Applied Energy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Thermodynamic analysis and optimization of a novel combined power and ejector refrigeration cycle – Desalination system

Mohsen Sadeghi, Mortaza Yari*, S.M.S. Mahmoudi, Moharram Jafari

Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran

HIGHLIGHTS

- A multi-generation system for producing power, cooling and fresh water is proposed.
- The proposed system is based on the combined power and ejector refrigeration cycle.
- To recover some energy, the HDH desalination unit is integrated with the top cycle.
- A zeotropic mixture is selected as the working fluid in the proposed system.
- Thermodynamic analysis and two scenarios of optimization are carried out.

ARTICLE INFO

Keywords:
Exergy
Multi-generation system
Ejector
Zeotropic mixture
Desalination

ABSTRACT

A novel multi-generation hybrid system is proposed and analyzed in details from the viewpoint of thermodynamics. Using a zeotropic mixture as working fluid, the system consists of a power and ejector refrigeration cycle as well as a desalination system based on humidification and dehumidification processes. A parametric study is performed to specify the decision variables influencing the system performance prior to the optimization process. The optimization is conducted in two cases. In the first case, a single-objective optimization is carried out to maximize the overall exergy efficiency. In the second case, a multi-objective optimization is accomplished considering the net output power and refrigeration capacity as the objective functions.

The results in the first case reveals a maximum overall exergy efficiency of 17.12% for which the net output power is 57.03 kW and the refrigeration capacity is 91.25 kW. In the case of multi-objective optimization, the results obtained from Pareto frontier shows a net produced power of 52.19 kW and a refrigeration capacity of 120.4 kW. With these data an overall exergy efficiency of 16.46% is calculated. The amount of fresh water calculated in case two is slightly higher than that obtained in case one.

1. Introduction

Nowadays, due to the fossil fuel shortage and the global warming associated with consumption of this energy, the use of medium and low temperature heat sources and also the utilization of more effective systems such as multi-generation systems are becoming increasingly important. In multi-generation systems such products as power, refrigeration, heating and distilled water are produced, simultaneously. A lot of configurations and also working fluids have been proposed for the multi-generation systems and also for their sub-systems. In these systems, the working fluid plays an important role on its performance from the viewpoint of second law of thermodynamics. In this regard, zeotropic fluids have been paid a lot of attention in recent years. A zeotropic fluid is a mixture of two or more substances with different boiling point. The temperature of zeotropic mixtures varies during the phase change processes, so that it leads to a better temperature profile matching in the heat exchangers as illustrated in Fig. 1. This brings about a reduced value of exergy destruction in such components as the evaporator, generator and condenser [1,2].

Based on the discussions made above and the literature review, it seems that using the organic Rankine cycles (ORCs) with zeotropic mixtures as a working fluid is an appropriate way of utilizing the low grade heat sources to produce power [3–12]. This is because, the ORCs are simple, flexible and reliable [13]. Using zeotropic mixtures as working fluid, Sadeghi et al. [2] carried out energy and exergy analyses for three different configurations of organic Rankine cycles including simple ORC, parallel two- stage ORC (PTORC) and series two-stage ORC (STORC). They also performed multi-objective optimization to

---

* Corresponding author.
E-mail address: myari@tabrizu.ac.ir (M. Yari).

http://dx.doi.org/10.1016/j.apenergy.2017.10.047
Received 31 December 2016; Received in revised form 6 October 2017; Accepted 11 October 2017

Please cite this article as: Sadeghi, M., Applied Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.10.047

Nomenclature

A	area (m^2)
c_p	specific heat at constant pressure (J/kg·K)
ΔT	temperature difference
$\dot{E}$	exergy rate (kW)
$\dot{e}_{ch}$	specific chemical exergy (kJ/kg)
Erms	root mean square error (%)
h	specific enthalpy (kJ/kg)
$\dot{m}$	mass flow rate (kg/s)
P (kPa)	pressure (kPa)
$\dot{Q}$	heat transfer rate (kW)
R, r	radios (m)
R_g	universal gas constant (J/kg·K)
S	salinity (g/kg)
s	(kJ·K/kg)
T	temperature (K)
V	velocity (m/s)
w	specific humidity
$\dot{W}_{net}$	net output power (kW)

Acronyms

CAOW	closed-air open-water
GOR	gain output ratio
HDH	humidification/dehumidification
MR	mass flow rate ratio
RR	recovery ratio (%)
ORC	organic Rankine cycle

Subscripts

Br	brine
cond	condenser
cw	cooled water
D	dehumidification
eje	ejector
eva	evaporator
f	saturated liquid state during the heating process
fw	fresh water (distilled water)
gen	generator
H	humidification
ppc	pinch point in condenser
ppg	pinch point in generator
sw	seawater
wf	working fluid
wh	water heater

Greek symbols

$\eta_{ex,Overall}$ (%)	overall exergy efficiency
ω	entrainment ratio

determine the optimal values of design parameters. Their results indicated an improvement of 27.76% in power generation when a zeotropic mixture is used instead of pure fluid as working fluid.

