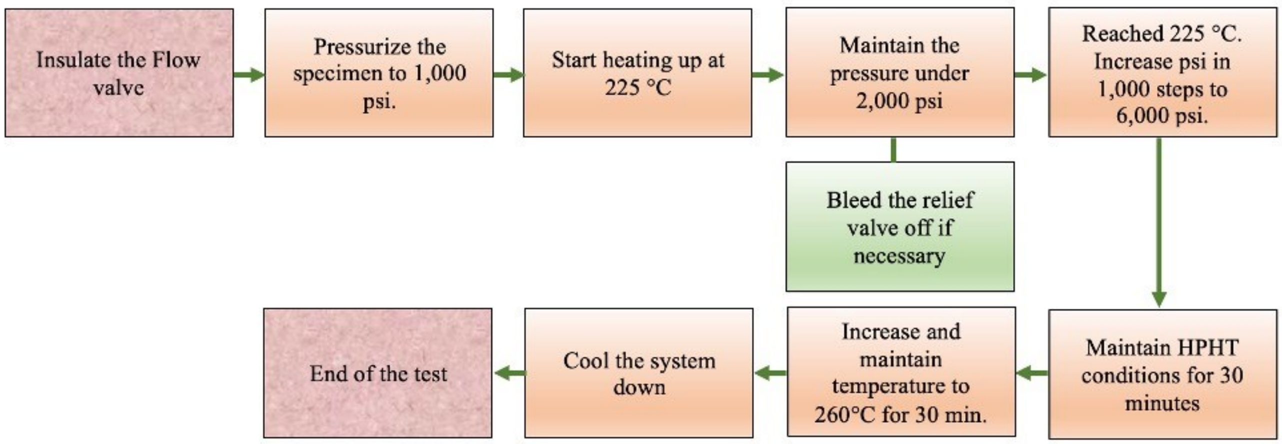

Figure 6 Workflow of the test

3. RESULTS

Two different flow valves were tested at the WCTC Geothermal Laboratory sponsored by FORGE. For the first test, the target conditions were established at 6,000 psi and 225 °C. It can be seen in Figure 7 that for the first 75 minutes of the test, the pressure had to be brought down to 2,000 psi because the increase in temperature was also causing the rise in pressure. Therefore, the pressure had to be released whenever it exceeded 2,000psi. When the temperature was around 180 °C, the pressure was increased to 5,000 psi, and after some minutes, it was raised to 6,000 psi. When the target pressure was achieved, bleeding off was performed every 5 minutes until the temperature became constant, around 190 °C. Then, the temperature and pressure conditions were observed for 30 minutes. No leakage was noticed during this time. However, the target temperature of 225°C was not achieved because one of the wires connected to the conductors/thermocouples got burned. As a result, the test was stopped.

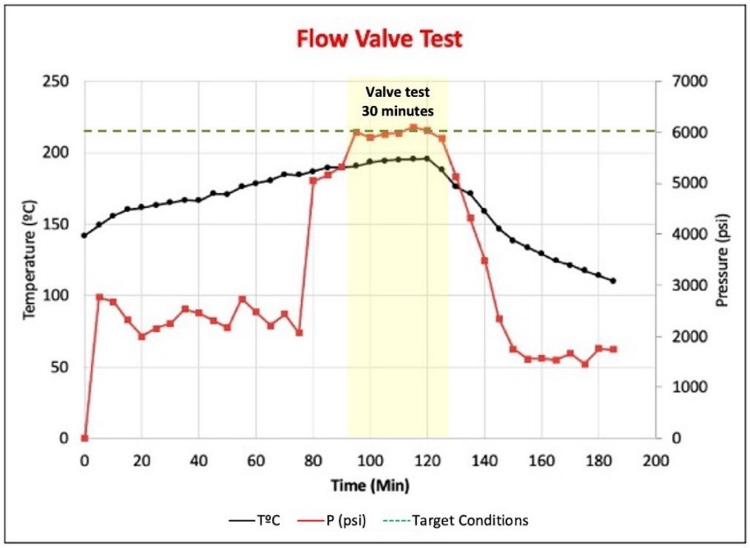

Figure 7: Pressure and temperature during the first test of the first flow valve

After fixing the wires of the conductors, a second test on the first flow valve was performed. It can be seen from Figure 8 that the temperature was constant during the first twenty minutes, and the pressure was controlled between 1,300 psi and 2,000 psi as the temperature was increased to 190 °C before the failure of the system happened due to the leak from a relief valve. As a result, the testing had to be stopped.

