

## REINJECTION STRATEGY FOR KIZILDERE GEOTHERMAL FIELD

Umran Serpen

Department of Petroleum and Natural Gas Engineering  
Istanbul Technical University  
Istanbul, 80626, Turkey  
e-mail: serpen@itu.edu.tr

### ABSTRACT

In this study, the reinjection into the Kizildere reservoir and injection of disposal water produced from the field into a remote area (3 km away) options are considered. Previous reinjection tests were reevaluated. Then, all idle wells were assessed for reinjection. Injectivities of idle peripheral wells tapping different horizons are evaluated for reinjection. A potential rate of reinjection of 650 tons/hr to 6 wells was estimated. On the other hand, hot (147°C) or relatively cool (100°C) reinjection options are also compared from the silica and calcite deposition point of view. Finally, two reinjection strategies are devised: (1) reinjecting the disposal water to the existing idle wells, and (2) phasing out the existing production wells in the future by converting them to the reinjection wells and exploiting the deeper and hotter reservoir, boosting power generation.

### INTRODUCTION

Located in the eastern extreme of the B. Menderes graben where it intersects with Gediz and Çürüksu grabens, the Kizildere geothermal field has a liquid dominated system with temperatures of 195-242°C at depths of 300-2000 meters. The field was discovered in mid 1960's and 17 wells were drilled until mid 1970's, assessing the capacity of the field. A power plant with 17.8 MW<sub>e</sub> generation capacity was installed, and power generation started in 1984 with 6 production wells. Three additional production wells were drilled two years later to increase the fluid production. The field has been generating an average 7.5 MW<sub>e</sub> of power for the last 17 years.

A total of 23 wells, of which 3 are for reinjection and the rest are for production purposes, have been drilled in the field. First two reinjection wells TH-2 and R-1 are very deep (2000 m and 2300m, respectively) and they could not be used for reinjection due to their moderate to low permeability. The third one, R-2 struck high permeability, but it is relatively shallow

(1400 m) with respect to other reinjection wells and close to production area with a possibility of cooling nearby production wells.

During the exploratory and development stages, 3 stratigraphically separate zones in the field were identified in the hydrothermal system: (1) shallow one in limestones of Miocene with temperatures of 196-200°C and moderate permeability, (2) few hundred meters deeper one in marbles of Paleozoic with temperatures of 200-212°C and high permeability, and (3) another one at more than 1500 m depth in Paleozoic schist and gneiss with temperatures of 240°C and moderate permeability. Reservoir engineering studies (Serpen, 2000) identified one relatively shallow hot water reservoir with moderate temperatures of 196-210°C covering limestones and marbles and a deep thermal reservoir with high temperatures of 243°C. Fig-1 shows the well locations in the Kizildere field. Of these wells KD-1, 2, 3, 4 and 12 tap the upper part of hot water reservoir in limestones, and the others tap the deeper part of the hot water reservoir in marbles. The drilled wells have varying permeability ranging from low to high. Particularly, the wells drilled in the area delimited by geological and geophysical studies present much higher permeability. Reservoir rocks especially marble and gneiss do not have primary porosity and permeability, but secondary porosity and permeability.

Produced hot waste water has been disposed into nearby Büyük Menderes River, from where the water is used for agricultural irrigation. The adverse effects of high boron and bicarbonate content of geothermal water on agriculture has put a limitation on both the discharge and the production rates, and thus on power generation capacity. On the other hand, reinjection of waste water back into the reservoir seems to be the only viable method for both disposal and reservoir pressure maintenance. Therefore, the reinjection attempts in Kizildere field arose as a result of both the environmental and economical concerns.

**PRESENT STATUS OF KIZILDERE GEOTHERMAL FIELD**

Kizildere geothermal field has been operating since 1984 with an average yearly power generation of  $80 \times 10^6$  kWh. During the 17 years of operation, approximately 105 million tons of geothermal fluid was produced at an average rate of 900 tons/h, and in the meantime average reservoir pressure declined about 10 bar. The reservoir pressure drop at different wells is shown in Table 1. One sixth of 60 bar estimated average hot water reservoir was lost in the last 17 years. In the past, the geothermal field was operated at low production rate of 900 t/h instead of 1800 t/h of maximum production rate needed for the full capacity of power plant (17.8 MW<sub>e</sub>). Had the field been operated at full capacity, reservoir pressures might not have sustained the necessary wellhead pressures for power generation today, as modeling studies for 10 MW<sub>e</sub> and 20MW<sub>e</sub> suggested (Serpen, 2000). Therefore, the observed pressure loss must be taken as a serious warning for the sustainable reservoir management.

