Determination of Appropriate Injection Conditions for Kizildere Geothermal Waste Fluid to Avoid Scale Formation and Cooling

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Abstract

As encountered in most of the injection applications of geothermal systems in the world, scaling and thermal breakthrough are essentially two problems associated with injection of waste geothermal fluids from Kizildere power plant. The power plant dumps about 7.4 million tons/year wastewaters into the Büyük Menderes River. This creates a major environmental problem and needs to be solved. The way to overcome this problem is to be able to inject the wastewaters into the geothermal reservoir without creating scaling formation and cooling effects. If the injected fluid flows rapidly into the aquifer of producing wells without appropriate surfical treatment, it may cool and plug the fractures of production well aquifer. Calcite scaling which creates a serious problem during production will not cause any constraints during the reinjection. The fear of thermal breakthrough and silica scaling are the most obvious parameters that effect the reinjection in opposite directions. To avoid silica precipitation in the boundaries of production well fields at Kizildere, it is of special interest to study retaining of amorphous silica scale formation at the surface by rapid cooling of the wastewater to <50°C. Such a technical solution would open up the possibility of utilizing heat from waste geothermal fluid before injecting it.

Introduction

The Kizildere geothermal field is a liquid geothermal field located at the Büyük Menderes Graben in the western part of Turkey. The Kizildere power station of 20 MWe, incorporating in a single flash system, has been in operation since 1984.

A three-month long test, from May to June 2000, was carried out to determine the optimum reinjection conditions of Kizildere geothermal field wastewater from the power plant which has been in operation since 1984.The test was performed on the nine production wells namely KD-6, KD-13, KD-14, KD-15, KD-16, KD-20, KD-21, KD-22, R1 feeding the 20 MW geothermal power plant (Figure1). The total amount of wastewater discharged from the nine wells' separators with a temperature of 145-147 ^{o}C is approximately1185 ton/h. Disposal of the wastewater into B. Menderes River has never been an option in Kizildere, because the wastewater contains high boron concentration and disposal to the river would certainly harm the agricultural activity in the region [1]. Another reason for the reinjection is that the improvement in steam production needed for power plant can only be achieved through successful reinjection.

The thermal breakthrough and silica scaling are the most obvious parameters that affect the reinjection in opposite directions. As a water-dominated type field, the Kizildere geothermal field contains high concentration of silica dissolved from rocks. When the hot water evaporates at the separators' pressure or discharges at an atmospheric pressure it is cooled and concentrated with its dissolved solids. The cooled and concentrated geothermal waters are usually supersaturated with respect to amorphous silica solubility. This may eventually be resulted in precipitation of various silica forms such as colloidal silica, gelatinous silica fibrous or opaline silica sinter.

