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Need for a Facility to Study the Behavior of Rocks, Proppants, Diverters, Cements, Instrumentation and Equipment at Greater Than Supercritical Conditions

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ABSTRACT

SuperHot rock (greater than 374°C) is much more energy dense than conventional hot dry rock (less than 225°C) and the higher temperatures mean that more efficiency steam turbine technology can be used for power generation to achieve a 10X increase in power generation over EGS at 200°C. Production of supercritical steam through Enhanced Geothermal Systems (EGS) would represent an energy breakthrough. Recovery of just 1–2% of the thermal energy stored in hot rock at 3 to 10 km depths would be sufficient to meet world energy consumption for many centuries. Recovery of this energy can be achieved through creation of Enhanced Geothermal Systems (EGS), which involves injection of high-pressure water into a well to enhance or create fracture permeability and connect two or more wells separated by several hundred meters of hot rock, effectively creating an underground heat exchanger. Despite significant worldwide investment in the last two decades, EGS development has been limited, and the goal of economic EGS may not be achieved unless power production per well can be greatly improved. Typically, EGS developers target rock temperatures between 150 and 225°C, but super-hot rock (SHR) (greater than 374°C) is much more energy dense, and a SHR EGS well would produce 5 to 10 times as much electricity as other well types. However, significant technology improvement is needed to be able to routinely drill into and harness the energy in high temperature rocks. In order to develop this technology, laboratory testing of materials, components, instrumentation and equipment is needed to reduce risk and cost. This means modifying existing test equipment to handle higher temperatures and pressures and developing new equipment that can test larger rock samples and downhole tools and equipment at those higher temperatures.

1. INTRODUCTION

The most geothermal savvy countries in the world, Iceland, Italy, Japan, Mexico, and New Zealand, are pursuing projects to produce supercritical geothermal fluids. Geothermal wells have been drilled to 400°C or hotter in the USA, Japan, Iceland, and Italy. Given the enormous potential economic benefits of supercritical geothermal wells, what is holding back the research, technology development, and testing needed to make super-hot geothermal energy viable?

Some of the barriers holding back the development of SuperHot Rock EGS reservoirs are technical or scientific. Others are social or political. To move past the technical barriers there is a need for gaps to be filled with laboratory and field testing which will reduce risk for wellfield operations.. Materials behavior at very high temperatures, including rocks, casing, casing connections, cements, proppants, drilling fluids and tracers all need to be studied so more data can be gathered for modeling and selection. Instrumentation for downhole measurements of temperature, pressure, stress, rock porosity, fracture incidence and orientation, density and sonic velocity already in use for high temperature need to be hardened and then tested to SuperHot temperatures. To reduce risk these tests should first be conducted in the laboratory followed by field testing.

Currently available laboratory test equipment generally is limited to temperatures 300°C or below, most often at temperatures below 200°C. This high temperature equipment is usually only set up for smaller scale samples at universities or at national laboratories although there is some high temperature test equipment available at commercial laboratories.

Several types of high temperature test equipment would be needed for measurement of:

- Rock and cement mechanical properties at high temperatures, thermal cycling and over time
- Rock and cement porosity, density, and permeability at high temperatures, thermal cycling and over time
- Rock seismic velocities and attenuation
- Rock, cement, insulation and casing materials thermal properties at very high temperature – thermal conductivity, thermal diffusivity, thermal expansion and heat capacity
- Fluid/rock interactions – solution and deposition in rocks and cements at high temperatures, thermal cycling and over time
- Materials properties - solubility, stability and strength and thermal properties for materials such as cements, proppants, diverters, drilling fluids, tracers and additives such as corrosion and scale inhibitors, treatment chemicals, friction reducers, foaming agents and others

- Mechanical properties of casing materials and casing components at very high temperatures and under stresses produced with thermal cycling
- Downhole instrumentation and tools such as logging instruments and cables as well as methods for conveying and deploying downhole tools and instruments.

2. ROCK PROPERTIES AND MECHANICS TESTING

The in-situ physical, geochemical, and mechanical characteristics and behavior of rock and produced fluids at temperatures up to 500°C and pressure greater than 22 Mpa are not well understood. At these pressures and temperatures the mechanical behavior of rocks are changing from brittle to ductile and the extent of fracturing and the associated changes in the permeability of the formation remain big unknowns. The role of thermal fracturing is also important since low temperature fluids are used during drilling and stimulation inducing thermal shock in the immediate proximity of the well and in natural and induced fractures. Empirical observation suggests that thermal fracture may improve rates of penetration during drilling and and thermal stresses during stimulation may be used to produce more complex fracture networks. This fracturing mechanism is poorly studied in the range of SHR temperatures.

