INFLUENCE OF FEED FLOW RATE AND FEED CONCENTRATION ON THE AMMONIA ABSORPTION REFRIGERATION SYSTEM

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The absorption refrigeration system is a type of heat-driven system. The working pairs used most commonly are the lithium bromide-water and the ammonia-water pairs. Compared to the lithium bromide-water pair, the ammonia-water pair can achieve lower evaporation temperature and has a wider range of applications in industry. Feed flow rate and feed concentration are key factors affecting the system's performance, which have significant effects on the ammonia concentration and flow rate at the outlet of the distillation tower, as well as the COP of the system. In this paper, the relationship between feed concentration, feed flow rate, and system performance is investigated by numerical simulation and experimental study. The results show that increased feed concentration can effectively improve the ammonia concentration at the outlet of the distillation tower. At the same time, there is an optimal feed flow rate in the system, and when the feed flow rate rises gradually to the optimal value, the COP of the system also increases. When the feed flow rate exceeds the optimal value, the ammonia concentration at the outlet of the distillation tower will be rapidly reduced, as well as the COP of the system.

Key words: *ammonia-water absorption refrigeration, simulation, feed flow rate, feed concentration;*

1. Introduction

Absorption refrigeration utilizes thermal energy [1], including low-grade heat sources as well as renewable heat sources, to drive the system [2], which makes it a potential technology, especially in the field of waste heat recovery and utilization [3]. Compared to vapor compression refrigeration, absorption refrigeration has obvious advantages [4]. Firstly, absorption refrigeration can be driven by low-grade heat, which will reduce the consumption of electrical energy [5-8]. Secondly, the key components of absorption refrigeration include the absorber, the generator, the distillation tower, and other heat and mass exchange equipment [9], and the only moving parts used in the system are the circulating pumps. Fewer moving parts make the absorption system more reliable than compression refrigeration systems. Thirdly, there is a wide load adjustment range of the absorption refrigeration system within 10%~120% [10]. Moreover, static equipment has a longer service life and lower depreciation cost than moving equipment, which will reduce the operation and maintenance costs of the system.

The working pairs used most commonly for absorption refrigeration are the lithium bromide-water pair and the ammonia-water pair. In the lithium bromide-water absorption refrigeration system, water is used as the refrigerant, thus the evaporation temperature cannot be lower than 0℃, which limits the application of the system [11]. While with ammonia-water as the working pair, the evaporation temperature of a single-effect ammonia absorption refrigeration system can reach about -30℃ which brings a wide range of system applications.

In an ammonia-water absorption system, the feed concentration of the distillation tower has a significant impact on the purity of ammonia distillation. Sun [12] found that with the decrease of ammonia distillation purity, evaporation pressure, and absorption pressure decreased, resulting in the decrease of solution concentration at the end of absorption, and the increase of system circulation rate, which eventually led to the increase of unit heat load of generator and the decrease of system COP.

Sun [13] also discovered that under the condition of constant reflux ratio and operating pressure, the larger the feed flow rate, the greater the heating amount required by the generator to ensure the purity of ammonia distillation at the top of the tower remains unchanged, and the smaller the COP of the system.

Bulgan [14] modeled a single-effect ammonia absorption refrigeration system based on Ziegler's ammonia equation of state [15] to analyze the effect of parameters such as concentration of the concentrated solution, condenser reflux ratio, and heat transfer temperature difference of the solution heat exchanger on the COP, and also tested the effect of feed concentration on the circulation multiplier.

Lu [16] established a steady-state lumped parameter model for the main components of the ammonia absorption refrigeration system to conduct numerical simulation and analyzed the influence of feed concentration on the performance of the refrigeration system from qualitative and quantitative perspectives.

In this paper, the effects of feed concentration and feed flow rate on the performance of the ammonia absorption refrigeration system are investigated with experimental studies and numerical simulation, to provide guidance and a basis for the operation control and performance optimization of the system.

