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Evaluation of Geothermal Scaling Possibilities and the Effective Scale Mitigation Methods at Different Type Geothermal Power Plants in Western Anatolia (Turkey)

Füsun S.Tut Haklıdır[1], Tuğbanur Özen Balaban[2], Raziye Şengün[3]

[1] İstanbul Bilgi University, Depth. of Energy Systems Engineering-İstanbul, Turkey,

[2]İzmir Katip Çelebi Üniversitesi,-İzmir, Turkey,

[3] Zorlu Energy, Denizli-Turkey

[1]fusun.tut@bilgi.edu.tr, [2]tugbanur.ozen.balaban@ikc.edu.tr, [3]raziye.sengun@zorlu.com

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ABSTRACT

Flash and ORC-binary type geothermal power plants are widely used for power generation at moderate or moderate-high temperature water-dominated reservoirs. For the effective management of these power cycles, it is critical to understand the effects of controlling pressure at different sections of a power plant as well as temperature changes and the pH levels of geothermal fluids. The expectation of energy efficiency at an advanced geothermal power plant is higher than for flash and binary systems, while the management of these systems are more complex because of high reservoir temperatures and multi-separation processes. Western Anatolia has important high-medium geothermal systems that are suitable for power production, depending on the large graben systems. Geothermal power plants in Turkey are generally designed as binary and flash types, based on the reservoir temperatures (in Germencik-Aydın, Kızıldere-Denizli, Alaşehir-Manisa regions etc.) in Western Anatolia. The scale types may change with respect to geothermal fields even if they are in close proximity to each other. At the same time, in addition to specific scale types, some minerals are commonly found across each of the geothermal fields. The most important scale types in production wells and lines as well as surface equipment are carbonate minerals such as calcite and aragonite. In addition, silica minerals also tend to precipitate at re-injection lines. Scale types in re-injection lines and wells have been commonly identified as celestine, strontium and barite minerals mixed with silica and carbonates at some of geothermal power plants. Scale prevention inhibitors and inhibitor systems with different chemical properties are generally used for anti-scaling. Another method is to use control coupons for scale precipitation to realize pressure drop points along pipelines. Controlling re-injection temperatures and pH levels have had success for anti-scaling. This study is mainly focused on mineral precipitation conditions and the effective scale inhibition applications at different type geothermal power plants in Western Anatolia (Turkey).

1. INTRODUCTION

Turkey is one of the first countries generating geothermal power with more than 45 geothermal power plants in 2019. Total installed geothermal power capacity is around 1.5 GW_e and increasing number of power projects still continue in the country.

Geothermal power generation is a good option with high capacity factors and independence of weather conditions compared to other renewable energy sources. However, the power plant management is harder than for the other energy sources because of thermodynamic changes of fluids from depth to surface conditions in liquid-dominated reservoirs. General problems in the operational phase of the geothermal power plants are scale precipitations in production wells, surface equipment and re-injection wells, corrosion effect due to non-condensable gases and applying correct reservoir management in the geothermal system (Haklıdır Tut and Balaban Özen, 2019). Some of operational problem can change with power cycle type. The flash-multi-flash power cycles treatment show differences compared to ORC-binary in geothermal systems and scale mitigation is one of them (Haklıdır Tut and Şengün, 2016).

2. GEOTHERMAL POWER PRODUCTION IN WESTERN ANATOLIA

Geothermal power production is mainly provided from two different geothermal systems, the Büyük Mendes Graben (BMG) and the Gediz Graben (GG) in Western Anatolia (Fig.1). The reservoir temperatures vary between 170°C to more than 260°C for geothermal power production in the Western Anatolia (Haklıdır Tut and Balaban Özen, 2019). Depending on the reservoir temperatures, different geothermal power production technologies have been used such as ORC-binary, flash, double-flash, and bottoming cycle (multi-flash and binary) in Turkey. While most of geothermal operator companies in the Gediz Graben have preferred to select ORC-binary, different geothermal power cycles have been used such as; single flash (17.2 MW_{egross}), triple flash and binary systems (60+20 MW_{egross}), (72 +23 MW_{egross}), (50 +23 MW_{egross}) in Kızıldere (Denizli) at the east edge of the BMG and double flash systems (47.2 x 2 units W_{egross}) in Germencik (Aydın) at the west edge of the BMG beside different ORC-binary systems in the middle part of the BMG (Fig.1).