The knowledge and modeling of all these phenomena constitute important factors of development for supercritical steam geothermal energy and here are some important questions that need to be addressed:

- How can complex fracture networks develop in the brittle to ductile transition zone?
- Can an EGS reservoir be created and sustained in these conditions?
- What are the corresponding porosity and permeability changes?
- Do rock thermal properties change at very high temperature?
- What are the main mechanisms for fracturing?
- How do the host rock and in situ fluids react with injected fluids over time?
- Can these rock fluid interactions be controlled to improve reservoir longevity and maintain reservoir permeability over time?

To obtain some answers, laboratory fracturing experiments are needed at the temperatures where we plan to develop the geothermal resource. These tests need to be performed using water, CO_2 and other fluids on various rocks representative of the most common geological settings for this kind of geothermal reservoirs and at SHR pressure and temperature (T greater than 374°C, P greater than 22 MPa). To complete these experiments, the following equipment is needed:

- Load frame for tri-axial compression testing at high temperature capable of handling larger samples (up to 10 cm) and thermal cycling and pressure cycling to study fracture creation
- Load frame for tri-axial compression testing with very high temperature control to study fracture propagation on larger samples of > 10 cm whether core or other shapes
- Very high temperature flow reactor system to study the changes in permeability and rock/fluid interaction with thermal cycling and various fluid compositions over time.
- System for measuring rock thermal properties – laser based system to measure thermal properties in cuttings and core.

Currently, rock mechanical properties under shear, compression or tension are tested with either uniaxial confined or unconfined or tri-axial load frames. Some of this equipment is set up for temperature control up to 200°C and sometimes higher temperatures. (Figure 1) However, very few test facilities can handle a thermal or pressure cycling history. Most sample sizes are smaller core of less than 10 cm in diameter. A few test facilities can handle other than cylindrical samples but none are set up to hand large sample sizes greater than 10 cm. It's important to be able to test large samples since rock properties can vary over relatively short distances. The 'representative elementary volume' of a rock sample is the smallest volume that be studied that will represent the bulk property of the rock whether rock strength or physical properties. In some rocks that host very high temperatures, this may be a fairly small volume, but in many cases rock properties vary over a large volume. In these rock facies the sample size for testing needs to be much larger to reflect bulk rock properties.

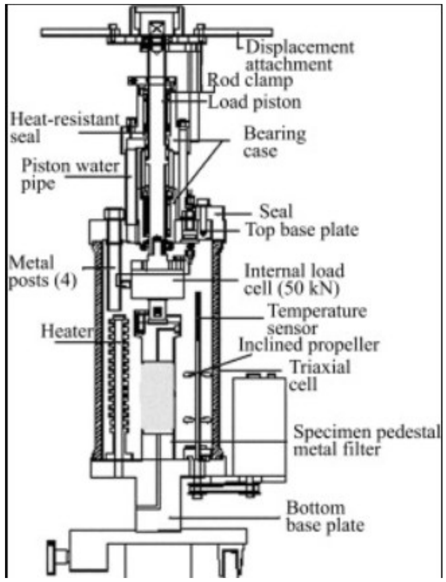

Figure 1 Temperature controlled triaxial compression testing apparatus (

Rock density, porosity and permeability in rocks that may host a superhot created reservoir are important for creating and long term management of the reservoir as well as for numerical modeling. The porosity of rock can consist of fracture porosity and matrix porosity and the porosity may be interconnected or not. There are techniques for determining the total interconnected porosity through both laboratory and field measurements made by well testing and any laboratory measurements need to be conducted on samples at temperature and then compared to field test data for scaling. Test equipment for bulk porosity and interconnected porosity is generally not available that can perform these tests at very high temperature, particularly on large samples that are more representative of the reservoir rock properties. However, methods used at lower temperature such as gas or oil injection systems may be adapted to measure the porosity and permeability of the rock matrix. (Figure 2)

