Analysis of a compression-assisted absorption heat transformer

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Abstract

Energy consumption of space heating and domestic hot water increases continuously. A kind of compression-assisted absorption heat transformer (CAHT) can meet the ever-increasing building heating load when the ambient temperature decreases, it is air-cooled and driven by low-grade heat and electricity simultaneously. By establishing the model with NH_3-H_2O, the performance of CAHT is compared with that of conventional absorption heat transformer (AHT) for low-temperature heating under different working conditions, investigating the necessary of the compressor in CAHT. As a conclusion, the CAHT is more appropriate for low-temperature heating than conventional AHT due to the existence of the compressor, and the heating capacity of conventional AHT is 54.85-100% less than that of CAHT. Besides, compared with conventional AHT, the compressor leads to wider working conditions for CAHT.

Keywords: Absorption heat pump (AHP); compressor; low-grade heat; cold region; ammonia-water

1. Introduction

The energy consumption for space heating and domestic hot water is very large and is predicted to increase continuously due to the increase of building area and living standard [1]. Thus it is essential to develop heating source with high efficiency and low emission. However, most of the existing heat supply systems meet the heating demand by fossil fuel direct burning. This method is not effective enough and leads to environmental pollution [2]. Therefore, more efficient heat pump is developed to produce 30-60 ^{o}C water for space heating and domestic hot water supply [3].

However, when the weather becomes colder, the heating load of the building will increase gradually [4], but the performance of electrical heat pumps tends to descend. For example, both the *COP* and heating capacity of air source electrical heat pump (ASEHP) will decline with the decrease of ambient temperature, and this cannot match the variation trend of the building heating load [5]. Water source electrical heat pump (WSEHP) is a great alternative to ASEHP when there exists enough low-grade heat water source with constant temperature, however, the heating capacity of WSEHP remains unchanged as the ambient temperature becoming lower, so it is also unable to meet the over-rising building heating load. Consequently, the design capacities of ASEHP and WSEHP are usually chosen to be very large, preparing for poor working conditions, and this is a huge waste.

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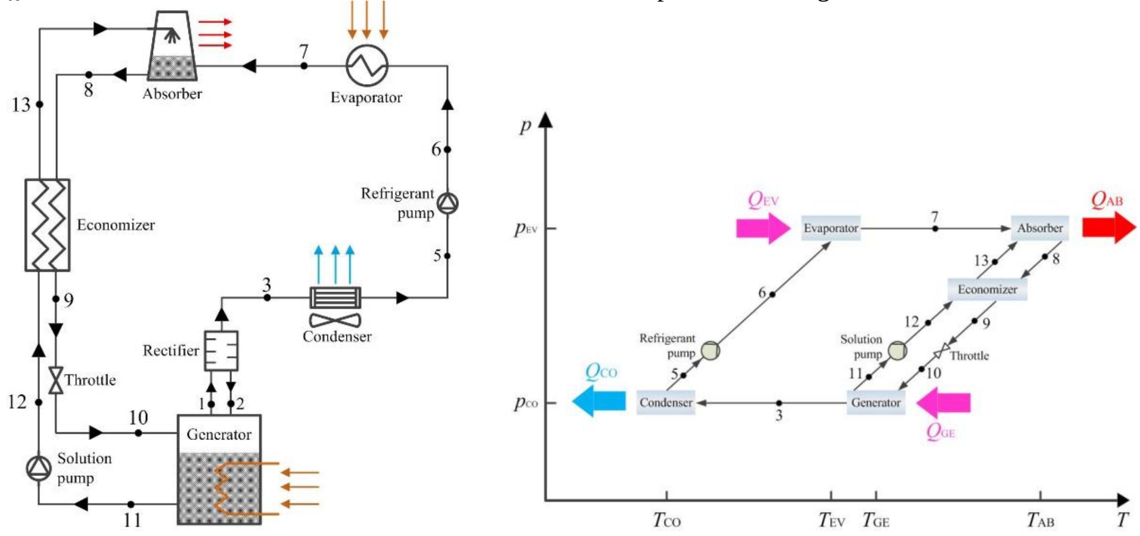
Facing this situation, a kind of new heating system, compression-assisted absorption heat transformer (CAHT), was proposed by Wang et al. [6]. It was used for low-temperature heating and driven by low-grade heat and electricity simultaneously. Based on the conventional absorption heat transformer (AHT), there was an additional compressor between the generator and the condenser in CAHT. The results indicated that CAHT showed a unique adaptability to low temperature ambient, and its *COP* increased with the decrease of ambient temperature.

