

MODELING SCALING OF SILICA FROM REINJECTION WATERS AT WELL HEAD CONDITIONS IN THE BERLIN GEOTHERMAL FIELD, EL SALVADOR, CENTRAL AMERICA

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ABSTRACT

Generation of electricity at the Berlin Geothermal Field (Eastern El Salvador) started in February 1992. All the residual waters (~ 350 kg/s) produced during the conversion of thermal to electrical energy have been reinjected to the same field. Reinjection was the only feasible option for this field. However, silica scaling problems in the reinjection wells decrease the capacity of these wells to absorb water. The temperature of the reinjected waters is 175 °C and the reservoir temperature at the reinjection wells ranges from 280 °C to 200 °C. The mineral that presents a higher saturation index and it is more likely to precipitate at the pressure and temperature conditions of the water transport pipes and wellhead is amorphous silica. However, high precipitation of amorphous silica is not happening in the water transport system and the waters are reinjected supersaturated. Modeling of cooling of the hot reservoir waters in equilibrium with quartz and mixing with reinjection waters was done using the programs SOLVEQ and CHILLER.

The modeling results show that the mass of quartz precipitated within the reservoir per unit mass of reinjected water strongly depends on the initial silica concentration of the reinjected water. The temperature and mixing fraction of the reservoir does not seem to have a deep effect if the reservoir is at a higher temperature. Most of the silica precipitated is coming from the reinjected water with only a minor fraction coming from the temperature reequilibration of the reservoir. However, a slightly higher mass fraction of silica is precipitated when the temperature difference between reinjected and reservoir water is greater. Considering the flow rate of reinjected water at well TR-1A, the volume of quartz precipitated per kg of reinjected water, a 10% porosity, and a thickness of the reservoir of 200 m, the volume of pores clogged per year was found as well as the percentage of clogged reservoir volume assuming different radius for the deposition of quartz around

the well. A radius between 5 and 15 m for the precipitation of quartz could explain the decline in absorption capacity. Higher radius would give only a few percent change in porosity that cannot explain the change in absorption capacity. As the clogging of the pores seems to happen close to the wells, hydraulic effects are proposed to explain the abrupt response of nearby wells when reinjection starts in a new well.

INTRODUCTION

In El Salvador, Central America, geothermal energy is one of the few national energy resources available for the generation of electrical energy. The generation of electrical energy from geothermal resources in El Salvador produces 21% of the total electrical energy generated in the country (SIGET, 2005). This high percentage places El Salvador as the country with highest percentage of total electrical energy produced from geothermal resources.

One of the two most important geothermal fields in El Salvador is Berlin Geothermal Field (Figure 1) located in the eastern part of the country. Berlin Geothermal field started its operations in February 1992 with a turbogenerating backpressure unit that had 5 MW of minimum nominal power. In March, 1995, another similar unit was incorporated. These two units stopped operations in December, 1999, when two turbogenerating condensating units of 28.12 MW each of nominal power were installed. These units continue in operation today.

One important characteristic of the operations at Berlin Geothermal Field is that 100% of the waste water generated during the process of generation of electrical energy (about 350 kg/s) is reinjected back to the reservoir. One of the main problems produced by the reinjection of residual water is the high silica content of the geothermal waters. The silica supersaturated reinjected waters precipitate silica within the reservoir, incrusting and plugging the

pores, and decreasing the water absorption capacity of the reinjection wells. The understanding of the conditions, evolution, and possible future behavior of the silica scaling process is important for the exploitation of this geothermal field.

The objective of this paper is to present results of our simulations of silica scaling at Berlin Geothermal Field under different scenarios of mixing between reservoir and reinjected waters, and to compare these results with field observations. These simulations can help to understand how the precipitation process is happening and how it is affecting the circulation of the geothermal fluids. The programs used for these simulations are SOLVEQ (Reed M. H. et al, 2001) and CHILLER (Reed M. H. et al, 2000).

GEOLOGICAL SETTING

Berlin Geothermal Field is located in Eastern El Salvador, on the N-NW slope of Tecapa volcano. The volcanic chain in this region is related to the subduction between the Coco's Plate below the Caribbean Plate (Molnar and Sykes, 1969). Another important tectonic feature of the area is the boundary of the Caribbean with the Northamerican Plate in nearby Guatemala that defines the Motagua-Polochic fault system. Parallel to the Central American Pacific Coast, from Guatemala to Nicaragua, a graben system has been formed. This graben crosses El Salvador from West to East (Molnar and Sykes, 1969). The volcanic chain follows the southern margin of this graben. Figure 1 shows the location of Berlin Geothermal Field in El Salvador and Central America and the faults in the area.