In recent years, ejector- refrigeration cycles have been paid more attention compared to some other refrigeration systems. This is because of their fewer moving parts, lower operating, installation and maintenance costs [14] and being more environmental friendly. Moreover, these systems are able to utilize the low temperature heat sources (lower than 350 K) [15] such as solar energy, geothermal energy and waste heat rejected from industrial processes [16]. Recently, Allouche et al. [17], developed a dynamic model to investigate performance of an integrated solar-driven ejector based air conditioning system combined with a PCM cold storage. Their results showed that under the optimized condition, a maximum COP of 0.193 is achieved for the system. The effects of ejector geometries on the performance of a two-phase ejector refrigeration cycle has been investigated by Jeon et al. [18]. They reported that for the optimized value of mixing section diameter, the maximum COP of system could be improved up to 6.8% compared to the basic cycle. A comprehensive study to investigate performance of an ejector refrigeration cycle under overall modes (critical/sub-critical) was conducted by Chen et al. [19]. They reported that the cycle using R290 as the refrigerant has higher COP under critical mode and could operate at low evaporator temperature.

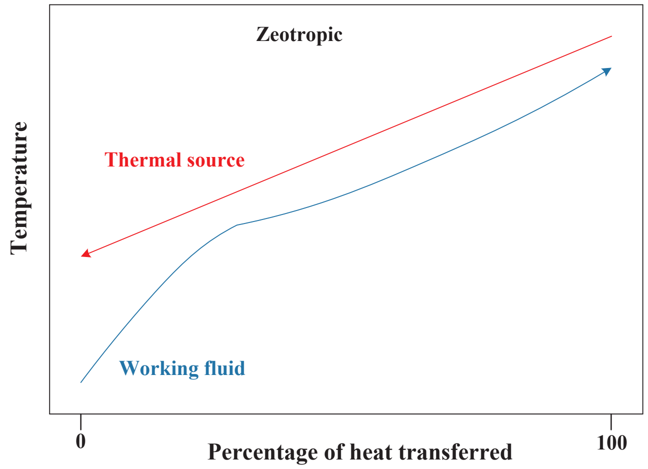

Fig. 1. Improvement of the temperature mismatching during the evaporation and process for zeotropic mixtures.

Considering advantages mentioned for ORCs and ejector refrigeration systems, numerous studies based on combination of these two cycles are conducted to utilize low temperature heat sources. According to arrangement, the combined power and ejector refrigeration cycles could be divided into two categories: parallel and series. In parallel configuration, the working fluid exiting generator is divided into two streams; one part enters turbine and generates power and the other one enters ejector as the primary flow. This configuration was proposed by Oliveira et al. [20] as the first time. It was shown that COP of the combined cycle could be achieved about 0.45 for a generator temperature of 140 °C. Alexis [21] proposed a cogeneration system based on the combination of Rankine cycle producing 2 MW power and steam ejector refrigeration cycle. In his proposed system, the part of steam was extracted from turbine to supply the ejector refrigeration cycle. Wang et al. [22] studied a combined power and ejector refrigeration cycle with extraction of turbine exiting stream between heat recovery steam generator (HRSG) and ejector. It was reported that the highest value of exergy destruction occurs at the HRSG and the exergy efficiency of combined cycle could be obtained 27.51%. Also a combined cooling, heating and power (CCHP) system driven by solar energy was developed by Wang et al. [23]. They showed that the maximum exergy efficiency of 60.33% could be achieved for the proposed system.

In the second type of combined power and ejector refrigeration cycle arranged in series form, the steam exiting the turbine enters the ejector as a primary flow. This configuration was proposed as the first time by Die et al. [14]. They investigated performance of a combined cycle from the view point of exergy. Their results showed that the exergy efficiency of cycle under the optimized condition could be attained about 27.10%. Using R245fa as the working fluid, Zheng et al. [24]