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GEOCHEMISTRY OF FLUIDS IN NEW WELLS OF KIZILDERE GEOTHERMAL FIELD IN TURKEY

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ABSTRACT

In Kızıldere Geothermal Field, there were 25 drilled wells until 2009, 9 of which are currently being produced for 15 MWe GPP now.

After the evaluation of geological and geophysical exploration studies conducted at the field, new well locations were determined for the planned new power plant. The drilling work commenced in November 2009 and as of January 2011, 11 wells are completed. In this regard, geochemical sampling, tests and measurements are performed at two phase fluids: Chemical, stable isotope samplings are realized for brine, while gas samples are taken for NCG and 13C-CO2 isotope and steam condensate sampling are conducted for gas/steam phase. For the determination of Gas/Gas+Steam ratio in-situ, measurements are performed at steam phase.

Geochemical characterization of wells mainly depend on different reservoirs in Kızıldere Geothermal Field.

INTRODUCTION

Kızıldere Geothermal Field, which is located in the northeastern part of the Büyük Menderes Graben, is one of the most well-known geothermal fields in the world (Fig.1).

The initial explorations at the field, which were conducted by General Directorate of Mineral Research and Exploration (MTA), lead to the discovery of the first high enthalpy field in Western Anatolia in 1964. Following this discovery, drilling studies were started by MTA (Table.1) in order to generate electricity from the field, Kızıldere Geothermal Power Plant (GPP) was installed by Turkish Electricity Authority (TEK) in 1984 and operated by the state in the period 1984- 2008 (Fig.2).

Following the privatization tender in 2008, Operating License of Kızıldere Geothermal Field and operation rights of the 15 MWe power plant were transferred to Zorlu Energy Group for 30 years. After this transfer, the Group has started to work on both the rehabilitation of existing single flash power plant and the construction of a new power plant that is planned as 60 MWe (Kındap et.al, 2010).

Figure.1 Kızıldere geothermal field and main tectonic lines in Turkey (NAFZ: North Anatolian Fault Zone; EAFZ: East Anatolian Fault Zone and AEZ; Aegean Extension Zone)

Intensive rehabilitation work conducted at the field has improved the performance of the existing 15 MW GPP significantly by means of both an increase and stabilization of the amount of electricity generated (Fig.3). During rehabilitation study inhibitor applications and reinjection studies have started in the field.

During these studies reservoir monitoring studies and tests of new wells continue at Kızıldere Geothermal Field. In this regard, interference between new and old wells are continuously being investigated through reservoir tests and geochemical studies. Geochemical parameters are used for both monitoring the effects of reinjection on existing production wells and to achieve a better understanding of reservoir

conditions and reservoir character of the Kızıldere Geothermal Field.

Table.1Existing wells in Kızıldere Geothermal Field

Well ID	Total depth(m)	T_{mak} (°C)	Current use
KD-1	540	198.3 °C @ 535 m	Abandoned
KD-1A	573.1 (650m)	193 °C @ 403 m	Reinjection*
KD-2	769	173.8 °C @ 650 m	Reinjection*
KD-3	370	158 °C @ 320 m	Abandoned
KD-4	486	172.5 °C @ 486 m	Abandoned
KD-6	851	200.4 °C @ 700 m	Observation
KD-7	667.5	201.7 °C @ 647 m	Observation
KD-8	576.5 (650m)	185 °C @ 540 m	Reinjection*
KD-9	1241 (1635m)	184 °C @ 1500 m	Abandoned
KD-12	404.7	161.5 °C @ 390 m	Abandoned
KD-13	760	201 °C @ 590 m	Production*
KD-14	597	208 °C @ 451 m	Production*
KD-15	510	206 °C @ 445 m	Production*
KD-16	666.5	209 °C @ 450 m	Production*
KD-17	365.2	157 °C @ 272 m	Production*
KD-20	810	204 °C @ 491 m	Production*
KD-21	897.5	205 °C @ 526 m	Production*
KD-22	887.5	201 °C @ 555 m	Production*
KD-111	504.85	164 °C @ 443 m	Abandoned
R-1	2261	242 °C @ 1600 m	Production
R-2	1482.2	204.8 °C @ 1370 m	Reinjection*
R-3	2250	241.1 °C @ 2164 m	Production*

