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Exergoeconomic analysis of solar absorption-subcooled compression hybrid cooling system

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ABSTRACT

The solar absorption-subcooled compression hybrid cooling system is a novel and better solution for the building with many floors. The existing study only reports the thermodynamic study of solar absorption-subcooled compression hybrid cooling system but does not refer to the cost effective design of system. Hence, the paper mainly deals with the exergoeconomic investigation of solar absorption-subcooled compression hybrid cooling system and aims to present the design guideline of system. The exergoeconomic model of solar absorption-subcooled compression hybrid cooling system was developed at first. Subsequently, the corresponding analysis was performed and the effect of primary design parameter on the product cost flow rate was obtained and discussed. Finally, the global optimal design of system was carried out by the nonlinear direct search method. The result showed that the cost effective design of system mainly depends on the reasonable design of cooling capacity of absorption subsystem as well as component in the compression subsystem, i.e., condenser, evaporator and compressor. Besides, it was found that the trade-off between the investment cost and exergy destruction should be considered in the above-mentioned design. Compared to the base case, the product cost flow rate in the optimal design comes down by 11.58%. The paper is helpful to improve the design of solar absorption-subcooled compression hybrid cooling system and make system cost effective.

1. Introduction

The amount of air conditioning grows rapidly with the improvement of living standard. Therefore, the consumption of air conditioning plays an important role in the social energy consumption. The solar refrigeration, i.e., solar $LiBr/H_2O$ absorption chiller is considered as the promising way to reduce the consumption of air conditioning in respect that the cooling demand of office building is coincident to the solar irradiance. Because the solar thermal gain of collector locating at the facade of building is very low, it was recommended that the collector should be installed at the roof of building [1]. It was shown that the specific collector area of solar $LiBr/H_2O$ absorption chiller is about 4 m^2/kW cooling capacity [2]. If the mean cooling load of building is assumed to be 0.1 kW/m^2 (like the building in subtropical city), it can be inferred that the auxiliary heat is essential for the solar cooling system to match the size of chiller with the cooling demand of building when the number of floor exceeds three. The more the number of floor is, the higher the auxiliary heat consumes. Consequently, the operational cost of solar $LiBr/H_2O$ absorption chiller is even greater than that of vapour compression chiller for the building with many floors [3]. It is attributed to that the cost of auxiliary heat exceeds the gain associated with the saving of electric energy. In this case, the extra cost of solar refrigeration system caused by the collector and other components cannot be returned so that the solar/auxiliary heat driven $LiBr/H_2O$ absorption chiller is economically infeasible for the building with many floors. Actually, the economically feasible solution for the building with many floors is based on a new working mode that an undersized absorption chiller exclusively driven by solar energy (no backup thermal energy) with the auxiliary vapour compression chiller (UACAVCC) [4]. The working principle of such solution is like the absorption-compression hybrid system with parallel configuration [5]. Although this solution is economically better than the solar/backup heat driven absorption chiller, its payback period is unsatisfactory since the energy saving of such system is still poor [4]. Subsequently, we [6] proposed a novel type UACAVCC, i.e., solar absorption-subcooled compression hybrid cooling system (SASCHCS), to provide a better solution for the building with many floors. In the SASCHCS, the cooling output of absorption chiller does not directly

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Nomenclature

A	area (m^2)
Ar	Archimedes number based on tube diameter
c	cost per exergy unit ($/GJ)
c_p	specific heat (kJ/kg °C)
C	cost flow rate ($/s)
$CEPCI$	chemical engineering plant cost index
CRF	capital recovery factor
e	specific exergy (kJ/kg)
E	exergy rate (kW)
d	diameter (m)
f	exergoeconomic factor
F	fouling factor (m^2 °C/kW)
g	acceleration of gravity (m/s^2)
h	specific enthalpy (kJ/kg), heat transfer coefficient (W/m^2 °C)
I	solar irradiance (W/m^2)
$LMTD$	logarithmic mean temperature difference
m	mass flow rate (kg/s)
Nu	Nusselt number
Pr	Prandtl number
q	heat flux (kW/m^2)
Q	heat load (kW)
r	latent heat (kJ/kg), relative cost difference
Re	Reynolds number
s	specific entropy (kJ/kg)
T	temperature (°C)
W	work (kW)
x	concentration of solution
Y	ratio of exergy to total exergy supplied to the system
Y^*	ratio of exergy destruction to total exergy destruction
Z	investment cost