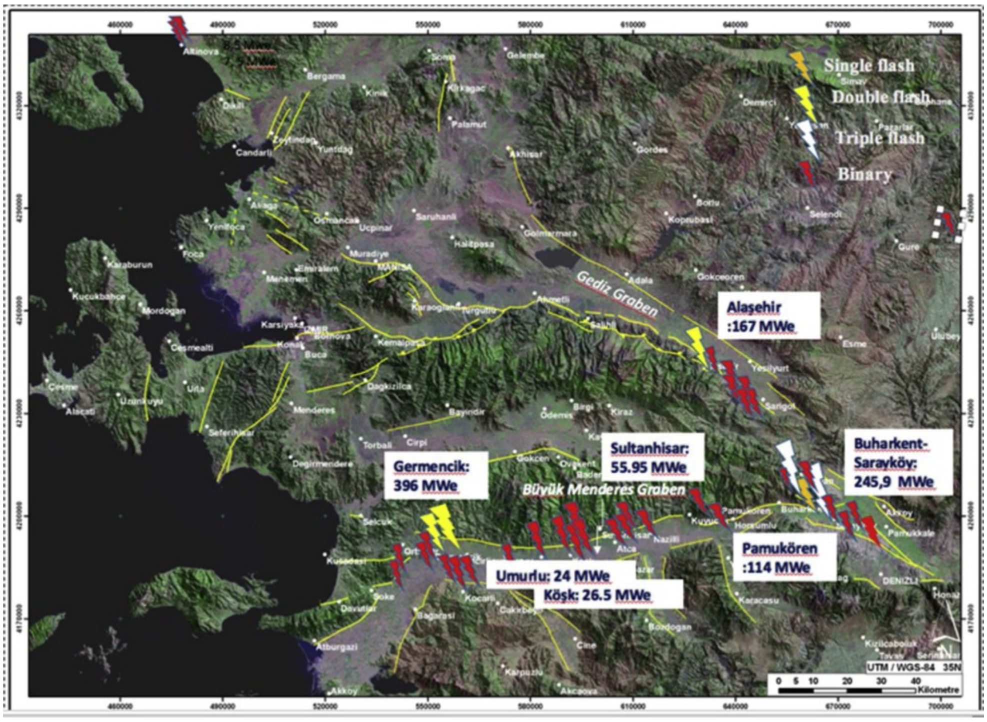

Figure 1: Installed geothermal power plants in Turkey (2018; Haklıdır Tut and Balaban Özen, 2019).

3. THE SCALE PRECIPITATION IN WESTERN ANATOLIA GEOTHERMAL POWER SYSTEMS

The discovered high temperature reservoirs are identified as liquid-dominated type and geothermal fluids consist of hot water, non-condensable gases, and steam in liquid-dominated systems. With this reason, geothermal fluids carry dissolved minerals and dissolved gases to the surface conditions under high temperature and pressure conditions. In a production phase, the flashing process begins in the deeper zones and thermodynamic conditions start to change and it will also provide the first mineral precipitation conditions in the system. At this point, reservoir rock information, NCG amount and temperature will be critical parameters for the determination of precipitated minerals (Haklıdır Tut, 2017). Possible scale minerals can be revealed by water modelling program such as; PhreeqC, Watch software based on the water chemistry and reservoir conditions in a geothermal system.

3.1 The Scale Precipitation in the Medium Temperature Geothermal Systems

If the reservoir temperature is higher than 150°C, an ORC-binary cycle power plant's efficiency will be better (DiPippo, 2016). In Western Anatolia, ORC-binary type geothermal power cycles have been used for electricity production for more than 170°C reservoir temperature conditions. Although the reservoir temperatures is near to 200°C, some of the operator companies also prefer this cycle with easier operational conditions than flash type. At ORC-binary cycle type plants, the thermal energy is transferred through heat exchanger systems from the geothermal fluid to the organic secondary working fluid, which is then vaporized and the steam is sent to the turbine.

