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Optimization design of the large temperature lift/drop multi-stage vertical absorption temperature transformer based on entransy dissipation method

Sheng Wang, Xiaoyun Xie*, Yi Jiang

Department of Building Science, Tsinghua University, Beijing 100084, China

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ABSTRACT

In the district heating system, the AHE (Absorption Heat Exchanger) can transfer the heat of the primary network with a large temperature drop to the secondary network with a small temperature lift in a heating station. Triangular heat transfer processes exist in a traditional AHE, and limit the performance of the system. In order to eliminate the mismatched heat transfer processes, the new ATT (Absorption Temperature Transformer) is suggested, which can separate the condensation or evaporation pressure into several levels. A new method based on entransy dissipation analysis is applied to conduct an optimization design to the ATT. Simulation results show that the minimum total *KA* (multiplication of the heat transfer coefficient by the heat transfer area) is obtained when entransy dissipation per transferred heat is uniformly distributed in the four basic components. The flow path of the ATT is also optimized. The best different flow direction is obtained which has the lowest flow mismatched coefficient. The total *KA* reduction becomes not obvious when the stage number is over 3. And the total *KA* reduction of a 4-stage ATT reached 28.9% compared to a 1-stage AHE.

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1. Introduction

In recent years, a series of new district heating systems based on absorption heat pumps have been developed in the cities of Datong and Chifeng in China in order to recover the low-grade waste heat (30–80 °C) from industries [1–3]. The key equipment of these new district heating systems is the AHE (Absorption Heat Exchanger) installed in the heating station near a residential district, which transfers the heat of the primary network with a large temperature drop (130 °C–20 °C, for example) to the secondary network with a small temperature lift (45 °C–60 °C, for example). An AHE consists of an absorption heat pump and a heat exchanger, as shown in Fig. 1. The primary network water firstly flows into the generator to generate the diluted solution. Then it flows into the water–water heat exchanger to heat a part of the secondary network water. After that it flows into the evaporator to be cooled, and finally returns to industrial heat source. Other secondary network water is heated in the absorber and condenser, either in a series or parallel connection.

In the absorption heat pump, the temperature lifts/drops of the cooling/heating sources of the four basic components are large (30–40 °C for the generator; 20–30 °C for the evaporator; 10–20 °C for the absorber or condenser if the secondary network water is in a parallel connection). In a traditional AHE, a 1-stage absorption heat pump is used, and mismatched heat transfer processes appear in the absorption heat pump. The 1-stage AHE faces the problems of excessively large heat transfer area, large volume, and high return temperature of the primary side. So an exploration of grand new flow paths and structures of the absorption heat pump is particularly important.

A new type of elementary unit for the generation and condensation process or evaporation and absorption process were proposed by Jiang et al. [4]. In the elementary unit, the condensation or evaporation pressure is separated into several levels. In this way the mismatched heat transfer processes in the AHE can be greatly improved. A new kind of absorption heat exchanger which is composed of the elementary units proposed by Jiang et al. [4] is called the Large Temperature Lift/Drop Multi-stage Vertical Absorption Temperature Transformer, or ATT (Absorption Temperature Transformer) for abbreviation. This is an analogy with the voltage transformer which transforms high voltage electrical energy into low voltage electrical energy. In this study, the absorption

* Corresponding author. Building Energy Research Center, Tsinghua University, Beijing 100084, China. Tel.: +86 13521180452; fax: +86 1062770544.
E-mail address: xiexiaoyun@tsinghua.edu.cn (X. Xie).

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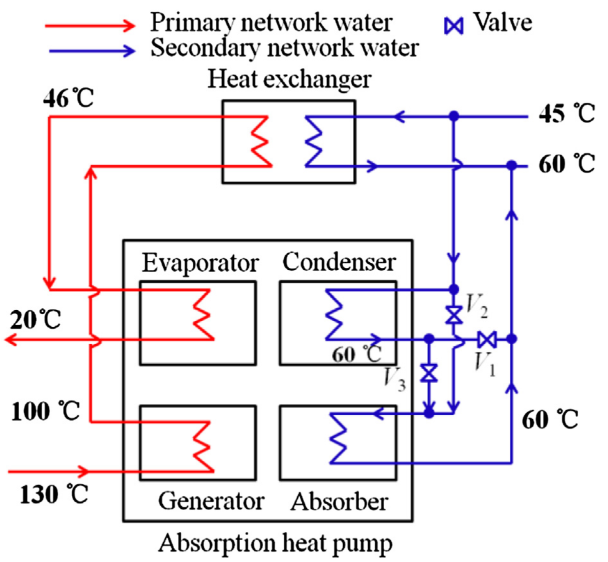

Fig. 1. The schematic diagram of an Absorption Heat Exchanger (AHE).

heat pump in the ATT is of main concern. The research objective is minimizing the total *KA* of the absorption heat pump by the optimized allocation of *KA* among the four basic components, and the optimization design of the flow path. The *KA* is a multiplication of the heat transfer coefficient by the heat transfer area, which represents the heat transfer capacity.