In order to analyse the necessary of the compressor in Ref. [6] under different ambient temperature and temperature of low-grade heat, this work is to investigate the performance difference between CAHT and conventional AHT, and to study the existence value of the compressor under different working conditions.

2. Principle

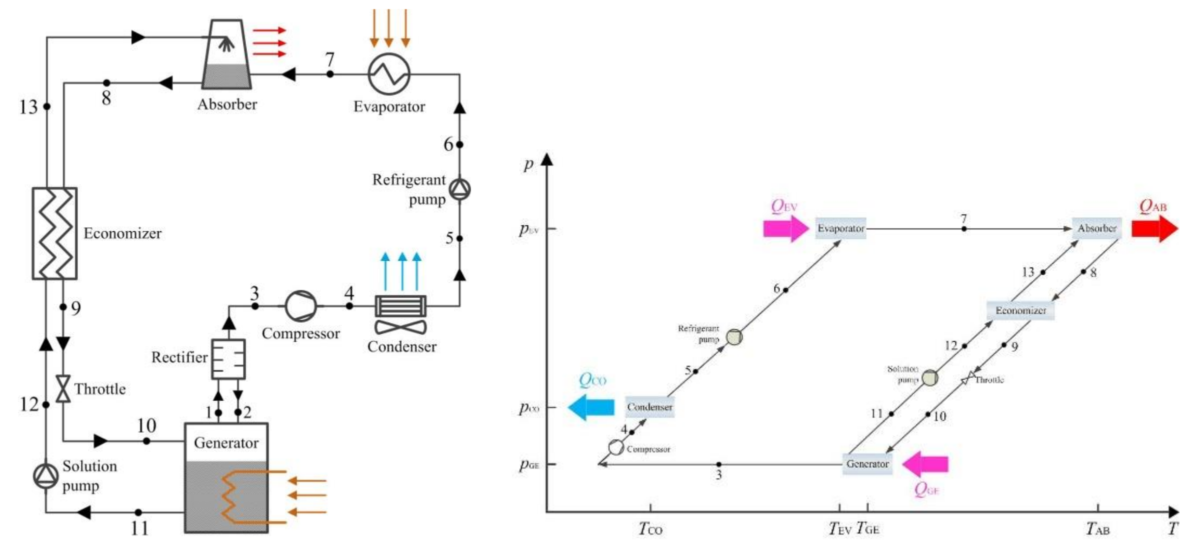
Fig. 1 shows the schematic and *p-T* diagram of conventional AHT [7]. The low-grade driving heat is supplied to the generator and the evaporator; the condenser is cooled with ambient air, taking fully advantage of the natural cooling source; and the absorber releases the heat used for low-temperature heating.



(a) Schematic (b) *p-T* diagram

Fig. 1. Schematic and *p-T* diagram of conventional AHT

The principle of CAHT is displayed in Fig. 2. There is a compressor between the rectifier and the condenser in CAHT, so the generation pressure can be lower than the condensation pressure, just as shown in Fig. 2(b). And then, compared with conventional AHT, the concentration of the weak solution at the outlet of generator is lower under the same generation temperatures. Therefore, CAHT can operate under lower driving temperature, higher condensation temperature and absorption temperature, while conventional AHT might stop. Furthermore, the performance of CAHT increases with the decrease of ambient air temperature.



(a) Schematic (b) *p*-*T* diagram

Fig. 2. Schematic and *p*-*T* diagram of CAHT

3. Modeling

In conventional AHT, NH_3-H_2O is unsuitable for high temperature applications, mainly because the working pressure required is too high [8]. But in present study, the working pressure corresponding to low-grade driving heat is not high, and the cooling temperature may be below 0 °C, so NH_3-H_2O is selected as working fluids.

