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REASSESSMENT OF THE KIZILDERE GEOTHERMAL RESERVOIR

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ABSTRACT

This study aims to reassess the different aspects of the Kizildere field after 15 years of exploitation not only to provide better understanding of the geothermal reservoir that, in our opinion, has been underexploited, but also to set conditions for better reservoir management.

Rock and fluid properties of Kizildere geothermal reservoir were studied through reassessment of well logs, well tests, geochemistry of geothermal fluids and pressure and temperature surveys. Production performance of the field was also examined. Based on the production history and on geological and geophysical work the water in place, recharge and heat balance of the Kizildere geothermal system were estimated. Moreover, reinjection experiments conducted in the past were reassessed. This work, coupled with modeling studies helped to explain the physical changes such as two phase formation that have occurred during the exploitation of the field over the last 14 years.

The possible discovery of a deeper and hotter reservoir provides new horizons for the field in the future. New reservoir management policy and reinjection alternatives are proposed. The economics of the field and power plant is also evaluated, and the results are reported.

1. INTRODUCTION

The Kizildere geothermal field is located in the western extreme of the B. Menderes graben where it intersects with Gediz and Curuksu grabens. It is a liquid dominated reservoir with temperatures of 195-212°C at depths of 300-800 m. The field was discovered in the mid 1960's, and 17 wells were drilled until mid 1970's assessing the capacity and at the same time developing the field. A power plant of 20 MW_e generation capacity fed by 6 production wells (KD-6, 7, 13, 14, 15,16) was installed at the field, and power generation started in 1984. Three additional production wells (KD-20, 21, 22) were drilled two years later to increase the steam production. The field has been generating approximately 7.5 MW_e of energy for the last 15 years. A well recently drilled for reinjection purposes intersected an unexpected deeper zone with temperature of 243°C giving a new dimension to the field for exploitation rather than reinjection.

Two stratigraphically separate zones in the field were initially identified as 1st and 2nd reservoirs during the exploratory stage; shallow one in Miocene limestones with temperatures of 196-200°C and moderate permeability, and few hundred meters deeper one in Paleozoic marbles with temperatures of 200-212°C and high permeability. Since limestones are not continuously distributed and therefore not encountered in all wells, and the marbles are much more continuous and thicker with better permeability, the deeper marble zone was targeted for exploitation. Fig-1 shows the well locations of the Kizildere field. Of these wells, KD-1, 2, 3, 4 and 12 tap the shallow limestones, and the others tap somewhat deeper marbles of the geothermal reservoir. The drilled wells have some permeability ranging from low to high. Particularly, the wells drilled in the area delimited by geological and geophysical studies show much higher permeability. Reservoir rocks, especially marbles, do not have primary porosity and permeability, but secondary porosity and permeability.

2. RESERVOIR CHARACTERIZATION ASSESSMENT

In a reservoir characterization effort, temperature and pressure surveys, well logs, well tests and analysis of water samples were evaluated (Serpen *et al.*, 1995 and Serpen and Gulgor 1995). The assessment of the collected data provided valuable information on rock and fluid properties (Serpen *et al*., 1998 and Serpen and Ugur 1998). A new reservoir model was established based on the physical changes occurred in the reservoir. Moreover, the results obtained were utilized in model simulation runs.

In the past, the limestones and marbles at shallow levels had been considered as separate reservoirs (No.1 and 2) from the stratigraphical viewpoint. The measured temperature profiles have lead us to better understand the geothermal reservoir that is formed in a fracture system independent of stratigraphy, and helped to define a single hot water reservoir formed between 300 and 1000 m depth with an average temperature of 205°C (Serpen *et al*., 1998). Geochemical studies (Serpen and Ugur 1998) strengthened this finding by showing a similar chemical environment in both limestones and marbles. The temperature profiles also helped us to locate the permeable horizons within the geothermal reservoir (Serpen *et al*., 1998). Moreover, temperature measurements indicate the direction of hot water recharge (north) and relatively cool water influx (south) into the reservoir (Fig. 1). Geochemical studies have also identified two different sources of recharge:, a hot flow coming from north and a relatively cool flow coming from the south. Therefore, they corroborate the finding obtained by temperature surveys. Cl/B isocontours in Fig. 2 confirm the existence of two different recharge components.