In the literature, the exergy analysis was often applied to analyze the irreversibility of internal heat transfer processes of an absorption heat pump, and provide a basis for the optimization design or operation. The exergy is the maximum useful work that could be produced as the system and the environment reach equilibrium [5]. Zebbar et al. [6] made an optimization of the exergy efficiency by adjusting the solution concentration and the ratio of condensation and evaporation pressure. Aphornratana et al. [7] discussed the influences of the solution circulation ratio to the internal irreversibility at the absorber and the generator. Gebreslassie et al. [8] evaluated the exergetic efficiencies for single, double, triple and half effect absorption cycles. Ji and Ishida [9] applied the energy utilization diagrams to investigate the exergy losses of a two-stage absorption heat transformer. In other literature, the total exergy efficiency and exergy loss distribution of the absorption heat pump were analyzed under different operation conditions of external cooling/heating sources [10–14]. However, the purpose of this paper is optimizing the allocation of *KA* among the four basic components when the external operating parameters are fixed, and the exergy analysis may not an ideal method. First, the exergy describes the ability of heat-work conversion of an objective. But when considering the allocation of *KA*, the heat transfer processes inside the four basic components are of main concern. Second, the exergy loss is influenced not only by the temperature difference, but also the temperature level of fluids on both sides. So the exergy losses in the four basic components do not reflect an accurate comparison of their heat transfer irreversibility, and cannot provide a basis for optimized allocation of *KA*. Third, the exergy and exergy efficiency are influenced by the choice of the zero exergy temperature. So the exergy efficiency does not accurately evaluate the total performance of the absorption heat pump.

A new physical quantity named the entransy was identified as a basis for optimizing heat transfer processes by Guo et al. [15]. The extremum principle of entransy dissipation for heat transfer optimization was also developed. The entransy describes the heat transfer ability of an object. Entransy dissipation occurs during a heat transfer process as a measure of the heat transfer irreversibility. Chen et al. [16] applied minimum thermal resistance principle to obtain maximum heat transfer rate of a heat exchanger couple. Zhang et al. [17] applied the entransy dissipation extremum principle to optimize the heat transfer processes in the HVAC system, such as the indoor cooling process. Entransy dissipation-based optimizations were also made for building central chilled water systems [18] and district heating networks [19]. In this paper, the entransy may provide a more reasonable basis for the optimization of the absorption heat pump than the exergy. The entransy is a specialized quantity for the analysis of the irreversibility of heat transfer processes. The entransy dissipation of a heat transfer process is not influenced by the temperature level but only the temperature difference of fluids on both sides. Besides, the entransy and entransy dissipation are also independent of any “zero entransy temperature”.

This study will make an optimization design of the ATT based on the entransy dissipation method. Through the analysis of the entransy dissipation of heat transfer processes inside the absorption heat pump, the optimized allocation of the *KA* among the four basic components, as well as the optimized design of the flow direction and stage number will be investigated.

2. Principles of the ATT

A triangular heat transfer process means that one end of the heat transfer process has a large temperature difference, while the other end has a small temperature difference. If a triangular heat transfer process appears in the absorption heat pump, when the *KA* gets very large and the mean temperature difference between two sides gets very small, the thermodynamic perfectness of the absorption heat pump still can hardly be improved.

A 1-stage AHE (Fig. 2) only has one condensation or evaporation pressure. In the condenser or evaporator, the heat transfer processes happen between the cooling water or chilled water and a saturated water film covering the surface of the coils. The

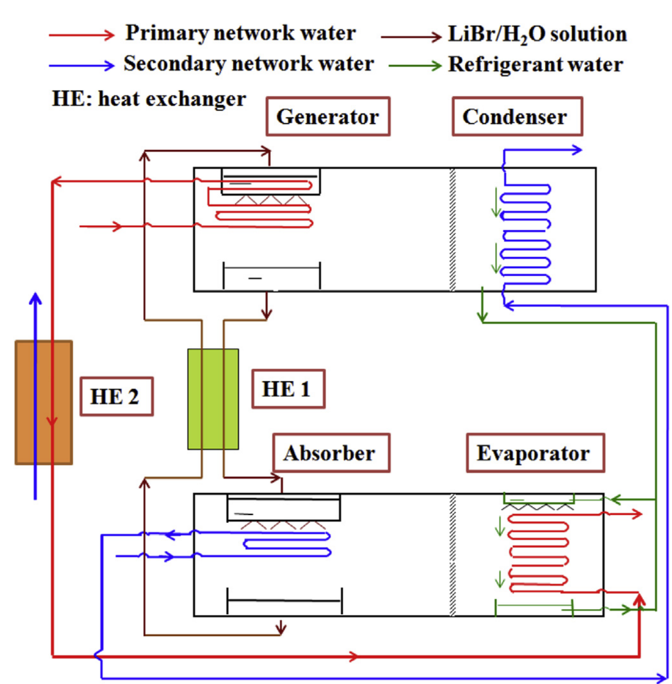

Fig. 2. The schematic diagram of a 1-stage AHE.

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