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Thermodynamic analysis and assessment of a novel integrated geothermal energy-based system for hydrogen production and storage

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ABSTRACT

In this paper, thermodynamic analysis and assessment of a novel geothermal energy based integrated system for power, hydrogen, oxygen, cooling, heat and hot water production are performed. This integrated process consists of (a) geothermal subsystem, (b) Kalina cycle, (c) single effect absorption cooling subsystem and (d) hydrogen generation and storage subsystems. The impacts of some design parameters, such as absorption chiller evaporator temperature, geothermal source temperature, turbine input pressure and pinch point temperature on the integrated system performance are investigated to achieve more efficient and more effective. Also, the impacts of reference temperature and geothermal water temperature on the integrated system performance are studied in detail. The energetic and exergetic efficiencies of the integrated system are then calculated as 42.59% and 48.24%, respectively.

Introduction

The power demand of world is expected to increase considerably depending on the results of population growth and increasing demands in the living standards. Nowadays, the fossil fuels (oil, coal and natural gas) are widely used to provide power. In conjunction with this, one may note that fossil fuels are limited and that the world is expected to run out of fossil fuels in the foreseeable future. It is estimated that the world oil production may reach the peak in 2030 [1]. This situation may have a negative impact on the economies of countries, especially the economies of those importing oil and its products. Therefore, it is a necessity to develop clean, sustainable and sufficient energy resources. The geothermal power is the considered as one of the promising alternative energy resources, which can be utilized for electricity, heating, cooling, hydrogen or other synthetic fuels, hot water, etc. production aims.

Although some geothermal energy sources are not feasible enough, there are lots of studies evaluating the performances of geothermal energy sources for various potential applications. Single energy production options produce much waste heat and it cannot be recovered in those systems. In order to

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utilize waste heat, multigeneration energy production systems offer advantageous alternatives. During the past decade, cogeneration and trigeneration energy production systems have attracted more attention than the single generation systems. However, integrated multigeneration systems, going beyond trigeneration, are relatively new. Therefore, it is expected that integrated multigeneration systems will be used more in the future because of their higher efficiencies and lower environmental impact and hence cost.

Lee [2] has conducted comparative studies among alternative and nuclear sources for hydrogen generation. Under alternative sources, renewables, such as solar, wind, biological process, tidal and geothermal energy resources were compared. For forecasting purposes, the comprehensive economic design named Taiwan General Equilibrium Model-Clean Energy (TAIGEM-CE) was been utilized. According to the results, the most promising method for hydrogen generation is the wind energy. On the other hand, geothermal energy was considered the most critical to external investment as the resource of electricity for hydrogen production based on the analytical results.

Balta et al. [3] have investigated the geothermal power usage for hydrogen generation by using thermodynamic assessment through energy and exergy analyses. In order to produce hydrogen, they considered the high temperature electrolysis system driven by the geothermal resource. As a result, they also calculated the energetic and exergetic efficiencies of geothermally driven hydrogen generation process as 87% and 86%, respectively.

Ratlamwala et al. [4] have performed a thermodynamic analysis to a new geothermal energy production process producing electricity, cooling, heating, hot water and hydrogen. According to their results, changing of geothermal source temperature from 440 K to 500 K increases daily hydrogen production from 1.85 kg to 11.67 kg.

Akrami et al. [5] have proposed a geothermal based multigeneration process. They have conducted energetic, exergetic and exergoeconomic investigations on the multigeneration system proposed. Also, some parameters have been investigated for evaluation of system performance. The units cost of products ranges between 22.73 $/GJ and 23.18 $/GJ according to their analysis results.

One should note that cost analyses are as important as energetic and exergetic analyses, however environmental impact assessment studies should not be ignored [6,7]. In order to achieve a successful cost, environment and performance, some optimization studies are also performed. Boyaghchi and Safari [8] have proposed a quadruple energy production system using geothermal heat as energy source. They have conducted parametric analysis and multi-objective optimization on their proposed system. After having performed multi-criteria optimization, they found that it is possible to improve the total avoidable exergy destruction rate and total avoidable exergy cost rate by 3.27 and 4.9 times, respectively, and the total cost rate then becomes 17.4% better than the base case.

Another cost analysis study of hydrogen generation driven by a geothermal source is performed by Yilmaz et al. [9]. In that study, a binary geothermal power system has been utilized for water electrolysis to produce hydrogen. They have used the specific exergy cost method (SPECO) for evaluation of hydrogen production cost from geothermal based hydrogen production process which produces 0.253 g hydrogen per kilogram geothermal water. As a result, it is found that the unit exergetic cost of power and hydrogen are 6.495$/GJ and 19.7$/GJ (or 2.366 $/kg H_2).

Yilmaz [10] has performed a thermoeconomic modelling and optimization to the integrated flash-binary geothermal power process producing electricity and hydrogen. The main output of this study is to minimize the cost of integrated system products. In the result part of this study, thermoeconomic optimal values are presented and compared with the corresponding actual base case values.

Yuksel and Ozturk [7] have also conducted a thermodynamic and thermoeconomic analyses to an integrated geothermal power plant mainly generating electricity and hydrogen via organic Rankine cycle and PEM electrolyzer, respectively. In that study, the quadruple effect absorption cooling process is integrated to the system for utilization of waste heat. In addition, with the parametric analyses, the impacts of some indicators such as geothermal water temperature and pressure have been revealed.

In this paper, thermodynamic assessment is carried out to better understand the impacts of the process components and whole system performance on the power and hydrogen generation rate by utilizing the Engineering Equation Solver (EES) software program. The major objective of this paper is to perform a thermodynamic analysis to a novel geothermal energy system. Also, this study consists of the following objectives:

- To develop a novel integrated system operating primarily on the geothermal power for hydrogen generation and storage.
- To conduct the thermodynamic analysis for geothermal energy based integrated process for useful outputs.
- To define the exergy destruction rate and exergetic performances of each sub-systems along with the entire system.
- To investigate the system design indicators and performing cases on the process performance.
- To analyze some important indicators influencing the integrated process and its parts for hydrogen production from geothermal energy.

System definition

A schematic draft of the novel geothermal energy based integrated process is given in Fig. 1. As seen from this diagram, the integrated process investigated in this paper consists of mainly four parts, such as i-) geothermal power conversion, ii-) Kalina cycle, iii-) single effect absorption cooling process, and iv-) hydrogen generation and storage process. The geothermal water gives its heat energy to the ammonia water (NH_3-H_2O) working fluid of Kalina cycle at the HEX-I.

The Kalina process is a type of Rankine cycle using NH_3-H_2O as a working fluid. The advantage of using Kalina cycle is that it provides user to switch the temperature by changing ammonia water concentration [11]. After gaining heat energy

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