Figure.2 Kızıldere GPP

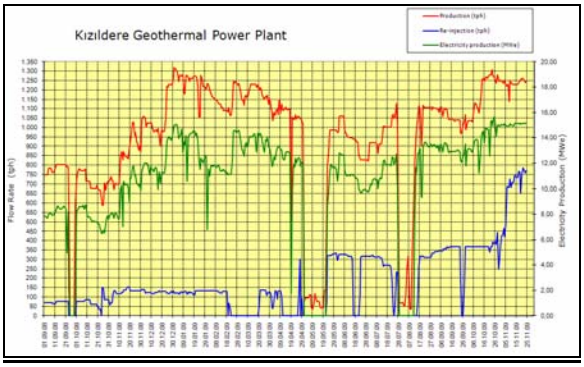

Figure.3 Electricity Production in Kızıldere GPP in 2009

GEOLOGY OF THE KIZILDERE GEOTHERMAL FIELD

Because of the Alpine-Himalayan orogenic belt, Anatolia has tectonically areas which are been along high stress zones such as North Anatolian Fault, East Anatolian Transform Fault and Western Anatolia Extension Zones (Fig.1) (Şengör, Yılmaz 1981, Ketin, 1957).

Western Anatolia has large graben systems because of crustal thinning in the region (Doglioni, 2002). Büyük Menderes Graben, Alaşehir Graben and Simav Graben are the major grabens in Western Anatolia (Fig.1) where the geothermal fields with higher enthalpy such as Kızıldere, Germencik, Salavatlı, Simav, Alaşehir are located (Tut Haklıdır, 2007, 2010).

In Kızıldere Geothermal Field, basement consists of Paleozoic Menderes Massive Metamorphic rocks which are represented by different types of schists, quartzite and marbles (Fig.4). Pliocene and Quaternary sediments rocks cover the metamorphic from bottom to top levels (Şimşek, 1985, Şimşek et. al,, 2009).

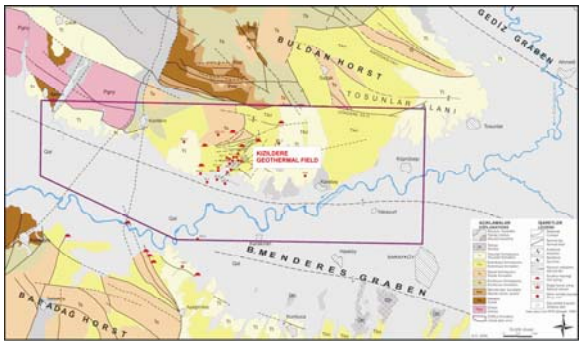

Figure.4 Geology of Kızıldere Geothermal Field (Şimşek et al, 2010)

Main Reservoir Rocks in Kızıldere Geothermal Field

So far, three different reservoirs are discovered in the Kızıldere Geothermal Field. First and second reservoirs mainly depend on limestones and marbles. The third reservoir which lies under the second reservoir mica-schists which have a temperature approximately 40 °C higher than the second reservoir (Şimşek, 2003).

The first reservoir in Kızıldere Geothermal Field Pliocene aged Sazak Formation, which consist of limestone, siltstone, clay stone, marl and lignite is determined as the first reservoir in Kızıldere geothermal field (Şimşek 1985, Kastelli 1971, Taner 1974).

Seven wells were drilled in Sazak Formation, however, none are used as a production. Average temperature of the first reservoir is around 170 °C (Şimşek, et. al, 2009).

The Second Reservoir in Kızıldere Geothermal Field

Paleozoic aged İğdecik Formation of Menderes Metamorphics, which consist of marble-quartize schists, is called as second reservoir in the field (Şimşek, 1985). This part of the reservoir has more porosity and permeability compared to the first reservoir. The reservoir is also 100-300 m thicker than the first reservoir.

