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Developing Geothermal Power Plants for Geothermal Fields in Western Turkey

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ABSTRACT

In this study, characteristics of geothermal resources in Western Turkey are presented, and their influence on the performance of power plants is described. The performance of existing single flash, double flash, and binary ORC power plants are compared and discussed. Finally, it is demonstrated that some advanced versions of ORC plants provide an efficient solution for specific thermodynamic and chemical properties of geothermal fluid sources.

1. INTRODUCTION

Most of Turkey's geothermal fields are located in the western part of the country. Large graben structures such as B. Menderes and Gediz that formed in this Aegean region house some of the most important geothermal systems discovered so far in Turkey. Geothermal fields found along the Menderes and Gediz valleys are characterized as having low to medium enthalpy levels and relatively high content of non condensable gases (NCG), which are typical for Turkish geothermal systems. While these gases create problems in power generation facilities and scaling within wellbores and surface facilities (which require special creative solutions for prevention), they are useful for providing energy in the driving mechanism within the geothermal reservoirs because of their high partial pressures. On the other hand, bicarbonate type geothermal fluids have a high $CaCO_3$ scaling tendency. Geothermal power plant design must take all these resource characteristics into account.

There are three types of power plants installed in Turkey: single flash, double flash and binary plants. Bottoming binary plants could also be included in this power plant stock. In this paper, some solutions of utilization of the geothermal energy in western Turkey is analyzed using the data of the fields with installed power generation facilities. In this analysis, single flash technology is compared to double flash, simple binary, two level binary, and two phase binary plants. In addition to the degree of enthalpy, the effects of NCG and scaling problems on the selection of of cycle type and on power plant performance were also investigated. Moreover, experience gained and lessons learned from the power plants in these geothermal fields are presented, which will be transferred to future plants. Finally, recommendations are made concerning the installment of future geothermal power plants in this area.

2. GEOTHERMAL RESOURCE CHARACTERISTICS AFFECTING POWER PLANT DESIGN

Geothermal resources discovered in Western Turkey are of the "Basin and Range" type. Exploration efforts revealed that they are mainly low to medium enthalpy geothermal systems, with a handful of high enthalpy exceptions. Their enthalpies range from 600 – 1060 kJ/kg. Geothermal systems that developed in the metamorphic environment of this region have similar geothermal fluid compositions. That is, they are bicarbonate (soda) waters, with typical total dissolved solids (TDS) levels of 1500 – 4500 mg/L (Mutlu, and Gulec, 1998). They have low Cl and high SO_4 contents. Further, geothermal fluids have high amounts of non-condensable gases, with contents ranging from 1 – 2.5% by weight of fluid (Serpen and Uğur, 1998).

Studies conducted on different geothermal fluids at different temperatures by Mutlu (1996), Serpen and Palabiyik (2008), and some other authors indicate that geothermal waters in Western Turkey are oversaturated with calcite and aragonite at all temperatures and therefore, precipitation of calcite and aragonite occurs in the Turkish geothermal fields. $CaCO_3$ scaling is a serious concern in almost all Turkish geothermal fields since two-phase flow occurs in the wellbores. Separation of CO_2 results from flashing in the wellbore due to pressure decline during the flow to the surface, and this triggers immediate oversaturated calcium carbonate precipitation. So far, this problem in the medium to high enthalpy Kizildere geothermal field has been handled by mechanical cleaning. This results in substantial power production losses due to throttling of well diameter between mechanical cleaning operations.

On the other hand, silica precipitation might be a potential problem in the case of double flash power plants installed in medium to high enthalpy geothermal fields because of the very low pressure of the second flash. A modeling study by Lindal and Kristmandotter (1989) pointed out that at saturation temperatures around 115 – 120^{o}C, silica scaling is very likely in the Kizildere geothermal field. If geothermal fluid is not properly handled before reinjection, silica precipitation in the reservoir is possible. Thus, calcium carbonate and silica scaling is a potential problem for these moderate and high enthalpy geothermal waters.

Since $CaCO_3$ concentration is high in the geothermal fields of western Turkey, heat exchangers reduce the deposition potential due to the retrograde solubility of calcite. Therefore, a binary cycle design can eventually be considered suitable. Another important advantage of the binary cycle technology is its ability to overcome the carbon dioxide problem caused in the condenser. The fluid produced from the well travels through the heat exchangers and is reinjected. This operation has a second benefit since it might feed CO_2 into the reservoir (if CO_2 sequestration is desired), enhancing its energy level, providing pressure maintenance, and reducing scaling tendency by increasing the reservoir pH level (Serpen and Türkmen, 2005). At present, CO_2 is sold to liquid CO_2 producers.

