PROCEEDINGS, 47th Workshop on Geothermal Reservoir Engineering
Stanford University, Stanford, California, February 7-9, 2022
SGP-TR-223

Moving Technology from Oil and Gas to SuperHot EGS

AltaRock Energy

spetty@altarockenergy.com

Keywords: SuperHot, fracturing, stimulation, EGS, Oil and Gas

ABSTRACT

The oil and gas industry has made enormous strides in the development of fracturing technology since the late 1970s when fracturing first became a significant part of the industry. Multistage fracturing, proppants, microseismic fracture mapping and advanced fracturing fluids combined with horizontal drilling has allowed the recovery of oil and gas stored in very low permeability formations. This has significantly extended the availability of these fossil fuels for energy production. A long period of low prices for oil and gas along with the concerns about CO2 emissions and global climate change has resulted in a return of interest in geothermal energy on the part of oil and gas and service companies. Can the technologies that made the shale revolution possible be applied to geothermal energy? This paper examines the similarities and differences between geothermal and oil and gas and suggest the areas where technologies developed for oil and gas can be applied to geothermal to reduce the cost and risk in producing geothermal heat and power.

1. INTRODUCTION

Enhanced Geothermal Systems (EGS) and unconventional oil and gas extraction appear at first look to be trying to accomplish the same thing: Moving fluids from very low permeability rock into the wellbore. However, in geothermal reservoirs the heat is stored in the solid rocks and the fluids moving through the fractures is transferring that heat to the wellbore. In a shale reservoir, hydrocarbons are stored in the pore space in the rock. The fractures access that pore space to allow the hydrocarbon fluids to move to the wellbore. Also, oil and gas are commodities that can be sold once they reach the surface. Geothermal heat needs some kind of energy conversion system: A power plant either binary or steam, or a heat exchange system for direct use of the heat is required at the surface to enable us to use the heat. Moving the heat long distances from the well is generally not economic due to heat loss from piping even with insulation so the heat must be used where the well is drilled.

Early efforts to use stimulation technology in geothermal focused on high temperature rock at relatively shallow depths. Because the energy density of geothermal fluids produced in the temperature range where drilling tools, bits, instrumentation and completions were possible is low, very high flow rates are needed to make drilling for these resources economic. The initial focus in technology development for stimulation in geothermal was therefore on producing high flow rates using massive hydraulic fracturing methods. It was clear that in order to produce these high flow rates, large diameter completions with either open hole or hung perforated or slotted liners were needed to avoid high pressure drop that would result in loss of energy to pumping. High surface area to fractured rock volumes are needed to extract heat as close to possible to the rock temperature and maintain that temperature over long periods of time.

While packers and other mechanical ways to isolate zones for fracturing were available for temperatures encountered in oil and gas, these devices failed regularly in geothermal stimulation efforts. Packers set in the open hole failed to hold or release or fractures grew around the packer without extending away from the wellbore. Cement and perforate completions typically used in oil and gas that would have made it possible to set packers against casing resulted in high pressure drop as the fluid entered or exited the wellbore. Fracturing fluids clumped up or lost viscosity even at lower geothermal temperatures and carbonized at high temperatures. Proppants dissolved or failed to stay in place in production wells. Horizontal drilling methods were expensive at high temperature and weren't applicable to geothermal since these techniques are used to follow a thin sedimentary layer over long distances. The result was that most geothermal fracturing was done by bull heading cold water from the surface for extended periods to create a massive volume of fractured rock to get good heat exchange. Hydroshearing with self-propping and thermal contraction of the rock kept fractures open. One primary exit point from a well deviated to be orthogonal to the direction that fractures would form created large complex fracture networks. However, flow rates were limited to 30-40 kg/s due to the lack of ability to create multistage fractures.

