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Technical engineering design, thermal experimental and economic simulation analysis of absorption cooling/heating systems in China

Zisheng Lu*

Institute of Refrigeration and Cryogenics, Key Laboratory for Power Machinery and Engineering of M.O.E, Dongchuan Rd. 800#, Shanghai Jiao Tong University, Shanghai 200240, China

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ABSTRACT

In low temperature heat sources driven cooling/heating absorption systems, there are many equipment combinations. Usually, there are contradictions between the equipment efficiency and their economy; for example, the high efficiency- solar collector usually has a high price. So, in this paper, ten absorption cooling/heating systems with different heat sources and different absorption technologies are investigated for technical-economic-thermal analysis. The heat sources are flat plate solar collector, evacuated U-pipe solar collector and middle-temperature high efficiency solar collector and waste heat. The absorption chillers are 1-effect LiBr absorption chiller, 2-effect LiBr absorption chiller, novel 1–2 effect LiBr absorption chiller and novel high efficiency-heat-recovery ammonia water absorption system. The results show that 2-effect absorption chiller with heat source of waste heat is the most optimized choice, which lowest payback period is about 1.9 years. The second choices are the 2-effect LiBr absorption system with novel middle-temperature solar collectors/natural gases and the novel ammonia water absorption system with waste heat sources.

1. Introduction

The through utilization of low-grade heat sources in building's cooling and heating, can effectively reduce the consumption of fossil fuels as well as the emission of pollutants and greenhouse gases. The most common low-grade heat sources are solar energy and waste heat from industry or diesel engine's waste gases. Therefore, many researchers have studied this issue. For example, Beccali et al. [1] studied the thermal and environmental performance of four solar energy driven absorption heating cooling systems in different localities with thermal energy storage. Hang et al. [2] analyzed the systematic mechanism of the design of solar absorption cooling and heating system using the research methods of central design, regression and optimization. Gutiérrez-Urueta et al. [3] make a energy and exergy analysis on a solar driven 1-effect LiBr absorption cooling and heating system. They find that the first candidate to optimize in the chiller is the absorber, due to its lowest exergy efficiency. Shirazi et al. [4] researched different solar energy driven absorption cooling systems. These are single effect chiller with evacuated tube collectors, double effect chiller with parabolic trough collectors, linear Fresnel micro-concentrating collector and evacuated flat plate collectors. Fahlén et al. [5] investigated the integration of thermal energy-driven absorption cooling and heating in a district cooling/heating system. In Sweden, district heating systems (DHS) have covered most the areas with potential cooling demand. Yao et al. [6] studied the absorption cooling system driven by forging production process. The COP (coefficient of performance) varies dramatically from 0.35 to 1.82, because of the instability of waste heat from industry process. Rodgers et al. [7] studied the gas turbine waste heat driven-single-effect, double-effect and cascaded cycle chillers in liquefied natural gas plants. The results show that the coefficient of performance and cooling capacity can be improved by 13% and 23%, respectively, by the sub-cooling propane after the propane cycle condenser. Cao et al. [8] designed and investigated the waste heat driven absorption cooling cycle in shipboard application. The simulation results show that waste heat powered cooling system has a high coefficient of performance of 9.4, and the CO_2 emission can be reduced by 62%. Anand et al. [9] studied the ammonia water absorption cooling and heating system driven by waste heat. The simulation results show that the generator and absorber have a highest exergy loss. So, the two components should be optimized. Macía et al. [10] described a solar driven absorption system with ground coupled heat. The simulation results show when the condenser temperature is as low as 25 °C, the global efficiency can increase significantly by 40% when the generator temperature decreases from 84 to 76 °C [10]. Wu et al. [11] studied the ground source absorption heat pump, integrated with borehole free cooling. The results show that this system can provide comfortable

* Corresponding author.
E-mail address: zslu@sjtu.edu.cn.