3.1. Assumptions

AHT and CAHT are all assumed to be steady, and some other necessary assumptions are made [9]:

(1) All heat losses, pressure losses or flow resistance are ignored;
(2) The fluids leaving the generator, the absorber, the condenser and the evaporator are all saturated;
(3) After the rectifier, the refrigerant is considered as pure NH_3;
(4) The approaching temperature the economizer is $\Delta T_{\min}$;
(5) The enthalpies of the fluids at the inlet and outlet of throttle valve are equal.

3.2. Mathematical model

Analyses are completed with the help of the Engineering Equation Solver (EES) software, and it is used by a lot of researchers for thermal modeling of absorption systems with validated accuracy [10, 11].

Mathematical models of conventional AHT and CAHT are built up according to mass and energy conservation [12].

(1) Mass conservation:

$$\sum m_{in} = \sum m_{out} \tag{1}$$

$$\sum m_{in} \cdot x_{in} = \sum m_{out} \cdot x_{out} \tag{2}$$

(2) Energy conservation:

$$Q + \sum m_{in} \cdot h_{in} = \sum m_{out} \cdot h_{out} \tag{3}$$

(3) Compressor:

$$W_c = m \cdot \frac{h_{out,c} - h_{in,c}}{\eta_{\text{isen}}} \tag{4}$$

Where $h_{out,c}$ is the specific enthalpy of refrigerant at the exit of the compressor when the process is isentropic, kJ/kg; $h_{in,c}$ is the specific enthalpy of refrigerant at the inlet of the compressor, kJ/kg; and η_{isen} is the isentropic efficiency of the compressor, equal to 0.6 [13].

(4) Pump:

$$W_p = m \cdot g \cdot 10 \cdot \frac{p_{out,p} - p_{in,p}}{\eta_p} \tag{5}$$

Where g is gravitational acceleration, equal to 9.8 m/s^2; $p_{out,p}$ is the exit pressure of the pump, bar; $p_{in,p}$ is the inlet pressure of the pump, bar; and η_p is the mechanical efficiency of the pump, with a value of 0.8.

(5) Efficiency:

Primary energy efficiency (*PEE*) is chosen to compare the system performance:

$$PEE = \frac{Q_{AB}}{Q_{GE} + Q_{EV} + \dfrac{W_c + W_{pr} + W_{ps}}{\eta_e}} \tag{6}$$

Where Q_{AB}, Q_{GE} and Q_{EV} are the absorption heat, generation heat and evaporation heat, respectively, kW; W_{pr} and W_{ps} separately are the electricity consumption of the refrigerant pump and solution pump, kW; η_e is the transformation efficiency between natural gas and electrical power, with a value of 0.5 [1, 14].

4. Results and discussion

To investigate the necessary of the compressor, the performance of CAHT is analyzed under different driving temperature and condensation temperature, and then the results are compared with those of conventional AHT for low-temperature heating. The input working parameters and variation range are selected as in Table 1.

Table 1. Input working parameters and their range.

Parameter		value
	Low-grade heat source T_{DR}	9~25
Temperature / °C	Condenser T_{CO}	-30 ~ -7
	Absorber T_{AB}	45
Compression ratio for CAHT	e	2
Minimum temperature difference / °C	ΔT	5
Mass flow / kg·s^{-1}	Strong solution m_{11}	1
Mass concentration of NH_3 / %	Refrigerant X_{NH3}	99.8

4.1. Effects of driving temperature (T_{DR})

When the condensation temperature T_{CO} and absorption temperature T_{AB} separately are -10 °C and 45 °C, Fig. 3 shows the effects of T_{DR} on *PEE* for conventional AHT and CAHT, the generation temperature T_{GE} and the evaporation temperature T_{EV} are all equal to T_{DR}, and the compression ratio e is 2.0 in CAHT. As T_{DR} becomes higher, the *PEE* of CAHT increases at first and then keeps stable roughly, while the *PEE* of conventional AHT has been increasing all long. Meanwhile, the *PEE* of conventional AHT is higher than that of CAHT when T_{DR} is higher than 19 °C in Fig. 3, because these two systems can work simultaneously under this condition, but the electricity consumption in CAHT makes its *PEE* lower.