Drilling for very high temperature rock, above the critical point for water, can increase the energy density for geothermal fluids and therefore improve the economics of geothermal energy development. What technology from unconventional oil and gas development can be applied now at these very high temperatures and what needs to be developed for the future? We can drill deviated wells with the large diameters needed to reduce pressure drop. We have cements for temperatures up to about 350C and well designs using casing materials that will withstand the temperature and possible corrosivity of the produced fluids. Casing connections have been an issue in these very hot wells, but advances that include expandable casing connections, advanced thread designs and sealing sections are now available that should solve these problems. Logging tools, instrumentation for measurement while drilling and steering can be heat shielded and run in the cooled wellbore. While zonal isolation using the sliding sleeve devices and packers used in oil and gas is not yet available, setting scab liners using external casing packers (ECPs) with metal to metal seals can allow isolating sections of the well for multizone stimulation. Thermally degradable zonal isolation materials that allow for diversion of fractures both near the wellbore and in the far field can help to create complex fracture networks. While microseismic monitoring, initially developed for the geothermal industry and advanced by the oil and gas industry, is used in geothermal fracture mapping, the temperature range of seismic instruments restricts the potential for deep monitoring. New technology is needed for cementing, logging, directional control, proppants and fracturing fluids and methods to enable multistage fracturing at very high temperatures.

2. CURRENT OIL AND GAS FRACTURING TECHNOLOGY

The oil and gas industry has honed methods for extracting hydrocarbons from very tight shales and other unconventional resources to the point where fossil fuel reserves have increased dramatically over the last 20 years. Current methods for hydraulic fracturing have made it possible to extract hydrocarbons from rocks that were viewed as sealing formations that capped productive high permeability sandstones and carbonates. Because the low permeability of these resources requires fracturing to access as much of the shale or other tight formation as possible, multistage fracturing of horizontal wells that follow a sedimentary layer for long distances has succeeded in economically extracting gas and oil from resources considered unproducible in the past. Figure 1 shows a typical multistage fractured horizontal well in shale layer.

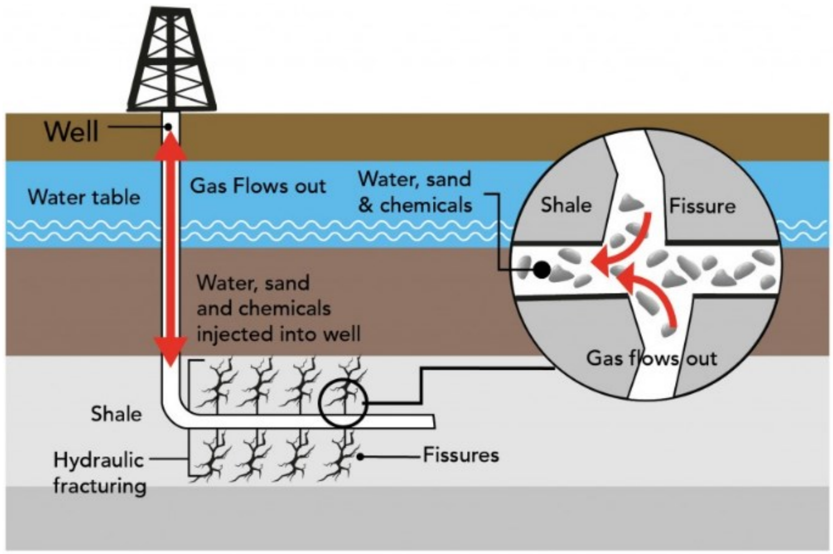

Figure 1 Multistage hydraulic fracturing in shale. (Briggle, 2015)

What are the techniques currently used in O&G to achieve the successful development of these unconventional resources? Table 1 below documents current methods used in O&G fracturing.

Innovation in fracturing of unconventional petroleum resources has focused recently on data analysis and numerical simulation to optimize fracturing for specific subsurface conditions. The availability of high-speed Wi-Fi, cloud storage and machine learning software has resulted in the ability to not only optimize the treatment program but to modify the program in real time to improve the result. Recent innovations have increased the potential production from unconventional resource while at the same time reducing cost through optimization using machine learning.