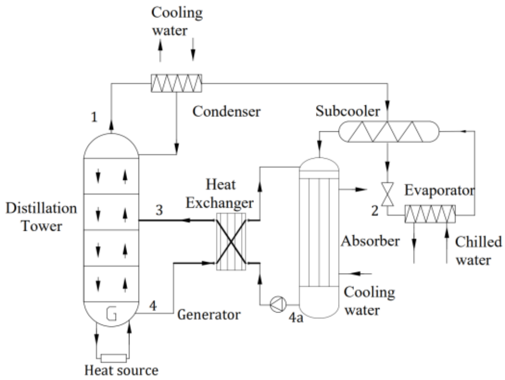
2. Experiments and principles of absorption refrigeration systems

In order to study the effect of feed flow rate and feed concentration on the system, a single-effect ammonia-water absorption refrigeration system was set up, as shown in Fig. 1(a). The experimental facility and the experiment study was performed in 2024 in the Library of CEGT (Shanghai) Technology Co Ltd, Pinghu, China.

2.1. Working principle

The schematics of the ammonia-water absorption refrigeration system are shown in Fig. 1(b). The main components of the system include the generator, the distillation tower, the condenser, the subcooler, the throttle, the evaporator, the absorber, and the heat exchanger for heat recovery, etc. The operation processes of the system can be roughly divided into the generation process, the condensation process, the evaporation process, and the absorption process [17].

(a)



(b)

Fig. 1. Schematics of the ammonia-water absorption refrigeration system

During the generation process, the concentrated ammonia solution leaving the absorber enters the distillation tower from the inlet and then passes through several plates into the generator, where it is heated. Since the boiling point of ammonia is lower than that of water, a part of the ammonia, as well as a small amount of water, will be vaporized. The separated ammonia-water gas will enter the distillation, while the dilute solution is pumped into the absorber. Equations. (1-3) are the mass balance equation and heat transfer equation for the generator.

Ammonia-water mass balance equation:
$$m_3 = m_1 + m_4 \tag{1}$$

Ammonia mass balance equation:
$$m_1 + m_4 x_4 = m_3 x_3 \tag{2}$$

Heat transfer equation:
$$Q_{\mathrm{g}} = c_1 m_h (T_{h1} - T_{h2}) \tag{3}$$

During the distillation process, the ammonia-water gas from the generator is cooled by the ammonia solution from the absorber to further increase the purity of the ammonia gas, which finally leaves the distillation tower and enters the condenser.

In the process of condensation, the high-temperature ammonia gas condenses into saturated liquid in the condenser and then gets further cooled in the subcooler. Next, the subcooled liquid enters the throttling valve and flows out as a liquid-vapor mixture at a lower pressure and temperature. Equations. (4-5) are the heat transfer equation and cooling water discharge temperature for the condenser.

Heat transfer equation:
$$Q_{\mathrm{cond}} = c_2 m_{cw1} (T_{cw1} - T_{cw}) \tag{4}$$

Cooling water discharge temperature:
$$T_{cw1} = T_{cw} + (1 - e^{-\frac{UA}{m_{cw1} c_2}})(T_c - T_{cw}) \tag{5}$$

In the process of evaporation, the dual-phase ammonia through the throttle valve flows into the evaporator, absorbing heat from the chilled water and evaporating into gas. The low-temperature ammonia gas leaving the evaporator is then used as the cooling source for the subcooler before entering the absorber. The Eq. (6) is the throttle flow calculation formula. The Eq. (7) is the heat transfer equation for the evaporator.

Throttle flow calculation formula: $$m_2 = C\sqrt{\rho \Delta P} \tag{6}$$

Heat transfer equation: $$Q_c = c_2 m_r (T_{r1} - T_{r2}) \tag{7}$$

In the absorption process, ammonia gas leaving the subcooler enters the absorber and gets absorbed by the dilute solution from the generator, releasing a large amount of heat to the cooling water. After the absorption process, the concentrated solution obtained is sent back to the generator by a circulation pump to complete the working cycle. There is a heat exchanger between the generator and the absorber for heat recovery. Equations. (8-10) are the mass balance equation and heat transfer equation for the absorber.

