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The Importance of Geothermal Power Plant Monitoring for Sustainable Power Production

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ABSTRACT

Power production from geothermal resources in Turkey has increased significantly over the last ten years. The first geothermal drilling in Turkey was carried out in 1963. Then, the Kızıldere field was discovered in 1968. The first geothermal power plant, Kızıldere-I was installed in 1984 and the first private geothermal power plant, Dora-I started to generate power in 2006. Although initially there were just two power plants and a total 23 MWe installed capacity in 2006; according to EMRA (Energy Market Regulatory Authority) 2018 year-end data, geothermal based power generation projects reached an installed capacity of 1347 MWe. In addition, 7 new power plants have been under construction with total capacity of 223 MWe.

Geothermal power plants are operated as base-load power plants and therefore, sustainable power production is the most important issue for this type of plant. Sustainable power production of the plants is dependent upon not only the geothermal reservoir conditions, but also the operating conditions and monitoring of power plants.

In this study, the importance of geothermal power plant monitoring is emphasized, and the effects of monitoring and operating conditions of geothermal power plants on sustainable power production during the plant life are explained. Moreover, in order to identify the reasons of performance failures for not reaching full capacity production level of the plants, their operating parameters are continuously followed, and their continuous performance is calculated and monitored. By this way, performance losses are diagnosed whether they are attributable to the plant or to the resource. Several examples are presented.

1. INTRODUCTION

Geothermal power plant investments have increased substantially since 2006 and the installed capacity of geothermal power plant in Turkey has reached 1347 MW. The construction of 7 new power plants with a capacity of approximately 223 MW is still in progress. The geothermal power plant fleet consists of 64 independent units ranging in size from 2.5 to 100 MW (Aksoy, 2019). Figure 1 shows that the change of installed capacity of geothermal power plant in Turkey over time. It is clearly seen that geothermal power plant capacity has increased exponentially over the time. If we assumed that the exponential increase will continue over the near future (in 2020), installed capacity would be estimated close to 2000 MW. The main reason of increasing geothermal power generation in Turkey, is the investment incentives given for private sector in years of 2011 and 2015.

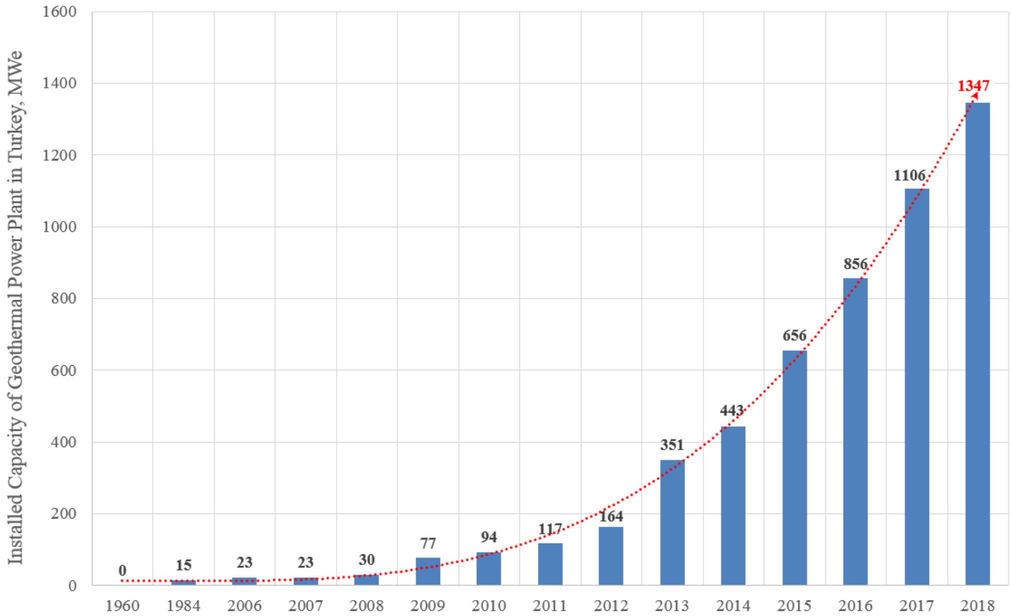

Figure 1. Installed capacity change of geothermal power plant in Turkey.

Sustainable power generation is the most important issue for base-load power plants such as a geothermal power plant. Even though the geothermal resources are one of the renewable and sustainable resources, during the power generation from geothermal power plant, there are some performance failures or unsustainable power production. The main cause of performance failure is due to change of geothermal reservoir conditions, such as; decreasing the reservoir and related well head pressures and temperatures, not enough geothermal fluid production, decreasing the CO_2 in the reservoir, scaling or increasing the formation damage. Another cause of performance failure of power generation from geothermal power plants is mechanical problems, such as; change of operation condition, scaling problem of heat exchangers, insufficient cooling and pump problems.

Monitoring is the best way of understanding how reservoir conditions are changing and how operating conditions affect power production. Different monitoring methods, such as geochemical, geophysical, environmental and mechanical methods are used to maintain sufficient power generation. Moreover, most reservoir and operational data can be collected for the system and therefore, it is a special database that can be easily collected during the long-term plant life. In order to achieve sustainable and optimum power production, operating parameters can be continuously followed, and their continuous performance is calculated and monitored.

2. IMPORTANCE OF POWER PLANT MONITORING AND ITS METHODOLOGY

As mentioned above, Turkey geothermal power plant sector has increased rapidly in the last ten years, and total installed capacity of plants has reached up to 1347 MWe. Although the increasing trend of installed capacity of geothermal power plants has continued, actual average production of plants is nearly 69% of full of operating capacity in Turkey. Figure 2 shows that the change of operating capacity and actual production of geothermal power plants between January-2018 and March-2019. Total operating capacity, which differs from the installed capacity, is the guaranteed capacity at the design point of power plant. Operating capacity can vary between the operating limits of plant. Actual average production means the real time electrical production from geothermal power plant and it is calculated as the arithmetical average of real time hourly production data each month. Capacity usage is the rate of actual average production per total operating capacity. According to Figure 2, capacity usage is decreasing to 60% during the summer term, and then it is increasing during the spring-winter term. Maximum capacity usage is calculated as 76% in February 2019. The main cause of this trend is that most of geothermal power plants in Turkey have an air-cooled condenser system and it is known that air-cooled condenser system performance declines at higher ambient temperatures than design ambient temperature values. On the other hand, there are some power plants with an air-cooled system that can produce 20% higher than expected production during the winter term. According to overall capacity usage value, the performance loss of geothermal power plants is calculated as 31% in Turkey. It is very remarkable that 31% performance loss of geothermal power plant has occurred for the last 5 years. The main reasons for this performance loss are excessive plant capacity installation, declining well productivities depending on the NCG decline in the reservoir, scaling problems in heat exchangers and reinjection wells, nonefficient cooling system design, pump and general plant failures, Aksoy (2019).