In Western Anatolia, the calcite scaling can be observed in each production well due to carbonates levels of the Paleozoic aged Menderes Metamorphic rocks in the geothermal reservoirs in the BMG and GG. Beside calcite precipitation, a metal sulfide mineral which is called stibnite can also be seen as scale mineral at vaporizer and preheater equipment in the system (Haklıdır Tut, 2017; Fig.2). The source of this mineral is thought as gneiss and granite type rocks in geothermal reservoirs (Dost, 2018). At the ORC-binary type, increased H_2S concentration and decreased pH caused by returning steam or condensate to the brine may cause precipitation of stibnite mineral in heat exchangers at the lower temperature in a geothermal system (Haklıdır Tut and Balaban Özen, 2019).

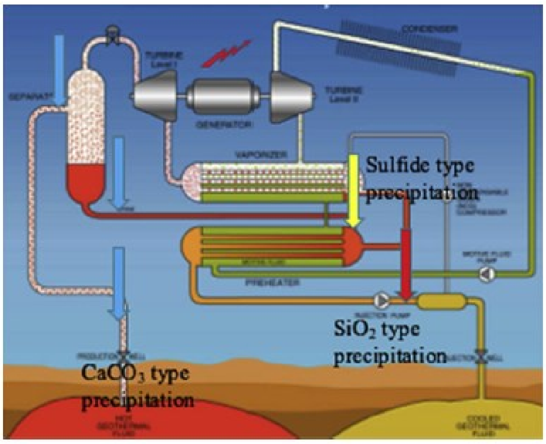

Figure 2: The possible mineral precipitation points in an ORC-binary cycle (Haklıdır Tut and Balaban Özen, 2019).

In the ORC-binary type power plants in Western Anatolia, calcite may precipitate in the production wells and throughout the system. The geothermal fluid flow from the reservoir and through the system, metals silicates and amorphous silica may also precipitate with decreasing temperature conditions. At this type of binary power plants, geothermal fluids provided from the medium temperature geothermal systems in Western Anatolia, reinjection temperature is lower than with flash type power systems and brine requires treatment before the reinjection (Fig.3).

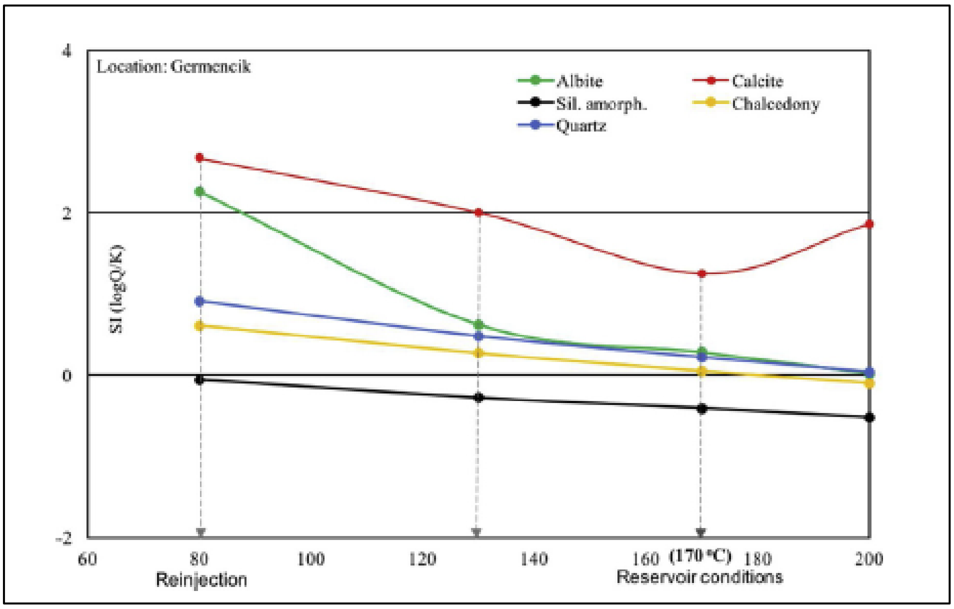

Figure 3: The mineral precipitation ORC-binary cycle systems in Western Anatolia (Haklıdır Tut and Balaban Özen, 2019).

