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Thermodynamic Analysis of a Novel Power, Cooling, Hydrogen and Oxygen Multi-Generation Combined Cycle Based on the Sabalan Geothermal Wells

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ABSTRACT: The use of multi-generation systems is rapidly developing in the world. Although Sabalan geothermal field is one of the important geothermal fields of Iran, the possibility of using the multi-generation systems has not yet been performed. As an attempt to fulfill the gap in the field, a new cooling, hydrogen, oxygen, and power multi-generation cycle for using Sabalan geothermal wells is proposed and analyzed. In the proposed system, the double flash configuration from the Sabalan geothermal wells as the heat source is used. An organic Rankine cycle is used to generate power for the proton exchange membrane for hydrogen production and a LiBr-H_2O absorption refrigeration system is used for cooling production. First, a simulation was done by Engineering Equation Solver software and then the effects of some design parameters, such as separators pressures, evaporator temperature, pinch point temperature difference in the Rankine evaporator, generator temperature and ambient temperature on the integrated system performance are studied. A parametric study shows that the value of the thermal efficiency and cooling continuously increases with separators' pressures. According to the results, the value of the net output power, hydrogen production, cooling and thermal and exergy efficiencies of the cogeneration system are obtained as 14739 kW, 13.25 kg/hr, 10925 kW, 22.34% and 50.62% respectively.

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1. INTRODUCTION

In the Sabalan region that is located in northwestern Iran, two wells with different thermodynamic conditions have been exploited [1]. According to the thermodynamic properties of the wells, the new configuration of a double flash with ORC that uses actual data for the Sabalan Geothermal Power plant (GPP) is studied by Aali et al. [2]. They showed that the specific cost of output power is calculated 4.766 $/GJ in optimum conditions for R141b as working fluid. Abdolalipouradl et al. [3] studied the new combined cycle that includes two single-flash, transcritical carbon dioxide and organic Rankine cycles. Results show that for the optimal condition, the net power, thermal and exergy efficiencies are 19934 kW, 17.05% and 65.38%, respectively. So far, all studies have been conducted to power generation for the Sabalan GPP; in this work, a new multi-generation cycle is proposed that can produce power, heating, cooling, oxygen and hydrogen. Some main objectives of the current study are as follows:

- Using two wells from Sabalan fields as the energy resource for multi-generation cycles to produce power, heating, cooling, oxygen and hydrogen.
- Simulation of the proposed cycle from the energy and exergy viewpoints.
- A comprehensive parametric study is accomplished.

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2. SYSTEM DESCRIPTION

Schematics of the new proposed cycle for power, cooling, hydrogen, oxygen and power multi-generation from Sabalan GPP are shown in Fig. 1. In this study an Organic Rankine Cycle (ORC) and double flash are used to produce power, Proton Exchange Membrane (PEM) is utilized for hydrogen and oxygen production, and a LiBr-H_2O absorption refrigeration system is used for cooling production.

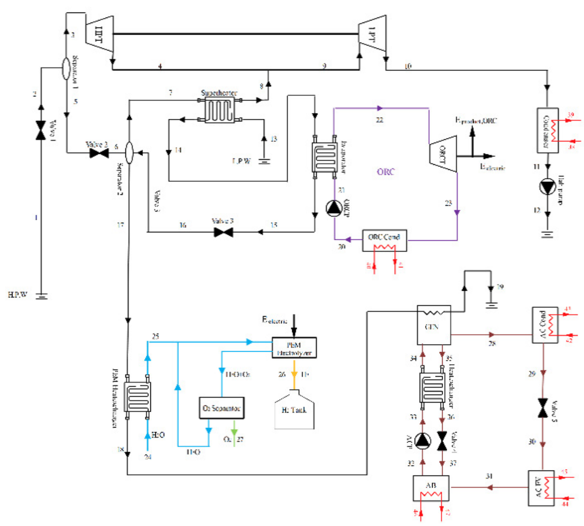

Fig. 1. The new multi-generation cycle from Sabalan geothermal wells

3. RESULTS AND DISCUSSION

In the multi-generation cycle and R123 as working fluid in ORC and initial thermodynamic conditions ($P_2 = 10\text{bar}$, $P_6 = 2\text{bar}$, $\Delta T_{PP,evap} = 10^{\circ}\text{C}$, $a = 0.5$ and $T_{PEM} = 80^{\circ}\text{C}$), the hydrogen production, net output power, cooling, thermal and exergy efficiencies are calculated as, 13.25 kg/hr, 14749 kW, 10925 kW, 22.34% and 50.62% respectively.

The effects of the first and second separator pressures on the hydrogen production, net output power, cooling, thermal and exergy efficiencies are shown in Fig. 2 and Fig. 3, respectively. When P_2 increases, the High Pressure Turbine

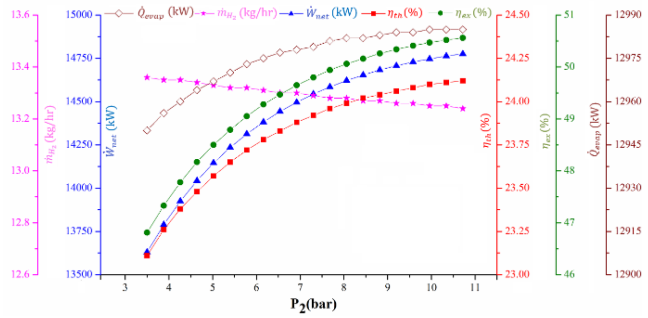

Fig. 2. Effects of the first separator pressure on hydrogen production, net output power, thermal efficiency, exergy efficiency, and cooling

