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Reservoir and Hydrogeochemical Characterizations of the Salihli Geothermal Fields in Turkey

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ABSTRACT

The study area is located in southern rims of the Gediz Graben in Western Anatolia region in Turkey. In this study, geothermal and hydrochemical characteristics of thermal waters in the Salihli geothermal fields are described. Thesegeothermal fields are geographically divided into four main groups; Kursunlu, Caferbey, Ufuruk and Sart-Çamur geothermal fields. In the study area, the thermal waters have outlet temperatures between 30-55°C in springs and from 51°C to 155°C in wells. However, their discharges are between 2-80 l/s from springs or wells. According to IAH (International Association of Hydrogeologists), chemical classifications, waters in the study area reflect the water types of Na-HCO_3, Ca-Mg-HCO_3, Ca-Na-HCO_3 and Ca-Mg-SO_4 in Kursunlu, Caferbey, Sart-Çamur and Ufuruk, respectively. Cold waters are mainly dominated by the HCO_3 and SO_4 anions and Na, Ca and Mg cations. Kursunlu geothermal field is one of the most important geothermal areas in the Gediz Graben on the basis of location and potential. It has a shallow reservoir about 250m deep and contains hot springs and wells. Approximately, 5900 residences in Salihli town have been heated by using the production wells in this field. Understanding of the behavior of re-injected waters in the subsurface, tracer tests were performed inKursunlu geothermal fields. Na-fluorescein was pumped into two different re-injection wells. Results of tracer tests showed that water injected from the re-injection wells flowed through the shallow aquifer velocities varied between 2.14 and 17.96 m/h and the peak arrival times varied between 13 and 97 hours. Therefore, the tracer tests indicated a geothermal reservoir with quite permeable fractures in the geothermal field and may be caused cooling in the production wells.

Results of environmental isotope and chemical analysis show that thermal waters are of meteoric origin and major hydrogeochemical processes are the water-rock interactions under high temperature conditions. According to silica geothermometers, reservoir temperatures vary between 90ºC to 200ºC. Cation geothermometers give also temperatures ranging from 190 to 300ºC. Thermal waters in the study area are oversaturated with respect to carbonate minerals (calcite, dolomite and aragonite). These are likely to cause scaling problems during the production and utilization of thermal water.

1. INTRODUCTION

Western Turkey is one of the most spectacular and best-studied regions of the world where continental lithosphere has been stretched following crustal thickening due to orogenic contraction.

Western Turkey is one of the most spectacular regions of widespread active continental extension in the world. The most prominent structures of this region are E–W trending grabens like Gediz Graben. The study area is centered on latitude 38 10'N, longitude 28 10'E and is located southern rims of the Gediz Graben in Western Anatolia region in Turkey. Salihli geothermal fields geographically divided into four main groups; Kursunlu, Caferbey, Ufuruk and Sart-Çamur geothermal fields (Figure 1). Kursunlu and Sart-Çamur thermal waters are used for bathing and balneological purposes since Prehistoric times. The semi-arid climate of the area is characterised by hot dry summers and warm wet winters. The mean annual temperature and the total annual rainfall at Salihli are about 16^{o}C and 500 mm, respectively.

In this study, geothermal and hydrochemical characteristics of thermal waters in the Salihli geothermal fields are described.

2. MATERIAL AND METHODS

Water samples of springs and wells were collected during four site visits between October 2005 and September 2008.

Conductivity (EC), pH and temperature were measured in the field using standard hand-held calibrated field meters. Water samples were analyzed for their chemical (major ion) compositions by inductively coupled plasma–mass spectrometer (ICP–MS) in the ACME laboratories in Canada. Total alkalinity was measured by potentiometric titration with Nitric acid to a final pH of 4.2. SO_4^- were analyzed gravimetric preciperation method in Geochemistry Laboratuary from Department of Geological Engineering in Dokuz Eylul University. Stable isotope ($\delta^{18}O$ and $\delta^{2}H$) were measured using a mass spectrometer in TUBITAK-MAM (The Scientific and Technological Research Council of Turkey - Marmara Research Center) Earth and Marine Sciences Institute Isotope Laboratuary. Tritium (^{3}H) was measured in Hacettepe Universtiy Department of Geological Engineering Laboratory. Na-Fuorescein (MERC, KgaA, 64271, Demstadt, Germany) dye was injected from K-1 reinjection well in February 2008 and from K-17 reinjection well in March 2008 at reinjection rate of 1500 kg and 750 kg respectively. Tracer test was monitored from production wells (K-2, K-5, K-11, K-15 and K-19). Samples were collected in 50 ml dark glass cap from each production wells changing intervals 15 minute-3 hours. Na-Fuorescein concentrations in the samples were measured during a month period using a TURNER 10AU–005-CE digital fluorometer.

3. GEOLOGY AND HYDROGEOLOGY

Western Anatolia forms one of the most seismically active and rapidly extending regions in the world. This region has been experiencing N–S directed extension since, at least, latest Oligocene–Early Miocene and is currently under the

influence of forces exerted by subduction of the African Plate beneath the southern margin of Anatolian Plate along the Aegean-Cyprean subduction zone and the dextral slip on the North Anatolian Fault System and approximately E–W trending several grabens like Gediz Graben. The evolution of the N–S extension along the Gediz Graben occurred during two episodes, each characterized by a distinct structural styles: (1) rapid exhumation of Menderes Massif in the footwall of low-angle normal fault (core-complex mode) during the Miocene; (2) late stretching of crust producing E–W grabens along high-angle normal faults (rift mode) during Pliocene–Quaternary times, separated by a short-time gap. The later phase is characterized by the deposition of now nearly horizontal sediments of Pliocene age in the hanging walls of the high-angle normal faults and present-day graben floor sediments. Although the stratigraphy of the Gediz Graben has been studied in considerable detail, there are many discrepancies in the interpretation of the age of the graben fill. In adition many authors (Cohen et al., 1995; Emre, 1996; Seyitoglu and Scott, 1996; Yılmaz et al., 2000) have created numerous new formation names for sediments (Bozkurt and Sozbilir, 2004).