Ammonia-water mass balance equation: $$m_3 = m_{4a} + m_2 \tag{8}$$

Ammonia mass balance equation: $$m_2 + m_{4a} x_4 = m_3 x_2 \tag{9}$$

Heat transfer equation: $$Q_{ab} = c_2 m_{cw2} (T_{cw2} - T_{cw}) \tag{10}$$

COP (Coefficient of Performance) is a measure of the efficiency of thermodynamic equipment. It describes the relationship between the amount of energy consumed and the amount of energy provided by the equipment under specific operating conditions. Equation. (11) is the calculation formula for COP.

COP: $$COP = Q_c / Q_g \tag{11}$$

2.2. System architecture

（1）Generator

The generator is one of the key components of an ammonia absorption refrigeration system. In the generator, the ammonia gas is separated from the solution. This process requires the provision of a high-temperature heat source (steam or other heat source) to desorb the ammonia from the solution. However, a small quantity of water will also evaporate, affecting the purity of ammonia in the gas. Thus, the distillation tower is required to remove water from the ammonia-water gas.

（2）Distillation tower

The operating principle of the distillation tower is based on the difference in volatility between the liquid and gas phases of ammonia and water. The ammonia solution enters the distillation tower from the feed plate, flows through the plates of the distillation tower, and descends layer by layer to the generator at the bottom of the tower.

In this process, the solution will be heated by the high-temperature vapor from the generator. Since ammonia and water have different boiling points, ammonia in the solution will first evaporate into gas and leave the solution. The water vapor in the gas will condense into a liquid and be removed from the ammonia-water gas. This process is repeated in the distillation tower, and by the time the gas reaches the top of the tower, it will be almost pure ammonia.

（3）Condenser

The ammonia gas leaving the distillation tower enters the condenser and condenses into liquid state. The heat released is carried away by cooling water.

（4）Evaporator

In the evaporator, dual-phase ammonia fluid from the throttling valve absorbs heat from the chilled water and turns into a gaseous state.

（5）Absorber

The absorber is another important component of the ammonia absorption refrigeration system. In the absorber, ammonia gas is absorbed, and the highly concentrated ammonia solution will be sent back to the distillation tower. The absorbing process releases heat, which is taken away by the cooling water.

The specific equipment parameters for the system are shown in Tab.1.

Table 1. Equipment parameters

<table>
<tr><th>Installations</th><th colspan="4">Detailed parameters</th><th colspan="2">Value</th></tr>
<tr><td rowspan="3">Generator</td><td colspan="4">heat exchanger structure</td><td colspan="2">Spray Heat Transfer</td></tr>
<tr><td colspan="4">Heat transfer area [m^2]</td><td colspan="2">15.83</td></tr>
<tr><td colspan="4">heat source</td><td colspan="2">thermal oil</td></tr>
<tr><td rowspan="3">Distillation tower</td><td colspan="4">Number of plates</td><td colspan="2">10</td></tr>
<tr><td colspan="4">Feed plates</td><td colspan="2">6</td></tr>
<tr><td colspan="4">Reflow rate</td><td colspan="2">0.3</td></tr>
<tr><td>Heat source (Oil heater)</td><td colspan="4">Thermal Capacity [kW]</td><td colspan="2">10</td></tr>
<tr><td rowspan="4">Condenser</td><td colspan="4">Flow [kg/h]</td><td colspan="2">11.00</td></tr>
<tr><td colspan="4">Thermal Capacity [kW]</td><td colspan="2">3.539</td></tr>
<tr><td colspan="4">Heat transfer area [m^2]</td><td colspan="2">0.572</td></tr>
<tr><td colspan="4">Heat transfer coefficient [Wm–2K–1]</td><td colspan="2">1672</td></tr>
<tr><td rowspan="4">Evaporator</td><td colspan="4">Flow [kg/h]</td><td colspan="2">7.73</td></tr>
<tr><td colspan="4">Thermal Capacity [kW]</td><td colspan="2">3</td></tr>
<tr><td colspan="4">Heat transfer area [m^2]</td><td colspan="2">4.18</td></tr>
<tr><td colspan="4">Heat transfer coefficient [Wm–2K–1]</td><td colspan="2">188.9</td></tr>
<tr><td rowspan="2">Absorber</td><td>Inner diameter of the shell</td><td>300mm</td><td>Total heat transfer area</td><td>2.6m^2</td><td>Wall thickness of heat exchanger tube</td><td>4mm</td></tr>
<tr><td>Length of heat exchanger tube</td><td>1000mm</td><td>Number of heat exchanger tubes</td><td>36</td><td>Inner diameter of Heat exchanger tube</td><td>12mm</td></tr>
</table>

