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Energetic and exergoeconomic assessment of a multi-generation energy system based on indirect use of geothermal energy

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A B S T R A C T

In this paper, a geothermal based multi-generation energy system, including organic Rankine cycle, domestic water heater, absorption refrigeration cycle and proton exchange membrane electrolyzer, is developed to generate electricity, heating, cooling and hydrogen. For this purpose, energetic, exergetic and exergoeconomic analysis are undertaken upon proposed system. Also, the effects of some important variables, i.e. geothermal water temperature, turbine inlet temperature and pressure, generator temperature, geothermal water mass flow rate and electrolyzer current density on the several parameters such as energy and exergy efficiencies of the proposed system, heating and cooling load, net electrical output power, hydrogen production, unit cost of each system products and total unit cost of the products are investigated. For specified conditions, the results show that energy and exergy efficiencies of the proposed multi-generation system are calculated about 34.98% and 49.17%, respectively. The highest and lowest total unit cost of the products estimated approximately 23.18 and 22.73 $/GJ, respectively, by considering that geothermal water temperature increases from 185 °C to 215 °C.

1. Introduction

The importance of the environmental pollution caused by energy production from fossil fuels and increasing energy consumption has focused the studies and scholarly research on finding alternatives to fossil fuels. In addition to finding more environmentally friendly solutions, sustainable development would need further emphasis meanwhile. One of the strategies to achieve this is the widespread use of renewable energy. Using non-emission energy sources to produce several types of products simultaneously, including electricity, heating, cooling and etc. can be one of the solutions.

From the other hand, growing concerns about the efficient use of energy resources have urged investigators to develop a technique called exergoeconomic to deal with the thermodynamics and economic aspects of energy converting systems [1]. Exergoeconomic is a combination of exergy analysis with conventional cost analysis to reveal the cost formation in system components and determine product unit cost which is a very important criterion in optimizing the system performance [2]. Application of exergoeconomic analysis to the cogeneration systems can be valuable from the viewpoint of unit product cost calculation.

A literature review of cogeneration systems and application of exergoeconomic analysis in thermal systems is presented in this section. Dincer and Zamfirescu [3] enumerated the advantages of the multi-generation systems by taking several system modes based on renewable energies and examined thermodynamic properties, greenhouse gas emissions and payback period for own proposed energy systems. Al-Sulaiman et al. [4] proposed a tri-generation system, based on biomass and analyzed its related efficiencies of energy and exergy. They also proposed a new multi-generation system, in which the solar energy is utilized as the renewable energy [5]. Nami et al. [6] proposed a novel cogeneration system, including a gas turbine, a heat recovery steam generator and supercritical recompression CO_2 cycle to produce power and steam. They reported that under the optimized condition the average product unit cost of the system (the cost of produced power and steam) is decreased by 0.56 $/GJ when compared to the value obtained under a base condition. Y. Bicer and I. Dincer [7] have proposed a new combined system to produce hydrogen in which solar energy and geothermal source are utilized. Moreover,

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by studying the thermodynamic characters of the proposed system for a geothermal water temperature of 210 °C, the energy and exergy efficiencies are obtained 10.8% and 46.3%, respectively. A comprehensive study on a novel multi-generation energy system for residential buildings has been done by Ahmadi et al. [8]. They estimated the exergy efficiency and the total cost rate of the system products. They have mentioned that minimizing the total cost rate will be possible with maximizing exergy efficiency (by applying the multi-objective optimization). Nami et al. [9] introduced a novel cogeneration system to produce power and hydrogen. They used waste heat of GTMHR cycle to produce hydrogen using ORC cycles. Also, they concluded that the exergy efficiency and sustainability index of their proposed system are 49.21% and 1.972, respectively, under the optimized condition. El-Emam et al. [10] carried out the exergy and exergoecanamic analyses on the geothermal based organic Rankine cycle. Optimum performance is investigated for various geothermal water temperatures, in order to achieve 5 MW net power output. Hydrogen production based on geothermal energy is proposed by C. Yilmaz et al. [11]. They applied a heat recovery unit in organic Rankine cycle to obtain energy within the geofluid. Generated power in ORC was used for hydrogen production in the PEM water electrolyzer. The corresponding energy and exergy efficiencies of the overall system are calculated 6.8% and 23.8%, respectively. Another complementary study has been conducted upon the hydrogen production system powered by geothermal energy from a thermoeconomic prospective by C. Yilmaz et al. [12]. Based on their results, the unit exegetic cost of hydrogen production estimated 2.366 $ per kilogram. F. Calise et al. [13] investigated a novel poly-generation system, based on hybrid-solar, geothermal, including an organic Rankine cycle (ORC), a parabolic trough collector (PTC), a multi-effect distillation (MED) and a thermal recovery subsystem (TRS) unit in order to produce fresh water and power. They carried out a dynamic simulation and evaluated their proposed system from the viewpoints of exergy and exergoeconomics. The Exergy efficiency of the entire system and costs associated with each system products have been estimated during the thermal recovery mode and cooling mode operation time. Calise et al. [14] presented a novel heating and cooling, geothermal based system. In this literature, a dynamic simulation study has been investigated to estimate energy and monetary performance of the system. The results indicated that the system performance is mainly affected by the nominal geothermal flow rate and natural gas cost.