Table 1 Current Oil and Gas Fracturing Technology for Unconventional Resources

Process/Outcome	Purpose	Needed to Accomplish Purpose	Current Technology	Temperature Limits
Multistage fracturing	Create surface area and access to formation to optimize drainage	Zonal isolation to allow for multiple fractures. DTS to monitor exit points from wellbore	Cement and perforate completion with set and release packers. Sliding sleeve devices. DTS to determine which zones are taking the most fluid. Diverters can be used within stages/zones to balance fluid exit points.	Cements up to 350C. DTS to ~250C
Tensile fractures	Open up fractures to allow for increased permeability particularly near the wellbore	High pressure pumping	Hydrofack with proppants - typically silica sand. High compressive strength proppants needed with high closure stress.	No limit
Proppants	Prevent fractures from closing	High compressive strength materials in sizes to maintain fracture aperature	Ceramics, silica sand, resin coated silica sand, bauxite with various strength ratings	Resin coated sand - 250C
Fracturing fluids				
Viscosifiers and gels	Increase carrying capacity of fluids for best proppant placement. Increase fracture effectiveness	High enough viscosity to carry proppants. Gel breakers needed for most	Natural, modified or synthetic polymers	Natural gels-175C Synthetic polymers-200C Gel breakers-125C
Solvents	Help to dissolve components of the formation or the formation fluids that can block pore spaces	Ability to dissolve solid hydrocarbons. Ability to dissolve carbonates and other soluble formation	Organic hydrocarbons, acids-depends on nature of potential pore filling material	Varies widely. Most acids increase in activity with temperature. Volatile organics have various limits for temperature and pressure
Scale inhibitors	Reduce the risk of precipitation of scale deposits in the fractures and pore spaces	Understanding of geochemistry of pore fluids and formation geochemistry	Organo-phosphates, Polyphosphino Carboxylic Acid (PPCA), phosphonic acids (DTMP for example)	DTMP-Tested to 250C. Might stable at even higher temperatures
Friction reducers	Decrease pumping pressures by reducing frictional pressure drop	Chemistry fracturing water and formation fluids High salinity vs. fresh water = different products. Temperature very important	Polyacrylomide polymers	150C
Surfactants	Promote movement of oil by reducing surface tension, emulsify oil based fracturing fluids	Chemistry fracturing water and formation fluids High salinity vs. fresh water = different products. Temperature very important	Detergents, Viscoelastic surfactants (VES)-amphiphilic molecules	Detergents - 300C or higher, VES tested to 125C
Biocides	Kill organisms that feed on organic material in the pore spaces	Temperature, types of hydrocarbons and biota	Chlorinating agents, bromating agents, many others	Biota up to 200C
Injection Pressure	Overcome tensile strength of rock to initiate and jack open fractures	High rate, high pressure pumping equipment	Pump trucks using positive displacement (piston) pumps	No limit
Long reach horizontal dri	Maximize access to hydrocarbon rich sedimentary layers.	Directional drilling system - Mud motor, MWD, steering tools, LWD-optionsal	Continuously monitor hole deviation and direction. Make turn with steering tool and mud motor. Maintain deviation and direction using LWD info to stay in boundary of zone	Mudmotors-300C MWD-125C but can cool while using Batteries-125C Steering tools-125C
Microseismic monitoring	Map fractures	Monitoring well(s), seismic monitoring equipment, DAS in some cases	Monitor treatment well and nearby wells downhole with string of seismic instruments or DAS	Electronics-125C DAS -250C, but maybe higher soon
Zonal isolation	Separate zones for multistage fracturing	Cement and perforated completion Sliding sleeve devices can work in open hole Perforating guns or jet cutters to open zones in cemented casing	Set and release packers with degrading perf balls to block zones already fractured Sliding sleeve devices can open and close ports and can be used in open hole completions	Elastomeric seals-225C Cement up to 350C Differential thermal expansion may limit use to low dT
Data Collection	Store surface and downhole data for later or real time analysis	High speed wifi access Mass storage on site when no wifi Software for data collection Data analysis software including ML	Payson system to collect data in the field Transmission via wifi to central cloud storage ML and big data analytics	No limit

2. DIFFERENCES BETWEEN UNCONVENTIONAL OIL AND GAS AND EGS

The primary difference between O&G fracturing and EGS is that the fluid is the resource in a hydrocarbon reservoir. In a geothermal system of any kind, the heat stored in the rock is the resource and fluid circulating through the fractures or porous matrix is just carrying that heat to the wellbore. In a hydrothermal system the combination of natural fractures and matrix permeability allows for that circulation. In an EGS, the fractures are created to allow for circulation.

Rock of all types has a very high heat capacity but a relatively low thermal conductivity. This low thermal conductivity makes moving the heat out of the rock and into the wellbore and then to the surface difficult. Various methods The fracture surface area and spacing between fractures that the circulating fluid contacts determines the rate at which the heat can be produced. The ratio of the surface area contacted to the flow rate is a useful metric for determining the economic viability of an EGS system. (Armstead and Tester, 1987)

The temperature of the rock has an important control over the amount of recoverable heat. Figure 2 shows the impact of resource temperature on the electrical power potential of 60 kg/s of water flow through a created EGS fractured reservoir. Examples for actual EGS projects are shown on the curve. Current research and development efforts are focused on EGS systems with temperatures below 225°C. Moving the focus to higher temperatures can mean a significant increase in power output from each well, not only due to the higher enthalpy of the produced fluid, but also the improved electrical conversion efficiency gained.