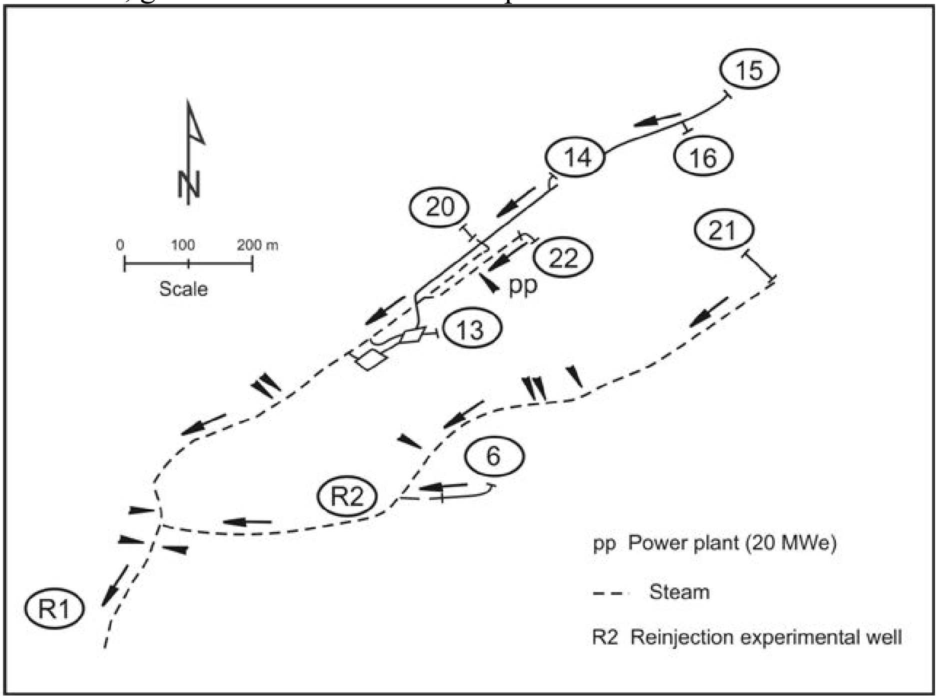

Figure 1. Location map of production and reinjection wells

Chemical Characteristics

The chemical composition of geothermal fluids can vary depending on the source of water that feeds the reservoirs. Hot spring and discharge waters of the Kizildere geothermal field have moderate total dissolved solids (≈ 5000 mg/l) and are rich in bicarbonate and sulfate (Table1). The Kizildere geothermal fluids have been classified as Na-HCO_3-SO_4 type and contain high total dissolved solids including B (27 mg/l), F, and moderate Li. The power plant dumps about 7.4 million tons/year wastewaters bearing the above-mentioned characteristics into the Büyük Menderes River. This creates a major environmental problem and needs to be solved. The way to overcome this problem is to be able to inject the wastewaters into the geothermal reservoir without creating any problems. Thus the reservoir pressure is kept in proper order.

Table 1. Composition of the Kizildere,Tekkehamam and surrounding geothermal waters

Place	**KD6** W.B	**KD13** W.B	**KD14** W.B	**KD15** W.B	**KD16** W.B	**KD20** W.B	**KD21** W.B	**KD22** W.B	**R1 WB**	**Waste Water**	**Tekke Ham.**
Reserv.(^oC)	196	198	207	205	211	201	202	202	242	92	190
Sampling(^oC)	92.5	92.1	93.6	94.2	96	89.6	92.3	96	96	63.6	97.2
µS/25^oC	5830	5940	6160	5890	5835	6180	5940	5830	5820	5500	4000
pH/25^oC	8.97	8.89	8.96	8.82	8.94	8.92	9.02	9.3	8.8	9.25	7.71
Na	1220	1300	1410	1340	1400	1375	1325	1275	1556	1400	750
K	116	138	152	138	148	140	131	140	245	138	75
Ca	1.0	2.0	1.2	1.2	3.2	1.6	1.8	1.2	2.67	1.2	12.
Mg	0.36	0.25	0.2	0.15	0.24	0.15	0.24	0.24	0.23	0.6	12
B	20.4	26.5	24.4	24.6	24	24.1	24.5	25	30	26	12.1
SiO_2	336	344	392	393	398	367	387	392	416	345	210
HCO_3	1586	1525	2403	1464	1525	1159	1220	1586	3074	1342	446
CO_3	540	600	720	660	730	780	780	600	100	720	-
SO_4	560	773	737	730	714	710	710	729	792	735	1350
Cl	124	128	144	140	136	140	140	136	134	136	76
F	17.8	20.0	24.8	22.3	23.5	22.5	21	22.5	26.4	21.7	8.3

In the studied area, the surface temperature is 99 °C and in the nine wells (KD-6, KD-13, KD-14, KD-15, KD-16, KD-20, KD-21, KD-22) and R1) the reservoir temperature ranges from 198 °C at the shallow zones of the Tertiary formations to 211-242 °C at the deeper zones of the Paleozoic metamorphic units. Isotopic studies revealed that there are three reservoirs in the area. The deepest reservoir $\delta^{18}O$ value makes the furthest shift to the local meteoric line [2]. $\delta^{2}H$ points out to at least 1300 m a.s.l recharge zone [3]. This corresponds to the metamorphic rocks in the region.

Composition of the scale formed during production

As a result of flashing and steam fraction the precipitation of the dissolved solids starts at different depths in the production wells of Kizildere. The variable Ca and SiO_2 concentrations of the analyzed water from the wells suggest different degrees of calcium carbonate and silica precipitation before the sampling points.

