Brine Chemistry, Scale Inhibitors and Dosing Systems Used at the Germencik Geothermal Field, Turkey

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ABSTRACT

Twenty-eight wells supply geothermal fluids to two steam turbine power plants and three ORC binary plants at the Germencik Geothermal Field, Turkey. Improved understanding and useful ability to model and predict the chemical behavior of geothermal brines has been developed in connection with analyzing and controlling chemical problems at Germencik and other geothermal fields.

The brine becomes supersaturated in respect to calcite and amorphous metal silicates when steam starts to separate from brine in the wellbore. Calcite inhibitor is injected in each well below the flash point to prevent deposits which would otherwise quickly choke off the well. Another inhibitor is injected at the wellhead to protect surface equipment against metal silicates, especially heat exchangers in the binary plants must be kept clean.

Chemical treatment has been successful in both the technical and economic sense in preventing the deposition of calcite and metal silicates in production wellbores, surface facilities and injection wells.

1. INTRODUCTION

The Germencik geothermal field is located at the western side of the tectonic valley known as Buyuk Menderes graben in SW Turkey. The reservoir is water dominated with high reservoir temperature up to about 276°C. The geothermal system is fault controlled. First exploration studies were conducted by the Mineral Research & Exploration General Directorate (MTA) between 1982 and 1986 and nine deep wells were drilled as exploration and production wells. Guris Electric Generation Company drilled nine additional wells and constructed a 47.4 MWe double flash type power plant in 2009. This power plant has produced electricity successfully for the last seven years. Guris increased investment in the geothermal sector by acquiring a neighboring field and started drilling in 2012. Forty-five wells have been drilled in the new field and drilling operations continue. Short term well completion tests have been conducted in these wells. Wellhead enthalpies, corrected for NCG, are between 697 and 947 kj/kg. Brine samples have been analyzed, and NCG content has been determined. The average NCG content is quite high: about 2.2 % by weight of geofluid. The results of the completion tests have been analyzed by the reservoir department of Guris. In 2014 and 2015, three 22.5 MWe (net) binary plants and one 47.4 MWe double flash plant started commercial production. The project currently has 28 production wells and 26 injection wells in operation for five power plants. The five plants have an installed capacity of 162.3 MWe.

Two types of scale inhibitors are used to control deposits in the production wells and surface equipment, and protect the injection wells. One product, formulated primarily to control calcium carbonate deposits, is applied downhole in each well via capillary tubing. The other product, designed to control silica and metal silicates, is added to the brine at the wellhead. The chemistry of brine and steam produced, and the condition of the production wells, surface equipment, and injection wells is monitored periodically by Guris reservoir department.

2. BRINE CHEMISTRY

2.1 Sources of information

Brine chemistry at EFE-1 was modeled representing the two steam turbine power plants at Germencik, and brine chemistry at EFE-3 was modeled representing the three binary power plants. The process conditions modeled for each unit were taken from the design heat and mass flow diagrams, modified as needed to account for different fluid enthalpy and to add some needed values.

Chemical analyses of brine samples of the 12 wells supplying these power plants were used, collected using a miniature separator and cooling coil 24 April 2015 and 5 November 2015 (separator P = 7.5 bar-a). The mass flow contributed by each well was taken from the Weekly Service Report of 04–11 March 2015. The maximum temperature recorded surveying each well was also used, and the mass fraction of Noncondensible Gases (NCGs, mostly carbon dioxide) in the combined fluid flow (brine and steam) from each well.

2.2 Computer programs employed

Powerchem's proprietary computer program STF ("Silica Temperature and Flash brine") was used to determine initial temperature of the brine in the reservoir based on the concentration of silica dissolved in the brine, separator pressure, salt content of the brine, and mass fraction of NCGs in the steam. STF was also used to calculate the partitioning of heat, water and carbon dioxide between liquid and vapor when steam is separated from the brine.

The commercially available computer program Geochemist's Workbench, Standard Edition, v. 9.03 was used to model chemical equilibrium of the brine with minerals in the reservoir, and to predict the potential for precipitation of minerals from the brine as it passes through the energy extraction process.

