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Investigation on operation strategy of absorption heat exchanger for district heating system

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ABSTRACT

The absorption heat exchanger (AHE) combined by an absorption heat pump (AHP) and a plate heat exchanger (PHE) is invented for replacing conventional plate heat exchangers at the heating substation in the district heating system, which could decease the return water temperature of primary pipe (PP) significantly when compared with the conventional PHE. The return water temperature of PP is much lower than that of secondary pipe (SP) in the AHE without consuming extra energy. The heating capacity of an original heating pipe is increased obviously, and it is much more convenient to recover different kinds of low grade industrial waste heat by the low temperature return water of PP. Meanwhile, inlet and outlet temperatures of PP and SP vary obviously during a whole heating period, therefore, the effect on heat exchange process caused by the LiBr (lithium bromide) solution circulating rate and the ratio of flow rates of PP and SP in the PHE is studied, which could ensure optimal performance of AHE under different working conditions. Operation regulation curves are given for regulation of the AHE during the whole heating period.

1. Introduction

The district heating has been developing rapidly in urban heating system due to its high energy efficiency and low air pollution, which is 78% of total heating area in northern China [1]. However, the rapid development of urban construction has led to increasing heating demand, which could not be met by the limited heating capacity of current heating pipes. Meanwhile, it is not feasible to lift the temperature of supply water of PP due to the heat-resistant requirement of the heat insulating material, and electric consumption of pumps will increase significantly when increasing the flow rate of PP. Therefore, how to decrease the temperature of return water of PP is important and significant, however, which is often more than 45 °C in current district systems. The low temperature return water of PP could bring many benefits for the district heating, which is an integrated part of future sustainable energy systems. Thus, geothermal energy, solar energy and industrial waste heat could be utilized efficiently.

A feasible and efficient way is to decrease the temperature of return water of SP at present, however, there is a necessary temperature difference between the reture water of PP and that of SP in a conventional heating substation using the PHE, which is often more than 5 °C [2]. Therefore, most efforts are put on how to decrease the temperature of return water of SP.

Decreasing supply and return temperatures of SP could reduce both energy loss and exergy loss. The exergy-based methodology is adopted for estimating the performance of a district heating system with CHP and heat pumps, whose exergetic efficiency could reach 50% by recovering the waste heat [3].

Low energy buildings could ensure the low temperature of SP, whose utilization potential of low temperature district heating system is discussed [4]. Besides, benefits for reducing heat loss, integrating additional heat sources and increasing efficiency are discussed with the low temperature district heating system [5]. Different solutions for low temperature systems are compared for buildings of various levels [6]. Costs of low temperature system from the point of view of energy and exergy are discussed [7], and details of exergy analysis are presented with a complete district heating system [8]. Besides, energy efficiencies of low and high temperature heating systems are compared [9].

Electrical heat pumps could be adopted for decreasing the temperature of district heating system. The CO_2 is suggested as an alternative natural refrigerant for low temperature heating [10], and several electrical heat pumps are compared with its exergy efficiency [11]. However, the electric consumption is quite huge due to long time of a whole heating period, therefore, this low tem-

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Nomenclature

AHE	Absorption heat exchanger
AHP	Absorption heat pump
a	Coefficient of heat diffusion, $m^2\,s^{-1}$
A1	High pressure absorber
G	Generator
A2	Low pressure absorber
C	Concentration of LiBr, wt%
C	Condenser
COP	Coefficient of performance
LiBr	Lithium bromide
D	Coefficient of mass diffusion, $m^2\,s^{-1}$
E1	High pressure evaporator
E2	Low pressure evaporator
F	Area, m^2
HW	Hot water in SP
H	Enthalpy, J
MS	Middle solution
PP	Primary pipe
SP	Secondary pipe
SS	Strong solution
WS	Weak solution
PHE	Plate heat exchanger
K	Coefficient of heat transfer, $W\,m^{-2}\,k^{-1}$
μ	Kinetic viscosity, Pa m
m	Mass flow rate, $kg\,s^{-1}$
p	Pressure, Pa
Q	Heat transfer rate, W
T	Temperature, °C
u	Velocity in the x direction, $m\,s^{-1}$
v	Velocity in the y direction, $m\,s^{-1}$
ρ	Density, $kg\,m^{-3}$
g	Acceleration of gravity, $m\,s^{-2}$

Subscripts

in	Inlet
out	Outlet
v	Vapor
w	Water

perature district heating system is restricted by its high running cost.