2.3. Experimental results

In this study, the generator temperature was controlled to a constant value of 383 K and the condensation temperature was 308 K. The evaporating temperature was kept at 268K, 273K, and 278K, and the feed flow rate was set to 70 L/h, 80 L/h, and 90 L/h. The changes in the cooling capacity of the evaporator and COP of the system were observed, and experimental results are shown in Fig. 2.

The system cooling capacity and COP were calculated by Equations 6 and 11. It could be found that when the feed flow rate remains constant, the cooling capacity of the system increases gradually with the increase of evaporation temperature, and the system COP also increases. When the feed flow rate rises from 70L/h to 80L/h at a constant evaporating temperature, the cooling capacity of the system increases, as well as the COP. When the feed flow rate rises from 80L/h to 90L/h, the cooling capacity and COP of the system decreases.

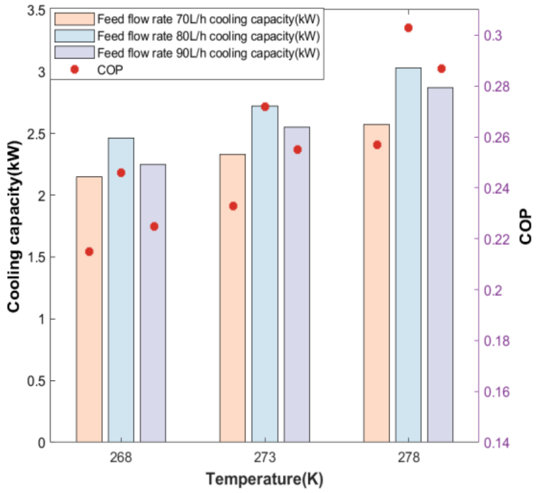


Fig. 2. Experimental data at different evaporation temperatures and feed flow rates

To investigate the effect of different distillation tower feed flow rates on the system performance, a numerical model of the single-effect ammonia absorption refrigeration system is considered for further study.

2.4. Uncertainty analysis

Accuracies of temperature and pressure sensors and flow meters are provided by the product manual. And the uncertainties of Q and COP are calculated according to the accuracy of the sensors. The results are shown in Tab.2.

Table 2. Accuracy and uncertainty analysis

Name	Instrument range	Accuracy
Temperature sensor (PT1000)	-50-150℃	0.50%
Pressure sensor	0-25Bar	0.50%
Cooling water flow meter	0-5.4m^3/h	0.50%
Chilled water flow meter	0-5.4m^3/h	0.50%
Ammonia solution flow meter	0-250L/h	0.50%
Q_{g}	\	1.00%
Q_{cond}	\	1.00%
Q_{c}	\	1.00%
Q_{ab}	\	1.00%
COP	\	0.49%

3. Thermophysical properties model and simulation process

3.1. Thermophysical properties model of ammonia

Ammonia in the absorption refrigeration systems exists in two main forms, pure ammonia, and aqueous ammonia solutions, and detailed physical properties of the ammonia-water system can be calculated within the temperature of 200K-450K and pressures of 0.9807kPa-2.452MPa by using the Schulz equation of state for aqueous ammonia solutions [18]. This equation originates from the ideal gas equation of state PV=nRT. With the pressure and temperature as independent variables, the Gibbs free energy of the gas and liquid phases of an ammonia-water mixture is calculated. Finally, the other parameters of the ammonia system can be calculated [19]. The Schulz equation of state for the ammonia-water system is used for the modeling of refrigeration systems because of its wide range of applicability and small error. Based on this equation, Xu [20] carried out some derivation and correction, to get the equations for solving the enthalpy, entropy, and hydrazone of ammonia solution as well as the phase equilibrium relation equation of ammonia solution, through which the various physical properties of ammonia solution can be solved [21].