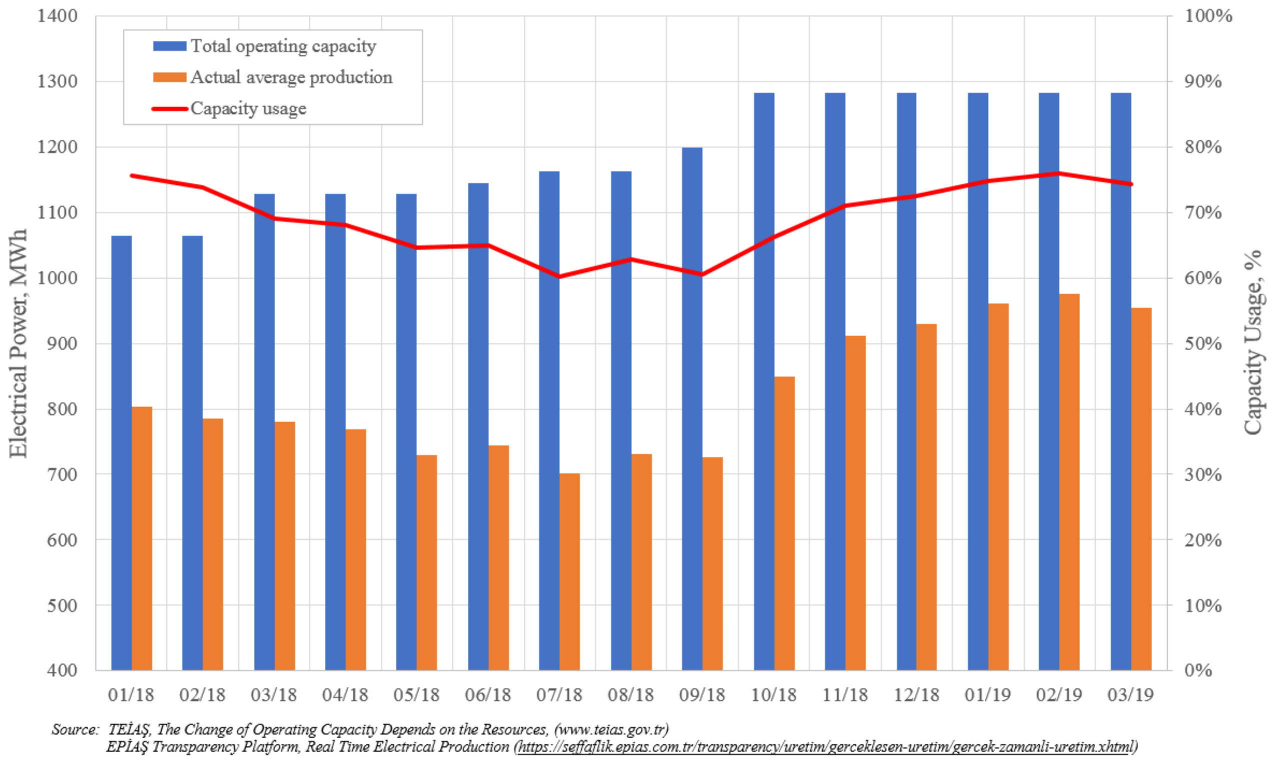

Figure 2. Change of capacity usage of geothermal power plant in Turkey

The main methodology of geothermal power plant monitoring depends on comparing the guarantied capacity of plant and actual power production. Moreover, when using monitoring systems, it can be possible to collect some important parameters and form a special database for each geothermal power plant. Another advantage of using the monitoring system during the power plant operation is easy control of the critical parameters such as geothermal fluid flow rate, geothermal fluid temperature, wellhead pressure, ambient temperature, heat exchangers inlet-outlet pressures, turbine inlet-outlet pressure and some ion concentrations of samples (for example; total $CaCO_3$ hardness and SiO_2) for geochemical analysis.

2.1 Monitoring Important Parameters

The most important parameters that are monitored by SCADA (Supervisory Control And Data Acquisition) in geothermal power plant are production and reinjection well wellhead conditions (pressure, temperature and flow rate), total brine inlet flow rate, total steam or NCG (non-condensable gases) flow rate, brine inlet temperature, reinjection flow rate and reinjection temperature, heat exchangers inlet-outlet pressure, turbine inlet-outlet pressure. All these data and other important parameters can be stored for many years in a single database in order to analyze them comparing with design parameters, and easily understand how parameters change over time and how power plant performance is affected.

2.1.1 Monitoring of Wellhead Conditions

Monitoring of the production and reinjection wells is the most important issue of the operating of geothermal power plant. Moreover, the geothermal power plant is generating power depending directly upon the geothermal resource; because of that, change of wellhead conditions should be monitored to analyze variation over time. Especially, pressure, temperature and flow rate of geothermal fluid from production and reinjection wells are monitored over time and they are stored in the same database every single minute. When it is necessary to analyze each value, it is possible to export the special report depending on time (hourly, monthly or yearly report). Figure 3 and Figure 4 show examples of wellhead monitoring of a production well and a reinjection well in a geothermal power plant in Turkey, respectively. Each figure includes variation of wellhead pressure, wellhead temperature and brine/ steam+NCG flow rate depending on hourly time values from the SCADA system.

According to Figure 3, wellhead pressure trend declines during the period between the first day and after 253 days of production. In these periods, brine flow rate increases with decreasing wellhead pressure. The variation of wellhead pressure during the production is a characteristic property of geothermal wells, and it depends on well productivity. In addition, especially for two phase production wells, the optimum production rate and optimum wellhead pressure can be determined in order to achieve sustainable production from the geothermal reservoir before the separation processes. Reducing the wellhead pressure of a production well is conducted by opening the wellhead control valve to increase the discharge. In that way, wellhead temperature decreases about 12°C within the one year of production. The productivity of the well will be declining with decreasing reservoir pressure directly and causes excessive and unsustainable power production.

