

Development of a Second-Generation Sleeve Based Conformance Control System for EGS

William Fleckenstein¹, Patrick Mays¹, George King², Santos Ortiz², Kris Wilden², Mariel Cantu², Garrett Casassa³, and Ben Alexander³

GTO Technologies Inc., 1916 Denver West Ct #2321, Lakewood CO 80401, USA¹

KSWC Engineering and Machining, 10909 Barely Ln, Houston, TX 77070²

Czero, 1306 Blue Spruce Drive, Fort Collins, CO 80524³

wflecken@gto-egs.com, pmays@gto-egs.com, gking@kswchercon.com, sortiz@kswchercon.com, kwilden@kswchercon.com,
mcantu@kswchercon.com, garrett.casassa@czero-solutions.com, ben.alexander@czero-solutions.com

Keywords: EGS, Geothermal, Conformance Control, Sleeve, Tractor

ABSTRACT

Enhanced Geothermal Systems (EGS) using induced and natural fractures require uniform fluid flow distribution for the most economic power production. An extended circulation test of August 2024 at the Utah FORGE Site between two extended reach wells completed with “Plug and Perf” methods yielded non-uniform flow between the wells in the induced fractures from the first three fracture zones. To overcome the differences in fracture conductivity between wells and wellbore friction that is the root of the non-uniform flow, a low-cost and rapid multistage fracture stimulation technology with cemented casing frac sleeves that also have the ability to regulate flow through the sleeve is being developed and tested with a high temperature tractor to detect and control flow of heat-carrier fluid. This paper reports on the progress of the development of a second-generation sleeve, actuation system, and high temperature tractor, with the goal to provide a uniform injection profile, regardless of the conductivity of fractures between injection and producing wells. Modeling has shown that conformance control may provide a 50% uplift in power generation over a 30-year life as compared to wells without conformance control, for similar costs and with less stress shadowing and a lower seismicity risk.

1. INTRODUCTION

This paper reports on the progress of the development of a second-generation sleeve, actuation system, and high temperature tractor, with the goal to provide a uniform injection profile, regardless of the conductivity of fractures between injection and producing wells. Modeling has shown that conformance control may provide a 50% uplift in power generation over a 30-year well life as compared to wells without conformance control, for similar costs and with less stress shadowing and a lower seismicity risk. This system’s sleeve overcomes the conflicting dynamic and static load requirements on the seals during actuation of the sleeve to the stimulation position with high pressures, and the requirements for low frictional forces allowing movement between the open, closed and regulation position. The use of a pump down actuator, similar to the pump-down system used in “Plug and Perf” minimizes the size, cost and complexity of the sleeve while maintaining full inner diameter from heel to toe, unlike telescoping ball systems. The lack of a downhole actuator incorporated into the sleeve avoids an unacceptably large diameter of the tool, and lowers the sleeve cost, facilitated by the new actuation system design. The second-generation actuation system reduces the conflicting demands of high static pressure seal loading during multistage hydraulic fracturing, and the need for low seal axial frictional forces during seal movement between stages. This sleeve system is designed to provide an economical alternative to “Plug and Perf”.

Enhanced Geothermal Systems, or EGS, in concept is simple and involves the injection of cooler water into the subsurface between horizontal wells connected by fracture stimulations. There, the earth acts as a giant heat exchanger, or “radiator”. As the fluid is heated to reservoir temperature, the hot water is produced to a power plant and converted to electricity. In the ideal scenario, an EGS System evenly distributes water across all the fractures in the network, creating a consistent thermal drawdown in the reservoir. Unfortunately, mother nature is not symmetrical, and a small subset of fractures will have higher conductivity and “short-circuit” the majority of the working fluid between wells. Even if the fractures are symmetrical, friction will push more fluid out the heel stages than the toe stages.

Traditional oilfield injection conformance control methods use an inner tubing string with packers set in the casing between the perforated intervals. Outflow Control Devices (OCDs) are installed with the tubing between packers to provide isolation between the OCDs. Because the fluid flow is confined to the smaller diameter tubing of the inner-string, flow velocities increase for the same flow rate, increasing the frictional pressure requiring additional pump pressure, and reducing the net EGS power generation. This parasitic loss must be minimized to improve EGS economics. Higher rates give higher power output, but the larger inner diameter of 9 5/8” casing have much less frictional losses than 7” casing, with lower resultant fluid velocities for a given flow rate due to the larger cross-sectional area of pipe. 4” tubing used with packers for conformance control has much higher frictional losses through the reduced pipe diameter and the resultant higher pump pressure needed to overcome the additional friction requires electricity, or parasitic losses of power, to run the pumps.

The Generation 2 Sleeve is designed to be a step change in performance and cost reduction. Smaller sleeve diameters require smaller hole sizes. The actuation system is pumped down in a manner similar to “Plug and Perf”, but with a sleeve vs. perf guns for formation access

through cemented casing and a dissolvable ball which is pumped down to frac against. Most importantly, the Generation 2 sleeve has 3 positions; blank, stimulation and regulate flow positions.