The geology and stratigraphy of the study area are shown in Figure 1. The basement of the study area consists of Menderes Massif rocks that are made up of high to low-grade metamorphics (gneiss, mica schists, phyllites, quartz schists, marbles).The proposed ages of the Menderes Massif metamorphic rocks are Pre-Cambrian to Paleocene (Dora and others, 1995). Neogene terrestrial sediments overlie the Menderes Massif rocks with a low-angle normal fault. This normal fault was identified as the “detachment fault” (Emre 1996). High-angle normal faults are found in the middle section of the graben. Structural characteristics of these faults were discussed in Emre 1996; Seyitoglu and Scott 1996; Sozbilir and Bozkurt 2004. The Quaternary alluvium, which is made up of unconsoli-dated granular sediments, is the youngest unit. Neogene terrestrial sediments, which are mainly made up of alluvium fan deposits (pebbles, pebbly sandstones, claystone-mudstones, interbedded conglomerate, clay-stones, siltstones, conglomerates comprising sandstone intercalations and limestone. The topography of this unit shows a hard base-relief construction. The thickness of the Neogene sediments is about 2000 m.

The permeability within the Menderes Massif rocks is highly variable. The carbonates (marbles and dolomitic marbles) of the Menderes Massif rocks are highly fractured and karstified and act as an aquifer for both cold ground waters and thermomineral waters depending on the location. Gneiss and quartz-schist units of the Menderes Massif act as aquifers form fractured rock aquifers. Schists and phyllites have relatively low permeability. The Neogene terrestrial sediments, which are made up of alluvial fan deposits including poorly cemented clayey levels, have very low permeability as a whole and may locally act as cap rocks for the geothermal systems. Clayey levels of the Neogene sediments occur as impermeable barrier rocks. From sandy to gravely and limestone levels of this Neogene unit contain minor aquifers. Alluvium is the most important and favorable unit for cold ground water production. It is possible to lift groundwater with 5-30 l/s discharges from 20-150-m deep wells. Ground water flows are towards the west. There are already many wells drilled by private companies in this unit.

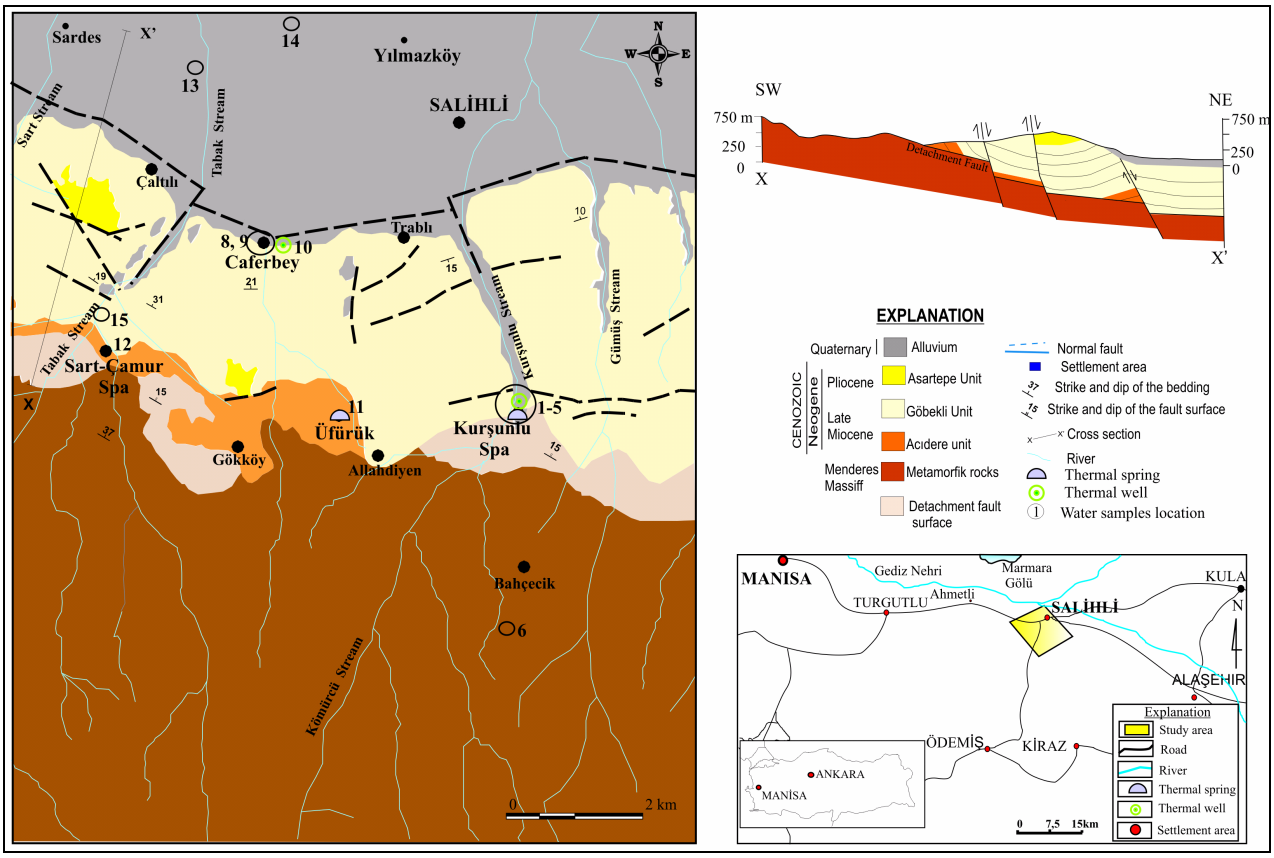


Figure 1: Simplified geological map of the study area and locations of the geothermal fields and sampled water points (Geological map is modified from Emre, 1996).