Analysis of the scaling made by MTA from the wells are as follows:

% $CaCO_3$	% $SrCO_3$	% $MgCO_3$	% SiO_2	Al, Ba, Na, Fe
70-78	18-20	0.5-1.8	0.2-5	trace

Analyses of the scales collected from the silencer and separator at the site of well 6 made by Virkir in Iceland [4]: 75 % CaCO3+$SrCO_3$ (both calcite and aragonite), % SiO_2 (with traces of iron, aluminium and potassium).

Samples of suspended materials analyzed semi quantitatively by XRF scanning were found to contain Ca with traces of Sr, Ba, Si, Fe, K, Al and S. Both the scale and suspended material show that precipitation of SiO_2 started even at the separating temperature and pressure.

Calculation of the bottom hole fluid composition

Considering that a single liquid phase is present at the bottom hole and that the measured bottom hole temperatures are representative of the reservoir, the bottom hole fluid composition can be calculated. The result of the calculations is shown in Table 2.

Since both the single phase analyses and single vapor fraction at the surface condition are known, it is possible to calculate the volatile and non-volatile species of the bottom holes.

The pH of the bottom hole single phase liquid has been calculated by taking into account H^+ involving weak acid species such as HBO_2, H_2S, HF, HSO^-_4, H_4SiO_4, $H_3SiO^-_4$ NH_4, HCl, H_2CO_3 and HCO^-_3 dissociation constants. The pH for the Kizildere reservoir calculated in this way is found to be around 5.9.

Table 2. The calculated bottom hole single-phase composition for the Kizildere wells.

PLACE	KD-6 BH	KD-13 BH	KD-14 BH	KD-15 BH	KD-16 BH	KD20 BH	KD-21 BH	KD-22 BH
Reservoir. (°C)	196	195	207	205	211	204	209	202
Surface (°o	92.5	92.1	93.6	94.2	96	89.6	92.3	96
pH	5.89	5.84	5.96	5.9	6.0	5.89	5.93	5.9
Na (mg/l)	1000	1060	1130	1070	1110	1080	1040	1000
K (mg/l)	95	112	120	110	117	112	107	112
Ca (mg/l)	10±5	10±5	10±5	10±5	10±5	10±5	10±5	10±5
Mg (mg/l)	0.32	0.22	0.18	0.13	0.21	0.13	0.21	0.21
B (mg/l)	16.7	21.2	19.5	19.6	19.2	19.3	19.6	20.2
SiO_2 (mg/l)	257	257	295	287	309	285	295	275
HCO_3 (mg/l)	2100	2125	2196	2025	2225	1945	2000	2150
SO_4 (mg/l)	554	620	590	585	570	550	550	550
Cl (mg/l)	1O1	100	112	110	104	112	111	108
F (mg/l)	14.6	16.4	19.8	17.8	18.3	18	17	16

Calcite scaling and reinjection

When the geothermal fluid flashed and triggered due to loss of CO_2 that caused a pH increase; it was seen that approximately 90 % of initial Ca had already precipitated in the boreholes before the fluid reached the surface. In spite of separation to liquid and vapor phases in the separators and then in silencers, the wastewater becomes undersaturated with respect to Ca, except in KD-16 (Figure 2).