3.2 The Scale Precipitation in the High Temperature Geothermal Systems

There are different potential mineral precipitations from reservoir conditions to the end of the reinjection process in a flash type geothermal power cycles (Fig.4). Based on water-rock interaction, calcite and some metal silicates such as albite tend to precipitate in production wells at high temperature reservoir conditions. During the separation process, the temperature of geothermal fluids decreases and different type of silica minerals tend to precipitate at the surface equipment. Due to decreasing temperature of brine, amorphous silica starts to precipitate and it directly affects reinjection pumps and reinjection lines in a flash type cycle (Fig.5).

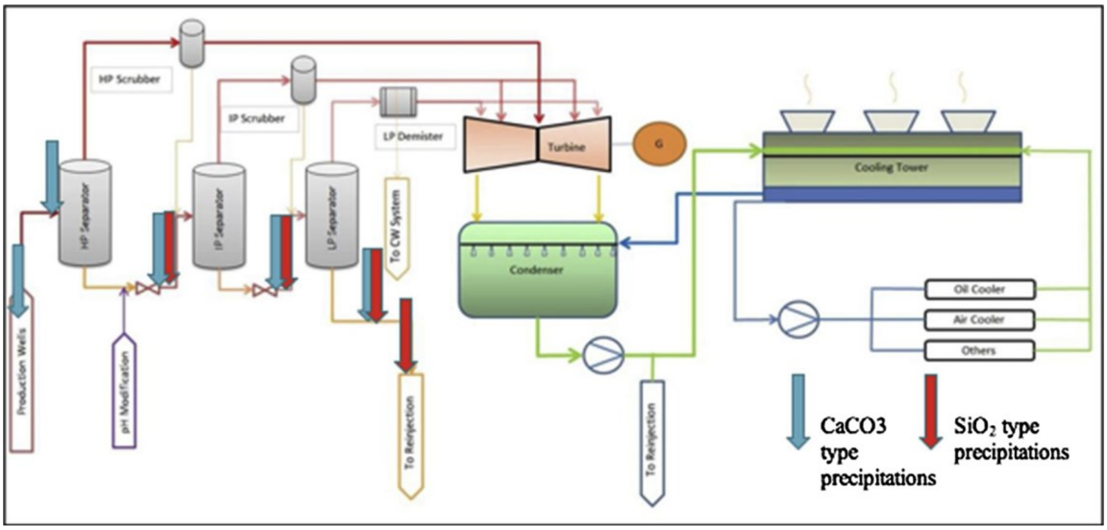

Figure 4: The working principle of a multi-flash type geothermal power plant, with possible precipitation points in the system (modified Richardson et al., 2014).

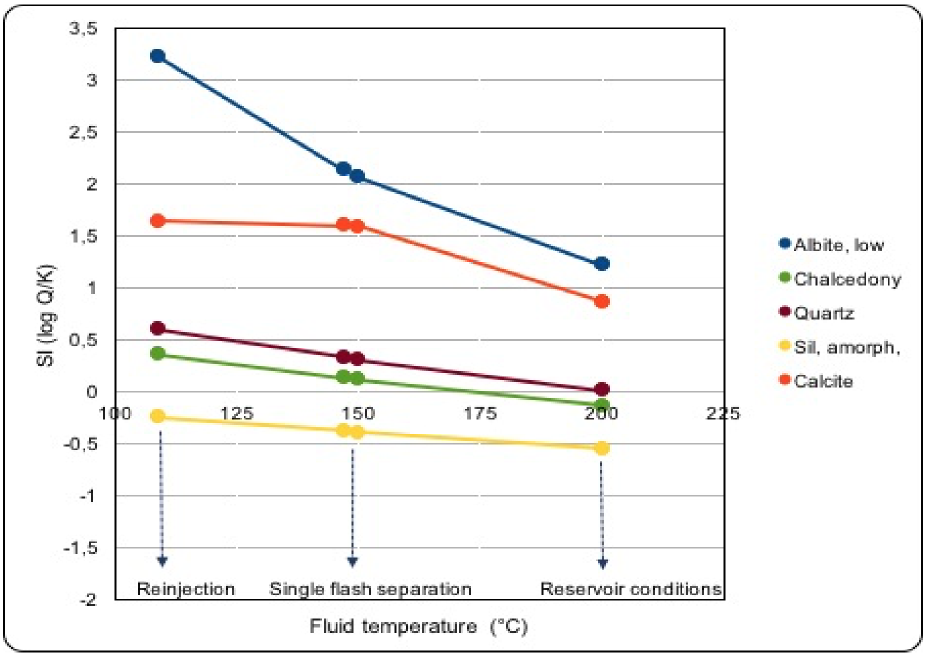

Figure 5: The precipitation points in the flash type power plant in Western Anatolia (Haklıdır Tut and Balaban Özen, 2019).