In Fig. 3, the conventional AHT only can work when T_{DR} is higher than 17 °C; however, the lowest T_{DR} for CAHT is 8 °C, thus CAHT can recycle more low-grade heat than conventional AHT does. This is because the generation pressure of CAHT can be lower than that of conventional AHT due to the existence of the compressor, thus the ammonia concentration of weak solution from the generator is smaller in CAHT, so the solution concentration difference is sufficiently high to make CAHT work effectively when T_{DR} is low, while conventional AHT might stop under the same conditions.

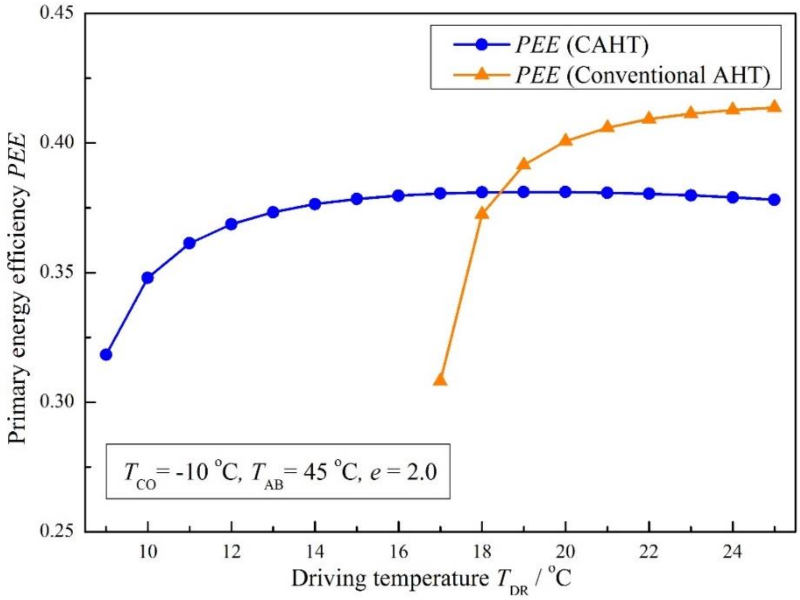


Fig. 3. Effects of T_{DR} on *PEE* for conventional AHT and CAHT

4.2. Effects of condensation temperature (T_{CO})

The ambient temperature can influence the condensation temperature T_{CO} and system performance, Fig. 4 shows the effects of T_{CO} on *PEE* for conventional AHT and CAHT when T_{GE}=T_{EV}=10 °C, T_{AB}=45 °C, and e=2.0 for CAHT. As ambient temperature decreases, so T_{CO} does, and the generation pressure becomes smaller, this is beneficial to the process of generation, so the *PEE*s of two systems increase. But when the ambient temperature is too high, none of them can operate normally.

Besides, the compressor in CAHT makes the solution concentration difference larger than that of conventional AHT under the same working conditions, thus CAHT can work normally when T_{CO} is lower than -6 °C, while the highest T_{CO} for conventional AHT is -22 °C in Fig. 4. So, CAHT can be applied to more heating-need cities and longer heating time.

In Fig. 5, the heating capacities of CAHT and conventional AHT increase with the decrease of condensation temperature, thus both of them can meet the ever-rising heating load of the building when the ambient temperature decreases. Furthermore, with the help of the compressor, the refrigerant mass flow of CAHT is always more than that of conventional AHT when two systems can operate at the same time. The values of Q_{AB} for AHT and CAHT are shown in Table 2. So, the heating capacity of conventional CAHT is 54.85-100% less than that of CAHT under the same external working conditions.