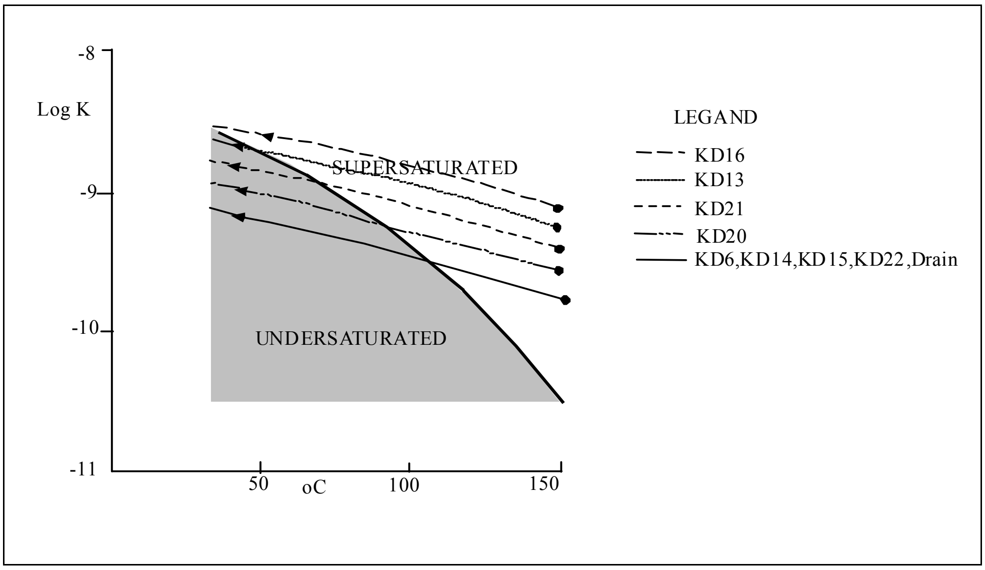

Figure 2. $CaCO_3$ saturation of discharged waters from the wells

The $CaCO_3$ that causes a serious operational problem during production will not create any problems at the stage of reinjection, provided an inhibitor is not used. When an inhibitor is used to avoid the scale formation during production, all the Ca will be held in fluids and will even be concentrated in the single liquid phase after steam extraction in the separators. If the wastewater is reinjected with a high Ca content, the mixture of the equilibrated reservoir water and reinjection water will be concentrated with respect to Ca. Also the pH of the mixture will increase because of high reinjection water pH (9.3). Thus, the carbonate precipitation may start in the reservoir fractures.

Silica scale and water compatibility

The mineral scale can also occur during reinjection operations. Reinjection water temperature at the injection wellhead is usually much lower than reservoir temperature because of steam and heat extraction from reinjection water. As it goes down the injection well bore, the water cools the surrounding formations, while its temperature and pressure increase. If the water is saturated at surface conditions with the materials whose solubility decrease with the increasing temperature the scale may form along the well string [6].

If it is not retained at the surface, the SiO_2 concentration of the Kizildere reinjection water will be much higher than the SiO_2 in the reservoir brine. At the moment of mixing, the temperature and pressure increase will not be enough to hold the excess SiO_2 in the solution. The pH of the mixture is not in the favor of SiO_2 solubility (Figure 3). The pH of the mixture will be around 8.0, which causes a low solubility and thus high deposition rate.

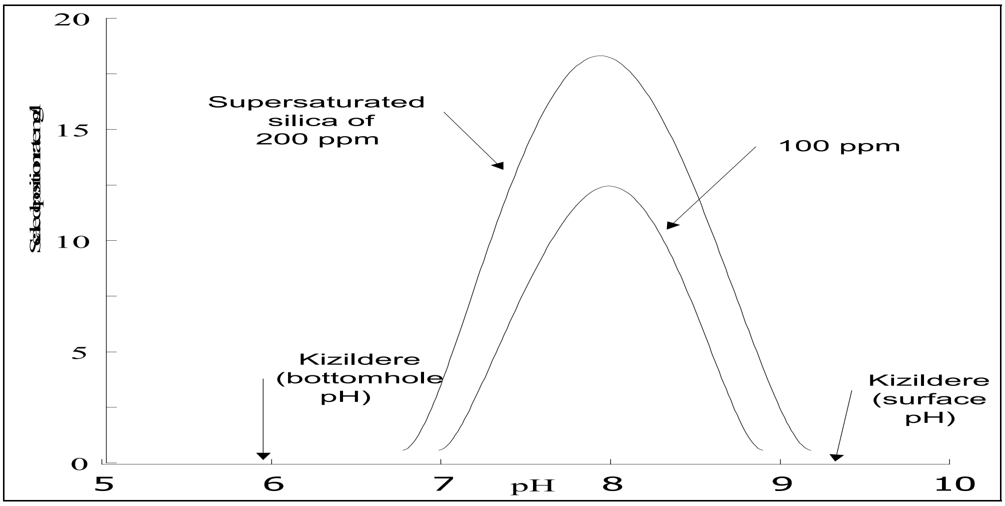

Figure 3. Silica deposition rate versus initial and final pH (modified from [5]).

