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Silica Scaling in Dispatchable Enhanced Geothermal System Modelling

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ABSTRACT

With an increasing demand for renewable energy, dispatchable geothermal power presents a reliable solution to balance intermittent solar and wind generation. Enhanced geothermal systems (EGS) are a robust solution as they are applicable in a greater range of locations compared to traditional geothermal systems. Granite, a silica rich rock, is a common target layer for EGS given the depth necessary to reach the target reservoir temperature. With the cyclical changes in pressure and temperature during dispatchable production, the reservoir is prone to silica scaling, requiring costly interventions if not adequately predicted. This paper addresses the effects of silica scaling in the reservoir during dispatchable production for EGS. A transient reservoir model using Eclipse to couple thermal and pressure cycling and their effects on the geochemistry of the geofluid was established. The model solves time-dependent flow and heat transport equations to capture transient behavior. It was applied to a series of dispatchable scenarios with varying production to assess the effect of silica precipitation. The simulation revealed that silica scaling in granite reservoirs cannot be neglected in dispatchable EGS. This study offers one of the first dispatchable EGS modelling approaches to account for silica scaling during transient operations. Actionable insights and operational thresholds are defined, improving reliability and reducing downtime in future dispatchable geothermal energy developments.

1 INTRODUCTION

1.1 Dispatchable EGS

With the goal of decarbonizing energy production, countries around the globe are increasing their installed capacity of solar and wind energy. Between 2018 and 2023 alone, the global installed capacity of solar and wind nearly doubled (IEA, 2024). To maximize the benefits of integrating variable renewable energy resources (VREs), supporting technologies such as dispatchable energy production are essential to maintain grid stability (IEA, 2024, Shaner et al., 2018).

To ensure grid stability, traditional ancillary methods resort to fossil fuel as the solution. However, geothermal energy is an excellent alternative. In addition to geothermal being a low carbon solution, the prices are not as volatile as with oil and gas. For utility companies to meet the unexpected rise in demand, they are reliant on spot market gas/oil purchases, that are highly dependent on geopolitics, amongst other factors (Matek, 2015).

Geothermal energy is a reliable and naturally occurring source of renewable energy; however, its regional limitations increase the difficulty to deploy compared to wind and solar energy. By not having to rely on aquifers and favorable reservoir permeabilities, enhanced geothermal systems (EGS) increase the applicability of geothermal energy in the energy mix (Horne et al., 2025).

Ricks et al. investigates the opportunities of dispatchable energy for EGS to increase the economic viability of EGS in their 2022 and 2024 papers. Due to the low permeability nature of EGS systems, the reservoir is naturally confined, which prevents leak off of the injected fluid away from the reservoir. Thus, with minimal effect on the reservoir pressure, EGS can store hundreds of MWh of energy per MW of surface capacity (Ricks et al., 2022). Ricks et al.'s subsequent 2024 paper found that whilst a dispatchable EGS will have a higher levelized cost of electricity relative to a baseload system, the increase in system value and extension revenue level more than make up for the difference. The added flexibility in dispatchable EGS allows the technology to access markets that it would otherwise not be valued. However, the successful, widespread implementation of EGS, dispatchable or baseload, is highly dependent on the ability to reduce geothermal drilling costs (Ricks et al., 2025).

1.2 Silica Precipitation in EGS

With dispatchable energy comes cyclical pressure and temperature changes to the reservoir, two known factors for affecting dissolution of minerals. A common target for EGS lies in the granite rich layers: the Pohang EGS project in South Korea (Li et al., 2024), the EGS Soultz Site in France (Hooijkaas et al., 2006) and the Haute-Sorne EGS pilot in Switzerland are all examples (Meier and Zingg, 2025). Various solutions to mitigating silica scaling are available from brine injection over or at amorphous silica saturation and adjustment of the brine pH (Gallup and von Hirtz, 2015); however, with each solution comes an associated additional cost to an already expensive process. Within the scope of EGS reservoir modelling, the effects of dispatchable production (Ricks et al., 2022) and silica scaling (Pandey et al., 2015, Rutqvist et al., 2020) have been investigated, but the combination of the two factors for EGS remains underexplored.