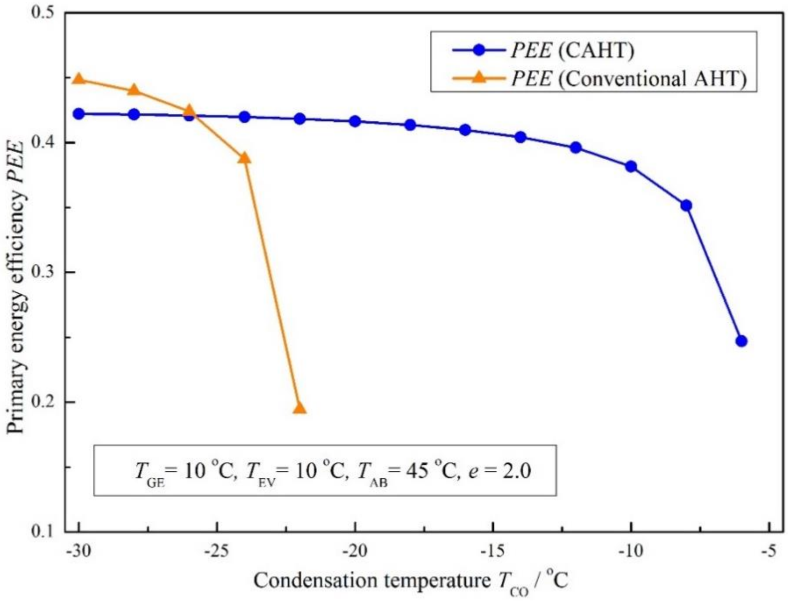


Fig. 4. Effects of T_{CO} on *PEE* for conventional AHT and CAHT

Table 2. Values of Q_{AB} for AHT and CAHT in Fig. 5.

T_{CO} / °C	-30	-28	-26	-24	-22	-20	-18	-16	-14	-12	-10	-8	-6
Q_{AB} (AHT) / kW	155.1	121.4	85.9	48.2	8.0	0							
Q_{AB} (CAHT) / kW	343.5	321.2	298.4	274.8	250.5	225.4	199.4	172.3	144.1	114.5	83.6	51.0	16.4

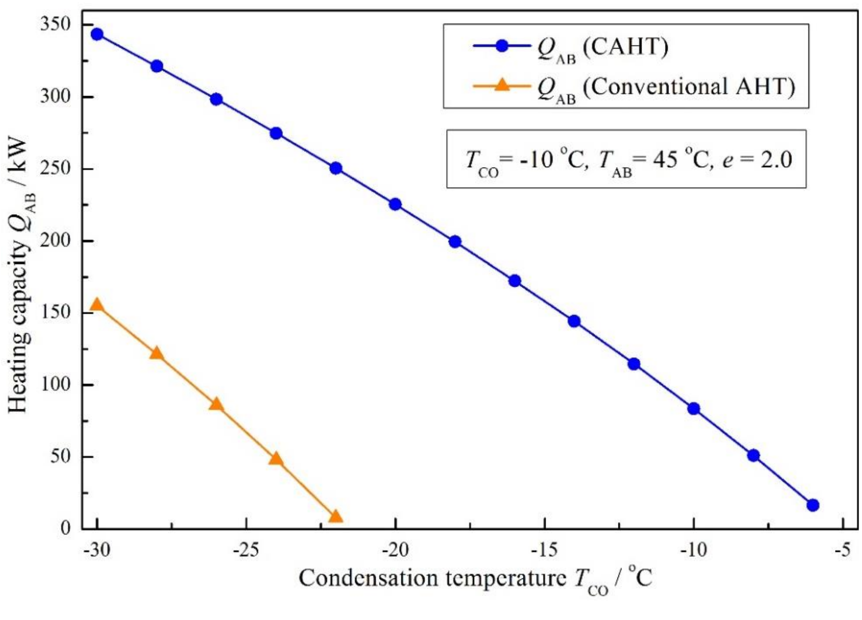


Fig. 5. Effects of T_{CO} on Q_{AB} for conventional AHT and CAHT

5. Conclusion

Both the conventional absorption heat transformer (AHT) and compression-assisted AHT (CAHT) can be applied for low-temperature heating by recycling low-grade heat, and they are cooled by ambient air in cold regions. By establishing mathematical models with NH_3-H_2O, the performance of CAHT is compared with that of conventional AHT, including the effects of driving temperature T_{DR} and condensation temperature T_{CO}. According to the content, some conclusions are drawn:

(1) For space heating and domestic hot water, the CAHT is more appropriate than conventional AHT due to the existence of the compressor.

(2) The heating capacity of conventional AHT is 54.85-100% less than that of CAHT.

(3) Compared with conventional AHT, the lowest T_{DR} drops from 17 ^{o}C to 8 ^{o}C and the highest T_{CO} increases from -22 ^{o}C to -6 ^{o}C by CAHT.

Acknowledgements

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