EXERGOECONOMIC ANALYSIS OF AMMONIA–WATER BASED POWER CYCLES

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ABSTRACT

An exergoeconomic analysis is reported for ammonia–water based Rankine (AWR) and ammonia–water based regenerative Rankine (AWRR) power cycles. For this purpose, these cycles are first thermodynamically analyzed through energy and exergy and temperature distributions of fluid streams in the heat exchangers are closely examined. Then cost balances and auxiliary equations are applied to subsystems, therefore, cost formation in the cycles is observed. The exergoeconomic analysis is performed based on the specific exergy costing (SPECO) approach. Finally a parametric study is performed to reveal the effect of ammonia concentration on important exergoeconomic parameters of the cycles. The results show that, among all components, condenser and regenerator have the highest exergy destruction cost rate in AWR and AWRR, respectively. The exergoeconomic factor is determined to be 36.35% and 46.31%, and the unit cost of electricity produced by turbine is calculated as 11.87 and 13.85 cent/kWh for AWR and AWRR systems, respectively. Also it is observed that increasing ammonia concentration increases the unit cost of electricity produced by turbine as well as the total exergy destruction cost rate and decreases the overall exergoeconomic factor for both AWR and AWRR.

Keywords: Energy, Exergy, Exergoeconomics, Rankine power cycle, Ammonia-water mixture, Ammonia concentration, Heat exchanger

INTRODUCTION

Increasing concern regarding the depletion of fossil energy resources and the pollution of the environment has led to the development of high efficiency energy systems. One of the more dependable methods for increasing energy generation efficiency is utilizing every useful power and thermal energy that can be extracted from a fuel source. Thus, great attention has been paid to the utilization of low grade waste heat to generate power in recent years.

Development of Organic Rankine Cycle (ORC) technology has been attained in waste heat recovery of low grade heat sources, such as geothermal sources, solar energy, bio-fuel electricity production plants and vehicle exhaust gases during the last one hundred years (Shu et al., 2012). Since pure fluids have the properties of boiling and condensing at constant temperature, large temperature differences occur in the vapor generator and condenser and therefore, exergy destruction increases in these components. On the other hand, the use of ammonia–water mixture, which is a zeotropic binary-mixture, as a working fluid in the power generating system has been found to be a promising candidate for utilizing low temperature heat source. In the power generation systems using ammonia-water as working fluid, heat can be supplied or rejected at variable temperature but still at constant pressure. The variable-temperature heat transfer process improves the temperature matching between hot and cold streams in heat exchangers and reduces the exergy destruction in the power cycles (Kim et al., 2012).

Zamfirescu and Dincer evaluated the performance of an ammonia–water Rankine cycle that uses no boiler, but rather the saturated liquid is flashed by a positive displacement expander for power generation. Their results showed that the efficiency of the cycle running with ammonia–water is 0.30 in contrast to steam-only case showing 0.23 exergy efficiency, which means an increment of 7.0%, is obtained for the same operating conditions (Zamfirescu and Dincer, 2012). Wagar et al. performed a thermodynamic analysis of an ammonia-water based Rankine cycle for renewable based power production as well as industrial waste heat. They developed a model to optimize the cycle for maximum power output. They found that the cycle efficiencies are drastically affected by the concentrations and temperatures and depending on the source temperature, the cycle energy efficiency varies between 5% and 35% (Wagar et al., 2010). Kim et al. comparatively analyzed ammonia–water based Rankine (AWR) regenerative Rankine (AWRR) power generation cycles by investigating the effects of ammonia mass concentration in the working fluid on the thermodynamic performances of systems. In this work, which will be discussed further in the present work, the characteristics of temperature distributions of the fluid streams in the heat exchangers are illustrated and effects of ammonia concentration on the thermodynamic performances of AWR and AWRR cycles are