2. SLEEVE SYSTEM

The Generation 2 EGS Fracturing and Conformance Control System is a selective sleeve designed for cemented casing or liner strings, actuated to the stimulate position via a pump down wireline system. It features three positions: closed (deployment), fully open (frac stimulation), and regulator (controlled flow), simplifying operation in horizontal wells and allowing passage of tractors while remaining cost-competitive with "Plug and Perf" systems. The sleeve can be selectively opened fully or to the regulate position using a wireline or tractor-conveyed actuator, which is removed after actuation to the fully opened position to enable stimulation or to the regulate position. This system offers both the simplicity of pump-down actuation and enhanced conformance control through a full-bore sleeve. The sleeve also supports rapid operation by opening and dropping a ball just before stimulation, minimizing the chance of a premature dissolution during stimulation. After stimulation, it can be shifted to the regulator position to control injection independently of fracture conductivity, enabling precise conformance control.

Applications include Enhanced Geothermal Systems (EGS) and In-situ Leaching (ISL) for mining, where the sleeve facilitates mineral extraction by controlling solution flow and stimulation in the rock. This design addresses limitations of previous versions by offering a third regulatory position and efficient pump-down actuation, simplifying the sleeve and greatly reducing the costs. Manufactured from robust downhole materials such as carbon steel and chrome alloys depending on operator preference, the sleeve incorporates detent features and optional shear screws for secure positioning of the sleeve in each locked position. Flow regulation uses orifices or injection/outflow control devices.

The actuator assembly is pumped through the frac sleeves until it reaches the targeted sleeve, with the collet serving to position the actuator precisely relative to the inner sleeve. The ball catch collet fingers are engineered to minimally decrease the sliding sleeve's ID, allowing a pump down assembly, fitted with locator at its distal end, to move past the collet fingers. This process produces a surface pressure signature so operators can track the assembly's location within or relative to the sleeves. When a dissolvable ball is deployed independently from the pump down assembly, it will pass an open collet and provide a distinct pressure signal, confirming its position when it lands in a closed collet, which prevents further passage of the ball. These pressure changes inform operators of the ball's whereabouts and the amount of pressure needed for movement. The ball can then be used as a plug to facilitate the stimulation and creation of an induced fracture of the formation through the ports of the sleeve.

Seal validation test fixtures are used to confirm seal performance under specific temperature, pressure, and dimensional constraints. Successful results are influenced by several interdependent factors, including extrusion gap size, seal type, lubricant selection, assembly configuration, and the use of backup rings. These parameters are tailored to the target geometry and operating temperature range. In applications requiring increased durability or elevated temperature capability, metal seals may be used to supplement or replace elastomeric seals.

To address earlier sealing issues, the design team consulted multiple seal manufacturers with relevant industry and application experience. Several seal options were down-selected based on confidence in the proposed solutions and the responsiveness of the vendors—particularly their willingness to develop custom designs tailored to the application requirements.

Surface qualification testing is a critical step in tool development and performance validation. It is well known that seals can be the *Achilles' heel* of a system, especially in high-temperature, high-pressure (HTHP) environments. Ensuring that seals and other critical hardware perform as required under expected operating conditions de-risks initial deployment and enables rapid iteration if issues are identified. While testing new technologies downhole is ultimately necessary, it is costly and inherently increases operational risk. Rigorous surface testing can dramatically reduce these risks.

As part of the design phase, a range of seal options are being tested under simulated downhole conditions, including significant temperature variations that will be experienced in an EGS injector: 60°F (15°C) → 450°F (230°C) → 130°F (55°C), rapid high pressure events up to 10,000 psi that will be experienced during fracture stimulation, port pass-through events, rapid shifting, and shifting while pressurized, to ensure reliable performance. Unlike the previous tool design, where seal drag force was a limiting factor, the updated design is not constrained by this parameter, allowing for a broader range of seal selections.

Figure 1 shows images of the test rig dedicated to surface performance validation of the seals under evaluation. Figure 2 presents the seal qualification test demonstrating the successful pressure-holding performance of the seals at a range of temperatures while undergoing multiple pressure cycles. Figure 3 presents a detailed view of the qualification testing emphasizing successful pressure-holding performance of the seals after heated to reservoir temperature then cooled to simulate fracture stimulation cooling effects while undergoing multiple pressure cycles. Figure 4 presents a different seal that passes the high temperature / high pressure test. However, when the system is cooled, simulating the cooling effect of the frac fluid on the wellbore, and the seal is retested, the seal has failed and it is no longer capable of holding pressure.

