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Optimal ammonia water absorption refrigeration cycle with maximum internal heat recovery derived from pinch technology

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ABSTRACT

Absorption refrigeration technology has attracted more and more interests due to its advantages such as making good use of low grade thermal energy and using environmental friendly refrigerants. The internal heat recovery capacity of an ammonia water absorption refrigeration system has significant influence on the system performance. According to cascaded utilization of energy to reduce the internal irreversible loss, this paper presents the optimal cycle with maximum internal heat recovery which is derived from a comprehensive method of pinch technology. The derivation of the optimal cycle is introduced. The internal integration is clearly shown in a temperature–heat load diagram. The optimal cycle derived from this method when there is a temperature overlap between the absorption and generation processes is exactly the GAX cycle. Performance analysis is carried out to discuss the performance improvement of the optimal cycle. The results show that the performance of the optimal cycle is enhanced significantly by 20% at least compared with a traditional one under common operating conditions. The performance improvement of the optimal cycle is more significant at a lower evaporation temperature and a higher generation temperature while it has a maximal value with the coolant temperature increasing.

1. Introduction

Due to the serious energy and environment problems, absorption refrigeration technology has attracted more and more interests due to its advantages such as making good use of low grade thermal energy and using environmental friendly refrigerants. Ammonia–water absorption cycle is well accepted for thermal driven refrigeration below 0 °C. Moreover, it is an alternative option for air-cooled absorption system [1,2]. However, a main drawback of an ammonia water absorption refrigeration system is its low COP (coefficient of performance). The internal heat recovery capacity of a system has a significant effect on the system performance. Hence, enhancing the internal heat recovery capacity is an effective way to improve the system COP. Usually, a SHE (solution heat exchanger) and a RHE (refrigerant heat exchanger) are used for the internal heat recovery in a traditional system. In addition, the rectification heat can be recovered by the strong solution [3]. However, if the total strong solution is used, the recovered heat does not increase much due to the temperature lift at the cold end of SHE. Thus the system performance is not improved obviously. Kang et al. [4] summarized the researches about the internal heat recovery of ammonia water absorption systems including condensation heat recovery such as a multi effect cycle [5] and absorption heat recovery such as a GAX (generator-absorber heat exchange) cycle [6]. Saghiruddin et al. [7] analyzed an ammonia water cycle with a heat recovery absorber. The strong solution was preheated by a part of the absorption heat. This method has the same drawback with rectification heat recovery by the total strong solution. Nevertheless, these cycles were originally proposed for the recovery of one type of the heat. There is no comprehensive planning in the internal heat recovery issue of a whole system. A common optimization method for internal heat recovery is needed.

Pinch technology is a graphical method for efficient use of energy [8]. The streams of a system are planned for maximum heat exchange. It is applicable for the internal heat recovery issue of an ammonia water absorption system. However, it should be noted that the generated vapor contains a certain amount of water because the partial pressure of water cannot be neglected compared with ammonia [9]. If water flows into the evaporator, the

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Nomenclature

ABS	absorber
CGCC	column grand composite curve
COP	coefficient of performance
CON	condenser
CSC	cold stream curve
CSCC	cold stream composite curve
D	mass flow rate of the distillate, kg/s
DC	distillation column
F	mass flow rate of the feed, kg/s
GAX	generator-absorber heat exchange
GEN	generator
HSC	hot stream curve
HSCC	hot stream composite curve
L	mass flow rate of the liquid, kg/s
m	mass flow rate, kg/s
Q	heat load, kW
q	parameter of feed condition
RHE	refrigerant heat exchanger
SHE	solution heat exchanger
T	temperature, °C
V	mass flow rate of the vapor, kg/s
x	mass fraction of the ammonia in the liquid
y	mass fraction of the ammonia in the vapor
x^*	equilibrium mass fraction of ammonia in the liquid phase
y^*	equilibrium mass fraction of ammonia in the vapor phase