Salihli geothermal fields geographically divided into four main groups; Kursunlu, Caferbey, Ufuruk and Sart-Çamur geothermal fields. The Sart-Çamur Geothermal field is located southeastern of the Sardes antique city is located in the Gediz region on the shore of the Sart Stream (Figure 2). The outlet temperatures and discharge quantities of Sart-Çamur Spa thermal waters are 52°C and 5 l/s, respectively. Caferbey and Ufuruk geothermal fields are situated between Sart-Çamur and Kursunlu geothermal fields. A deep geothermal well with the 1189 m depth was drilled by MTA (General Directorate of Mineral Research and Exploration) in Caferbey Geothermal field. Downhole temperature and discharge rates of this well were recorded as 155ºC and 2 l/s, respectively. In addition, geothermal exploration studies have been started in this field anew. The Ufuruk has mineral spring which contains CO_2 and H_2S gases intensely (Figure 2). Outlet temperature is 31°C with low discharge approximately 0.4 l/s.



Figure 2: Some views from the Salihli geothermal fields.

Kursunlu geothermal field is one of the most important areas in Turkey due to district heating. Since 1969s a total of 20 wells have been drilled in Kursunlu Geothermal field. Most of wells are shallow (between 40 and 400 m). The first shallow well (K-1) was drilled in 1976 by MTA. The well (42.5 m) is capable of discharging 20 l/s and at a temperature of 90ºC. Between 1992 and 1998s, 4 shallow wells, from 70 to 114 m deep, were drilled. These wells temperatures are various between 83 and 94ºC and discharges from 40 to 80 l/s. The geothermal district heating project started at Kursunlu geothermal field in 2000. At present, 5900 houses hotels and green houses have been heated with geothermal energy in surroundings of Salihli town. Total discharges of production wells are 160 l/s in year. Deep well drilling (about 900 m) has been continued by Salihli Municipality. Two reinjection wells (K-1 and K-17) are located in this field (Figure 3).

The circulation of thermomineral waters in the Salihli geothermal areas is closely related to major fault and fracture zones (MTA, 2005). So, heat sources of the systems may probably be related to the high thermal gradient caused by the graben structure of the area. Meteoric waters descending through the discontinuities are heated in the aquifer rocks, and move up to the surface along the faults. Isotopic data (^{18}O and ^{2}H) suggests that thermomineral waters in Salihli geothermal areas are of meteoric origins (Figure 4). Kursunlu thermal waters showed deviations from the meteoric water lines. This $\delta^{18}O$ shift is caused by water- rock interaction. Sart-Çamur thermal waters are located on the evaporation line in the ^{18}O–D diagram.

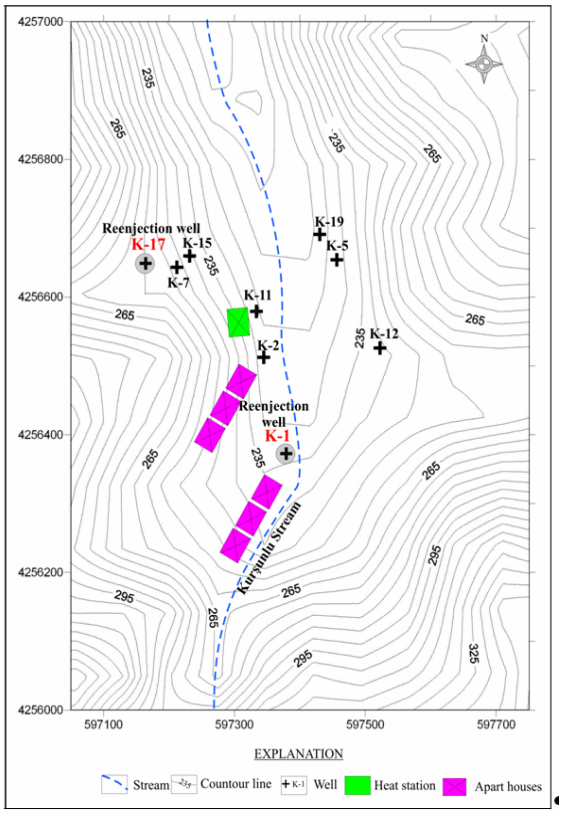


Figure 3: Some wells location in Kursunlu geothermal fields.

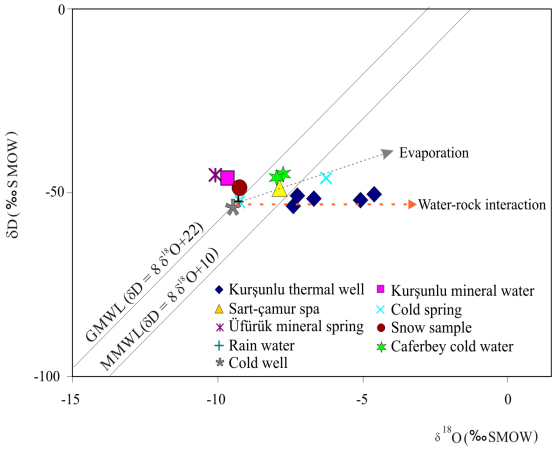


Figure 4: Plot of $\delta^{18}O$ - δ for waters in the study area. Global Meteoric Water Line (Craig, 1961). Mediterranean Meteoric Water Line (Gat and Carmi, 1970). Local Evaporation Line ($\delta^{2}H=\delta^{18}O*2.28-28.64$; Ozen, 2009).