Eight wells were drilled in İğdecik Formation and among these wells, KD-13, KD-14, KD-15, KD-16, KD-20, KD-21, KD-22 wells are selected to be the production wells which are currently feeding the existing power plant. KD-6 well was also utilized as a production well till 2010 but currently, it is being used as an observation well Maximum bottom hole temperature observed in the reservoir is 212 °C.

The Third Reservoir in Kızıldere Geothermal Field

Third reservoir is also located within Paleozic aged Menderes Metamorphics (Şimşek et. al, 2010, Şimşek, 2005). According to the well logs, this reservoir lies under the micaschists and it is not easy to observe the characteristics of the reservoir clearly due to the thickness of second reservoir. Meanwhile temperatures at the third reservoir are estimated to be significantly higher (230-245 °C) than second reservoir and geothermometer calculations (250-260 °C) also support these temperature estimations at these depths.

R1 well and new wells (KD-2A, KD-9A, KD-23A, KD-23B, KD-23D, KD-25A) were drilled in deeper part of Menderes Metamorphics in the field.

GEOCHEMISTRY

Methodology

Nine production wells are being used for electricity generation at the current Kızıldere GPP. Seven of these wells are producing geothermal fluid from the shallow reservoir while two wells are drilled in the deep reservoir. In the field, there are also 4 reinjection wells which are being used for reinjection purposes. Average flowrate of these wellsare kept between 1400-1500 tph for feeding the 15 MW GPP. In order to prevent calcium carbonate scaling and to achieve sustainable production, inhibitor injection is being applied since 2009 (Fig.5).

Figure .5 Inhibitor application in R-3 well in Kızıldere GPP

Kızıldere geothermal reservoir is being monitored continuously. Within in the scope of monitoring

work; well head pressures, well head temperature (also separation conditions) and selected geochemical parameters in the production wells are recorded and evaluated periodically. Some geochemical parameters are monitored not only for achieving a better understanding of the possible changes reservoir conditions due to external effects such as reinjection but also for controlling the performance of the inhibitor applications in the wells. These geochemical parameters are; ph, EC, Cl., SiO_2, boron, carbonate forms, total hardness, major anion-cation analyses, stable isotopes ($\delta^{18}O$-δD) for brine phase and noncondensible gas compositions for steam phase including stable isotope and SiO_2, Na^+, Cl^-, analysis for steam condensate. Meanwhile gas/steam ratio measurements are also periodically conducted by utilizing a flowmeter in the field (Fig.6).

In this regard, SiO_2, boron analyses are realized using a spectrophotometer with standards, chlorur and carbonate forms are determined by volumetric methods, total hardness of brine analyzed by EDTA at field laboratory. Other analyses are done at different laboratories located in Turkey or in Italy and USA at different periods.

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Figure.6 Gas/steam ratio measurement in production wells in Kızıldere GPP

There are a few sampling ports on the well heads in the plant. Hence, it is possible to take samples from before and after separator conditions by using the condensers at production wells, however, due to the re-injection, it is not possible to take samples from the weirboxes at wells. During well tests, portable test equipments (silencer and weirbox), mini separator are used for sampling (Fig.7).

Figure.7 Portable test equipments; silencer, sewage and, mini separator; for new wells in Kızıldere geothermal field

Wells tests are conducted after the completion of each drilling operation at the Kızıldere Geothermal Field. These tests are realized at every new well drilled in the field and include production tests, static and dynamic temperature, pressure and interference studies. During well tests geochemical sampling at brine and steam phase are taken and in-situ measurements are also carried out at well heads.

Chemical and Isotope Compositions of Existing Production Wells and New Wells

Locations of existing production, reinjection wells and new wells are shown in Fig.8.