Table 1. Observed Pressure Drop in Kizildere Wells.

Wells	Initial (1984) Pressure, (bar)	Final (2000) Pressure, (bar)
KD-6	67.3	58.3
KD-13	67.0	58.0
KD-14	50.1	38.7
KD-15	47.1	38.7

Table 2. Observed Temperature Drop in Kizildere Wells.

Wells	Temperature, (°C)		
	1984	1989	2000
KD-6	196	198	185
KD-13	196.7	198	185
KD-14	207.9	210	200
KD-15	202	208	192
KD-16	206.5	211.5	194
KD-20		208	195
KD-21		205	199.5
KD-22		205	202.8

On the other hand, as is shown in Table 2, the temperatures in different locations of the reservoir have also been declining probably due to pressure drop in the field. Two components of recharge, one shallow and one deep were identified (Serpen, 2000). Relatively cold water influx from neighboring shallow aquifers has partly invaded the reservoir. Therefore, reinjection into the Kizildere geothermal reservoir would also sustain reservoir temperature by maintaining reservoir pressure and preventing cold water influx. Besides, reinjection with separated

water at 147°C would thermally feed reservoir by supplying extra heat.

There are six idle wells KD-1, 1A, 2, 7, 8, 9 in the main producing and peripheral area (Fig.1). While four of these wells, namely KD-1, 1A, 2 and 8 tap upper part of the hot water reservoir, the other two wells, KD-7 and 9 tap relatively deeper part of the hot water reservoir. KD-1, 7, 8 and 9 have been utilized as monitoring wells since 1989. Continuous monitoring revealed hydraulic connection between all existing wells (Serpen, et. al., 1998). Wells R-1, KD-6, 13, 14, 15, 16, 20, 21 and 22 are producing a total 13 MW<sub>e</sub> of power of which 5 MW<sub>e</sub> are produced by R-1, the deepest (2300 m) and hottest (243°C) well of the Kizildere geothermal field. Except for R-1 and R-2, the age of the wells range from 15 to 32 years. They are old by geothermal standards, and they must be replaced with new ones in the future. The performance of these old wells has been declining for the last 17 years of operation due to calcite scaling in the near wellbore, pressure and temperature decline. For instance, the wells KD-15 and KD-16 used to have initial flow rates of 250 ton/hr and 400 ton/hr, respectively, at 15 bar wellhead pressure; now, they are producing less than half of those amounts. The wells have been repeatedly acidized, but decline in their performances has also sustained.

Table 3 gives some injection oriented information on the idle wells and the wells drilled for reinjection purpose, that is, TH-2, R-1 and R-2. There are 2 wells with major injectivity index, namely KD-6 and R-2. The well KD-6 has not only the highest injectivity index, but also the deepest water level, and therefore, it is in the most favorable position from injection point of view. As can be seen from the Table 3, huge amount of water (1100 ton/h) can be injected into this well disregarding frictional pressure drop due to  $9^{5/8} \times 6^{5/8}$  production casing and slotted pipe completion configuration. On the other hand, the well R-2 has large diameter,  $13^{3/8}$  production casing, and therefore frictional pressure drop is relatively low in this well (1 bar vs. 15 bar in KD-6). While the temperature in KD-6 at 800 m is of 185°C, it is 196°C in R-2. As Fig. 2 suggests, reinjection into R-2 might spoil an excellent production well with a thick reservoir section. On the other hand, it may also cool down R-1. Stratigraphically, they are also different at the same depth. While KD-6 cuts marble, R-2 intersects schist at the same interval of reservoir. These two wells might be tapping different aquifers at different temperatures. Geochemistry also points out that there is relatively cold water influx from the southern part of the field (Serpen and Ugur, 1998) affecting especially the well KD-6. Therefore, reinjection from well KD-6 might not influence the well R-2.

**Table 3. Injectivities of Kizildere Wells.**

Wells	Inject. Index, lt/s/bar	Water level m	Inject.** Pressure bar	Reinj. Rates, ton/hr
KD-1	2.78 <sup>+</sup>	34.55	10	97
KD1-A	2.3 <sup>+</sup>	34.55	10	83
KD-6	27.36 <sup>+</sup>	111.0	16.6	1100 (200*)
KD-7	2.51 <sup>+</sup>	134	18	140 <sup>+</sup>
KD-8	2.00*	58.80	10.4	75*
KD-9	0.75*	97.80	19.3	50*
R-1	2.01	70*	10	100 <sup>+</sup>
R-2	20.40 <sup>+</sup>	20*	11.5	845
TH-2	0.98	10	23	90
Total (except R-2 and TH-2)				645

\* Estimated values, <sup>+</sup> Measured values, \*\* (Separator pressure + Elevation + Water level in wells).

