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A comprehensive exergoeconomic analysis of absorption power and cooling cogeneration cycles based on Kalina, part 1: Simulation

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ABSTRACT

In this study, ammonia-water double effect absorption refrigeration/Kalina cogeneration cycle and two different configurations of ammonia-water absorption refrigeration/Kalina cogeneration cycles are considered for heat recovery from the high temperature heat source. In this type of cogeneration cycles, power generation and refrigeration cycles have become a single cycle that power and cooling are produced simultaneously in a common loop. After applying the first and second laws of thermodynamics on the components of the considered cycles and the validation of them, by developing SPECO approach on the considered cogeneration cycles, the cycles are simulated from the exergoeconomic viewpoint. For this purpose, the unit cost and cost rate of all streams of the cycles as well as the important thermodynamic and thermoeconomic parameters of each component and the considered cogeneration cycles are calculated. The simulation results indicate that although the thermodynamic efficiency of the double effect absorption refrigeration/Kalina cogeneration cycle is much higher than thermodynamic efficiency of other considered cycles, the economic performance of this cycle is not very desirable. Among the considered cogeneration cycles, the best thermoeconomic performance belongs to the first configuration absorption refrigeration/Kalina cycle. Also, in all cases, the boiler and the low pressure absorber have the highest sum of exergy destruction and capital investment cost rates and should be taken into consideration from exergoeconomic viewpoint for better performance of the cogeneration cycles. The most critical components from the exergy viewpoint are also included boiler, the low pressure absorber and rectifier.

1. Introduction

One of the optimization strategies in the energy section is heat recovery and using cogeneration systems for generating power, cooling and heating simultaneously. Today, burning fossil fuels is usually used to generate power and then convert it into electricity. In this process, a very small amount of fuel energy is converted into electricity and a large amount of input energy is wasted. Improved utilization of heat released during the burning process will increase the thermal efficiency and reduces fuel consumption and emissions of pollutants. On the other hand, absorption chillers are superior to compression chillers due to lower power consumption and the advantage of using waste heat as a heat source. In recent years, the use of absorption power and cooling cogeneration systems for heat recovery from low and medium temperature heat sources such as solar and geothermal, as well as high temperature heat sources such as exhaust gases from a diesel engine or gas turbine system is taken into consideration and several cycles have been proposed for this purpose.

So far, the valuable researches have been done on thermo-economic analysis of different cycles [1–16] which has been rising in recent years. Also, the number of investigations on Kalina cycle has increased significantly in recent years. The latest works are presented in Refs. [17–22]. Subsequently, several important studies on the exergoeconomic analysis of the Kalina cycle are being carried out.

A comparison between the Kalina cycle and the transcritical carbon dioxide power cycle are performed by Li and Dai [23]. These two cycles are compared in terms of six objective functions: output power, first law efficiency, second law efficiency, heat transfer area of heat exchangers, ratio of cost to output power and percentage of heat exchangers cost at the total cost of components. Geothermal fluid was selected as the heat source of these two cycles. The results have been shown that the net produced power and first law efficiency of the Kalina cycle are higher, while the amount of second law efficiency of the carbon dioxide cycle is higher. Also, the ratio of cost to output power and the contribution of heat exchangers cost at the total cost of components for the Kalina cycle was lower than the corresponding values for carbon dioxide cycle. Thermoeconomic comparison between trilateral Rankine cycle, organic Rankine cycle and Kalina cycle using a low grade heat source is

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Nomenclature

c	unit cost of exergy ($/GJ)
c_w	unit cost of produced power ($/GJ)
c_q	unit cost of cooling rate ($/GJ)
$\dot{C}$	cost rate ($/s)
$\dot{C}_D$	exergy destruction cost rate ($/s)
$\dot{C}_{D,overall}$	overall exergy destruction cost rate ($/s)
CRF	capital recovery factor
ex	specific exergy (kJ/kg)
$\dot{E}x$	exergy rate (kW)
f	exergoeconomic factor
h	specific enthalpy (kJ/kg)
i	interest rate
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa, bar, MPa)
$\dot{Q}$	heat transfer rate (kW)
r	relative cost difference
s	specific entropy (kJ/kg K)
T	temperature (°C or K)
$\dot{W}$	electrical power (kW)
$\dot{W}_{net}$	net produced electrical power (kW)
X	ammonia concentration
Z	capital cost of a component ($)
$\dot{Z}$	capital cost rate ($/s)
$\dot{Z}_{overall}$	overall capital cost rate ($/s)