Current production wells are mainly located at a narrow valley at the north of the Kızıldere Geothermal Field. The new wells, on the other hand, are situated at the middle and southern parts of the field. The reservoirs from which these wells produce are different and this difference directly affects their chemical and isotope compositions at different rates.

Figure.8 Location map of the all existing and new wells in Kızıldere geothermal field

Kızıldere geothermal waters are resembled Na-HCO_3 and it is understood that geothermal fluids have interacted with metamorphic rocks for a long time at deep elevations (Fig.9). Beside sodium and bicarbonate ions, remarkable sulphate ions also have been in water phase.

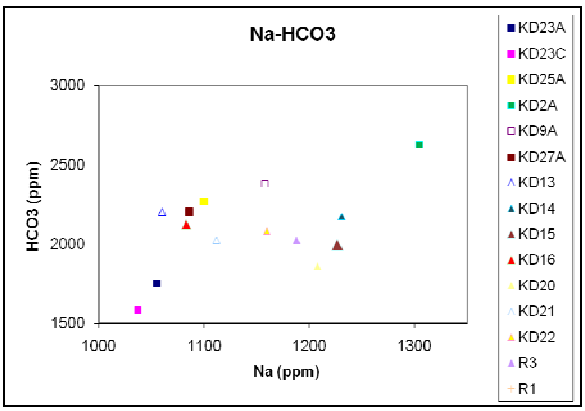

Figure.9 Na ions versus bicarbonate ions in Kızıldere geothermal wells

Silica is a important geochemical parameter for geothermal systems. Average silica concentration is observed as 550 ppm in the production wells which produce from the second reservoir and increased up to 664 ppm at the production wells in the deep reservoir. Silica concentration of new wells changes between 571-683 ppm (Fig.10).

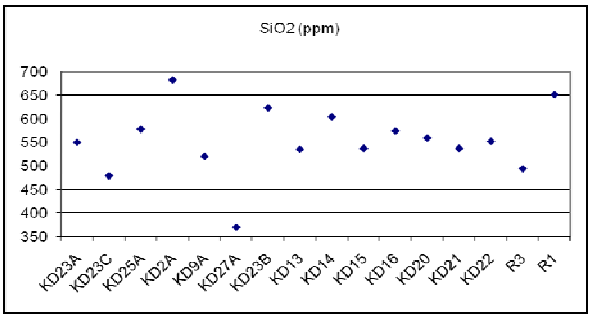

Figure.10 SiO_2 values in Kızıldere geothermal wells

Chlorur is also an important tracer for geothermal systems which reflects reservoir conditions at the surface. Cl^- values change between 92-125 ppm in all wells in the region (Fig.11).

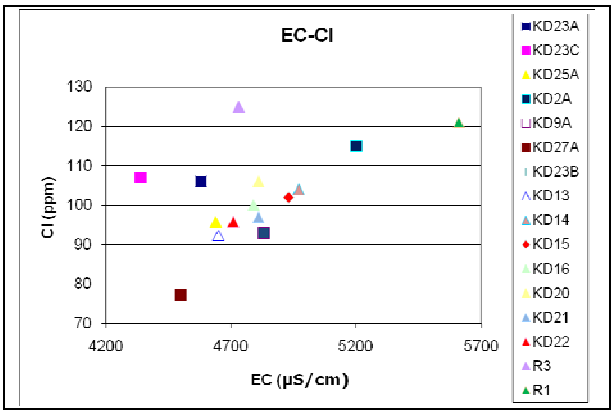

Figure.11 Cl ion- Conductivity Changes in Kızıldere geothermal wells

While boron concentrations change between 25-36 ppm in production wells, these values vary between 9-26 ppm at the new wells, depending on their depth. Arsenic shows similar values at the production and new wells, and the values at the new wells are 0,6-1 ppm higher than the values observed at the current production wells. Florur concentrations vary between 9-21 ppm in all wells (Fig.12). It is observed that reinjection study is a good means to prevent negative effects of especially boron and arsenic at surface.