Greek

ε	performance improvement ratio

Subscripts

a	absorber
c	condenser
C	cooling
CGCC	column grand composite curve
D	distillate
deficit	deficit
e	evaporator
F	feed
g	generator
H	heating
L	liquid
min	minimum

evaporating temperature will rise and the cooling effect will be reduced. Therefore, vapor purification is necessary. A distillation column is commonly used for the vapor generation and purification. Commonly, the mixture with component separation cannot be considered as a stream directly in a pinch point analysis. Likewise, the process in the distillation column should also follow that principle. As a result, a quasi-equilibrium process curve called CGCC (column grand composite curve) is applied to express the process. Dhole et al. [10] presented a method to calculate CGCC based on a PNMTC (practical near minimum thermal condition). PNMTC is a minimum loss condition after considering the inevitable losses caused by feed condition, pressure drop, sharp separation and configuration selection. Bandyopadhyay et al. [11] presented two methods to calculate CGCC and modified it at the feed stage based on relative volatility. The CGCC is commonly used in the chemical industry field. But it has not been found in the research of ammonia water absorption refrigeration systems.

Pinch technology is used in many applications such as the chemical industry field [12,13], heat exchanger network designs [14,15] and compound systems [16]. But few researches are found in ammonia water absorption refrigeration systems. Hanna et al. [17] and Jawahar et al. [18,19] analyzed their proposed cycles with pinch technology. However, they analyzed the internal heat recovery according to the conditions of the state points which are calculated by a cycle simulation rather than derived the optimal cycle directly from pinch technology. And the processes with component separation are not considered. In this paper, an optimal cycle with maximum internal heat recovery is derived directly from pinch technology according to the operating conditions. The internal heat recovery is planned as a whole and the heat integration of the cycle is obtained. A performance analysis is carried out versus different operating conditions.

2. Pinch technology

Pinch technology is a graphical method for process integration. Generally, a heat exchange process contains many hot and cold streams which can be distinguished by whether they are to be cooled or heated. The thermal characteristic of a stream can be expressed well in a temperature–heat load (*T*–*Q*) diagram as a HSC (hot stream curve) and a CSV (cold stream curve). An illustration of hot streams is shown in the left of Fig. 1.

The heat load versus the temperature interval of a stream is shown. In the diagram, the value of the abscissa axis represents the heat load and the value of the vertical axis represents the temperature. The difference of the value of the abscissa axis is the heat load of the stream versus the temperature interval. Hence, a *T*–*Q* curve can be moved horizontally or mirror imaged with respect to the vertical axis without affecting the temperature and the heat load of the stream. According to the thermal characteristics of the streams, the hot and cold streams are combined to be a HSCC (hot stream composite curve) and a CSCC (cold stream composite curve), respectively. The composite process of the hot streams can be found in Fig. 1. And the CSCC is obtained in the same way. Lines 1 and 2 represent the HSCC and CSCC, respectively. The overlapped part between the HSCC and CSCC is the integrated process. The

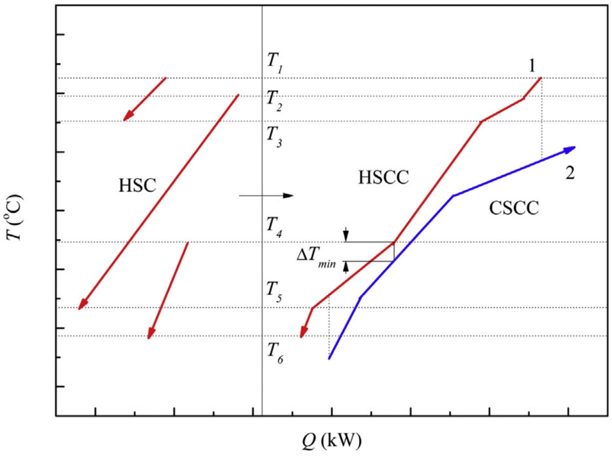

Fig. 1. Illustration of hot streams and the composite curves in a *T*–*Q* diagram.