2.3 Initial temperature and composition of brine in the reservoir

The concentration of silica in brine from five of the 12 wells considered was reported, allowing initial T of brine in the reservoir to be determined based on the solubility of quartz. Silica values were not available for seven of the wells supplying EFE-1. Reservoir T could be determined for 15 wells at Germencik based on silica concentration. The difference between maximum T and T based on quartz solubility, averaged over these 15 wells, was 10.6°C. This number was subtracted from the maximum T of each of the seven wells lacking silica values to produce an estimate of initial T in the reservoir.

The initial composition and T of the combined flow provided to each power plant was determined by averaging brine composition, NCG content, and initial T for the wells supplying the unit, weighted by the mass fraction of combined flow provided by each well. The averaged brine composition was corrected for water lost when steam was separated from the brine sample.

Deposits from geothermal brines commonly contain Al, Mg and Fe; predicting these deposits requires that concentrations of Al, Mg and Fe in the brine be know. As at Germencik, the concentrations of Al, Mg and Fe in geothermal brine often are too small to measure.

The rock matrix of the Germencik reservoir consists of gneiss, limestone and schist; the presence of gneiss and limestone suggests that the minerals K-feldspar and dolomite are present, and will control the concentrations of Al and Mg in the brine. The concentrations of Al and Mg initially present in the brine were calculated using Geochemist's Workbench (GWB), based on the averaged initial composition and T of the brine. The concentration of Fe in the brine is controlled by the solubility of pyrite (FeS_2) which depends on the concentration of H_2S in the brine. The concentration of H_2S in fluids produced was not reported; therefore, the initial concentration of Fe could not be determined.

The reconstructed initial brine compositions modeled are presented in Table 1. The minerals assumed present in the reservoir rock or potentially precipitated are presented in Table 2. In both cases the reconstructed brine is slightly undersaturated in respect to calcite, well within the accuracy of GWB; this result confirms the quality of the reconstruction.

2.4 Explanation and significance of the calculated results

Geochemist's Workbench calculates the thermodynamic driving force causing various minerals to precipitate or dissolve, and the amount of each mineral that might potentially precipitate unless it is inhibited. The thermodynamic driving force favoring precipitation of a mineral is quantified as (Log_{10} S) / N. The Saturation Ratio S is the product of ion activities of ions that combine to form a mole quantity of the mineral divided by the value of this product when the mineral is in chemical equilibrium with the brine. N is the number of ions in the nominal chemical formula for the given mineral as modeled by GWB. The quantity (Log_{10} S) / N is tabulated instead of Log_{10} S because it better reflects the thermodynamic driving force.

Amorphous silica is deposited from geothermal brines, despite the fact that quartz is more stable. Similarly, with rare exceptions, metal silicates deposited from geothermal brines are amorphous rather than well defined, crystalline minerals. Geochemist's Workbench cannot model amorphous metal silicates, but can predict when minerals of similar composition would precipitate unless inhibited. Experience shows that when GWB predicts the zeolite mineral clinoptilolite-K, an amorphous aluminosilicate with similar Si : Al ratio will precipitate, and that precipitation of an amorphous Mg,Fe,Ca-Silicate is reliably predicted as some combination of talc, minnesotaite and/or tremolite.

2.5 Calculated results for EFE-1

The calculated results for EFE-1, the steam turbine power plant, are summarized in Table 3.

The brine goes through two stages of steam separation. Each stage of steam separation removes water and heat from the brine, decreasing T while increasing the concentration of salts and silica in the brine. Separating steam from the brine also removes CO_2 which causes pH to increase. These changes cause the brine to become supersaturated in respect to a variety of minerals.

Steam condensing in the contact condenser adds more water than is evaporated in the cooling tower. The excess water is taken from the pipeline from condenser to cooling tower, and added to the separated brine. The added water dilutes the brine, decreases T and adds some CO_2. The degree of dilution is small, but it has a noticeable beneficial effect (Section 7, below).

The brine becomes supersaturated in respect to calcite as soon as steam starts to separate from the brine in the wellbore. The degree of supersaturation in respect to calcite is greatest in the wellbore, with (Log_{10} S) / N greater than the value calculated for the first stage steam separator and presented in Table 3. If untreated, calcite deposits just above the depth of steam separation would quickly choke-off the well. Each well is protected by injecting a calcite inhibitor downhole through a capillary tube, just below the point where steam starts to separate.

