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Investigation on the combined Rankine-absorption power and refrigeration cycles using the parametric analysis and genetic algorithm

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ABSTRACT

This study investigates the combined Rankine power and the absorption cooling cycles. The working fluid used in this cycle is the binary liquid mixture of water and ammonia. It produces both refrigeration and power simultaneously via a single heat source. Parametric analysis has been adopted to evaluate the thermodynamic parameters effects on the operation of the combined cycle where the Engineering Equation Solver (EES) is utilized. The obtained results show that environmental temperatures, heat source, refrigeration, inlet pressure, and temperature, and the density of the ammonia-water dilution have major effects on the exergy efficiency, the refrigeration output, and the net power of the system. In order to obtain the maximum exergy and thermal efficiencies, the optimization of the combined cycle has been performed via the genetic algorithm.

1. Introduction

In recent decades, a large amount of wasted heat has been released to the environment in the form of exhaust gases from turbines and engines [1]. Therefore, there is a growing trend to use the binary mixtures instead of Chlorofluorocarbons (CFCs) in gas cycles due to the global warming and its corresponding environment problems [2,3]. The application of binary mixtures such as the ammonia-water and/or the lithium-bromide [4] instead of the CFCs can help to mitigate the global warming.

In Ref. [5], the mixture of ammonia and water was first taken as the working fluid of an absorption cooling cycle to study whether it would afford high thermal efficiencies than these obtainable from a comparable steam power cycle. At the same time, the condensation process is performed at various temperatures to create more pressures than those for the conventional Rankine steam turbines. This high pressure is satisfied in order to preclude the air from entering the system, but is not favorable for the power production and the efficiency of the cycle. And then a power cycle was proposed to employ the mixture of ammonia-water as the operator fluid of the lower cycle [6]. The high-pressure problem in the cycle is solved by the replacement of the condensation process with an absorption process [7]. The combined refrigeration and power thermal cycle has been proposed by Goswami [8]. After that, other researchers have worked on the efficiency of this cycle [9,10]. Yang et al. [11] proposed a new combined power and ejector-refrigeration cycle and conducted the combined cycle analysis for zeotropic mixtures to illustrate effects of fluid compositions and working conditions. Mohtaram et al. [12,13] made detailed energy exergy analysis to find the effects of compressor pressure ratio and ammonia-water dilution on a combined cycle via the EES software. Ahmadi et al. [14] conducted many researches on power plants and combined cycles. They selected Shahid Montazeri power plant in Iran and firstly investigated all cycle equipment. The EES software was utilized for such analysis. In their study, Condenser was the main equipment to waste exergy. They also investigated the feed water heating of the power plant [15] and proposed energy efficiency and exergy destruction as the objective functions. The Cycle tempo software was used for the analysis conducted in these two cases: low pressure and high pressure heart recovery. They made a further investigation on Montazeri power plant on evaluating a full repowering with merging solar energy [16], in which a 400 MW gas turbine for full repowering and solar energy is used for evaporating a part of feed water in parallel with HRSG. Annual effects on fuel consumption, decrease in CO2 emission, and pressure levels of HRSG on cycle performance are evaluated. Then, they evaluated the use of solar thermal energy for heating parallel feed water in repowering Montazeri power plant [17].

By replacing all high-pressure feed water heaters with solar collectors [18], exergy efficiencies and net energy increased by 9.5% compared with the simple cycle, reaching 35.21% and 36.85%, respectively. Keshavarz et al. [19] modeled the industrial scale reaction furnace of Ilam gas treating plant by 3D computational fluid dynamics (CFD). They found that Oxygen and acid gas at center tend to swirl when encountering blades of air and acid gas diffusers. Akbari et al. [20] investigated the effect of semi-attached rib on heat transfer and

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Nomenclature

P	pressure (MPa)
t	temperature (°C)
T	temperature (K)
Q	heat transmitted (kW)
W	power (kW)
S	entropy (kJ/kg K)
h	enthalpy (kJ/kg)
g	heat resource
x	density of ammonia dilution
x_i	mass fraction of components
m	mass flow rate
η1	first low efficient
η2	second low efficiency
η	efficiency
E	total energy (kJ/S)
U	internal energy
E_{in}	exergy of heat source fluid
Q_{in}	total heat added to the cycle

Subscripts and superscripts

B	boiler
C	condenser
eva	refrigeration output
eva,i	evaporator inlet
eva,o	evaporator outlet
i, j,k,l	state points
0	environment state
eva, j	evaporator
rec	rectifier
Ph	physical
Ch	chemical
imf	initial mass fraction
vmf	vapor mass fraction

liquid turbulent flow [21] of Nano fluid [22] water–copper oxide in three-dimensional rectangular microchannel. The numerical results are compared with those of smooth channel.

