Cemented Frac Sleeve and Hi Temp Tractor for EGS

1. **Development of Multi-Stage Fracturing System and Wellbore Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores**
   - Organization or Affiliation: Colorado School of Mines, Golden Colorado
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   - Subcontractors and/or Participating Organizations: Tejas RE and KSWC, Houston Texas
   - Project Start and End Date: October/2021 – September/2024

2. **Project Objectives and Purpose**
   - **Goal 1:** Develop and demonstrate the use of a low-cost and rapid multistage fracture stimulation technology with cemented casing frac sleeves that eliminates packers.
   - **Goal 2:** Develop and demonstrate the devices to effectively detect and control flow of heat-carrier fluid solely from a long-reach injector through the network of induced and existing fractures and produced from a barefoot long-reach well to improve heat recovery.
   - Our project is a step change in achieving the DOE vision and goal to use the FORGE site to create a commercial pathway for large-scale, economically viable EGS. The focus of our research is developing economic, scalable completion methods for EGS using long-reach, horizontal geothermal wells. The use of cemented sleeves allows the casing to act as both the frac string and as the injection/production string. The cement sheath provides an annular barrier. Frac sleeves have been successfully cemented and used in oil and gas shale development walls; however, typically with sealing ball receptacles require a telescoping size from large to small (at the far end) with each sleeve that make it impossible to fit tools through them that are needed for injection and production conformance control. This project also develops a high temperature downhole tractor for horizontal wells. It will be tested at geothermal conditions in experimental facilities and then in a FORGE well. The tractor has fluid flow survey capability to detect "short circuiting" and shifting capability to plug or choke fluid movement through the sleeves based on real time fluid survey data. Unlike in oil field waterfloods, which use an inner tubing string with packers for waterflood conformance control, these methods have proven problematic at geothermal temperatures with the thermal tubing forces on packers and the inherent rate restrictions of tubing.
   - The tractor being developed will have the capability to be deployed on either a wireline or coiled tubing with a hydraulic sleeve actuation system that can be decoupled from the tractor. The actuation system could be used with coiled tubing or in pump down mode, with no tractor or coiled tubing for conveyance. This ability for customization will provide the flexibility and low cost for an economic EGS system. The research of this project is critical to developing a multi-stage stimulation technique incorporating a single sized, large ball, casing frac sleeve. The multi-stage stimulation technique has been applied successfully to reduce costs in unconventional oil and gas wells but not in geothermal wells, primarily due to material failures in tools. The use of cemented sleeves allows the casing to act as both the frac string and also as the injection/production string. The annular cement sheath provides both a barrier to confine the fracture growth, but also distributes the thermal loading from the casing to the cement to prevent the severe thermal forces. Frac sleeves have been successfully cemented and used in oil and gas shale development walls, but typically with telescoping sizes of the ball receptacles in each sleeve it is impossible to fit tools through that are needed for injection and production conformance control.
   - This project also develops a high temperature downhole tractor for horizontal wells for geothermal conditions. The tractor has fluid flow survey capability to detect "short circuiting" and capability to plug or choke fluid movement through the sleeves based on real time fluid survey data. The tractor being developed will have the capability to be deployed on wireline or coiled tubing with a hydraulic sleeve actuation system that can be decoupled from the tractor and used with coiled tubing or in pump down mode, with no tractor or coiled tubing for conveyance. This ability for customization will provide the flexibility and low cost needed to provide an economic EGS system.

- Finally, in an area beyond the scope of our project, the tools developed will be able to alleviate some of the conditions for induced seismicity prior to field operations, with associated modeling to demonstrate.