The idle wells KD-1, 1A, 7, 8 and 9 and production well KD-6 are considered for reinjection. As can be noted from Fig. 1, all considered wells are peripheral ones, and they mostly have topographical advantage with a potential of providing extra pressure for reinjection. A main reinjection line is planned starting from well KD-15 with highest elevation down to the KD-6 collecting waste water from all producing wells. Reinjection lines to the selected reinjection wells are also taken from the same main line and reinjection would be carried out by using separation pressure plus hydrostatic head created by topography plus hydrostatic head born by water level in the wellbore.

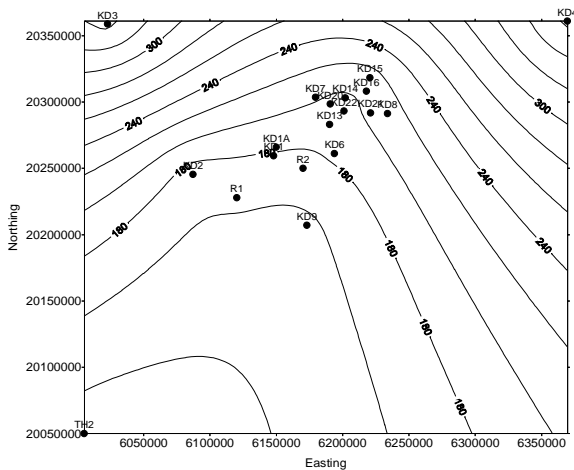


Fig. 1. Location of Kizildere wells

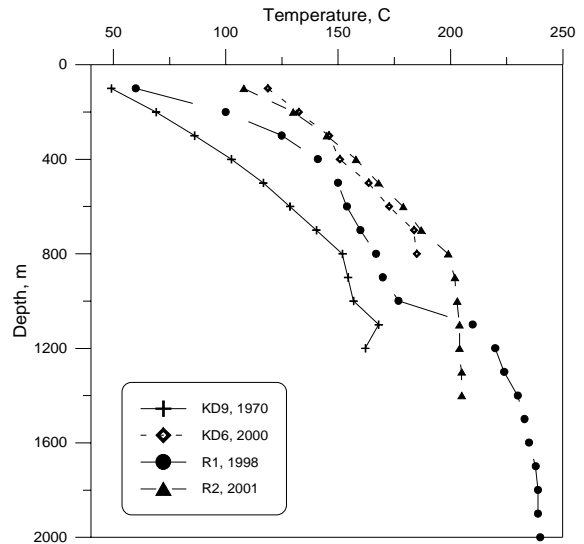


Fig. 2. Temperature profiles of southern wells.

## PREVIOUS REINJECTION TESTS

### KD-1

The first reinjection experiment in Kizildere field was carried out in Sept. 1971, and 1111 tons of cold waste water was pumped into well KD-1 for 25 hours. Reinjection results are given in Fig. 3. Reinjection was mainly conducted at moderate injection rates. Higher rates, such as 120 ton/hr were also tried. Reinjection wellhead pressures were rather high at that time due to liquid filled reservoir.

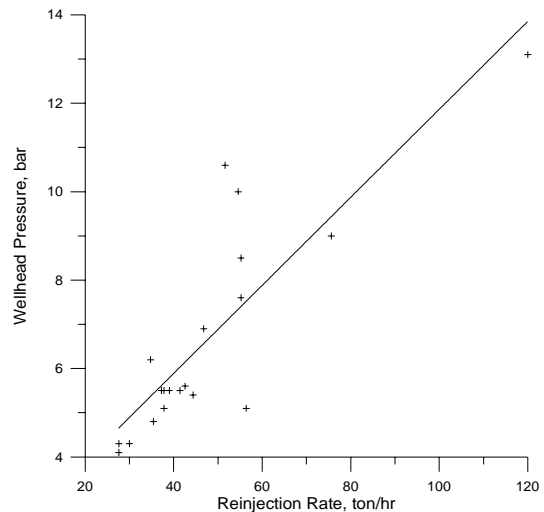


Fig. 3 Results of first reinjection test

### KD-1A

In 1976, disposal water from KD-15 was injected into well KD-1A at an average rate of about 85 tons/hr for 29 weeks. Injected water temperature varied from 35°C to 45°C. Well KD-1, which is 68 m away from KD-1A, was chosen as the observation well. Figure 4 illustrates the injection rate and wellhead pressure recordings at well KD-1A. For the first 5 weeks, the

