Advanced exergy investigation of combined cycle of Helium reactor gas turbine with organic Rankine cycle

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ABSTRACT

In this work, the combined cycle of a helium reactor gas turbine with an organic Rankine cycle is studied and compared from the perspective of conventional and advanced exergy analysis. Using Equation Solving Engineering (EES) software, modeling of this cycle has been done and the results of conventional energy and exergy analysis have been obtained. Then, to determine the appropriate prioritization of cycle component improvement from the perspective of advanced exergy analysis, it has been studied. In fact, advanced exergy analysis provides accurate information about the real potential for system performance improvement by dividing the exergy destruction of each component into endogenous, exogenous, avoidable, and unavoidable components. The results of advanced exergy analysis show that by modifying and upgrading the components of the system, 19.1% of the total exergy destruction of the system can be reduced. According to the advanced exergy analysis, the improvement priority belongs to the compressor and then to the reactor and gas turbine. However, from the conventional exergy analysis, the reactor's exergy destruction is greater than that of the compressor and the priority is with the reactor. In addition, based on the prioritization of advanced exergy analysis, it is possible to increase the cycle exergy efficiency from 75.21% to 82.51% and the cycle energy efficiency from 51% to 56.22%.

KEYWORDS

Advanced exergy analysis, Endogenous/Exogenous exergy destruction, Avoidable/Unavoidable exergy destruction

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1. Introduction

Achieving energy has been one of the most significant challenges for human societies from the past to the present. The advanced exergy analysis method is one of the methods that reduce exergy destruction and consequently increases the system efficiency by identifying the leading causes of inefficiency in the system components. This method was first proposed by Tsatsaronis [1].

In recent years, many researchers have studied thermodynamic systems from advanced exergy analysis. For instance, Fallah et al. [2-3] carried out an advanced exergy analysis on the SCO2/ORC system [2], and SCO2 cycle [3]. Mohammadi et al. [4,5] performed an advanced exergy study on the supercritical carbon dioxide recompression cycle [4] and a combined cooling and power system with low-temperature geothermal heat [5].

Zare et al. [6] proposed an exergoeconomic study of the system in which The waste heat from the Gas Turbine-Modular Helium Reactor (GT-MHR) is recovered by an ammonia-water power/cooling cogeneration system. They [7] also performed a comparative thermodynamic analysis and optimization for waste heat recovery from the Gas Turbine-Modular Helium Reactor (GT-MHR) employing the ORC and Kalina cycle.

To our knowledge, the gas turbine-modular helium reactor (GT-MHR) combined with ORC has not been evaluated using advanced exergy analysis, and the findings compared to conventional exergy analysis. As a result, the role of each component in terms of exergy destruction, as well as the impact of component interactions on one another, has yet to be defined for this system. The current study fills in the gaps in knowledge by revealing the true sources of irreversibilities as well as the actual possibility of modifying the cycle.

2. Methodology

The mass, energy, and exergy balances, which are shown below, are used to evaluate the system components as control volumes:

$$\sum \dot{m}_i = \sum \dot{m}_e \quad (1)$$

$$\dot{Q} + \sum \dot{m}_i h_i = \sum \dot{m}_e h_e + \dot{W} \quad (2)$$

$$\dot{E}_Q + \sum \dot{m}_i e_i = \sum \dot{m}_e e_e + \dot{W} + \dot{E}_D \quad (3)$$

The first and second law efficiencies are calculated as bellow for this system:

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{Q}_R} \quad (4)$$

$$\eta_{ex} = \frac{\dot{W}_{net}}{\dot{E}_{QR}} \quad (5)$$

Endogenous/exogenous and avoidable/unavoidable portions of the exergy destruction in the kth component can be separated:

$$\dot{E}_{D,k} = \dot{E}_{D,k}^{EN} + \dot{E}_{D,k}^{EX} \quad (6)$$

$$\dot{E}_{D,k} = \dot{E}_{D,k}^{AV} + \dot{E}_{D,k}^{UN} \quad (7)$$

The rates of endogenous and exogenous exergy degradation can also be divided into two categories: avoidable and unavoidable. Similarly, the rates of exergy destruction that are unavoidable and avoidable can be separated into endogenous and exogenous parts:

$$\dot{E}_{D,k}^{AV} = \dot{E}_{D,k}^{EX,AV} + \dot{E}_{D,k}^{EN,AV} \quad (8)$$

$$\dot{E}_{D,k}^{UN} = \dot{E}_{D,k}^{EX,UN} + \dot{E}_{D,k}^{EN,UN} \quad (9)$$

$$\dot{E}_{D,k}^{EN} = \dot{E}_{D,k}^{EN,AV} + \dot{E}_{D,k}^{EN,UN} \quad (10)$$

$$\dot{E}_{D,k}^{EX} = \dot{E}_{D,k}^{EX,AV} + \dot{E}_{D,k}^{EX,UN} \quad (11)$$

