Reservoirs and Reinjection of the Thermal Waters of Kızıldere, Western Anatolia, Turkey

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ABSTRACT

Turkey has high potential for the exploitation of geothermal energy. The thermal waters in Turkey are distributed along the North Anatolian Fault Zone (NAFZ), East Anatolian Fault Zone and in Western Anatolia intensively. The Thermal waters in western Anatolia are situated in the rift zones of the Gediz, the Kütük Menderes and the Büyük Menderes within the Menderes Massif. The thermal waters of Kızıldere are of meteoric origin. In the area, Groundwaters of meteoric origin percolated into the fault zones to a depth of up to 5 km in secondary rocks, in this case the Sakız and Iğdecik formations. These rocks are present as a reaction zone in the roof area of a magma chamber, situated at a probable depth of 2-4 km. Here, the meteoric waters are heated by the cooling magma and subsequently ascend to the surface of their low densities caused by convection calls. In the thermal field of Kızıldere, the basement is comprised by Paleozoic metamorphic rocks that consist of gneiss, schist, and Iğdecik formation alternating with quartzites, mica schists, and marbles. The basement rocks are overlain by Pliocene sediments of fluvial and lacustrine characters which consist of (i) the 200 m thick Kızılburun formation, (ii) the Sakız formation with a thickness ranging from 100 to 250 m, (iii) the Kolonkaya formation ranging in thickness from 350 to 500 m, and (iv) the 500 m thick Tosunlar formation. At the surface, the thermal field of Kızıldere is recognized by a distinct color change in the rocks. The rocks are intensively altered through fluid-rock interaction, and marked by silicic, carbonatized and hematitized alteration zones.

The thermal waters of Kızıldere are of meteoric origin. In the area, Groundwaters of meteoric origin percolated into the fault zones to a depth of up to 5 km in secondary rocks, in this case the Sakız and Iğdecik formations. These rocks are present as a reaction zone in the roof area of a magma chamber, situated at a probable depth of 2-4 km. Here, the meteoric waters are heated by the cooling magma and subsequently ascend to the surface of their low densities caused by convection calls. In the thermal field of Kızıldere, the basement is comprised by Paleozoic metamorphic rocks that consist of gneiss, schist, and Iğdecik formation alternating with quartzites, mica schists, and marbles. The basement rocks are overlain by Pliocene sediments of fluvial and lacustrine characters which consist of (i) the 200 m thick Kızılburun formation, (ii) the Sakız formation with a thickness ranging from 100 to 250 m, (iii) the Kolonkaya formation ranging in thickness from 350 to 500 m, and (iv) the 500 m thick Tosunlar formation. At the surface, the thermal field of Kızıldere is recognized by a distinct color change in the rocks. The rocks are intensively altered through fluid-rock interaction, and marked by silicic, carbonatized and hematitized alteration zones.

The thermal waters of Kızıldere are associated with NE-SW and NW-SE oriented faults, representing a compressional event that followed extensional formation of the rift zone. In the thermal field of Kızıldere, the basement is comprised by Paleozoic metamorphic rocks that consist of gneiss, schist, and Iğdecik formation alternating with quartzites, mica schists, and marbles. The basement rocks are overlain by Pliocene sediments of fluvial and lacustrine characters which consist of (i) the 200 m thick Kızılburun formation, (ii) the Sakız formation with a thickness ranging from 100 to 250 m, (iii) the Kolonkaya formation ranging in thickness from 350 to 500 m, and (iv) the 500 m thick Tosunlar formation. At the surface, the thermal field of Kızıldere is recognized by a distinct color change in the rocks. The rocks are intensively altered through fluid-rock interaction, and marked by silicic, carbonatized and hematitized alteration zones.