The brine is supersaturated in respect to clinoptilolite-K throughout the system, and amorphous deposits of similar composition would be observed throughout the system unless inhibited; deposits of Mg,Fe,Ca-Silicate would also form unless inhibited. A second product formulated to inhibit metal silicates is added to the brine at each wellhead to prevent such deposits.

2.6 Calculated results for EFE-3

The calculated results for EFE-3, the binary cycle power plant, are summarized in Table 4.

As with EFE-1, the wells supplying EFE-3 produce a mixture of brine and steam. The brine and steam are separated near to the wells, and separately delivered to the power plant. Heat is transferred from brine and steam to isopentane in the Vaporizer Units (each binary plant has two parallel process streams); the Vaporizers are tube-and-shell heat exchangers, wherein brine and steam flow separately through different sections. The steam is mostly condensed within the Vaporizer, producing condensate and a much reduced vapor phase which contains most of the NCGs plus a small amount of water vapor. The NCGs are separated from the condensate and vented, and then the condensate is added to the brine flowing out of the Vaporizer. The mixture of condensate and brine then flows through another heat exchanger called the Preheater. Finally, the cooled brine leaving the Preheater is pumped to the reinjection wells.

The brine chemistry at EFE-3 is similar to EFE-1, and the same treatments are applied. A calcite inhibitor is injected downhole in each well below the depth where steam starts to separate, and a silicate inhibitor is injected at the wellhead of each well, preventing deposits of metal silicates throughout the surface equipment and in the reinjection wells. Controlling metal silicates is especially important in a binary power plant, because fouling of heat exchangers must be prevented to maintain good performance and eliminate the need for outages and costly cleaning.

EFE-3 differs from EFE-1 in two major respects. There is no second stage of steam separation at EFE-3, which drives brine pH much higher in the case of EFE-1. Also, the relative volume of condensate added to the brine is greater than the cooling water added at EFE-1, and the condensate contains a much larger concentration of CO_2. These differences result in lower values of pH and (Log_{10} S) / N at EFE-3, whereby deposits are more easily controlled.

2.7 Silica chemistry

The brine is nowhere supersaturated in respect to amorphous silica at EFE-1, and no silica deposits are predicted or observed. At EFE-3, the small value of Log_{10} S calculated for amorphous silica at 95.5°C is practically the same as zero; no silica deposits are predicted or observed.

In fact, EFE-3 has a substantial margin of safety in respect to silica deposits, and could be operated with brine T exiting the Preheater at a lower temperature, generating more power. At 65°C, Log_{10} S = 0.193 for amorphous silica and S=1.56. Formation of silica deposits under these mild conditions would involve the following steps (Weres, 2015; Weres, 2016):

1. Metal silicates precipitate, forming nanoparticles dispersed in the brine; these particles would form early in the process at a higher temperature.
2. These particles seed the formation of colloidal particles of amorphous silica, which begin to grow by deposition of dissolved silica upon them.
3. The colloidal silica particles adhere to a solid surface; this process is mediated by calcium ions, which bridge between the negatively charged silica particles.
4. Further deposition of dissolved silica between the particles cements them, forming solid deposits.

The maximum amount of metal silicates which might precipitate if not inhibited has been calculated: 0.73 mg/kg of brine (Table 4). Once the amount and size of the seed particles has been specified, the nucleation and growth of colloidal silica particles can be modeled using the computer program SILNUC (Weres, *et al.*, 1980).

A “worst possible case” calculation was performed. It was assumed that (a) the scale inhibitors in the brine have no effect blocking precipitation of the metal silicates or deactivating them as seed particles, (b) the metal silicates form seed particles with radius = 1.92 nm, which is the “ideal” size under these conditions, and (c) 2.17 mg/kg of seed particles are produced, three times greater than calculated using GWB. Assuming a greater concentration of seed particles allows for the presence of rock dust and clay particles in the brine which would provide additional seeds. The amount of rock dust and clay in the brine may be greater, but such particles would be much larger than particles of metal silicates precipitated from the brine; 1 mg at R = 1.92 nanometers would equal to 1,000 mg/kg at R = 1.92 micrometers serving as seeds.