As the water enters the reservoir, 3 phenomena occur:

1-Temperature increases along the water-flow path due to heat exchange with the reservoir rock and fluids,

2- Pressure decreases along the flow path,

3-The concentrated reinjection water mixes with the equilibrated reservoir brine at the reservoir conditions.

During injection, three fronts occur in the reservoir: a pressure front, a thermal front and a chemical front. The two fronts travel with different velocities. The thermal front lags behind the chemical front. Solid precipitation from the injection water may occur behind the mixing zone as a result of temperature and pressure changes.

In the mixing zone the precipitation of insoluble salts may occur due to the injection of chemical species contained in the injection water with chemical species present in the reservoir brine (Figure 4).

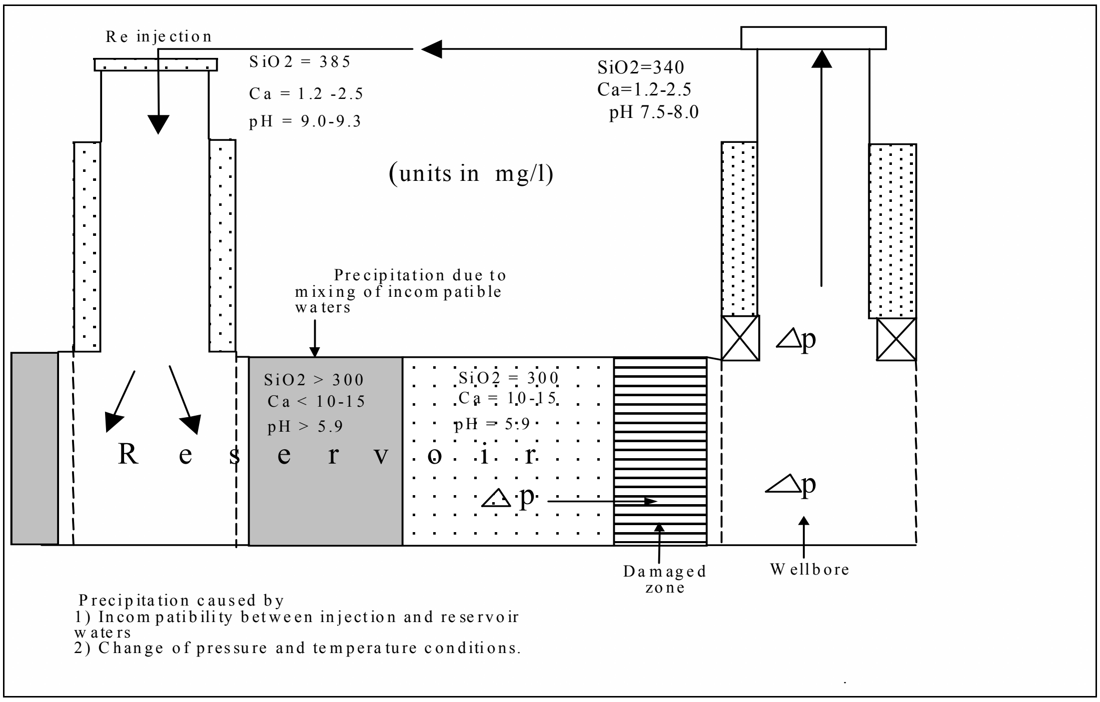

Figure 4 Location and causes of plugging in the reservoir (modified from [6].

Since silica concentration in the reinjection water is higher than that in reservoir and the mixing zone conditions are not in the favor of silica solubility, the deposition of silica may occur in the reservoir.
Considering the deposition rate before reaching the surface and the remaining calcium concentration in the liquid phase, it can be concluded that the Kizildere reservoir initialy contains 10 to 15 ppm Ca in the single-phase liquid at the bottom. The inhibitor injetion test applied to the some wells in the field has verified this concentration.