3. OPTIONS FOR RESERVOIR UTILIZATION

3.1 Low enthalpy reservoir

A typical example of a low enthalpy reservoir is the Salavatli field located 30 km east of Aydın. The enthalpy of this reservoir is between 640 and 730 kJ/kg, and it contains about 1% of NCG (weight % of total flow). The geothermal fluid flows spontaneously at a well head pressure of 12 bara and consists of a very small fraction (2.2%) of steam mixed with NCG (more than 50% of the gas content). At this very low enthalpy and high NCG content, single flash or double flash steam cycles would be an inefficient and uneconomical choice. The optimal well head pressure and separation pressure for a flash option must be very low in order to increase the steam portion, but even at a separation pressure of 4 bara, the steam fraction is only 4%, and the NCG content is 25% of total gases.

The selected solution for the Salavatli field (plants Dora 1 and Dora 2) was to use the integrated two level (ITLU) type of binary plant. The ITLU is a type of Organic Rankine cycle (ORC) in which the boiling of the working fluid is performed at two pressure levels, resulting in a better utilization efficiency and allowing for cooling of the geothermal fluid to a lower temperature. The process flow diagram of the Dora 2 plant is shown in Figure 1.

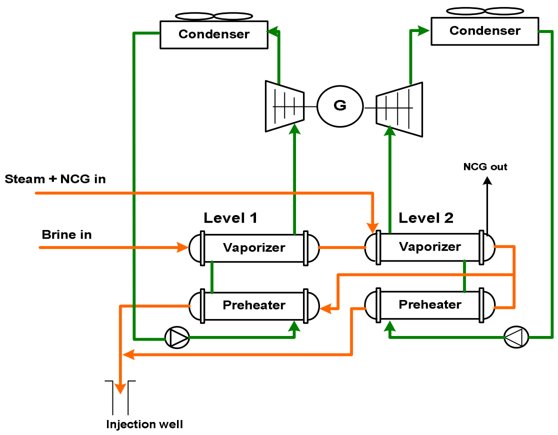

Figure 1: ITLU process flow diagram for the Dora 2 plant

As can be seen in the diagram, the gas portion of the heat source is introduced into the level 2 vaporizer, where it better fits the boiling temperature. The NCG are released from the rear end of the vaporizer with traces of the uncondensed steam. No compressor or vacuum pump is required to release the NCG, since the steam condensation is performed at above atmospheric pressure.

The relatively high well-head pressure of binary plants results in a much higher flash point within the wellbore, and the calcite scaling starts at a higher elevation and is less significant. This eliminates the risk of flashing and scaling within the formation, which is much more difficult to clean and to prevent. With the higher flash point, a shorter capillary tube can be installed in the well for the injection of inhibitors.

After 3 years of binary power plant operation in the Salavatli geothermal field, no scaling has been observed in the ORC heat exchangers or in the reservoir where waste water is reinjected. The application of inhibitor injection in the geothermal wells in this field has also helped to prevent scaling.

3.2 Medium enthalpy reservoir

The fields of western Turkey also include medium enthalpy reservoirs, with typical examples being the Kizildere and Germenchik fields. There are some higher enthalpy wells, but the average enthalpy in those fields is between 950 and 1050 kJ/ kg. Geothermal wells in western Turkey are characterized by a very high content of non condensable gases (NCG) consisting mainly of CO_2, which may reach 2.5% of the total flow. The brine contains high concentrations of bicarbonates (HCO_3) and relatively low content of silica (S_iO_2).

Utilization of the above medium enthalpy, high NCG fluid can be performed using a flash type steam cycle or a binary type plant.

A flash type steam cycle is very popular in medium enthalpy geothermal resources and can be found worldwide at power plants with capacities of 20 MW or higher. Such plants are usually water cooled and equipped with low pressure (vacuum) condensers with an NCG evacuation unit consisting of a mechanical compressor, steam ejectors, or a combination of the two. As long as the NCG content is no more than around 2% of the steam content, the power and/or the steam quantity spent on NCG pumping is at a reasonable level of no more than 5% of the generated power. At higher NCG levels, the power and steam spent on NCG pumping reach such high levels that the use of the steam cycle becomes a questionable choice. For example, the power required to pump NCG gases in the Kizildere plant is more than 15% of the generated power.

The alternative to the flash type steam cycle is a two-phase type binary plant. This type of plant uses both the steam and the brine coming from the separator as a heat source for an ORC type power unit. The steam enters the vaporizer, boiling the organic fluid while being condensed, and it is then mixed with the brine and used to preheat the working fluid in the pre-heater.

