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RECOVERY FACTOR FOR EGS

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ABSTRACT

Modeled performance of the Cooper Basin EGS system indicates a recovery factor of under 2%, much lower than values of up to 70% assumed in generic studies. Other projects appear to have similar fracture geometries, suggesting similar recovery factors.

INTRODUCTION

Geothermal resources are the natural heat of the crust of the earth, and constitute a huge potential source of energy. To-date, almost all of the commercially exploited geothermal resources have been of the hydrothermal variety, containing hot water and steam in naturally fractured and highly permeable formations. Hydrothermal systems constitute only a small fraction of the high temperature geothermal resources. Geothermal systems (also called Enhanced or Engineered Geothermal Systems –EGS) that are deficient in fluids or have poor permeability are much more abundant; exploitation of these systems will require creation of permeability by artificial means (e.g. by hydraulic and or chemical stimulation) and circulation of fluid in order to mine the heat. A 2006 study (MIT, 2006) sponsored by the U.S. Department of Energy concluded that EGS could provide 100, 000 MWe or more in 50 years. The latter projection is based on a review of past EGS projects and realization of performance criteria that include a thermal drawdown in the production well of no more than 10°C over 30 years, and a flow of 50 kg/s. The MIT study used the work of Sanyal and Butler (2005) to estimate the “heat recovery factor” (=heat recovered at well head/ heat in the reservoir) required for assessing the electrical potential. Sanyal and Butler (2005) assumed a double porosity fracture/porosity system (Warren and Root, 1963) for computing the heat recovery factors. A critical parameter in the latter calculations is the “fracture spacing”. For uniform (such as those assumed in Warren and Root model) and small fracture spacings (say of the order of 1 to 10 meters), the double porosity model yields results that do not differ substantially from those obtained from a uniform porous media model. If the fracture distribution is heterogeneous, or if the fracture spacing is large (100s of meters of more), flow channeling will reduce the “heat recovery”. Sanyal and Butler (2005) performed numerical simulations for fracture spacings of 3 m, 30 m, and 300 m. The computed heat recovery factor was between 40% and 50% for the two smaller fracture spacings (3m and 30 m). These recovery factors are unlikely to be realized in practice. The heat recovery factors for naturally fractured geothermal systems generally lie between 5 % and 15 % (Garg and Combs, 2010). Because of the difficulty in emulating naturally fractured systems, the heat recovery factors for EGS systems would be expected to be lower.

COOPER BASIN

Hydraulic stimulation of Habanero#1 stimulated a reservoir volume of 0.4 km^3, as indicated by acoustic emissions. The heat exchanger has an area of ~4 km^2 and a maximum thickness of 100 m (Wyborn et al. 2005, Chen and Wyborn, 2009).

Subsequent testing showed that the tracer-swept pore volume was 2x10^4 m^3 (Chen and Wyborn, 2009). A three-dimensional solute transport model was developed with projections of temperature drawdown . At a flow rate of 15 l/s, there is a drawdown of 10°C after about 10 years, and at 25 l/s, after about 5 years. The average reservoir temperature is 240°C. Assuming a rejection temperature of 80°C, and with granite density and specific heat of 2700 kg/m^3 and 920 J/kg.K, the total amount of heat stored in the reservoir is 1.6x10^{17} J. Taking the lower flow rate of 15 l/s (which produces a higher net heat recovery), total heat recovered over a period of 10 years in the stream of produced fluid is 2.6x10^{15} J, or a recovery of 1.6% of the heat in the reservoir. The fluid accesses only a small fraction of the reservoir – the fracturing is markedly non-uniform and the resulting fluid flow effectively permeates only a small fraction of the reservoir. The tracer-swept pore volume is only 0.005% of the reservoir volume indicated by acoustic emissions.