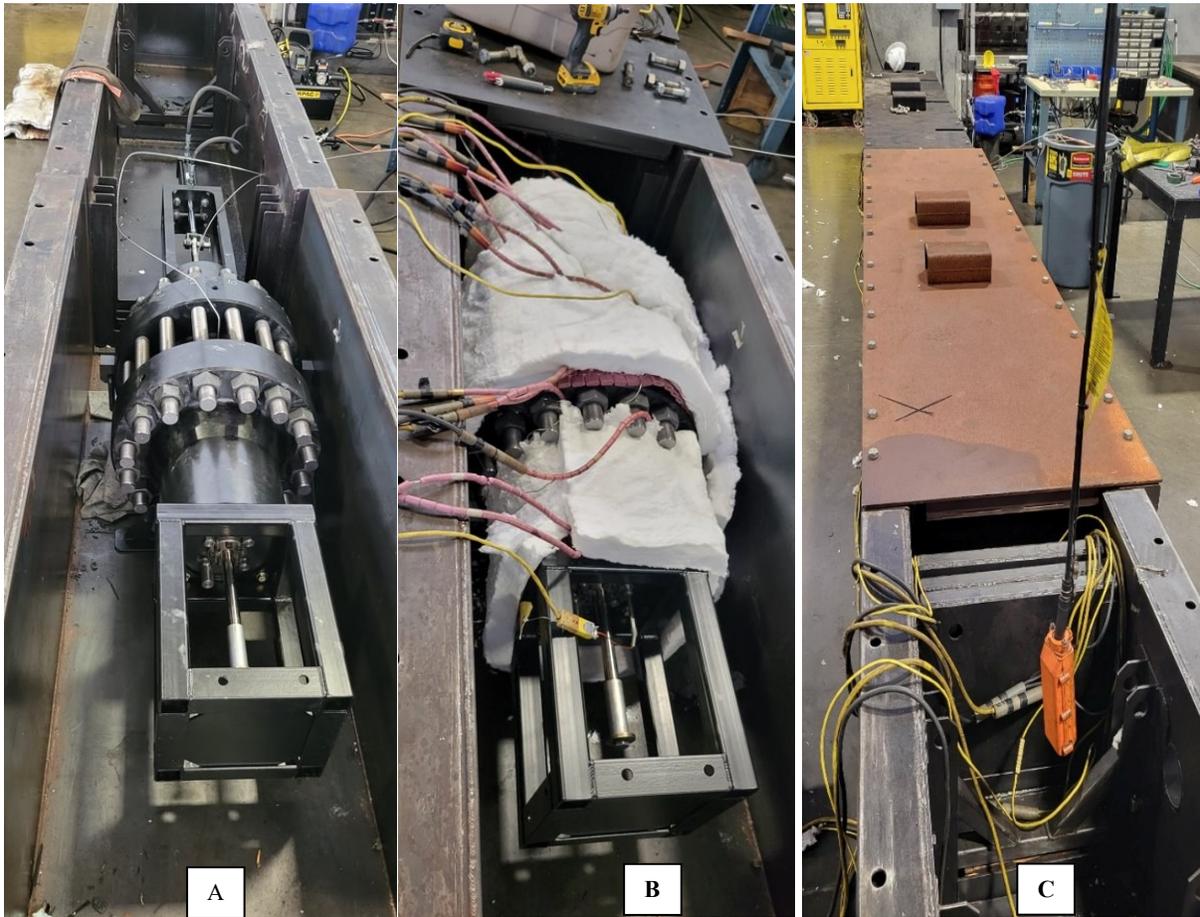


Figure 1. Seal Test Rig A) Without Heaters and Insulation B) With Heaters and Insulation C) Contained for HTHP Testing

