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Utilization of waste heat from GTMHR for hydrogen generation via combination of organic Rankine cycles and PEM electrolysis

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ABSTRACT

Energy and exergy analyses are carried out for hydrogen production via Gas Turbine Modular Helium Reactor/Organic Rankine Cycle (GTMHR/ORC) system coupled with a proton exchange membrane electrolyzer. A comprehensive parametric study is performed and the effects of some significant variables as compressor pressure ratio, turbine inlet temperature, evaporators' temperature, pinch point temperature difference in the evaporators and degree of superheat at the ORC turbines inlet on the exergy efficiency, rate of produced hydrogen and sustainability index of the integrated system are investigated. Using direct search method by the Engineering Equation Solver (EES) software, the combined system is optimized to achieve the maximum exergy efficiency. Results show that the exergy efficiency difference between the combined system and GTMHR cycle increases with an increase in pressure ratio. Also, it is observed that the rate of produced hydrogen increases with increasing turbine inlet temperature and takes the maximum value with change in evaporators' temperature. Under the optimized condition, exergy efficiency, rate of the produced hydrogen and sustainability index of the proposed combined system are calculated to be 49.21%, 56.2 kg/h and 1.972, respectively.

1. Introduction

Increasing energy demand in developed countries and limitation of fossil fuels along with the environmental impacts have led to the development of high efficiency energy converting systems. In order to design the efficient energy converting systems and decrease the associated environmental impact, utilization of waste heat of the energy systems can be a good technique [1,2]. Gas Turbine-Modular Helium Reactor (GTMHR) is one of the advanced power producing systems which has received much attention in recent years because of its safety, sustainability, proliferation resistance and low maintenance costs [3,4]. The GTMHR system includes two consecutive compressors which compress the circulated helium. Since the reduction in compressor inlet temperature leads to decrease in the consumed compression work, it is beneficial to cooling the helium before compression processes (to about 26 °C). Therefore, it is possible to run a bottoming cycle by the rejected heat from the cooling process [4–6]. Furthermore, there are some studies which indicate that utilizing waste heat from nuclear power plants is more valuable than using fossil fuel based energy conversion systems [7–9]. A number of research works have been reported about the utilization of waste heat from the GT-MHR cycle. The following literature review has included representing the authors' finding in this field.

Zare et al. studied the combination of GTMHR cycle with an ammonia-water cogeneration system. They resulted that the second law efficiency increases by 4–10% [10]. Dardoura et al. reported the cost decrease of fresh water by 34% compared to the conventional desalination systems, when they used the waste heat of the GT-MHR cycle for seawater desalination [11]. The combination of the GTMHR with two Organic Rankine Cycles (ORCs) proposed by Yari and Mahmoudi [12]. They concluded that the energy and exergy efficiency of the combined system is 3% higher than those of the simple GTMHR cycle and exergy destruction rate in the combined system decreases by 5% compared to the GTMHR cycle. Also, Yari and Mahmoudi studied the combination of different configurations of ORCs with GTMHR cycle from the viewpoint of thermodynamics and they resulted that the simple ORC is the most advantageous one to combine with the base cycle [13]. Mohammadkhani et al. investigated the combination of GTMHR with two ORCs from the viewpoint of exergoeconomic and they reported that the unit cost of produced electricity increases with increasing helium turbine inlet temperature [14].

From the other hand, due to rapid population growth in the industrialized countries and increase in the standards of living in

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