3.1 Hydrogeochemistry

The results of chemical analyses of the waters sampled for this study are shown in Table 1 and Table 2. These results are assessed AquaChem (Calmbach, 1997) program. The water types according to the IAH (1979) are shown in Table 1. Total equivalents of cations and anions were taken as

100% and ions with more than 20% (meq/l) were used for the classification. According to IAH chemical classifications, waters in the study area reflect the water types of Na-HCO_3, Ca-Mg-HCO_3, Ca-Na-HCO_3 and Ca-Mg-SO_4 in Kursunlu, Caferbey, Sart-Çamur and Ufuruk geothermal fields, respectively. Cold waters are mainly dominated by the HCO_3^- and SO_4^- anions and Na^{+2}, Ca^{+2} and Mg^{+2} cations. The thermal waters have outlet temperatures between 27 and 90°C with electrical conductivity values of about 1220-2700 µS/cm (Table 1). In order to classify water types, major ion composition was plotted on a Piper diagram (Figure 5). The sampled waters can be subdivided into two main groups. The first group Kursunlu and Caferbey includes Na-HCO_3 type water belonging to Caferbey-1 deep well (155°C). The second group Sart-Çamur Spa includes Na-Ca-HCO_3 water type and can be classified as hardness of carbonate is more than 50%. The decrease in Ca^{+2} and/or Mg^{+2} and the increase in Na^+ in the thermal waters can be explained by ion exchange. Exchange sites must have been clays of Neogene sediments and/or Menderes Massif schists.

The relations of the constituents in thermal water samples from the Salihli geothermal areas are presented in Figure 6. The concentrations of these ions were plotted against each others that are regarded as the chemically conservative for thermal waters from the study area. The correlation coefficients (r) between Cl with HCO_3, K, SiO_2, Na and B for waters from the study area are 0.72, 0.89, 0.90 and 0.84 that indicate very good fit. Similarly, The correlation coefficients between HCO_3 with Na, K and B show that good linear relationships. In addition, the correlation of coefficients of B with Na, K and Li are 0.99 and 0.98 and 0.94, respectively. These indicate very good fit. The close positive linear correlation between Li, As, B, HCO_3, Cl, Na, K and some of the other ions (Figure 6) corroborates that geochemical processes for thermal waters are combination effects of the dissolution of carbonates and silicates and the mixing phenomenon and ion exchange reactions.

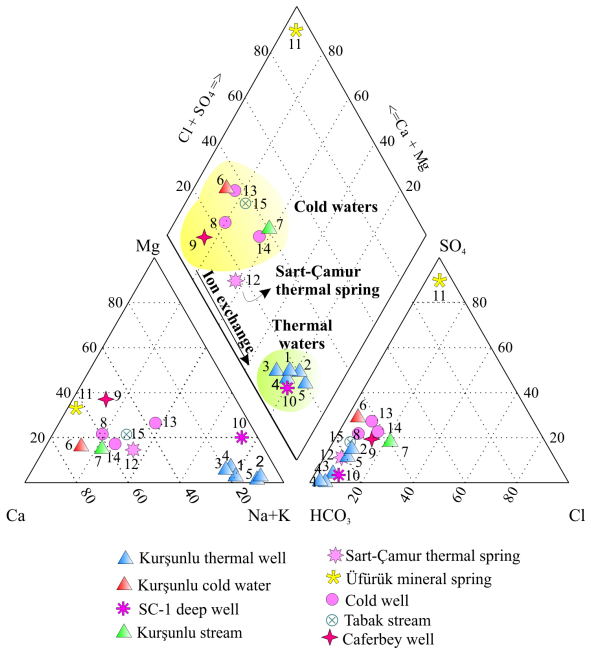


Figure 5: Piper trilinear diagrams of the waters from the study area (Sample numbers as in Table 1).

Thermal waters from the study area are used district heating, greenhouse heating, swimming pool, bathing and balneological purposes. But the chemical analyses (Table 2) revealed that the concentrations of As, B (for all thermal samples), Na (most of the thermal waters exceptional with samples 12) and K concentrations exceed the Turkish drinking water limits (TS-266, 2005 and WHO, 2004). This can cause environmental problems for ground and surface waters and soils in the study area. Thermal waters can not be used for any drinking purposes because of very dangerous for human healthy.

Table 1: Water points and some physicochemical properties of the Salihli geothermal fields, Turkey (Sample numbers are the same as in Figure 1).

No	Sample Location	Outlet T (°C)	pH	EC (uS/cm)	TDS (mg/l)	Total Fr. Hardness	SAR meq/l	Water type
1	K-1 well (reenj.)	39	7.25	2230	2687.2	27.56	10.68	Na-HCO_3
2	K-2 well	44.5	7.91	2630	3077.4	17.43	21.76	Na-HCO_3
3	K-5 well	54.9	6.59	2270	2620.0	31.80	9.49	Na-HCO_3
4	K-11 well	42.3	7.40	2210	2246.1	27.93	11.02	Na-HCO_3
5	K-15 well	38.6	6.52	2610	3531.6	11.07	26.47	Na-HCO_3
6	Cold well	13.1	7.95	235	251.0	10.14	0.24	Ca-HCO_3-SO_4
7	Kursunlu stream	10.4	8.36	428	496.9	15.26	1.33	Ca-Na-HCO_3-Cl-SO_4
8	Cold well	14.7	7.63	736	751.2	32.90	0.89	Ca-HCO_3
9	Caferbey well	27.4	6.65	1220	1091.7	58.81	0.95	Ca-Mg-HCO_3
10	*SC-1deep well.	90	7.80	2700	3518.9	51.67	13.02	Na-HCO_3
11	Ufuruk mine. water	8.2	5.69	3650	4740.3	305.3	0.46	Ca-Mg-SO_4
12	Sart-Çamur spring	40.7	6.61	1575	1540.7	56.03	3.02	Ca-Na-HCO_3
13	Cold well	28.3	8.76	399	406.8	13.95	1.32	Ca-Na-Mg-HCO_3-SO_4
14	Cold well	23.5	7.46	565	510.1	22.62	0.79	Ca-HCO_3-SO_4
15	Tabak stream	14.3	8.40	535	527.3	25.33	0.97	Ca-Na-HCO_3-SO_4

3.2 Geothermometer Applications

Various chemical geothermometers were used to estimate the reservoir temperature of the thermal waters in Salihli thermal waters (Table 3). Some results of the geothermometers seen in Table 3 are meaningless since they are lower than the measured outlet temperatures or minus value. Discarding these data, the rest of the data can be used to estimate the reservoir temperature.