The spacial development of the reservoir characteristic is understood as unfavorable pre-conditions for a reinjection. It seems to depict, that total inorganic carbon in cooler margins of this geothermal system increases clearly. Furthermore, it is intelligibly, because the solubility of CO₂ rises with decreasing temperature. The acidification of pH value in the margins of the system effectuates a clearly increase of saturation concentration of Ca²⁺, as long as the reservoir water could be saturated with calcite before. These facts create problems for a reinjection. During silica scalings in reinjection system main problems consistuate with silica scalings occur in the reinjection reservoir clearly which brings the proses to a standstill for a short term. An approach of the injection point to the production zone may reduces this main problem indeed, but it is to approve of thermic reasons. If inhibitors will be foregone, the one of the solutions are as follows: (i) the reinjection of HCl or better CO₂ for calibration of pH values at what a high expenditure must be operated against buffer capacity or (ii) drilling of a deeper injection well, in which the water is undersaturated due to calcite in enough amount. Under these considerations, the waste waters in Kızıldere are reinjected into the reservoir.

1. INTRODUCTION

Turkey has very high potential for the exploitation of geothermal energy. The tectonic position of the eastern Mediterranean area between the African and Eurasian plates is controlled by the Anatolian and Aegean microplates. The tectonic development results in the uplift of the Menders Massif showing a dome shaped structure due to compressional tectonic features from Oligocene to Middle Miocene (Özgür, 1998). From Early to Middle Miocene, the continental rift zones of the Büyük Menderes, Kütük Menderes and Gediz were formed by extensional tectonic features, which strike E-W generally and are represented by a great number of thermal waters, epithermal mineralizations and volcanic rocks of Middle Miocene to recent. The thermal waters and epithermal mineralizations are related to faults which strike preferentially NW-SE and NE-SW and locate diagonal to general strike of the rift zones within the Menders Massif. These faults are probably generated by compressional tectonic stress, which leads to the deformation of the uplift between two extensional rift zones.

The rift zone of the Büyük Menderes is marked by a large number of thermal waters and geothermal power plants. Therefore, the Kızıldere thermal field and environs with a geothermal power plant up to 100 MW were selected for study (Fig. 1). The purpose of this paper is (i) to present hydrogeological, hydrogeochemical and isotope geochemical features of the thermal waters in Kızıldere, (ii) to describe the reservoirs and to discuss the reinjection conditions of the thermal waters into reservoirs in the same area.
2. GEOLOGICAL SETTING

The thermal field of Kızıldere and environs consists of Paleozoic metamorphic rocks and Tertiary to Quaternary Sediments (Özgür, 1998). The metamorphic rocks are of gneisses, mica schists and İğdecik formation composed of mica schists, quartzites and marbles. The gneisses are located in NW part of the investigated area and show an immediately change with high metamorphic mica schists. The tourmaline content in gneisses is remarkable which plays together with biotites an important role for high boron contents in thermal waters. The mica schists overlie the gneisses and are considered as garnet-muskovite-biotite-schist. The İğdecik formation, which forms the last upper sequence in the thermal field of Kızıldere, consists of an alternate beddine of mica schists, quartzites and marbles and shows light metamorphic features. It is traversed by ruptures and fissures and forms the second reservoir with a temperature up to 240 °C. The Pliocene sediments are of continental lacustrine and overlie metamorphic basement. The sedimentation inserted in Late Miocene and continues up today. These sediments can be divided stratigraphically as follows (Fig. 2):

1. The Kızılburun formation consists of basic conglomerates, which is made up of good rounded gravels in metamorphic origin, clay stones, fine-graded sandstones and marls. This indicates a total thickness of 400 m and forms in the field a morphological monad lock due to high degree of consolidation. Because of its clay contents, the Kızılburun formation forms a ceiling of an aquiferous layer.

2. The Sazak formation stands particularly in contrast to other sediment formations due to its distinctly high carbonate contents. It consists of limestones predominantly which is more clayey and sandy in dependence upon facies. Moreover, a little amount of marls and sandstones can be compared additionally. The limestones in the Sazak formation is ostracods-, gastropods- and lamellibranchs-bearing. The total thickness of the Sazak formation is varying between 150 and 400 m. Tectonically, this formation is the hardest in geothermal field due to hydrothermal silification and reacts brittle and jointed outermost. This is a reason for the accumulation of block debriss in valleys in which the tectonical and physical erosion is faster than the chemical. The Sazak formation is strong fractured, porous to pitted and thereby an excellent aquifer. Therefore, it forms the first reservoir in the field of Kızıldere with a temperature of 200 °C. Due to its particular features, the Sazak formation as a thermal water reservoir has been located in the center of the continental rift zone of the Büyük Menderes in a depth of 800 m by gravimetric and geoelectric methods (Guidi et al., 1990).

