

A look at the long-term production story in geothermal fields with multiple flash power plants

Füsun Tut-Haklıdır¹, Raziye Şengün-Çetin¹, Sanem Kılınçarslan, Seray Işık-Tezel

¹ Zorlu Enerji Company, Kızıldere-Denizli Türkiye

fusuntut@gmail.com

Keywords: Geothermal power plants, multi-flash, geochemistry

ABSTRACT

Geothermal power plants still have an important place among renewable energy plants with their high capacity factors. The start of the adaptation process of geothermal hybrid power plants and new technologies to increase efficiency continue to support investment in geothermal power plants.

The efficient operation of geothermal power plants depends on the simultaneous and accurate management of underground reservoirs and power plant surface systems and equipment.

Whether steam-dominated or water-dominated reservoirs are used in geothermal power plants, thermodynamic changes and fluid dynamics require continuous careful operation of these plants. As the duration of geothermal fluid production in a field increases, the number of issues that need to be considered in both underground and surface equipment may begin to increase and changes in production and reinjection strategies may be needed. Sometimes additional investments and evaluations may be required due to updating legal regulations. In this respect, the operation of geothermal power plants depends on many dynamic conditions.

Within the scope of this study, the change of production conditions and geochemical monitoring studies in Kızıldere Geothermal Field (Türkiye), which is one of the important geothermal fields in the world and where triple flash cycle geothermal power plants are located, which has been in production for 50 years, will be shared.

1. INTRODUCTION

In the operation and maintenance of geothermal power plants, the behavior of the geothermal fluid and its interaction with the equipment are factors that directly affect the plant efficiency. For this reason, geothermal production scenarios, power plant cycle scenarios and equipment materials selection and a series of fluid conditionings are very important. Flash type cycles, which are preferred in water-dominated geothermal reservoirs where fluid temperatures are high, are important with their high capacity factor.

In a typical flash system, the geothermal fluid from the wells is first directed to the steam separator, which separates the steam + gas phase and hot water (brine). After its quality is improved, the steam is sent to the turbine and generates energy with the generator, while the incompressible steam and non-condensable gases are delivered to the cooling tower via the condenser, and the brine is sent underground through reinjection wells. Double or triple flash plants can be installed with fluid temperatures that allow the separation of steam and brine phases two or three times.

When the records for 2024 are analyzed, of the approximately 1.7 GWe geothermal installed capacity in 31 countries, the flash cycle ones constitute approximately 37% of all geothermal power plants, corresponding to 53% of the installed capacity with high energy production. These plants have capacity factors exceeding 70% on average and even higher values when integrated with binary cycle (Gutiérrez-Negrín, 2024, Bertani 2016).

Türkiye has made a significant investment in renewable energy since the mid-2000s, with around 66 geothermal energy units and an installed capacity of 1,734 GWe, mainly located in large grabens in Western Anatolia. Although most of these geothermal power plants are ORC binary cycle type, there are also multi-flash plants cascading using of binary and triple flash cycles in Germencik, Kızıldere and Alaşehir fields (Figure 1).

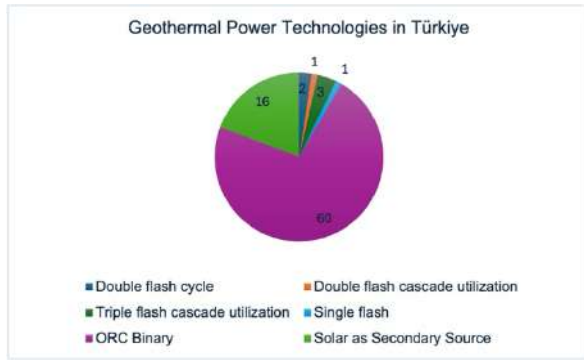


Figure 1: Geothermal power technologies in Türkiye (2025)

With the increased interest in geothermal power plant investments after 2010 due to government incentives, many geothermal wells were drilled, especially along the Büyük Menderes Graben and Gediz Grabens. As the geothermal power plants started to be commissioned, important lessons were learned from the technical problems observed in the plants and the solutions provided, which will contribute to long-term production.

