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Research Paper

Research on heat exchange and control method of the evaporative condenser in the equipment of flax fiber modification

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HIGHLIGHTS

- The heat exchange process of ammonia recovery system was analyzed.
- A mathematical model was developed to evaluate the heat exchange.
- Thermal load of ammonia recovery system was computed, and its main influence factors were analyzed.
- Spraying water pump and fan were controlled to improve the efficiency of evaporative condenser.

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ABSTRACT

Aiming at improving heat utilization of the evaporative condenser in the equipment of flax fiber modification, we proposed a new method to control the main factors that affect the heat exchange of the evaporative condenser. Firstly, a steady-state mathematical model was developed to evaluate the heat exchange of evaporative condenser after analyzing the heat exchange process of ammonia recovery system in the modification equipment and the thermal mass transfer process of evaporative condenser on details. Then, the thermal load of evaporative condenser was computed and analyzed through the numerical simulation. It is found that the suction pressure of compressor has obvious influence on the thermal load of evaporative condenser. Besides, under the maximum suction pressure, the thermal load is 291.4 kW, and the corresponding air speed and spraying water volumetric flow rate are 2.5 m/s and 12 m^3/h, respectively. When the thermal load decreases, the air speed and spraying water volumetric flow rate are adjusted accordingly.

1. Introduction

To reduce energy consumption and emissions in flax fiber modification equipment, new technologies, new processes and new equipment are extensively used as the breakthrough in the textile industry [1]. Ammonia recovery system is the key component in the equipment of flax fiber modification. The main heat-exchange device in the ammonia recovery system is an evaporative condenser, whose heat-utilization has direct influence on the energy consumption of the whole production process [2]. Therefore, analyzing and improving the heat-utilization of the evaporative condenser can lower energy-consumption of the equipment of flax fiber modification from a single device part [3–7].

Transmission efficiency of heat is the chief factor affecting heat-utilization. Researchers use new shape and layout of tubes, new fillings and new spraying patterns of cooling water to promote transmission efficiency of heat and heat-utilization, and then the heat-exchange capability of evaporative condensers could be improved [8–12]. The above mentioned means to increase transmission efficiency of heat can only be applied to the evaporative condenser, whose cryogen has the constant mass velocity and unaltered thermodynamic status. However, due to the mass velocity and thermodynamic status of ammonia medium changed in reactor in the flax fiber modification equipment during the ammonia recovery process, the methods above have their limitation of only increasing heat transmission efficiency and it will lead to a large amount of heat waste during heat-exchange of the evaporative condenser. To solve the problem, a combined condenser was developed by some researchers in the case of changeable mass velocity or various thermodynamic status of cryogen [13–16]. Combined condenser could decrease heat waste in the course of thermal exchange, when mass velocity and thermodynamic status of cryogen change slowly.

However, the working condition is special in this specific modification equipment. In the ammonia recovery process, the decreasing amount of ammonia in reactors leads to a constant change of the flow and thermal status of ammonia, which affects the amount of heat used for ammonia liquidation in the evaporative condenser. In this paper, a mathematical model has been developed after

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studying the details of the operating process of the evaporative condenser. The numerical simulation of this mathematical model is carried out to analyze the characteristic of heat exchange during the evaporative condenser working process. After that, a control method is proposed to improve energy-utilization of the ammonia recovery system and it is found that the energy-consumption of the equipment of flax fiber modification decreases.

2. Thermal load and heat exchange process of the evaporative condenser in the equipment of flax fiber modification

2.1. Brief description of the ammonia recovery system

Liquid ammonia is used as the modified medium in the flax fiber modification equipment. To remove the residual liquid ammonia off the flax fibers after modification reaction in the reactor, the liquid ammonia evaporates with the pressure decreasing and the temperature increasing in the reactor. Therefore, there must be ammonia vapor in the reactor. The function of ammonia recovery system in the modification equipment is to recycle, compress and condense residual ammonia in the reactor. Then, liquid ammonia obtained from the above process could be reused in the equipment to decrease ammonia vapor emission and improve utilization rate of liquid ammonia. Ammonia recovery system in the flax fiber modification equipment is shown in Fig. 1. Ammonia in the reactor is recycled by multistage compression. The main processes are as follows:

