Hydrothermal Spallation for the Treatment of Hydrothermal and EGS Wells: A Cost-Effective Method for Substantially Increasing Reservoir Production Flow Rates

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There is a need in many geothermal projects to greatly increase the productivity and/or injectivity of wells, with a direct impact on project economics. Flow testing in wells and associated modelling of EGS reservoirs has suggested that low productivity from EGS reservoirs can result from near-wellbore impedance, a restriction of fluid flow within the immediate vicinity of the borehole walls. Further modelling suggested that altering the geometry of an existing wellbore by longitudinally slotting the borehole wall could significantly decrease near-wellbore impedance. Hydrothermal spallation is an ideal technology to create slots in the hard rock found in these reservoirs. This paper describes the results of tests of hydrothermal spallation well enhancement technology in the laboratory and initial field trials as well as its application to increase production from geothermal wells.

Keywords: thermal spallation, hydrothermal spallation, well enhancement, Engineered Geothermal Systems, EGS

Background

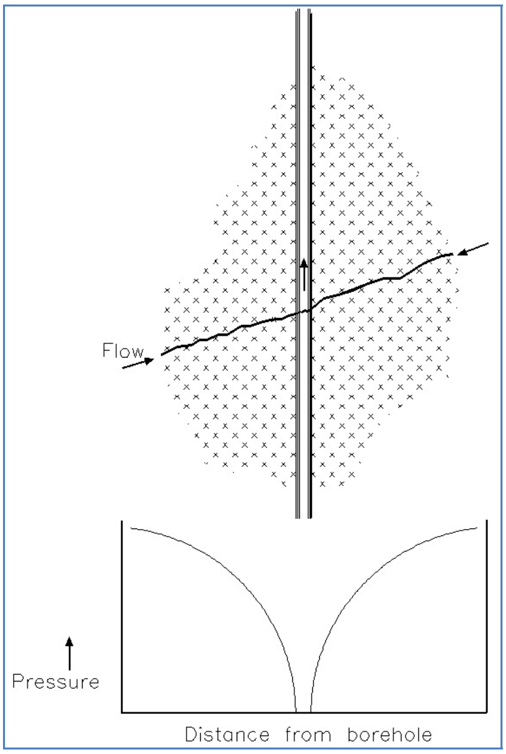
Enhanced Geothermal Systems (EGS) have the potential to generate clean, renewable, base load electricity using heated fluid produced from engineered reservoirs. These reservoirs are created by enhancing natural fractures in hot basement rock using hydraulic fracturing technology. Once the stimulation process is completed, injection wells deliver fluid from the surface into the reservoir where the fluid is heated, and production wells drilled into the fractured rock extract the heated fluid to drive a surface-based power plant.

This EGS technology is on the verge of reaching its tremendous potential. Projects around the world are achieving their temperature objectives, but face the challenge of low circulation rates after the hydraulic stimulation. Most models suggest that EGS wells must produce 80-100 kg/sec of fluid at 200 ˚C per well to be economically viable. However, such rates have proven difficult to achieve in EGS projects to date. The potential to create additional fracture zones within a reservoir exists, but adds considerable cost and risk to a project and has not been accomplished at this point. Meeting the productivity targets in EGS wells is critical to realizing the full potential of this promising renewable energy technology.

Geodynamics Limited ("Geodynamics"), a leading Australia-based developer of EGS projects worldwide, in collaboration with Australia's Commonwealth Scientific and Research Organisation (CSIRO), has conducted extensive field testing and associated modelling of EGS reservoirs. These studies suggest that low productivity from some EGS reservoirs primarily results from near-wellbore impedance, the restriction of fluid flow within the immediate vicinity (several inches or a few feet) of the borehole walls. This could be due to reduction in fracture permeability from drilling muds or other particulates, but the most influential factor is likely fluid turbulence due to rapidly increasing fluid velocities near the wellbore. To enter the production well, fluids must pass through pores and fractures in the walls of the borehole. Fluid velocities in the vicinity of the borehole are much higher than in the rest of the reservoir because of the limited surface area of the borehole walls and are estimated to exceed 55 km per hour near the entry into the wellbore in some cases. This near-wellbore impedance can limit both the output of production wells and, to a lesser extent, the input capacity of injection wells. A simple representation of this near wellbore effect is shown in Figure 1.