injection rate increases from 75 tons/hr to 90 tons/hr, and the wellhead pressure follows a similar trend by increasing from 7 bar to 9 bar. From 7th to 12th weeks, the injector wellhead pressure drops down to 8 bar, while the injection rate oscillates about 90 tons/hr. After the 12th week, the injection rate exhibits a rather sharp drop to 75 tons/hr, until the 15th week. In the mean time, the wellhead pressure increases to 11 bar. The reason for the rapid drop in injection rate is thought to be the filling up of the reservoir with the cumulative water injected by that time. As seen in Fig. 4 the injection rate suddenly increases and reaches 85-tons/hr level, as the wellhead pressure remains constant, between the 15th and 16th weeks. Such behavior is likely to be the initiation of hydraulic fracturing of the rock of a pressured up formation. It is well known fact that once the formation is fractured, it does not take much pressure to progress the fracture. Thus, the injection pressure in Figure 4 starts increasing up to 13 bar until the 17th week then remains constant for six weeks. Injection rate also remains constant for six weeks. After the completion of fracture progress at the 21st week, the injection rate declines slightly, and the pressure also declines with two-week delay, as illustrated in Fig. 4.

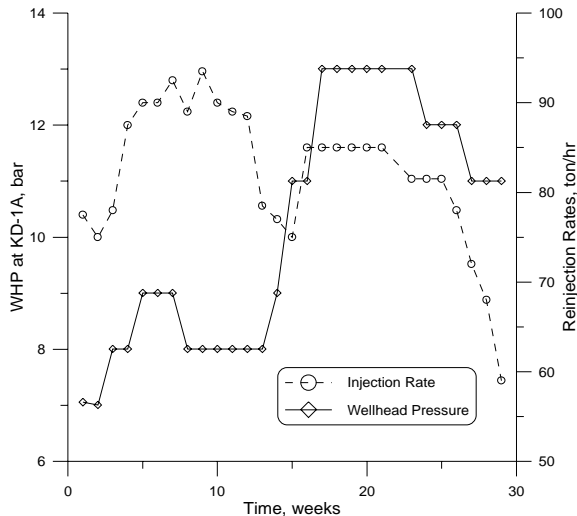


Fig. 4. Results of reinjection test in KD-1A

### KD-7

In the summer of 1995, the water produced from KD-20 was injected into well KD-7 by gravity. The wellhead injection temperature was 96°C during the 45-day operation. Pressure was monitored at the depth of 600 m in the 667-m deep injector. Recorded pressures and injection rates are shown in Figure 5. The producer KD-20 also served as an observation well for monitoring the produced water temperature and chloride (Cl) concentration. In Fig. 5, only the change in Cl concentration is provided since no cooling was detected in produced water at KD-20.

The major problem encountered in the reinjection operation was the continuous drop in injectivity. As seen in Fig. 5, 125-tons/hr rate of injection early in the operation decreases down to an average of 35 tons/hr by the end of the test. The problem of injectivity is attributed to the possible plugging of both the formation and the injector. Due to the limitations in technical conveniences at that time the actual reasons of plugging difficulty have never been revealed.

Fig. 5 illustrates that the chloride (Cl) concentration increases, from an initial 135 ppm to 146 ppm, in the water produced from well KD-20, after 25 days of reinjection. The increase in Cl concentration is due to the movement of the hydraulic front from KD-7 to KD-20. A material balance calculation, based on the cumulative injected water and Cl content in both injection and produced waters, has shown that about 40 percent of the injected water, with 135-ppm Cl content, arrived at well KD-20 (Satman et al., 2000).

