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Graphical analysis on internal heat recovery of a single stage ammonia–water absorption refrigeration system

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ABSTRACT

The internal heat recovery has great influence on the performance of an ammonia water absorption refrigeration system. This paper presents an intuitional graphical analysis to identify the characteristics of different cycles with different internal heat recovery strategies and to find out the key points which have significant influence on internal heat recovery. The different cycles can be illustrated clearly in a temperature–heat load diagram with the system construction and the energy target so that the better one can be obtained. And the optimal one can be verified from the comparison. The feed condition and the size of the pocket of the background process are regarded as the key points of internal heat integration for the reduction of the system heat input. The results show that saturated feed condition is the optimal feed condition due to the minimum irreversible loss of heat and mass transfer and reducing the heat flow rate in the pocket of the background process contributes to the heat integration between the column and background processes. The two key points on internal heat recovery can be the operating direction on internal heat recovery for system performance improvement.

1. Introduction

Ammonia water absorption refrigeration systems have been paid more and more attentions because they can make good use of low grade heat such as solar energy, industrial waste heat and geothermal energy. And ammonia itself is an environmental friendly refrigerant which has no harmful influence on the greenhouse effect and ozone sphere depletion. Moreover, there are many advantages compared to $LiBr–H_2O$ absorption systems such as no crystallization, easier maintenance and applications at deep freezing temperatures. Nevertheless, a major drawback is its low system COP which is important to be improved to extend the applications. Many cycles were proposed for performance improvement [1–3]. Actually, the internal heat recovery has significant influence on the system performance. Therefore, a good internal heat recovery arrangement is necessary. However, most researches on ammonia water absorption system focused on absorption enhancement [4–6] and combined systems [7–11] recently. And the researches on internal heat recovery are few and not comprehensive. Generally, a refrigerant heat exchanger and a solution heat exchanger are employed for the internal heat recovery in a traditional system. Besides, absorption heat recovery and condensation heat recovery are the main strategies such as GAX cycles [12] and multiple-effect cycles [1].

In addition, a distillation column is commonly designed to purify the generated vapor in a traditional ammonia water absorption system. The rectification heat is removed by the coolant directly which results in a decrease of the system COP especially in low evaporation temperature applications [13]. Rectification is actually a process of mixed vapor condensation. Thus rectification heat recovery can be considered as condensation heat recovery. It can be achieved by the strong solution [14–16]. However, the system performance will not be improved much if all of the strong solution is used. This is due to the temperature lift at the cold side of the solution heat exchanger thus a certain amount of the recovered heat is released in the absorber ultimately. Therefore, the rectification heat recovery by a branch of the strong solution is an alternative way for better use of energy. Fontalvo et al. [17] and Pouraghaie et al. [18] applied this approach in their researches. Nevertheless, the other branch of the strong solution is usually heated to be superheated by the weak solution which results in a large temperature difference between the solutions. It is indicated that the heat of the high temperature weak solution is not used properly. The strategies of internal heat recovery are various and there is no clear conclusion of the better cycle with better internal heat recovery.

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Nomenclature

BGCC	background process grand composite curve
CGCC	column grand composite curve
COP	coefficient of performance
CSC	cold stream curve
HSC	hot stream curve
Q	heat load, kW
SGCC	system grand composite curve
T	temperature, °C

Subscripts

c	cooling
e	evaporation
g	generation
r	rectification
rf	refrigerant flash

For a certain system, there is an optimal cycle with maximum internal heat recovery. The principle of the arrangement is that the streams are in their matched positions according to the amount and grade of the heat. The authors deduced the optimal cycle from pinch technology that maximum internal heat recovery could be achieved [19]. The optimal cycle was not unique which was determined according to the operating conditions. The COP of the optimal cycle was always 20% higher than the traditional system in the given operating conditions.

The T–Q (temperature–heat load) diagram was applied to illustrate the optimal cycle. Actually, the T–Q diagram can be also used for the analysis of the systems with different internal heat recovery strategies and it is convenient to get an intuitional comparison of the system construction and the energy target to identify the better one. And the key points for better internal heat recovery should be discussed as the direction for system construction operation. Therefore, this paper presents a graphical comparison analysis of the cycles with different heat recovery strategies for a thorough understanding of the internal heat recovery of a single stage ammonia water absorption refrigeration system. And the key points on internal heat recovery are studied for the reduction of the system heat input.