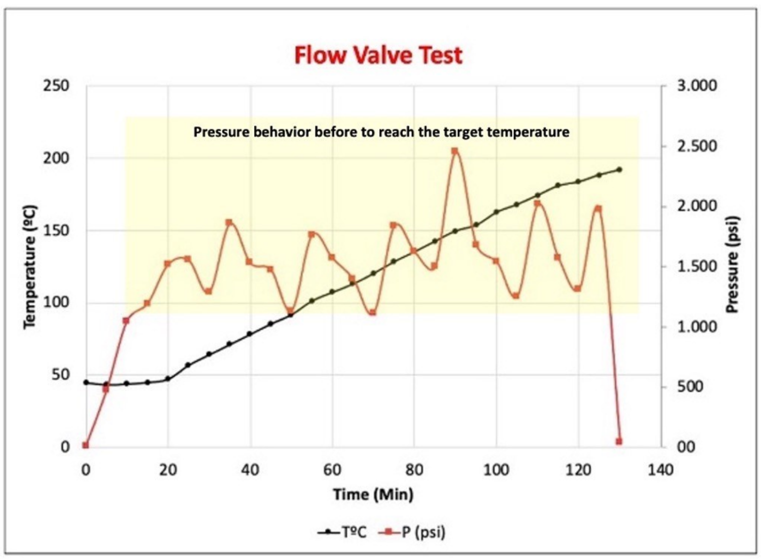

Figure 8: Pressure and temperature during the second test of the first flow valve

A third test was performed on the first flow valve. A small leak was identified on the flow valve once the target pressure (6,000 psi) was reached during the test, as shown in Figure 9. However, the test was continued by continuously pumping the pressure in the system to attain the target pressure and temperature of 6,000 psi and 225C. When the system reached the pressure of 3,000 psi and 200°C, the condition was maintained for 15 minutes. Then, the temperature and pressure were increased to the target condition, after which the system was observed for 30 minutes.

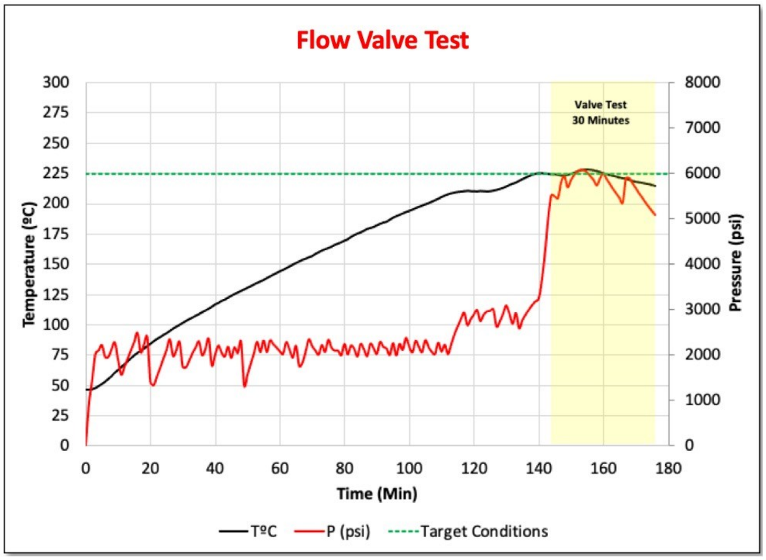

Figure 9: Pressure and temperature during the third test of the first flow valve

A second flow valve was assembled and tested at WCTC facilities. For this test, the aim was to verify that the valve could endure the high-pressure conditions. Figure 10 shows the results obtained. After reaching the 6,000 psi pressure, the system was observed for 30 minutes, and no leakage was noticed.

