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# Exergoeconomic analysis and optimization of single and double flash cycles for Sabalan geothermal power plant

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ABSTRACT

In this study single and double flash systems were designed to utilize the Sabalan geothermal fluid as a heat source. An Exergoeconomic model was applied on plant' equipment in order to calculate the thermodynamic and economic performances of the cycles. Parametric analysis was done to examine the effect of important key parameters including flash pressures and steam quality at turbine outlet on plant performance. Optimization process for maximum net power output was carried out on the plant using direct searching method in EES (Engineering Equation Solver). This process aimed to find the optimum flashing pressures corresponding to the maximum potential power output as an objective function. Additionally, the major exergy destruction locations were shown graphically and side by side for both systems to observe the effect of secondary flash process on exergy destruction at each component. Afterward, an environmental study was done in order to calculate the amount of fossil fuel saving and pollutants emission reduction compared to conventional fossil fuel power plants. The result showed that in double flash energy and exergy efficiency were increased from 16.26% and 40.06% to 17.73% and 50.89%, respectively. Moreover, double flash resulted in higher net power output compared to that of single flash (28,838 kW vs. 36,055 kW) while both cycles were using the same geofluid. Optimization results revealed that thermodynamically optimum cycle could not result the best and lower energy production cost and vice versa. Therefore, the single flash generates electricity within lower price compared to double flash system. Moreover, double flash considerably reduces the required fossil fuel and various pollutants emission more than single flash if they were replaced by fossil fuel power plants with same amount of production.

## 1. Introduction

Utilization of geothermal energy in order to power generation is being increased in the countries (Mohammadzadeh Bina et al., 2017). According to the latest geothermal energy report, the installed capacity in the world was 12,729 MW as of 2015. And it is forecasted to reach to 21,433 MW based on accounting existing geothermal projects (Bertani, 2016). Unfortunately, Iran as a developing country owns very low amount of this forecast; considering a project of 5 MW in the most promising geothermal field (Sabalan) from total 18 prospective in entire country (Fig. 1) (Yousefi et al., 2010). The first priority for power plant development was given to NW Sabalan and started in 1995, this field in the northwestern hillside of Sabalan mountain is located within Moeil valley about 16 km from the Meshinshahr in northwestern of Iran (Noorollahi and Itoi, 2011).

In recent years, geothermal energy has attracted the attention of energy policer and decision makers to harness this energy and supply electricity demand due to its reliability and environmental benefits (Mohammadzadeh Bina et al., 2016). Among the renewable energies, geothermal is a most reliable and stable independent of day and weather condition. In the case of geothermal energy if there is a reservoir in one region, its availability is constant. Different types of energy conversion technologies can be installed on geothermal reservoir which convert the energy of geofluid into electricity (DiPippo, 2012). These systems are being chosen based on either chemistry of geofluid or their thermodynamic specification like temperature and pressure. Additionally, the economic issues of systems like required investment of each system implementation are the other factors that should be taken into account for geothermal power plants development.

Among the geothermal power conversion technologies, the flash and the binary cycles are the most common methods to extract power from moderate to high temperature of hydrothermal type resources (Jalilinasrabady and Itoi, 2012; Jalilinasrabady et al., 2011; Jalilinasrabady et al., 2016). However, recently some innovative and

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**Nomenclature**

| | |
|---|---|
| $\dot{W}$ | Power (kW) |
| $\dot{m}$ | Mass flow rate (kg/s) |
| ex | Specific exergy (kJ kg$^{-1}$) |
| Ex | Exergy rate (kW) |
| h | Specific exergy (kJ kg$^{-1}$) |
| P | Pressure (bar) |
| s | Specific ectropy (kJ kg$^{-1}$ k$^{-1}$) |
| T | Temperature |
| h | Hour |
| Z | Investment |
| $\dot{C}$ | Cost rate |
| c | Specific cost |
| HEX | Heat exchanger |

*Greek letters*

| | |
|---|---|
| h | Energy efficiency |
| $\phi$ | Exergy efficiency |

*Subscribes*

| | |
|---|---|
| 0 | Dead state |
| 1,2,3,… | Cycle state |
| eva | Evaporator |
| tur | Turbine |
| wf | Working fluid |
| gf | GeoFluid |
| des | Destructive |
| en | Energy |
| s | Isentropic |
| pro | Production |
| O | Operation |
| M | Maintenance |
| eq | Equipment |
| Petro | Petroleum |
| Obj | Objective |

conceptual models have been introduced to maximize the usage of geofluid's energy content that increases overall efficiency of power plants. In these studies, commonly the performance of geothermal systems has been improved by combining the binary and flash cycle or varying the arrangement of components in the conventional systems. However, implementation of these cycles practically is difficult due to either their high capital cost or complexity which makes their installation and maintenance more difficult.