According to the thermodynamic theory, when the fluid reaches gas-liquid phase equilibrium, the chemical potentials of the gas and liquid phases of the fluid are equal, which is known as the Gibbs free energy [22]：

$$G_r^l = G_r^g \tag{12}$$

Where G_r^l and G_r^g are pure component contrast state Gibbs free energies for the liquid and gas phases.

Equation. (12) is a functional relationship between T_r and P_r, which can be used to complete the state parameter solution for pure substances by giving one of the parameters and thus the other.

Similarly, when the ammonia solution is at gas-liquid equilibrium, the chemical potentials of the gas and liquid phases are equal [23]:

$$y = e^{\frac{G_{rNH_3}^l + T_r lnx + G_r^E + (1-x)\frac{\partial G_r^E}{\partial x} - G_{rNH_3}^g}{T_r}} \tag{13}$$

$$1-y = e^{\frac{G_{rH_2O}^l + T_r ln(1-x) + G_r^E - x\frac{\partial G_r^E}{\partial x} - G_{rH_2O}^g}{T_r}} \tag{14}$$

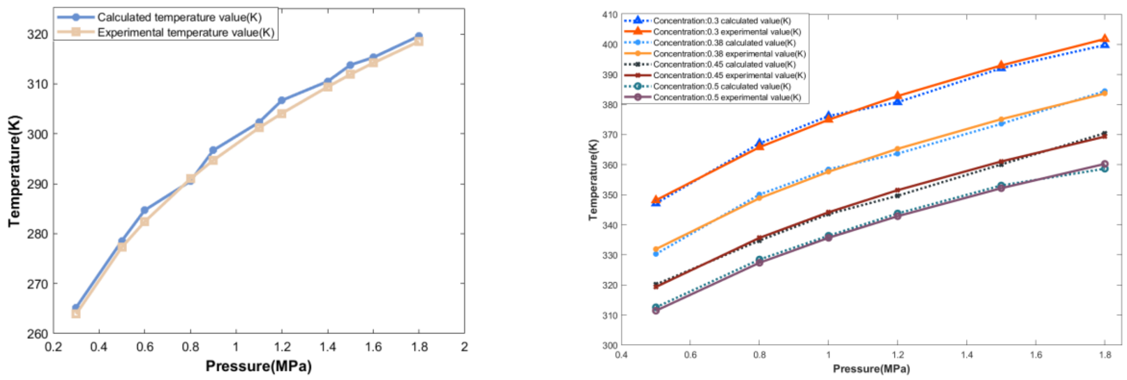
Where G_r^E is an intermediate variable concerning T_r and P_r.

There are four variables in Eq. (13) and Eq. (14): T_r, P_r, x and y. With any two of them given, the remaining two parameters can be determined. In this study, the equations above were adopted to calculate the physical properties of the ammonia system.

An appropriate computer program was established based on the presented mathematical model. The program uses the equations and coefficients presented in reference [15]. The calculation program is implemented using MATLAB. After the simulation program is built, it needs to be tested for accuracy.

First, in the pure ammonia calculation program, the corresponding saturation temperature can be calculated by entering different pressure values. Comparing the calculated saturation temperature with the experimental saturation temperature. The result is shown in the Fig. 3(a). In several tests, the maximum absolute error was 2.6K, the minimum absolute error was 0.3K, and the average error was 1.3K.

