Thermodynamic analysis and comparison of two new tri-generation (hydrogen, power, heating) systems using geothermal energy

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ABSTRACT

In this study, two new multi-generation (hydrogen, power, heating) systems are thermodynamically analyzed and optimized. For the proposed cycles, the two systems are distinguished by the power generation cycle, so that the organic Rankine cycle and the Kalina cycle are used to produce power. Both systems also use domestic water heater for heating and proton exchange membrane electrolyzer for hydrogen production. After the thermodynamic simulation, a comprehensive study was performed for evaluating the parameters affecting hydrogen production, net output power, heating, thermal efficiency and exergy efficiency of two cogeneration systems and finally an optimization was performed from an exergy efficiency point of view. According to the results of this study, for the organic Rankine cycle-based Tri-generation system, when evaporator temperature increases exergy efficiency and hydrogen production show optimum values while for Kalina cycle- based Tri-generation system, hydrogen production and exergy efficiency increase. Also, according to the study of various operating fluids for the organic Rankine cycle, the R152a as an organic Rankine cycle fluid produces more hydrogen. Furthermore, based on the optimized results for 120 °C heat source temperature, the Kalina cycle-based Tri-generation system has more exergy efficiency and more hydrogen production than the organic Rankine cycle- based Tri-generation system.

KEYWORDS

Thermodynamic analysis, Tri-generation systems, Proton exchange membrane, Kalina, Organic Rankine cycle.

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1. Introduction

Nowadays, limited fossil fuel sources and growing demand for world energy has led to consumption of renewable energies [1,2]. Geothermal energy is a type of renewable energy that has received much attention due to its sustainability, reliability, and unlimited sources [3]. These days, the cogeneration system is of great importance and is expanding worldwide due to its technical, economic and environmental benefits using geothermal energy sources [4]. The tri-generation (heating, hydrogen and power) systems of geothermal energy are important due to the flexibility in hydrogen production, power and heating. However, not many research works have been conducted in the field of employment of the tri-generation systems, and especially for use of low and medium heat sources, and also not enough attention has been paid to Kalina cycle as the source of power generation in simultaneous production systems and its performance comparison to other well-known cycle such as the organic Rankin cycle. Some principal purposes of the present study are as follows:

- Using geothermal energy as the heat source for tri-generation system to produce hydrogen, heating and power
- Modeling of the two tri-generation systems from the thermodynamic point of view.
- Parametric study and optimization of the systems.

2. System description

Schematics of the two tri-generation system for power, heating, hydrogen production from geothermal heat source are shown in "Figure 1" and "Figure 2" in which Organic Rankine Cycle (ORC), and Kalina Cycle (KC) are used to produce power respectively. Also, for the two tri-generation systems, domestic water heater (DWH) is used for heating and Proton Exchange Membrane (PEM) is used for hydrogen production.

3. Results and Discussion

In the ORC-based Tri-generation system, when isobutane is used as the ORC fluid and at optimum thermodynamic condition ($T_{geo}=120^{o}C$, $T_{evap}=89.06^{o}C$, $\Delta T_{PP,evap}=10^{o}C$, $a=0.1$ and $T_{PEM}=80^{o}C$), the net output power, heating, hydrogen production, and thermal and exergy efficiencies are 1165 kW, 13226, 1.901 kg/hr, 36.23% and 36.87%, respectively. Also, in the KC-based tri-generation system and optimum thermodynamic condition ($T_{geo}=120^{o}C$, $T_{evap}=110^{o}C$, $\Delta T_{PP,evap}=10^{o}C$, $a=0.1$, $P_9=39.25bar$ and $T_{PEM}=80^{o}C$), the net output power, heating, hydrogen production thermal and exergy efficiencies are calculated as 1197 kW, 12855, 1.951 kg/hr, 35.39% and 37.32%, respectively.

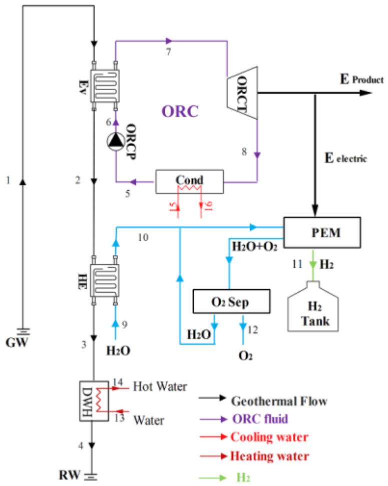

Figure 1. The new ORC based Tri-generation system

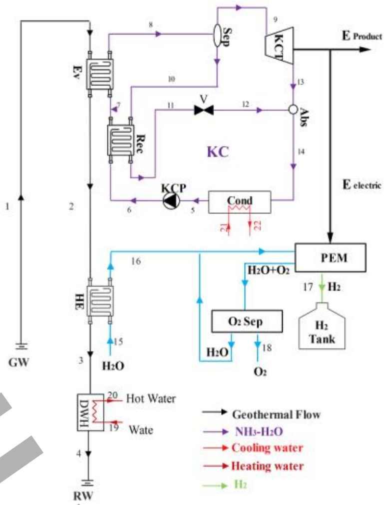

Figure 2. The new KC based Tri-generation system

On the other hand, in the ORC based tri-generation system when n-pentane , R245fa and R152a are used as ORC fluid, hydrogen production is obtained 1.743 kg/hr, 1.831 kg/hr and 1.973 kg/hr, respectively.