Geochemical studies (Serpen and Gulgor 1995, Serpen and Ugur 1998) have long been indicating the presence of a deeper thermal reservoir. Fig. 3 illustrates the results of Na/K and Na/Mg geothermometers in which all the samples fell on a line intersecting 240°C temperature on the mature water line. A recent deeper well (R-1) that was drilled to 2300m intersected the expected thermal reservoir of a temperature of 243°C. Geochemical studies (Serpen and Ugur 1998) also revealed that high Li and B content of Kizildere waters are not of magmatic origin, but, they are simply formed by leaching of Paleozoic gneisses and Miocene volcanic rocks, respectively. The same study also indicated that geothermal waters of Kizildere are of meteoric origin.

Using pressure surveys the pressure gradient (Fig. 4) of this non-static natural state reservoir was established, and geothermal system's vertical permeability was estimated as around 2 md (Serpen *et al.,* 1998). Moreover, the physical changes occurring such as the transition to two phases in the reservoir was detected. Fig. 5 illustrates the observed pressures during 1987-1992 period. The formation of two phases can be observed from the pressure trend change occurred in the 1989-1990 period (Fig.5). Although some problems, such as scaling and gas extraction from condensers are caused by the presence of CO_2, carbon dioxide plays an important role in the driving mechanism of the field, providing energy for the production. Therefore, Kizildere geothermal reservoir acts like a typical depletion or solution drive oil reservoir. A modeling study by Alkan and Satman (1990) established this type of behavior for geothermal fields in the presence of CO_2. Carbon dioxide, which is dissolved 1.5-1.7% by weight in Kizildere's geothermal fluid, has a computed and observed partial pressure 5 MPa in the hot water reservoir and 5.8 MPa in the deep thermal reservoir. The amount of CO_2 increases to 2.5-2.7% by weight in the deep thermal reservoir. These partial pressures are high, and according to the Alkan and Satman (1990) study, would provide enormous energy to the production process for a long period of time. Further studies by Ugur *et al*., (1996) provided models to compute the variation of bubble-point pressure, compressibility and viscosity of two-phase fluids with temperature in the Kizildere field.

The two-phase formation by separation of dissolved CO_2 from the liquid phase was also observed in well logging studies (Serpen *et al*., 1995). Fig. 6 shows a density-neutron cross-plot in which the gas presence is very much evident in one well situated at the center of the reservoir. Well logging surveys provided information on porosity of the reservoir. Unfortunately, no cores had been cut within the reservoir rock during drilling of previous wells. Therefore, 6% average porosity registered and computed from logs has been used. Since marbles do not have primary porosity because of metamorphosis, the porosity found from logs is only secondary. Another important quantity that the well logging made available was the density of marble. Beforehand, marbles were believed to be composed of pure $CaCO_3$. Higher densities observed (2.85-2.9 g/cc) from the logs led us to investigate the origin of the marbles. Since no cores were available, the fragments of marble expulsed from the wells during production were utilized and their x-ray difractometer and chemical analysis indicated the samples are dolomite (Serpen 1999). This important finding shed light on problems of non-successful acidizing operations. Acidizing of dolomite is a different process to calcite acidizing, and future operations will be designed accordingly.

Using well test data transmissivity, skin effect and porosity-thickness values were computed not only for individual wells, but also for different sections of the Kizildere geothermal reservoir (Serpen *et al*., 1998). The field liquid volume of $535x10^6$ m^3 and aerial extension of 3.45 km^2 were also estimated. Also, a good hydraulic connection between upper (limestone) and lower (marble) section of hot water reservoir was identified. Interference tests conducted between wells tapping only marble formation (horizontally) and between wells tapping limestone and marble (vertically) provided the same order of transmissivity indicating that they are both intersected by the same fracture system. This is more evidence that both limestones and marbles form a single reservoir. A further interference test conducted between the deep thermal reservoir and the hot water reservoir resulted in half the above transmisivity value (Serpen 1999) pointing out a hydraulic connection that couples the thermal and hot water reservoirs in a non-static natural state geothermal system. Fig. 7 shows the new model of the Kizildere geothermal field.