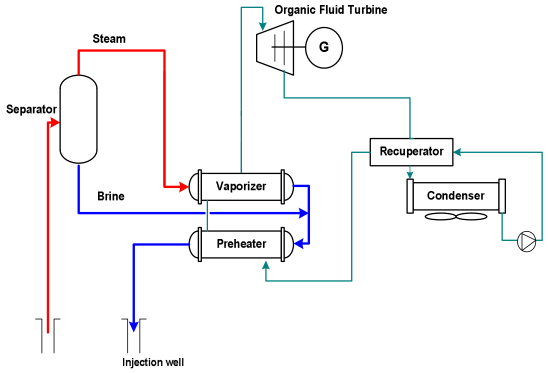

Figure 2: Two phase binary cycle PFD

There is a very good match between the heat required for preheating and boiling the organic fluid and the heat available in the steam and brine. The influence of the high

NCG content in the steam is not as significant as in the steam cycle case. As can be seen in the example calculation below, the power loss as a result of 10% NCG content is around 5% compared to the much higher influence of the same NCG level on a steam cycle.

4. TECHNOLOGY COMPARISON

A comparison between the two utilization concepts of medium enthalpy heat sources similar to the Kizildere field was performed. The double flash steam cycle and two phase binary cycle were compared at a low NCG content of 0% and a high level of 10%. The performance of a theoretical power plant was calculated using the heat source parameters given in Table 1.

Table 1: Heat source parameters of theoretical power plant

Total fluid flow	1000 t/h
Fluid enthalpy	950, 1000 and 1050 kJ/kg
Injection temperature	105ºC for the binary option and the optimal 2nd flash temperature for the flash option.
Ambient air temperature	15ºC
Condensing pressure for the flash option	0.1 bar a

For the double flash option, a set of calculations was run for each enthalpy level to find the 1st and 2nd flash pressures and calculate the maximum power output from the given resource parameters. The calculation of the two-phase cycle assumed both the steam and brine, cooling the mixture of brine plus condensate to a temperature of 105ºC.

Table 2: Analysis results at 0% NCG

Fluid Enthalpy (kJ/kg)	950	1000	1050
Double Flash gross (kW)	25,700	28,900	33,800
Double Flash net (kW)	23,100	26,000	30,400
Two Phase Binary gross (kW)	26,900	29,600	31,600
Two Phase Binary net (kW)	23,900	26,300	28,100
Separation press. for D. Flash (bara)	6	7.5	8.5
Second Flash press. (bara)	1.1	1.2	1.3
Separation press. for Binary (bara)	11	11	11

It is shown in Tables 2 and 3 that at 0% NCG, the double flash cycle has a small advantage at the higher enthalpy level, while the two-phase binary is better at lower enthalpy levels due to the higher content of brine.

In the case of 10% NCG content, the two-phase binary design has a significant advantage in the entire range of enthalpy levels due to the high levels of auxiliary power and/or steam consumed by the NCG compressors (vacuum pumps) and ejectors. The advantage of the two-phase binary cycle over the flash cycle begins to become apparent at much lower NCG levels.

Table 3: Analysis results at 10% NCG

Fluid Enthalpy (kJ/kg)	950	1000	1050
Double Flash gross (kW)	23,100	26,000	30,400
Double Flash net (kW)	17,900	20,200	23,600
Two Phase Binary gross (kW)	25,500	28,100	30,000
Two Phase Binary net (kW)	22,700	25,000	26,700

The power generated by a binary cycle plant may even be higher due to the relatively low content of silica in the brine, which may permit the extraction of more heat and the injection of the brine at lower temperatures.

As can be seen in Table 2, the optimum separation pressure of the binary cycle is higher than the one for the flash cycle. The high separation pressure and the resulting higher well head pressure cause the flash point in the wellbore to be at lower depths, thus reducing the carbonate precipitation and allowing the installation of a shorter capillary tube for the injection of inhibitors.

5. DISCUSSION AND RESULTS

The scaling tendency and high CO_2 content of Western Turkish geothermal fluids largely influences geothermal power plant cycle selection. Flash cycles (single and double) used in medium and high enthalpy fields do not seem suitable for this type of geothermal fluid because of the large scaling tendency at low separation pressures and the very high auxiliary power consumed by NCG pumping. It would be difficult to control precipitation of silica and calcite at low separation pressures even if inhibitors are used. In Kizildere, double separators (one standby) are used to provide continuous operation.

The high carbon dioxide content of geothermal fluids provides extra energy for the driving mechanism in the geothermal reservoir but creates serious problems in the surface installations. By using binary and combined cycles, the CO_2 extraction problem is solved, and extra power can be generated by lowering parasitic losses.

Modular type binary units provide an efficient and economical solution to the problematic conditions in the geothermal reservoirs of western Turkey. The modular units are of the integrated two level unit (ITLU) type for low enthalpy reservoirs and the two phase type for medium enthalpy reservoirs. The units utilize both the brine and the steam portions of the geothermal fluid and reduce the influence of the high NCG content significantly compared to flash type steam cycles.

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