Abbreviations

ABS	absorber
Cond	condenser
Eva	evaporator
Gen	steam generator
HX	heat exchanger
P	pump
Rec	rectifier
Tur	turbine

Subscripts

0	environmental stat
1, 2, 3, …	cycle location
ch	chemical exergy
D	destruction
e	output
f	fuel
hs	heat source
i	input
k	each component
L	loss
p	pump, product
ph	physical exergy

performed by Yari et al. [24]. These three cycles are optimized for the maximum net produced power and the minimum cost of products. The results show that increasing the inlet temperature of the expander in trilateral Rankine cycle increases the amount of net power while decreases the cost of products. The cost of products in this cycle is heavily dependent on the isentropic efficiency of the expander. In both ORC and Kalina cycles, the amounts of operating parameters were different in the maximum net produced power and the minimum cost of products states. Zare et al. [25] have carried out an exergoeconomic analysis of heat recovery from a gas turbine-modular helium reactor using the Kalina cycle. In this research, a parametric study is performed to determine the effects of operating parameters variations on the thermodynamic and economic performance of the combined cycle. The results indicated that in optimal economic conditions, the first law efficiency and the cost of products were 8.2% more and 8.8% lower than the optimal economic conditions for a gas turbine-modular helium reactor cycle. In this states, the capital investment cost rate of the components of the combined cycle is slightly higher than the corresponding value for turbine gas-modular helium reactor cycle. Oguz [26] has investigated an economic analysis of a geothermal power plant called Simav, using the KCS-34 Kalina cycle. The results of this research showed that, in the best conditions, it produces 41.2 MW power, and the energy and exergy efficiencies are determined to be 14.9% and 36.2%, respectively. A comparative study of simple ORC, dual pressure ORC, dual fluid ORC and Kalina cycle are performed by Shokati et al. [27]. In all cycles, a geothermal fluid with 175 °C is used as the heat source. The cycles are optimized for the maximum net power and the minimum unit cost of produced power. The results indicated that the Kalina cycle has the lowest unit cost of produced power among these cycles. This value is 26.23%, 52.09% and 66.74% less than the corresponding value for simple ORC, dual pressure ORC, dual fluid ORC in optimal state, respectively. Also, dual pressure ORC has the highest amount of net produced power among the studied cycles. Seyyed Mohammadi et al. [28] have analyzed the novel configuration of Kalina cycle and gas turbine-helium-modular reactor combined cycle in terms of exergoeconomics. The economic results of the analysis showed that in optimal state, the lowest cost of produced power in novel combined cycle is 11.3% and 2.53% lower than GT-MHR/Kalina combined cycle and GT-MHR cycle, respectively.

In recent years, absorption power and cooling cogeneration cycles have been widely studied and a lot of researches have been done on these cycles to improve their performance. For the first time, Goswami and Xu [29] presented the absorption power and cooling cogeneration cycle and showed that for using low and medium temperature heat sources, this cogeneration cycle is an appropriate option. In this cycle, the outlet strong ammonia-water solution from rectifier produces power after passing through the superheater and the outlet stream of turbine will generate refrigeration in evaporator. First law efficiency was obtained about 23.5% for a heat source higher than 137 °C, which is more than the usual steam power cycle first law efficiency in the same operating conditions. Electric power and refrigeration rate equal to 2 MW and 700 kW are produced in this cycle. In another study, Goswami and Lu [30] focused on productive refrigeration in low temperatures at the Goswami cycle. In this research, the temperature of the heat source was selected 87 °C and the cycle was optimized for the maximum second law efficiency using the GRG algorithm. They concluded that when the weight of the productive refrigeration in the second law efficiency equation is equal to one, at the temperature of −28 °C, the first and second law efficiency values will reach 17.4% and 63.7%, respectively, but these values decrease with increasing refrigeration temperature. If the productive refrigeration weight in the second law efficiency equation to be selected the reverse of the coefficient of performance (COP) in the ideal refrigeration cycle, both the first and second law efficiencies decrease with decreasing refrigeration temperature. Demirkaya et al. [31] have performed a parametric study on Goswami cycle using the ChemCAD simulator. In their study, they examined the effects on the performance of the cycle of a wide range of boiler pressure and concentration of ammonia-water solution. The results showed that for the isentropic efficiency of 75% for turbine, energy and exergy efficiencies are obtained 5% and 28%, respectively, at boiler temperatures of 83.4 °C and rectifier temperature of 41.7 °C. They also showed that if the heat source temperature is below 100 °C, it is still possible to generate power and refrigeration simultaneously. Pouraghaie et al. [32] have optimized Goswami cycle with respect to