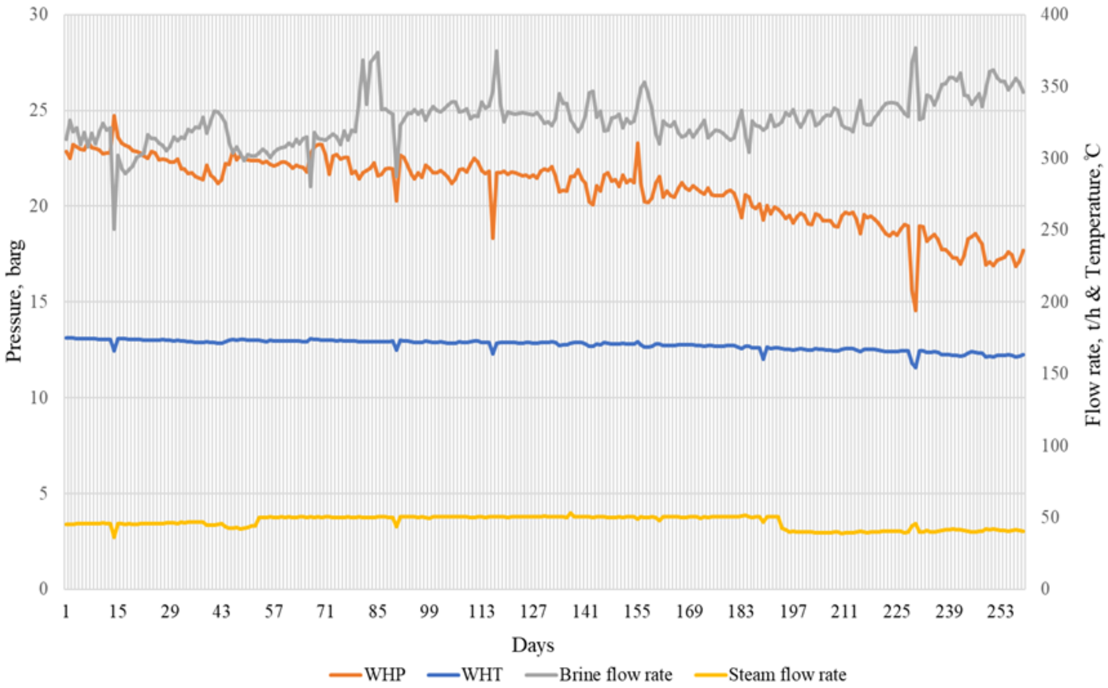

Figure 3. Wellhead monitoring example of one of the production wells for a geothermal power plant.

Figure 4 clearly shows increase of the wellhead pressure of one of the reinjection wells during 300 days of operation. The cause of this WHP increase could be attributed to a scaling problem of the reinjection well or formation damage after the 300 days of production. Acidizing operation was conducted in the reinjection well (Figure 4) to eliminate the scaling and reinjection was switched to other wells. Because of that, reinjection pressure decreased appreciably and then, reinjection pressure increased again over the last 100 days. Effective reinjection affects directly to sustainable geofluid production so monitoring the reinjection wellhead condition is very important for effective reinjection operation on site. In addition, regularly monitoring production and reinjection well parameters helps to plan for the management of a geothermal field.

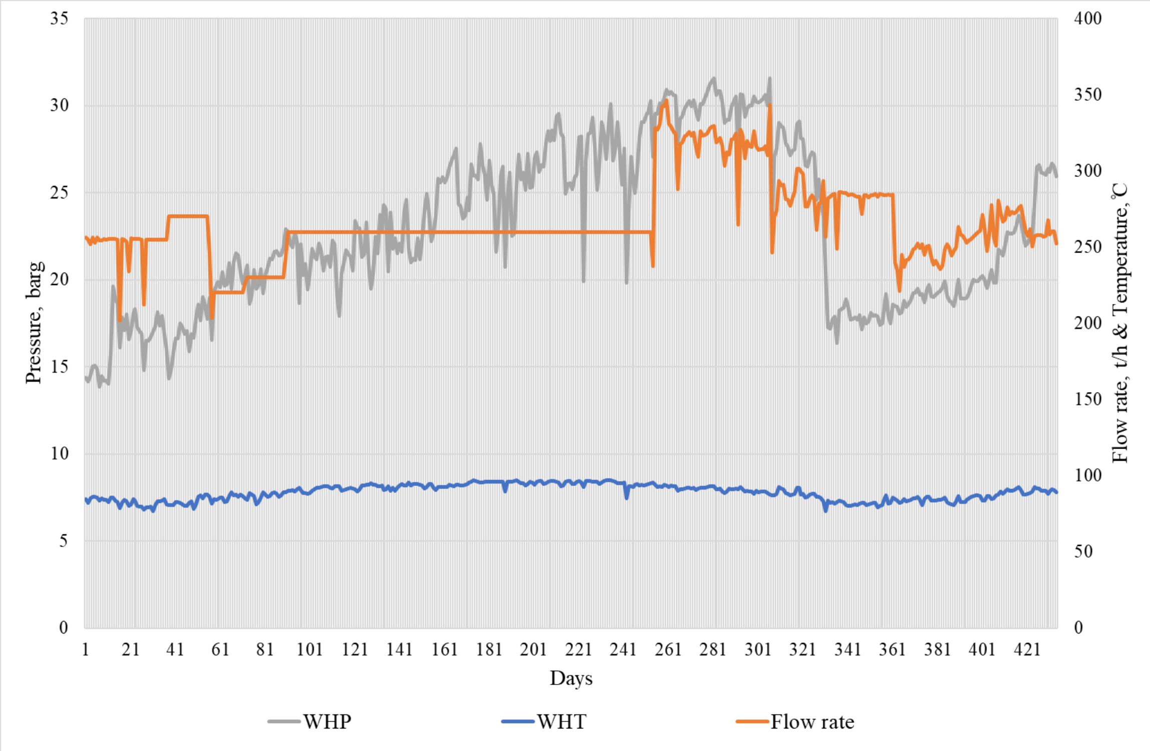

Figure 4. Wellhead monitoring example of one of the reinjection wells for a geothermal power plant.