The rocks found in this geothermal field are mostly andesitic lava flows intercalated with more silicic tuff layers. The tuff layers are thicker towards the middle of the rock profile (1883 to 1943 m) and they range from crystal poor to crystal rich layers. Close to the surface the tuff layers are thinner. At the reservoir depth, the main alteration minerals are quartz, calcite, chlorite and penninite, wairakita, epidote, illite, albite and iron oxides (CEL, 1999).

The average porosity of the reservoir has been estimated between 5-10%. The possible dimensions of the reservoir are around 6x7 km² with a thickness of 0.3 km, for a total volume of 12.6 km³ that includes both the production and reinjection zones (SIGET, 2000).

BACKGROUND

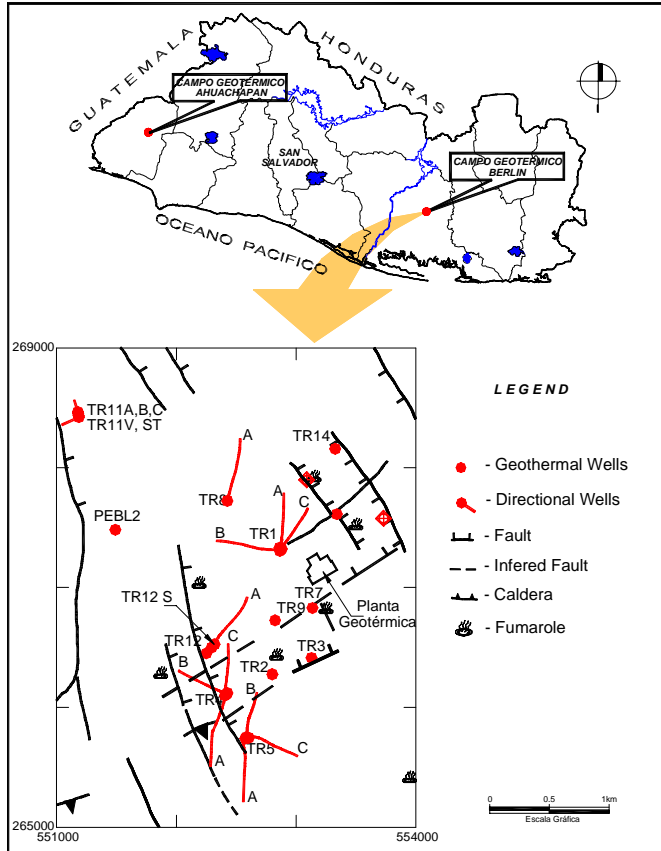
Electrical generation started at Berlin Geothermal Field in 1992, with vapor provided by wells TR-2 and TR-9 to two turbogenerating backpressure units.

The total residual waters were reinjected hot to wells TR-1, TR-8 and TR-14. When the turbogenerating condensating units started to operate in 1999, the following wells provided additional vapor: TR-4, TR-4B, TR-4C, TR-5, TR-5A, TR-5B, and TR-5C. The total hot residual waters were then reinjected to wells: TR-1A, TR-1B, TR-1C, TR-3, TR-4A, TR-8A, TR-10, TR-11ST, TR12, and TR-12A. Colder residual waters were reinjected to wells TR-7 and TR-11A.

The hot reinjection (average temperature 175°C) is done at a depth between 2000 and 2400 m; this is also the depth of the production reservoir implying that this reinjection takes place within the reservoir itself. On the other hand, the cold reinjection (average temperature 60°C) is done at a depth of only 500 and 700 m, within an intermediate depth aquifer of this geothermal field.

During the seven years of operation of the turbogenerating backpressure units, the reinjection wells showed a stable good absorption capacity with a slight decreasing behavior with time due to the high salinity of the residual waters (average 13000 ppm for Berlin Geothermal Field). However, when the exploitation of the field increased and the turbogenerating condensing units were installed, the absorption capacity of most of the reinjection wells declined with time. Figure 2 shows the reinjection history of wells TR-14, TR-1A, and TR-11ST. In this diagram, it is clearly shown that just after reinjection started at well TR-1A, the water absorption capacity of well TR-14 decreased from an average of 40 kg/s to an average of 10 kg/s during a time span of 1.25 years. Note that well TR-14 was very stable in its water absorption capacity during the 4 years prior to the reinjection in well TR-1A.

