Energy Conversion and Management 168 (2018) 329–342

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Parametric analysis and optimization of a cooling system with ejector-absorption chiller powered by solar parabolic trough collectors

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ARTICLE INFO

Keywords:
Solar cooling
Parabolic trough collector
Absorption chiller
Ejector-absorption chiller
Optimization

ABSTRACT

Solar cooling is one of the most promising technologies for covering the increasing needs of our society with a clean and sustainable way. This paper examines an ejector-absorption cooling system operating with the LiBr-H_2O working pair which is driven by parabolic trough solar collectors. The main objective of this investigation is to optimize the total solar cooling system and to compare it with the respective optimum system with conventional absorption chiller and parabolic trough collectors. The generator temperature and pressure, as well as the pressure drop in the ejector, are the optimization parameters, while the maximization of the system performance is the objective function. According to the final results, the system with the ejector leads to higher COP (coefficient of performance) for the majority of the examined operating scenarios. Moreover, the optimized ejector-absorption system presents performance enhancement up to 60.9% compared to the conventional absorption system for the case with 12.5 °C evaporating temperature and 30 °C condenser temperature. For this optimum case, the system COP is about 1.01, the chiller COP is 1.65 and the system exergy efficiency is 4.76%. Generally, the system COP is ranged from 0.473 to 1.01 for the system with ejector, while the demanded specific collecting area from 0.987 to 2.11 $m^2/kW_{cooling}$. The analysis is performed with a developed model in Engineering Equation Solver which is validated with literature results.

1. Introduction

The use of solar energy gains more and more attention the last years because of a series of issues as the population growth [1], the increasing rate of energy consumption [2] and the greenhouse emissions [3]. Solar energy can be utilized in numerous applications for heating, cooling, electricity production, as well as in industrial processes. Solar cooling is a promising technology because it presents high compatibility between the solar energy supply and the cooling demand. Moreover, it aids the electricity consumption reduction at the summer noon [4,5].

There are various solar cooling technologies which are usually based on sorption machines (absorption chillers, adsorption chillers and desiccant wheels). Among them, the absorption chiller presents the highest performance (COP) [5,6]. Moreover, there are also systems with ejectors [7,8] which operate with thermal energy input in a generator. The sorption machines generally lead to the higher coefficient of performance for the usual evaporating temperatures levels (~10 °C) [9] and thus they are more common than the ejector systems. However, the implementation of an ejector device in a sorption machine is an idea which leads to better performance than the conventional absorption chillers [10,11]. The disadvantage of this technology is the need for higher heat source temperatures (about 150–200 °C) [10] while the conventional absorption chillers need driven temperatures in lower levels (80–100 °C) [9]. In order to reach this medium–high temperature levels, the use of parabolic trough collector (PTC) seems to be a sustainable solution [12].

At this point, it is important to give a brief literature review with important studies for the various solar cooling technologies. In solar cooling with absorption chillers, the use of evacuated solar collector (ETC) or parabolic trough collector has been proved to be the most sustainable solutions. Shirazi et al. [13] conducted an energetic and economic investigation of some solar cooling systems with various solar collectors. According to their results, ETC was found to be the best technology for single stage absorption chillers while PTC is the most appropriate solar technology for the multi-stage absorption chillers. Bellos et al. [14] proved that the use of PTCs in a single stage absorption chiller leads to higher energetic performance compared to the other solar collectors, while ETC is the best solution financially. However, the decreasing rate of the PTC cost, which it is estimated at 200 €/m^2, is a crucial factor which can establish them as the best technology for this system. On this direction, there are also other literature studies with PTC and absorption chillers on a solar cooling system. Drosou et al. [15]

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https://doi.org/10.1016/j.enconman.2018.05.024
Received 20 February 2018; Received in revised form 4 May 2018; Accepted 8 May 2018

Nomenclature

A_{col}	collecting area, m^2
A_T	storage tank outer area, m^2
c_p	specific heat capacity, kJ/kg K
E	exergy flow, kW
G_b	solar beam radiation, W/m^2
h	specific enthalpy, kJ/kg
K	incident angle modifier, –
m	mass flow rate, kg/s
P	pressure, kPa
Q	heat rate, kW
T	temperature, °C
T_{sun}	sun temperature, K
T_o	reference temperature, K
U_T	tank total heat loss coefficient, kW/m^2 K
$(UA)_g$	total heat transfer coefficient in the generator, kW/K
V	velocity, m/s
V_T	storage tank volume, m^3
W_{pu}	pump work, kW
X	LiBr mass concentration,%