3. Results and discussion

In the present work, first, the analysis of energy and exergy of the desired cycle is performed. The results show that the total output power and efficiency of the first and second laws in real conditions are equal to 307.02 MW, 51%, and 75.21%, respectively. Also, the effect of superheating the output fluid of HRSG on the energy and exergy efficiencies is also shown in Figure 2. This diagram shows that by superheating the output fluid from HRSG, energy efficiency and exergy decrease from 51.17 to 50.55% and 75.21 to 74.3%, respectively.

Furthermore, the conventional exergy analysis results indicate that the first priority of improving belongs to the reactor, the compressor, the recuperator, the evaporator, the pre-cooler, the gas turbine, the condenser, the Rankin turbine, and the pump.

The effect of different components of the cycle on each other is determined using advanced exergy analysis, which divides exergy destruction into endogenous/exogenous and avoidable/unavoidable parts. Against of improvement priority determined by the conventional exergy analysis, the advanced exergy investigation suggests another priority such as: the compressor, the reactor, the gas turbine, the recuperator, the evaporator, the Rankin turbine, the pre-cooler and the condenser, respectively.

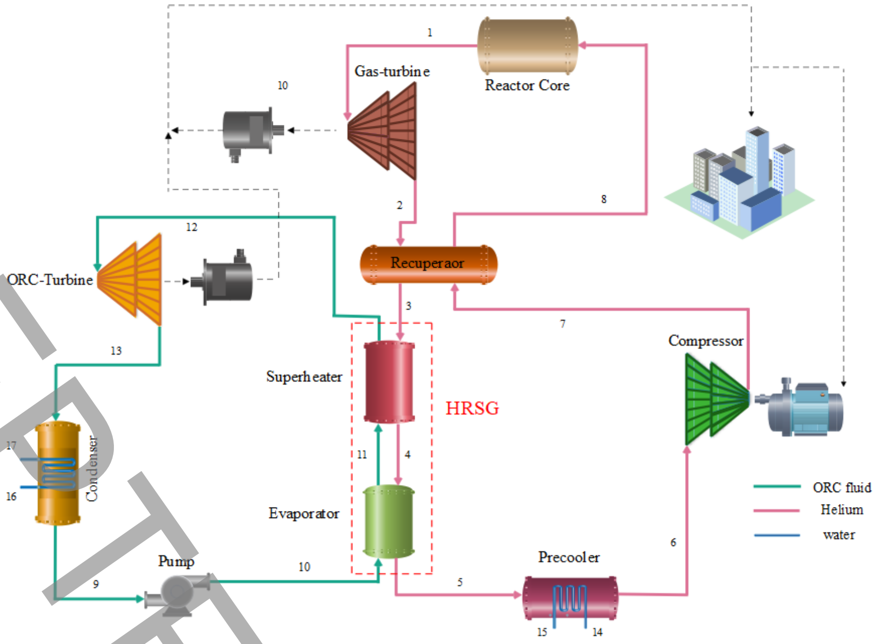

Figure 1. Schematic diagram for the combined GT-MHR/ORC

4. Conclusion

The results of comparing the performance of the cycle in unavoidable and real conditions show that if the cycle operates in unavoidable condition, its exergy efficiency is about 9.07% higher than in the real condition. Also, based on the prioritization of advanced exergy analysis, it is possible to increase the cycle exergy efficiency from 75.21% to 82.51% and the cycle energy efficiency from 51% to 56.25%. Furthermore, Comparing the parts of avoidable and unavoidable total exergy destruction, it can be seen that only about 19.1% of the total cycle exergy destruction can be reduced by improving the performance of cycle components or replacing them with better performing components.

The amount of avoidable exogenous exergy destruction in reactors, pre-coolers, Rankin turbines, condensers and pumps is greater than the amount of avoidable endogenous exergy destruction. Therefore, it can be concluded that improving the performance of other components of the cycle is more effective in reducing the inefficiency of these components compared to improving the performance of these components themselves.

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