2.1.2 Monitoring of Power Plant Operation Conditions

Monitoring of geothermal power plant operation condition can be used for the calculation of power plant performance. Moreover, monitoring operating conditions are not only used for performance analysis, but also controlling the whole system for continuous power production. The main parameters that are monitored by the SCADA system are pressure, temperature, flow rate at inlet and outlet of the geothermal power plant, heat exchangers inlet-outlet pressure, turbine inlet-outlet pressure and ambient air temperature.

Figure 5 shows the change of operating conditions of a geothermal power plant over time. All major parameters have been monitored continuously in the field for the analysis of plant performance. The graph includes brine inlet/outlet temperature, brine inlet/outlet flow rate and steam inlet flow rate parameters of a binary power plant. During the operation of geothermal power plant, important parameters are desired to be stable or to be within the operating ranges that are determined by the power plant manufacturers. If the operating conditions occur out of the operating ranges, power plant performance cannot be efficiently calculated. There is an air-cooled condenser system in this plant sample, so brine outlet temperature of the power plant varies with weather conditions. It is expected that when the air-cooled condenser system is used for a binary power plant, the efficiency of the cooling system will be increasing with decreasing ambient air temperature. Because of that, the graph clearly shows that brine outlet temperature of the plant is increasing during spring and summer terms to 95-100°C. Another important parameter is inlet and outlet of brine mass flow rate as is shown in Figure 5. Brine inlet mass flow rate has increased in one year and total inlet mass flow rate of the power plant reaches up to nearly 500 t/h. Outlet flow rate means the total reinjection flow rate. Differences between total inlet flow rate and outlet flow rate nearly equal to the NCG content in the steam phase. This sample geothermal fluid is two phases and includes 2% NCG content of total geofluid production.

During the power production from a binary power plant, heat exchanger pressure drop is one of the most important monitoring parameters for detecting scaling problem. If scaling forms in the heat exchangers, the heat between geofluid and working fluid is not properly transferred, and it may decrease the power production. Because of that, pressure differences in heat exchangers should be monitored and controlled regularly during the power production from binary power plant. Figure 6 shows that the pressure drops in heat exchangers over time for a binary power plant. Inlet and outlet pressures of heat exchangers are measured by pressure transmitters and all data is stored in the SCADA system of the power plant. According to these data, pressure differences of each heat exchanger are easily calculated during the selected time frame. There are two heat exchangers used in the sample power plant, and the variation of their pressure drops are shown in Figure 6. Line 1 represents the increasing trend of HEX-1's (heat exchanger-1) pressure differences between 75th and 225th days of production. Line-1 was reaching up from 0.25 bar to 1.5 bar within nearly 150 days. Line 2 represents the increasing trend of HEX-2's (heat exchanger-2) pressure differences between the first and 250 days of production. Line-2 was reaching up from 1.5 bar to 4.5 bar. According to these data, it can be said that scaling problem should be suspected in the HEX-1 and HEX-2 over that time frame. Monitoring the pressure differences of heat exchangers should be continuous for a long time during the operation of the geothermal power plant, and there are other evidences for identifying exactly the scaling problem. Geochemical monitoring supports these evidences on the scaling in the heat exchangers. If chemical monitoring supports the occurrence of some precipitation in the heat exchangers, it should be mechanically and/or chemically cleaned.

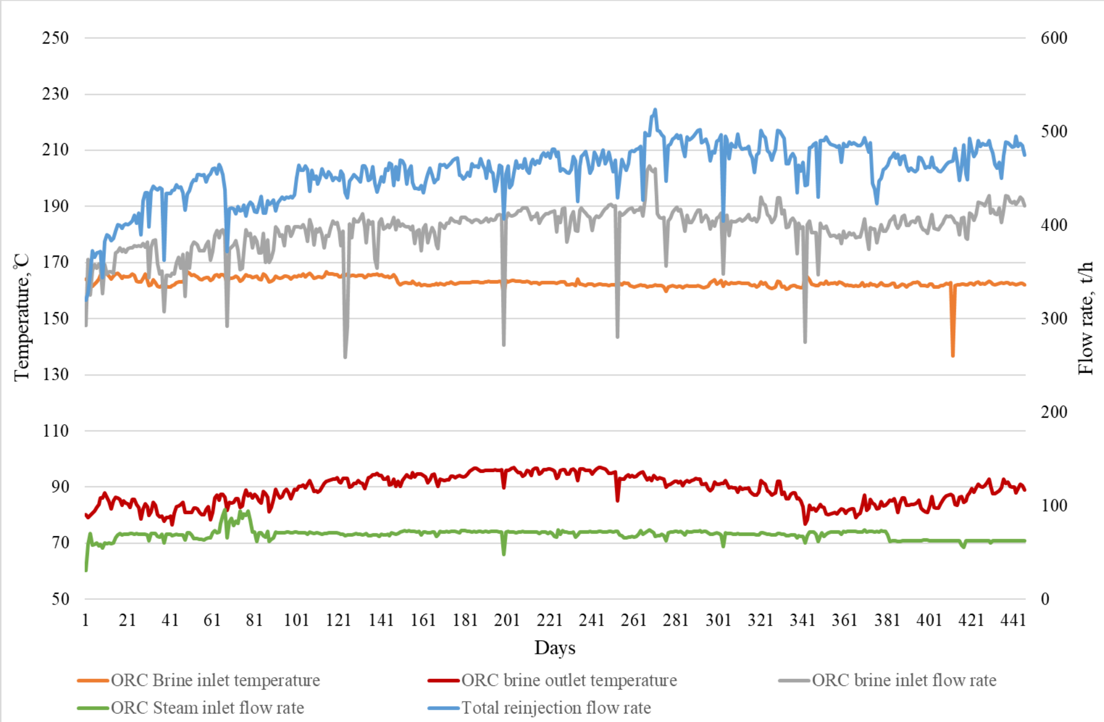

Figure 5. Monitoring of operating conditions of a geothermal power plant.