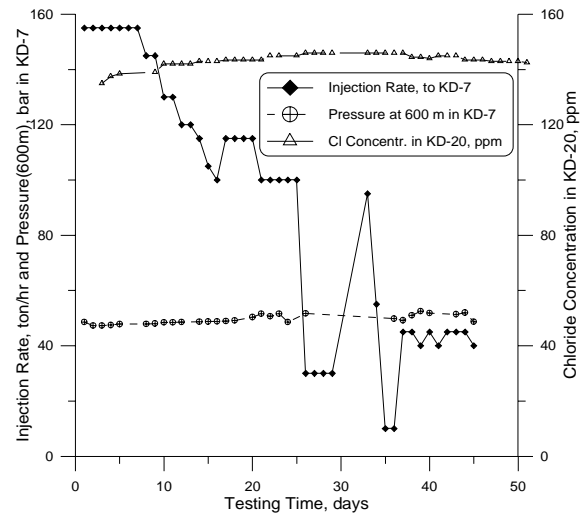


Fig. 5. Results of reinjection test in KD-7

The last reinjection experiment in Kizildere field was conducted in Jan. 2001. The reinjection test from well KD-20 to KD-7 by using a pump effectively took 330 hours, and approximately 15000 tons of waste water from the separator of KD-20 was reinjected. As shown in Fig. 6, wellhead pressure of KD-7 slightly dropped at reinjection rate of 55 ton/hr during the test. At the end of the test flow rate was reduced to 25 ton/hr due to scaling problems in the flow channels of the pump, and four days later the test was stopped because of the same problems. This was the first hot water reinjection test conducted at 147°C and it was successful one. No detectable pressure and temperature changes in the closest well KD-20 was observed.

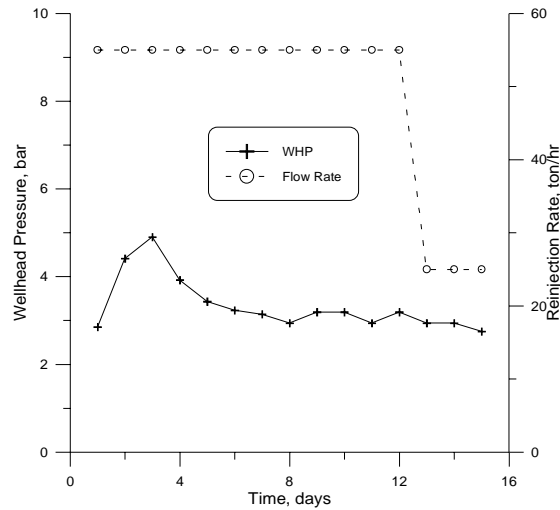


Fig. 6 Result of last reinjection test in KD-7

## CHEMISTRY OF REINJECTION

Since mineral deposition from injected fluid may block the well and/or damage formation permeability in the vicinity of the injection wells, or, reservoir itself, chemistry of the geothermal fluid must be carefully examined to impede mineral deposition problems. Two potential mineral deposition problems, silica and calcite are likely to occur in Kizildere geothermal field depending upon operational procedures, that is, under cold or hot conditions. The mechanism of deposition is completely different for silica and calcite under cold and hot water reinjection into the hot or cold reinjection environment, and therefore, both cases should be examined separately, as follows:

### Silica deposition

Silica occurs largely in aqueous solution as  $H_4SiO_4^0$ , and concentration of the  $H_4SiO_4^0$  species is equal to the concentration of total dissolved silica. When the concentration of monomer silica,  $H_4SiO_4^0$  in solution exceeds the solubility of amorphous silica polymerization of aqueous silica tends to form, and deposition occurs (Arnarson 1995). General experience shows that silica scales form neither in wells, nor in discharged waters as in Kizildere (Dominco, 1973) since considerable amorphous silica supersaturation is required. Other major factors that controls silica deposition is temperature, salinity and pH of the water (Arnarson 1995).

Experimental work (Lindal and Kristmandotter, 1989) carried out on silica deposition in Kizildere field indicated that amorphous silica supersaturation is reached at temperatures of 95°C, 107°C and 113°C in wells KD-6, KD-15 and KD-16, respectively. The salinity of Kizildere water is low (TDS $\cong$  4500 ppm), and therefore, rapid silica polymer growth is unlikely.

On the other hand, pH range of 8.5-9 of the discharged waters (optimum range of 7-8) diminishes the growth rate of polymers. In fact, silica deposition makes up only 1% of total scale observed within wells and discharge pipes of Kizildere field (Dominco, 1973).

In the light of above mentioned, two options are considered for reinjection in Kizildere from the silica deposition point of view: (1) reinjection of amorphous silica undersaturated disposal water, that is, hot water reinjection at 147°C directly from the separator, and (2) cooling the disposal water first, to precipitate supersaturated amorphous silica, then reinject it under boiling temperatures.