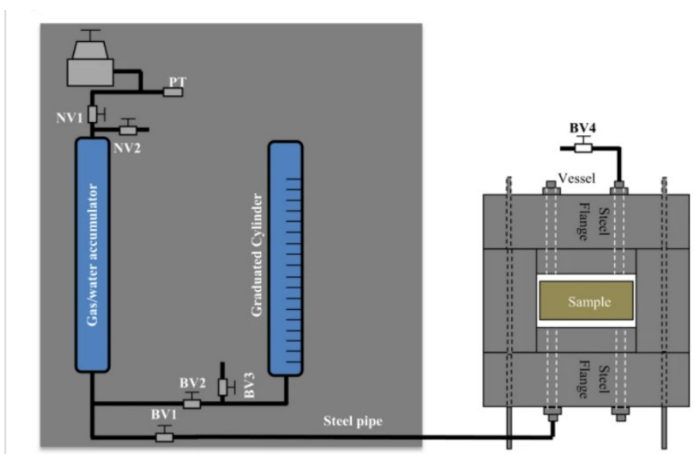

Figure 2 Porosity and permeability measurement equipment for very porosity rocks

Permeability coefficient, as obtained by laboratory experiments of core samples may not represent the behavior of the bulk rock in the field. The problem of determining the relationship between porosity and permeability in fractured rock is not well understood for the crystalline rocks that are likely to be the targets of SuperHot EGS reservoirs. Flow through a single rough fracture artificially created in a rock sample can be compared to flow through isotropic porous rock. It's important to understand fracture flow behavior in crystalline rock with very low permeability to translate laboratory testing to reservoir scale rock behavior especially for the purpose of numerical modeling. A large scale flow reactor with temperature controls for up to 500°C that can accommodate large scale rock samples with a single created fracture can be used for this type of testing. For measuring the very low porosities in crystalline rock, acoustic velocities as well as x-ray and microwave testing are preferable to the methods used for porous sedimentary rocks.

Rock thermal properties such as thermal conductivity, heat capacity, thermal diffusivity and thermal expansion may change with temperature and pressure and should be measured in temperature controlled conditions for very high temperatures. Laser testing of samples as small as cuttings and also larger samples can be done and then a large number of sample results can be averaged. (Figure 4)

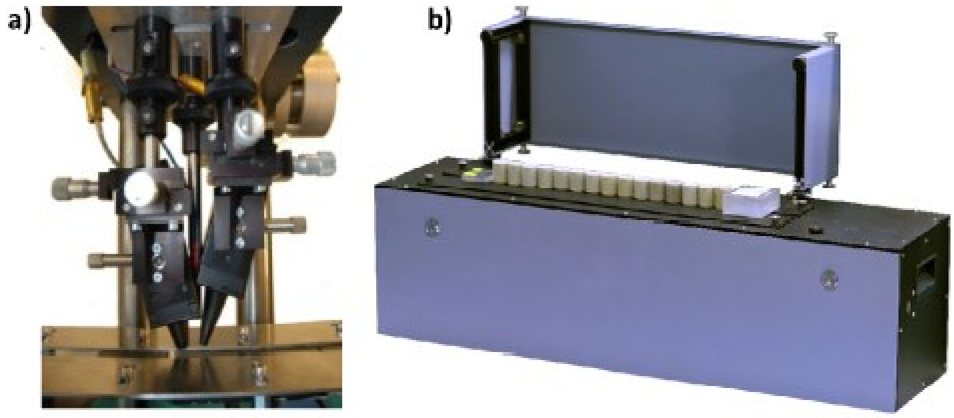

Figure 3 Laser optical scanning instruments for high-resolution profiling of rock thermal properties (Popov, et al, 2019)

3. MATERIALS TESTING

Materials used for stimulation and longterm reservoir and well maintenance have not been tested at temperatures over 300°C and most not over 200°C. The materials which need testing include:

- Proppants
- Diverters
- Drilling fluids
- Tracers
- Fluid additives such as corrosion and scale inhibitors, treatment chemicals, friction reducers, foaming agents
- Cements

There are several tests needed for materials used in completion of a very high temperature well. Strength under compression, tension and shear, durability, solubility and degradation for each material in the conditions of the wellbore need to be measured in the lab. For cements and proppants the permeability of the material after emplacement is important. AltaRock is currently testing possible high temperature proppants for strength with NER and permeability with Oklahoma University at the high temperatures for superhot stimulation. However, solubility of proppants has been an issue in geothermal fracturing since most oilfield proppants dissolve fairly rapidly. Coatings that improved the solubility of proppants are typically not stable at very high temperatures.