Silica precipitates/dissolves in water with the following (Rimstidt & Barnes, 1980).

$$SiO_{2\,(s)} + 2H_2O_{(l)} \leftrightarrow H_4SiO_{4\,(aq)} \quad (1)$$

As amorphous silica is more reactive and has a higher dissolution/precipitation rate under reservoir conditions that its crystalline counterpart quartz, it is important to model amorphous silica scaling. Temperature, pressure, and fluid injection rate are all factors that affect the silica deposition in the subsurface. Other factors are known to influence siliceous scales such as pH and presence of metal ions (Gallup and von Hirtz, 2015); however, at this stage of the research, these factors are not addressed.

The temperature of the fluid has the largest effect on silica dissolution in the system. From the Arrhenius equation, temperature has an exponential dependence on the reaction rate. Compared to the effect of temperature, the effect of pressure on the dissolution of silica is minor (Rimstidt and Barnes, 1980). The location of silica scaling is dependent on the rate of injection. At higher rates, silica scaling occurs further from the injector, whilst at lower rates, near wellbore scaling is more prominent (Ontoy et al., 2003). This means that at the beginning of the life of the EGS, silica scaling is more evident further from the wellbore, however as this reduces the ability to inject into the reservoir, the injection rate decreases, with the near wellbore effect being seen in the near wellbore area.

2 METHODOLOGY

2.1 Transient Reservoir Modelling Method

To model the effect of cyclical pressure changes on the geochemistry of the geofluid, ECLIPSE was selected as the simulator. The THERMAL option was used within the simulation to allow for the thermal effects of geothermal energy to be evaluated. ECLIPSE was selected as the reservoir modelling software as it has been validated for its geothermal applications (Stacey and Williams, 2017).

2.2 Model Description

The model is of a hypothetical geothermal doublet system with a single horizontal fracture connecting the injector with the producer. The system is in a hot and impermeable granite matrix, where the fluid flow is mostly restricted to the fracture. The 50 by 50 by 45 numerical model represents a 1000 m by 1000 m by 191.105 m section 1704.45 m deep in the subsurface. A diagram of the grid can be found in Figure 1. The fracture is situated across the X-Y plain at grid block depth 23, with the injector at (25,25,23) and the producer at (45,25,23). The injected water contains trace amounts of silica (0.00556 mol/kg). The fracture lies at a depth of 1800 m with a reservoir temperature of 260°C. The grid blocks in the X and Y direction have a constant length of 20 m, whilst in the Z direction it has a width of 5 m, with the thickness symmetrically becoming finer the closer it is to the fracture. More information on the parameters for the model can be found in Table 1.