The option of cold water reinjection is studied by Yildirim, (1996) analyzing water samples from separators, weirs and water channels and carrying out silica precipitation tests. The silica contents defined after analysis are given in the Table 4. As can be observed from Table 4, silica concentrations of 290-310 mg/l at separating conditions increase to 345-398 mg/l just under boiling conditions (92°C-96°C), then it diminishes to the concentration of 237-323 mg/l at 50°C. The latest values observed after some silica precipitation are around or close to the silica content of reservoir fluid. Silica solubility of this latest fluid after precipitation may not create deposition problem, but, waste water should be cooled down in a pool, therefore, it is aerated. It is well known that the aeration of injected water enhances silica scale formation. Waste water with pH of 9 may also have pH of 7-8 by mixing reservoir water with pH of 5.9, increasing the likelihood of deposition within the reservoir. Therefore, it can be concluded that cold water reinjection has some serious deposition risks. On the other hand, hot water reinjection from separator at 147°C will not reach saturation with respect to amorphous silica, and it will not contact with the atmosphere.

Table 4. Silica Contents of Kizildere Wells at Different Temperatures(Yildirim, 1996).

Well	Tem. °C	SiO <sub>2</sub> mg/l	Tem. °C	SiO <sub>2</sub> mg/l	Tem. °C	SiO <sub>2</sub> mg/l
KD6	145	276	93	364	48	293
KD13	145	278	92	364	48	302
KD14	145	324	94	395	50	335
KD15	146	320	94	392	45	323
KD16	147	340	96	398	48	304
KD20	146	310	90	367	50	292
KD21	146	325	92	387	46	273
KD22	147	297	96	378	54	237
Canal	76.5	352	67.5	345	-	-

### Calcite Deposition

When geothermal water cools by boiling and loses its CO<sub>2</sub> at the same time, it is the interplay of increased calcite solubility and decreased H<sup>+</sup>(increased pH) and aqueous CO<sub>2</sub> activities that

determine the state of calcite saturation as a function of the temperature of the boiling water. Arnarson, (1995) reported that most waters at low temperatures (<150°C) plot close to the calcite saturation curve. However, as flashing of CO<sub>2</sub> ends with some calcite precipitation, the water becomes progressively less saturated at lower temperatures and eventually even undersaturated with respect to calcite.

Kizildere field has 1.5% of CO<sub>2</sub> by weight and high partial pressure of CO<sub>2</sub> (≈50 bar). Therefore, large quantities of calcium carbonate deposition are observed in wellbore as well as in surface installations. While calcite is deposited within the wellbore, aragonite is precipitated in surface pipelines after second flashing.

Unlike silica saturation, calcite saturation increases with increasing temperatures, and therefore in the injection case, deposition will not tend to occur until the water gained sufficient temperature. On the other hand, continued heating will not bring about as rapid supersaturation as boiling does (Arnarson, 1995).

Injection of waste water into cold formations is preferred in order to avoid deposition. The lower the temperature of injected water and the lower the temperature of receiving formation, the smaller are the changes that the water will attain calcite saturation. Lindal and Kristmandotter, (1989) reported in their study on 3 Kizildere wells that waters of KD-6, KD-15 and KD-16 wells are supersaturated with respect to calcite after separation. If this waste water is reinjected, calcite might be precipitated in the reservoir. The use of inhibitors would impede the calcite deposition both in wellbore during production, and in reservoir during reinjection.

## **MODELING STUDIES FOR REINJECTION**

In modeling studies, two alternatives are considered: (1) injection into nearby potential geothermal area and (2) reinjection into Kizildere reservoir.

### **Injection outside area**

Tekkehamam is a separate geothermal area 3 km south of the Kizildere field. Modeling studies were carried out considering the injection of Kizildere waste water into Tekkehamam area. The temperatures of Kizildere and Tekkehamam reservoirs were assumed the same. Spherical flow, radial flow, linear flow and linear flow through single fracture cases were studied (Satman et.al., 1990) and the following results were observed:

**Spherical Flow:** In this model, the disposal water from Kizildere field with a rate of 1000 tons/hr was assumed to be injected in Tekkehamam field at

130°C. After 25 years the waste water would fill a sphere with a radius of 430 m around the injection well with no potential cooling effect on Kizildere geothermal field.

**Radial Flow:** This model also assumes the above mentioned data. After 25 years, waste water would remain in a cylinder with 730 m radius without affecting the temperatures of Kizildere reservoir.