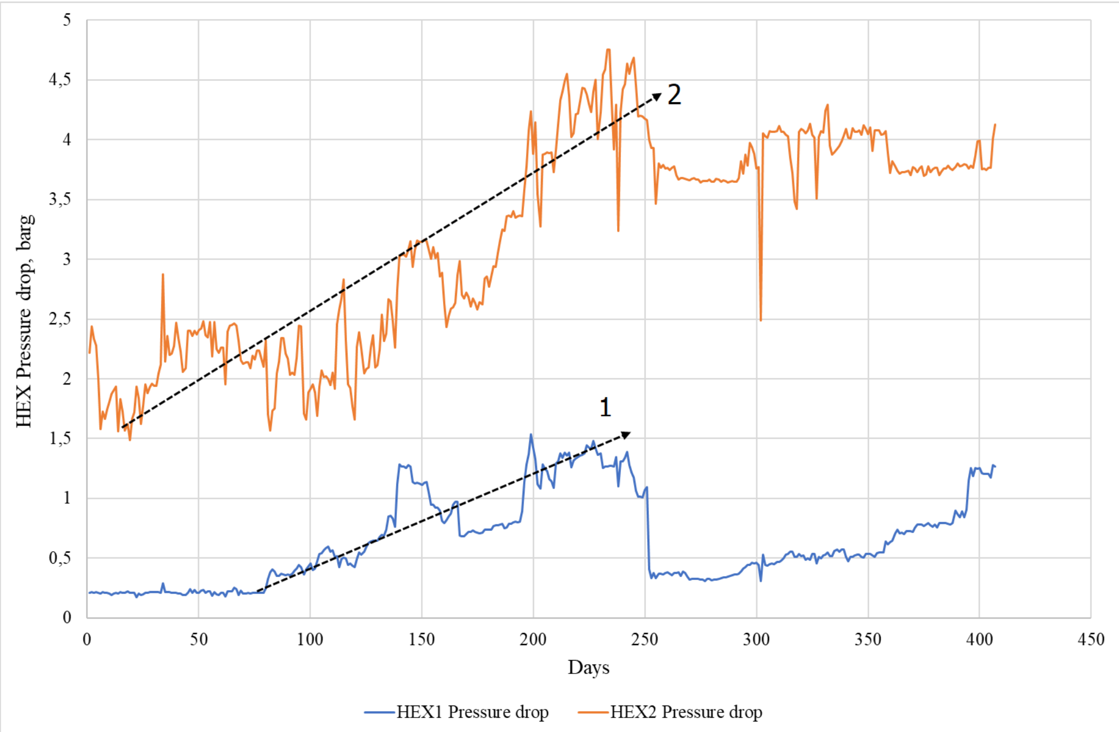

Figure 6. Monitoring of heat exchangers pressure example in a binary plant.

2.1.3 Geochemical Monitoring

Fluid geochemistry is an important property that should be regularly considered during the plant's operation. Some parameters are changed during operation with the aim of improving the performance of the plant, especially; changing controllable parameters such as the fluid pressure and flow rates would affect the plant performance, Toksoy et al. (2007). Moreover, as a result of changing operation conditions, mineral saturation of geofluid might cause precipitation.

Geochemical monitoring follows some important elements and ions which are contained in geofluid and how their concentration is varying with production and reinjection processes over time. The collection of samples from each well in the geothermal field is started after the completion of drilling operation and these data are used as an initial condition of each well and reservoir. Afterwards, during commissioning of the power plant, samples are taken from each production and reinjection well, and also selected special sample points such as; inlet-outlet brine or steam line of power plant and heat exchangers inlet-outlet points. Especially, heat exchanger inlet-outlet lines are the most important points for sampling, because heat exchangers are the most likely scaling problem sites. Every day or sometimes two times a day, the samples should be collected from all selected sample points and important chemical parameters such as; pH, TDS (total dissolved solid), electrical conductivity, alkalinity, Cl, B, F, SiO_2 concentration and $CaCO_3$ hardness are analyzed in the field laboratory.

Figures 7 and 8 show the variation of silica concentration of wells and heat exchangers of two different binary plants. Figure 7 shows the variation of silica concentration of a well during the 6 years of production. Although silica concentration of the sample well was 250 ppm in the first production year, it was decreasing to 188 ppm since 2017. According to following monitoring data, SiO_2 was increasing and reaches up to 230 ppm. Moreover, Figure 8 shows the change of silica concentration at inlet and outlet line of the heat exchangers for another example. It shows that the silica precipitation problem occurred between the 140th and 160th days of the production.

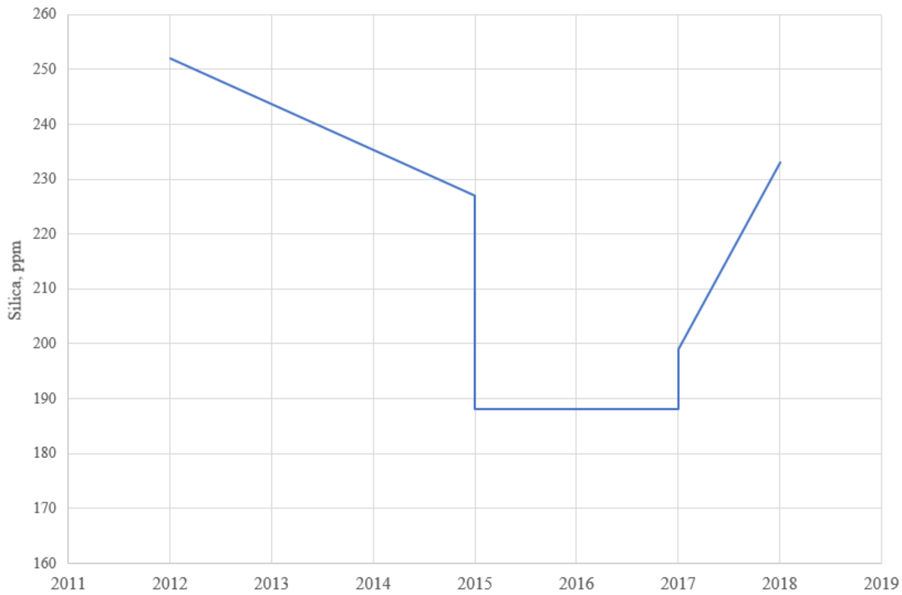

Figure 7. Example of silica concentration change for a sample production well.