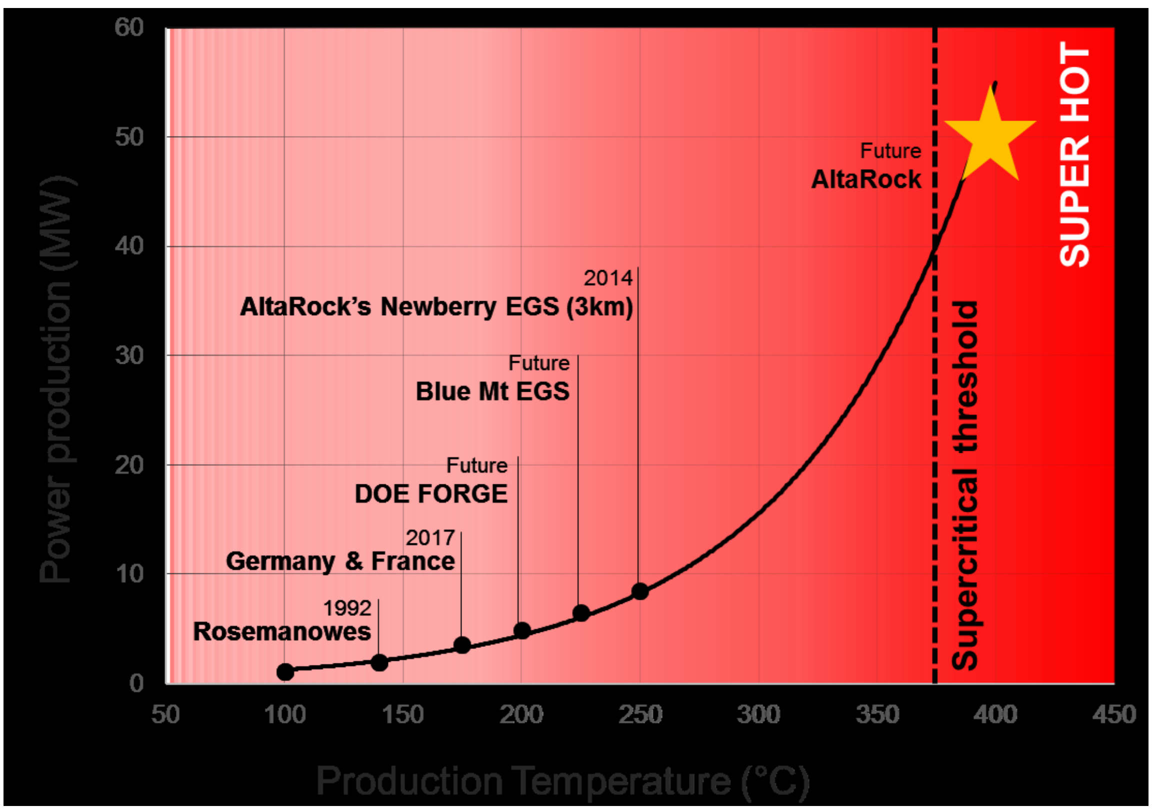

Figure 2 Power Potential of 60 kg/s of water produced from different temperatures from an EGS reservoir

Closed loop advanced geothermal systems (AGS) have been proposed that rely on conductive heat transfer from the rock to the wellbore to move heat to the surface. When we compare the metric of flow rate to heat exchange area recommended by Armstead and Tester (1987) we can look at the effectiveness of the heat extraction process for different configurations. Figure 3 shows some of the proposed closed loop configurations. (Beckers, et al. 2022) A stimulated EGS fractured reservoir would have a flow rate/heat exchange area of ~2 x 10^{-5} kg/s/m^2 or smaller which would maintain temperature drop over time to only about 10°C over 20 years. A U-loop style system with two 2 km long laterals would have a flow rate/heat exchange area of ~5 x 10^{-3} kg/s/m^2. (Beckers, et al.2022) Even with very high starting temperatures, this higher flow rate to smaller heat exchange area results in very rapid cooling below the rock temperature followed a slower stabilized decline in temperature over time. In order to take advantage of very high temperatures with the least expense to drill to those superhot temperatures and develop a resource, EGS uses a fracture network to act as a heat exchanger in the rock keeping initial temperature drop to a minimum below the rock temperature and the decline as low as possible over time.