3. Technical Barriers and Targets

- Multistage Hydraulic Fracturing: Conventional stimulation tools have a variety of inherent limitations for EGS applications; Packers and bridge plugs have a variety of leak paths that must be sealed with elastomers in the presence of severe thermal stresses resulting from high geothermal temperature. Packers and bridge plugs must grippingly and sealingly engage the wellbore and maintain the seal throughout the life of the EGS well in the face of geothermal temperatures. Packers and tubing strings either increases the diameter of the wellbore to support desired injection and production rates or limits those rates. Frac sleeves are mechanically simple with an outer tubular that connects to the casing string with a port and an inner tubular that moves downward when a ball lands in it to uncover that port. Thousands of frac sleeves have been successfully used in the oil and gas industry. The primary difficulty with frac sleeves is the method of locating the correct sleeve, which relies on a series telescoping balls of increasing size from the toe to the heel of the horizontal well, and limits tools that can traverse those sleeves.
- Conformance Control: The same difficulties listed above exist for conformance control of the injected fluids to ensure that the heat is harvested from the entire heat exchange drainage volume (HEDV). In addition, sleeves need to have modest ID restrictions and allow passage of tractor or non-tractor conveyed conformance tools. Further, the sleeve needs to have the ability to be located by the conformance tools and repeatably be shifted as desired for conformance control operations.
- The frac sleeves are planned to use a single-sized dissolvable ball to open for a subsequent fracture stimulation eliminating many of the challenges for multi-stage fracturing. The sleeve design was successfully built into a Prototype Solidworks model of a functional sleeve. An animated model was developed, and FEA was used to look at both the fluid impacts and resulting stresses on the system, with acceptable Safety Factors for 8,000 psi burst pressures expected during treatment.
- Proof of Concept test fixtures were built to test the ball catch mechanism and seal drag.
- The Collet Ball Catch mechanism was a technical barrier. The 5.75” ball catch/release was successfully tested for a Collet Load Test, first with a mechanical test then with a flow test.
- We have performed at least 16 seal drag tests and are working to overcome temperature and pressure limits.
- A separately designed wellbore tractor, capable of both fluid detection and valve manipulation, is in development. Elevated temperatures was identified as a major risk to system electronics.
- Reviewed technical risk of tractor options and determined hybrid electromechanical/hydraulic drive utilizing electromechanical wheel system powered surface wireline system is the best option. This is a change from the original plan of a mud motor driven tractor using coiled tubing, but within the original project plan to consider alternative tractor designs.
- Completed detailed assembly design drawings other than drive chassis and pressure balance assembly.
- Acquired primary tractor and actuator design and build and transferred from Defiant to KSWC.
- Identified flasking as a solution to heat dissipation and identified a suitable Flask company (NKW).
- Modeling of flasking provided assurance that 175C temperature lasted for 12 hours estimated duty cycle at 225°C wellbore temperature. Completed all testing of board assemblies to 175 F. Tested mechanical hardware including pressure gauges, solenoids, sensors, and revised PC boards. Segmented out actuator design to operate independent of tractor which allows use of pump down and coiled tubing deployment.

4. Technical Approach

- The design approach is flexible and heuristic and is not anchored on any preconceived biases that may interfere with a successful final product. This design approach uses Failure Mode Effects and Criticality Analysis (FMECA) meetings, review, and update schedules as required. This process began before the FOA was announced and has continued throughout the project.

- Prior to the FOA, the team considered methods to modify frac sleeves and tractor technology used in the oil and gas industry. Existing methods were examined over a multi-year period and concepts were tested and prototyped through the Mines Senior Capstone Design Program.
- Existing methods were re-examined in light of the FOA. Composite bridge plugs used in "perf and plug" completions are unable to perform at geothermal temperatures and conventional bridge plugs, even if able to perform at higher temperatures, will be unable to be removed by drilling and will necessitate the slower removal by a rig, needing each plug to be unset and pulled to the surface. Dissolvable balls have no moving parts and must survive only long enough to have a fracture stimulation performed against them. Current dissolvable balls easily dissolve at the temperatures considered and take advantage of the cooling of the wellbore during stimulation. Frac sleeves have been used for many years, but the use of single sized balls was not possible until the funding for development by Tejas RE of Fleckenstein's next generation hydraulic sleeve designs. A high temperature electro-hydraulic tractor is being developed which improves upon the proposed coiled tubing hydraulic tractors and replaces the high cost and slow coiled tubing with a electric tractor and hydraulic actuation system that can be used with coiled tubing, an electric tractor or in it simplest and least expensive form, as a pump down tool on wireline, using the high rate injection fluid to move the tools to the sleeve(s) that are causing the short circuiting, and close those sleeves.

5. Project Timeline (list milestones achieved and/or decision points)

- Milestone 1.1.1 – Revised PMP was completed (12/31/2021)
- Milestone 1.2.1 – Preliminary Engineering for the Frac Sleeve is completed (6/31/2022)
- Milestone 1.2.2 – Sleeve Basic Eng. Seal Drag & Collet Load Test (8/31/2022)*
- Milestone 1.3.1 – Initial Tractor Project Planning 2/28/2022
- Milestone 1.3.2 – Initial Tractor Design 8/30/2022
- Milestone 1.3.3 - Constructed ambient temperature prototype testing system 11/30/2022
- Milestone 1.3.4 - Assessed existing high temperature motors, electronics, and tools 11/30/2022
- GO/NO GO #2: - Test mission critical components of initial prototype. 11/30/2022

* Milestone 1.2.2 is be completed with manufacturing of Test Fixtures. The Milestone 1.2.2 calls for Basic Engineering to be completed – approved proof of concept design for subcomponents and authorized for manufacturing and testing, completed Collet Load testing, and completed 16 seal drag load tests. Will complete Milestone 1.2.2 with completion of Seal Drag and Fluid Timing system testing