3. ASSESSMENT OF KIZILDERE GEOTHERMAL RESERVOIR

In order to determine the capacity of Kizildere geothermal system, pivotal parameters such as reservoir size and the fluid and heat contained within the system were estimated by using conventinal methods. Heat energy in place was computed as $4x10^{18}$ J, and water in place was calculated as $600x10^6$ tons using material balance (Ugur 1997) and $490x10^6$ tons by conventional oil field approaches, such as volumetric method and decline curve analysis (Serpen and Ugur 1998). Heat discharge to atmosphere of the Kizildere geothermal field was also estimated as 53 MW_t. A heat balance of Kizildere geothermal system was also established (Serpen 1999).

The Kizildere geothermal system is closed, and is fed by a complex recharge system, whose components were defined as a relatively cool, shallow lateral aquifer and a deep, hot aquifer. Utilizing a plot of total flow rate of the field versus reservoir pressure in Fig. 8, recharge flow rate was estimated 550 t/h by observing the flow rate at constant pressure (Serpen and Gulgor 1995). The same trend was also observed in monitoring wells KD-7, 9 and 2 that are situated in different parts of the field, and tap different sections of the reservoir. No appreciable temperature changes were observed during 15 years of explotation, and by using a simple energy-material balance the estimated contributions of the lateral and deep components are 50% each (Serpen 1999). Applying a pressure balance and using temperature gradients, the deep water circulation depth is estimated at approximately 3000m (Serpen 1999).

The physical changes occurring within the reservoir were investigated for 15 years of production using geochemical data. Fig. 9 illustrates the physical changes within the reservoir for this period (Serpen and Ugur 1998). The pH of geothermal fluids gradually increased during this period from 8.5 to 9.3. This indicates CO_2 separation and gas phase formation. Total dissolved solids have decreased by approx. 5%. This is a good agreement with net water production of $21x10^6$ tons (excluding the recharge) out of estimated $490x10^6$ tons water in place (Serpen 1999). Chloride content of produced water for the last 10 years has decreased faster in peripherial wells than in central wells as it can be seen in Fig. 10 (Serpen 1999), indicating an active lateral aquifer.

The production performance of the Kizildere reservoir can be evaluated on the basis of productivity index relating total production to the pressure drop due to long term production. Two long term production tests were conducted in 1972 and 1976 when there was only liquid phase in the Kizildere geothermal reservoir, and productivity indexes are calculated as J = 0.33 kg/s/kPa and J = 0.35 kg/s/kPa, respectively. Productivity index for the exploitation period of 1990-1998 is computed as J = 0.69 kg/s/kPa. The doubled productivity index demonstrates the effect of solution gas drive after CO_2 separation.

Data and knowledge obtained from the characterization studies were also utilized in model simulations, and long term production performances of the field were predicted under different production scenarios. Two type of models were used for performance prediction.

The first was based on heat production approach proposed by Muffler and Cataldi (1978). A stochastic model was designed, and Monte Carlo simulations were run by using data distributions obtained from reservoir characterization studies (Serpen 1999). Both hot water and thermal reservoirs were evaluated and the results are presented in Fig. 11. Expected overall power potential is calculated as 36 MW_e.

The second group of simulations was run with the model developed by Alkan and Satman (1990). This lumped-parameter model was also used with the data obtained from characterization studies for both shallow hot water and deep thermal reservoirs. The results for the hot water reservoir are illustrated in Fig. 12. As can be seen from Fig. 12, the hot reservoir maintains the reservoir pressure for 30 years of varying production schemes, and similar behavior was observed for deep thermal reservoir.