3. The Kolonkaya formation is an alternation of sandstones, clay stones and clayey limestones. This has a thickness of 500 m and is gastropods- and lamellibranchs-bearing. It is distinguished by a local hydrothermal alteration of silification ± hematitization at the outlets of thermal waters and steams.

4. As a youngest, Pliocene to Plio-Quaternary sediment formation, the Tosunlar formation in the thermal field of Kızıldere shows an insignificant degree of consolidation, differs from the Kolonkaya formation scarcely and forms an alternation of sandstones, gravel stones, fine-graded sandy and clayey marls and limestones. It changes into Quaternary alluvium and is cultivated partly. This has a thickness of 500 m.

5. In Middle Miocene, the continental rift zone of the Büyük Menderes forms, which shows a general strike of E-W direction. Tectonically, the thermal waters in Kızıldere and environs are associated with the faults in NW-SE or NE-SW directions which are located diagonal to general strike. These subsequent faults can be generated by a compression situation, which leads to a deformation of two horst areas lying between two extension rifts. The rift zone of the Büyük Menderes is associated with Thermal waters in Kızıldere and other localities and volcanic rocks in Denizli, Söke und Seçük. The volcanic rocks in Denizli show an Upper Pliocene age, during the volcanic rocks of Kula in the rift zone of the Gediz have an age varying from 7.5 Ma to 20,000a (Ercan et al., 1992).
3. HYDROGEOLOGICAL, HYDROGEOCHEMICAL AND ISOTOPE GEOCHEMICAL FEATURES

3.1 Hydrogeological features

The groundwater conditions in drainage area of thermal waters of Kızıldere can be reconstructed by morphological criterious and proof of analogy. The ground water flows northwards at the northern side of the rift zone of the Büyük Menderes within the Buldan Horst, where the thermal waters are supplied immediately (Fig. 2). The distance from the watershed to the thermal waters is about 10 km. Consequently, the drainage area occupies an area from 100 to 150 square kilometer. With an annual precipitation of 430 mm and average annual temperature of 17.6 °C, the region of Kızıldere has semiarid climatic conditions. A great part of the precipitation takes place in the winter months from December to March, during aridity is predominant in the remainder of the time. The time of aridity leads to a deficit of groundwater; therefore, the surface waters play a secondary role for the feeding of thermal waters only. For the discharge of thermal waters by channels, a discharge rate of 8.1 to 8.5 \( \times 10^6 \) m\(^3\)/a has been measured. The river of the Büyük Menderes is a watercourse which springs as karst spring at Dinar near Isparta, flows past by Sarayköy, Aydın and Söke and leads into Aegean Sea at Akköy. The discharge rate of river is 15-20 m\(^3\)/s in winter and 2 m\(^3\)/s in summer.

3.2 Hydrogeochemical features

During the present study, the outflow of 20 thermal springs, 12 drill holes, 16 groundwater springs were sampled in different seasons from 1992 up to now. Additionally, we have collected about two hundred rock samples (Özgür, 1998). Generally, the thermal waters of Kızıldere can be classified as Na\(^+(\text{SO}_4\text{-HCO}_3\text{)}\) type (Fig. 3). In the drainage area of Kızıldere, the thermal waters of Kızıldere, Tekkehamam and Babacık can be classified as Na\(^+(\text{SO}_4\text{-HCO}_3\text{)}\) type, during the thermal waters of Pamukkale and Karahayt show Ca\(^2+\)-Mg\(^2+\)-HCO\(_3\) type exchange waters (Özgür, 1998). The origin of Na\(^+\) in the thermal waters is linked to metamorphic rocks in substratum, while carbonate rocks in the reservoir form the origin for Ca\(^2+\) and Mg\(^2+\).