Well TR-14 was cleaned mechanically in July, 2000 and in October, 2001 to improve its water absorption capacity. In addition, chemical cleaning to remove the precipitated minerals was done within the absorption zone (Cartagena, M. 2001). A decrease in the pipe diameter due to mineral incrustation was not found during the mechanic cleaning, from the top to the bottom of the well. This observation implies that mineral precipitation was not happening within the pipe of the well but more likely within the zone of the reservoir that was receiving the residual water. The chemical cleaning with one system of hydrochloric Acid (10%) and one system of hydrochloric acid (10%) – hydrofluoride acid (5%) mix (Castro, M. 2001) improved the water absorption capacity of the well to almost the original conditions. After the cleaning, reinjection was initiated again. However, after that the well has shown a similar decreasing absorption capacity as it can be observed in Figure 2.



LaGeo S. A. de C. V. (which is the company that operates the Berlin Geothermal Field) makes routine and systematic analysis of waters and gases of the production and reinjection fluids of this geothermal field. Examples of these chemical analyses are presented in tables 1A, 1B, 1C, and 1D. These tables show the chemical components used in the simulation work of our research. In Figure 2, the water absorption capacity of well TR-11 ST seems to have been stable during the whole period of operation. This is an interesting result because TR-11 ST is located in the colder region of the geothermal field, away from the hot upflow zone. This well presents the highest saturation index of all the wells -S.I. = 1.30 at the wellhead reinjection temperature- (Castro et al., 2005). The behavior of this well suggests that the precipitation of silica is not happening at the wellhead conditions and within the pipe but in the internal deep zones of the reservoir. It also suggests that very likely silica precipitation is not the only cause of the decrease of water absorption capacity of the other reinjection wells, but other hydraulic conditions are probably also affecting the capacity to absorb water of the reservoir.

Fig. 1. Berlin geothermal field and tectonic setting of the study area.

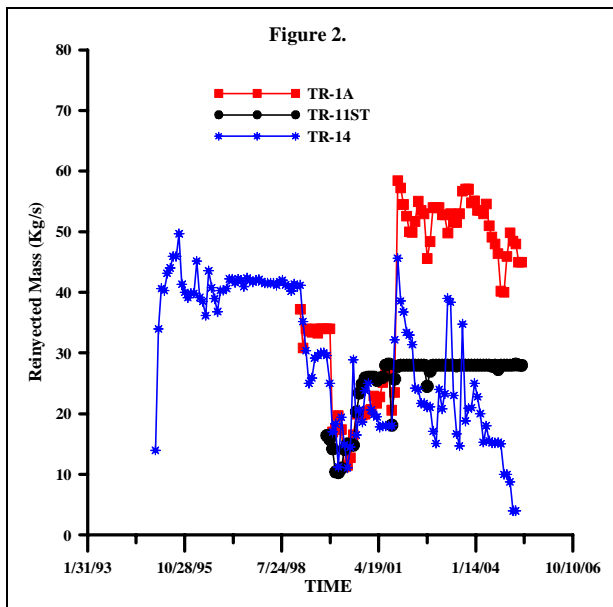


Fig. 2 History of the water absorption capacity of some of the wells of Berlin Geothermal Field.

MODELING PROCESS

The computer programs SOLVEQ and CHILLER were used in our simulation work. SOLVEQ is a FORTRAN program that can find the speciation of multicomponent aqueous systems in chemical equilibrium. CHILLER is also a FORTRAN program that calculates the chemical speciation and reaction path of multicomponent heterogeneous systems in chemical equilibrium. It includes equilibrium with solids, gases and an aqueous phase. The mineral assemblage found in Berlin Geothermal Field (quartz, calcite, K-feldspars, plagioclase, spinel, pyroxenes, and iron oxide) can be approximated with the end member components found in the file SOLTHERM, which is the data base for CHILLER and SOLVEQ.

In our work, the fluid compositions of the production well TR-9 were used as representative of the reservoir composition, and the composition of the water reinjected at well TR-1A was used as representative of the reinjection fluids. The following processes were modeled:

Table 1A. Example of chemical analysis of reinjected water at well TR-1A

| Date | Sampling point | Na | K | Ca | Mg | Cl | SO4 | HCO3 | SiO2 | B | Li | Cond. | pH | Temp. | WHP |
|----------|----------------|------|-------|-------|-------|------|------|------|-------|-----|-------|----------|------|-------|------|
| | | ppm | | | | | | | | | | umhos/cm | Camp | °C | barg |
| 08/02/05 | Wellhead | 3645 | 751.3 | 112.9 | <0.01 | 6503 | 19.3 | 2.24 | 775.4 | 121 | 12.54 | 18970 | 6.5 | 27.0 | 26.3 |