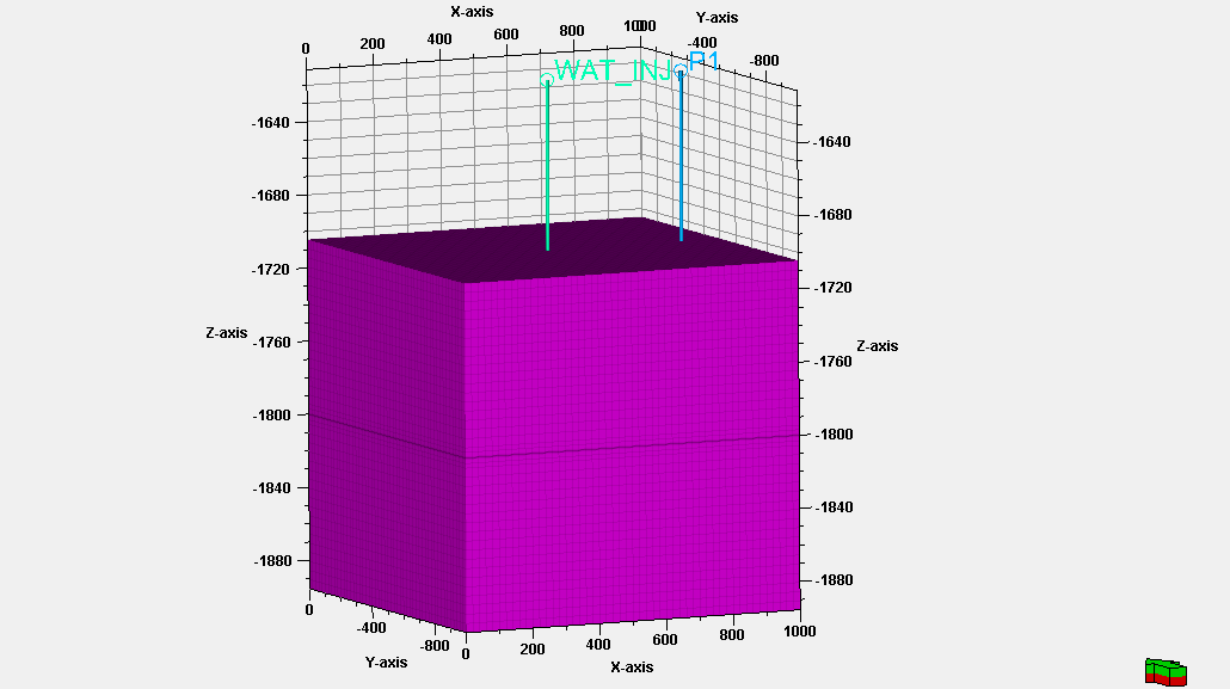


Figure 1. Model of the EGS doublet system with a single horizontal fracture

Table 1. Parameters used in the model

Property	Value	Unit
Initial fracture aperture	5	mm
Rock permeability	10^{-18}	m^2
Rock matrix porosity	0.01	-
Rock density	2500	kg/m^3
Fluid heat capacity	4180	J/kg/K
Rock thermal conductivity	2.5	W/m/K
Fluid thermal conductivity	0.6	W/m/K
Mass flow rate	40	kg/s

3 RESULTS

3.1 Comparing the effect of the reaction on baseload production

To understand the extent to which silica scaling is an issue for geothermal systems, a verification test was run. Two cases were run with identical parameters, the difference between the two being one having a silica precipitation/dissolution reaction and the other case having no reaction. The verification test was run to understand the effect under conventional, baseload production conditions.

Figure 2 shows how the effect of silica scaling cannot be ignored, the solid precipitation increases by a factor of 10. It is evident that the grid blocks furthest away from the injector at (25,25,23) have the greatest solid saturation content, these results are supported by Ontoy et al.'s paper's claim that at higher rates silica scaling occurs further from the injector.

The effect of the silica scaling is also seen in Figure 3 that shows the productivity index of the two models. Between the two models there is a difference of roughly 800 sm^3/day/bar. Thus stressing the importance of including silica precipitation/dissolution reactions in silica rich reservoirs.