Most of these materials can be tested for strength and durability in the same heated triaxial load cell equipment used for rock testing. However, solubility and degradation with time and temperature are best tested in a temperature and pressure controlled flow reactor. Altarock has worked for a number of years with the Energy and Geoscience Institute at the University of Utah (EGI) on the solubility and degradation of diverter materials using flow reactor test equipment for temperatures up to 300°C. Both large and small scale flow reactors have been used to test a variety of materials for geothermal use. (Figure 4)

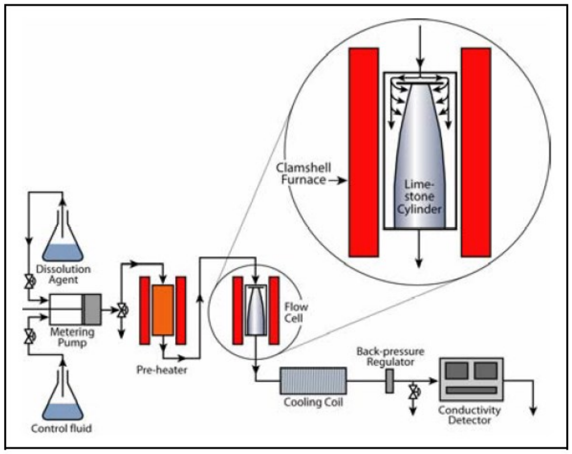

Figure 4 Schematic of high temperature flow reactor

4. DOWNHOLE INSTRUMENTATION TESTING

Geothermal downhole logging equipment as well as directional drilling equipment (measurement while drilling – MWD) is currently available for temperatures up to about 175°C with some production logging tools (pressure, temperature, gamma, spinner) available for temperature up to 300°C. Cables for surface read out are available for up to 300°C and for temperatures above that, heat shielded memory tools can be used on slick line or wire cable without surface readout. Heat shielding and high temperature electronics can extend the temperatures at which logging tools and instrumentation can be used, but these must be tested in the laboratory before testing in the field in a well. For this type of testing a mock wellbore which can be filled with fluids at temperatures and pressures representative of expected conditions in the field are needed that can accommodate the full size tools. Seals and sensors exposed to the wellbore fluids at temperature fail at lower temperatures than they were tested to.

More and more fiber optic methods are being used for temperature and acoustic sensing downhole. Fiber optic seismic sensors and fiber optic cables for data transmission are planned for higher and higher temperature use. However, testing in an autoclave doesn't simulate the downhole environment and fiber optic equipment has failed at temperatures lower than the test temperature regularly.

As an example, a downhole fluorimeter for high temperature tracer flow rate measurement was developed by AltaRock and EGI but the tool is too long and wide for testing in any of the mock wellbore set ups available at the University of Utah. Commercial test facilities don't hand very high temperatures since high temperature oilfields are generally not over 200°C. Some service companies have facilities for testing downhole tools and equipment but again they aren't set up for high temperature and aren't generally available for public use.

5. DOWNHOLE EQUIPMENT TESTING

Downhole equipment includes:

- Casing and casing materials
- Casing connections
- Packers or other zonal isolation tools
- Expansion joints
- Sealing assemblies
- Mudmotors

A system for testing casing components and cements at very high temperatures under stresses produced with thermal cycling is needed for a wide range of downhole tools and equipment. Any downhole assembly that must seal at high temperature that has typically used elastomers must be adapted to use metal to metal seals and then the ability of these seals to hold under in situ conditions in the wellbore should first be tested in the lab to avoid the high risk related to testing in wellbores.

Casing materials and casing connections are particularly difficult to test since they are not only extremely important to the safety and longevity of the well, but also are large and need to be tested at scale. Most testing of this type of equipment is done in air with heaters and insulation while the casing and connections will need to last cemented in the wellbore and filled with fluid.

CONCLUSION

A large scale very high temperature test facility equipment with a flow reactor, triaxial heated load cell, simulated wellbore and materials thermal measurement equipment would help to advance the development of methods for creating SuperHot EGS reservoirs. Such a facility would need to allow users from industry, academia and government. Such a facility would have to accommodate testing at temperature up to at least 500°C for downhole equipment at a scale appropriate for geothermal wells. The facility would need to not only be constructed but also supported either by user fees or by government funding for an extended period of time to enable the development and testing of materials, equipment and methods for creating reservoirs in very high temperature rock. Testing at lower temperature would also be supported, but this type of test equipment is available at other facilities. A mid-scale research facility with multi-user capabilities could provide for this level of infrastructure.

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