Energy Conversion and Management 167 (2018) 165–175

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Energetic, economic and environmental study of cooling capacity for absorption subsystem in solar absorption-subcooled compression hybrid cooling system based on data of entire working period

Liming Liu[a,b,c], Zeyu Li[a,b,c,*], Yue Jing[a,b,c], Shiliang Lv[d]

[a] School of Electric Power, South China University of Technology, Guangzhou 510640, China
[b] Guangdong Province Key Laboratory of High Efficient and Clean Energy Utilization, South China University of Technology, Guangzhou 510640, China
[c] Guangdong Province Engineering Research Center of High Efficient and Low Pollution Energy Conversion, Guangzhou, 510640, China
[d] Guangdong Province Guanghong Food Group Co., Ltd, Guangzhou 510160, China

ARTICLE INFO

Keywords:
Solar cooling
Absorption
Subcooled compression
Economic
Environmental

ABSTRACT

The rated cooling capacity of an absorption subsystem in a solar absorption-subcooled compression hybrid cooling system is difficult to design for the entire working period owing to the differences in monthly meteorological data. In addition, the annual performance of the hybrid system deteriorates significantly when the size of the absorption subsystem is designed improperly. Accordingly, the effect of the nominal cooling capacity in the absorption subsystem on the annual performance of an SASCHCS is assessed by means of energy, economic, and environmental analyses. A corresponding model is developed. Additionally, the annual total energy savings, payback period, net present value, and CO_2 emissions for different sizes of absorption subsystems are calculated and analysed. It is found that the size of the absorption chiller in the solar absorption-subcooled compression hybrid cooling system should be designed according to the meteorological data for the month of May, when the solar irradiance is at a medium level. The maximum energy saving fractions of a hybrid facility from April to October are 7.67%, 9.42%, 7.62%, 9.16%, 9.29%, 10.2%, and 11.0%, respectively. The minimum values of LCCP and CO_2 emissions are 2532.46 t and 113.04 t, respectively. The rated cooling capacity of the absorption subsystem should be designed as 50 kW according to the maximum energy savings and optimal CO_2 emissions. It turns to be 47 kW based on the shortest payback period of 17.73 years, as well as the highest net present value. This paper is helpful in improving the performance of solar absorption-subcooled compression hybrid cooling system during the entire operational period.

1. Introduction

International Energy Outlook 2013 reported that world energy consumption would grow by 56% between 2010 and 2040; in addition, energy-related carbon dioxide emissions would rise from about 31 billion metric tons in 2010 to 36 billion metric tons in 2020, and then to 45 billion metric tons in 2040 [1]. Because the hourly value of solar irradiance is coincident with that of cooling loads of buildings [2], the application of solar cooling technologies can notably reduce air-conditioning energy consumption, thus efficiently decreasing fossil energy consumption. Current technologies for air cooling with solar thermal energy consist of solid adsorption, solid and liquid desiccant, and absorption machines. The most commercial solutions are the absorption systems [3,4], which can make use of low-grade thermal energy and save high-grade mechanical energy. However, the low performance of absorption chillers has become the main barrier to commercial application [5]. Therefore, it is essential to increase the performance of the absorption chiller.

Hidalgo et al. studied the influence of component size on the performance of a solar cooling facility [6]. It was determined that the specific volume of a storage tank was 40 L/m^2 in the collector area from an experimented single absorption AC system on a typical summer day in Spain. Mateus et al. evaluated the potential of an integrated solar absorption system for different climates and building types [7], and it was found that vacuum tube collectors can reduce the collector area by between 15% and 50% compared to flat-plate collectors. However, flat-plate collectors led to higher economic viability owing to their initial cost. Joudi et al. [8] developed a thermodynamic model to simulate a simple LiBr-H_2O absorption refrigeration system, and studied the influence of the inlet hot water temperature and inlet condenser cooling

* Corresponding author at: School of Electric Power, South China University of Technology, Guangzhou 510640, China.
E-mail address: epzeyuli@scut.edu.cn (Z. Li).

https://doi.org/10.1016/j.enconman.2018.04.102
Received 1 January 2018; Received in revised form 7 April 2018; Accepted 27 April 2018