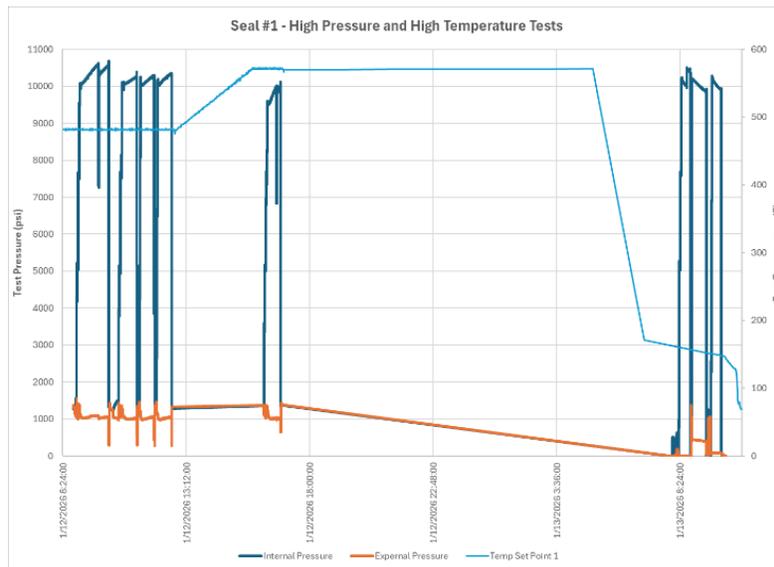


Figure 2. Seal #1: Qualification Tests

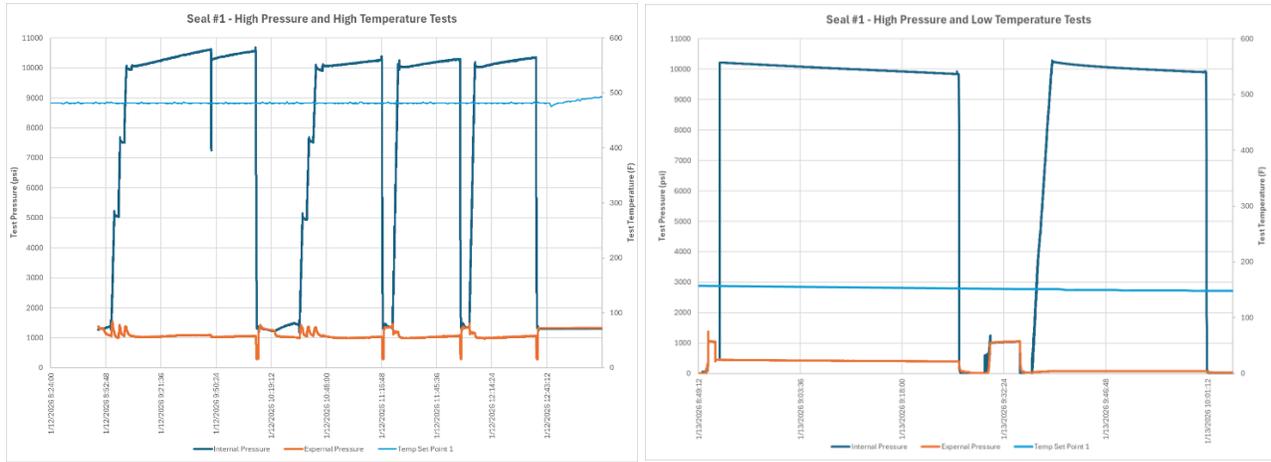


Figure 3. Seal #1: Expanded View of Qualification Testing

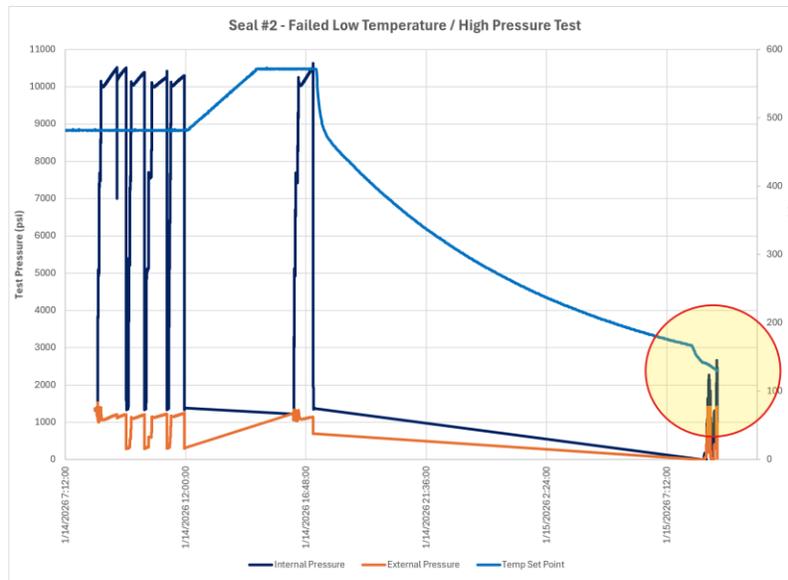


Figure 4. Seal #2: Failed High Pressure / Low Temperature Seal Test After Heat Up & Cool Down

The seal component testing proved to be a critical step in the design process. Four seals were tested by reputable manufacturers. Two sets of rod seals that were part of the pressure vessel and two sets of primary sleeve seals (Seal Under Test). All sets of seals were rated at 250°C and 10,000 psi. However, only 1 set of rod seals and 1 set of primary sleeve seals withstood the test temperatures and pressures. This is critical information indicating that without extensive temperature and pressure testing at surface, there is no way of knowing if the seals will perform as required in the wellbore.

Additional component level and full assembly testing are planned. Additional component level testing during the design phase will evaluate collets and regulator ports. Later, comprehensive system testing in a large scale, heated pipe run will verify actuation, and regulator flow performance. Together, these efforts are intended to maximize the likelihood of success during field deployment.

To improve both economics and reliability, the new generation frac sleeve has been significantly simplified compared to its predecessor. The redesigned tool incorporates nearly 50% fewer custom-machined components and is approximately half the overall length, substantially reducing raw material requirements. In addition, the number of internal connections has been reduced by half (from four to two), there is a significant reduction in sealing interfaces (from nine to two), and the tool outside diameter (OD) was reduced to fit in a standard 8-1/2” hole for 7” casing. Collectively, these design changes reduce manufacturing complexity, assembly time, and hardware cost while minimizing potential leak paths and mechanical failure modes, thereby improving overall system reliability and economics.

3. ACTUATION SYSTEM

As illustrated in the figures, the sleeve is actuated via a pump-down actuator or shifting assembly, analogous to the pump-down plug-and-perf system commonly utilized in shale horizontal well completions. The operator hydraulically positions the pump-down actuator by

referencing surface pressure and pump rate data, wireline tension and depth readings, and identifying location pressure spikes as the tool traverses the wellbore. Collets assist in spacing the actuator relative to the inner sleeve. The pump-down actuator receives both instructions and power through an electrical wireline connected to the surface, and in certain scenarios, a wireline tractor may provide additional assistance.