The disposal of geothermal water into B. Menderes River has continued for the last 15 years, and it is still the biggest issue for the project. Two major reinjection trials (Satman et al. 1999) have been carried out in the past, and a third is under way. Two reinjection wells, one in the Tekkehamam area 3 km away and another at the border of the field, have been drilled in the last 3 years and a third is being drilled with some mixed results. Modeling studies by Satman et al. 1990 indicated that reinjection in the Tekkehamam area would not have a cooling effect on the Kizildere reservoir. Other simulations with a model developed by Satman *et al*., (1990) pointed out that the Kizildere reservoir would not be cooled appreciably by a reinjection rate of 500 t/h. The best reinjection strategy for Kizildere system would be to produce from the deeper and hotter thermal reservoir and to reinject into the shallow hot water reservoir. Since the thermal reservoir produces more steam (11% vs. 19%) than the hot water reservoir, the amount of water to reinject will decrease approximately by half, so less water would be reinjected to the shallow hot water reservoir, and as a result, the cooling effect will be alleviated. Lindal and Kristmandotter (1989) indicated that hot water reinjection directly from the separator would cause no silica scaling problems unless the water temperature drops below 115^{o}C. Therefore, hot water (147^{o}C) from the separator is suggested for the reinjection inside the reservoir. Reinjection outside the reservoir could be done with cooled water with no silica and minimal calcite scaling.

A detailed economical analysis conducted (Serpen, 1999) for Kizildere field results in negative NPV due to low power production (7.5 MW_e instead of 20 MW_e installed) and delayed investments. Kizildere geothermal power plant was built in 1984, 16 years after first discovery. Exploratory expenditures of $3,000,000 in 1968 valued $16,000,000 at the time of plant installation. Despite this setback, had the plant produced the installed capacity of 20 MW_e, NPV of the project would have been $25,000,000 with a ROR of 24% (Serpen, 1999). On the other hand, had the plant been built with 10 MW_e of installed capacity, the project would have had a positive NPV of $3,500,000. Another reason for low power generation is the mechanical scale removal operations. If inhibitors were used, power generation would increase by 25%. It must be mentioned that inhibitors were successfully tested up to 10 months in 1988-1989 in Kizildere. Taking into account that deep R-1 well produces 6 MW_e and power generation could be boosted by 25% using inhibitors, power production could be increased to 16 MW_e in the short term. In the long term, new production wells must be drilled into the deep thermal reservoir, and reinjection must be started into the shallow hot water reservoir. This sort of management not only will solve the actual problems of Kizildere geothermal system but also maximize the electricity generation and improve the project economics.

4. CONCLUSIONS

After the assessment the following conclusions are reached:

- A new geothermal model was established for the Kizildere geothermal system.
- Short and long term geothermal reservoir management are proposed for economical and optimal exploitation of the field.
- A new reinjection strategy is also recommended.

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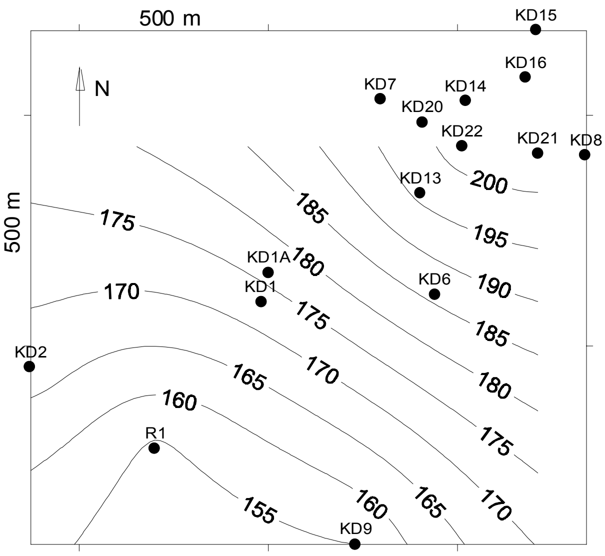

Fig. 1. Well locations and temperature iso-contours 500musl.

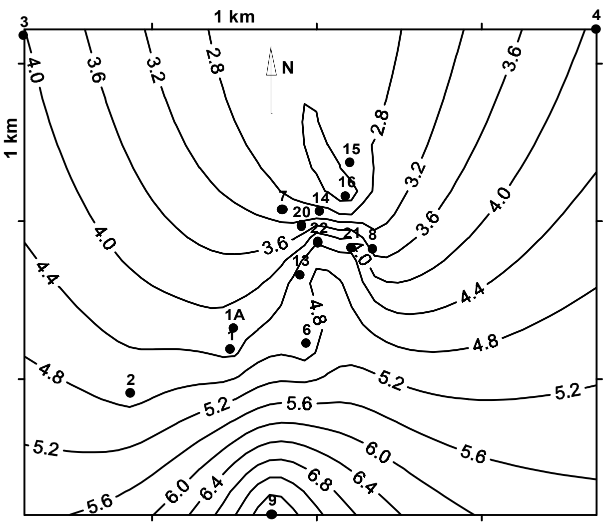

Fig.2. Isocontourmap of Cl/B values of spring and well waters.