According to silica geothemometers, the reservoir temperatures of Kursunlu, Caferbey and Sart-Çamur geothermal fields was calculated between 113 − 213°C, 157 − 180°C and 91 − 142°C, respectively. Comparing the measured outlet (aquifer or spring) temperatures, it is opinion that the Na/K geothermometers are mostly higher than the silica geothermometers.

Table 2: Chemical analyses of waters from the Salihli geothermal fields, Turkey (Sample numbers are the same as in Figure 1. Blanks refer no record).

No	Sample Lacation	K mg/l	Na mg/l	Ca mg/l	Mg mg/l	Mn mg/l	As mg/l	B mg/l	Li mg/l	Cl mg/l	SO_4 mg/l	HCO_3 mg/l	SiO_2 mg/l
1	K-1 well (reenj.)	49.71	407.33	83.19	16.48	0.03	0.11	44	2.44	77	80.89	1403.4	231.05
2	K-2 well	84.42	660.22	46.82	13.92	0.03	0.37	60	5.14	125	68.9	1339.9	322.11
3	K-5 well	51.07	388.89	96.46	18.73	0.05	0.01	39	3.38	65	86.16	1460.7	187.21
4	K-11 well	51.05	423.21	84.90	16.33	39.32	0.21	44	3.08	78	77.89	1028.7	224.50
5	K-15 well	82.14	639.90	31.34	7.86	0.12	0.05	61	4.50	130	26.96	1684	396.06
6	Cold well	1.75	5.49	32.56	4.87	0.001	0.006	0.01	0.004	4	38.95	112.3	17.45
7	Kursunlu stream	5.31	37.84	46.75	8.70	7.76	0.87	2.31	0.20	50	56.92	231.9	23.23
8	Cold well	4.42	36.92	102.14	17.95	143	0.004	1.72	0.13	18	83.88	412.5	20.81
9	Caferbey well	5.36	52.98	132.47	62.47	1.05	0.003	0.50	0.004	51	86.88	602.8	32.05
10	*SC-1deep well.	70	680	42	6.10					115	34	1983	214
11	Ufuruk mine. water	22.23	57.89	808.47	251.11	1.02	0.004	0.55	0.07	62	2387.81	219.7	33.33
12	Sart-Çamur spring	21.14	164.03	183.77	24.62	0.23	23.39	14	0.23	32	65.91	793.2	108.03
13	Cold well	4.41	35.71	31.93	14.52	0.09	19.13	2	0.21	12	51.7	198.9	18
14	Cold well	4.18	27.21	69.46	12.81	0.24	0.005	1.09	0.086	28	60.31	214.8	22
15	Tabak stream	6.03	35.62	76.87	14.90	0.03	0.004	1.51	0.15	14	62.91	231.9	30.19
TS-266, 2005 (MAC)		12	200	250	200	50	0.01	1		250	250	200	
WHO, 2004						400	0.01	0.3		250	250		

MAC (TS-266): Maximum admissible concentrations according to the Turkish Drinking Standards (TS-266, 2005).

Table 3: Using some geothermometric equations for Salihli geothermal fields.

Referance No	Name	Geothermometric Equations	Referance
1	SiO_2 (Quartz)	$t = 1309 / (5.19 - \log SiO_2) - 273.15$	Fournier (1977)
2	SiO_2 (Quartz buhar kaybı)	$t = 1522 / (5.75 - \log SiO_2) - 273.15$	Fournier (1977)
3	SiO_2 (Calcedony)	$t = 1032 / (4.69 - \log SiO_2) - 273.15$	Fournier (1977)
4	SiO_2(Calcedony, cond.cooll.)	$t = 1112/ (4.91 - \log SiO_2) - 273.15$	Arnorsson et al. (1983)
5	SiO_2 (α Cristobalite)	$t = 1000 / (4.78 - \log SiO_2) - 273.15$	Fournier (1977)
6	SiO_2 (Quartz buhar kaybı)	$t = 1264/ (5.31 – \log SiO_2) - 273.15$	Arnorsson et al. (1983)
7	SiO_2 (Quartz buhar kaybı)	$t = 1021/ (4.69 – \log SiO_2) - 273.15$	Arnorsson et al. (1983)
8	SiO_2(Quartz buhar kaybı)	$t = 1164/ (4.9 – \log SiO_2) - 273.15$	Arnorsson et al. (1983)
9	SiO_2(Quartz buhar kaybı)	$t = 1498/ (5.7 – \log SiO_2) - 273.15$	Arnorsson et al. (1983)
10	SiO_2(Calcedony) (mol)	$t = 1101/(0.11-\log SiO_2) - 273.15$	Arnorsson et al. (1983)
11	Na/K	$t = 856/(0.857 + \log Na/K) - 273.15$	Truesdell (1976)
12	Na/K	$t = 1217/(1.483 + \log Na/K) - 273.15$	Fournier (1979)
13	Na/K	$t = 933/(0.933 + \log Na/K) - 273.15$	Arnorsson et al. (1983)
14	Na/K	$t = 1319/(1.699 + \log Na/K) - 273.15$	Arnorsson et al. (1983)
15	Na/K	$t = 1390/(1.750 + \log Na/K) - 273.15$	Giggenbach et al. (1983)