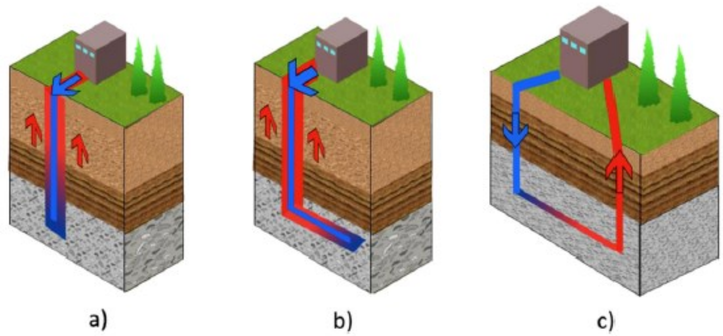

Figure 3 Closed loop AGS configurations. Fluid color in wells representing temperature. Blue is cool fluid. Red is hot. a) Vertical coaxial. b) Coaxial with horizontal extension. c) U-loop

In contrast, while fracturing in shale requires maximum drainage area contacting the layer, the focus is less on developing that contact area over a very large volume of rock than on staying within the shale layer with the fractures. There is a need for containing he fracture growth within the layer while getting as much access to as much of the pore space as possible.

TECHNOLOGY THAT CAN TRANSFER TO SUPERHOT EGS

While temperature may seem like the most important limiting factor for moving fracturing technology from unconventional oil and gas to superhot EGS, in many ways the high flow rates needed to make an economic geothermal project are the biggest difference. In order to achieve those high flow rates while maintaining the benefit of the very high temperatures, the stimulated fracture network has to be large, extend far from the well to allow a long travel path between the injector and the producers and have a complex network of fractures accessed by the fluid. Limiting the flow rate to maintain temperature means not extracting as much energy from the system.

Let's look at each of the technologies in Table 1to determine applicability to EGS stimulation in general and SuperHot EGS in particular.

- **Multistage fracturing** – Multistage fracturing is the key to developing a large heat exchange area fractured EGS reservoir. The O&G industry often uses plug and perf systems with packers that can be set in a cement and perforated completion interval, the zone opened by perforating and then closed again using perf balls or frac balls that later degrade to open the zone back up. Also widely used is the sliding sleeve system with zones in the open hole isolated with packers, often swellable packers.

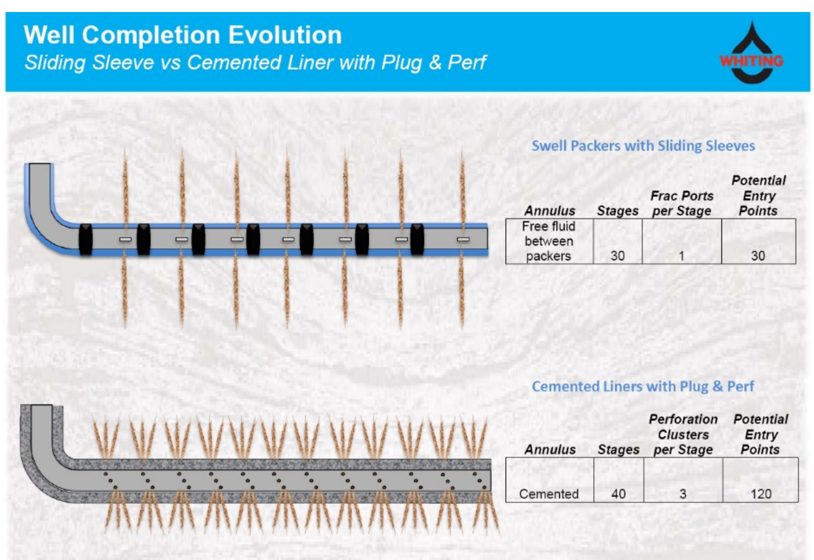

Figure 4 Sliding sleeve vs cemented liner with plug and perf completion

Figure 4 shows the comparative differences between sliding sleeve and plug and perf systems. Ither system can close off zones already fractured using frac balls, while plug and perfed zones can be closed using perf balls that fit into the perforated holes. In either case the frac or perf balls can be thermally or chemically degradable to leave the completion open after fracturing. In addition sliding sleeve devices can be opened and closed using coil tubing or electronic system. Clearly, the electronic systems have a very limited temperature range and would be tough to use at high temperature. While plug and perf better controls the location and number of fracture initiation points, the cemented and perforated liner increases pressure drop as the fluid enters the wellbore.

