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A novel internally hybrid absorption-compression heat pump for performance improvement

Wei Wu[a,*], Tian You[b], Jian Wang[b], Baolong Wang[b], Wenxing Shi[b], Xianting Li[b,*]

[a] School of Energy and Environment, City University of Hong Kong, Hong Kong, China
[b] Department of Building Science, School of Architecture, Tsinghua University, Beijing 100084, China

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ABSTRACT

Heat pump technologies play significant roles in building energy saving and emission reduction. Combing the opposite characteristics of the electrical and absorption heat pumps, a novel internally hybrid absorption-compression heat pump was proposed for performance improvement. The thermodynamic models for the hybrid heat pump using two cycles (single-effect and generator-absorber-heat-exchange) were built for component design and performance simulation with various refrigerant distribution ratios. Results show that a higher absorption-side refrigerant ratio generally makes the primary energy efficiency less sensitive and the capacity more sensitive to working condition. In the heating mode, a higher absorption-side refrigerant ratio brings about a higher efficiency when the evaporator inlet temperature is below 16 °C and 20 °C for the two cycles. In the cooling mode, a lower absorption-side refrigerant ratio contributes to a higher efficiency. The hybrid absorption-compression heat pumps can realize flexible heating/cooling capacity ratios to accommodate the design heating/cooling loads as necessary. Generally, a higher absorption-side refrigerant ratio is preferred in colder conditions owing to the higher heating efficiency and the higher heating/cooling capacity ratio, well matching the heating-dominant building loads. This study focuses on the principle and performance of the novel hybrid heat pump, the applications in actual buildings will be conducted through year-round simulations in future studies.

1. Introduction

The building sector accounts for about 30–40% of the total energy consumption in developed countries and 15–25% in developing countries [1]. Spacing heating, space cooling, and water heating play important roles in building energy efficiency, due to the highest energy use and CO_2 emissions [2]. Air source heat pumps (ASHPs) show great potentials in energy saving and emission reduction [3]. Another popular technology is ground source heat pump (GSHP), which provides high efficiency due to favorable ground temperatures [4]. The hybrid GSHPs are also used to further improve the long-term performance of independent GSHPs [5]. Depending on the driving energy sources, heat pumps can be classified as electrical heat pump (EHP), gas-engine heat pump (GHP, the compressor is powered by the output mechanical work of the gas engine), and absorption heat pump (AHP). Both the EHP and GHP are based on a vapor-compression cycle, while the AHP is based on a vapor-absorption cycle. To date, the electrically-driven EHP has been the most widely used owing to its convenient connection to the power grid and the high coefficient of performance (COP).

The thermally-driven AHP is mainly used for cooling and is less competitive with the EHP in terms of COP. Recently, the AHP heating technologies attract increasing attention for the potential to improve the primary energy efficiency (PEE) of the conventional fuel-based heating systems [6]. AHPs have been used in district heat network [7]. They showed great potentials in increasing the heat recovery from power plants and reducing the pump energy consumption [8]. Latent heat recovery from exhaust gas has been conducted through the open-cycle AHP [9]. The closed-cycle AHP has also been adopted for waste heat recovery [10]. In addition, the air-source AHP (ASAHP) was found to save primary energy by 20–40% compared to the conventional boiler systems [11]. Reasonable simple payback periods were achieved after optimal designs [12]. Furthermore, studies indicated that the ground-source AHP (GSAHP) could reduce the soil thermal imbalance and the number of boreholes of the conventional electrical GSHP in cold regions [13].

The previous studies revealed that the EHP and the AHP had opposite characteristics in terms of efficiency and capacity [14]. Compared to the EHP, the AHP yielded higher heating PEEs in cold conditions (Fig. 1(a)) but lower cooling PEEs in most occasions. The heating/cooling capacity ratio (Q_h/Q_c) was usually higher for the AHP than for

* Corresponding authors.
E-mail addresses: wuwei61715253@126.com (W. Wu), xtingli@tsinghua.edu.cn (X. Li).

