Applied Thermal Engineering 111 (2017) 8–19

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Thermodynamic analysis of a Kalina-based combined cooling and power cycle driven by low-grade heat source

Liyan Cao, Jiangfeng Wang *, Hongyang Wang, Pan Zhao, Yiping Dai

Institute of Turbomachinery, State Key Laboratory of Multiphase Flow in Power Engineering, School of Energy and Power Engineering, Xi'an Jiaotong University, Xi'an 710049, China

HIGHLIGHTS

- A Kalina-based combined cooling and power cycle is proposed to recover low-grade heat source.
- The effects of several parameters on cycle performance are examined.
- An optimization is conducted by GA to obtain optimum performance.

ARTICLE INFO

Article history:
Received 23 July 2016
Revised 24 August 2016
Accepted 16 September 2016
Available online 17 September 2016

Keywords:
Low-grade heat source
Kalina cycle
Absorption refrigeration cycle
Combined cooling and power
Optimization

ABSTRACT

This paper investigates a Kalina-based combined cooling and power (CCP) cycle driven by low-grade heat source. The proposed cycle consists of a Kalina cycle and an absorption refrigeration cycle. By establishing the mathematical model, numerical simulation is conducted and parametric analysis is performed to examine the effects of five key parameters on the thermodynamic performances of Kalina-based CCP cycle. A performance optimization is conducted by genetic algorithm to obtain the optimum exergy efficiency. According to parametric analysis, an optimum expander inlet pressure can be achieved; exergy efficiency increases with expander inlet pressure and concentration of ammonia-water basic solution, but exergy efficiency decreases when terminal temperature difference of high-temperature recuperator and low-temperature recuperator increases. Refrigeration exergy increases with expander inlet pressure and decreases as expander inlet temperature and concentration of ammonia-water basic solution rise. However, the refrigeration exergy keeps constant as the terminal temperature difference of high-temperature recuperator and low-temperature recuperator vary. Furthermore, the optimized Kalina-based CCP cycle is compared with a separate generation system which is also optimized. The optimization results show that the exergy efficiency and net power output of Kalina-based CCP are higher than those of separate generation system.

1. Introduction

In recent years, energy and environmental problems have increased interest in utilization of low-grade heat sources. Ammonia-water mixture is a low-boiling point working fluid, which exhibits favorable thermodynamic property in low-grade heat sources recovery. As a non-azeotropic mixture, ammonia-water mixture evaporates and condenses over a range of temperature. This characteristic of temperature glide enables the ammonia-water mixture to achieve a better temperature match between the working substance and the heat sources.

In 1984, Alexander Kalina [1] came up with a novel power cycle named Kalina cycle on the basis of ammonia-water mixture, in which a distiller condensate sub-system was innovatively proposed to solve the condensation problem of ammonia-water mixture at a relatively low turbine backpressure. Kalina cycle has the potential to accomplish efficient energy conversion of the low-grade heat sources. Mid/Low-temperature geothermal energy utilization with Kalina cycle drew researchers' attention, and Kalina cycle showed satisfactory thermodynamic performance [2–6]. In addition, Kalina cycle could be applied to solar energy utilization. Flat plate collector was usually chosen to boost Kalina cycle [7–9] owing to its low cost. However, the heat collecting temperature of flat plate collector is relatively low, the parabolic trough collector [10] and the compound parabolic collector [11] were employed to increase the heat collecting temperature.

Besides Kalina cycle, ammonia-water absorption refrigeration cycle was also expected to play a significant role in the low-grade heat source recovery. Researchers [12,13] conducted energy

---

* Corresponding author.
E-mail address: jfwang@mail.xjtu.edu.cn (J. Wang).

http://dx.doi.org/10.1016/j.applthermaleng.2016.09.088
1359-4311/

Nomenclature

E	exergy, kW
HRSG	heat recover steam generator
h	specific enthalpy, kJ·kg^{-1}
I	exergy destruction, kW
m	mass flow rate, kg·s^{-1}
P	pressure, MPa
Q	heat rate, kW
SHX	solution heat exchanger
s	specific entropy, kJ·(kg·K)$^{-1}$
T	temperature, K
t	temperature, °C
W	power, kW
x	ammonia mass fraction, %

Greek letters

η	efficiency
Δ	difference

Subscript

a	absorbent
abs	absorber
amb	ambient
b	ammonia-water basic solution
com	compressor
ex	exergy
exp	expander
gen	generator
HTR	high-temperature recuperator
in	inlet
isen	isentropic
LTR	low-temperature recuperator
net	net
out	outlet
p	ammonia-poor solution
pump	pump
r	ammonia-rich vapor
re	refrigerant
rec	rectifier
ref	refrigeration
s	strong solution
th	thermal

and exergy analysis for ammonia-water absorption refrigeration and found an optimum temperature of heat source to maximize the coefficiency of performance (COP) [14,15]. An experiment system has been established to verify the feasibility of ammonia-water absorption refrigeration cycle [15–17].