2. Graphical cycle representation for different heat recovery strategies

An optimal cycle with maximum internal heat recovery has been derived by the authors. And there are different strategies for internal heat recovery of a single stage ammonia water absorption refrigeration system such as rectification heat recovery and absorption heat recovery. An intuitional graphical comparison of the system construction and the energy target is conducted to identify the effects of the different heat recovery strategies. In order to ensure the equity and continuity, the same operating conditions, the minimum reflux ratio and the minimum temperature difference are set as used in Ref. [19]. The streams whose temperatures are lower than the condensation temperature are neglected in the diagram [19]. A traditional cycle in the T–Q diagram is shown in Fig. 1.

The dotted curve called CGCC (column grand composite curve) represents the column process while the full curve represents CSC (cold stream curve) which is the strong solution actually. The dashed curves represent HSCs (hot stream curve) including the

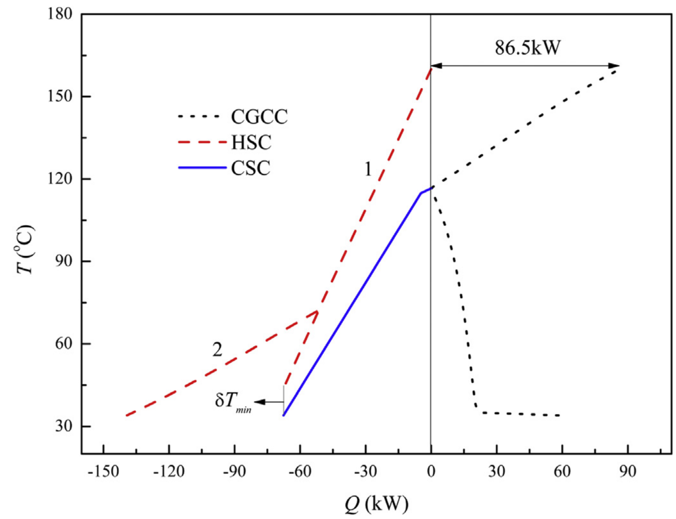

Fig. 1. The traditional cycle in the T–Q diagram.

weak solution marked with 1 and the absorption process marked with 2. The overlap between curve 1 and 2 is caused based on the assumption of quasi-equilibrium absorption process. It can be found the minimum temperature difference is located at the cold side of the solution heat exchanger. The strong solution is heated to be superheated which decreases the heat input in the generation process. The system construction as well as the system heat input can be obtained as shown in Fig. 1. In a traditional cycle, the rectification heat is taken away by the coolant directly. Actually, the dissipated rectification heat is high grade which might be recovered. Fig. 2 shows the cycle with rectification heat recovery by the total strong solution.

It can be found the position of the minimum temperature difference is lifted due to the rectification heat recovery. The superheat degree of the strong solution at the feed stage is larger than that of the traditional cycle. The heat input of the generation process required, therefore, can be reduced. However, it can found from Fig. 2 that the recovered rectification heat is about 20 kW but the system heat input is just reduced by 4 kW. The reason is that most of the recovered heat is released in the absorber ultimately due to the temperature lift of the cold side of the solution heat

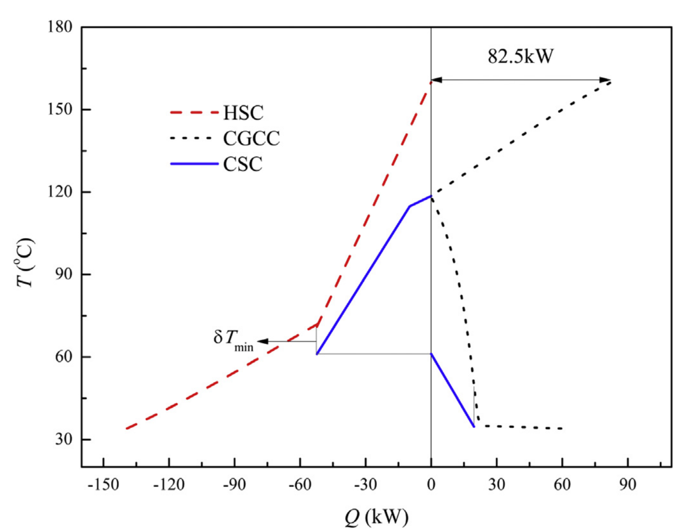

Fig. 2. The cycle with rectification heat recovery by total strong solution.