Table 1B. Example of chemical analysis of separated water from well TR-9

| Date | Sampling point | Na | K | Ca | Mg | Cl | SO4 | HCO3 | SiO2 | B | Li | Sampling conditions | | | | |
|----------|----------------|------|-----|-----|-------|------|-------|------|------|-----|------|---------------------|------|------|------|------|
| | | ppm | | | | | | | | | | pH | T °C | WHP | Psep | PMx |
| 16/02/05 | Wellhead | 3387 | 679 | 185 | <0.01 | 6600 | 18.69 | 6.74 | 739 | 138 | 12.9 | 7.02 | 22.2 | 10.8 | - | 10.6 |

Table 1C. Example of chemical analysis of gases from well TR-9

| Date | Sampling point | He | H2 | N2 | Ar | CH4 | O2 | CO | SH2 | CO2 | NH3 | P Mx | PS | WHP |
|----------|----------------|--------------------------|------|------|-------|-------|-------|----|-------|------|-----|------|------|------|
| | | m.mol / 100 mol de Vapor | | | | | | | | | | | Barg | |
| 16/02/05 | Wellhead | 0.253 | 1.45 | 1.08 | 0.107 | 0.265 | 0.025 | | 11.96 | 84.2 | - | 10.6 | | 10.8 |

Table 1D. Trace elements for geothermal well waters

| Date | Well | Sampling point | Fe | Cr | Cd | Pb | Rb | Cs | Al | Sb |
|----------|-----------|----------------|-------|-------|-------|-------|------|--------|------|--------|
| | | | ppm | | | | | | | |
| 14/01/04 | TR-1A | Wellhead | 0.309 | 0.115 | <0.05 | <0.05 | 11.7 | 0.0670 | 0.13 | 0.5100 |
| 14/01/04 | TR-9/TR-2 | Water tank | 0.356 | <0.05 | <0.05 | <0.05 | 13.0 | 0.0366 | 0.15 | 0.0967 |

A. Restoration of the reservoir water from the composition of separated waters and gases of well TR-9

The chemical analysis of waters and gases obtained for samples from the wellhead of well TR-9 were used in this simulation (date 16/02/05). The program SOLVEQ was used to calculate the composition of the original water at the reservoir conditions from the water and gas analysis at conditions of the wellhead. A gas fraction in the discharge equal to 0.2504 was used. The composition of the reservoir water at a temperature of 290 °C and a pressure of 120 bars was calculated.

In a similar way, the compositions of the reinjection waters at the wellhead conditions from the sampling conditions were calculated. The water collected at the wellhead of TR-1A (date 08/02/05) was used to restore the water composition at a wellhead temperature of 175 °C. In this case, a gas phase was not present.

B. Cooling of the reservoir water along the water path

The isotherms of the reservoir of Berlin Geothermal Field show that the waters cool down as the waters move from the high pressure region at higher elevations to the lower pressure regions in the discharge direction. For that reason the original restored reservoir water at 290 °C in the production zone of well TR-9 was cooled down to 150 °C at 10 °C decreasing steps. These simulations were done in two different ways: i) without interaction between the water and rock minerals, and ii) with interaction between water and the rock minerals. In both cases fractionation (or separation) of minerals after each temperature step was assumed to happen. In these simulations, the only mineral precipitated was quartz. The options in CHILLER for change of temperature, water-rock interaction, and equilibrium minerals were used in these simulations.

C. Water Mixing and Silica Scaling

The reinjection waters restored to a temperature of 175 °C for well TR-1A were mixed with restored reservoir waters (well TR-9) in different proportions adding reservoir water to 1 kg of reinjection water up to a proportion of only 10% of reinjection water. The water mixing options in CHILLER were used for this purpose. The compositions of reservoir waters at two different temperatures (obtained from simulations in B above) were used: 250 °C and 200 °C. These temperatures were selected because they are within the range of temperatures observed at the Berlin Geothermal Field wells. In addition, for each temperature two scenarios were modeled: without water-rock interaction and with water-rock interaction. Fractionation and no-fractionation of minerals were also modeled in all these different scenarios.

For the simulations that considered the interaction between water and rock minerals, the mineral assemblage observed at Berlin Geothermal Field production zone and that were included in the thermodynamical data base of CHILLER was used. This assemblage includes the minerals: albite, anhydrite, calcite, chlinochlore, galena, hematite, magnesite, muscovite, pyrite, and quartz.