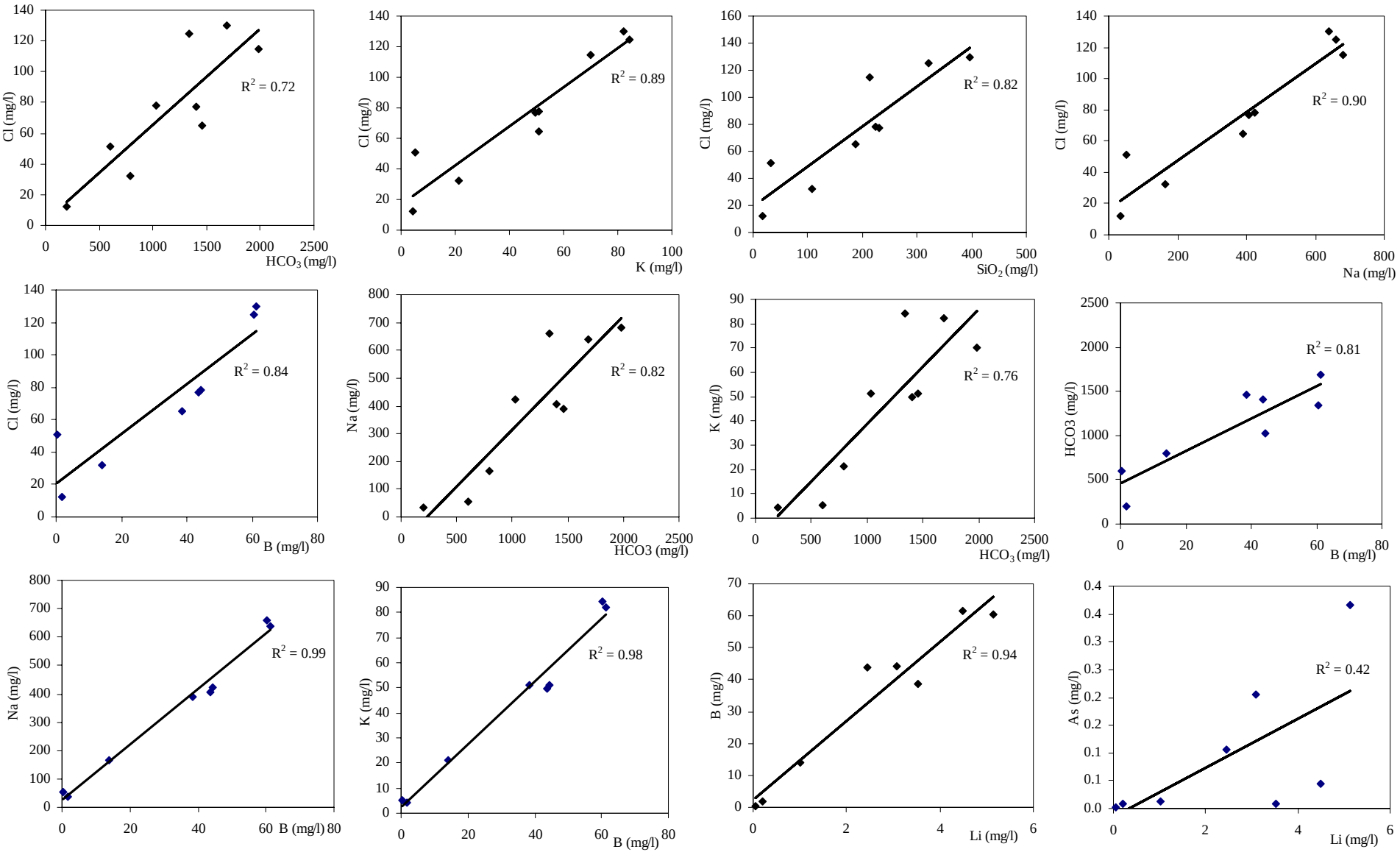


Figure 6: Relations between various ions for thermal waters from the Salihli geothermal fields, Turkey (r is correlation coefficients for linear regression between major ions).

Table 4: Calculated reservoir temperatures of the thermal waters in Salihli geothermal fields, Turkey (Reference numbers are the same as in Table 3, "¤" refers that it is lower than outlet temperature).

Sample No	Sample Location	Outlet T (°C)	SiO_2 1	SiO_2 2	SiO_2 3	SiO_2 4	SiO_2 5	SiO_2 6	SiO_2 7	SiO_2 8	SiO_2 9	SiO_2 10	Na/K 11	Na/K 12	Na/K 13	Na/K 14	Na/K 15
1	K-1 well	92	190	176	170	164	141	156	166	186	176	163	210	244	216	232	249
2	K-2 well	94	215	196	200	190	167	178	195	213	196	189	216	249	221	236	253
3	K-5 well	83	175	164	154	148	126	143	149	170	164	148	290	306	290	285	303
4	K-11 well	104	188	175	168	161	139	154	163	184	174	161	209	243	215	231	248
5	K-15 well	115	141	136	115	113	¤	115	115	136	138	116	¤	¤	236	246	263
10	Caferbey, deep well	155	185	172	164	158	¤	¤	160	180	171	157	191	229	198	218	235
12	SartÇamur, spring	52	142	136	115	113	91	113	111	133	135	113	217	250	222	236	253

The ternary plot of Na/1000-K/100-$Mg^{0.5}$ proposed by Giggenbach (1988) for this study is illustrated in Figure 7. The samples 1, 2, 3 and 5 fall into the field "partially equilibrated waters" and The sample 4, Caferbey-1 deep well and Sart-Çamur Spa (samples 10 and 12) fall into the border of the immature and partially equilibrated fields. This combining geothermometer diagram shows that the reservoir temperatures of the Salihli geothermal systems vary between 200°C.

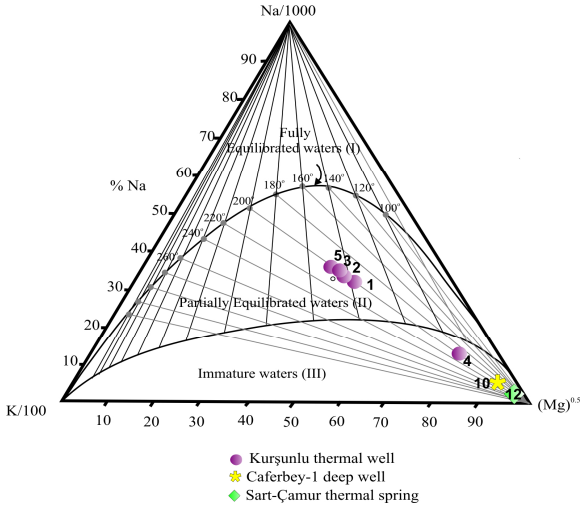


Figure 7: The Na-K-Mg diagram (Giggenbach, 1988) for waters in Salihli geothermal fields (Sample numbers are the same as in Table 1).