The injection and production wells (Habanero 1 and 3) are located about 560 m apart, and the reservoir has a transmissivity of ~ 2 Darcy-m. Options for increasing heat recovery are to increase the distance between the wells and to stimulate multiple-layer fracture zones (Chen and Wyborn, 2009; Grant and Bixley, 2011). Whether these options can be realized in practice remains to be seen.

OTHER EGS PROJECTS

There is similar geometry at other EGS projects. Testing at Basel showed that "the reservoir has evolved along a distinct facture zone confined to a relatively narrow plane of a few tens of metres" (Häring et al., 2008, Ladner & Häring 2009)

At Soultz, Rose et al. (2006) obtained a tracer-swept pore volume of 16,000 m^3. In their analysis, Rose et al. (2006) utilized only the first 48 days of tracer return data. Using the complete tracer return record of 104 days, Garg (unpublished, 2011) showed that the tracer-swept pore volume is almost twice (~30,000 m^3) that quoted by Rose et al. In any event, the tracer-swept volume is a small fraction, 0.0013%, of the AE reservoir volume of 2.4 km^3 (MIT 2007), and detailed tracer interpretation shows a "limited, high-permeability zone" (Kosack et al. 2011).

A difficulty that limits fluid circulation in EGS projects is the rather low productivity of EGS wells. The productivity index for Habanero #3 is ~0.5 kg/s-bar (Chen and Wyborn, 2009), and is more or less the same as those (0.4 to 0.5 l/s-bar) obtained for Soultz wells GPK 2, 3 and 4 (Portier et al., 2009). These productivity indices are an order of magnitude smaller than those for productive hydrothermal wells (see e.g. Garg and Combs, 1997). The low productivity indices for EGS wells are most likely due to the inability to create an extensive fracture net work like that present in naturally fractured hydrothermal systems.

RECOVERY FACTORS: THEORY AND PRACTICE

Generic studies based on modeling (Williams 2010, Sanyal & Butler 2005) have suggested recovery factors as high as 50-70%. These are based on modeling of fractured rock. Crucially, the fractures are assumed to be uniform and to be closely spaced. The Cooper Basin results indicate that the fracturing and consequent flow is markedly preferential, and these generic studies overestimate recovery by a factor of up to 20. While sensitivity testing was carried out for a number of parameters, neither study considered the case where one extensive fracture has much higher permeability than all others – which appears to be the real case. MIT (2006) assumed that adding two to three times more volume would be sufficient to counteract the effects of channeling, but the actual flow is far more preferential than a factor of 2-3.

A similar but less extreme overestimation occurred in estimating recovery from natural hydrothermal systems. Originally models of flow in porous media (Nathenson 1975) were used to suggest an average value for the recovery factor of 25%. However post-audits of actual field performance (Sanyal et al. 2002, Sanyal et al. 2004, Williams 2004) showed actual values averaged only a third of this, with much variability between fields. A value of 10% is a representative rough average.

The recovery factor here calculated, of 1.6%, is a fraction of that achieved in hydrothermal systems. This is perhaps not surprising. The permeability in hydrothermal systems is due to formation porosity, natural fracturing associated with volcanic flows, tectonic movements, and hydrothermal alteration, all mechanisms that are volumetrically extensive. In contrast fracturing in an EGS is created by a point process – pressure or chemical stimulation applied at the fracture-wellbore intersection. The focussed process of hydraulic fracturing or chemical stimulation produces a focussed permeability structure, which is far from the uniform fracturing assumed in modelling. The creation of multiple fracture zones, as hypothesized by Petty (2011) should give some improvement in recovery by spreading the major flow over multiple zones. How effective this will be is yet to be tested.

The low recovery factor creates a further problem for EGS projects. The power density available is correspondingly reduced; with at best a few MW per square kilometre. Wellfields will need to extend over a wide area for a project of any economic size, and this loads additional costs onto the project. MIT (2006) assumed a 100MW plant would need a wellfield of 2.1 km^2 (based on a recovery factor of 20%), but it would have to be ten times this area.

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