Conductivity values change 4650-4930 µS/cm at shallow reservoir wells, and reach to 5400 µS/cm at deep reservoir. Conductivity values of new wells change 4580-5200 µS/cm in the field.

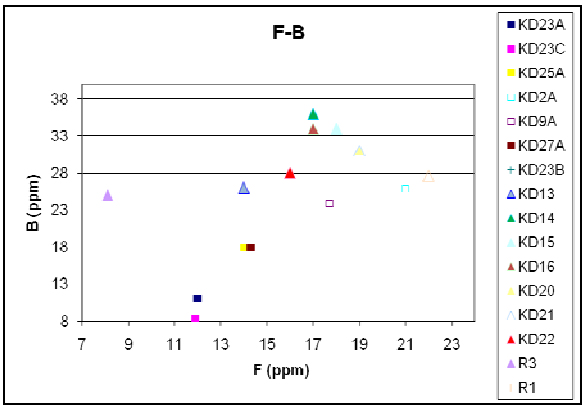

Figure.12 Total boron and Flour ions in Kızıldere geothermal waters

Existing production wells and new wells characterization are shown in Piper diagram in Fig. 13.

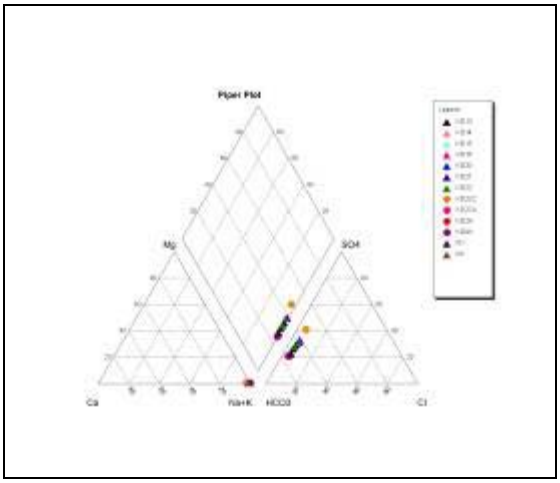

Figure.13 Geothermal waters of Kızıldere geothermal field on Piper Diagram

Kızıldere Geotherrnal Waters are partial equilibrated/mature waters (Fig.14). It is understood that geothermal waters show intensive water-rock interaction in the geothermal system.

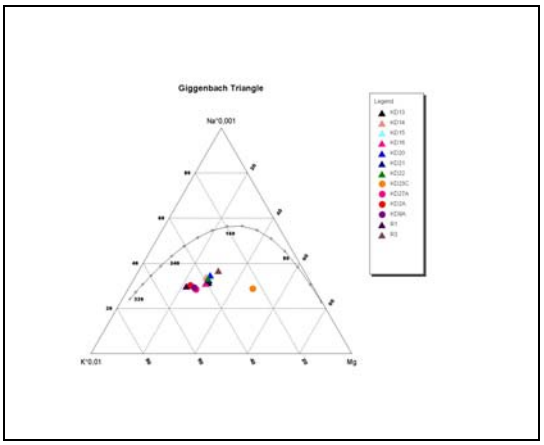

Figure.14 Kızıldere geothermal waters on Giggenbach Triangle

The variations of δ^{18}O-δD isotopes at the new and existing production wells are shown in Fig.15.

The highest δ^{18}O value is observed at R1 (-4,40%0) which also has the highest temperature among all other production wells whose δ^{18}O values vary between -6 %0 and -7,38%0.

When δ^{18}O values at the new wells are analyzed, it is seen that, these values vary between (-4,30 %0) – (-7,8%0). KD-2A has the highest δ^{18}O value among the newly drilled wells until January 2011 (Fig.15).

Based on the results of δ^{18}O analysis, it can be concluded that there is an intensive water-rock interaction in R1 and KD-2A wells at reservoir conditions.