4. TRACER TEST

Tracer study is an important technique for reservoir characterization. To obtain inflow performance characteristics for the Kursunlu geothermal fields production wells we used Na-Fluorescein dye. Information of production and reinjection wells in the Kursunlu geothermal fields is given Table 5. At the beginning of the tracer test, 1500 g uranine was pumped into K-1 reinjection well. Uranine consantrations in the production wells (K-2, K-5, K-11) were measured during 15 days. The test data-the tracer return curves are shown in Figure 8. These plots illustrate the information contained in Table 6. In this table, the peak arrival times varied between 21 and 56.5 hours. To describe the velocities varied between 2.14 and 12.11 m/s.

Table 5: Information of production and reinjection wells in the Kursunlu geothermal field.

Well No	Depth (m)	Discharge (l/s)	Temperature °C
K-1 reenj.	40	60	90
K-2	73	16	94
K-5	115	45	83
K-11	114	40	95
K-17 reenj.	190	60	104

Table 6: Computed parameters according to first tracer curves. "pat", peak arrival time; "u", fluid velocity.

Well No	Distance to K-1 (m)	Path (hour)	u m/hour
K-2	120.9	56.5	2.14
K-5	96	30	9.87
K-11	254.3	21	12.11

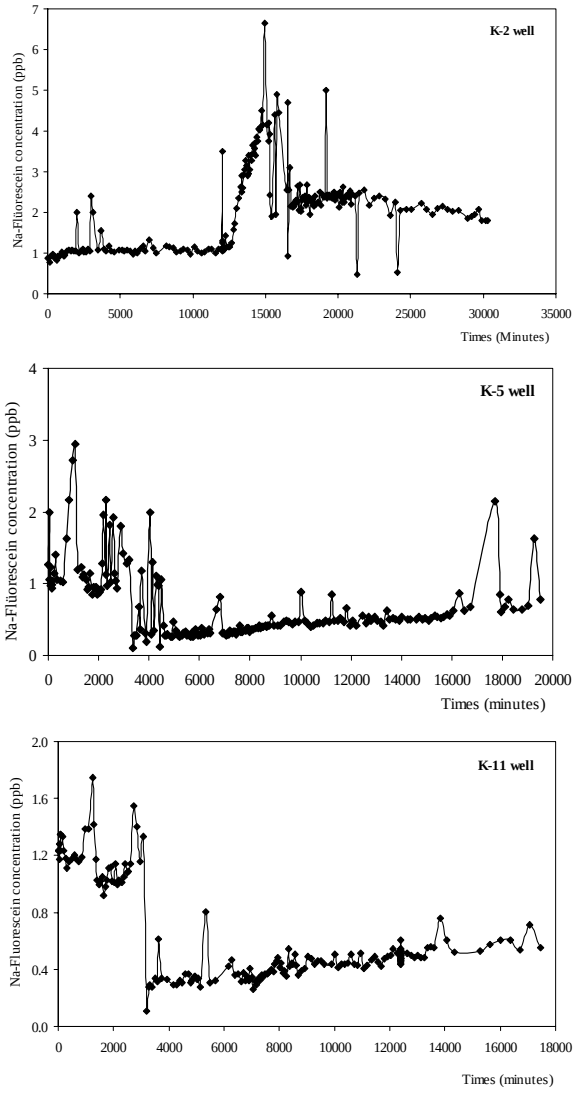


Figure 8: Measured tracer curves for Kursunlu production wells K-2, K-5 and K-11 (reinjection well: K-1)

Table 7: Computed parameters according to second tracer curves. "Pat", peak arrival time; "u", fluid velocity.

Well No	Distance to K-17 (m)	Path (hour)	u m/hour
K-2	363.2	41.5	8.75
K-5	445.9	97	4.60
K-11	330.1	22	15.00
K-15	233.5	13	17.96

Second tracer test were carried out in K-17 reenjection well. 750 g Na-Fluorescein was pumped in this well. Figure 9 have been showed plots of uranine concentrations from the production wells (K-2, K-5, K-11 and K-15) during 10 days. These plots illustrate the information contained in Table 7. In this tracer test, the peak arrival times varied between 13 and 41.5 h and calculated velocities are varied between 4.60 and 17.96 m/h. Throughout each tracer tests, flow rates in the production wells (K-2, K-5, K-11 and K-15) and reinjection wells (K-1 and K-17) were keep constant. As a result, two tracer tests showed that geothermal reservoir of Kursunlu geothermal field has very quite permeable fractures. Thus, this case can be a risk for cooling in the production wells.