Sliding sleeve systems can be used with an open hole completion to reduce pressure drop. The number of exit points from the wellbore can be increased between the pack off points using diverters. Thermally degradable diverters (TZIM) adapted for very high temperature can be used between isolation points to increase the number of exits from the wellbore. (Petty, et al., 2013) Adapting the sliding sleeve device for high temperatures pushes the limits of swellable elastomers. However, silicone and fluorocarbon based extend the range for elastomers to 300°C. Additives may allow for the silicone based elastomers to solidify and ceramicize for a permanent zone isolation at high temperatures. (Li, et al., 2020) Another adaptation for very high temperature to use an open hole completion with sliding devices could be to use a swellable elastomer that would degrade thermally at the rock temperature after remaining in place during the cool water stimulation. This would leave an open hole completion. Refracturing can be accomplished in the open hole using diverters.

- **Tensile fractures –** The emphasis in oil and gas fracturing is in the creation of tensile fractures using high pressure pumping to break down the rock (hydrofracking). In order to keep these fractures open, proppants are emplaced carried into the fracture with fracturing fluids. While open tensile fractures result in excellent near wellbore pressure drop, a very large number of stages of tensile fracturing is required to produce a large surface area interconnect fracture network. Fortunately, it is becoming increasing clear that away from the wellbore as the tensile fracture extends outward, shear failure (hydro-shearing) begins to dominate the fracturing regime. Fractures created through shear failure can self-prop in the hard brittle rocks encountered in EGS reservoirs. (Gischig and Preisig, 2015). Formation of tensile fractures results in lower or no microseismic emissions making seismic fracture mapping more difficult. However, shear failure fractures increase the risk of seismicity of concern for people in areas with pre-existing faults and large scale fractures.
- **Proppants –** Proppants are important for keeping tensile fractures open, but in temperatures of interest for geothermal development, they may dissolve it too short a time to be useful. Studies conducted by Brinton, McLin and Moore (2011) indicate that dissolution of sintered bauxite proppant occurred in the presence of geothermal water at 230°C. Silica sand proppants dissolve readily at temperatures up to the maximum temperature for silica solubility of 340°C. Pressure dissolution of silica sand can also increase the rate of dissolution. Resin coated silica sand may extend the time for dissolution, but the resins breakdown at high temperature limiting the temperature range for these products. New high temperature stable proppants are needed to improve the success of hydraulic fracturing in high temperature geothermal system. However, for superhot rock, silica may again become a useful proppant material since silica solubility decreases above 340°C. Test facilities and protocols for such high temperature testing are very limited and are much needed to extend the range of hydraulic fracturing.
- **Fracturing fluids –** The temperature limits for most fracturing fluids preclude their use in EGS fracturing. For very high temperatures >350°C, there are no available materials for reducing friction or increasing viscosity. As a result clear water fracturing has been the accepted as the standard practice. Solvents such as acids and chelating agents have been tested and successfully used in temperatures up to 250°C but further research is needed to determine if there is applicability for these materials at superhot temperatures. Dissolution of the rock could be used to keep tensile fractures open near the wellbore if high temperature proppant materials can't be found. Friction reducers would greatly aid in fracturing at very high temperatures but the temperature limits of materials used to reduce friction in fracturing fluids are so low that these have not been found to be effective for geothermal stimulation. Weighting of clear water geothermal fluids has been tested to increase downhole pressure without increasing surface pressure.
- **Injection Pressure** – Pressure pumping is the bread and butter of oil and gas fracturing. Pump trucks with piston pumps are available widely and have been used extensively both in stimulation of geothermal and EGS wells. However, the impact of thermal fracturing has been found to be an important component of successful geothermal fracturing, particularly in EGS reservoir creation. In order to extend the cool water front away from the wellbore, long term pumping for days or even years has been seen to be the most effective method for creating a large scale connected fracture network in EGS stimulation. (Bradford, et al., 2015) Using piston pumping systems for these long duration fracturing efforts requires triple redundancy of pumps to ensure pumping is continuous since such pumps require maintenance every 6-24 hours and also experience frequent breakdowns. Multistage centrifugal pumps can be used for this type of long duration pumping and are also cost effective. The systems can be set up for a wide range of flow rates and pressures by adding stages and varying the rotation frequency. While a goal of the future of fracturing in very high temperature rock may be to reduce the time for creation of the reservoir, it is clear from modeling that long duration pumping to improve thermal fracturing may still be needed.
- **Long reach horizontal drilling** – While crucial for following a shale layer over a long distance to maximize the number of stages and contact with the formation, horizontal drilling is generally not useful for geothermal situations. Temperature increases with depth so drilling to a target temperature and turning horizontal means that the wells is not accessing higher temperatures that could be reached with the same drilled distance. Making high angle turns is possible at very high temperatures, but the methods used in oil and gas such as MWD with steering tools, mud motors and continuous measurement of hole angle and direction are limited for very high temperature situations. While almost all geothermal wells are directionally drilled to intersect the fracture direction as close to orthogonal as possible, they rarely are drilled at angles greater than 45° due to the high cost and temperature limits on equipment. Since most geothermal reservoirs and all superhot geothermal reservoirs are in either igneous or metamorphic crystalline rock, there is no advantage to drilling horizontal. A completion interval long enough for many stages of fracturing can be achieved with lower than 9est0° angles.