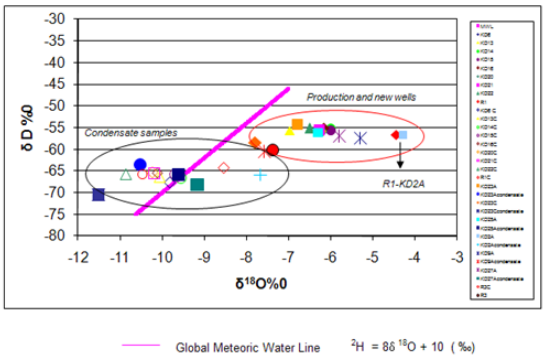

Figure.15 δ^{18}O- δ D Variations in Kızıldere Geothermal wells

<u>Gas Compositions and Gas/Steam Ratio Calculations of Existing Production Wells and New Wells</u>

The major gas in Kızıldere Geothermal Wells is CO_2 (Table.II) and this is the main reason of the formation of calcium carbonate scaling in well bores. Over the flash point, CO_2 degasifies and scaling occurs at this point (Fig.16).

Table.II Gas Compositions of Existing Production Wells and New Wells

NCG dry comp %	Sampling date	CO_2	H_2S	N_2	CH_4	Ar	He
KD-23A	March,10	98,836	0,0031	0,6540	0,3779	0,0052	0,000019
KD-23C	March,10	98,717	0,0044	0,8710	0,3856	0,0042	0,000018
KD 25A	May,10	98,7380	0,0035	0,6868	0,5504	0,0081	0,000032
KD2A	September,10	98,354	0,0066	0,9530	0,6610	0,0110	0,000037
KD13	May,09	98,767	0,0054	0,668	0,528	0,0339	0,000031
KD14	May,09	99,205	0,0058	0,4423	0,3357	0,0211	0,000012
KD15	May,09	98,357	0,0052	0,894	0,741	0,0254	0,000019
KD16	May,09	99,416	0,0035	0,275	0,300	0,0148	0,000011
KD20	May,09	99,012	0,0039	0,551	0,427	0,0276	0,000023
KD21	May,09	99,309	0,0030	0,348	0,334	0,0187	0,000013
KD22	May,09	99,372	0,0041	0,323	0,296	0,0163	0,000012
R1	Dec,09	98,860	0,0051	0,586	0,546	0,0202	0,000024
R3	Dec,09	99,050	0,0049	0,631	0,308	0,0020	0,000120

He values are very low in Kızıldere Geothermal Field.

Gas/steam ratio calculations show that gas in steam is lower in production wells compared to the newly drilled wells in field: While G/S ratio values change between 8-19,5 %wt in production wells, it is observed at the preliminary well tests that in the new wells these values vary between 13-27 %wt.

Figure.16 Calcium carbonate scaling in pipes before inhibitor application in production wells in Kızıldere geothermal field

DISCUSSION

Currently at the field 9 production wells are being operated to produce steam for existing Kızıldere GPP while 4 reinjection wells are being used for reinjection of the brine produced. All of these wells are drilled at the second reservoir which is called İğdecik Formation, with the exception of R1, which is drilled to deeper depths than the second reservoir.

In 2009, after the privatization of the Kızıldere Geothermal Field, Zorlu Energy Company has conducted intensive rehabilitation programme to improve the field conditions and stabilize electricity generation at the 15 MWe geothermal power plant. Meanwhile, a detailed exploration programme at the field is performed and as a result of this programme, the company has decided to build new geothermal power plant in Kızıldere Geothermal Field. After the completion of the feasibility study for this new power plant, new drilling locations are determined and drilling operations started at the south of the existing production wells.

As of January 2011, 11 new wells are drilled at the field and first well tests of these new wells commenced. Geochemical studies are also being performed in new wells within the scope of well tests which still continue.

First test results at the field confirm that Kızıldere Geothermal System consists of different reservoirs. Geothermal fluids which come from deeper reservoirs contain high amounts of saline and have high silica values in the field. Meanwhile these fluids have high $\delta^{18}O$ values which signify that there exists an intensive water-rock interaction in geothermal waters in the field.

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