Nowadays, combined cooling and power cycle is a booming technology for efficient utilization of energy. Ammonia-water, which is widely used as working fluid in power cycle and refrigeration cycle, exhibits excellent thermodynamic performances. Therefore, many researchers have attempted to construct combined cooling and power cycles adopting ammonia–water as working fluid to improve overall energy conversion efficiency.

Zheng et al. [18] proposed a combined cooling and power cycle on the basis of Kalina cycle to generate power and refrigeration output simultaneously. The authors substituted the separator with rectifier to purify the ammonia vapor and inserted a condenser and an evaporator between the rectifier and the absorber. On this basis, Luo et al. [19] further analyzed combined cooling and power cycle proposed by Zheng. They conducted a sensitive analysis and mainly focus on the impact of the split ratio and the concentration of ammonia-water on cycle performance. Their results indicated that appropriate split ratio and concentration of ammonia-water could enable the cycle to satisfy the power and refrigeration demands of users. Sun et al. [20] combined a Rankine cycle with an absorption refrigeration cycle to generate power and refrigeration output by utilizing waste heat source. The high-temperature portion of the waste heat was used for power cycle, and the exhaust heat and low-temperature part were used to drive the refrigeration cycle. Their results showed that the combined cooling and power cycle was more efficient than separated power and refrigeration systems. The proposed combined cooling and power cycle only recover the heat carried by turbine exhaust. Besides, the turbine exhaust contained a certain amount of ammonia. In order to achieve heat and ammonia mass recovery, Sun et al. [21] modified their combined cooling and power cycle, in which the turbine exhaust was brought into the bottom of rectifier to act as the upward vapor in the process of rectification. Sun et al. combined the Rankine cycle with a single-effect refrigeration cycle. The single-effect absorption refrigeration system is the most commonly used design. But its coefficient of performance (COP) is relatively low comparing with double-effect refrigeration cycle. Therefore, researchers investigated the combination of power cycle and double-effect refrigeration cycle. Yu et al. [22] integrated a modified Kalina cycle and a double-effect absorption refrigeration cycle by mixing and splitting process to produce power and cooling. The flow rates could be adjusted by varying the split ratio, which enabled the cooling to power ratio to be adjustable. Jing and Zheng [23] coupled the Kalina cycle and the double-effect absorption refrigeration cycle as well. And they compared the coupled-configuration with the separated Kalina and double-effect absorption refrigeration cycle. The results showed that energy cascade utilization was enhanced by the coupled-configuration.

Zhang and Lior [24] came up with a parallel connected power and cooling cycle on the basis of absorption refrigeration cycle. The purified ammonia vapor was condensed and throttled down to produce refrigeration output in an evaporator. Meanwhile, the ammonia-poor solution absorbed heat in a boiler and expanded in a turbine. This cycle generated power and produced refrigeration in parallel, which took full advantage of ammonia-rich vapor and ammonia-poor solution, achieving cascade utilization of energy. Liu et al. [25] proposed a series connected ammonia-water refrigeration and power combined cycle. The ammonia-poor solution mixed with the ammonia-rich vapor in the absorber. And the mixture absorbed heat in the boiler and entered the turbine to expand. For the series connected cycle, the working fluid has higher ammonia concentration in heating process, which reduces the irreversibility of heating process. Based on the parallel connected and series connected combined cooling and power cycles, Liu and Zhang [26] proposed a concentration-adjustable combined cooling and power cycle by introducing splitting/absorption unit. In this cycle, the ammonia concentration increases in heat addition process and the decreases in absorption–condensation process. The irreversibility of both processes could be reduced simultaneously. Zhang and Lior [27] summarized the general principles for integration of power cycle and refrigeration cycle to achieve higher energy and exergy efficiencies.

As summarized above, the combined power and cooling cycles with excellent thermodynamic performance could generate power and cooling simultaneously. However, all these combined power