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Research Paper

Performance analysis of an absorption-compression hybrid refrigeration system recovering condensation heat for generation

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HIGHLIGHTS

- An absorption-compression hybrid refrigeration system is investigated.
- The performance of the hybrid refrigeration system with NH_3-H_2O is simulated.
- The primary energy efficiency of the hybrid system can be 97.1% higher.
- The hybrid refrigeration system can recover all condensation heat.
- The hybrid system can decrease generation heat inputted from outside by 70–80%.

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ABSTRACT

Absorption refrigeration systems (ARSs) are widely used both in commercial and industrial projects. In the conventional ARS, much high-temperature heat is supplied to the generator; meanwhile, a large quantity of low-temperature heat is rejected to the environment directly through the condenser and the absorber. In order to enhance the performance of conventional ARS, an absorption-compression hybrid refrigeration system is studied, and it can recover all condensation heat for the generation of refrigerant by improving the grade of condensation heat through a vapor compressor. The effects of different parameters on the performance of this hybrid refrigeration system are investigated by simulation. As a conclusion, the absorption-compression hybrid refrigeration system recovering condensation heat for generation (RCHG-ARS) shows a 70–80% decrease of the generation heat inputted from outside, and the primary energy efficiency (*PEE*) of RCHG-ARS can be 97.1% higher than that of conventional ARS.

1. Introduction

Air-conditioning is responsible for 40–55% of energy consumption in buildings, which is about 20% of total energy consumption for all of China [1]. Conventional absorption refrigeration systems (ARSs), which are mainly driven by heat coming from burning fuel or waste heat, have a competitive primary energy efficiency (*PEE*) compared to electricity driven chillers. Meanwhile, ARS can also use refrigerant-absorbent pairs with 0 ODP (ozone depletion potential) and low GWP (global warming potential), so they are quite consistent with the current international need of environmental protection [2–4]. Due to the merits of energy saving and environmental protection, ARS is becoming more and more widely applied in different areas and has been studied by many researchers [5–7].

However, looking into the typical ARS, it is found that a substantial amount of high-temperature heat is supplied into the system through the generator; meanwhile, a large quantity of low-temperature heat is rejected from the system through the condenser and the absorber. For ARS for cooling, the discharged heat is usually useless and obviously a huge waste. Recovering the exhausted heat to enhance system performance has become an important research direction of the cycle optimization for ARS, which includes generator-absorber heat exchange (GAX) technology, multi-effect absorption technology, absorption-compression hybrid technology, and so on [8–11].

In the GAX system, part of the discharging heat of the absorber is used for solution concentration in the generator, because there is a temperature overlap between the generator and the absorber. As a result, the heat input of the generator from outside is reduced, which leads to a higher *COP* than conventional single-stage and

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Nomenclature

h	specific enthalpy, kJ/kg
m	mass flow rate, kg/s
p	pressure, bar
Pa	state parameters of systems
Q	heat exchange rate, kW
T	temperature, °C
x	mass concentration of NH_3, %
W	compressor power consumption, kW

Greek symbols

ΔT_{min}	approaching temperature in heat exchangers, °C
η_e	energy transformation efficiency from natural gas to electricity
η_h	energy transformation efficiency from natural gas to heat
η_{isen}	isentropic efficiency of compressor

Abbreviations

ARS	absorption refrigeration system
COP	coefficient of performance
GAX	generator absorber heat exchange
GWP	global warming potential
MVR	mechanical vapor recompression
ODP	ozone depletion potential
PEE	primary energy efficiency
RCHG-ARS	absorption-compression hybrid refrigeration system recovering condensation heat for generation