RESULTS

A. Simulation Results

In this section we present the results of our simulations in several graphs showing the evolution of the precipitation of quartz as a function of the mixing fraction between reinjected and reservoir waters. We also present the results for the silica content of the reinjected and reservoir waters in the deep absorption zone of the reservoir. The simulations show that several minerals could be precipitating in the different scenarios, such as galena, muscovite, pyrite, and anhydrite. However, we do not include them in our discussion of results because in all cases the percentage of these minerals

was very low, averaging no more than 0.05% of the total precipitated solids.

Figure 3 shows the results for the cooling of reservoir water with the initial composition of the restored TR-9 water and an initial temperature of 290 °C. Figure 3A shows the results assuming no interaction with the rock matrix and Figure 3B shows results assuming water-rock interaction or equilibrium with respect to the mineral assemblage mentioned earlier for the production zone of Berlin Geothermal Field. Both runs were done assuming fractionation of the precipitated minerals (quartz). It seems that there is not a significant difference for the precipitated quartz in both runs. As other minerals do not precipitate in large quantities the chemical composition of the water (in molalities) does not change significantly except for the silica content. Note that the highest quartz precipitation occurs during the first change of temperature (290 °C to 280 °C) as the supersaturated water equilibrates. During the subsequent steps, quartz precipitates due to the decrease in temperature that produces a lower solubility of quartz. The molal composition of other elements such as Cl, K, Na, Mg, Ca, etc. remained constant during the simulation.

Figure 4 shows results for the mixing simulation of 1 kg of restored reinjection water at 175 °C and the addition in steps of different masses of restored reservoir water at 250 °C, without water-rock interaction (Figure 4A) and with water-rock interaction (Figure 4B). Values in the X axis vary from 0.99 to 0.1 mass fraction of reinjected to reservoir water. It can be observed in these graphs that the temperature of the mixed solution at the end of each step is the same for both graphs. Other parameters such as the mass and volume of quartz precipitated at each step, the final concentration of silica in solution, and the mass of quartz precipitated per total mass of water behave in similar way with values that are very similar for both runs. The highest precipitation of quartz occurs at the very first step when the reinjected water equilibrates thermally and mixes with 0.01 kg of reservoir water. After that, only very small amounts of quartz precipitate due to the cooling of the reservoir water that mixes with the reinjected water. One important result of these simulations is that the total mass of quartz precipitated depends only on the initial concentration of silica in the reinjected water and the mass of reinjected water. The total mass precipitated is almost constant and only depends on the mass reinjected and its concentration. For this particular case, the total mass of quartz precipitated from 1 kg of reinjected water is 0.672 g for the run without water-rock interaction and 0.679 g for the run with water-rock interactions.

The simulations presented in Figure 5 are similar to those in Figure 4, except that the reservoir water is the TR-9 water cooled to 200 °C instead of 250 °C. In Figure 5, the total mass of quartz formed during the

first step is again 0.612 g (case without and with water-rock interaction) similar to the previous case. After that step and with the subsequent addition of reservoir water a total mass of quartz of 0.623 is formed without water-rock interaction, and 0.621 g with water-rock interaction. In terms of the mass of quartz precipitated, the results are similar to those for 250 °C. The reason is that the initial precipitation of quartz corresponds to the equilibration of the supersaturated reinjected water that precipitates quartz to achieve equilibrium at the reinjection temperature. The subsequent addition of reservoir fluid and increase in temperature only generates precipitation due to equilibration of the hot reservoir fluid and the colder reinjected fluid to the new mixing fraction and equilibrium temperature. The concentrations of silica in the mixing solutions are lower than the concentration achieved when the reservoir is at 250 °C as silica solubility decreases with temperature (Ellis A. J. and Mahon, 1977). These simulations show that the mass of reinjected water, its silica composition, and reinjection temperature determine the mass of quartz that can precipitate and plug the pores. The temperature of the reservoir and its composition has only a minor effect if chemical equilibrium with quartz in the original reservoir is assumed.

Several simulations similar to those presented in Figures 4 and 5 were done but without mineral fractionation. Comparison of the simulations with and without fractionation (but with water-rock interaction) shows that there is not significant difference for the fractionation and no-fractionation cases. The fact that all these simulations do not give different results can be explained considering that the only reaction that seems to be occurring is the precipitation of quartz. As quartz is precipitating and not dissolving in all the mixing steps, there is not reason why the results for the two runs should be different. Only if other reactions were happening or quartz could dissolve in a reaction step, the fractionation and non-fractionation cases could give different results.