Since this combined cycle applies the high-density ammonia gas for power generation in turbine, the gas passes through heat exchanger after the turbine exhaust, and meanwhile losses the sensible heat which is needed for chilling water. Consequently, the output of refrigeration is comparatively minuscule [23]. In order to yield greater refrigeration outcomes, the fluid is required to change phases in cooler [24]. Zheng et al. [25] proposed an absorption power/cooling combined cycle, in which the thermodynamic analysis of cycle is performed by using log p–T, log p–h and T–s diagrams. Their considered cycle was based on the kalina cycle [26–28] where a rectifier is used to provide higher densities of ammonia water vapour for the cooling. The evaporator and condenser are placed between the second absorber and the rectifier. With these changes, the cycle is capable to produce more refrigeration and power. Zhang et al. [29] suggest a novel ammonia water cycles for the combination of power and refrigeration. They employ an absorbent separator in their investigations. As a result, new cycle is introduced in [30,31] for the simultaneous production of refrigeration and power which employs the mixture of water and ammonia as the operator fluid. By using this working fluid, high energy and exergy efficiency are achieved for their considered cycles. Although these cycles results in high efficiencies, but they are quite complicated and involve high costs in terms of investment. Wang et al. [32] present a refrigeration and power cycle which is a combination of the Rankine cycle and the absorption refrigeration cycle, and high exergy efficiency is obtained for this cycle. Pouraghaie et al. [33] proposed a combined thermal power and cooling cycle where thermal energy was used to produce work and to generate a sub-ambient temperature stream. The main purpose of their research was to employ multi-objective algorithms with Pareto approach optimization of thermodynamic performance of the cycle. The main conflicting thermodynamic objective functions considered in their investigation was turbine work, thermal efficiency and cooling capacity. It was shown that some important relationships among optimal objective functions and decision variables involved in the combined cycle can be recognized from this study. Joachim-André Raymond Sarr and François Mathieu-Potvin [34] conduct a theoretical analysis in order to increase the thermal efficiency of Rankine cycles by using a refrigeration cycles by connecting it to a refrigeration cycle. Their idea is to use the refrigeration cycle to create a low temperature heat sink for the Rankine cycle.

As shown in Fig. 1, the cycle considered in this study combines the Rankine power cycle with the absorption cooling cycle to be capable of producing both power and refrigeration with the use of a single low temperature heat source such as solar or geothermal energy. Due to the feature of the considered structure, the internal functioning parts as well as assumed optimum conditions of this cycle, it is capable of producing higher refrigeration output which is related to other refrigeration and power cycles. Heretofore, the exergy efficiency of

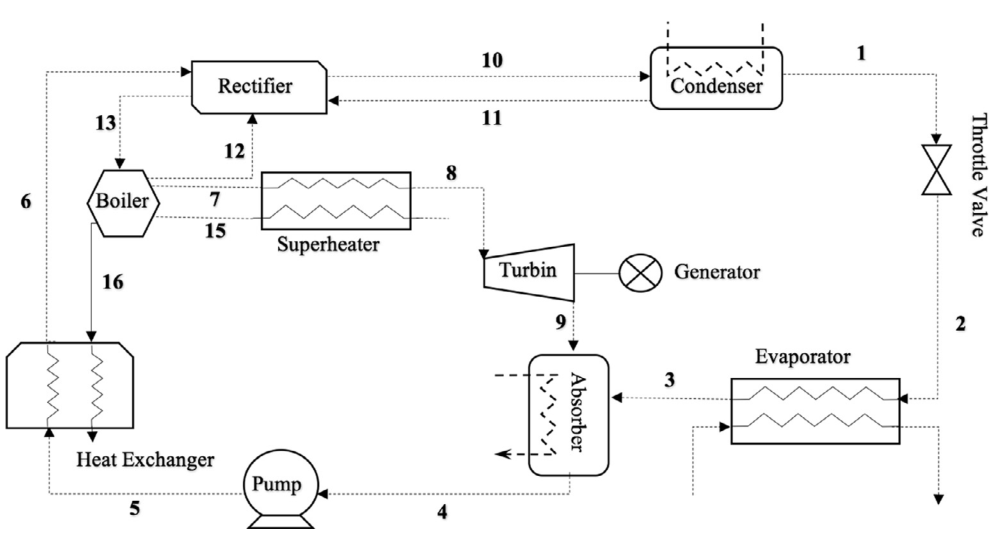

Fig. 1. The considered schematic diagram of the combined power and refrigeration cycle.