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Improvement potential of a real geothermal power plant using advanced exergy analysis

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ABSTRACT

The main purpose of this paper is to quantitatively evaluate thermodynamic performance of a geothermal power plant (GPP) from potential for improvement point of view. Thus, sources of inefficiency and irreversibilities can be determined through exergy analysis. The advanced exergy analysis is more appropriate to determine real potential for thermodynamic improvements of the system by splitting exergy destruction into unavoidable and avoidable portions. The performance critical components and the potential for exergy efficiency improvement of a GPP were determined by means of the advanced exergy analysis. This plant is the Bereket GPP in Denizli/Turkey as a current operating system. The results show that the avoidable portion of exergy destruction in all components except for the turbines is higher than the unavoidable value. Therefore, much can be made to lessen the irreversibilities for components of the Bereket GPP. The total exergy efficiency of the system is found to be 9.60%. Its efficiency can be increased up to 15.40% by making improvements in the overall components. Although the heat exchangers had lower exergy and modified exergy efficiencies, their exergy improvement potentials were high. Finally, in the plant, the old technology is believed to be one of the main reasons for low efficiencies.

1. Introduction

Geothermal energy is utilized for generating electricity, space heating and cooling, greenhouse heating and industrial processes. Geothermal heat energy has been identified as an efficient source of power for over ten decades. The number of geothermal based power plant systems available in practice is quite high. There are three major types of geothermal power plants (GPPs) operated nowadays: dry and flash steams and binary cycle plants. Binary and combined flash/binary plants are more recent designs. The suitable technologies for geothermal source with high-temperature (above 150 °C) are single and double flash power plants. Geothermal water can be directly used to produce power by these plants. Binary power plants that operate indirectly on geothermal are more convenient for geothermal source with medium temperature (between 90 and 150 °C) [1].

In geothermal power plant systems with high or medium temperature geothermal fluid, the energy consumption, the energy losses, the thermodynamic efficiency, and the product costs are inevitable topics. Focus associated with thermal efficiency is shifting from thermal analysis method to further thermal analysis methods that evaluate thermodynamic inefficiencies for achieving sustainable development. The conversion efficiency of geothermal power developments is generally lower than that of all conventional thermal power plants. According to Ref. [2], the average conversion efficiency of binary cycle GPPs is 12% around the world. The overall conversion efficiency is affected by many parameters including the power plant design (single or double flash, triple flash, dry steam, binary, or hybrid system), size, gas content (non-condensable gases – NCG), dissolved minerals content, heat loss from equipment, turbines and generators efficiencies, parasitic load, ambient conditions and other parameters.

Both better energy efficiency and reduced system costs are two challenges facing the energy engineer in the design of modern GPPs. There is an increasing need to reduce the impact of waste created by these systems on the environment and an increasing global demand for energy; thus, more accurate and systematic approach to enhance the design of energy systems has become

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extremely important. Especially exergy analysis is the used exergy consumption (due to irreversibilities) to perform a process and exergy transportation to environment, namely, for determining the identification and the amount of exergy losses. These real inadequacies can illuminate improvement areas of a system. Such an analysis has been discussed extensively over the years and has been applied to GPP systems. Some studies on thermodynamic evaluation of GPP systems with the exergy analysis have been summarized as follows: Exergy efficiencies of single and double flash cycles were reported by Bodvarsson and Eggers [3]. They are 38.7% and 49.0%, respectively, based on the resource water temperature in 250 °C and the sink temperature in 40 °C. DiPippo and Marcille [4] used a 140 °C resource and 10 °C sink, as 20% and 33.5% based on the exergy input to the plant and to the Rankine cycle, respectively to find the exergy efficiency of the existing binary GPP. A binary GPP considered by Kanoglu and Cengel [5], using a 158 °C resource and 3 °C sink, had an exergy efficiency of 22.6% and 34.8% for the plant and the Rankine cycle, respectively. Kanoglu [6] evaluated exergy analysis in the Stillwater dual-level binary GPP with 12.4 MW in Nevada (USA) by using real operating data. Cerci [7] used the exergy analysis to thermodynamically evaluate by using actual operating data for a single-flash GPP in Denizli (Turkey). The second law efficiency of the plant was calculated to be 20.8%.