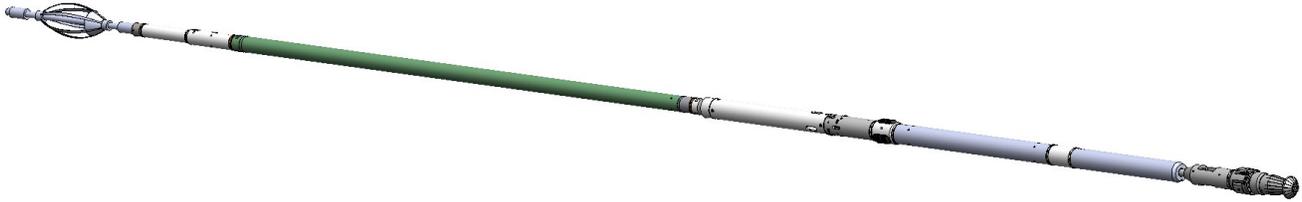


Figure 5. Pump down actuation tool assembly.

Force is necessary to overcome resistance from the collet fingers, which must be displaced to allow the pump-down actuator or balls to pass each sleeve. As a dissolvable ball, locator, or plug passes through these fingers, it generates a pressure signal and a corresponding change in wireline tension, informing the operator of the number of sleeves traversed. Within the wireline unit, the operator utilizes a depth indicator, surface wireline tension, pressure readings, fluid volume pumped, and other position detection methods—including CCL or load cell data—to track sleeve passage until the target sleeve is reached. An expandable collet locator is partially opened to act against the sleeve collet to determine the relative position of each one of the sleeves (Figure 6) as the tool travels downhole.

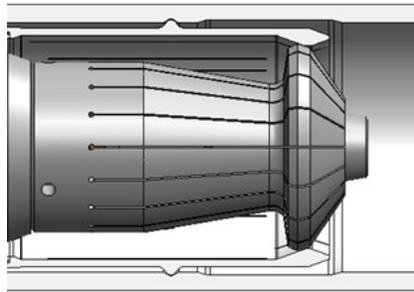


Figure 6. Pump down actuation tool collet locator partially opened.

Additionally, pump-down assemblies may employ spring-loaded keys that indicate location based on the axial force required to retract and compress the spring, thereby identifying specific profiles. Alternative locating methods, such as spring-loaded drag dogs used in slickline operations, can also be integrated; these are designed to expand each profile and provide positive location confirmation.

When the relative position of the selective sleeve is located, an internal hydraulic mechanism inside the pump down actuator tool activates an expandable collet. This collet acts as a seal indicator against the inner sleeve collet fingers showing a pressure spike, this change in pressure indicates that the pump down actuator tool is making direct contact with the inner sleeve collet to determine the position of the locking profile inside the sleeve (Figure 7).

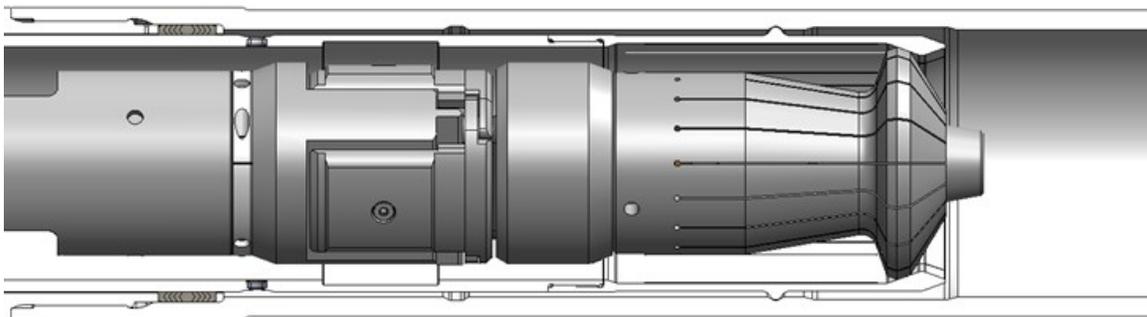


Figure 7. Pump down actuation collet locator fully opened.

Once the pump down actuator is in position, the locking dogs are extended hydraulically from the actuator tool assembly to provide full locking engagement with the profile allowing compressive force to be hydraulically applied to the profile compression shoulder (Figure 8). This compressive force releases the inner sleeve for movement to the sleeve's second position.