Similarly, the calculation program can also be applied to the physical properties of ammonia solution. By entering the concentration and pressure of the ammonia solution, the temperature of the solution can be calculated. The result is shown in the Fig. 3(b). Comparing the calculated solution temperature with the experimental temperature, the maximum absolute error is 2.05K, the minimum absolute error is 0.6K, and the average value is 1.2K.



(a) (b)

Fig. 3. Comparison of calculated and experimental values of thermal physical properties

3.2. Simulation program

3.2.1 Premise assumptions

To develop a mathematical model of an ammonia absorption refrigeration system, it is necessary to make some assumptions to simplify the system calculations, the main assumptions are as follows:

(1) The system is at steady state operation;

(2) Neglecting losses due to heat exchange between the absorption refrigeration system and the environment;

(3) Neglecting pressure losses due to local frictional resistance.

3.2.2 Calculation process

Mass and energy conservation equations for each component are required to establish the mathematical model of the system. Which are introduced in section 2.1. The working fluid in the generator is an aqueous ammonia solution, and separate equations can be developed for the solution and ammonia. The heat exchange equations for ammonia and cooling water need to be established in the condenser and for ammonia and chilled water in the evaporator. The enthalpy is assumed to be constant before and after the throttle valve, and the flow rate can be calculated from the empirical equation for the mass flow rate of the valve. The flow chart calculation process is shown in Fig. 4.

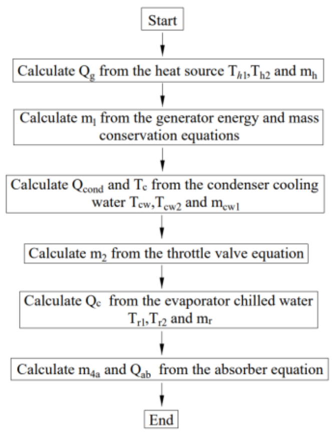


Fig. 4. Calculation process

4. Mathematical model validation and analysis of simulation results

4.1. Experimental verification of accuracy

When the input parameters are set to the generator temperature of 383K, evaporating temperature of 273K, and condensing temperature of 308K, the calculated values and experimental results are compared in Fig. 5. As shown in Fig. 5, compared to the experimental results, the calculated temperature of the working fluid in each process of the refrigeration cycle shows high accuracy.

It can be seen in Fig. 5 that the maximum difference between the calculated and experimental temperatures is 1.84K, the minimum difference is 1.28K, and the average temperature difference is 1.57K.

Absolute error is defined as the calculated value minus the experimental value. Relative error is determined as the experimental value minus the calculated value and then divided by the experimental value. The COP calculated by simulation is 0.28, and compared with the experimental result of 0.272, the relative error is 2.86%. The calculated refrigerant flow rate is 17.54L/h, and compared with the experimental value of 18.53L/h, the relative error is 5.34%.

The average temperature difference is 1.57K and the maximum relative error is 5.34%, which is within the acceptable range that can be concluded according to [21]. The calculated values of the single-effect absorption refrigeration model are in good agreement with the experimental values.

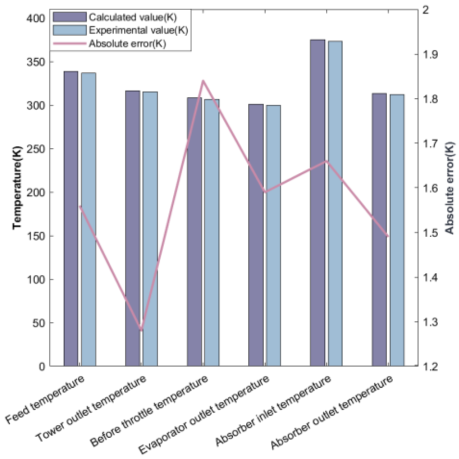


Fig. 5. Comparison of calculated and experimental values for different locations of the absorption refrigeration system

4.2. Effect of feed concentration on system performance

With the evaporating temperature, generator temperature, and cooling water temperature held constant, Fig. 6 shows the variations of ammonia distillation purity, absorption solution concentration, generator heat load, and system COP as the feed concentration increases.