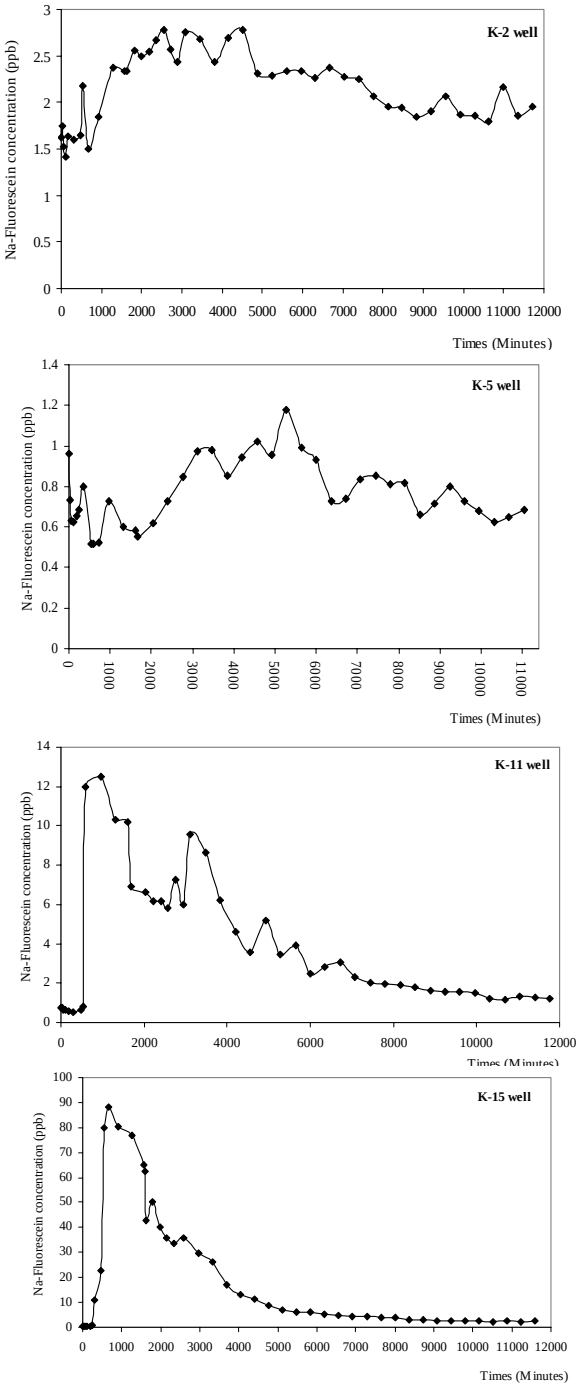


Figure 9: Measured tracer curves for Kursunlu production wells K-2, K-5, K-11 and K-15 (reinjection well: K-17)

5. CONCLUSIONS

The study area is located in southern rims of the Gediz Graben in Western Anatolia region in Turkey. In this study, geothermal and hydrochemical characteristics of thermal waters in the Salihli geothermal fields are described. The basement of the study area consists of Menderes Massif rocks

that are made up of high to low-grade metamorphics (gneiss, mica schists, phyllites, quartz schists, marbles). Neogene terrestrial sediments overlie the Menderes Massif rocks with a low-angle normal fault. The Quaternary alluvium, which is made up of unconsoli-dated granular sediments, is the youngest unit. Neogene terrestrial sediments, which are mainly made up of alluvium fan deposits (pebbles, pebbly sandstones, claystone-mudstones, interbedded conglomerate, clay-stones, siltstones, conglomerates comprising sandstone intercalations and limestone. The permeability within the Menderes Massif rocks is highly variable. The carbonates (marbles and dolomitic marbles) of the Menderes Massif rocks are highly fractured and karstified and act as an aquifer for both cold ground waters and thermomineral waters depending on the location. Gneiss and quartz-schist units of the Menderes Massif act as aquifers form fractured rock aquifers. Schists and phyllites have relatively low permeability. The Neogene terrestrial sediments, which are made up of alluvial fan deposits including poorly cemented clayey levels, have very low permeability as a whole and may locally act as cap rocks for the geothermal systems. Clayey levels of the Neogene sediments occur as impermeable barrier rocks. From sandy to gravely and limestone levels of this Neogene unit contain minor aquifers. Alluvium is the most important and favorable unit for cold ground water production.

Salihli geothermal fields geographically divided into four main groups; Kursunlu, Caferbey, Ufuruk and Sart-Çamur geothermal fields. The outlet temperatures and discharge quantities of Sart-Çamur Spa thermal waters are 52 °C and 5 l/s, respectively. A deep geothermal well with the 1189 m depth was drilled by MTA (General Directorate of Mineral Research and Exploration) in Caferbey Geothermal field. Downhole temperature and discharge rates of this well were recorded as 155ºC and 2 l/s, respectively. The Ufuruk has mineral spring which contains CO_2 and H_2S gases intensely. Outlet temperature is 31°C with low discharge approximately 0.4 l/s. Kursunlu Geothermal field is one of the most important areas in Turkey due to district heating. Total discharges of production wells are 160 l/s in year. Production wells temperatures are various between 83 and 112ºC and discharges from 40 to 80 l/s in the Kursunlu geothermal field.

The circulation of thermomineral waters in the Salihli geothermal areas is closely related to major fault and fracture zones. Meteoric waters descending through the discontinuities are heated in the aquifer rocks, and move up to the surface along the faults. Isotopic data (^{18}O and ^{2}H) suggests that thermomineral waters in Salihli geothermal areas are of meteoric origins. Kursunlu thermal waters showed deviations from the meteoric water lines. This $\delta^{18}O$ shift is caused by water- rock interaction.

The sampled waters can be subdivided into two main groups. The first group Kursunlu and Caferbey includes Na-HCO_3 type water belonging to Caferbey-1 deep well (155°C). The second group Sart-Çamur Spa includes Na-Ca-HCO_3 water type and can be classified as hardness of carbonate is more than 50%. The decrease in Ca^{+2} and/or Mg^{+2} and the increase in Na^{+} in the thermal waters can be explained by ion exchange. Exchange sites must have been clays of Neogene sediments and/or Menderes Massif schists. The close positive linear correlation between Li, As, B, HCO_3, Cl, Na, K and some of the other ions corroborates that geochemical processes for thermal waters are combination effects of the dissolution of carbonates and silicates and the mixing phenomenon and ion exchange reactions. The chemical analyses revealed that the concentrations of As, B (for all thermal samples), Na (most of the thermal waters exceptional with samples 12) and K concentrations exceed the Turkish drinking water limits (TS-266, 2005 and WHO, 2004). This can cause environmental problems for ground and surface waters and soils in the study area. Thermal waters can not be used for any drinking purposes because of very dangerous for human healthy.

According to silica geothemometers, the reservoir temperatures of Kursunlu, Caferbey and Sart-Çamur geothermal fields was calculated between 113–213^{o}C, 157-180^{o}C and 91-142^{o}C, respectively. Comparing the measured outlet (aquifer or spring) temperatures, it is opinion that the Na/K geothermometers are mostly higher than the silica geothermometers.

To obtain inflow performance characteristics for theKursunlu geothermal fields production wells we used Na-Fluorescein dye. As a result, two tracer tests showed that geothermal reservoir of Kursunlu geothermal field has very quite permeable fractures. Thus, this case can be a risk for cooling in the production wells.

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