6. Technical Accomplishments

- The next generation hydraulic sleeve design was successfully built into a Prototype Solidworks model of a functional sleeve with acceptable Safety Factors for 8,000 psi burst pressures expected during treatment. The Solidworks model is an important benchmark and meets milestones, 1.2.1, 1.2.2 (with the exception of the fabricated test fixtures) and will facilitate design modifications for both the sleeve and tractor.
- Seal Drag Test and Collet Load Test Fixtures were fabricated and effective in testing sleeve components.
- The 5.75" ball Collet Load Test was successful, first with a mechanical test then with a flow test. The collet did not damage the Frac Ball during multiple pump throughs. The system was highly repeatable when catching and releasing the frac ball. The target forces obtained were within the original design intent.
- Assessed of existing tractor proto-types and other tractors and chose a electromechanical/hydraulic tractor design with available components without coiled tubing.
- Completed manufacturing key components such as the full latch anchor assembly and solenoid bodies.
- Completed layout of electronics chassis and tool wire routing. Started assembly of latch bodies for testing. Completed design of the high temperature swivel.
- Completed Go/No-Go #1 – Critical Tractor Components Tested to 225°C at 12 hour duty cycle with flask.
- The actuator design was segmented out to operate independent of tractor. This allows use of pump down and coiled tubing deployment with or without a tractor.
- Built and ran a stochastic cashflow model to quantify the effect of conformance control on EGS economics.

7. Challenges to Date

- Supply chain issues impacted design choices as lead times for certain components for testing became unrealistic. Component availability and previous testing of an electro-mechanical tractor design by Defiant was available for immediate use. This elevated the chance of success by starting with a wireline tractor that could be modified for use with coiled tubing.
- The sleeve must work for the project to be successful; and the tractor must support the successful design and operation of the sleeve. The tractor initial design period was kept open as the tractor design had to integrate with the sleeve design. The sleeve testing program was modified to include capabilities of integrating with the tractor and rebudgeting was needed to free additional funds for continued seal testing.
- Firmware delays on controllers for the tractor are an example of supply chain complications as well as materials and machining availability for components have doubled lead times. We are using more modeling to minimize risk of component failure.

8. Conclusion and Plans for the Future

- We have successfully completed the first year and second year Frac Sleeve Technology Development and the complementary Tractor Design, Build, and Test program but with some impacts on scheduling due to supply chain and seal testing complications. We are on schedule for field testing at FORGE in 2024 and are exploring other opportunities for field testing as well.

9. Geothermal Data Repository

- Data sets have been uploaded to the GDR for analysis of Pressure Falloff in Stage 1 of Well 16A(78)-32 in PPT and PDF formats. DFIT analyses of 2021 Data, and Stages 2 and 3 (April 2022). A 3-D heat transfer code for use in HF and well spacing design.

10. Publications and Presentations, Intellectual Property (IP), Licenses, etc.

Mindygaliyeva, B., Uzun, O., Kazemi, H., Amini, K., and Fleckenstein, W. W., "Experimental Fracture Creation in Cores: Permeability and Porosity Measurements of the Fractured Cores and the Use of Such Measurements in Analysis of Pressure Falloff Tests Following Well Stimulation" 57th US Rock Mechanics/Geomechanics Symposium, 25-28 June 2023, Atlanta, Georgia, USA, Fleckenstein, W. W et al, "System To Enable Multi-stage Stimulation And Enhanced Geothermal System Operations In Parallel Horizontal Wellbores", SPE-210210-MS, SPE Annual Technical Conference and Exhibition, October 3-5, 2022, Houston, Texas, USA. (Will be peer reviewed), "Let's Come Clean, Is Net Zero Achievable?", Nabors Energy Transition Panel at 2022 OTC, Houston TX, April 28th 2022, "GeoThermOPTIMAL-Renewable Energy 24/7", Enercom - The Energy Venture Investment Summit, Golden, Colorado, February 17, 2022, Fleckenstein, W. W, Miskimins J. L., Eustes, A. W, Kazemi, H., Hill, T., Mailand, J., Ortiz, S., and King, G., "Development of Multi-Stage Fracturing System and Wellbore Tractor to Enable Zonal Isolation During Stimulation and EGS Operations in Horizontal Wellbores", The Geothermal Rising Conference 2021 (GRC), October 3-6, 2021, San Diego, California, USA. GRC Transactions, Vol. 45, 2021, Provisional Patent Application filed August 26, 2021 and has been filed as a Patent application August 25th, 2022; "System and Method for Harvesting Geothermal Energy from a Subterranean Formation" (Serial No. 63/237,425) with office action in progress.

11. Publicity and outreach (Optional)

- We have given numerous media interviews, presentations to Senator Hickenlooper's staff, Boulder's Innovation Center, CREA Energy Innovations Summit, CEATI Executive Roundtable, the Heiland Lecture, EGS Innovators Roundtable and Dr. Fleckenstein traveled to Washington DC in Sept. 2022 and lobbied the Colorado Congressional and Senate Delegations, and numerous other politicians and Administration officials in support of geothermal research appropriations. Dr. Fleckenstein is scheduled to repeat this trip in Sept. 2023.