4. POSSIBLE EFFECTIVE SCALE MITIGATION METHODS IN THE POWER PLANTS IN WESTERN ANATOLIA

The scale precipitation has been prevented by different types of chemical inhibitors since 2009 in Western Anatolia. Before this time, there was no effective chemical inhibitor application and mechanical cleaning in borehole was realized every 6 months by MTA in a certain field (Kızıldere). Nowadays many geothermal power plants are operated by different companies and people have noticed that the scale mitigation is quite important to uninterrupted power production in geothermal power plants.

The effective scale mitigation study depends on the understanding of reservoir characterization, fluid chemistry and the application of the correct inhibitors at optimum dosages for each part of the power plant. It is noted that each geothermal system is unique and to find the best chemical inhibitor and the optimum dosages require field tests. The other important issue is to find the best chemical inhibitor dosages points to prevent scale precipitation in a geothermal power plant. This directly depends on the power cycle, chemistry of geothermal fluids and the operational budget.

In the geothermal market, there are different chemical products and they are mainly categorized as; phosphate salts, polymer type and phosphonate salts+polymer mixture type inhibitors in Western Anatolia. Although the phosphonate type inhibitors are a very effective solution to prevent calcite precipitation, they are generally only suitable up to 200°C reservoir condition and it may corrode metal equipment such as capillary tubing and diffusers in a borehole. The pH of chemicals and dilution factor are also important factors to protect both borehole and surface equipment during the inhibitor application. Polymer type inhibitors are generally preferred for more than 200°C in reservoir conditions, however, they cannot quickly prevent calcite scaling on surface equipment. Using a phosphonate type can prevent the scaling on surface part of the system, as has been tested many times in Kızıldere and Germencik fields in Western Anatolia (Haklıdır Tut and Şengün, 2016).

Due to fast and intensive calcite precipitation, the inhibitor dosing is required at the wellhead and before the separator system just before the steam separation in Western Anatolia. If a power cycle consists of multi separation stations, inhibitor dosing is recommended between different pressured separation stations to prevent calcite and metal silicate precipitation because of pressure and temperature drops of fluids. Calcite and silicate mineral precipitations are the total opposite each other, and that is why we need pay attention to possible precipitations at these points and the water modelling softwares may help to predict them. Silica scaling may be a big problem after steam separation due to dropped water temperature and pH adjustment and controlling brine temperature are the most effective solution. However, weak acid solution or chemical inhibitor application are also applicable alternatives to minimized the scale precipitation.

Stibnite precipitation has been observed in ORC binary type plants such as; Pamukören and Germencik (Efeler-4) binary power plants (Kaypakoğlu et al., 2015; Haklıdır Tut and Balaban Özen, 2019). In binary type power plants, stibnite mineral precipitation has been observed after the vaporizer, preheaters, or reinjection phase, depending on rapid temperature and pressure changes. Cleaning of equipment with high pressure water jets, pH adjustment or the use of caustic chemicals have also been tested as options for dissolution of the mineral in Western Anatolia.

5. CONCLUSION

The scale precipitation is one of the biggest challenge to provide continuously power production in a geothermal system. Calcite, silicate, metal silicates and metal sulfides have been observed as potential scale minerals in geothermal systems. In a system, changing pressure and temperature conditions of geothermal fluids control mineral precipitation from the production to reinjection phase. Although the controlling of scale mitigation is more complex in multi-flash and advanced geothermal power systems than binary cycles, mineral precipitations require physical and chemical monitoring studies to uninterrupted electricity production in geothermal power plants. There are many geothermal power plants and different geothermal reservoir conditions along the BMG and the GG in Western Anatolia. Scale mitigation applications of each geothermal system are evaluated separately to provide the most effective solution to prevent scale precipitations along the graben systems.

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