With these unrealistically pessimistic assumptions, it would take about 8 hours for 10 mg/kg of the silica dissolved in the brine to deposit on the seed particles. By this time, the brine would be back down in the reservoir with temperature increasing, effectively stopping particle growth. Once formed, the colloidal silica particles would adhere to solid surfaces slowly and weakly, because the concentration of calcium in the brine is small (0.058 mmolal = 2.32 mg/kg). The rate at which dissolved silica deposits directly upon solid surfaces would be completely insignificant, about 1.65 micrometers/year.

It is therefore likely that EFE-3 could safely be operated with exit T = 65ºC. Operation at lower T could easily be tested using a small heat exchanger on a test skid before considering any changes to the actual power plant.

3. WELLBORE DOSAGE EQUIPMENT

Mineral deposits in the wells and surface equipment at Germencik are controlled by applying a scale inhibitor in the wellbore and another inhibitor at the surface. The wellbore treatment is designed primarily to control calcium carbonate scaling and is applied downhole using 6.35mm (0.25in) OD Inconel 625 capillary tubing. The wellhead is fitted with a lubricator assembly which allows for the capillary tubing to be lowered into the wellbore (Figure 1). At the end of the capillary tubing is an injection nozzle and sinker bars which are properly sized to hold the tubing in the well during operation.

Figure 1: Wellhead fitted with lubricator assembly to allow installation of 6.35mm capillary tubing.

A chemical storage tank, metering pumps and control system are located at each production well. The concentrated inhibitor is diluted in a central warehouse and the dilute inhibitor is delivered to the well pad storage tank (Figure 2).

Figure 2: Dilute inhibitor is delivered to a chemical storage tank for wellbore treatment. Protective housing contains inhibitor pumps and control system.

Programmable Linear Controllers control the wellbore chemical dosage units which continuously and reliably provide the required inhibitor dose according to set dosage values with minimal supervision. Figure 3 shows the control system, chemical metering pumps and day tank with load cells which accurately monitor usage.

Figure 3: PLC control system, chemical metering pumps and day tank with load cells.

4. WELLBORE CALCITE SCALE CONTROL

Chemical modeling predicts that severe calcite scaling would occur in the wellbore and steam separators unless inhibited. As the fluid flows up the well, steam starts to separate and the fluid changes from single phase to two phase flow. The pH of the brine increases and the brine becomes highly oversaturated in respect to calcite. Because of the extremely high calcite scaling characteristics in this region, severe scaling has often occurred in production wells resulting in serious plugging and loss of flow.

The inhibitor applied in the wellbore at Germencik is designed primarily to control calcite scaling under these severe conditions. PowerChem Geosperse 8466 (GS8466) is dosed continuously in each well. The dosage point is approximately 50 meters below the flash zone, where steam starts to separate. The injection nozzle at the end of the capillary tubing is carefully lowered to the correct depth using a wireline pulling unit with a meter counter.

Since shortly after start-up in 2009 of the double flash plant at Germencik 1, the production wells have not experienced any significant scaling while being treated with GS8466. Wellhead flow control valves are clean and operate normally. Well flows have been maintained at or near maximum rates. Pressure-Temperature-Spinner (PTS) surveys continue to show there has been no loss of well flow.

In 2014 and 2015, the three binary plants (EFE-2, EFE-3 & EFE-4) and the second double flash plant (EFE-1) started generating power. The same calcite inhibitor has been successfully applied in the production wells in these four plants since start-up. The severe calcite scaling characteristics of the brine supplying these plants have been very effectively controlled. PTS surveys at the wells supplying these plants continue to show stable production well flows since start-up.

Wellhead pressures, temperatures, flow rates and geofluid chemistries have been carefully monitored since 2009. All of these critical parameters have been maintained and confirms GS8466 works very efficiently.

5. SURFACE DOSAGE EQUIPMENT

A second inhibitor is applied at the wellhead (or just downstream) and is designed to control scaling in the surface facilities. The surface dosage equipment is similar to the wellbore equipment, but without the need for a lubricator assembly. A chemical storage tank, metering pumps and control system are located at each production well. A protective house contains the pumps and control system. The concentrated inhibitor is diluted in a central warehouse and the diluted inhibitor is delivered to the well pad storage tank (Figure 4). The inhibitor is injected into the pipeline using 6.35mm (0.25in) stainless steel capillary tubing and an injection quill.

Figure 4: Diluted inhibitor is delivered to a chemical storage tank at the well pad.