Of course, much more problems were encountered in flash type power plants with high fluid production, higher number of wells and intense temperature and pressure changes. These problems range from reservoir management, mineral scalings, fluid-equipment interaction, cooling tower treatments, disposal of non-condensable gases to data management due to multi-layered dense data flow.

One of the best examples of applications that are likely to be observed in flash power plants in the long term, which have the potential to cause problems or to prevent problems by anticipating them in advance is the Kızıldere geothermal field where the first production was realized in 1974. Therefore, the development of this important field located in Western Anatolia is of great interest for the geothermal sector.

2. KIZILDERE GEOTHERMAL FIELD

2.1. Discovery of Kızıldere Geothermal field and evolution of the electricity production

Kızıldere Geothermal Field is located on the Büyük Menderes Graben, one of these grabens. The field has been producing since 1974, and this production, which started with a single well, has evolved into an environment where around 80 wells are included and electricity is produced from 3 main geothermal power plants (Figure 2).

The first well was completed in 1968 at a depth of 540 m and a temperature of 198 °C was recorded. In 1974, a 500 kWe pilot turbine was installed in the Kızıldere geothermal field to generate electricity using the KD-13 well. Based on initial production tests, the 17.4 MWe single-flash Kızıldere Power Plant was built by the Turkish Electricity Authority in 1984. The plant

was powered by steam produced from 6 wells. The first reinjection application was initiated in 2002. In 2008, Zorlu Enerji acquired the operation of the Kızıldere-I geothermal power plant and the rights to use a 70 km² geothermal field for 30 years. The company then initiated a rehabilitation program to maintain electricity production from Kızıldere-I, a single-flash geothermal power plant. In this context, work-over operations were carried out for mechanical cleaning in geothermal wells. Chemical inhibitor system was adapted to the production wells and reinjection lines were constructed on site. The cooling tower was rehabilitated and conditioned to improve turbine performance (Tut-Hakkıdır et al., 2021).

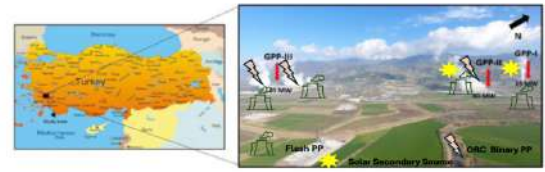


Figure 2: Kızıldere (Türkiye) Geothermal Field: flash& ORC binary power plants with additional source solar

2.2. The Capacity Expanding Stages Between 2010-2018

Following the rehabilitation of Kızıldere-I power plant, work was initiated in 2010 to develop the site. For this purpose, following a series of geology, geophysics and geochemistry assessment studies, the potential of the site was revealed and the necessary legal process was initiated. After successful 2 years of drilling and reservoir testing following the design criteria, Kızıldere-II power plant was commissioned in 2013 with a capacity of 80 MWe (i.e. 60 MWe_{gross} triple flash and 20 MWe_{gross} binary cycle). In this context, a total of 25 production and reinjection holes, including directional drilling, were drilled at depths between 1100-2900 m.

In the triple flash system, which was experienced for the first time, short and long term chemical inhibitors were tested in the field to prevent both the wells and the separation system from being affected by mineral encrustations. A comprehensive geochemical monitoring study was initiated by monitoring the physical and chemical properties of the fluid in all wells. Monitoring tests were conducted to understand the interaction between wells. Level observations and monitoring of temperature and pressure changes in primordial conditions were started in the wells. Meanwhile, the Kızıldere-I geothermal power plant continues production. By creating a new design that will provide a connection between the two plants, the reinjection fluid of Kızıldere-I geothermal power plant was transferred to the low pressure separator of Kızıldere-II power plant due to its high temperature, and a joint reinjection strategy was initiated.

Kızıldere-III GPP has a total installed capacity of 165 MWe_{gross} and consists of two separate triple flash and

binary ORC units with 99.5 MWe and 65.5 MWe capacity and each binary units has 23 MWe capacity (Mainar-Toledo et al., 2023). Unit 1 (U1) was initially commissioned in August 2017 and U2 in March 2018, with a total of 24 production wells producing 4313 tph of fluid and 11 reinjection wells. The well depths reached up to 3500 m. at this stage (Figure.3).



