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Exergoeconomic assessment and parametric study of a Gas Turbine-Modular Helium Reactor combined with two Organic Rankine Cycles

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ABSTRACT

An exergoeconomic analysis is reported for a combined system with a net electrical output of 299 MW in which waste heat from a Gas Turbine-Modular Helium Reactor (GT-MHR) is utilized by two Organic Rankine Cycles (ORCs). A parametric study is also done to reveal the effects on the exergoeconomic performance of the combined system of such significant parameters as compressor pressure ratio, turbine inlet temperature, temperatures of evaporators, pinch point temperature difference in the evaporators and degree of superheat at the ORC (Organic Rankine Cycle) turbines inlet. Finally the combined cycle performance is optimized from the viewpoint of exergoeconomics. The results show that the precooler, the intercooler and the ORC condensers exhibit the worst exergoeconomic performance. For the overall system, the exergoeconomic factor, the capital cost rate and the exergy destruction cost rate are determined to be 37.95%, 6876 $/h and 11,242 $/h, respectively. Also, it is observed that the unit cost of electricity produced by the GT-MHR turbine increases with increasing GT-MHR turbine inlet temperature but decreases as the other above mentioned parameters increase.

1. Introduction

Limitations in supplies of fossil fuels and environmental impacts due to their use have led to the development of high efficiency energy systems. In developing such systems, it is important to understand mechanisms which degrade energy and to develop and apply systematic approaches for improving the design of energy systems and reducing the associated environmental impacts [1,2]. Among advanced electrical generating systems, Gas-Cooled Reactors (GCRs) and in particular Modular Helium Reactors (MHRs) have received much attention in recent years because of their safety, proliferation resistance, sustainability and low operation and maintenance costs [3,4].

Various investigations of such systems have been reported. For instance, El-Genk and Tournier investigated the attributes and limitations of noble gases and binary mixtures as potential working fluids for gas-cooled nuclear power plants [4,5]. Using multiple reheat and intercooling states for sodium cooled fast reactors, Zhao and Peterson investigated the performance of helium Brayton cycles [6]. They reported a cycle thermal efficiency ranging from 39% to 47%, which is comparable with that of supercritical recompression CO_2 cycles (SCO_2 cycle). They concluded that the multiple reheat helium cycle performs better than the SCO_2 cycle when operated with sodium cooled fast reactors.

The circulating helium in the GT-MHR is compressed in two successive stages. Cooling the helium before compression processes (to about 26 °C) is beneficial, as a reduction in compressor inlet temperature results in a reduction in the required compression work. The cooling process before compression is more favorable as the rejected heat (at a rate of about 300 MW) can be utilized to run a bottoming cycle [4,5,7].

Recently, research has been carried out on the utilization of waste heat from a GT-MHR. Dardoura et al. [8] investigated the use of this waste heat for seawater desalination and reported a cost reduction of around 34% compared to conventional desalination methods. Other studies have also shown that utilizing waste heat from nuclear power plants is more beneficial than using fossil fuel-based energy conversion systems [8–11]. Zare et al. reported enhancements of 9–15% and 4–10% in energy utilization and second law efficiencies, respectively, for the GT-MHR cycle when it is

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