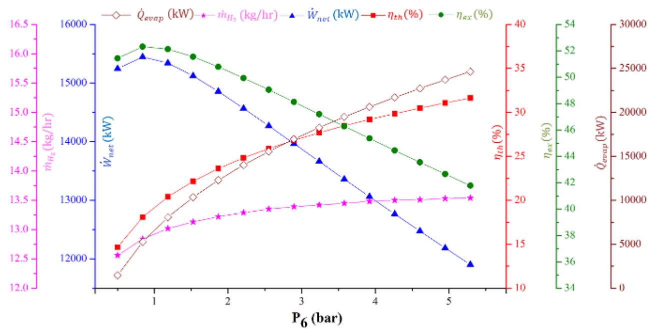

Fig. 3. Effects of the second separator pressure on hydrogen production, net output power, thermal efficiency, exergy efficiency, and cooling

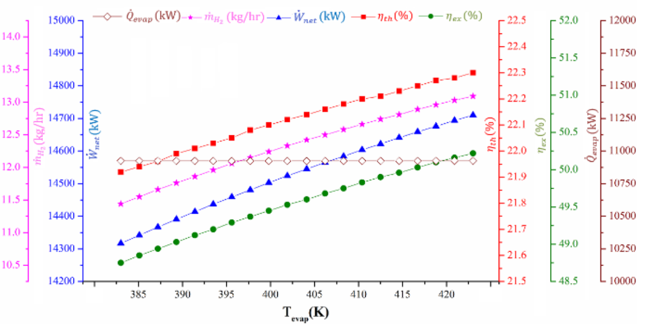

Fig. 4. Effects of the evaporator temperature on the hydrogen production, net output power, thermal efficiency, exergy efficiency, and cooling

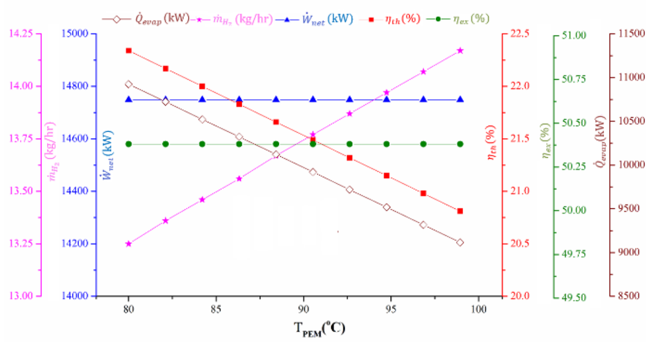

Fig. 5. Effects of the proton exchange membrane temperature on the hydrogen production, net output power, thermal efficiency, exergy efficiency, and cooling

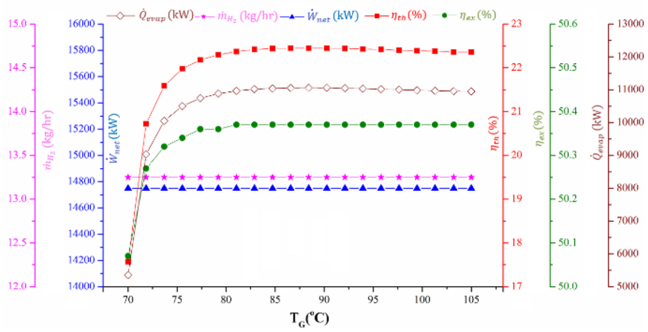

Fig. 6. Effects of the generator temperature on the hydrogen production, net output power, thermal efficiency, exergy efficiency, and cooling

(HPT) power production increases, while Organic Rankine Cycle Turbine (ORCT) power production decreases, but the increase of HPT Power production of HPT dominates and makes net output power, thermal efficiency, exergy efficiency increase. Hydrogen production decreases because of the decrement of ORCT power production.

The Low Pressure Turbine (LPT) and ORCT power production increase while HPT power production decreases with P_6, these trends lead the net output power and exergy efficiency to have optimum value but hydrogen production, cooling and thermal efficiency increase with second separator pressure. Fig. 4 demonstrates the variation of performance of the multi-generation cycle with ORC evaporator temperature, T_{Evap}, which indicates that the values of the net output power, hydrogen production, thermal and exergy efficiencies increase but cooling is constant with T_{Evap}.

Variations of the performance of the proposed multi-generation cycle with T_{PEM} are shown in Fig. 5. With increasing T_{PEM}, the current density in the PEM system and consequently hydrogen production increase while net output power remains constant and the cooling decreases. Thus these trends lead the thermal efficiency to decrease while exergy efficiency almost remains stable.

The influences of the five performances of the proposed cycle with regard to the generator temperature, T_G, are displayed in Fig. 6. Due to the independent production of hydrogen and the net power of the cycle from the T_G, the trend of changes in thermal and exergy efficiency with regard to the generator temperature is shown in Fig. 6.

4. CONCLUSIONS

The main achieved results are as follows:

- The hydrogen production, net output power, cooling, thermal and exergy efficiencies are calculated as, 13.25 kg/hr, 14749 kW, 10925 kW, 22.34% and 50.62% respectively.
- By increasing the first separator pressure, the value of cooling, net output power, thermal and exergy efficiencies increase while hydrogen production decreases.
- The net output power and exergy efficiency have optimum values Relative to second separator pressure.
- With increasing evaporator temperature the hydrogen production, net output power, thermal and exergy efficiencies increase for a proposed multi-generation.

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