Subscripts

AB	absorber
c	compressor
CA	cooling water
CO	subcooler/condenser
EX	economizer
EV	evaporator
GE	generator
in	inlet
m	middle pressure
new	new ARS, RCHG-ARS
old	conventional ARS
out	outlet
RE	rectifier

single-effect ARS. Zheng et al. [12] studied a conventional ARS and a single-effect GAX absorption chiller system with NH_3-H_2O. When the heat medium input temperatures of the generator, absorber/condenser and evaporator were 120 °C, 25 °C and 5 °C, respectively, the *COP* of the GAX system was enhanced to 0.776 from 0.589 of conventional ARS. Engler et al. [13] completed a simulation using NH_3-H_2O, and found that the *COP*s improved from about 0.50 for conventional ARS to around 1.08 for the GAX refrigeration cycle. Saravanan et al. [14] investigated the performance of a GAX absorption cooling system. Compared with the single-effect absorption system, the *COP* of the GAX system was found to be 30% higher. Kumar and Udayakumar [15] simulated a GAX-compression hybrid system using NH_3-H_2O as working fluids, and with a compressor at the entrance of absorber. The author found that the maximum *COP* of this proposed system was about 1.60, and it was 28.13% higher than 1.15, which was the maximum *COP* of a conventional GAX system.

In the multi-effect system, the refrigerant vapor from the high-temperature generator condenses in the lower-temperature generator, and the condensation heat originally dispatched from the condenser is used for the generation of refrigerant in low-temperature cycles. Therefore, this kind of absorption system can reduce the condensation heat exhausted and the generation heat inputted from outside, and achieve a higher *COP* than conventional single-stage and single-effect ARS. Garimella et al. [16] found that the ideal maximum *COP*s of single-effect ARS and double-effect ARS were 0.7 and 1.2, respectively; their research also illustrated that the *COP* of a triple-effect system using NH_3-H_2O can reach 1.25–1.50. Kaushik and Arora [17] studied single-effect and double-effect ARSs by simulation, results showed that the *COP* of the double-effect system was nearly 60–70% higher than that of the single-effect system. Kim et al. [18] simulated a single-effect ARS, a double-effect ARS, a triple-effect ARS and four different kinds of compressor-assisted triple-effect ARSs, finding that the *COP*s of the first three cycles can be 0.75, 1.24 and 1.54, respectively. And the *COP*s of four compressor-assisted triple-effect ARSs are all around 1.71.

However, a multi-effect system generally needs a higher-temperature driving source. Domínguez-Inzunza et al. [19] found that the generation temperature of the double-effect system usually needed to be higher than 140 °C to obtain high COP, and the lowest driving temperature for the triple-effect system was 150 °C. Moreover, although the multi-effect system can reuse condensation heat, this heat cannot be recovered fully, because part of the condensation heat is still exhausted to the environment directly.

The aforementioned two kinds of technologies are realized by directly recovering the exhausted heat of condensation or absorption. Actually, based on mechanical vapor recompression (MVR), the condensation heat can be recovered for the generation of refrigerant in self-cycle. In this kind of system, part or all of the refrigerant vapor from the generator is compressed by the compressor to a higher pressure. At that pressure, the saturation temperature of the refrigerant is higher than the generation temperature. After that, the superheated refrigerant gas flows into the heat exchanger in the generator and is condensed. At the same time, the condensation heat is provided for the generation of the refrigerant. Obviously, the generation heat can be largely decreased or even eliminated completely, and part or all of the condensation heat can be recovered.

Chen and Hihara [20] evaluated an absorption-compression hybrid refrigeration system. The refrigerant vapor from the generator was divided into two parts: one part went to the condenser directly; the other part was compressed by the compressor and went back to the generator, where the refrigerant condensed and released heat to the process of generation. Finally, the liquid refrigerant went through a three-channel heat exchanger and a throttle valve, flowing to the condenser. The simulation illustrated that the maximum *COP*s of this cycle and conventional single-stage and single-effect ARS were 0.83 and 0.70, respectively. However, only part of the condensation heat was reused in that study, and the generator still needed much high-temperature heat to operate.

Furthermore, it is possible to recover all condensation heat. Patent [21] presented an absorption-compression hybrid refrigeration system to realize the full recovery of condensation heat for the generation of refrigerant. All refrigerant vapor from the generator was compressed by a compressor, and then it condensed and released heat in the generator. After that, the refrigerant exchanged heat with the strong solution entering the generator in a three-channel heat exchanger to preheat it. Finally, the liquid