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Analysis and performance assessment of a combined geothermal power-based hydrogen production and liquefaction system

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ABSTRACT

In this paper, the thermodynamic study of a combined geothermal power-based hydrogen generation and liquefaction system is investigated for performance assessment. Because hydrogen is the energy of future, the purpose of this study is to produce hydrogen in a clear way. The results of study can be helpful for decision makers in terms of the integrated system efficiency. The presented integrated hydrogen production and liquefaction system consists of a combined geothermal power system, a PEM electrolyzer, and a hydrogen liquefaction and storage system. The exergy destruction rates, exergy destruction ratios and exergetic performance values of presented integrated system and its subsystems are determined by using the balance equations for mass, energy, entropy, energy and exergy and evaluated their performances by means of energetic and exergetic efficiencies. In this regard, the impact of some design parameters and operating conditions on the hydrogen production and liquefaction and its exergy destruction rates and exergetic performances are investigated parametrically. According to these parametric analysis results, the most influential parameter affecting system exergy efficiency is found to be geothermal source temperature in such a way that as geothermal fluid temperature increases from 130 °C to 200 °C which results in an increase of exergy efficiency from 38% to 64%. Results also show that, PEM electrolyzer temperature is more effective than reference temperature. As PEM electrolyzer temperature increases from 60 °C to 85 °C, the hydrogen production efficiency increases from nearly 39% to 44%.

Introduction

The geothermal resources are plenty worldwide and widely used for power generation or space heating applications [1], clean (effectively no harmful gas emissions, including CO, CO_2, NO_x, SO_x, etc.), safe and reliable (renewable and sustainable), and also they can play significant role for meeting of world energy needs [2]. Among the alternative energy resources, geothermal energy is found in abundance, and a completely free source of energy, and also is mainly used for

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electricity production, residential or greenhouse heating and cooling processes, industrial drying, distillation and desalination, depending on the geofluid source conditions [3]. The geothermal energy sources are divided into three groups based on the geofluid temperature range such as low temperature (until 90 °C), moderate temperature (90 °C–150 °C) and high temperature (above 150 °C). These temperature ranges are suitable for many industrial applications [4].

Zare [5] has compared ORC and Kalina cycles in geothermal power based integrated systems and performed thermodynamic assessment and optimization. Recently, after having higher efficiencies from cogeneration and trigeneration systems compared to conventional ones, a new challenge started to gain more outputs from energy production systems. Suleman et al. [6] have investigated a new integrated process using geothermal and solar power as sources. The process outputs are electricity, cooling and drying. The overall energetic and exergetic efficiencies of that process have been calculated as 54.7% and 76.4%, respectively. Similarly, another integrated process using solar and geothermal energy for power, cooling, heating, hot water and industrial heat is analyzed by Al-Ali and Dincer [7]. They have compared the energetic performances of single generation and multigeneration and found as 16.4% and 78%, respectively. On the other hand, their exergetic efficiencies of single generation and multigeneration applications are calculated as 26.2% and 36.6%, respectively. In addition, it is suggested that solar collectors should be improved because of having the highest exergy destruction rate.

There are different studies in the literature associated with the thermodynamic assessment of integrated systems based on geothermal resources and also for hydrogen generation. In this paper, by using ORC and PEM electrolyzer, power and hydrogen generations are targeted, respectively. The reason of hydrogen production and liquefaction is that this method is an alternative way for energy storage. Hydrogen is the most promising energy carrier for future but it is quite expensive for near term. The most economical and environmental model for now is photovoltaic-electrolysis method with photovoltaic power generation according to the literature [8].

According to Dincer and Acar, based on their review study on hydrogen production methods, fossil fuel reforming for hydrogen production is still the cheapest method however it is not environmental friendly. The cleanest method in terms of global warming potential is photonic based systems [9].

Geothermal sources are good alternatives for district energy systems in order to decrease the energy dependence. In this paper, a novel hydrogen generation and liquefaction system by using geothermal power is investigated based on thermodynamic analysis to increase the efficiency of integrated process. Geothermal energy sources are good alternatives as local energy suppliers, and the hydrogen is the most promising energy carrier. For this reason, the electricity production from geothermal energy coupling with hydrogen production and liquefaction is investigated and analyzed in this paper. Also, this study will be helpful for decision makers about the efficiency of hydrogen production from geothermal source. By using parametric analysis results, the effect of reference temperature, geothermal source temperature and PEM electrolyzer temperature on the system performance can be understood. The specific objectives of this paper can be given as follows;

- To conduct a comprehensive energetic and exergetic analysis of geothermal energy based integrated system.
- To calculate the exergy flow rate of each stream of the integrated system for multi-generation.
- To determine the exergy destruction rate, exergy destruction, exergy efficiency, and power or heat rate of each component.
- To perform the complete parametric studies and the performance assessment of integrated system.

System description

The integrated process investigated in this study consists of mainly four subsystems, such as i-) double flash geothermal process, ii-) ORC, iii-) PEM electrolyzer, and iv-) hydrogen liquefaction process as shown in Fig. 1. The double flash geothermal process and ORC are used in the integrated system to produce heat and power for PEM electrolyzer.

The ORC process runs when the geothermal working fluid goes into the vaporizer at point 7 and 12. Thermal energy of geothermal fluid is transferred by using the vaporizer to the working fluid (isobutane) for use in ORC process. Isobutane is chosen for ORC process as a working fluid because of the suitability of isobutane to the geothermal source temperature ranges. Isobutane which is heated and vaporized in vaporizer goes into the turbine at point 16 to generate power, and leaves at point 17 then enters HEX-II. Working fluid of ORC enters the condenser to be condensed. After that it is pumped to the HEX-I. Geothermal fluid exiting from vaporizer enters HEX-I in order to transfer its heat energy to the isobutane before entering the PEM electrolyzer. Also, the power generated using by the ORC process is used in the proton exchange membrane electrolyzer to generate hydrogen.

In PEM electrolyzer part, electrolysis water at point 23 enters the preheating unit to be heated by the geothermal fluid. Geothermal fluid transfers its remaining heat energy to the electrolysis water up to the 80 °C which is proper temperature for electrolyzing process. The heated water at point 24 enters PEM electrolyzer unit to be split hydrogen and oxygen. Pure oxygen exits from unit at point 25 to be utilized for further use.

Generated hydrogen gas at point 26 goes through mixer and compressor at points 27 and 28, relatively. The hydrogen liquefaction sub-system is used for more efficiently hydrogen storage. The hydrogen liquefaction process is comparatively more energy intensive than compaction of hydrogen process, whereas, the density of liquid hydrogen is nearly 1120 kg m^{-3} and, also liquid hydrogen is 29 times better than compacted hydrogen at 700 bar, in terms of volume work. Therefore, the Linde–Hampson hydrogen liquefaction process with-secondary nitrogen cooling is defined for hydrogen storage.