An experiment on SiO_2 precipitation at different conditions (pH, temperature) and the optimal reinjection temperature

When deep geothermal wells of Kizildere are discharged, the fluid is a mixture of water and steam. When the steam is separated and piped to the power station, the remaining wastewater becomes saturated with silica, because of steam loss (Figure 4). So the wastewater should be cooled and retained to keep excess silica at the surface to avoid plugging the reservoir fractures. The concentration of the silica in the wastewater should be lowered to at least 300 ppm to be the same as in the reservoir.
In order to minimize the impact of the relatively cool reinjected water on the hot resource, the reinjection wells are usually located far away from the production zones, at the margins of the hot rock or even outside the geothermal field. The performance of the production wells will be affected if the cooler water returns quickly to the production area. To follow the movement of reinjected water, sensitive tracers are used to detect and map the underground fluid flow paths. By using tracers any zone of rapid return of cool fluid between the reinjection and production zones can be identified before there are serious cooling effects on the production zone.
A tracer test with Na-fluorescein (uranina) was carried out at Kizildere in July 2002, to grasp flow direction of the reinjected water in the underground. The test has revealed that the reinjected water has been moving rather slowly to the northern wing of the field, where production wells are located. A prolonged traveling time will allow the injected water to regain the upflow zone's temperature. So, in the case of Kizildere, it is safer to locate the reinjection wells at the southern wing and deep part of the reservoir, to avoid thermal breakthrough.

The selection of injection temperature

In most cases, the selection of injection temperature has been closely depending on the silica saturation of disposal water. The fluid has been either injected directly after separation or allowed to precipitate at the surface prior to reinjection. Geothermal fluids are in equilibrium with the rocks at the reservoir conditions. After flashing, the separated fluid becomes supersaturated with respect to SiO_2. Excess silica will precipitate from the fluid.
Silica precipitation test carried out at different temperatures and pH values on both the production wells and the disposal water of Kizildere. Test result illustrated in Figure 5.
As it can be seen in the figure, there is a virtual relationship between silica concentration and temperature. When the temperature decreases, initial silica concentration begins to drop because of precipitation. This dropping continues till the second equilibrium established in the disposal water. Adding some chemicals such as limes, CaO, MgO and $CaCl_2$, can accelerate the establishing of the second equilibrium.