DiDippo [8] enquired binary type power plants having geothermal fluids with low temperature to assess their exergy performances. He revealed that these plants can operate with very high exergy efficiencies even in geothermal fluids with the nominal temperature and nominal exergy. Dagdas et al. [9] performed thermodynamic optimization of the Denizli-Kızıldere flash GPP by using real data, and investigated the most suitable working fluid for the binary cycle. Ozturk et al. [10] gave an energy and exergy evaluations of GPPs and analyzed the effect of changing dead state properties on exergy efficiencies of the Kizildere GPP to elicit optimum performance and operating conditions. Coskun et al. [11] performed thermodynamic analysis of the Tuzla GPP located in Canakkale (Turkey) by using actual plant data considering the various outdoor temperature distributions and different exergetic performance parameters in the exergy calculations. Ganjehsarabi et al. [12] conducted an exergy analysis of the Dora II GPP with 9.5 MW in Salavatli village near Aydin province (Turkey) by using actual plant data. In their study, exergy efficiency and total exergy destruction were evaluated according to pressure and temperature of turbine inlet. Yildirim and Ozgener [13] investigated an exergy analysis of the Dora I and Dora II GPPs with 7.3 MW and 9.5 MW in Salavatli 94 village near Aydin province (Turkey) by using actual plant data, respectively. They considered the various outdoor temperature distributions. Unverdi and Cerci [1] evaluated efficiency of exergy in the Germencik GPP with power output of 47.4 MW. Pambudi et al. [14] applied exergy analysis and optimization of the Dieng single flash GPP (Indonesia). The results of the analysis were used to optimize the separator pressure to enhance the efficiency of the power plant and thus achieve higher output power.

Considering some hypothetical geothermal resources and hypothetical power plants with assumed operating conditions or idealized operations; Yari [15] investigated on the thermodynamic analysis and optimization of GPPs. Jalilinasrabady et al. [16] employed exergy concept to work on flash cycle optimization of Sabalan GPP. They summarized the most significant values of power plant in both single and double flash types. The result of the analysis suggested that a double flash cycle is more suitable for this GPP. Tunc et al. [17] investigated efficiencies of organic rankine cycle by using four different fluids as isobutene, HCFC123, R134a, and R12. They compared the results with the existing single flash steam technology. The results showed that isobutene yielded 30%, which is almost twice as much as existing efficiency. Li [18] systematically investigated 14 working fluids of organic Rankine cycle under various heat source levels, i.e. the various application domains. This comprehensive study for both energy and exergy performance under different operating conditions and various system configurations of organic Rankine cycle, such as reheat, regenerative organic Rankine cycle and organic Rankine cycle with internal heat exchanger was performed. Instead of adopting only one working fluid for an ORC system, a mixture of several different working fluids has been accepted in recent years. El-Emam and Dincer [19] performed thermodynamic and economic analyses on a novel-type geothermal organic Rankine cycle based on both energy and exergy concepts. Its exergy efficiency value was found to be 48.8% for optimum operating conditions from 78.49 °C to 116.2 °C.

Although many studies have been conducted to reveal the main problems which influence the GPP systems and their components as mentioned above, it is necessary to investigate the improvement potential of their components on the performance of the GPP systems. One of the reasons is that the technological and economical design limitations on the system components always vary in terms of performance indices. In recent years, advanced exergy analyses have been successfully applied to few power plant systems including simple and complex systems. Tsatsaronis and Moung-Ho [20] were the first to develop the concepts of avoidable and unavoidable exergy destructions, which are used to determine the potential of improving the thermodynamic performance and the cost effectiveness of a system. Cziesla et al. [21] analyzed all components of an externally fired combined power plant in relation to both avoidable and unavoidable exergy destructions; the associated costs were defined, and the results of their study were discussed. Razmara and Khoshbakhti Saray [22] divided the exergy destruction of the system into endogenous and exogenous portions for a simple gas turbine cycle and a cogeneration system that operated with different fuels. Approximately 64% of total exergy destruction rate was endogenous in simple gas turbine cycle and similarly, about 78% of the total exergy destruction rate was endogenous in the cogeneration system. Wang et al. [23] analyzed a power plant that operated under supercritical conditions using an advanced exergy analysis at the system and determined the improvement potentials of the system. It was determined that endogenous exergy rate was 85% and avoidable exergy destruction rate was 8%. Petrakopoulou et al. [24] employed advanced exergy analysis to research a combined power plant. Endogenous exergy rate was 83% and the improvement potential of the system was 33%. Manesh et al. [25] introduced a systematic procedure for optimal design and evaluation of cogeneration systems based on the accurate cogeneration targeting model and the development of the R-curve concept through advanced exergetic, exergoeconomic and exergoenvironmental analyses. Yang et al. [26] applied both conventional and advanced exergy analyses to a large-scale ultra-supercritical coal fired power plant. Their main focus was the thermodynamic interactions among components and the sources for energy-saving potential of each component.

The results of these applications show that when energy saving potentials is considered, the approach becomes a promising and powerful tool to improve complex energy systems effectively. However, this method has not been used yet to analyze and evaluate any geothermal power plant (GPP). The reviewed literature makes it clear that no research is focusing on advanced exergy analysis and assessment of GPPs, to the best of the authors' knowledge. The present study aims to fill in this gap in the literature. This was the main motivation behind performing this contribution, which compared the system considered through both traditional and advanced exergetic analysis methods. Thus, the main objective of the present study is to apply both the exergy