(1) A certain amount of ammonia will flow from the reactor to register 1 driven by the differential pressure between them.
(2) When the pressure of register 1 is near the pressure of the reactor, the front ammonia compressor stars to pump a part of the rest of the ammonia in the reactor into register 1.
(3) When the pressure of the reactor is down to 100 kPa, the front ammonia compressor stops, the vacuum pump starts to pump out the rest of the ammonia in the reactor into register 2; when the pressure of the reactor is down to 200 Pa, the vacuum pump stops.
(4) When the pressure of register 2 is up to 250 kPa, the front ammonia compressor starts to pump ammonia in register 2 into register 1; when the pressure of register 2 is down to 150 kPa, the front ammonia compressor stops.
(5) When the pressure of register 1 is up to 450 kPa, the rear ammonia compressor starts to compress the ammonia in register 1 into the evaporative condenser. At the same time, the evaporative condenser starts to condense ammonia. After the compressing and condensing, ammonia is turned into liquid ammonia stored in the auxiliary storage. When the pressure of register 1 is down to 300 kPa, the rear ammonia compressor stops.

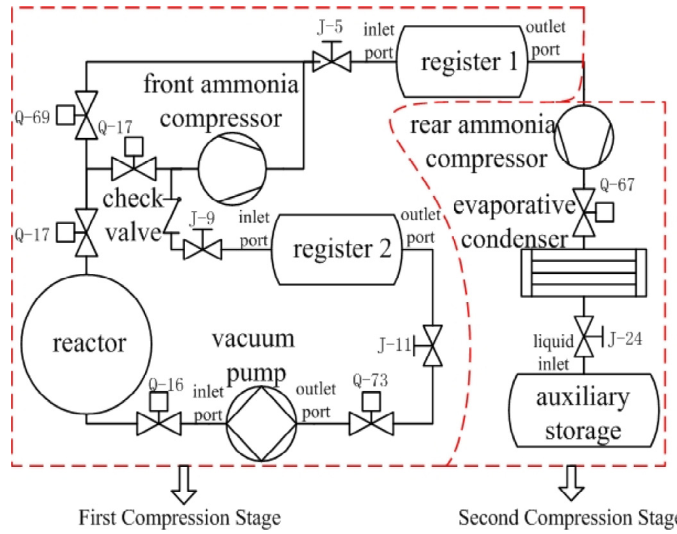

Fig. 1. Ammonia recovery system in the modified equipment of flax fiber.

2.2. Thermal load of the evaporative condenser

Thermal load of the evaporative condenser in the ammonia recovery system consists of the actual consumption power of rear ammonia compressor and ammonia refrigerating capacity in the process of phase transition, which is mainly affected by the thermodynamic state of ammonia vapor entering into the rear ammonia compressor and that of liquid ammonia discharging from the evaporative condenser. From Fig. 1, the suction pressure of rear compressor is equal to the pressure of Register 1. Consequently, the working pressure of Register 1 has direct influence on the inlet pressure, the thermodynamic state of ammonia and the actual consumed power of the rear ammonia compressor. The thermodynamic state of liquid ammonia discharging from the evaporative condenser depends on the condensation temperature. Therefore, the thermal load range of evaporative condenser is estimated from the working pressure range of Register 1.

The specific enthalpy of ammonia in the inlet of evaporative condenser is calculated by Equation (1).

$$h_{in} = h_{dk} + w_{ts} \tag{1}$$

where:

$$w_{ts} = p_{s0} v_{s0} \frac{k}{k-1}\left(\varepsilon^{\frac{k-1}{k}} - 1\right) \tag{2}$$

Thermal load of the evaporative condenser, which is the heat rejection of ammonia compressor, is simulated numerically by Equation (3) based on the parameters shown in Table 1. The results are shown in Table 2.

$$\begin{aligned} Q_0 &= q_{mt}\eta_v (h_{in} - h_{so}) \\ &= q_{mt}\eta_v (h_{dk} + w_{ts} - h_{so}) \end{aligned} \tag{3}$$

In Table 2, the pressure of Register 1 has obvious influence on the thermal load of evaporative condenser. Especially, the thermal load under maximum pressure of Register 1 is 1.5 times as much as

Table 1
Original data about calculating thermal load of the evaporative condenser.

Parameter	Value
Inlet temperature of rear ammonia compressor (K)	291.15
Inlet pressure of rear ammonia compressor (kPa)	300~500
Exit pressure of rear ammonia compressor (kPa)	2000
Volumetric efficiency of rear ammonia compressor	0.8766
Nominal volume flow of rear ammonia compressor (m^3/min)	0.4
Working pressure of register 1 (kPa)	300~500

Table 2
Working pressure of register 1 p_{so} and thermal load of the evaporative condenser Q_0.

Working pressure of Register 1 p_{so} (kPa)	Thermal load of evaporative condenser Q_0 (kW)
300	178.69
340	201.32
380	223.88
420	246.40
460	268.90
500	291.40