From Fig. 6, it can be seen that as the feed concentration increases, the purity of ammonia in the distillation process also rises. When the feed concentration reaches 0.36, the purity of distilled ammonia increases to 0.998, which can be considered pure ammonia.

According to Konoalnv's rule, for the evaporator inlet dual-phase ammonia-water fluid with high vapor pressures, the ammonia mole fraction of the gas phase is greater than that of the liquid phase [24].

It could be concluded from Fig. 6 that the purity of distilled ammonia increases with increasing feed concentration. When the purity of distilled ammonia increases, the mole fraction of the gas phase of the gas-liquid mixture after the throttle will exceed that of the liquid phase, resulting in an increase of the evaporation pressure from 1.67 Bar to 2.38 Bar.

This is because when the purity at the outlet of the distillation tower increases, the purity of ammonia in the gas phase at the inlet of the evaporator also increases. And higher purity of the gas phase ammonia-water will lead to higher pressure. So, the evaporator pressure will increase.

As the evaporation pressure rises, the pressure of the gas phase ammonia-water in the absorber increases. The main driving force for the absorption process is the pressure difference between the saturation vapor pressure of the gas at the liquid surface and the gas phase pressure. Therefore, the increase in the pressure difference will lead to an enhanced absorption rate, which in turn increases the concentration of the solution in the absorber from 0.242 to 0.346.

When the feed concentration increases, the generator heat load for desorbing of the ammonia gets smaller, while the system cooling capacity remains the same, and the system COP rises from 0.12 to 0.24.

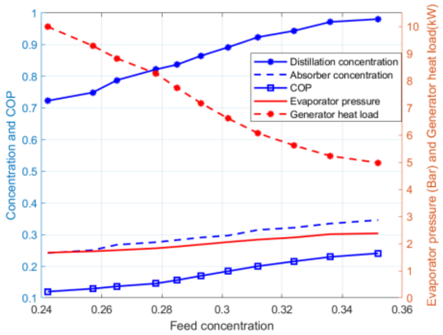


Fig. 6. Effect of feed concentration on ammonia distillation purity, absorption concentration, generator heat load, evaporation pressure, and COP

4.3. Effect of feed flow rate on system performance

Simulation results show that when the feed flow rate increased from 50L/h to 80L/h, the ammonia purity at the top of the distillation tower is always maintained at 0.998; however, when the feed flow rate continues to increase to 110L/h in this process, the ammonia purity quickly decreased from 0.998 to 0.971, as shown in Fig. 7.

The reason is that there is a maximum capacity of the distillation tower, and when the feed flow rate exceeds the maximum value, an overflow phenomenon occurs. Overflow can cause too much liquid on the plates in the distillation tower, which prevents ammonia from rising and affects the heat exchange in the distillation tower. Which can lead to a reduction in the ammonia flow rate and purity at the outlet of the distillation tower.

In Fig. 8, along with the increase in feed flow rate, the generator heat load is rising. This is because when the feed flow rate increases, the amount of solution in the generator also increases. To ensure that the ammonia purity at the outlet of the distillation tower can be maintained at a stable level, greater heat load of the generator is needed. As a result, the system COP increases first and then decreases. There is an optimum operating point for the system that the highest COP is performed.

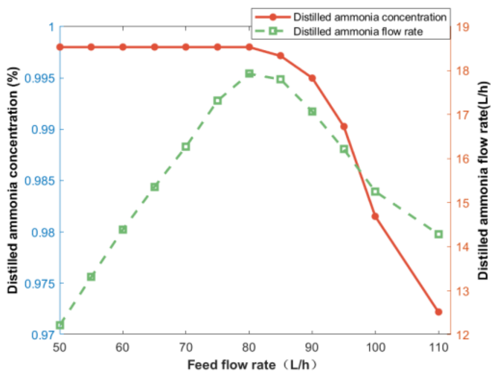


Fig. 7. Effect of feed flow rate on distilled ammonia purity and distilled ammonia flow rate