By altering the geometry of an existing wellbore through increasing the effective diameter, it is possible to reduce the near wellbore effect. This can be accomplished by slotting the borehole wall, as illustrated in Figure 2.

Spallation has been proposed as an effective means of expanding the diameter of a wellbore or a way to create underground caverns. For example, in Pedernal, New Mexico, Bob Potter and Ed Williams, from Los Alamos National Laboratory, demonstrated the ability to create 60-cm diameter holes in hard rock using only a 10-cm diameter axially-oriented flame jet. An illustration of this process is shown in Figure 3.



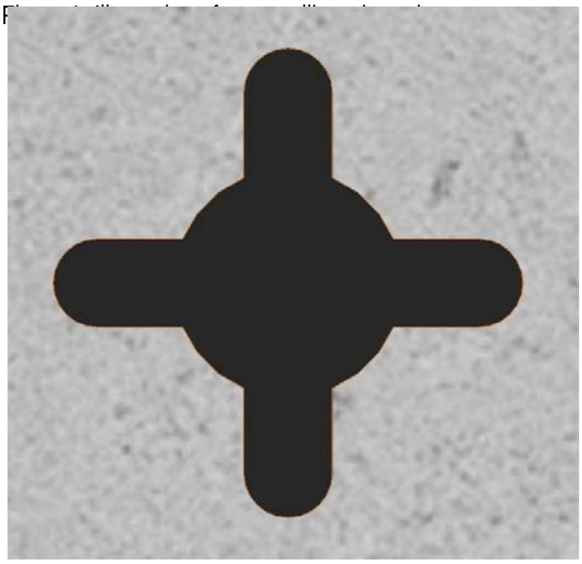


Figure 2: Borehole geometry for reduced wellbore impedance

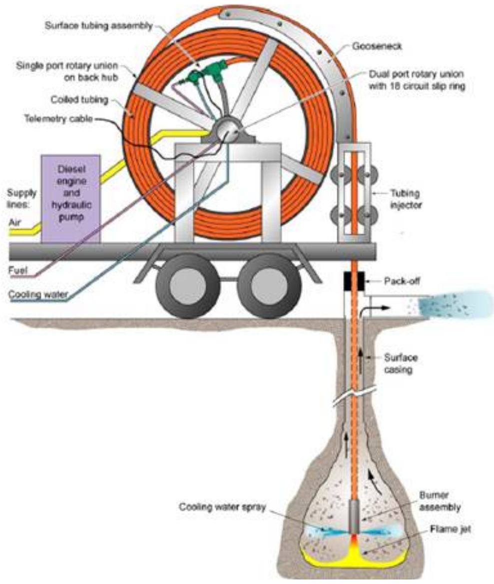


Figure 3: Flame spallation cavity maker

Flame jet spallation processes continue to be used commercially. For example, in Canada, thermal fragmentation mining employs a variation of this excavation technique to extract precious metals in thin, near surface ore deposits. In a typical operation, a small pilot hole is drilled into the ore zone and an 8cm diameter flame jet drill is used to cut larger caverns up to about one meter in diameter. The spalls are then processed for their precious metals.

However, this air-based technology can only be used near the surface and to moderate depths in regions where air drilling is feasible. At the depths required for EGS, the wellbore will very likely need to be filled with fluid to prevent excessive water or gas flows and maintain circulation and hole stability. For flame jet spallation, a fluid-filled wellbore poses serious challenges for both the transport of chemicals from the surface and for down-hole combustion.

As a result, hydrothermal spallation has been investigated as a viable means for the enhancement of deep, water filled EGS wellbores.

Experimental Application

A hydrothermal spallation test apparatus was used for proof-of-concept tests on the laboratory scale. The test system shown in Figure 4 is capable of independently applying controlled hydrostatic, confining, and axial loads on 10 cm rock cores to simulate varying wellbore conditions to 2400 m.

Figure 4: Hydrothermal spallation deep well test rig

This system which uses superheated steam to spall the rock was used to create single axial slots of the desired depth in holes and investigate their interactions with induced fractures.

The process was then further scaled to cut the axial slots 10 cm wide and more than 25 cm deep in open-hole sections of granite blocks, as shown in Figure 5, using a full-scale well enhancement test rig.