The high-temperature thermal waters of Kızıldere demonstrate TDS values from 5000 to 5500 mg/l and high mineralization rate (Özgür, 1998). Before the separator, the pH values of these waters range from 6 to 7, which correspond with the pH values of natural thermal springs in the environs. The HS\(^-\) ions in Babacık show values up to 5 mg/l. In comparison, the thermal waters of Kızıldere show HS\(^-\) values below 0.02 mg/l. For the sulfur system in this aquatic environment, the following reactions are demonstrated (Giese, 1997; Özgür, 1998):

\[
\begin{align*}
\text{H}_2\text{S} + 4\text{H}_2\text{O} & \Rightarrow \text{H}_2\text{SO}_4 + 4\text{H}_2 \\
\text{SO}_2 + 4\text{H}_2\text{O} & \Rightarrow 3\text{H}_2\text{SO}_4 + \text{H}_2\text{S}
\end{align*}
\]

It means, that magmatic sulfur promotes as a source for H\(_2\)S, H\(_2\) and SO\(_4^{2-}\) (Hattori and Cameron, 1986; Özgür, 1998). The entry in sulfur compound can be assimilated and transported to the surface which could be observed in reinjection wells in Tekkehamam in depth of 2000 m and in Kızıldere in depth of 2261 m:

\[
\text{FeS}_2 + 2\text{H}_2\text{O} \Rightarrow \text{FeOOH}^+ + \text{H}_2\text{S} + \text{HS}^-
\]

HS\(^-\) or H\(_2\)S ions in thermal waters, which are either magmatic origin or can be dissolved from sulfides by weathering, can be oxidized and ascend to the surface and set sulfur free:

\[
2\text{H}_2\text{S} + \text{O}_2 \Rightarrow 2\text{H}_2\text{O} + 2\text{S}
\]
In the carbonate-bearing sedimentites, which are associated with thermal springs immediately, gypsum efflorescences could be observed. The formation of gypsum stand in contrast to carbonatization thereby.

$$2\text{CaCO}_3 + \text{HCO}_3^- + 2\text{H}^+ + \text{HS}^- + 4\text{O}_2 \Rightarrow 2\text{CaSO}_4 + 3\text{H}_2\text{O} + 3\text{CO}_2$$

It indicates thereby, that the sulfur system carries the principal responsibility; thereby, the existence of water is assumed.

![Diagram](attachment:image.png)

**Figure 3.** Geothermal waters of the thermal fields of Kızıldere, Bayındır and Salihli within the Menderes Massif.

In connection with nitrogen spezies, the following formula is valid.

$$3\text{H}_2 + \text{N}_2 \Rightarrow 2\text{NH}_3$$

The existence of traces of CO and COS can be explained as follows:

$$\text{CO}_2 + \text{H}_2\text{S} \Rightarrow \text{COS} + \text{H}_2\text{O}$$

$$\text{CO}_2 + \text{H}_2 \Rightarrow \text{CO} + \text{H}_2\text{O}$$

Hydrogeochemically, the thermal waters of Kızıldere and environs are distinguished by (i) an enrichment of F\textsuperscript{−}, Si\textsuperscript{4+} and B\textsuperscript{3+}, (ii) an enhancement of trace metals such as As\textsuperscript{3+} and Sb\textsuperscript{3+} and (iii) a depletion of base metals in combination with Fe\textsuperscript{2+} and Mn\textsuperscript{2+} (Özgür, 1998). B\textsuperscript{3+} occurs in the thermal waters with a values of up to 30 mg/l. The origin of enriched B\textsuperscript{3+} can be linked to the solubility product by fluid-rock interaction in the reservoir; thereby, the magmatic origin can not be ruled out completely.