6. SURFACE SCALE CONTROL

Chemical modeling predicts oversaturation in respect to several mineral solids in the surface equipment at Germencik. In addition to calcite, amorphous metal silicates resembling the minerals clinoptilolite, talc, minnesotaite and/or tremolite are predicted to precipitate from the brine, potentially forming tenacious mineral scales. If not treated properly, serious plant operating issues would quickly occur. Scaling of surface equipment and the injection wells would result in outages, increased maintanence costs, and loss of power generation revenue.

PowerChem Geosperse 5195 (GS5195) scale inhibitor is applied at the surface and is designed to control silica and metal silicate minerals scales. It is applied at the wellhead or just downstream of the flow control valve adjacent to the wellhead. This powerful, multifunctional product is dosed continuously. Treatment results have been excellent and there has been no significant scaling occurring in the flash separators, control valves, heat exchangers, surface pipeline or reinjection wells.

Since start-up in 2009, the Germencik 1 double flash plant has not experienced any significant scaling in the plant equipment. Plant operation continues to be free from any scaling conditions effecting surface facilities and injection wells. There has been no disruption of power generation due to scaling.

In 2015, start-up began of the three 22.5 MWe binary plants (EFE-2, EFE-3 & EFE-4) and the second 47.4 MWe double flash plant (EFE-1). No problems have been encountered related to scale deposits in the steam separators, power plants, other surface equipment or reinjection wells. After more than one year of operation, the heat exchangers in the EFE-2 binary plant were inspected. The vaporizer tubes and tube sheet at EFE-2 were clean (Figure 5), with only sand in the bottom. Excellent heat exchanger performance and power generation have been obtained at these plants.

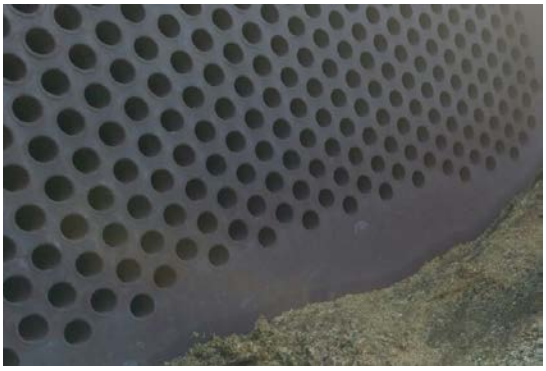

Figure 5: Clean vaporizer tubes and tube sheet at EFE-2 after more than 1 year of operation.

The injection wells at Germencik plants have not experienced any significant mineral scaling. Injection flows have been maintained at or near original flow rates. The very high maintanence costs of well workovers have been avoided and optimal power generation has been realized.

7. MONITORING PERFORMANCE

Regular monitoring of scale control performance of wellbore and surface treatment is imperative. Successful treatment depends on ensuring the correct inhibitor and dosage rates are continously applied.

A monitoring program using using retractable coupons has been employed at Germencik from start-up. Coupons installed at the wellhead enable performance of the wellbore treatment to be monitored. The virtually clean coupons shown in Figure 6 demonstrate the treatment is highly effective and the well is not scaling with calcite.

Coupons at the production wells are removed weekly, inspected and photographed, and the weight gains are recorded. Clean coupons are installed for the next weekly cycle.

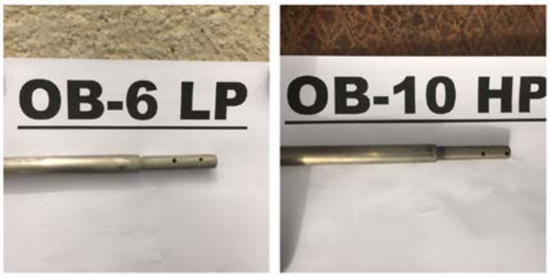

Figure 6: Retractable coupons from two production wells confirm effective calcite scale control.

Retractable coupons are also employed before the injection wells. These coupons monitor effective control of deposits in the surface facilities and injection wells. Because the brine delivered to the injection wells has the lowest temperature in the system, scaling by metal silicates tends to be most severe at these locations. Figure 7 shows coupons removed from the injection well locations after approximately 30 days. The coupons show very tiny weight gains confirming successful treatment is occuring all the way to the injection system. The coupons are inspected and photographed, and weight gains are recorded. Clean coupons are installed for the next monthly cycle.