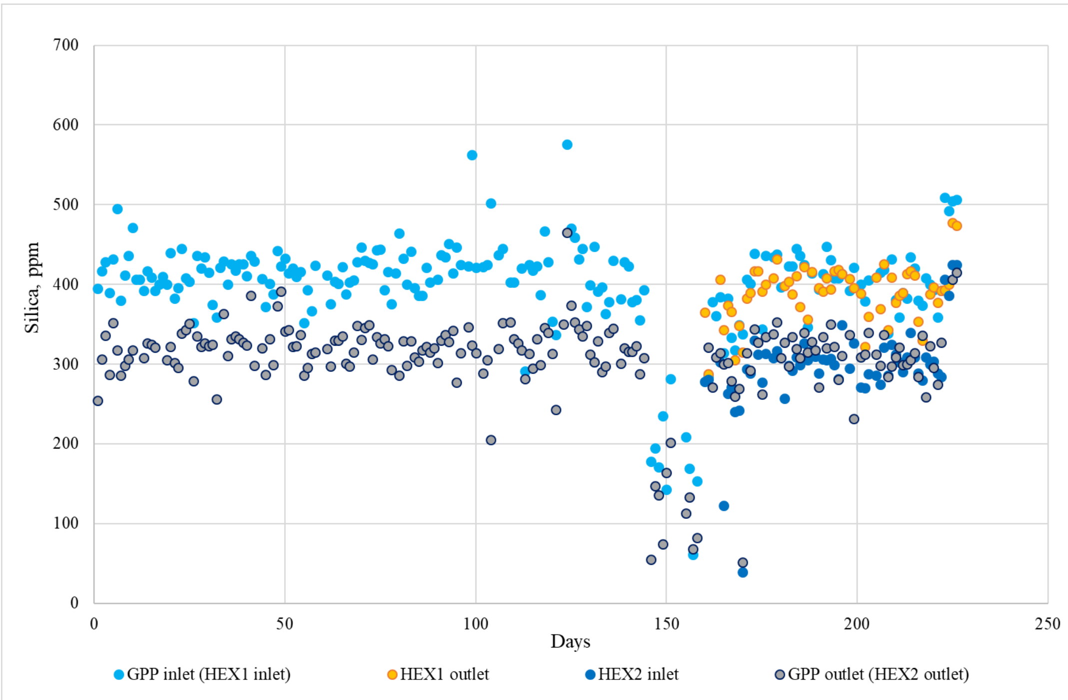

Figure 8. Example of heat exchanger silica concentration change for a binary power plant.

Figure 9 and Figure 10 show the variation of $CaCO_3$ hardness of wells and heat exchangers for a binary plant. These figures were composed from geochemical analyses of wells and heat exchanger inlet/ outlet points during 225 days of production. Although $CaCO_3$ hardness was decreasing from production and reinjection wells in the first 100 days of production, they were stable within the next 125 days. In addition, $CaCO_3$ concentration of P2 and R1 wells started to increase in the last 100 days and P1's $CaCO_3$ hardness was stable. The change of $CaCO_3$ hardness values for heat exchanger inlet and outlet lines are illustrated in Figure 10. It is shown that $CaCO_3$ hardness decreases at each point in the first 2 months after the plant's commissioning, but in the following days it was nearly stable. The $CaCO_3$ concentration differences between the inlet and outlet of heat exchangers were taken into account for determination of $CaCO_3$ precipitation. If the differences of $CaCO_3$ hardness is increasing, there may be $CaCO_3$ precipitation within the heat exchangers. When the $CaCO_3$ or silica precipitation occurs within the heat exchangers; the heat transfer between the geofluid and working fluid will decrease and result in lower power production.

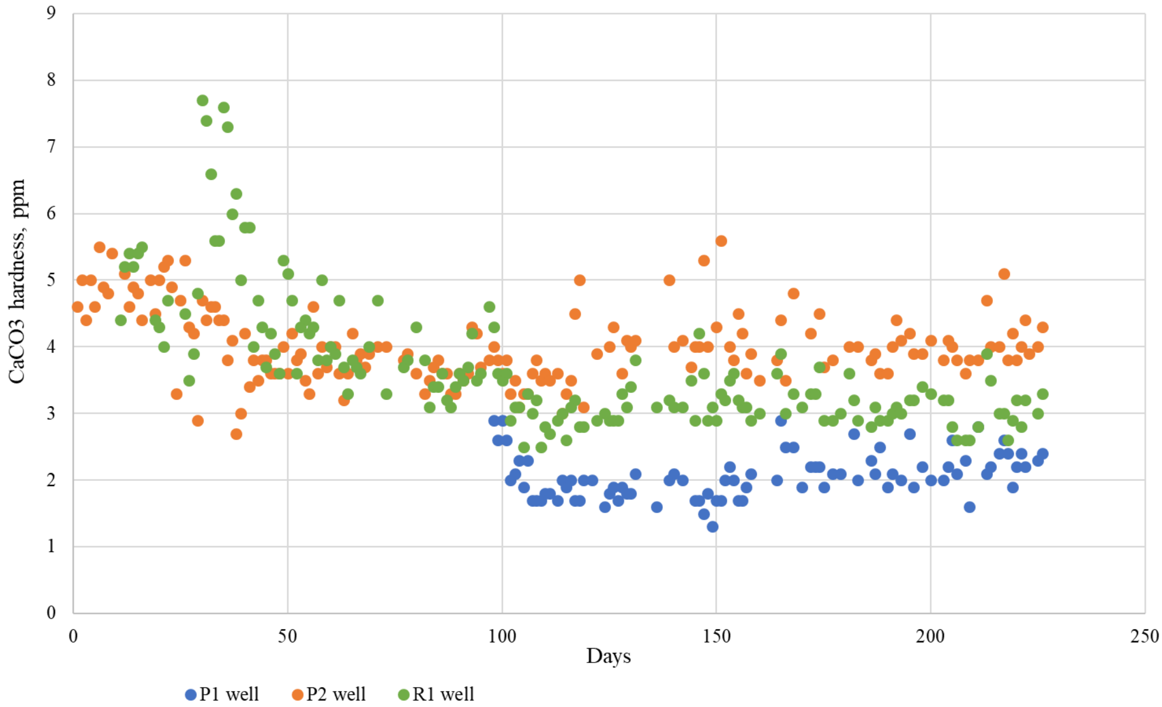

Figure 9. Example of well CaCO3 hardness change for a power plant.