According to tendency, the volatile components of CO\textsubscript{2}, HS\textsuperscript{−} and NH\textsubscript{3} indicate a magmatic input; this could be confirmed by isotope analyses of \textsuperscript{11}B/\textsuperscript{10}B conditionally (Özgür, 2001). In connection with fluid-rock interaction, the boron contents in thermal waters can be leached from mineral phases such as tourmaline and biotite in metamorphic rocks and boron minerals in sedimentary rocks. The experimental leaching tests of different rocks from Kızıldere show, that gneiss and mica schist play an important role as boron source. The thermal waters in Kızıldere and environs represent fluorine contents up to 35 mg/l. On the one hand, these high contents can be led to a magmatic origin as volatile component; on the other hand, the increasing value of fluorine in thermal waters depends upon Ca\textsuperscript{2+} contents, because there must be a corresponding Ca\textsuperscript{2+} offer in the environment in order to precipitate a corresponding amount of F\textsuperscript{−}. Otherwise, fluorine ions remain released, and the fluid is enriched with F\textsuperscript{−}. In depending upon temperature, fluorine and boron show a close correlation in thermal waters of Kızıldere and environs (Özgür, 1998). Accordingly, fluorine and boron show an approximating positive correlation which is probably based on (i) interconnection of thermodynamic control process, (ii) applicability of boron as tracer and (ii) substitution of both elements in boron-bearing minerals.

The Thermal waters of Kızıldere represent average Si\textsuperscript{4+} contents of 115 mg/l which have been leaked from the silicates in reservoir at a temperature of about 200 °C by fluid-rock interactions conditionally. Solubility equilibrium of Si depends upon the modification of amorphous silica, which allow high concentrations. The separation, where the thermal waters are separated as steam and fluid phase, gives rises to a 25 percent water loss in terms of water steam, a CO\textsubscript{2} leakage and a Si enrichment in the fluid on 150 mg/l. Thereby, the CO\textsubscript{2} leakage causes a pH increasing on 9 at a temperature of 100 °C. At a temperature of 45 °C, the thermal waters in drainage basins represent average Si contents of 150 mg/l and a pH value of 9. The thermal waste waters of geothermal power plant of Kızıldere should be reinjected, in order to supply the thermal water reservoir constantly and remove agricultural danger for citrus fruits in the rift zone des Büyük Menderes in view of environmental aspects. The precipitation of Si as precipitates represents a danger potential for the reinjection system as documented by thermodynamic and kinetic results (Giese, 1997). Thereby, the Si precipitates occur in the reinjection well in depending upon time with regard to ion strength of pH values and temperature (below 100 °C).
The thermal waters in Kızıldere represent As values up to 1.08 mg/l and Sb values up to 0.21 mg/l (Özgür, 1998). The both elements of As and Sb in thermal waters show a close correlation in depending upon temperature which is case in the rocks as well. The rocks of the thermal field of Kızıldere have Au contents up to 6 ppb and Sb contents ranging from 194 ppb to 1373 ppb. The cap rocks which are close connected with thermal water reservoirs represent high Ag contents of 1.21 ppm; thereby, these high Ag contents in the metamorphic rocks are represented by a high background value of 0.5 ppm. It shows, that the metamorphic rocks form a formerly source for Au and Ag. The carbonate and silicate precipitates show Au contents up to 3.5 ppm and Ag contents up to 194 ppb. The base metals in the thermal waters show distinct low contents as expected.

3.3 Isotope geochemical features

The thermal waters of Kızıldere can be classified as meteoric water due to isotope ratio of $\delta^{18}$O and $\delta^2$H (Fig. 4; Özgür, 2002). The $^3$H contents in investigated thermal waters are attributed to atmospheric and anthropogenic effects. They indicate, that the thermal waters of Bayındır and Salihli can be considered as mixing water. The thermal waters of Kızıldere show scarcely mixing of young groundwaters, because $^3$H contents are below the detection limit. The ratios of $\delta^{13}$C in groundwaters, mixing waters and thermal waters reveal, that the origin of CO$_2$ can be linked to a magmatic activity by a subvolcanism in basement and to reactions with carbonate rocks (Fig. 5). The $\delta^3$He surplus in thermal waters of Kızıldere reveal interactions of these fluids with basic to intermediate still cooling volcanic rocks of mantel and the existence of a subvolcanic intrusion. The CO$_2$ production in connection with carbonate rocks in reservoir dilutes $^{14}$C in thermal waters, by which the age determination with $^{14}$C is impossible almost.