Figure 7: Retractable coupon from an injection well confirm effective metal silicate scale control.

Figure 8 shows weigh gains recorded monthly on coupons at an injection well over a period of 20 months. A seasonal pattern is evident. Winter months show a lower weight gain than summer months. Cooling tower blowdown is added to the brine being injected and the higher blowdown rate during winter months provides greater dilution. The dilution effect of the blowdown added to the brine overides the effect of lower seasonal temperature, resulting in improved scale control.

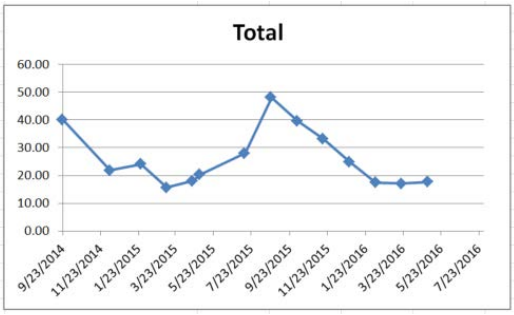

Figure 8: Weight gains (mg/day) of retractable coupons from an injection well illustrating the seasonal effect of greater dilution by cooling tower blowdown during the winter.

8. STIBNITE

Approximately 0.6 mg/kg of antimony is present in the EFE-2 produced brine. Even very low levels of antimony can potentially result in serious fouling from stibnite (Antimony Sulphide Sb_2S_3).

A very thin reddish film has been observed in an injection well coupon at the EFE-2 binary plant (Figure 9). The analysis of the coupon indicates the deposit consists of 78% stibnite (Sb_2S_3). A trace of stibnite was also observed on an injection well coupon at the EFE-4 binary plant.

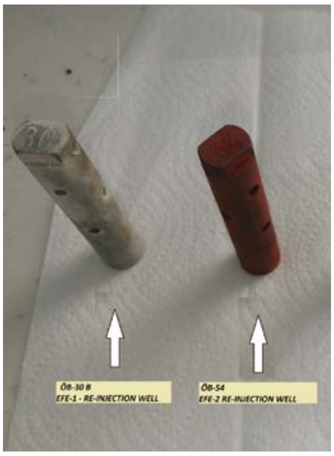

Figure 9: Analysis of coupon on the right (OB-54 EFE-2 REINJECTION WELL) shows reddish film is 78% stibnite (Antimony Sulfide, Sb_2S_3)

Recent inspections of the EFE-2 vaporizers and preheaters show clean heat exchanger surfaces and no fouling from stibnite has occurred (Figure 5). Furthermore, there has been no loss of flow to the OB-54 injection well.

The use of GS5195 may be helping to control stibnite fouling in the binary plant heat exchangers and injection wells. The solubility of stibnite decreases with pH and with decreasing temperature. The lowest pH and temperature is at the injection well and only a very thin fouling from stibnite is observed. Injection flows to all wells have not shown any decline and, thus, no significant fouling caused from stibnite has occurred. No stibnite has been observed in connection with the steam turbine plants, because the pH of brine discharged from these plants is much higher than pH of brine discharged from the binary plants (compare Tables 3 and 4).

Additional data is being gathered to assess the extent and practical significance of stibnite control at Germencik. As with silica, stibnite deposits are produced by the accumulation of colloidal particles which form in the brine. PowerChem's inhibitors control scaling through multiple mechanisms, including by acting as dispersants.

A thorough review of the data will be done and an evaluation of control options will be conducted. Process modifications will be considered as well as chemical treatment, and the choice between control options identified will be made based on economic as well as technical grounds.

9. CONCLUSIONS

Experience at the Germencik Geothermal Field has demonstrated that chemistry of geothermal brine can be modeled providing useful results, and that scale deposits can be controlled in a highly effective and economical manner.

Modeling of the brine has further indicated that, when using proven scale control inhibitors, the binary plants at Germencik very probably could be operated with a lower exit temperature, allowing more power to be generated.