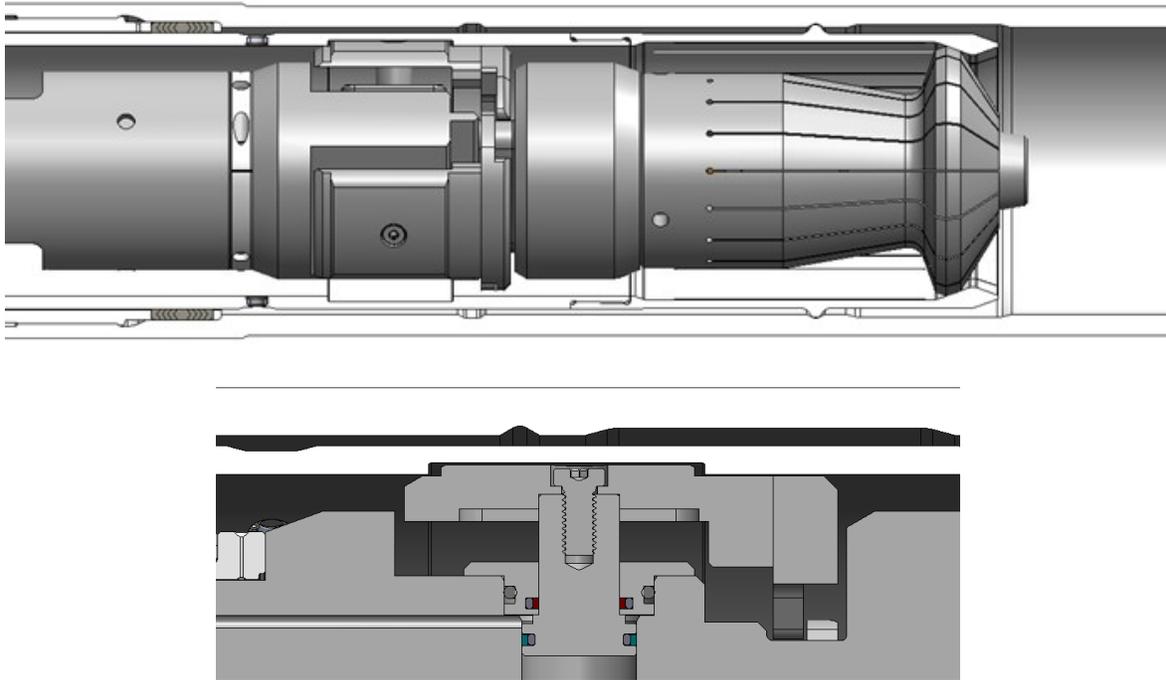


Figure 8. Locking dogs extended into the sleeve profile.

Once the locking dogs are engaged in the sleeve, the collet locator is closed and pump pressure from surface is applied to shift the sleeve from close to open position (Figure 9). The surface pump can also supply the compressive force to release the inner sleeve from the releasable engagement with the outer sleeve housing or disengage the detent mechanism from the initial indexed position to the next desired indexed position. The locking dogs and seal assembly simultaneously engage with the inner sleeve to provide a sufficient seal effective to allow pressure from surface to be distributed over the large cross-sectional area to supply a pressure/area compressive force sufficient to shift the sleeve from one position to another.

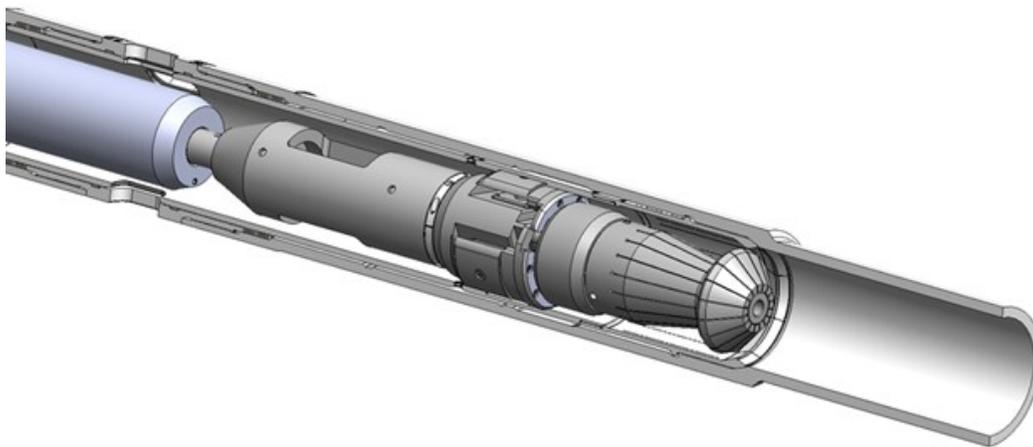


Figure 9. Sleeve shifted from close to open position by Actuation Tool using pump pressure.

In the case of pump pressure not being sufficient to shift the sleeve and further assistance is needed; the actuation tool includes a linear shifting mechanism and anchor system controlled hydraulically by a set of solenoids that adds additional force to shift the sleeve (Figure 10). This system was proved in our tractor assembly at ambient temperature in a pull test that demonstrated axial force generation of approximately 20,000 lbs.

The same process as described above can be utilized for the actuation tool to locate the correct sleeve and engage the locking dogs into the sleeve profile. Once in position the same process of setting the slips and using the solenoids to hydraulically retract the linear shifting mechanism, pulling the inner barrel of the sliding sleeve from the open “Frac” position to the “Regulator” position for long term injection.

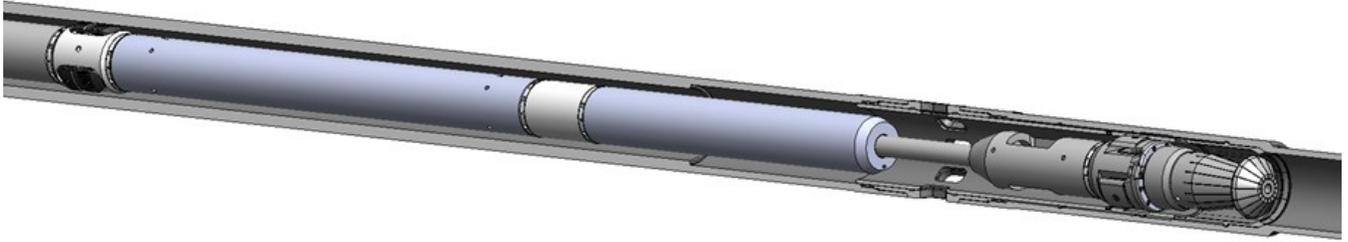


Figure 10. Sleeve shifted from close to open position by Actuation Tool using hydraulic shifting.