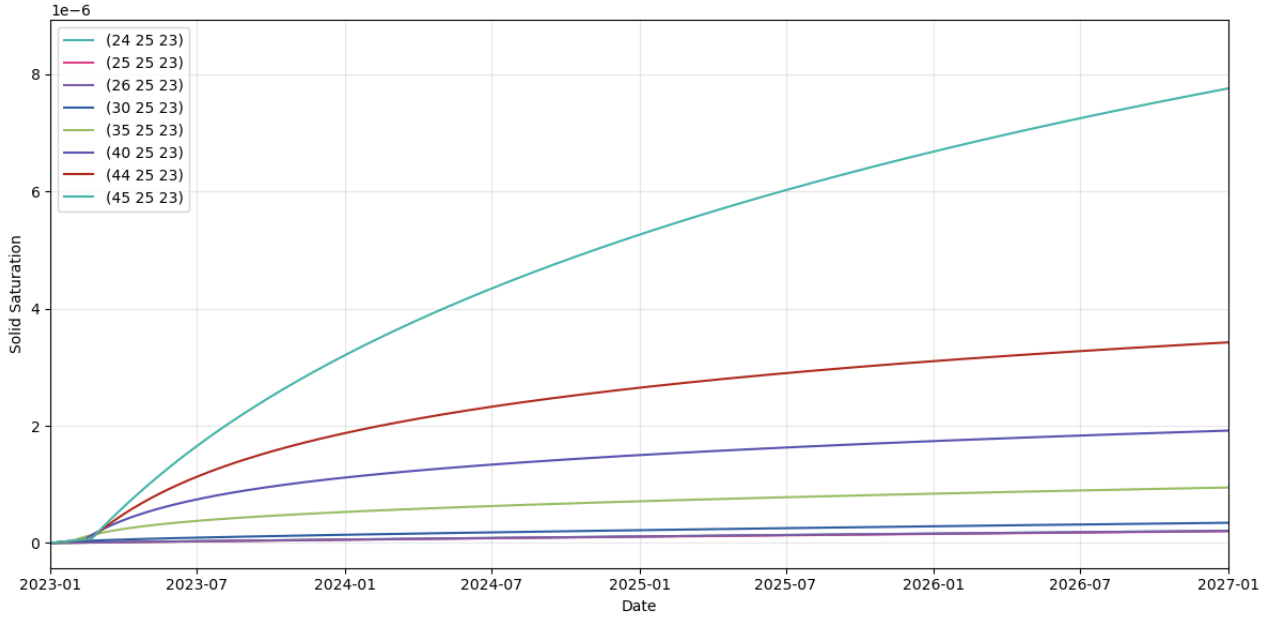


Figure 2. Silica saturation at different grid blocks at the fracture for the baseload model considering the silica precipitation/dissolution reaction.