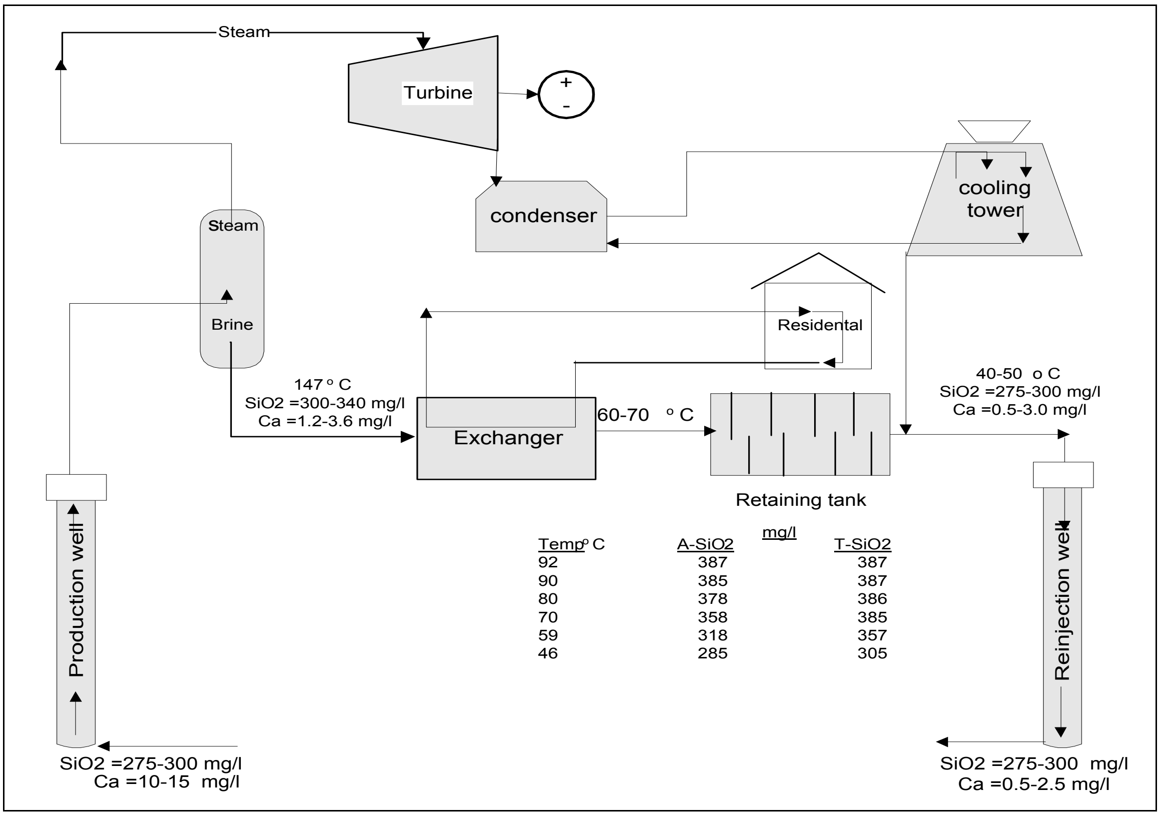

Figure 5. Recommended flow chart for Kizildere geothermal used fluid, from production to reinjection wells.

Inhibiting methods of silica deposition

Methods of inhibiting silica deposition in cooled separated geothermal water have been recently developed. One of these methods involves the keeping of the excess silica at the surface. If the concentration in wastewater is high enough, the recovery of the silica as a useful commercial product is possible. Removing up to 25 percent of the silica contained in the separated water of Kizildere limits the deposition tendencies of wastewater thus makes it safer to be reinjected.

Temperature and pH are the most important factors for silica scale formation. At high pH and low temperature, the silica precipitation is rapid. In a retaining tank, which retains the effluent for one hour, the silica concentration of the Kizildere wastewater can be decreased to the desired level by lowering its temperature down to about 55-60^{o}C. The separated water pH, which is about 9.3, is not in the favor of precipitation of silica in the retaining tank. This method, regardless of how promising it may seem for the Kizildere, has its negative sides. The risk of cooling the reservoir by reinjecting rather cooled water is the most important negative side.

The finding and evaluation of the test result

1. It has been determined by analyses that Kizildere geothermal fluids contain from 360 to 400 mg/l SiO_2 at the weir boxes.
2. According to the bottom hole temperature measured with Amerada equipment, it was calculated that prior to flashing, the Kizildere geothermal fluid contains 275–310 mg/l SiO_2.
3. The concentration of the SiO_2 at the weir boxes is 15-20 % higher than that in the bottom holes.

4. The composition of the scale formed up to separator mainly consists of $CaCO_3$. Very little SiO_2 identified in the scale formed before the separation.
5. The concentration of the silica in the wastewater should be lowered to at least 300 ppm to be the same as that in the reservoir. To accelerate the precipitation rate of the silica in the retaining tank, some chemicals such as lime, CaO, MgO and $CaCl_2$ can be added.
6. The concentration of Ca in the boreholes prior to flashing was calculated to be around 10 to 15 mg/l. The content of Ca ranges from 1.2 to 3.2 mg/l at the surface. Unless the inhibitor treatment is applied, the Ca content at the surface does not create any problem during the reinjection operations.
7. If it is to be used in district heating, the disposal water of Kizildere which contains approximately 380 mg/l SiO_2, 1.5 mg/l Ca, 26 mg/l B and 4500-5000 mg/l TDS should be prepared for the reinjection according to the above-mentioned chart flow (Figure 5).
8. The deepest reservoir $\delta^{18}O$ values make the furthest shift to the local meteoric line.

Conclusion

The rate of silica deposition depends strongly on the temperature, the pH value of the fluid, concentration of SiO_2 and coexisting solutes. The Kizildere geothermal field tested from the above point of views. As a result, the SiO_2 concentration should be lowered to 300 mg/l to be the same as in that the reservoir. To do this, the reinjection temperature of the fluid should be around 55-60 ^oC . If $CaCO_3$ is allowed to precipitate during the production, it will not cause any problems during the reinjection. To avoid some problems, the conditions of the reinjection site should be considered to be as follows [5]:
(1) High temperature zone, (2) Acidic water zone less than pH5, (3) Low water level zone, (4) High permeability zone in the reservoir, (5) Zone free from interfering with production zone.

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