As mentioned in the offered literature review, effective use of geothermal energy sources has been the focus of attention in the recent years. In this regard, several co-generation systems have been proposed and analyzed in detail. Therefore, to the best of authors knowledge, an additional research is required to investigate geothermal heating, cooling, hydrogen production and electricity generation via a proposed multi-generation system comprised of ORC/PEME with an absorption refrigeration cycle and also a domestic water heater as a novel benchmark configuration that provides the most efficient way of producing power, heating, cooling and hydrogen, simultaneously. In this framework, the main motivations of the present work are to develop a novel multi-generation energy system based on carbon free geothermal energy and to provide an overall picture of how decision variable variations (such as geothermal water temperature, turbine inlet temperature and pressure, generator temperature, geothermal water mass flow rate and electrolyzer current density) affect the energy, exergy and exergoeconomic performance of the proposed system, by using the comprehensively parametric analysis.

2. System description

The schematic diagram of the proposed multi-generation system is shown in Fig. 1. The proposed cogeneration system consists of different sections, namely: organic Rankine cycle, geothermal wells, absorption cooling system, domestic water heater and proton exchange membrane electrolyzer subsystems. The extracted geofluid from the regions of the earth's crust at 200 °C runs an organic Rankine cycle whose working fluid is Isobutane. As the water temperature at ORC evaporator outlet is high and has not exceeded the lower limit defined for it (temperature lower limit is defined for reinjection in order to have sustainable geothermal resources) [13], we can utilize it in the domestic water heater to produce hot water. The turbine inlet working fluid is completely superheated and then expands in the turbine to produce electricity. A portion of the power generated will be assigned to hydrogen production by a PEME. The hydrogen produced in the electrolyzer unit is stored in a

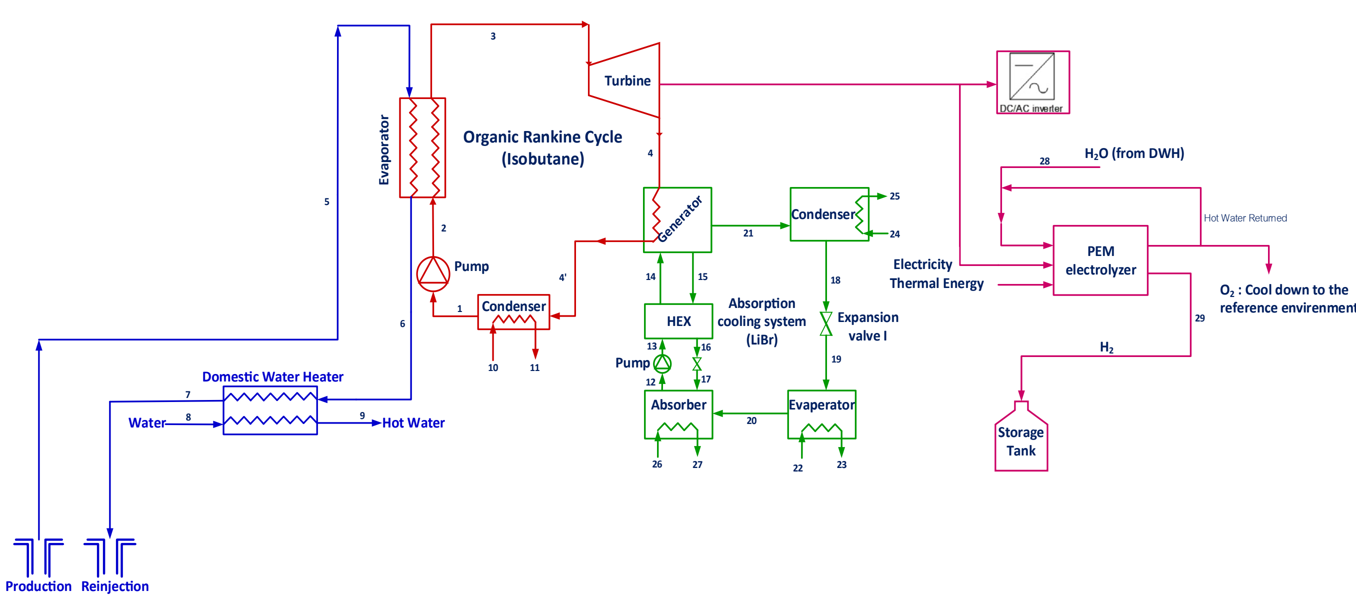

Fig. 1. Schematic diagram of the proposed multi-generation energy system.