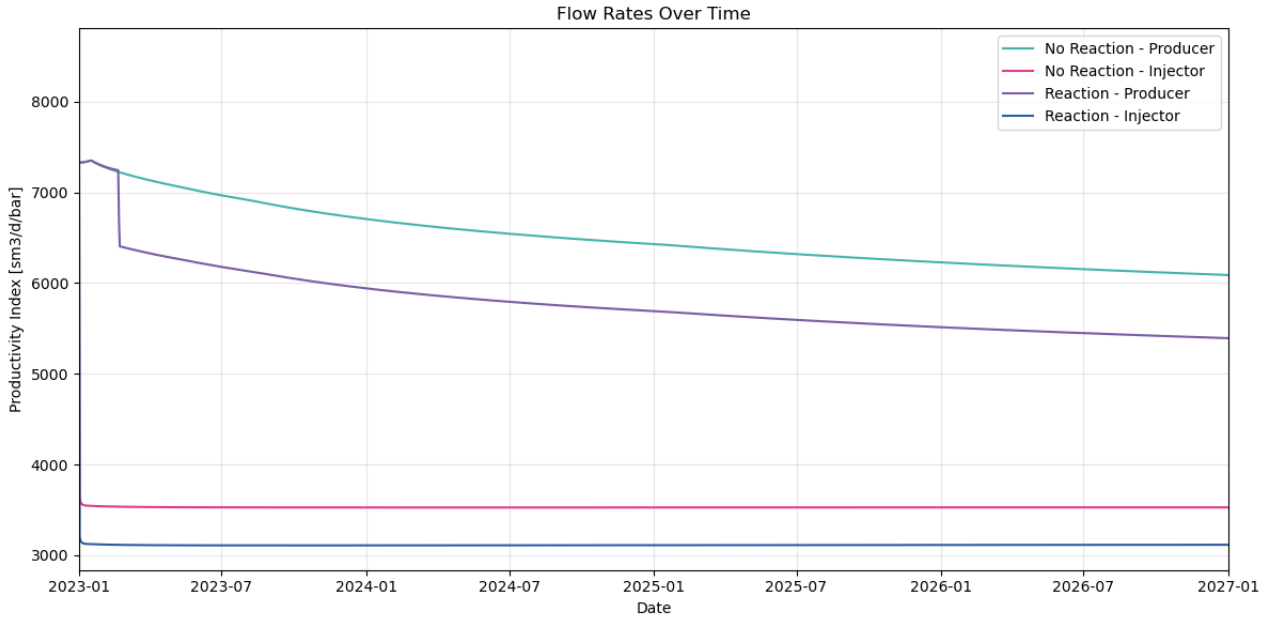


Figure 3. Productivity index of the two models over the course of 4 years.

3.2 Comparing the effect of varying production-rest cycle patterns

In this section, the effect of baseload versus dispatchable geothermal energy generation can be seen. For the dispatchable case, a diurnal production-injection regime was run. Then during the respective rest cycle of injection-production regime, the rate was cut by 50% instead of completely shutting off the well to prevent drastic changes in water saturation in the reservoir. For the purpose of an initial investigation, the model was run for 4 years to evaluate the effect of silica saturation within the early stages of the geothermal system's life.

Figure 4 shows the spatial distribution of the solid silica concentration at the fracture layer after a period of 1-4 years given the assumption that the silica was fully saturated, and thus there was no solid silica precipitation, at the beginning of the geothermal system's production. The same color concentration scale was used to provide direct comparison between the baseload and dispatchable cases. It is evident that there are stark differences in the behavior of the solid silica precipitation being the radius of influence, the shape of the area affected as well as the location of the highest concentration.