Figure 3: Kızıldere-III GPP units (by Zorlu Enerji)

In 2020, Kızıldere-I power plant was shut down for operational reasons and its wells were shifted to 2020. In the process, re-injection strategies have changed in the field. In 2009, the reinjection within the field was moved to the east of the field, and then with the commissioning of Kızıldere-III, the reinjection strategy started to be carried out in different parts of the field.

2.3. Operational requirements at the power plants and changes observed in the reservoir over time

In the triple flash geothermal power plants, there is a series of temperature and pressure changes until the fluid reaches the reinjection well after reaching the separation station from the production well and after the vapor separation in each separation system. As a result of these thermodynamic changes, the minerals in the fluid tend to precipitate and enter the scaling tendency.

As a result of these thermodynamic changes, the minerals in the fluid tend to precipitate and enter the crusting tendency. Controlling temperature drop and fluid pH is important in the final stage to achieve the appropriate reinjection temperature and to ensure that silica minerals in particular do not precipitate along the lines until they reach the injection well. The continuous monitoring and appropriate chemical treatments are therefore necessary (Figure 4).

Monitoring and maintenance of cooling towers is important for turbine performance. Especially in water-cooled towers used in flash type power plants, ambient conditions combined with non-condensable gases create favorable environments for bacteria and algae growth. For this reason, the chemical and biological conditions of the tower interior conditions can be determined and conditioned with automatic systems can give very effective results. With increased evaporation in hot weather conditions in summer, water supply becomes critical. In long-term fluid production, it is important in the production phase of power plants to focus on automation by reducing the effect of human operators and to recognize changes in time with data tracking.

Shortly after the commissioning of the second power plant in Kızıldere field in 2013 and intensive fluid production, the non-condensable gas rates in the wells started to decrease. With the commissioning of the first and second units of Kızıldere-3 GPP, the geothermal system had time to rebalance of the reservoir in 2018. (Figure 5). After the intensive fluid production, the issue of switching to artificial production was brought to the agenda in 2020 due to pressure drops in some wells.

With this reason, the pumped production in geothermal wells step by step in the Kızıldere after 2020 (Aydın et al., 2021). Of course, the operational challenges were different with installed electrical submersible pumps in shallow wells compared to those in deep wells. Although the temperature effect and the setting of the inhibitor pipes cause problems in pumps installed in deep wells sometimes and different solutions have started to be developed following field experiences. One of the important issues in pumped production is also the additional internal electricity consumption.

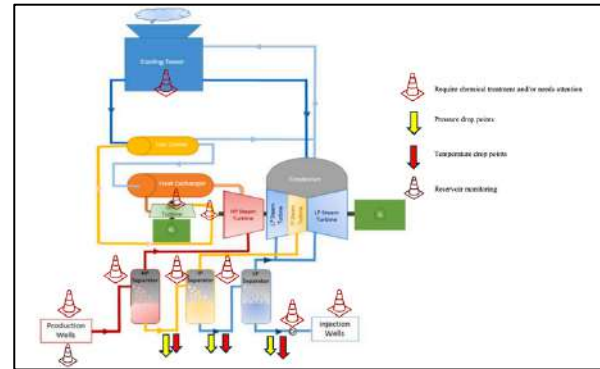


Figure 4: Operational requirements of the Kızıldere GPPs (modified after Tut-Haklıdır et al., 2021)

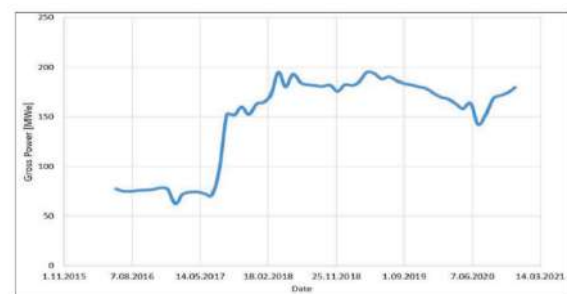


Figure 5: Geothermal power production in Kızıldere between 2015-2020

There are four main productive reservoirs have been identified according to their depths by nearly 100 drillings since 1965 in Kızıldere-I geothermal field. Sazak Formation (shallow, reservoir I), Igdecik Formation (reservoir II), fractured quartzite-calcschist of the Menderes Metamorphics and deep marble section of the Menderes Metamorphics (the deepest reservoir IV).