B. Implications for silica scaling at Berlin Geothermal Field.

The results of these simulations give important insight into the silica precipitation processes and its impact for the water absorption capacity of the reinjection wells. It is clear from the simulations that the total mass or volume of quartz precipitated only depends on the mass of reinjected water and its silica concentration. The reinjection of 1 kg of water with the composition found in well TR-1A can precipitate between 0.612 g to 0.672 g when mixing with reservoir water between 200 and 250 °C regardless of the mixing fraction. This corresponds to a range of 0.231 to 0.254 cm³. This is a very narrow range that allows us to make some calculations to determine the

possible volume of reservoir affected by quartz precipitation and the corresponding decrease in porosity.

Additional information is needed for these calculations. Well TR-1A has been reinjected at an average rate of 38.8 kg/s during a period of time of 6.3 years (Romero, 2005). The thickness of the absorption zone for this well is 200 m, the diameter of the well in this zone is 0.22 m for a well volume of 7.6 m³ at the absorption zone (Mayorga et al., 2001). One of the unknowns of this problem is the radius of the area affected by the scaling process. However, previous chemical treatment of Berlin wells to restore the permeability, suggest that radius of 5 to 15 m are probably a good guess for the affected area (Schlumberger Surencó, personal communication). This estimation of the radius is based on the cone of depression formed when flow rates of 32 l/s are used and in the amount of chemical needed to stimulate the wells. With this information we can estimate the volume of the reservoir around the well for different radius, the mass or volume of quartz precipitated per year, the percentage of volume (assuming different radius) clogged by quartz per year, and the percentage of volume clogged after 6 years of reinjection. The results for the two scenarios modeled here are presented in Tables 2A and 2B.

For the two initial reservoir temperatures and the two extreme ratios of reinjected to reservoir water (0.99 and 0.10), a radius of 5 m seems unlikely. If the deposition occurs within 5 m of the well, after 6 years all the pores should be completely clogged and water could not circulate. A radius of 10 or 15 m seems more likely since the reduction in porosity per year could be between 2% and 5%, which seems more consistent with the decrease in absorption capacity observed in the wells. However, if the deposition of quartz is occurring at distances larger than 15 m, a relatively small decrease in porosity should be observed and the reduction in the water absorption capacity of the wells should be negligible. These results suggest that the precipitation of silica in the wells occurs in the near region. If this is true, precipitation in a well should not affect the water absorption capacity in another well because they are located several hundred meters away of each other. At least, the impact of silica scaling in one well should not be observed in a short period of time in nearby wells. The response of well TR-14 to the reinjection in TR-1A cannot be due to silica scaling processes. Instead changes in the hydraulic regime of the reservoir due to the additional volume of water reinjected should be investigated.

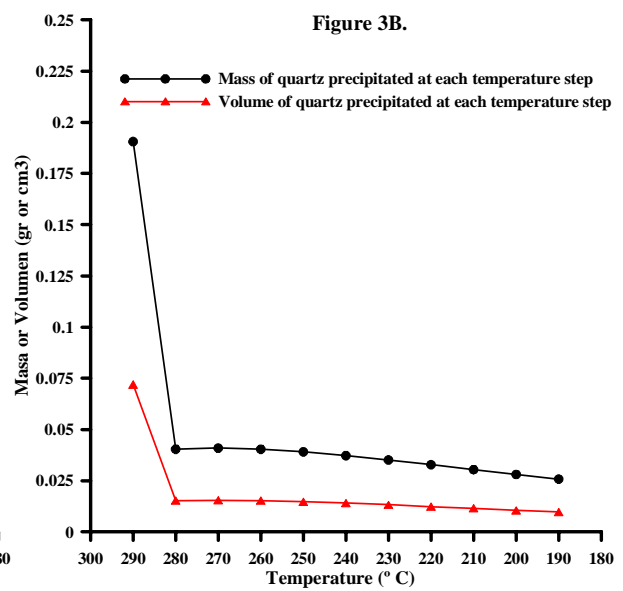
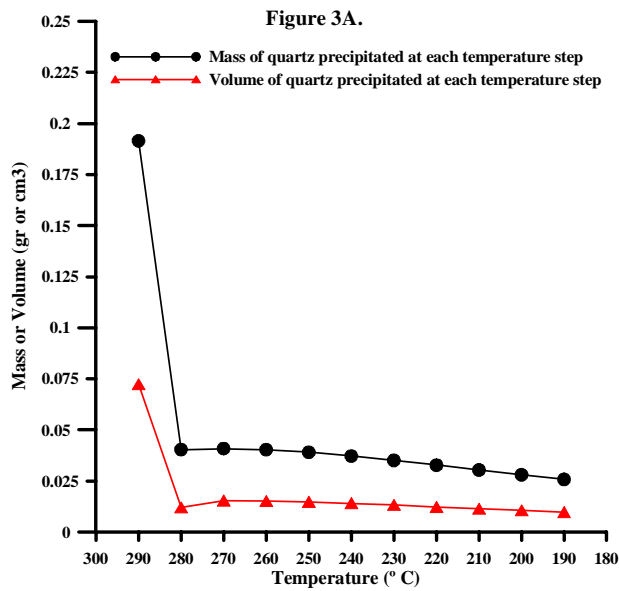


Fig. 3. Evolution of precipitation of quartz as restored reservoir water from well TR-9 cools down from 290 °C to 190 °C assuming fractionation. A) Without and, B) With water-rock interaction.