- **Microseismic monitoring** – Microseismic monitoring is a key piece of modern fracture stimulation. Originally developed as part of the Hot Dry Rock project (Hendron, 1987) to map fractures in development of a EGS system, this technology has allowed the mapping of fractures in a wide variety of hydraulic fracturing situations. In oil and gas seismic monitoring equipment can be installed in a nearby well, a monitoring well or even in the treatment well itself. However, in high temperature applications over 300°C, use of seismic equipment downhole is not practicable currently. EGS fracture mapping is generally done using surface installations or in shallow boreholes that reach below the water table but not so deep as to reach high temperatures. Use of distributed acoustic sensing to map fractures is an innovation from oil and gas that is just beginning to be used in oil and gas fracturing and may extend into high temperature applications as the temperature limits of fiber optic cable are extended. Distributed temperature sensing (DTS) combined with DAS can not only determine the location of fractures and fracture exit points from the well, but also quantify the amount of fluid exist each point.
- **Zonal isolation –** The ability to isolate an area of the wellbore to concentrate pressure and initiate fracturing is critical to multistage fracturing. The performance of packers at high temperature has been a serious impediment to achieving multistage fracturing in EGS stimulations. Tests using a packer designed to perform at 250°C at the FORGE EGS test site in Utah found that while the packer held for the duration of the test, thermal damage to the elastomers prevented the device from releasing (J. Moore, personal communication). Past tests of packers in high temperature wells have resulted in failure of the packer to hold pressure, failure to release and fracturing around the packer to communicate with the annulus above the set point. Packers with all metal seals have recently been developed and tested at high temperatures, but the availability of high temperature test facilities for temperatures over 400°C and large size test elements seriously limits our ability to determine if this type of packer will work for superhot rock. Sliding sleeve devices hold great interest for zonal isolation in multistage fracturing. If these systems can be extended to very high temperatures and combined with frac balls that remain in place for opening and closing stages zonal isolation in superhot rock can become much more efficient and cost effective. However, much materials research and ultra high temperature test facilities capable of handling larger test elements is needed for a successful deployment of a sliding sleeve system for superhot rock.
- **Data Collection** – One of the major areas where oil and gas has made huge advancements is the use of real time data collection and analysis during fracturing. Geothermal fracturing has not had the level of data collection done routinely in oil and gas fracturing. Real time data analysis, particularly when combined with machine learning, can help to control the fracture treatment and make changes that improve success of the fracturing operation. Studies currently being done of the use of machine learning to optimize geothermal drilling are finding that the level of data collection now current in geothermal drilling lags behind that done for oil and gas. Applying the methods for data collection and real time analysis now being used in oil and gas may help to advance EGS stimulation operations and improve the success of EGS fracturing. These methods should be just as applicable at very high temperatures as at lower temperatures.