Figure 4. Plot of $\delta^2$H versus $\delta^{18}$O of thermal waters of Kızıldere. For comparison, the contents of $\delta^2$H and $\delta^{18}$O from the thermal waters of Bayındır and Salihli are recorded.

Figure 5. $\delta^{13}$C ratios in thermal waters of Kızıldere and environs within the Menderes Massif. For comparison, $\delta^{13}$C contents of Bayındır, Seferihisar und Salihli were registered.
4. RESERVOIRS

The thermal waters of Kızıldere show two different reservoirs, namely the first reservoir of Sazak formation in depth of about 400 m and the second reservoir of İğdecik formation in depth from 1000 to 2500 m.

4.1 Shallow reservoir

The Sazak formation stands in particular contrast to other sediment formations due to its distinctly high carbonate contents (Fig. 2 and 6). It consists predominantly of limestones, which are more clayey and sandy depending upon the facies. Moreover, a small amount of marls and sandstones are also present. The limestones in the Sazak formation are ostracod-, gastropod- and lamellibranch-bearing. The total thickness of the Sazak formation varies between 150 and 400 m. Tectonically, this formation is the hardest in the geothermal field due to hydrothermal silicification and reacts brittlely, forming the outermost joints. This is a reason for the accumulation of block debris in valleys in which the tectonic and physical erosion is faster than the chemical. The Sazak formation is strongly fractured, porous to pitted, and is thereby an excellent aquifer. Therefore, it forms the first reservoir in the field of Kızıldere with a temperature of 200 °C. Due to its particular features, the Sazak formation has been located as a thermal water reservoir in the center of the continental rift zone of the Büyük Menderes, at a depth of 800 m by gravimetric and geoelectric methods (Guidi et al., 1990).

Figure 6. Schematic depicting the rock sequence in cross-section of production and exploration wells in thermal field of Kızıldere and environs

4.2 Deep reservoir

The thermal field of Kızıldere and environs consists of Paleozoic metamorphic rocks and Tertiary to Quaternary sediments (Özgür, 1998). The metamorphic rocks are composed ofgneisses, mica schists and the İğdecik formation, which is composed of mica schists, quartzites and marbles. The gneisses are located in the NW part of the investigated area and show an immediate change with highgrade metamorphic mica schists. The tourmaline content in the gneisses is remarkable, and together with the biotites plays an important role for high boron contents in thermal waters. The mica schists overlie the gneisses and are considered to be a garnet-muscovite-biotite-schist assemblage. The İğdecik formation, which forms the last upper sequence in the thermal field of Kızıldere, consists of alternating beds of mica schists, quartzites and marbles and shows light metamorphic features. It is traversed by ruptures and fissures and forms the second deep reservoir with a temperature of 216 °C (Fig. 2 and 6; Şimşek, 1985). The Pliocene sediments are of continental lacustrine origin and overlie metamorphic basement.

5. REINJECTION OF THE THERMAL WATERS OF KIZILDERE

A lowering of the pressure of thermal waters in the reservoir can be established due extremely production; it lies on the lack of reinjection well clearly. Moreover, there are hits for the shift of points of steam outlets from higher areas to lower located areas today. This shows disappear of the old points of steam outlets. It shows that a distinct lateral movement of the fields of steam outlets to catchment area of the geothermal power plant took place. The lowering of the steam outlet level of about 100 up to 150 m is a decrease of pressure of about 15 bar. The surface temperatures show 96-100 °C in Kızıldere, 62-88°C in Tekkehamam and Babacık, 37-55 °C in Pamukkale and Karahayt and 40-54 °C in Yenice I and II, during Na/K-thermometer (Fournier, 1979) give reservoir temperatures of 220-248 °C in Kızıldere, 211-234 °C in Tekkehamam and Babacık, 260-313 °C in Pamukkale and Karahayt and 251-288 °C in Yenice I and II.