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Nomenclature

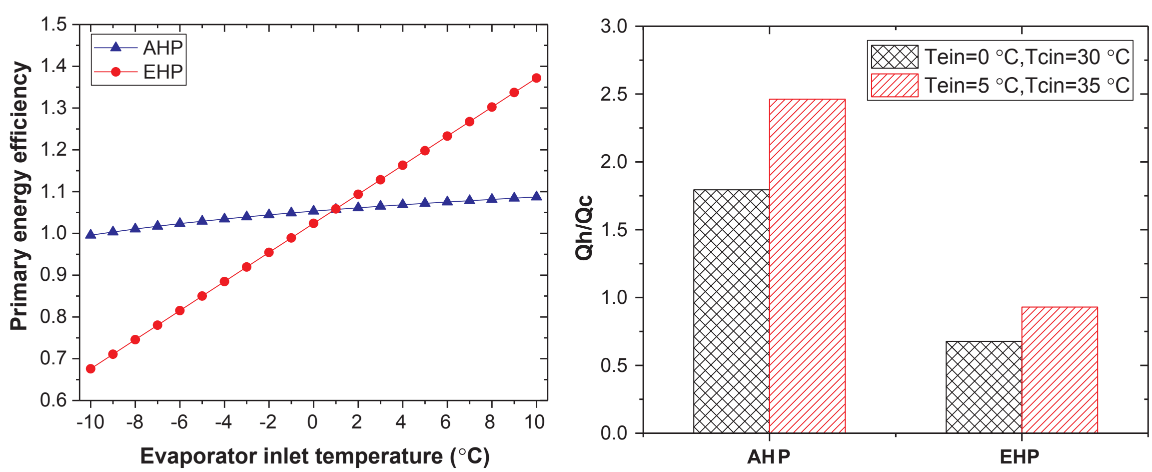
A	heat transfer area, m^2
c_p	specific heat, $kJ\,kg^{-1}\,°C^{-1}$
f	circulation ratio
h	specific enthalpy, $kJ\,kg^{-1}$
IC	initial cost, €
$LMTD$	logarithmic mean temperature difference, °C
m	mass flow rate, $kg\,s^{-1}$
p	pressure, kPa
Pr	pressure ratio
Q	heat duty, kW
R_{AHP}	the ratio of refrigerant flow distributed to the absorption sub-cycle
t	temperature, °C
U	heat transfer coefficient, $kW\,m^{-2}\,°C^{-1}$
V	volumetric flow rate, $m^3\,h^{-1}$
v	specific volume, $m^3\,kg^{-1}$
W	power, kW
x	concentration, %
η	efficiency
ρ	density, $kg\,m^{-3}$

Abbreviations

AHP	absorption heat pump
ASAHP	air source absorption heat pump
ASHP	air source heat pump
COP	coefficient of performance
ECA	externally-cooled absorber
EHG	externally-heated generator
EHP	electrical heat pump
GAX	generator-absorber heat exchange
GAXA	GAX absorber
GAXG	GAX generator
GHP	gas-engine heat pump
GSAHP	ground source absorption heat pump
GSHP	ground source heat pump
HACHP	hybrid absorption-compression heat pump
PEE	primary energy efficiency
SCA	solution-cooled absorber
SHG	solution-heated generator

Subscripts and superscripts

a	absorber
b	boiler
c	condenser, cooling
cp	compressor
e	evaporator, electricity
f	fluid
h	heating
i	isentropic
in	inlet
me	mechanical
mo	motor
g	generator
out	outlet
p	pump, precooler
r	refrigerant, rectifier
s	strong
v	volumetric
w	weak
x	solution heat exchanger



(a) heating PEE (b) capacity ratio

Fig. 1. Comparisons on the PEE and capacity ratio of different heat pumps [14].

the EHP (Fig. 1(b)). The PEE determines the primary energy consumption, while the capacity ratio affects the heat pump sizing and operation adjustment.

Combing the opposite characteristics of the EHP and the AHP, a novel hybrid absorption and compression heat pump is studied for both efficiency improvement and capacity adjustment. Although there have been many studies on hybrid absorption and compression cycles, they were not able to address the above problems. Depending on the sub-cycle in dominance, there are currently two kinds of hybrid cycles. The first is the compression-assisted absorption cycle (absorption is dominant, and compression is auxiliary) [15]. The second is the absorption-assisted compression cycle (compression is dominant, and absorption is auxiliary) [16], as shown in Fig. 2.

The compression-assisted absorption cycle has a compressor installed after the evaporator (called low-side compression), as shown in Fig. 2(a) [17]. The compression can increase the absorption pressure [18]. The compressor can also be installed before the condenser (called high-side compression) to decrease the generation pressure [19]. In these manners, the evaporation temperature or the generation temperature can be lower. Xie et al. [20] presented an experimental