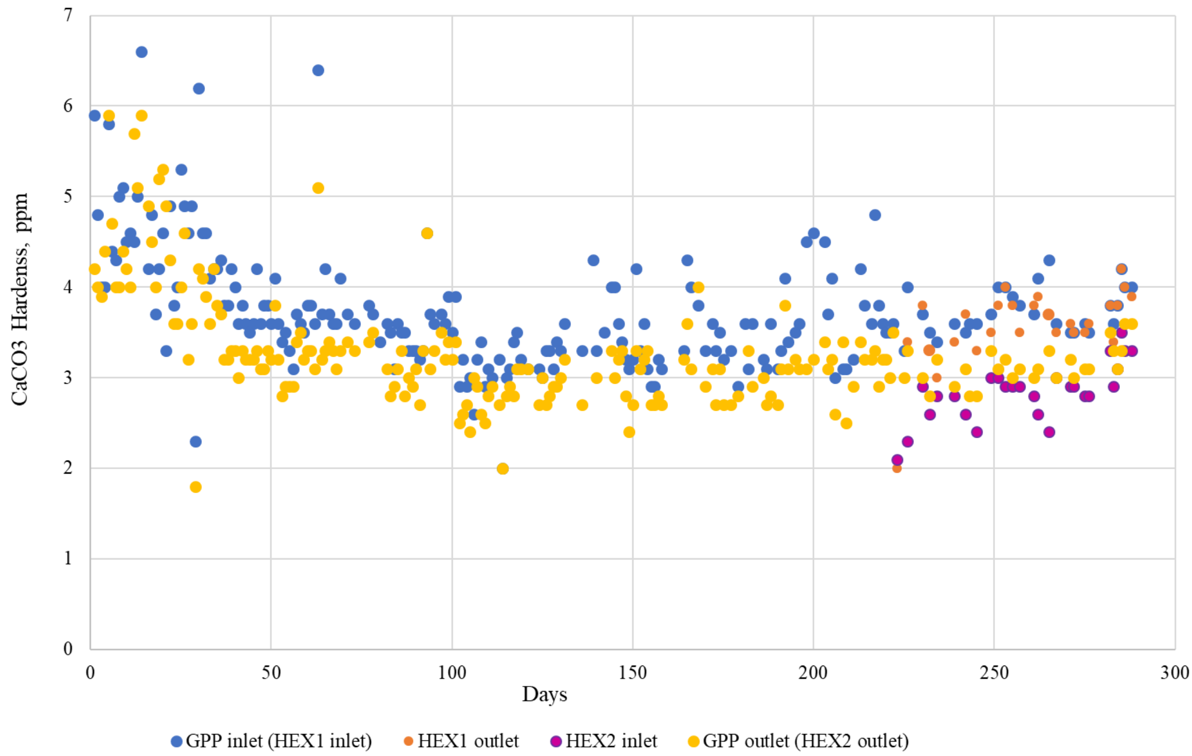

Figure 10. Example of heat exchanger $CaCO_3$ hardness change for a binary power plant.

3. GEOTHERMAL POWER PLANT PERFORMANCE ANALYSIS

According to all the issues mentioned earlier, in order to identify the main reasons of performance failures and calculating the power plant performance, continuous monitoring of all operating parameters and wellhead conditions is needed.

The calculation of power plant analyses depends on the design conditions such as; ambient air temperature, brine or steam inlet flow rate, NCG content of steam, brine inlet temperature. The manufacturing company of the power plant determines the design values and working conditions of all parameters depending on the resource characteristics. The performance of the geothermal power plant is indicated by the ratio of corrected net or gross power and guaranteed power of plant. Corrected gross or net power is calculated using the correction factors of design parameters at any specific working conditions.

Figure 11 shows clearly that the change of performance on net power for a binary power plant depends on the varying ambient air temperature. The design conditions line (blue one) shows how the power performance at different ambient air temperature values is changed. The measurement data (red points) is calculated as the corrected net power divided by guaranteed net power of plant at different ambient air temperature values. According to Figure 11, actual net power is calculated close to the design line and average capacity usage is determined as 98%.

