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A comparative study on the ammonia–water based bottoming power cycles: The exergoeconomic viewpoint

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ABSTRACT

A comparative exergoeconomic assessment is reported for Ammonia-Water Rankine (AWR) and Ammonia-Water Recuperative Rankine (AWRR) bottoming power cycles. Through investigating temperature distributions of hot and cold fluids and pinch point location in heat exchangers, first energy and exergy analysis is performed and then cost balances and appropriate auxiliary equations are developed for components, so exergoeconomic variables are quantified. A parametric study is also performed to examine the effects on exergoeconomic performance of the cycles, of turbine inlet pressure and ammonia mass fraction in the working fluid. As a result, unit cost of electricity produced by turbine is determined to be 11.87 and 13.85 cent/kWh for the AWR and AWRR systems, respectively. Based on these values it is interesting to note that, unlike the energy and exergy analysis, the exergoeconomic viewpoint prefers the AWR system to AWRR. Also parametric study revealed that ammonia concentration has a great effect on exergoeconomic performance of the both systems. Increasing ammonia mass fraction increases total exergy destruction cost rate as well as unit cost of electricity produced by turbine in the both AWR and AWRR systems. This shows the advantage of using a binary mixture such as ammonia–water as a working fluid in these cycles.

1. Introduction

Increasing the consumption of fossil fuels to satisfy the growing world energy demand leads to increasing concerns about depletion of fossil fuel resources and air pollution. So the interest in efficient methods of energy generation has increased. One of the trustworthy methods is effective use of every power and thermal energy that can be utilized from a fuel source. Thus, in recent years, greater attention has been paid to the utilization of low grade waste heat for electrical power production.

Among the bottoming cycles, Organic Rankine Cycles (ORCs) have several promising features that make them a suitable choice for production of electrical power from low and medium temperature heat sources [1]. At low temperatures, organic fluids cause higher efficiency than water for power cycles [2]. Since pure fluids evaporate and condense at constant temperature, a large temperature difference occurs in the evaporator and condenser of the cycle. This increases the irreversibility and consequently degrades the performance of the system. To improving the performance, using the zeotropic binary mixtures such as ammonia–water as a working fluid is suggested. Heat can be rejected from or supplied to these fluids at constant pressure but at variable temperature. This improves the temperature matching between cold and hot streams in the heat exchangers and reduces the exergy destruction in the power cycle. The use of ammonia with water in a binary mixture has several advantages. For example, existing designs for the steam turbines can still be used in ammonia–water based power cycles since water and ammonia have close values of the molecular weights. Also, the boiling temperature of ammonia is lower than water which improves the performance of the cycle in power producing from a low grade heat source [3].

Changing ammonia concentration in the ammonia–water mixture as a working fluid enables the power cycle to adapt with renewable energy sources fluctuations. Wagar et al. [4] carried out a thermodynamic analysis of an ammonia–water based rankine cycle for power production from the renewable energy resources and industrial waste heat. They reported that the source temperature and ammonia concentration in the mixture dramatically affect the cycle performance. Roy et al. [5] performed a thermodynamic analysis of two ammonia–water based

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