Geomechanics Issues in Warm Dry Rock EGS

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ABSTRACT

In Canada, high-quality geothermal energy ($z < 3$ km; $T > 150$°C) is only available in a few hot spots in British Columbia and the Yukon, sometimes with sufficient natural fluid flux capability, but more often not. Intermediate-grade fluids 90°C-150°C are found in the Western Canada Sedimentary Basin below 3 km depth, but all the other sedimentary basins in the more populated eastern part of Canada that sits on sediments have insufficient permeability and porosity to allow large-scale exploitation of the heat energy through conventional means. Hence, the vast majority of Canada has only warm deep rock with unexceptional geothermal gradients, requiring penetration depths of 4 km to encounter temperatures greater than 80-90°C. I will refer to this as **IGGE** – Intermediate-Grade Geothermal Energy.

Nevertheless, there may be economic value in **IGGE** because of the need for both space heating and power in northern communities that currently depend 100% on diesel fuel shipped in thousands of km in special bladders. Energy from the diesel generators that both power and heat homes in the north is more than $0.50/kWhr, and if geothermal energy could displace this, issues of CO_2 emissions, environmental risk, black carbon emissions, and security of energy could be greatly improved. Indeed, if reliable heat sources for space heating are available year-round, with some power for photosynthesis LED lights, even greenhouses might be viable for many months of the year.

The five large EGS issues are drilling costs, HF stimulation, geochemistry and scaling, energy recovery, and ΔT-ΔV-$\Delta\sigma$-Δp analysis to predict stress changes that govern natural and induced fracture aperture changes and impact induced microseismicity. Let us assume that drilling costs are now acceptable (recent developments), that geochemical scaling can be managed or avoided (perhaps through use of supercritical CO_2), and that well linkage is feasible (based on recent developments). The remaining issues are the THM coupling and possible induced seismicity.

Circulation in a jointed rock mass (cooling) causes rock shrinkage, increasing induced and natural fracture apertures, increasing the rock mass effective permeability. A 2-D thermohydromechanical (THM) model for jointed rock masses (Jalali and Dusseault 2012) showed that permeability increases dominate flux as the cooled region migrates outward, thus advective heat transfer efficiency grows with time. Access to heat farther from the well array will also slowly develop, extending the energy volume available in a deep EGS system. Cooling and thermoelastic shrinkage lead to large-scale stress redistribution ($\Delta\sigma'$). A first-order approximation for $\Delta\sigma'$ in a cooled zone is $\Delta\sigma'_h \approx \beta\cdot\Delta T\cdot E/(1-\nu)$, where β = thermal compressibility (~14 $\mu\varepsilon$/°C), ΔT = temperature change (~80°C), E = Young's modulus (~100 GPa), and ν = Poisson's ratio (~0.2). These values give $\Delta\sigma'_h \approx 140$ MPa; at 6 km depth, an initial stress of ~160 MPa may be assumed, hence expected stress changes will generate substantial induced seismicity. The most important environmental issue in EGS will be seismicity, as suggested by the Basel experiment (Goertz-Allmann et al 2011). To quantify risk, one must perform geomechanics stress analysis and apply an appropriate slip theory (e.g. Mohr-Coulomb theory) probabilistically, scaled to stress magnitude changes in a specified volume. Since seismic moment as a function of stress drop $\Delta\sigma'$ and stressed volume V (stored strain energy – $W \approx \Delta\sigma'\cdot V$), a THM coupled analysis can use inputs of [$\Delta\sigma'$] and Δp to estimate the spatiotemporal distribution of zones approaching slip conditions.

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