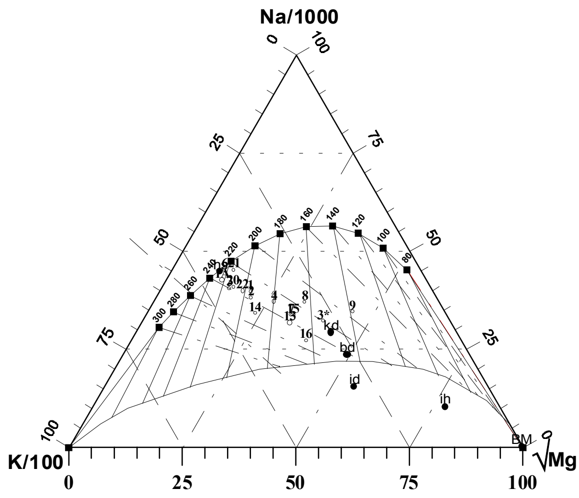

Fig.3. Distribution of spring and well waters in Na/K and K/Mg geothermometers diagram.

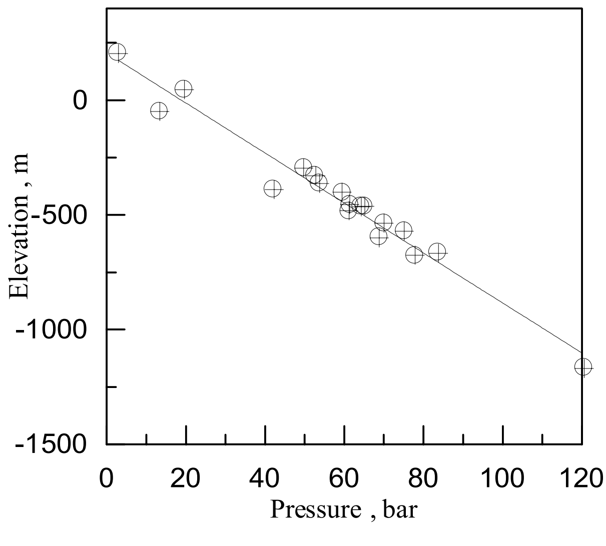

Fig. 4. Kizildere reservoir pressures.

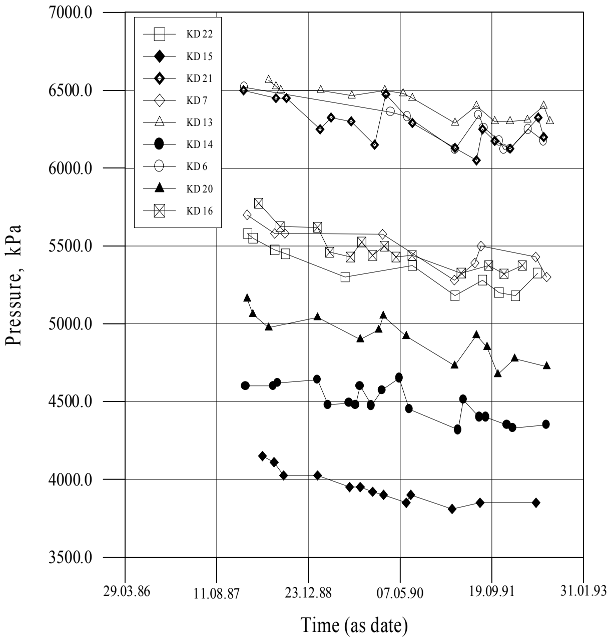

Fig. 5. Variation of well pressures with time.