4. TRACTOR SYSTEM

The tractor incorporates components rated for high temperatures, including a cable head, swivel joint, casing collar locator, and a high-resolution temperature and pressure real-time sensor package, all commonly employed in oil and gas operations at temperatures up to 500°F (260°C). Analysis of electronic component failure reports from EGS wells indicates that many electronics typically fail between 155°C and 175°C. A review of potential protective methods identified flasking as the most effective option for safeguarding electronics in high-temperature environments.



Figure 11. Tractor module assembly

Modeling results demonstrate that flasking maintains internal electronics below the 175°C threshold for a 12-hour duty cycle at a wellbore temperature of 225°C. The design was enhanced by removing coiled tubing, allowing for modularity and enabling pump-down capability. Electronic section assembly is protected from elevated wellbore temperatures by an insulating flask similar to those used in thermal applications. The electronics section utilizes PC boards rated for continuous operation at 350°F (175°C), with the flask providing protection at 440°F (225°C) for up to 12 hours—sufficient for production logging and downhole sleeve operations. Actual wellbore duty cycles may vary based on cooling effects from injection water, absence of cooling in low-flow or undisturbed wells, in-situ temperature variations, and heat generated within the flask. Mission-critical components were validated to endure a 12-hour duty cycle at 225°C.

National K Works - Theoretical temperature profile
 20-Sep-22
Project: KS-001
Flask dimensions: 3.75 OD x 2.96 ID, 20,000 psi
Flasked portion: 86.0 long, including 2.0 of insulator
Chassis: Compilation of components totaling 76.9 lbs, 17,524J/K
Heat Sinks: Compilation of components totaling 16.1 lbs, 2,817J/K

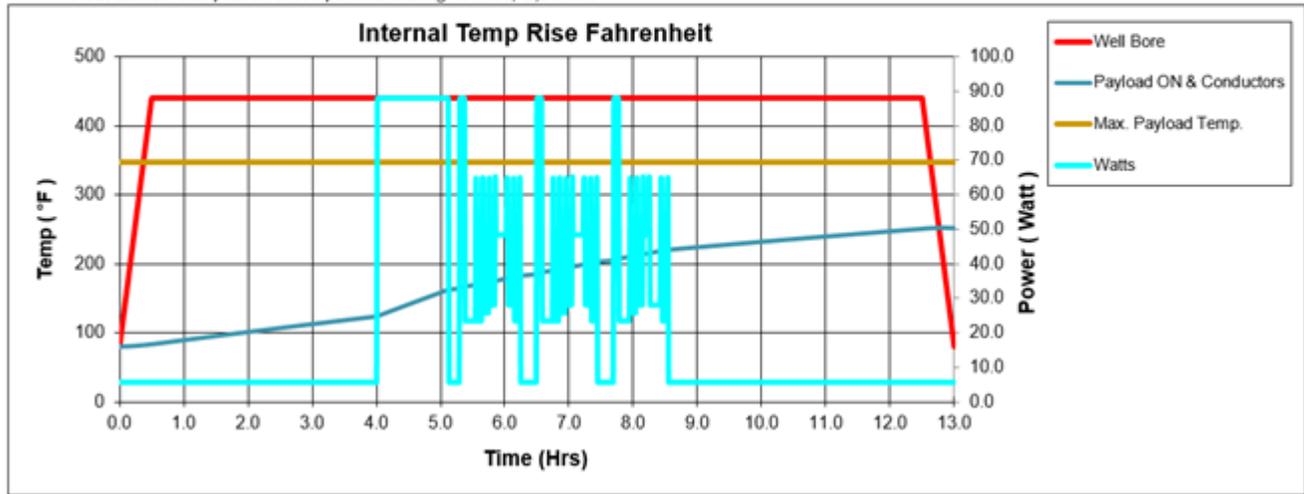


Figure 12. Simulated Flask Performance shifting 3 sleeves.

The tractor modules were tested and operated individually; a wheel pull test was performed confirming reliability at 425 lbs. linear force per wheel sub-assembly. All tractor components successfully passed operational temperature tests.



Figure 13. Tractor module wheel extended.



Figure 14. Tractor module wheel retracted.

5. CONCLUSIONS

The Generation 2 EGS Fracturing and Conformance Control System is a selective sleeve designed for cemented casing or liner strings, actuated to the stimulate position via a pump down wireline system. It features three positions: closed (deployment), fully open (frac stimulation), and regulator (controlled flow), simplifying operation in horizontal wells and maintaining full bore inner diameter thus allowing passage of tractors while remaining cost-competitive with "Plug and Perf" systems. The sleeve can be selectively opened fully or to the regulate position using a wireline or tractor-conveyed actuator, which is removed after actuation to the fully opened position to

enable stimulation or to the regulate position. The sleeve and actuation system was successfully re-designed to overcome the seal failures of the Generation 1 system and now fits a conventional hole size for 7” casing. We successfully qualified the sleeve seals to 10,000 psi and 250°C, with low seal drag frictional forces at all temperatures and pressures. An additional qualification test was performed on the selected seal to verify the seal was capable of operating at 300°C and 10,000 psi with a cool down test at 65°C and 10,000 psi. The sleeve project is scheduled for a System Integrity Test (SIT) Completion by 4/15/2026, and sleeve availability for field demonstration deployment by 5/15/2026.