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Table 1. Brine compositions modeled

Concentrations in units of (mg-mole / kg-H_2O)

Species	EFE-1	EFE-3	Calculated Value based on
Na^+	60.91	57.70	
K^+	3.83	3.93	
$Mg(OH)^{+1}$	**0.00172**	**0.00158**	Solubility of Dolomite
Ca^{+2}	0.065	0.058	
$Al(OH)_3$	**0.00119**	**0.00112**	Solubility of K-Feldspar
Cl^-	**43.78**	**37.70**	Charge Balance
SO_4^{-2}	0.19	0.22	
SiO_2	**5.80**	5.93	Note (a)
$B(OH)_3$	5.16	5.20	
OH^- (b)	21.01	23.88	Alkalinity
Total CO_2 (c)	368.64	428.91	CO_2 in Steam plus Bicarbonate
T(°C)	221.4	222.0	
pH at T	**6.05**	**6.05**	
Factor applied to correct for steam separated	0.8846	0.8830	

Calculated values in **boldface** type.

(a) Silica concentration for EFE-1 calculated based on solubility of quartz.
(b) Represents alkalinity
(c) "Total CO_2" includes bicarbonate in addition to CO_2(aq).

Table 2. Minerals assumed present in reservoir or potentially precipitated

Mineral	N	Nominal Composition
Quartz	1	SiO_2
Calcite	2	$CaCO_3$
Dolomite	4	$CaMg(CO_3)_2$
K-Feldspar	5	$KAlSi_3O_8$
Calcite	2	$CaCO_3$
Talc	7	$Mg_3Si_4O_{10}(OH)_2$
Minnesotaite	7	$Fe_3Si_4O_{10}(OH)_2$
Tremolite	15	$Ca_2Mg_5Si_8O_{22}(OH)_2$
Clinoptilolite–K	14	$K_2Al_2Si_{10}O_{24}\cdot 8\ H_2O$
Amorphous silica	1	SiO_2

The nominal chemical composition tabulated for each mineral is that used by Geochemist's Workbench to model the solubility of that mineral. N is the number of ions in the nominal chemical formula for the mineral as written.

Table 3. Minerals potentially precipitated at EFE-1

	First Stage Steam Separator	Second Stage Steam Separator	After Blowdown Added
P (bar-a)	6.15	1.28	1.28
T(°C)	158.1	106.8	103.2
H_2O remaining in brine	0.8642	0.7794	0.8237
Total CO_2 (mmole/kg)	25.69	15.68	14.92
CO_2 (aq) (mmole/kg)	2.42	0.029	0.026
pH at T	7.66	9.02	9.03
Mineral	(Log_{10} S) / N before anything precipitates		
Calcite	0.53	0.73	0.70
Talc	0.84	1.43	1.39
Tremolite	0.73	1.33	1.29
Clinoptilolite–K	0.40	0.44	0.44
Amorphous Silica	–0.25	–0.33	–0.32
	Amount potentially precipitated (mg/kg-H_2O in reservoir brine)		
Calcite	5.98	6.25	6.22
Talc	0.21	0.0	0.0
Tremolite	0.0	0.28	0.28
Clinoptilolite–K	0.56	0.56	0.56

The amount of solids potentially precipitated at each stage calculated assuming that (i) no solids precipitated at an earlier stage, and (ii) precipitation reached chemical equilibrium at the present stage. Therefore, the values in the columns cannot be added across the table.

Table 4. Minerals potentially precipitated at EFE-3

	Brine Entering Vaporizer	Brine Leaving Vaporizer	After Condensate Added	Brine Leaving Preheater
P (bar-a)	7.5	7.0	7.0	5.7
T(°C)	165.4	140.5	141.1	95.5
H_2O remaining in brine	0.8830	0.8830	0.9859	0.9859
Total CO_2 (mmole/kg)	29.90	29.90	29.31	29.31
CO_2 (aq) (mmole/kg)	3.74	3.47	5.42	5.26
pH at T	7.58	7.43	7.20	6.96
Mineral	(Log_{10} S) / N before anything precipitates			
Calcite	0.52	0.34	0.21	–0.14
Talc	0.80	0.54	0.32	–0.23
Clinoptilolite–K	0.36	0.48	0.44	0.67
Amorphous Silica	–0.27	–0.17	–0.22	+0.005
	Amount potentially precipitated (mg/kg-H_2O in reservoir brine)			
Calcite	5.29	4.59	3.54	0.0
Talc	0.20	0.19	0.16	0.0
Clinoptilolite–K	0.53	0.53	0.53	0.53