Nomenclature

A	area (m^2)
C	cost ($)
CEC	CO_2 emissions cost ($)
CI	capital investment ($)
CRF	capital recovery factor
d	diameter (m)
e	specific exergy (kJ/kg)
EC	electricity cost ($)
ESF	energy saving fraction
g	acceleration of gravity (m/s^2)
h	specific enthalpy (kJ/kg)
i	average annual interest (discount) rate
I	solar irradiance (W/m^2)
IRR	internal rate of return (%)
LCC	life cycle cost ($)
LCCP	life cycle climate performance (t)
m	mass flux (kg/s)
n	system lifetime (year)
NCF	net cash flow ($)
NPV	net present value ($)
OC	operating cost ($)
PBP	payback period (year)
q	heat flux (kW/m^2)
Q	heat load (kW)
ref	reference system
T	temperature (°C)
V	volume (m^3)
VCRS	vapor compression subsystem
W	work (kW)
x	concentration of solution (kg/m^3)
Z	investment cost ($)

Greek symbols

β	power plant emissions factor
η	efficiency (%)
λ	thermal conductivity (kW/m·°C)
μ	viscosity (kg/m·s)

Subscripts

0	environmental state; first year
a	surrounding
AS	absorption subsystem
c	unit cost
COM	compressor
CS	compression subsystem
e	evaporator
ETC	evacuated tube collector
g	generator
HE	heat exchanger
hyb	hybrid system
i	inlet; inflation
IN	installation cost
k	each system component
L	levelisation
n	nominal
o	outlet
r	rate; real
SC	subcooler
st	storage tank
tot	total
v	vapour

water temperature. Gomri et al. [9] conducted a comparison between single-effect and double-effect absorption systems using the second law of thermodynamics. It was found that there was an optimum generator temperature for each condenser and evaporator temperature. It was also shown that the COP of the double-effect system was approximately twice the COP of the single-effect system. A control strategy for the absorption chiller was presented by Gebreslassie et al. [10] to make the system less sensitive to fluctuations in energy prices. Allouhi et al. [11] performed annual simulations in six climatic zones to estimate the cooling loads of solar sorption technologies for a typical Modern Moroccan House. The major finding was that solar cooling systems in hot climates must be an attractive solution to mitigate CO_2 emissions and increase energy savings. A high value of exergo-economic factor for any component suggests that the cost of capital investment should be reduced even at the expense of exergetic efficiency [12], and a low value of exergo-economic factor indicates that the exergetic efficiency of the component should be increased even at the expense of the cost of the capital investment.

Although the performance of solar absorption chillers has increased adequately, it is still not an economically feasible solution for a high-rise building. For a high-rise building, the cooling power exclusively supported by a solar absorption system cannot meet the building's cooling demands [13,14]. It was found that the specific collector area of a solar absorption cooling facility is about 3–4 m^2/kW, which means that the collector with a full roof area can match only the cooling load of three floors. Thus, using a gas-fired heater as backup is necessary. Nevertheless, it is not economically feasible to use a gas heater, mainly owing to high operation costs caused by the abundant consumption of natural gas [13]. A hybrid cooling system which combines different types of chillers has higher energy-saving potential. This not only saves on operation costs but also contributes additional environmental benefits [15,16]. Xu et al. [17] compared the performance between two kinds of 100-kW hybrid absorption-compression refrigeration systems, which both have the potential of energy savings. The researchers recommended a better cycle in different working conditions. Fong et al. [18] proposed a hybrid solar cooling system for high-rise offices by combining absorption refrigeration with desiccant dehumidification. It was found that the annual primary energy consumption of the solar hybrid cooling system was 36.5% lower than that of a conventional vapor compression chiller. For a high-rise building, Shirazi et al. [19] analysed a parallel configuration based on coupling an undersized single-effect absorption chiller with a vapor compression chiller. This supported better economical feasibility than the gas backup absorption chiller, with a payback period of 36.2 years. The PBP is higher than the plant's lifetime owing to the poor energy savings. Therefore, a novel absorption compression hybrid cycle-solar absorption-subcooled compression hybrid cooling system (SASCHCS) is proposed to solve the cooling demand for the high-rise building. In an SASCHCS, the cooling power of a solar single-effect absorption chiller is used to subcool the refrigerant in a traditional vapor compression chiller. In most hypothetical working conditions, the COP of an SASCHCS is 16.1% higher than that of a traditional vapor compression cycle [20]. This system is able to lower the temperature of the driving heat source and provides the possibility for the efficient utilisation of low-grade solar energy [21,22]. It was demonstrated that the SASCHCS is comparable to a solar PV cooling system in economic aspects, and the annual total cost of an SASCHCS is less than that of a solar PV cooling system [23]. As a result, the potential of the SASCHCS is great [24]. In our previous study, the SASCHCS was investigated thermodynamically and exergo-economically to increase the energy savings and obtain a cost-effective design.