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Nomenclature

A	area (m^2)
C	specific heat (kJ/(kg K))
COP	coefficient of performance
G	solar irradiation intensity (W/m^2)
h	latent heat or enthalpy (kJ/kg)
m	mass flow (kg/s)
q	cooling or heating capacity (kW)
Q	heat (kJ)
T	temperature (°C)
t	time (hour)
X	refrigerant uptake (g/g)

Greek letters

α	revision constant
μ	combustion value (kJ/kg)
γ	energy inflation rate (%)
δ	refrigerant mass concentration
ε	cost ($)
η	solar collector efficiency
λ	root-mean-square-percent error
σ	measurement accuracy
ω	asset loss ratio (%)
ϑ	boiler efficiency

Subscripts

abso	Absorption
1	1-effect
2	2-effect
ambi	ambient
boil	boiler
chil	chilled
coll	solar collecting
cond	condensation
cool	cooling
deso	desorption
dilu	dilution
elec	electricity
evac	evacuated solar collector
evap	evaporation
flat	flat plate solar collector
gas	natural gases
gene	generation
h	heat pump
heat	heating
high	highest
in	inlet
inst	installation
low	lowest
main	maintenance
max	maximum
midd	middle-temperature high efficiency solar collector
min	minimum
out	outlet
refr	refrigerant
soul	solution
sour	source
syst	system
tota	total
vapo	vapor

indoor conditioning; reduce underground thermal imbalance; increase system's performance. Jayasekara et al. [12] studied the multiple sources driven absorption cooling system. The results show that the combined cycle can reduce capital investment and operation costs. Karlsson et al. [13] demonstrates the utilization of the waste heat from engine condensation heat in absorption cooling, heating and power (CHP) system. Chaiyat et al. [14] developed an organic Rankine cycle (ORC) with a combined cooling, heating and power. The results show that the ORC efficiency can be increased by 7% by the using of the absorption cooling system. Shirazi et al. [15] studied the single effect LiBr absorption cooling system, using evacuated tube solar collectors as heat source and gas-fired heater as a back-up. The solar fraction is about 72% and the primary energy can be reduced by 55% [15].

The above research has made a significant improvement in the application of the thermal energy driven absorption systems. However, few researchers make a full view of thermal energy driven absorption cooling/heating system. So, the objectives of the paper are as the following: different solar collectors of flat plate solar collectors, evacuated pipe solar collectors, middle-temperature high efficiency solar collectors are designed and investigated in the absorption cooling/heating systems; novel 1–2 effect LiBr absorption and high efficiency–heat-recovery ammonia water absorption cycles are studied to improve the system's efficiency; technical-economic-thermal experimental and simulation analysis is made for ten technology strategies with different heat sources and chillers to find the most suitable strategy.

2. Novel solar absorption cooling/heating systems

One novel 1–2 effect LiBr absorption chiller is designed, shown in Fig. 1. We can see that in this system, there are one high generator, one low generator, one condenser, one evaporator, two absorbers, one low heat recoverer and one high recoverer. The high temperature heat source can drive the high generator and the high temperature vapor or solar hot water can drive the low generator. The two absorbers have a larger heat-mass transfer surface. The weak solution from the absorber goes through the low heat recovers to be heated by the strong solution from the low generator. One part of the weak solution can continuously

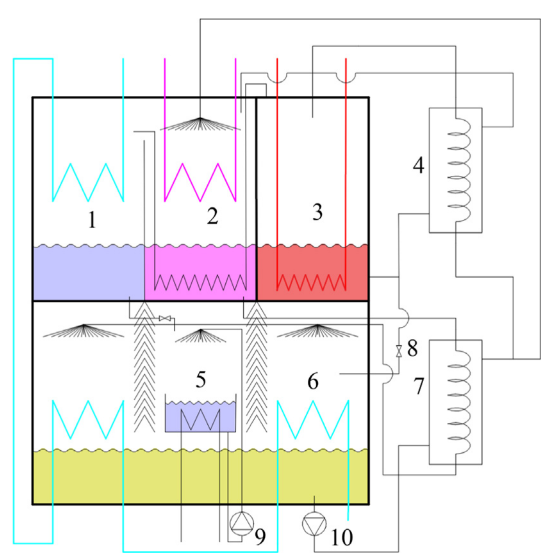

Fig. 1. The schematic diagram of 1–2 effect absorption cycle in one system (1: condenser; 2: low generator; 3-high generator; 4-high heat recoverer; 5-high efficiency-evaporator; 6-absorber; 7-low heat recoverer; 8-valve; 9-refrigerant pump; 10-solution pump).