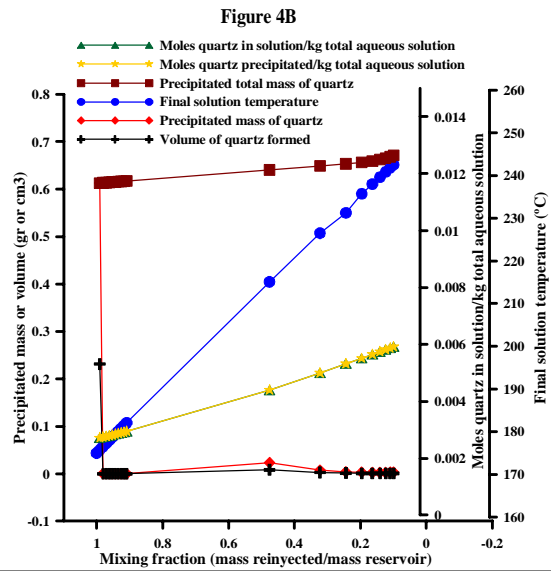
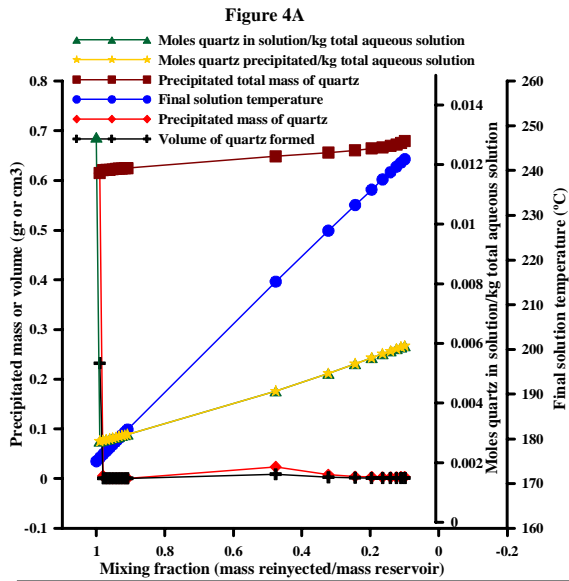


Fig. 4. Silica results for the mixing of restored reinjection water at 175 °C with reservoir water (cooled TR-9 water) at 250 °C assuming fractionation. A) Without and B) With water-rock interaction.

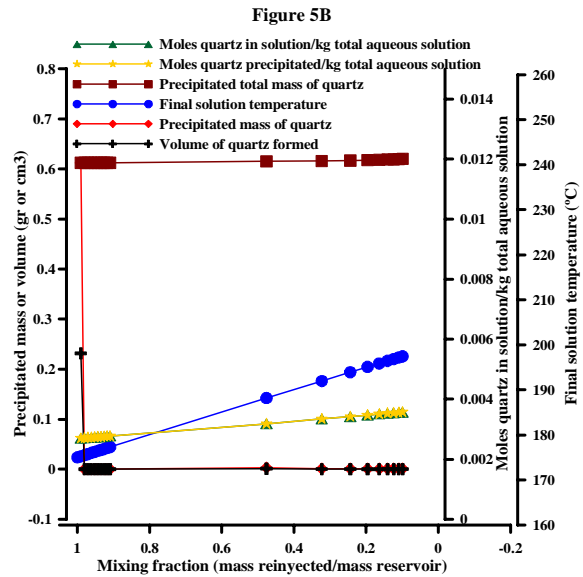
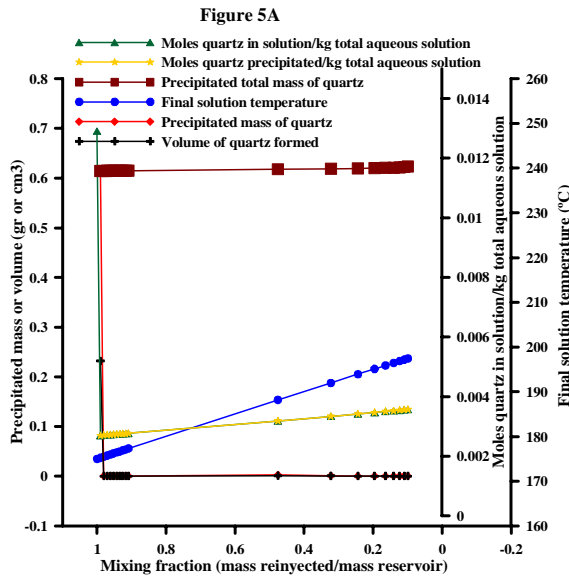