**Linear Flow:** In this model, the disposal water is assumed to be injected through a 200 m thick formation that reaches to the Kizildere field. After 25 years, a temperature drop of 10°C was estimated at a distance of 1650 m from the injection well without affecting Kizildere reservoir.

**Linear Flow Through Single Fracture:** In this model, after 25 years the temperature of 131.4°C was predicted at the Kizildere end of the fracture.

As model study indicates, the temperature of Kizildere reservoir would be adversely affected only in single fracture case. Studies conducted until now have identified no such fracture connecting the two area.

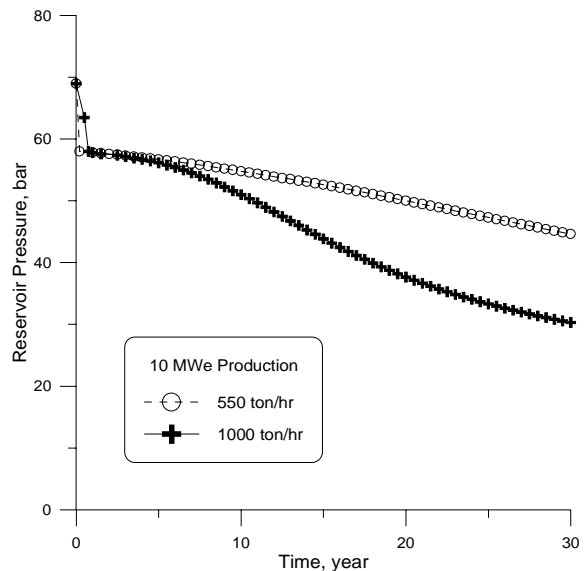


Fig. 7. Results of modeling study for reinjection.

### **Reinjection into Kizildere reservoir**

Reinjection within the Kizildere geothermal reservoir was also studied using lumped parameter model by Alkan and Satman, (1990). Two reinjection rates of disposal water at 147°C, namely 550 ton/hr and 1000 ton/hr with a power generation of 10 MW<sub>e</sub> were considered in a study by Serpen et.al., (1994). The results of modeling study with these rates are illustrated in Fig. 7. As the Fig 7 indicates, higher reinjection rate has negative effect on reservoir pressure. Although better pressure maintenance is

expected with higher reinjection rate, the opposite occurs, due to cooling effect of high rate reinjection. Enthalpy drop with higher reinjection rate is observed after 7 years of reinjection operation. If higher reinjection rate is an immediate concern for environmental reasons, this strategy can give ample time to find an alternative solution without contamination of environment.

### **REINJECTION STRATEGIES**

Reinjection of disposal water has been considered since the early stages of development, even before power plant was installed. Unlike the other geothermal fields with low formation pressure around the world, Kizildere geothermal field was originally overpressured as can be seen in Fig. 8. Relatively high mud weights ( $1.25 \text{ g/cm}^3$ ) applied during drilling and high wellhead pressures observed during reinjection tests performed in KD-1 and KD-1A were all indications of difficulties of reinjection because of liquid filled reservoir. Under these conditions, rate of fluid injection is controlled by the viscosity and compressibility of reservoir fluid. Any formation that is completely saturated with liquid can not accommodate additional fluid without the fluid in the reservoir being compressed. Pumping power consumption would have been very high if reinjection started at the beginning of the field exploitation. Ten bars of pressure decline after 17 years of production created a favorable medium for reinjection in Kizildere field. Two reinjection strategies, short and long term are considered in the following:

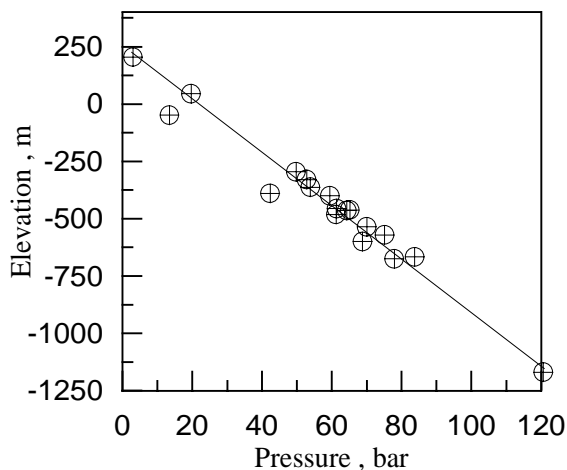


Fig. 8. Reservoir pressures of Kizildere field.