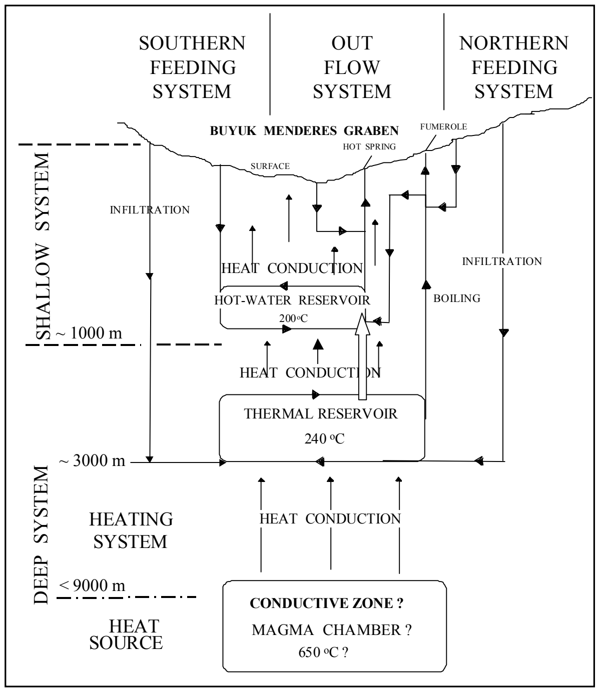

Fig. 7. New model for Kizildere geothermal system.

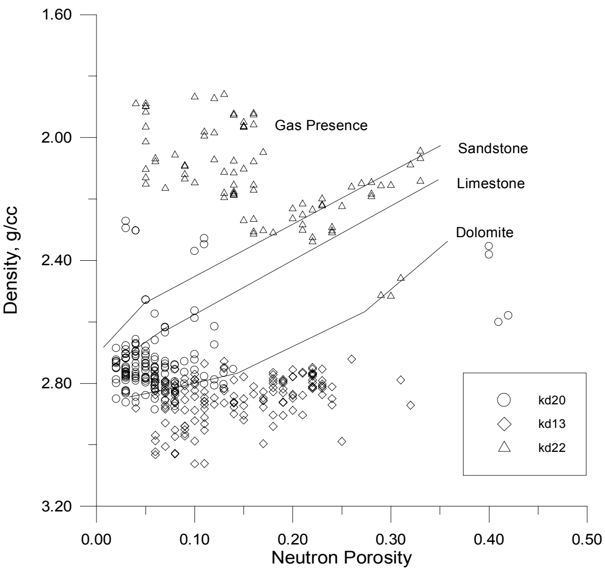

Fig.6. Density-neutron cross-plots of various wells.

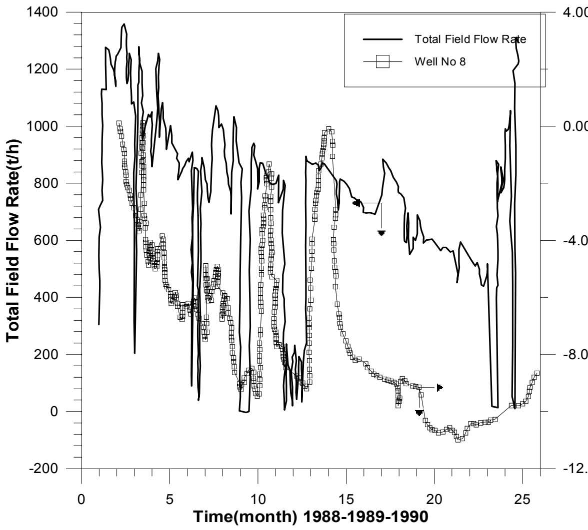

Fig. 8. Pressure response of field to total production.

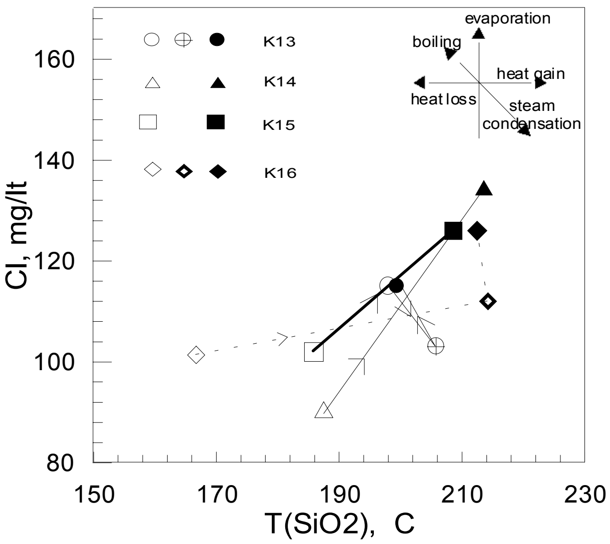

Fig.9. Trend lines relating changes in chloride concentrations to various processes.