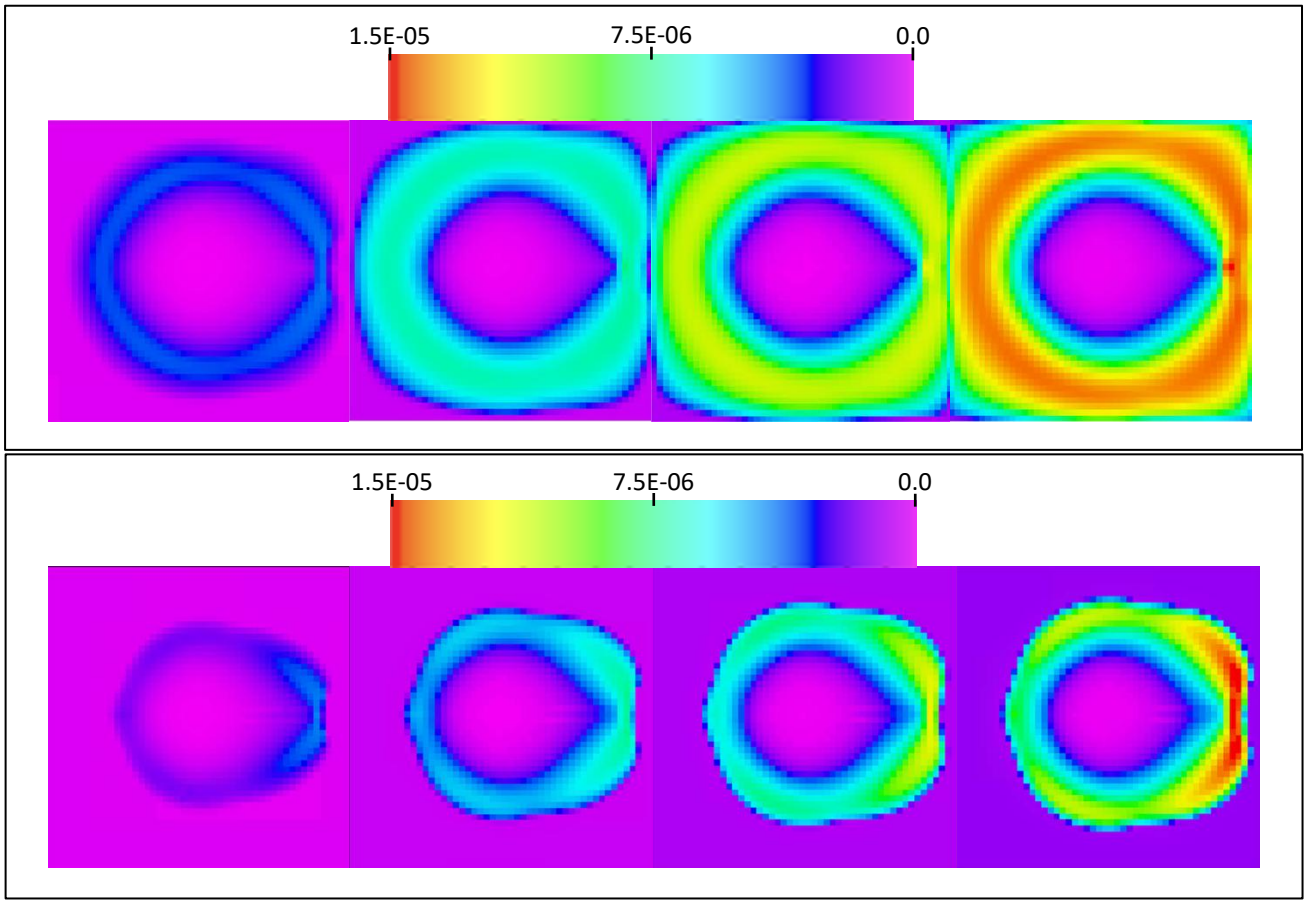


Figure 4. Top - from left to right the solid silica saturation for the baseload case at the fracture level is seen after 1 year, 2 years, 3 years and 4 years. Bottom - from left to right the solid silica saturation for the dispatchable case at the fracture level is seen after 1 year, 2 years, 3 years and 4 years.

As expected, the solid silica precipitation is able to reach a much larger radius of influence in the baseload case in comparison to the dispatchable case, this is due to the constant injection at the maximum rate of water. This also affects the overall shape that the affected area grows into. As it is able to reach the boundaries of the simulation at a much faster than its dispatchable counterpart, the baseload model has a far more uniform degradation of silica concentration. An interesting finding is the collection of silica precipitation creating a high concentration front at the producer for the dispatchable case. This is likely due to the low injection rate times that prevent the string constant flow pushing the fluid to the extremities of the layer. Further investigation of the fluid velocities at the different sections of the reservoir would provide additional valuable insight into this behavior.

4 DISCUSSION

Taking all these differences in behavior of solid silica precipitation between the classical baseload cases to the dispatchable cases, it is evident that further research is required in this area. The current assumption of similar silica deposition behavior in both the dispatchable and baseload production scenarios is not valid in all cases, thus, research on silica precipitation in EGS with baseload power generation cannot be directly applied to EGS with dispatchable power generation. This paper is an initial probe into the complex behavior of silica deposition in dispatchable EGS, evaluating the effect within the early stages of an enhanced geothermal system's life. Within the early stage of a 4-year timeframe, the need to incorporate the silica precipitation reactions at a baseload level stressed with the reduction of the productivity index of the model with the silica precipitation. Discrepancies between the silica precipitation behavior at a dispatchable level were found to differ regarding the radius of influence, the shape of the area affected as well as the location of the highest concentration. Whilst the radius of influence is smaller, and thus more favorable, during dispatchable production, there is a far larger concentration of silica creating a barrier at the producer. This example is one of many ways that the different production regimes differ regarding silica precipitation behavior. This initial research raises questions on how

factors such as injection temperature, flow rate, production regimes, amongst other factors further influence silica precipitation behavior.

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