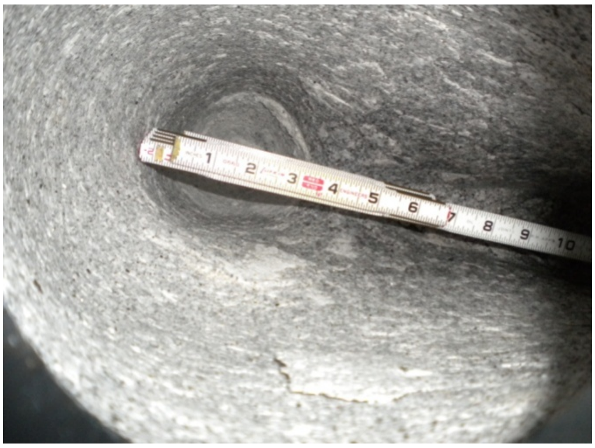


Figure 5: Axial slots cut into 10 cm open hole section of Sierra White Granite using a full scale tool

Figure 6: Full scale well enhancement test rig

A 8.8 cm iteration of the slotting drill head was designed and fabricated for field trials. The drill head interfaces with a dynamic seal to isolate the working fluid from the cooling water, followed by instrumentation and controls, tension release, and connector subassemblies, as shown in Figure 7.

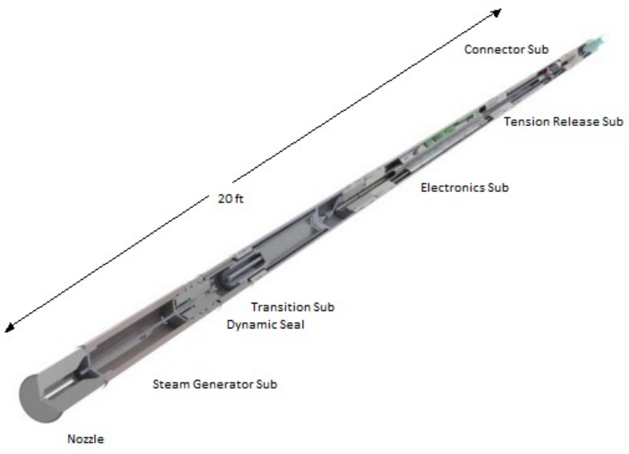


Figure 7: Cutaway rendering of field prototype bottom hole assembly

A coiled tubing string was assembled for purpose by nesting a 9.5 mm OD stainless steel capillary and 7-conductor wireline cable inside of a 50 mm OD, 3.40 wall, HS-90 steel coiled tubing string. The string was mounted on a tracked coiled tubing unit, shown in Figure 8. Rotating swivels and slip rings added to the reel allowed for transmission of the cooling water, electrical, and reactants through the hub.

Figure 8: Coiled tubing unit for field testing of hydrothermal spallation well enhancement.

A field location was chosen in the foothills of the Sierra Mountains in northern California, where competent granite could be found close to the surface.

At the time of publication, the results from the field drilling tests were not yet available. The results will be presented orally at the 2010 Australian Geothermal Energy Conference, November 16-19 in Adelaide.

References

Calaman, J. and Rolseth, H.C., 1961, Technical Advances Expand Use of Jet-Piercing Process in Taconite Industry: International Symposium on Mining Resources, University of Missouri.

Dreesen, D. and Betz, R., Coiled-Tubing Deployed Thermal Spallation Hard Rock Cavity Maker, FWP-02FE15.

O'Leary, B., 2010, Longitudinal Slotting for Wellbore Enhancement Purposes: Quantified Cost Benefit: Geodynamics Report.

Potter, R. M., Potter, J. M., and Wideman, T.W., 2010, Laboratory Study and Field Demonstration of Hydrothermal Spallation Drilling: GRC Meeting, Sacramento, California.

Williams, E., 1986, Thermal Spallation Excavation of Rock: U.S. Symposium on Rock Mechanics (USRMS), 27th annual meeting.

An Evaluation of Enhanced Geothermal Systems Technology: Geothermal Technologies Program, U.S. Department of Energy, Energy Efficiency and Renewable Energy; IPGT Workshop, August 27-28, 2010. Reykjavik, Iceland.

Flow Test Update: Geodynamics ASX Announcement, released April 22, 2008.

The Future of Geothermal Energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century, Massachusetts Institute of Technology and Department of Energy Report, 2006: Idaho National Laboratory INL/EXT-06-11746.