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Simulation and experimental study of solar-absorption heat transformer integrating with two-stage high temperature vapor compression heat pump

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ABSTRACT

In this study, simulation and experiment studies of a 10 kW solar H_2O–LiBr absorption heat transformer (AHT) integrating with a two-stage vapor compression heat pump (VCHP) were carried out. The whole system was named as compression/absorption heat transformer (CAHT). The VCHP was used to recover rejected heat at the AHT condenser which was transferred back to the AHT evaporator at a higher temperature. The AHT unit took solar heat from a set of flat-plate solar collectors in parallel connection. R-134a and R-123 were refrigerants in the VCHP cycle. From the simulation, the total cycle coefficient (COP) of the solar-CAHT was 0.71 compared with 0.49 of the normal solar-AHT. From the experiment, the total cycle COPs of the solar-CAHT and the solar-AHT were 0.62 and 0.39, respectively. The experimental results were lower than those of the simulated models due to the oversize of the experimental compressor. The annual expense of the solar-CAHT was found to be 5113 USD which was lower than 5418 USD of the solar-AHT. So it could be concluded that the modified unit was beneficial than the normal unit in terms of energy efficiency and economic expense.

1. Introduction

In a conventional absorption heat transformer (AHT), low temperature heat is absorbed at the generator and the evaporator while high temperature heat is delivered at the absorber and there is waste heat rejected at the condenser. Studies on energy analysis of the AHT have been reported by various literatures. Kiatsiriroat et al. [1] reported thermal performance of a H_2O–LiBr AHT for upgrading low temperature heat such as waste heat from industrial processes or solar heat. The coefficient of performance (COP) did not exceed 0.5 because there was a high heat rejection at the condenser. Xuehu et al. [2] also reported test results of the first industrial-scale H_2O–LiBr AHT in China which was used to recover waste heat released from organic vapor at 98 °C in a synthetic rubber plant. The recovered heat was used to heat hot water from 95 °C to be 110 °C. The AHT system was operating with a heat rate of 5000 kW with a mean COP of 0.47. The payback period was approximately 2 years. Sotsil et al. [3] presented a heat transformer absorption cycle operating with water-Carrol^{TM}

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Nomenclature

A	area, (m^2)
C_P	heat capacity, (kJ/kg K)
COP	coefficient of performance
DT	different temperature, (°C)
GTL	gross temperature lift, (°C)
I_T	solar radiation, (W/m2)
$\dot{m}$	mass flow rate, (kg/s)
P	pressure, (bar)
Q	heat rate, (kW)
s	entropy, (kJ/kg K)
SC	subcooling, (°C)
SH	superheating, (°C)
t	time, (s)
T	temperature, (°C)
U	overall heat transfer coefficient, (W/m^2 K)
v	specific volume, (m^3/kg)
W	work, (kW)
X	concentrate, (%LiBr)

Greek symbol

η	efficiency, (%)
ε	effectiveness, (%)
ρ	density, (kg/m3)

Subscript

A	absorber
amb	ambient
bulk	bulk temperature
C	condenser
Coll	solar collector
Comp	compressor
CW	cooling water
e	super heat
E	evaporator
EC	economizer
H	high
HS	heat source
HW	hot water
HX	heat exchanger
i	inlet
L	low
max	maximum
min	minimum
o	outlet
O	outlet steam, ambient
P	pump
r	compression cycle
ref	refrigerant
S	start
SC	solar collector
SP	solution pump
ST	storage tank
Sup	supply
UF	useful
UG	upgraded

mixture which was more soluble than aqueous lithium bromide mixture. It could be found that the COP was higher and less crystallization risk was obtained compared with the water-lithium bromide solution. Sozen [4] reported performance of the AHT that was used to increase a solar pond's temperature. The COP and the maximum temperature were around 0.4 and 150 °C, respectively. Sencan et al. [5] presented performance analysis of a H_2O–LiBr absorption system. It could be seen that the cooling and heating COPs of the system increased slightly when increased the heat source temperature. Rivara et al. [6] reported energy analysis of a single-stage H_2O–LiBr AHT. It was found that the highest COP was obtained at the highest solution concentration at around 0.4.

Normally, the overall COP of the H_2O–LiBr AHT could not be over 0.5. If the heat rejected at the condenser could be recovered and supplied back to the evaporator then the COP could be increased. In this study a method to improve thermal performance of a single-stage H_2O–LiBr AHT by taking a two-stage vapor compression heat pump (VCHP) to recover the waste heat was considered. The modified unit was named as compression/absorption heat transformer (CAHT). Simulation and experimental studies of the H_2O–LiBr AHT with and without the VCHP were performed to study the thermal performances. The main heat source came from a set of flat-plate solar collectors.

2. System descriptions and simulations

Fig. 1 shows a schematic sketch of the solar-absorption heat transformer (solar-AHT). Solar heat is supplied to the AHT generator and the AHT evaporator at a medium temperature (around 60–80 °C) and rejected heat at a lower temperature (around 35–45 °C) at the AHT condenser. A higher temperature heat (around 90–120 °C) is obtained at the AHT absorber.

When the VCHP is combined to the AHT cycle to recover the heat rejected from the AHT condenser which is supplied back to the AHT evaporator, the solar heat could supply at the AHT generator only. Fig. 2 shows a schematic diagram of the CAHT and a two-stage VCHP having R-134a and R-123 as working fluids.

Both units got heat from a solar water heating system that had a set of 2 m^2 flat-plate solar collectors each in parallel connection. The total solar collector areas were 70 and 36 m^2 with a 3000 and 1500 l water storage tank, for solar-AHT and solar-CAHT, respectively. The solar collector characteristics, $F_R(\tau\alpha)$ and F_RU_L, were 0.802 and 10.37 W/m^2 K [7], respectively.