Fig. 5. Silica results for the mixing of restored reinjection water at 175 °C with reservoir water (cooled TR-9 water) at 200 °C. A) Without and, B) With water-rock interaction.

Table 2A. Effect of quartz precipitation on the porosity of the reservoir close to the well. The temperature of the reinjection water is 175 °C (TR-1A) and the temperature of the reservoir is 250 °C.

| Fraction reinjected/reservoir water | Radius absorption (m) | Volume absorption zone (m ³) | Volume precipitated per kg reinjected water (cm ³) | Total volume precipitated (m ³ /year) | % volume clogged per year | % volume clogged in 6 years |
|-------------------------------------|-----------------------|--|--|--|---------------------------|-----------------------------|
| 0.99 | 5 | 1563 | 0.231 | 283.1 | 18.1 | 108.6 |
| 0.99 | 10 | 6276 | 0.231 | 283.1 | 4.5 | 27.0 |
| 0.99 | 15 | 14130 | 0.231 | 283.1 | 2.0 | 12.0 |
| 0.10 | 5 | 1563 | 0.254 | 310.3 | 19.9 | 119.4 |
| 0.10 | 10 | 6276 | 0.254 | 310.3 | 4.9 | 29.4 |
| 0.10 | 15 | 14130 | 0.254 | 310.3 | 2.2 | 13.2 |

Table 2B. Effect of quartz precipitation on the porosity of the reservoir close to the well. The temperature of the reinjection water is 175 °C (TR-1A) and the temperature of the reservoir is 200 °C.

| Fraction reinjected/ reservoir water | Radius absorption (m) | Volume absorption zone (m ³) | Volume precipitated per kg reinjected water (cm ³) | Total volume precipitated (m ³ /year) | % volume clogged per year | % volume clogged in 6 years |
|---|--------------------------|---|--|--|---------------------------------|-----------------------------------|
| 0.99 | 5 | 1563 | 0.231 | 282.9 | 18.1 | 108.6 |
| 0.99 | 10 | 6276 | 0.231 | 282.9 | 4.5 | 27.0 |
| 0.99 | 15 | 14130 | 0.231 | 282.9 | 2.0 | 12.0 |
| 0.10 | 5 | 1563 | 0.234 | 286.8 | 18.4 | 110.4 |
| 0.10 | 10 | 6276 | 0.234 | 286.8 | 4.6 | 27.6 |
| 0.10 | 15 | 14130 | 0.234 | 286.8 | 2.0 | 12.0 |

CONCLUSIONS

a. Quartz is the silica phase that precipitates in the deep reinjection zone of the reservoir in the different modeled scenarios. The effect of interaction between the water and the rock minerals do not have a major effect on quartz precipitation. Precipitation of other minerals seems unlikely, or it is very low compared to the mass of quartz precipitated.

b. The mass of silica precipitated as quartz during the mixing of reservoir and reinjection waters depends on the concentration of silica in the reinjected water (supersaturated) and the mass of reinjected water, if the reservoir water is assumed to be in equilibrium with quartz before mixing. Most of the precipitated silica comes from the reinjected water with only minor amounts coming from the reequilibrated reservoir water.

c. The temperature of the receiving reservoir (if higher than the reinjection temperature) and the mixing fraction (reinjected/reservoir water) does not seem to affect deeply the mass of silica precipitated, the mass of reinjected water is more important.

d. The volume of reservoir surrounding the injection wells and affected by quartz precipitation should have a radius lower than about 15 m to explain the decrease and water absorption capacity of the reinjection wells. A higher radius would produce only a small effect and could not explain the decrease in permeability.

e. The abrupt decline in water absorption capacity observed in some wells (e.g. TR-14) when reinjection starts at another nearby well (e.g. TR-1A) cannot be explained with precipitation of quartz alone. Instead, the new injection of water can increase the reservoir pressure, decrease the head gradient and water velocities, and the capacity of the wells to transfer water to the reservoir.

h. The results of these simulations at Berlin Geothermal Field are likely to be applicable to other geothermal fields in exploitation with similar characteristics.

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