Although geothermal wells in Kızıldere generally produce from reservoirs 3 and 4, it is observed that major faults and secondary faults in the field play an important role in transporting these fluids when reinjection scenarios change, especially when reinjection is carried out close to the production wells in the field (Şengün-Çetin et al., 2025). Within the scope of a project initiated in 2024, microseismological monitoring of the potential paths of the reinjected fluids in the field is carried out in addition to the tracer studies previously carried out in the field.

Extensive intensive hydrogeochemical observation studies in the field also reveal results parallel to the changing fluid flow rates and temperature changes during the time production process. All these studies reveal very important information for this field where complex thermodynamic changes take place and long-term production is carried out (Figure.6).

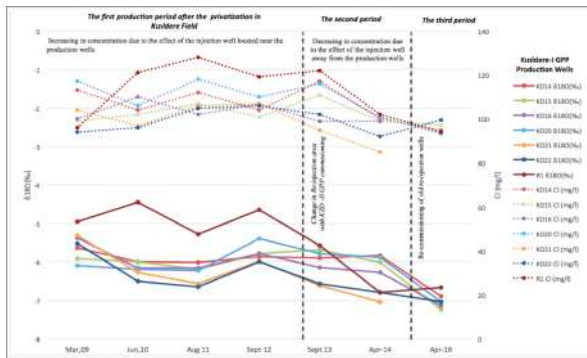


Figure 6: An example for hydrogeochemical monitoring in Kızıldere (Tut-Haklıdır et al., 2021)

3. CONCLUSIONS

Flash type plants can be designed as multi-flash considering reservoir temperatures with designs based on increasing efficiency. Although they appear to be advantageous in electricity generation for a long time, the operation of these plants sometimes requires considerable attention. The Kızıldere geothermal field, where production and reinjection strategies changed significantly between 1984 and 2024, is one of the plants where a lot of experience has been gained in terms of reservoir and power plant operations, and it is

a field where efforts are frequently made to adapt new developments over time with technology providers in order to maintain to the production.

REFERENCES

- Aydın, H., Akın, S., Tüzen, M.K., Şentürk, E. Artificial Lifting in Liquid Dominated High-Temperature Geothermal Fields in Turkey: Lessons Learned, 2021. *46th Workshop on Geothermal Reservoir Engineering Stanford University, CA*
- Bertani, R. Geothermal Power Generation in the World 2010-2014 Update Report. Geothermics, 2016; 60, 31-43.
- Mainar-Toledo, M.D., Halaçoğlu, U., Sahiller, H.A., Hazar, T., Zuffi, C., Diaz-Ramirez, M., Manfrida, G. Environmental benefits for a geothermal power plant with CO₂ reinjection: case study of the Kızıldere 3 U1 geothermal power plant. Energy Storage and Saving 2023. V:2, Issue: 4 631-638.
- Negrin, L. G. Evolution of worldwide geothermal power 2020-2023. Geothermal Energy 2024, 12.
- Tut-Haklıdır, F.S., Şengün, R., Aydın, H. Characterization and Comparison of geothermal fluids geochemistry within the Kızıldere Geothermal Field in Turkey: New findings with power capacity expanding studies. Geothermics 2021. 94;102110.
- Şengün Çetin, R., Görgülü, İ.S., Emiroğlu, E.C., Demircioğlu, Ö. Kaygısız, U., Kılınçarslan, S., Işık Tezel, S., Canbaz, H., Tut Haklıdır, F.S., Sevim, F., Açıkgöz, C., Tarancıoğlu, A., Ökeler, A., Tapırdamaz, M.C., Zor, E. Investigation of Re-injection Strategies in Geothermal Energy Production with Multi-disciplinary Approaches. *77th Geological Congress of Türkiye with International Participation* April 14-18, 2025, Ankara Türkiye.