Greek symbols

ΔP	pressure drop, kPa
η	efficiency, –
θ	incident angle, –
μ	entertainment ratio, –
ρ	density, kg/m^3

Subscripts and superscripts

a	absorber
am	ambient
c	condenser
ch	chiller
col	collector
d	diffuser
e	evaporator
ex	exergy
HEX	heat exchanger
in	inlet
is	isentropic
g	generator
loss	heat losses
low	low pressure in the mixing region
m	mixing region
n	nozzle
opt	optimum
out	outlet
pf	primary flow
r1	refrigerant primary
r2	refrigerant secondary
s	heat source to the generator
sf	secondary flow
sn	suction nozzle
sol	solar
st	storage tank
str	strong
sys	system
st,1	storage tank first mixing zone
st,2	storage tank second mixing zone
st,3	storage tank third mixing zone
u	useful
w	weak

Abbreviations

COP	coefficient of performance
EES	Engineering Equation Solver
ETC	evacuated tube collector
FPC	flat plate collector
PTC	parabolic trough collector

studied a double stage absorption chiller with LiBr-H_2O driven by PTC for Greek climate conditions. They found the solar fraction over 50% for 1716 m^2 collecting area and cooling load equal to 1147 kW. Tzivanidis and Bellos [16] found that a PTC module of 14 m^2 is able to drive a single stage absorption chiller for covering the daily cooling demand of a 25 m^2 space area in Athens. The use of an alternative working pair (LiCl-H_2O) in a double stage absorption chiller driven by PTC is examined in Ref. [17] by Bellos et al. In this study, the optimum generator temperature was determined for operation with LiCl-H_2O and LiBr-H_2O as working pairs. According to the final results, the alternative working pair (LiCl-H_2O) is found to be 7.5% more efficient than the LiBr-H_2O. Moreover, Cabrera et al. [18] compared various solar collectors in solar cooling systems with absorption chillers and they indicated the use of PTC for using lower collecting area.

The next part of the presented literature review is associated with the use of ejector systems with generators. These systems have generally lower performance than the system with absorption chillers. Flat plate collectors (FPC) and ETC are the most usual solar technologies for driving refrigeration systems with ejectors. Huang et al. [19] examined a solar cooling-ejector system with various solar collectors and they found that the use of FPC leads to system COP equal to 0.19 and with ETC equal to 0.28. Yapici et al. [20] examined a solar cooling ejector system with FPC and they found the optimum generator temperature close to 75 °C. On the other hand, Guo and Shen [21] found the optimum generator temperature close to 85 °C for a system with ETC and an extra auxiliary heater. The use of PTCs on similar systems is restricted in the literature. The studies of Pollerberg et al. [22–24] are the most representatives. In these papers, the authors calculated the daily system COP close to 0.20.

The combination of absorption chillers and ejectors has also been examined in the literature. As it stated in Refs. [10,11], this configuration performs better than the conventional absorption systems. However, the examination of the ejector-absorption chiller configuration driven by solar energy is seldom examined. Sozen et al. [25] examined the use of ejector between the absorber and the generator for operation with NH_3-H_2O. They used PTCs in their study and they investigated their system in various cities of Turkey. According to their results, the maximum COP was found close to 0.75, while the generator temperature was examined up to 130 °C. Boyaghchi and Taheri [26] investigated the use of the ejector between the generator and the condenser in a system with NH_3-H_2O as working pair. They used ETCs while there was an auxiliary heater in order to keep the generator temperature constant at 85 °C. The final results proved that the maximum COP was about 0.5. Abed et al. [27] investigated experimentally a solar cooling system with ejector-absorption technology. They used three ejectors between generator and condenser, the examined solar technology was ETCs, while the working pair was NH_3-H_2O. Their results proved the system COP to be from 0.23 up to 0.47.

As it is obvious from the previous literature review, there are numerous studies on solar cooling applications. The combination of absorption chillers and ejectors is a promising cooling technology which has been highlighted in the literature. However, there is lack of studies