Zhao and Wang (Zhao and Wang, 2016) presented an exergoeconomic analysis of flash-binary and calculated the levelized cost per unit of exergy produces ($c_{system}$) for the overall system. Optimization process conducted for minimum $c_{system}$ and maximum exergy efficiency. The maximum exergy efficiency and levelized cost of exergy produces of 42.89% and 11.39 $/kWh are achieved when the exergy efficiency is considered as objective function of system. These results were 44.22% and 11.39 $/kWh in economic optimized system. Shokati et al. (Shokati et al., 2015) compared double flash and binary-single flash geothermal power plant base on exergoeconomic criteria. they reported that the double flash cycle has lower unit cost of produced power.

Coskun et al. (Coskun et al., 2013) compared the performance of double-flash, binary, combined flash-binary and Kalina cycles for low temperature geothermal reservoirs and concluded that the combined flash-binary cycle has the highest energy conversion efficiency.

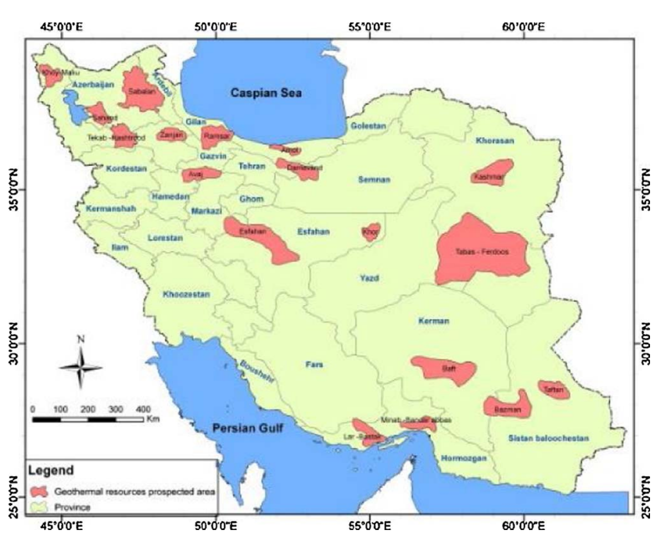


**Fig. 1.** Geothermal resource map of Iran (Yousefi et al., 2010).

Yilmaz et al. (Yilmaz et al., 2015) proposed a combined flash-binary geothermal plant, the power of which is used for hydrogen production by water electrolysis. A geothermal resource temperature of 200 °C with a flow rate of 100 kg/s is considered and thermodynamic and exergoeconomic analyses are performed. They reported an exergy efficiency of 46.6% for the power plant and a unit exergetic cost of electricity of 4.76 $/GJ and 3.35 $/GJ for the generated power of binary and flash turbines.

Wang et al. (Wang et al., 2015) examined the performance of a Kalina cycle for the binary unit of a flash-binary GPP and conducted a parametric optimization for exergy efficiency as the objective function. They showed that the optimum system exergy efficiency could reach 37.01% under the given conditions. For a geothermal brine temperature of 170 °C, the performance of a binary-flash geothermal system from the viewpoint of the first thermodynamics law, is analyzed by Pasek et al. (Pasek et al., 2011), who reported a thermal efficiency of 12.29% and a utilization efficiency of 23.06% for the considered system.

Furthermore, some efforts have been conducted specifically for Sabalan in order to deal with increasing geothermal power generation in Iran. Sabalan is the only active geothermal field located in the north west of country that the potential of 55 MW for 30 years has been shown by pervious feasibility studies (Noorollahi and Itoi, 2011). The comparison of single and double flash power plant in Sabalan was done by jalilinasrabady (Jalilinasrabady et al., 2012). The results showed that according to the actual field data, maximum exergy efficiency of 32.7% and 43.3% was achievable using proposed single and double flash systems, respectively. Aali et al. (Aali et al., 2017) introduced and optimized a new combined flash-binary system for Sabalan. The new system could deliver 5.81% and 3.17% higher energy efficiency, respectively, comparing conventional single and double cycles in Ref. Jalilinasrabady et al. (2012). These improvement values also for exergy efficiency were calculated as 2.65% and 10.03%, for single and double flash, respectively. Additionally, the system generates 16,860 kW of power under specific cost of 4.766 $/GJ at its optimum operation conditions.

According to the mentioned literature, only few number of works compare the single and double flash systems for sabalan field in a thermoeconomically manner. Thus the present work aims to model a single and double flash cycle which efficiently utilizes the heat source of Sabalan. In the current work, the actual well head data were used to calculate the feasibility of Sabalan's power generation potential. In order to calculate the produce cost and also the total cost of plant the specific exergy costing method is employed.