The effects of the evaporator temperature on the hydrogen production, net output power, thermal efficiency, exergy efficiency and heating for the ORC based system are displayed in "Figure 3". When T_{Evap} increases, the inlet enthalpy of ORCT increases, while ORC mass flow rate decreases, these opposite trends lead to power production and consequently hydrogen production reaches optimum value. Also when T_{Evap} increases, heating and thermal efficiency are increased.

Variations of the performance of the ORC based system with T_{Evap} are illustrated in "Figure 4". In regard to T_{Evap} increase, the net output power increases and consequently hydrogen production and exergy efficiency increase as well as heating and thermal efficiency decrease.

The exergy destruction of components in the ORC based and Kalina tri-generation systems are shown in "Figure 5" and "Figure 6", respectively. Results show that the highest exergy destruction for the two tri-generation systems belongs to D.W.H, condenser and evaporator, respectively.

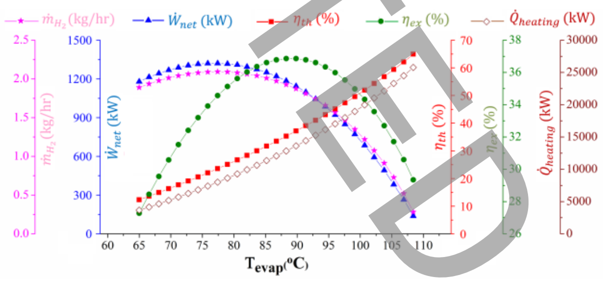

Figure 3. Effects of the evaporator temperature on the hydrogen production, net output power, thermal efficiency, exergy efficiency and heating in the ORC based tri-generation system

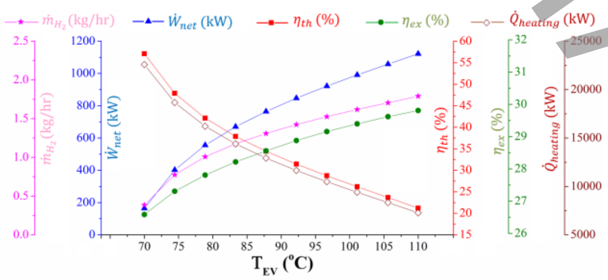

Figure 4. Effects of the evaporator temperature on the hydrogen production, net output power, thermal efficiency, exergy efficiency and heating in the KC based Tri-generation system

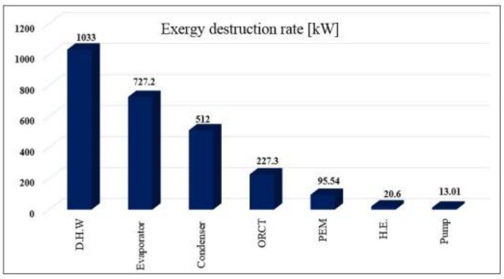

Figure 5. The exergy destruction of components in the ORC based tri-generation system

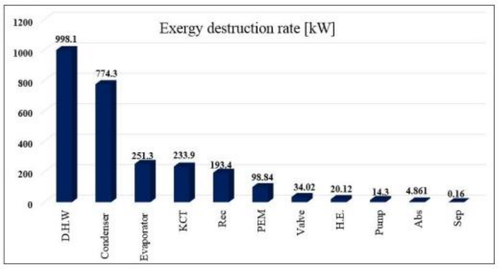

Figure 6. The exergy destruction of components in the Kalina based tri-generation system

4. Conclusions

The main results can be listed as follows:

- The net output power, heating, hydrogen production thermal and exergy efficiencies are 1165 kW, 13226, 1.901 kg/hr, 36.23% and 36.87%, respectively.
- The R152a as an ORC working fluid produces more hydrogen compared to other selected fluids.
- The hydrogen production and exergy efficiency have optimum values with regard to evaporator temperature in the ORC based system while hydrogen production and exergy efficiency increase in the KC based system.
- The highest exergy destruction of the two tri-generation systems belongs to D.W.H, condenser and evaporator.

5. References

[1] M. Abdolalipouradl, S. Khalilarya, S. Jafarmadar, The thermodynamic analysis of new combined cycle using Sabalan geothermal wells and LNG cold energy, Amirkabir Journal of Mechanical Engineering, 52 (6) (2019) 21-30. (in Persian)

[2] M. Abdolalipouradl, S. Khalilarya, S. Jafarmadar, Exergy analysis of a new proposal combined cycle from Sabalan geothermal source, Modares Mechanical Engineering, 18(4) (2018) 11-22. (in Persian)

[3] M. Abdolalipouradl, S. Khalilarya, S. Jafarmadar, Exergoeconomic analysis of a novel integrated transcritical CO2 and Kalina 11 cycles from Sabalan geothermal power plant, Energy Conversion and Management, 195 (2019) 420-435.

[4] M. Abdolalipouradl, S. Khalilarya, S. Jafarmadar, Energy and Exergy Analysis of a New Power, Heating, Oxygen and Hydrogen Cogeneration Cycle Based on the Sabalan Geothermal Wells, International Journal of Engineering, 32(3) (2019) 445-450.