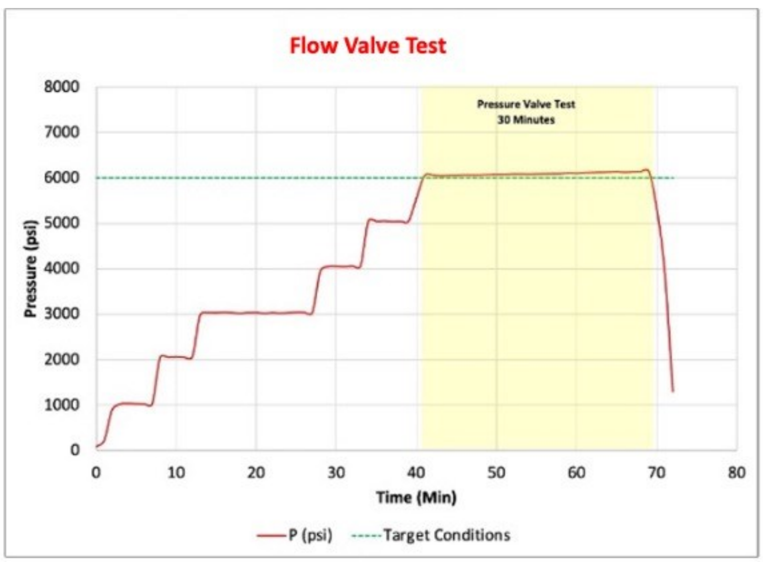

Figure 10: Distribution of pressure during the high-pressure test on the second valve

The valve was then prepared for the HPHT test. In this test, our target conditions were 6,000 psi pressure and 225 and 260 °C temperature. The pressure and temperature in this test were increased the same way as they were done for the previous test by bleeding the pressure when the temperature increased. The only difference was that the pressure was held at 3,000 and 4,000 psi for ten minutes each to ensure no leakage was taking place. Two yellow regions in Figure 11 can be noticed. For both areas, the pressure was set at 6,000 psi while the temperature was at 225C and 260C, respectively, which was observed for 30 minutes. The test was successful, as the system showed no leakage during the observation period.

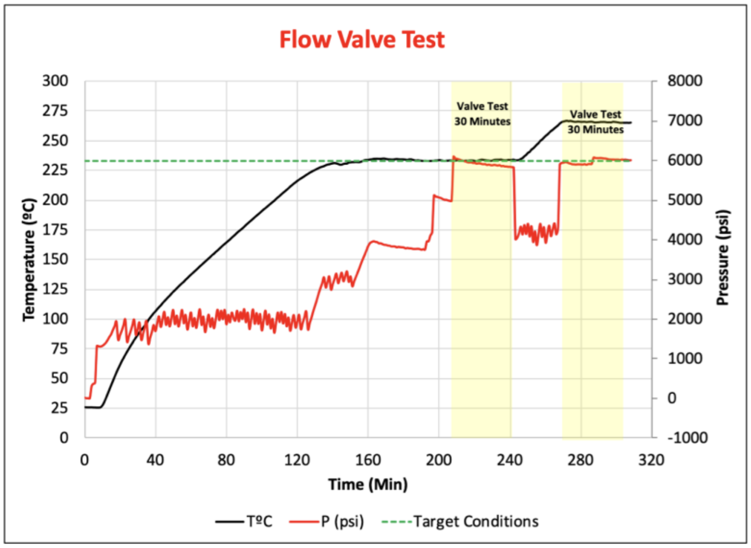

Figure 11: Pressure and Temperature values during the first test of the second flow valve

Another test on the second flow valve was conducted at a target temperature and pressure of 260C and 6,000 psi, respectively. It can be seen from Figure 12 that the system was able to maintain the pressure and temperature conditions for 30 minutes without any leakage at the targeted conditions, and the test was successful.