Greek symbols

ρ	density (kg/m^3)
η	efficiency
λ	thermal conductivity (kW/m °C)
μ	viscosity (kg/ms)
σ	surface tension (N/m)
Γ	mass flow rate per wetted perimeter (kg/ms)

Subscripts

0	environmental state
a	surrounding
AS	absorption subsystem
COM	compressor
CS	compression subsystem
D	exergy destruction
ex	exergy
E	evaporator
ETC	evacuated tube collector
F	fuel
g	generator
HE	heat exchanger
i	inlet
l	liquid
L	loss
o	outlet
oy	original year
pool	pool boiling
P	product
R	reference state
s	isentropic
sat	saturation
sys	system
SC	subcooler
SP	solution pump
ST	storage tank
v	vapour
w	wall

cool the chilled fluid but subcools the refrigerant of auxiliary vapour compression chiller to increase the variation of specific enthalpy in the evaporator and save the work of compressor. Owing to the improvement of evaporator temperature in the absorption chiller, the performance of absorption-subcooled compression hybrid cycle is higher [7]. In addition, the low grade solar energy of which temperature is just 60 °C can be utilized in the SASCHCS [8]. As a result, the economic performance of SASCHCS is better and its potential is great [9]. The SASCHCS was studied thermodynamically to increase the energy saving in our previous investigation [10]. Since the rise of energy saving usually accompanies with the growth of investment cost, the cost effective design of SASCHCS is essential.

It is highly important to design the cost effective solar cooling system since the economic obstacle seriously influences the commercial application in recent [11]. The exergoeconomics combining the thermodynamics and economics is helpful to design the cost effective system [12]. The exergoeconomics uses exergy instead of energy as the thermodynamic criteria to describe the cost balance of component in the system. The corresponding result includes the product cost flow rate, product cost per exergy unit, exergoeconomic factor and so on. A lot of exergoeconomic studies of absorption chiller are found in the open literature. This method is firstly introduced to analyze the single effect LiBr/H_2O absorption machine [13]. Subsequently, it is extended to the double effect LiBr/H_2O absorption chiller [14]. Additionally, the NH_3/H_2O absorption system is also included [15]. It was shown that the product cost per exergy unit of NH_3/H_2O absorption cycle is the lowest and the exergoeconomic factor of LiBr/H_2O absorption cycle is the highest [16]. A more exact exergoeconomic analysis of different type double effect LiBr/H_2O absorption chillers was performed by the consideration of correlation of heat transfer coefficient [17]. The exergoeconomic analysis is extended to the hybrid cycle as well. It was found that the product cost flow rate of ejector-double effect absorption hybrid cooling system is much lower than that of double effect absorption machine [18]. For the cascade absorption-compression cooling system, there is a trade-off of energy saving and investment cost in the design of cooling set and solution heat exchanger [19]. Compared with the standard generator-absorber heat exchange (GAX) absorption cycle, the hybrid GAX absorption cycle in which a compressor is employed has better thermodynamic performance but its product cost per exergy unit goes up by 13.5% [20]. For the multi-effect absorption heat pump with vapour compression machine, it has high flexibility and is able to allocate the different energy sources upon varying prices of steam and electric power [21]. The product cost flow rate of this system goes down by 33.33% in the optimal condition [22].

The exergoeconomics is also used widely in the solar thermal application. For the integrated solar combined cycle system, the combustion chamber should be designed carefully [23]. By the multi-objective optimization based on the evolutionary algorithm, the exergy efficiency of above-mentioned system rises by 3.2% and the product cost flow rate reduces by 3.82% [24]. However, the product cost per exergy unit grows by 44% when the system construc-