In a word, it is significant to decrease the return water temperature of a district heating system, which is aimed for recovering the low grade heat and reducing exergy loss. However, the return water temperature of PP could not be decreased to a lower level than that of SP due to a necessary temperature difference in the conventional heating substation using the PHE. Meanwhile, the electric consumption of the electrical heat pump is significant due to the long period of heating. Therefore, the AHE is invented [2], which could make the return water temperature of PP be far lower than that of SP without consuming extra energy. Temperatures of 120 °C/30 °C for PP and 45 °C/60 °C for SP could come true by using the AHE, which is compared with a conventional PHE in Fig. 1.

The AHE is combined by an AHP and a PHE, which is shown in Fig. 2. The return water of SP is divided into two parts, which are heated in the AHP and PHE separately. Therefore, the first key operation parameter is the flow rate ratio of PP and SP in PHE. Larger ratio could increase the temperature drop of PP in the AHP, however, will reduce its temperature drop in the PHE. Thus, how to adjust this ratio should be discussed under different working cases for the maximum heat exchange quantity. Besides, two stages of evaporation (E1 and E2) and absorption (A1 and A2) are employed in the AHE, which is aimed for lower temperature of the return water of PP. Thus, the second key operation parameter is the solution circulating rate of AHP, too low solution circulating rate will lead to incomplete coverage of solution on tubes of generator (G) and absorbers (A1 and A2), which could reduce efficient heat exchange area. Besides, too high solution circulating rate will reduce its concentration difference of LiBr solution, which decreases the coefficient of performance (COP) of AHP. Therefore, it is necessary to adjust its solution circulating rate under different working cases.

In a word, the AHE shows good performance under the standard working case, however, its supply and return temperatures of PP and SP vary significantly during a whole heating period, which is different from other conventional heat pumps. Therefore, how to exchange the maximum heat by the AHE under different outdoor temperatures is significant for its actual application. In order to investigate new operation strategies for AHE, a steady mathematical model of AHE is built and compared with experiment.

2. Mathematical model of AHE

In order to investigate how the exchanged heat varies caused by these two key operation parameters, the mathematical model of AHE is presented and compared with its designed working case [2]. Energy and mass balance equations for all units are solved in E.E.S. (Engineering Equations Solver), which includes thermal parameters of lithium bromide solution and vapor. The mathematical model of A2 is given in Fig. 3, and models of A1 and G are similar. Following assumptions are used in this model:

(1) Thermal parameters are in steady state.
(2) Solutions leaving G, A1 and A2 are saturated.
(3) Condensed water leaving C is saturated.
(4) Vapors out from E1 and E2 are saturated.

Equation of total mass conservation:

$$m_{ss} + m_v = m_{ms} \tag{1}$$

Equation of mass conservation of LiBr:

$$m_{ss} \times C_{ss} = m_{ms} \times C_{ms} \tag{2}$$

Equation of energy conservation:

$$H_v \times m_v + H_{ss} \times m_{ss} - H_{ms} \times m_{ms} = (H_{w,out} - H_{w,in}) \times m_{HW} \tag{3}$$

Equation of heat transfer:

$$Q_{A2} = (H_{w,out} - H_{w,in}) \times m_{HW} = K_{A2} \times F_{A2} \times \Delta T_{A2} \tag{4}$$

Mathematical models of C, E1 and E2 are built when considering the condensation or evaporation process of water outside horizontal tubes, which are similar as the model of A2.

Compared with conventional AHPs with steady external thermal parameters, working cases of AHE vary significantly during the long heating period. Therefore, the conventional simulation method for AHP with constant heat transfer coefficients is not feasible for simulation of AHE. Thus, a new 2D heat and mass transfer model for absorption and generation of lithium bromide solution outside horizontal tubes is given in Fig. 4., thus, heat transfer coefficients of G, A1 and A2 could be calculated.

The concentration of SS becomes weak after absorbing vapor when flowing outside horizontal tubes. The HW inside the tube takes the absorption heat. Equations of continuity, momentum, energy and mass diffusion are used for heat transfer coefficient calculation of absorption and generation.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{5}$$