REFERENCES

Doe, Thomas, Robert McLaren, and William Dershowitz. 2014. "Discrete Fracture Network Simulations of Enhanced Geothermal Systems." Stanford, CA: Thirty-Ninth Workshop on Geothermal Reservoir Engineering.

Fercho, S., Norbeck, J., Dadi, S., Matson, G., Borell, J., McConville, E., ... & Rhodes, G. 2025 Update on the Geology, Temperature, Fracturing, and Resource Potential at the Cape Geothermal Project Informed by Data Acquired from the Drilling of Additional Horizontal EGS Wells. Paper presented at the Thirtieth Workshop on Geothermal Reservoir Engineering, Stanford University.

Fleckenstein, W. W., Kazemi, H., Eustes, A. W., Mindygaliyeva, B., Amini, K., Hill, T., Mailand, J., Henschel, R., King, G., Ortiz, S., Cantu, Mariel, Mays, P., and Garrett Casassa. "Development of Multi-Stage Fracturing System and Wellbore Tractor for Zonal Isolation During Stimulation Processes in Horizontal Wells Intended for EGS Operations – Lessons Learned for Development of Next Generation Fracturing Systems." Paper presented at the SPE Annual Technical Conference and Exhibition, Houston, Texas, USA, October 2025. doi: <https://doi.org/10.2118/228044-MS>

Fleckenstein, W. W., Kazemi, H., Miskimins, J. L., Eustes, A. W., Abdimaulen, D., Mindygaliyeva, B., Uzun, O., Amini, K., Hill, T., Mailand, J., Henschel, R., King, G., Ortiz, S., and C. Keyes. "Development of Multi-Stage Fracturing System and Wellbore Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores – Third Year Progress Report." Paper presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, September 2024. doi: <https://doi.org/10.2118/220758-MS>

Gringarten, W. A., A. P. Witherspoon, and Y. Ohnishi. 1975. "Theory of Heat Extraction from Hot Dry Rock." (Journal of Geophysical Research) 80, 1120-1124.

Mays, P.; Fleckenstein, W.; Kazemi, H.; Amini, K.; Mindygaliyeva, B. "An Economic Evaluation of Parasitic Losses and the Impact of Conformance Control on Parasitic Losses in an EGS Horizontal Well." Transactions - Geothermal Resources Council 48: 657-681 2024 ISSN/ISBN: 0193-5933

McLennan, J., England, K., Rose, P., Moore, J., and Barker, B. 2023. Stimulation of a High-Temperature Granitic Reservoir at the Utah FORGE Site. Presented at the SPE Hydraulic Fracturing Technology Conference and Exhibition, The Woodlands, TX

Mindygaliyeva, Balnur and Uzun, Ozan and Amini, Kaveh and Kazemi, Hossein and Fleckenstein, William Winfrid, Assessment of Two Recent Hot Dry Rock Thermal Energy Production Projects. Geothermics, Volume 122, 2024, SSRN: <https://ssrn.com/abstract=4675948>

Norbeck, J. H., and Latimer, T. M. 2023. Commercial-scale demonstration of a first-of-a-kind enhanced geothermal system. <https://eartharxiv.org/repository/view/5704/>.

Olasolo, P., Juárez, M. C., Morales, M. P., D’Amico, S., & Liarte, I. A. (2016). Enhanced Geothermal Systems (EGS): A review. Renewable & Sustainable Energy Reviews,

Olsen, J; Augustine, C; Eustes, A. W.; Fleckenstein, W. W.: "Design Considerations for Applying Multi-Zonal Isolation Techniques in Horizontal Wells in a Geothermal Setting", Fortieth Workshop on Geothermal Reservoir Engineering Proceedings, January 26-28, 2015, Palo Alto, California, USA

Ortiz, Santos, KSWC Engineering and Machining, Document No, 746.001 Rev A, "1-2551 Project Status Phase 1", Report prepared for Colorado School of Mines for UTAH FORGE, Houston, Texas, USA November 9, 2022.

Rytlewski, G. L., & Cook, J. M. (2006, January 1). A Study of Fracture Initiation Pressures in Cemented Cased-Hole Wells Without Perforations. Society of Petroleum Engineers. doi:10.2118/100572-MS

Webb, Patrick David, Gauthier, Joshua , and Craig Skeates. "Field Trial Results of Ball Activated Outflow Control Devices for SAGD." Paper presented at the SPE Annual Technical Conference and Exhibition, Calgary, Alberta, Canada, September 2019. doi: <https://doi.org/10.2118/195877-MS>

Yuan, Feng, Blanton, Eric, Convey, Brent, and Chris Palmer. "Unlimited Multistage Frac Completion System: A Revolutionary Ball-Activated System with Single Size Balls." Paper presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, USA, September 2013. doi: <https://doi.org/10.2118/166303-MS>