CONCLUSIONS

Drilling for very high temperature rock, above the critical point for water, can increase the energy density for geothermal fluids and therefore improve the economics of geothermal energy development. What technology from unconventional oil and gas development can be applied now at these very high temperatures and what needs to be developed for the future? We can drill deviated wells with the large diameters needed to reduce pressure drop. We have cements for temperatures up to about 350C and well designs using casing materials that will withstand the temperature and possible corrosivity of the produced fluids. Casing connections have been an issue in these very hot wells, but advances that include expandable casing connections, advanced thread designs and sealing sections are now available that should solve these problems. Logging tools, instrumentation for measurement while drilling and steering can be heat shielded and run in the cooled wellbore. While zonal isolation using the sliding sleeve devices and packers used in oil and gas is not yet available, setting scab liners using external casing packers (ECPs) with metal to metal seals can allow isolating sections of the well for multizone stimulation. Thermally degradable zonal isolation materials that allow for diversion of fractures both near the wellbore and in the far field can help to create complex fracture networks. While microseismic monitoring, initially developed for the geothermal industry and advanced by the oil and gas industry, is used in geothermal fracture mapping, the temperature range of seismic instruments restricts the potential for deep monitoring. New technology is needed for cementing, logging, directional control, proppants and fracturing fluids and methods to enable multistage fracturing at very high temperatures.

REFERENCES

Armstead, H.C.H. and Tester, J.W., Heat Mining, E.F. Spon, London (1987).

Koenraad F. Beckers, Nicolas Rangel-Jurado, Harish Chandrasekar, Adam J. Hawkins, Patrick M. Fulton, Jefferson W. Tester: Techno-Economic Performance of Closed-Loop Geothermal Systems for Heat Production and Electricity Generation, Geothermics 100 (2022) 102318.

Jacob Bradford, Joseph Moore, Mary Ohren, John McLennan, William L. Osborn, Ernie Majer, Greg Nash, Robert Podgorney, Barry Freifeld, Randy Nye, William Rickard, Douglas Water, Douglas Glaspey: Recent Thermal and Hydraulic Stimulation Results at Raft River, ID EGS Site, PROCEEDINGS, Fortieth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 26-28, 2015 SGP-TR-204.

Adam Briggle - 'A Field Philosopher's Guide to Fracking' Liveright Publishing Corporation. New York and London. 2015.

Daniel Brinton, Kristie McLin, Joseph Moore, The Chemical Stability of Bauxite and Quartz Sand Proppants Under Geothermal Conditions, PROCEEDINGS, Thirty-Sixth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, January 31 - February 2, 2011 SGP-TR-19.

Raul Antonio Di Toto, Frederic Bruyneel, Davide Parravicini, Amy T. Kan, Mason B. Tomson, Fei Yan: Development of the First Readily Biodegradable OECD306 Phosphonated Amino Acid Chemistry for the Control of Calcium Carbonate and Calcium Sulphate in HTHP and UHT Unconventional Productions, SPE International Oilfield Scale Conference and Exhibition, SPE-190733-MS, https://doi.org/10.2118/190733-MS, June 20–21, 2018

Michael Fitzsimmons: Whiting's Q3: Cemented Liners, Plug-N-Perf Completion Technique Should Lead To Higher Valuation https://seekingalpha.com/article/1769682-whitings-q3-cemented-liners-plug-n-perf-completion-technique-should-lead-to-higher-valuation

V. S. Gischig, G. Preisig: Hydro-Fracturing Versus Hydro-Shearing: A Critical Assessment of Two Distinct Reservoir Stimulation Mechanisms, Paper presented at the 13th ISRM International Congress of Rock Mechanics, Montreal, Canada, May 2015.

Robert H. Hendron: The U.S. Hot Dry Rock Project, PROCEEDINGS, Twelfth Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, Januiay 20-22, 1987 SGP-TR-109

Penghu Li, Haiyun Jin, Shichao Wei, Huaidong Liu, Naikui Gao and Zhongqi Shi : Ceramization Mechanism of Ceramizable Silicone Rubber Composites with Nano Silica at Low Temperature, MDPI, 21 August 2020

Susan Petty, Yini Nordin, William Glassley, Trenton T. Cladouhos, Mike Swyer: Improving Geothermal Project Economics With Multi-Zone Stimulation: Results From The Newberry Volcano EGS Demonstration, PROCEEDINGS, Thirty-Eighth Workshop on Geothermal Reservoir Engineering Stanford University, Stanford, California, February 11-13, 2013 SGP-TR-198.

Frantisek Stanek, Ge Jin, James L. Simmons: Fracture Imaging Using DAS-recorded Microseismic Events, manuscript submitted to Geophysical Research Lettershttps://www.essoar.org/pdfjs/10.1002/essoar.10508635.2, November, 2021.