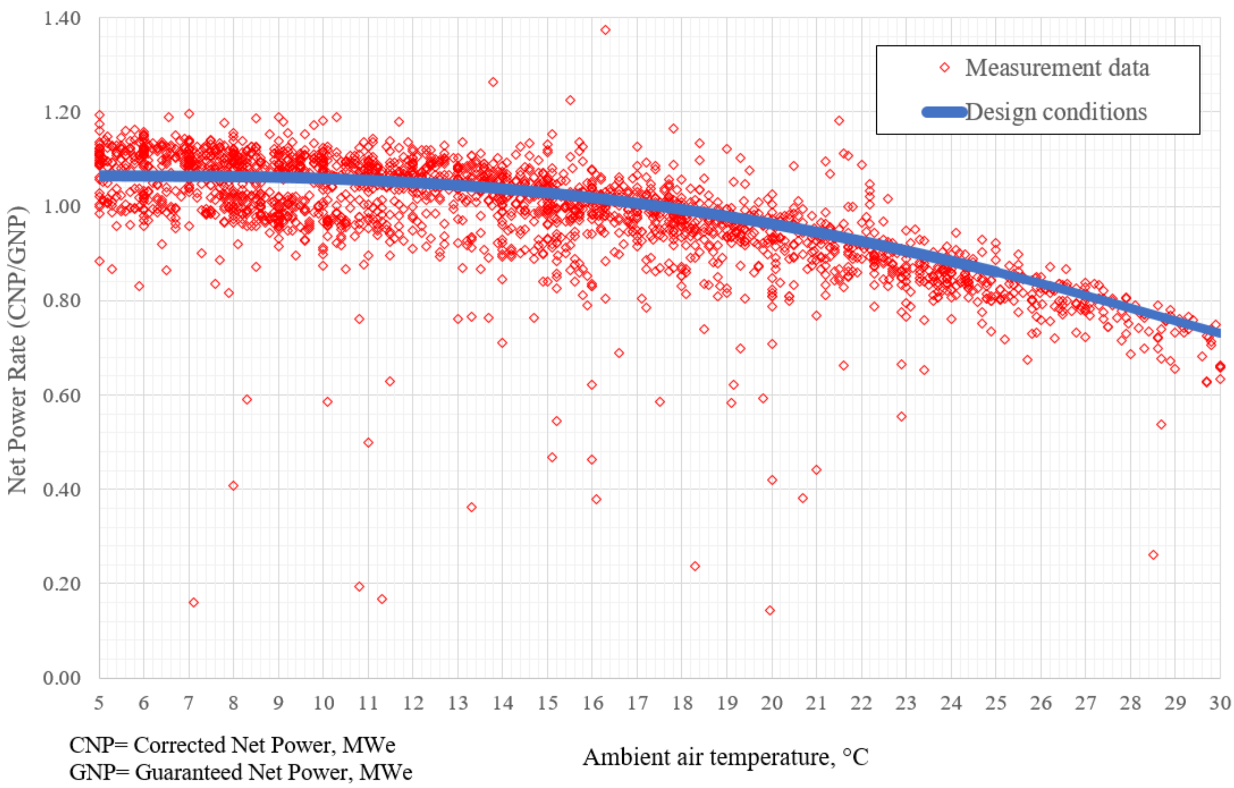

Figure 11. The net power performance for a binary power plant.

Another example of performance for a binary power plant is presented in Figure 12. It shows the change of gross power performance in terms of varying ambient air temperature values for a binary geothermal plant. The corrected gross power values are calculated with one-year real time monitoring data. According to Figure 12, the sample power plant gross performance is less than the guaranteed gross power value depending on the varying ambient air temperatures. Average gross power capacity usage value is calculated as 90%. The lower capacity usage can be attributed to decrease of the productivity of wells and operational problems such as; scaling, non-effective cooling system, pump or general power plant failures. There are different reasons that combined to cause lower capacity for the sample power plant. Two of them are associated with the geothermal resource, namely flow rate and temperature values. Current average brine inlet flow rate and temperature values are under the design values during the one year production period. Another reason for the lower capacity usage of the sample power plant is the non-effective cooling system. Although the design reinjection brine temperature is 79°C, the current average reinjection temperature is 87°C. It means that the air-cooling condenser system does not work efficiently. Another reason for lower capacity usage was found to be a scaling problem within the vaporizer. Evaluating of monitoring data and calculating the pressure drop of all heat exchangers identified the scaling problem in the second level vaporizer. The pressure drop of the vaporizer increased from 1.5 barg to 4.8 barg.

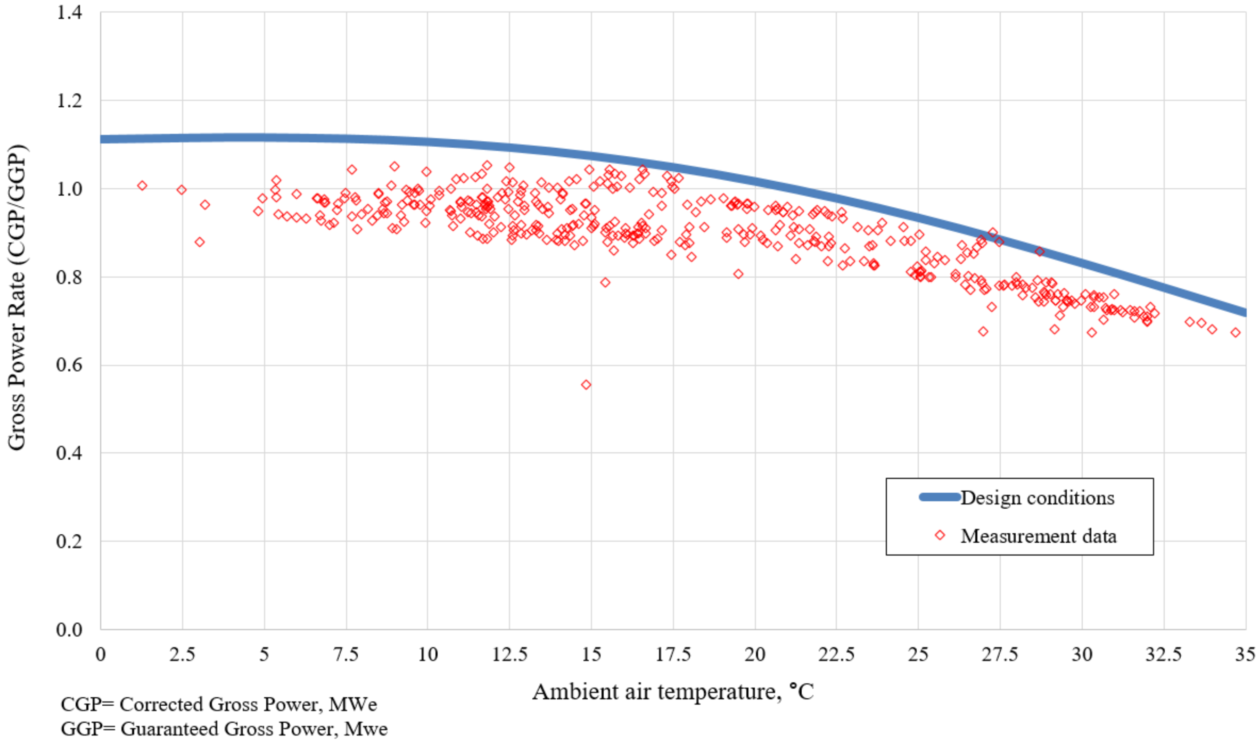

Figure 12. The gross power performance for a binary power plant.

4. CONCLUSION

The installed capacity of geothermal power plants in Turkey has reached 1347 MWe. Unfortunately, themaximum capacity usage of geothermal power plant in winter was calculated to be 76% according to real time electrical production. Causes for lower capacity usage might be associated with the resource or operational or general failure of plant. Power plant monitoring is very important and useful for diagnosing the true reasons of failure. At the same time, the monitoring systems have formed a special database for long term production history and comparison.

The purpose of this study is emphasizing the importance of power plant monitoring in order to identify the reasons of performance failures. In this study monitoring parameters (wellhead and operational conditions), geochemical monitoring and gross/ net performance were investigated with specific examples.

In conclusion, using monitoring systems and evaluating all parameters depending on the design and operational conditions should be used for sustainable power production.

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