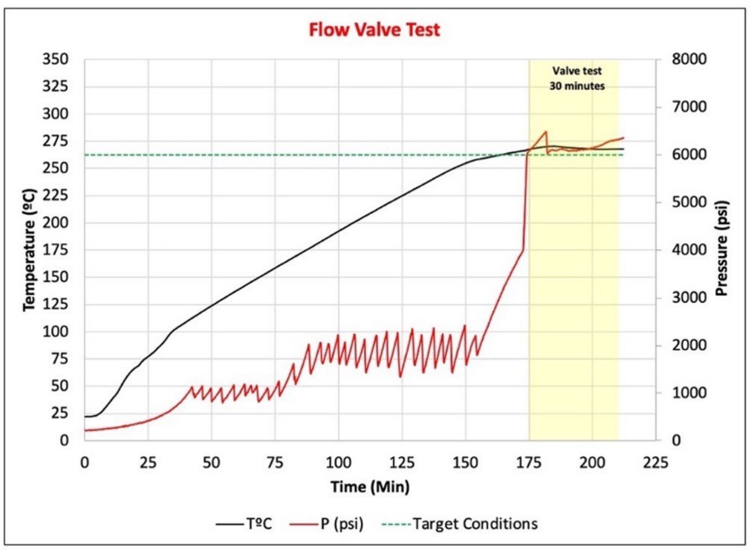

Figure 12: Pressure and Temperature values during the second test of the second flow valve

Finally, for flow valve 2, a last test was performed in which the target temperature was increased to 320°C, and the pressure was set at 6,000 psi. However, the pressure could not go above 4,500 psi, as shown in Figure 13, due to the failure of a backup ring placed in one of the endcaps.

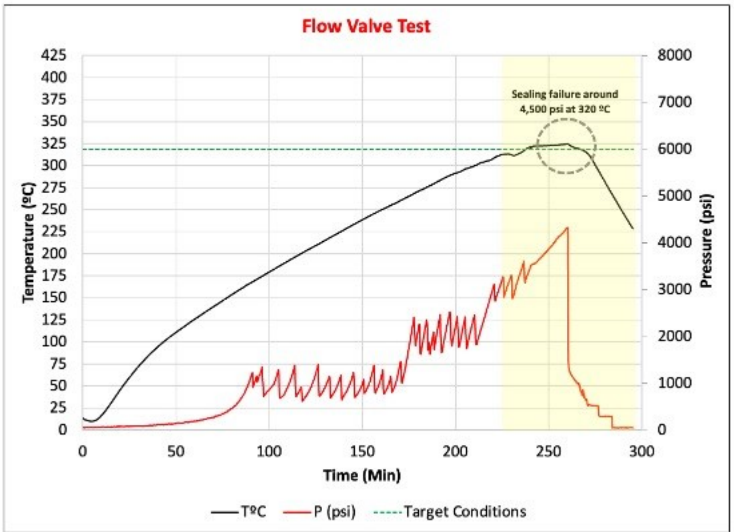

Figure 13: Pressure and Temperature values during the third test of the second flow valve

4. DISCUSSIONS

The results showed that two flow valves provided by Weltec performed well under the target temperature (225 ºC and 260 ºC) and pressure (6,000 psi). Both the flow valves were able to maintain the pressure and target temperatures for 30 minutes. However, some issues unrelated to the product itself were encountered while testing the flow valve, such as the burning of the conductor wires, problems with the relief valve, and welding problems with the end cap. These issues were solved, and the HPHT test was conducted on the flow valve. It could be said that the problems faced were more from the experimental setup than from the flow valve's body. Therefore, it could be said that from the design perspective of the flow valve, no issues were identified. For the last test, when the experiment was to be held at 320 ºC and 6,000 psi, the backup ring of the end cap failed, so the test was not completed. As a precaution, the backup rings will be changed after each high-temperature cycle for future experiments. One lesson learned during the testing procedure was that although a full steam chamber was generated during the o-ring catastrophic failure, the flow valve seals have not been damaged, although they have been exposed to an instantaneous pressure drop from 4500psi to 200psi. This is another proof of good engineering design of the flow.

5. CONCLUSIONS

It can be concluded that the flow valve showed a satisfactory performance under the HPHT conditions of 6,000 psi and 225 ºC as well as for 6,000 psi and 260 ºC. More tests will be conducted so that all the target temperature and pressure of the project will be achieved. The minor issues that were identified during the test were remodified, and lessons were learned from them. It can be said that the flow valve from Welltec has the capability to work in the HPHT environment and can be installed in Utah FORGE. According to Moore et al. (2019), the temperature range for the field in Utah FORGE (the proposed field to use the tool) is between 175 ºC and 225 ºC, which has already been successfully tested in this study.

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