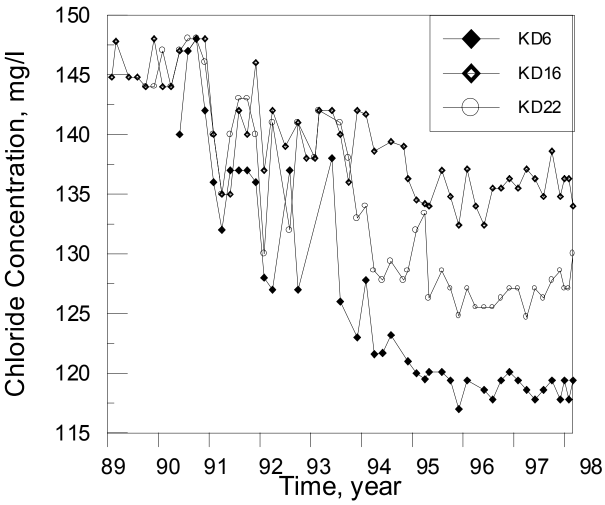

Fig. 10 Change of chloride concentration with time in wells.

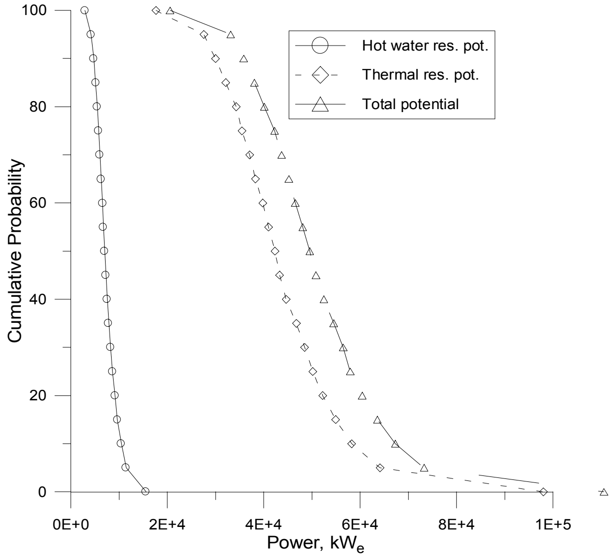

Fig. 11. Distribution of power potential of Kizildere field.

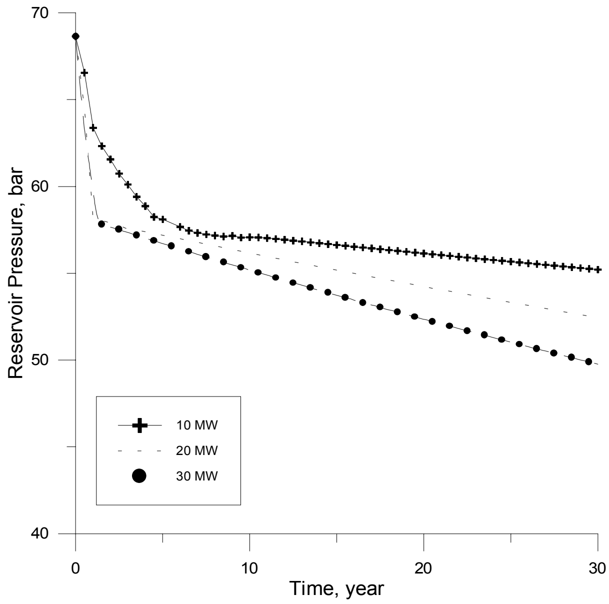

Fig. 12. Pressure response of hot water reservoir of Kizildere field for various power production rates.