#### **Short Term**

Presently, nine production wells are in operation in Kizildere geothermal field, one tapping from deep thermal reservoir, and the other 8 wells tapping from shallow hot water reservoir. While the deep well R-1 produces  $5 \text{ MW}_e$ , the rest 8 wells generate a total 8

$\text{MW}_e$  of power. Waste water disposed by these wells is roughly 900 ton/hr.

Six wells that are not presently utilized for production and situated at the peripheral area of the field are selected for reinjection purpose. Estimated total reinjection rate of these wells (KD-1, KD-1A, KD-6, KD-7, KD-8, KD-9) is approximately 650 ton/hr. This leaves 250 ton/hr of rate to be injected elsewhere. As modeling studies indicate reinjecting all 900 ton/hr would risk the cooling of the reservoir in the long run. Therefore, the remaining 250 ton/hr of disposal water could be injected into TH-2 well 3 km away from the Kizildere field. While reinjection to the peripheral wells would be carried out under hot condition (at  $147^\circ\text{C}$ ) from the separator, injection to the well TH-2 would be implemented under cold conditions (at  $35\text{-}40^\circ\text{C}$ ) by carrying the waste water through a open canal to the well site and pumping into the well.

Field administration plans to reinject all disposal water into well R-2. As can be seen in Table 3, the well R-2 has a potential reinjection capacity of 845 ton/hr, it may practically absorb almost all disposal water. On the other hand, R-2 has a bottomhole temperature of  $205^\circ\text{C}$ , which is higher than all present producing wells (Table 2), and this well might produce another  $5 \text{ MW}_e$  of power that is very much needed to boost the power production to the full capacity, improving also the economy of the project. The power generation of this well might relieve some poor producing wells, such as KD-13, or KD-15 whose temperatures have declined more than the other production wells. Therefore, considering their peripheral positions, they might be used for reinjection to absorb the waste water of the R-2. Besides, the possible permeable zone in R-2 is around 1000-1400 m, it is close to the permeable horizon of R-1 at 1400-2000 m (Fig. 2).

#### **Long Term**

This strategy essentially foresees efficient utilization of the resource and power production increase. In this context, reinjection will play a pivotal role. Reinjecting into deeper strata to allow heating of reinjected fluid is generally accepted concept in geothermal industry. On the other hand, producing from deep thermal areas with moderate permeability and reinjecting into outflow zones with higher permeability would be a logical alternative approach.

Second approach is suggested in this strategy; fluid production from relatively shallow hot water reservoir with  $200^\circ\text{C}$  would be shifted to deep thermal reservoir with temperatures of  $240^\circ\text{C}$ , and reinjection would be directed to relatively shallower horizons. Since the performance of existing production wells ( $1 \text{ MW}_e$  each) is low, the deeper thermal reservoir is preferred by having not only

higher temperature but also higher CO<sub>2</sub> content providing more energy for the production. On the other hand, producing from the thermal reservoir will result in 73% extra power generation per unit produced fluid in comparison to hot water reservoir. Hence, the amount of waste water to be reinjected will be cut almost by half.

In this strategy, the most critical point is downward cooling effect of injected water due to gravitational forces. Kizildere geothermal system was formed thorough a well developed fracture network (Serpen, 1998). Well tests and other studies (Serpen, 2000) have confirmed that fact. There is hydraulic connection between wells. For instance, during the production testing of R-1, very small pressure drop was observed in well KD-9, which is close to R-1 distancewise, and depthwise. Vertical permeability in the field was estimated as 2.2 md (Serpen, 1998). Therefore, injected water might find preferential paths to the deep thermal reservoir. In this strategy, shallow and distant northern wells would be selected, and wells, such as KD-9, KD-6 and KD-13 would not be utilized to prevent the cooling effect of injected waste water. By this way, a long path would be created, because there would be a distance of 800 m to 1000 m between shallow injection and deep production strata. If a small temperature change was observed, some of the disposal water could always be directed to the distant TH-2 well to mitigate the cooling effect of reinjected water.

## **CONCLUSIONS**

In the light of above mentioned, thorough implementation of a reinjection strategy it is possible to preserve the environment and maintain pressure of Kizildere geothermal field by reinjecting the waste water of power plant. To implement reinjection strategy the following operations should be carried out:

- Projection and building of collection and distribution of waste water pipelines depending upon short or long term strategy applied.
- Workover operations, such as repair cementing of KD-8, cleaning of selected wells, injection testing of KD-1, KD-1A, KD-8, KD-9 and depending on the testing results, carrying out acidizing.
- Tracer testing for monitoring the reinjection operation.

## **Acknowledgements**

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