The spacial development of the reservoir characteristic is understood as unfavorable pre-conditions for a reinjection. It seems to depict, that total inorganic carbon in cooler margins of this geothermal system increases clearly. Furthermore, it is intelligibly, because the solubility of CO₂ rises with decreasing temperature. The acidification of pH value in the margins of the system effectuates a clearly increase of saturation concentration of Ca²⁺, as long as the reservoir water could be saturated with calcite before. These facts create problems for a reinjection clearly. During silica precipitations in reinjection system constitute main problems, carbonate precipitations occur in the reinjection reservoir clearly which brings the process to a standstill for a short term. An approach of the injection point to the production zone may reduces this main problem indeed, but it is to approve of thermic
reasons. If inhibitors will be foregone, the ones of the solutions are as follows: (i) the reinjection of HCl or better CO₂ for calibration of pH values at what a high expenditure must be operated against buffer capacity or (ii) drilling of a deeper injection well, in which the water is undersaturated due to calcite in enough amount. Under these certain considerations, the waste waters in Kızıldere can be reinjected into the reservoir.

6. DISCUSSION

In thermal field of Kızıldere and environs, groundwater flow takes place in drainage area from higher spheres around the watershed in horst to the lower located rift zones where the groundwaters find the watercourse ultimately (Fig. 7).

Figure 7. Simplified presentation of geothermal model of the thermal waters of Kızıldere in the rift zones of the Büyük Menderes within the Menderes Massif.

These meteoric waters in the drainage area percolate at fault zones and permeable clastic sediments into the reaction zone of the roof area of a magma chamber situated in a probable depth of up to 5 km where meteoric fluids are heated by the cooling magmatic melt and ascend to the surface due to their lower density caused by convection cells. The volatile components of CO₂, SO₂, HCl, H₂S, HB, HF, and He out of the magma reach the geothermal water reservoir where equilibrium between altered rocks, gas components, and fluids persists. Thus, the geothermal waters ascend in the tectonical zones of weakness at the continental rift zones of the Menderes Massif in terms of hot springs, gases, and steam. These fluids are characterized by high to medium CO₂, H₂S and NaCl contents. It is very important, that the fluids indicate a reduced pH-neutral environment after equilibrium adjustment with hard rocks in the reaction zone, namely in the roof area of magma chamber (Giggenbach, 1992). In superficial areas, i.e. beneath a depth of 550 m in Kızıldere with a pressure of 50 to 100 bar, a temperature of 200 to 220 °C and a pH value of lesser than 5,0, it comes to boiling by decrease of pressure; thereby, CO₂ and H₂S rich steams are splitted off from thermal waters which can lead to formation of sulfate rich waters after condensation and surface oxidation. The thermal waters are exploited for various uses consequently, i.e. for geothermal energy, balneology, and green houses.

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In summary, Fig. 8 shows the development of saturation indexes of main scaling minerals of calcite aragonite and silica for heat exchanger and reinjection system in the area of Kızıldere and environs (Giese, 1997),
Figure 8. Development of saturation indexes of main scaling minerals calcite, aragonite and silica in heat exchanger and reinjection system.

The spatial development of the reservoir characteristic is understood as unfavorable pre-conditions for a reinjection. It seems to depict, that total inorganic carbon in cooler margins of this geothermal system increases clearly. Furthermore, it is intelligibly, because the solubility of CO$_2$ rises with decreasing temperature. The acidification of pH value in the margins of the system effectuates a clearly increase of saturation concentration of Ca$^{2+}$, as long as the reservoir water could be saturated with calcite before. These facts create problems for a reinjection clearly. During silica scalings in reinjection system main problems constitute, carbonate scalings occur in the reinjection reservoir clearly which brings the proceed to a standstill for a short term. An approach of the injection point to the production zone may reduces this main problem indeed, but it is to approve of thermic reasons. If inhibitors will be foregone, the one of the solutions are as follows: (i) the reinjection of HCl or better CO$_2$ for calibration of pH values at what a high expenditure must be operated against buffer capacity or (ii) drilling of a deeper injection well, in which the water is undersaturated due to calcite in enough amount. Under these considerations, the waste waters in Kızıldere are reinjected into the reservoir.

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