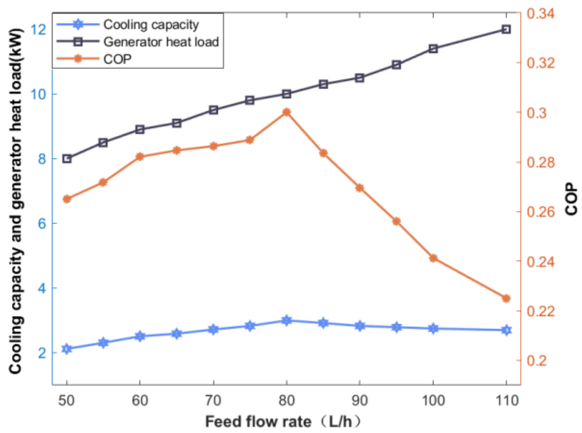


Fig. 8. Effect of feed flow rate on cooling capacity, generator heat load and COP

5. Conclusions

In this paper, a single-effect ammonia absorption refrigeration system was built for experimental study. A simulation program of the system was developed, and the performance of the system under different operating conditions was calculated.

The experimental and simulation studies are mainly carried out to investigate the effects of feed concentration and feed flow rate on the system performance, and the main conclusions are as follows:

(1) The thermal physical parameters of the working fluid, such as temperature, pressure, enthalpy, and concentration, can be accurately calculated by the calculation programmed using Schulz's equation of state for the ammonia system, and it is found that the error between the calculated value and the experimental value is within 5%.

(2) When the feed concentration of the concentrated solution increases, the ammonia purity at the outlet of the distillation tower will rise, which in turn will lead to an increase in the evaporation pressure and the absorber pressure. And increased absorber pressure will lead to higher solution concentration. The distilled ammonia is almost pure when the feed concentration reaches 36%.

(3) When the feed flow rate is less than 80L/h, distilled ammonia purity remains at a high value, and the system COP increases with the feed flow rate. When the feed flow rate reaches 80L/h, further increasing the feed flow rate will lead to the rapid decline of the distilled ammonia purity, and the system COP decreases, too. There is an optimal feed flow rate, with which the system shows the optimal operating performance.

Nomenclature

C	-Specific heat capacity of ammonia, [kJkg^{-1}K^{-1}]	c_1	-Specific heat capacity of heat source, [kJkg^{-1}K^{-1}]
c_2	-Specific heat capacity of water, [kJkg^{-1}K^{-1}]	COP	-Coefficient of performance
$G_{rNH_3}^{l}$	-Comparative state free energy of ammonia liquid, [KJkmol^{-1}]	$G_{rNH_3}^{g}$	-Comparative state free energy of ammonia gas, [KJkmol^{-1}]
$G_{rH_2O}^{l}$	-Comparative state free energy of water liquid, [KJkmol^{-1}]	$G_{rH_2O}^{g}$	-Comparative state free energy of water gas, [KJkmol^{-1}]
G_r^E	-Intermediate variable concerning T_r and P_r, [KJkmol^{-1}]	m_1	-Ammonia flow rate at generator outlet, [kgh^{-1}]
m_2	-Flow after throttle, [kgh^{-1}]	m_3	-Generator feed flow rate, [kgh^{-1}]
m_4	-Dilute solution flow rate at generator outlet, [kgh^{-1}]	m_h	-Heat source flow rate, [kgh^{-1}]
m_{cw1}	-Condenser cooling water flow, [kgh^{-1}]	m_{cw2}	-Absorber cooling water flow, [kgh^{-1}]
m_r	-Flow rate of chilled water, [kgh^{-1}]	P_r	-Contrast pressure, [MPa]
ΔP	-Differential pressure of throttle valve, [Bar]	ρ	-Density of ammonia, [kgm^{-3}]
Q_g	-Heat exchange between generator and heat source, [kW]	Q_{cond}	-Heat exchange of condenser cooling water, [kW]
Q_c	-Heat exchange of chilled water, [kW]	Q_{ab}	-Heat exchange of absorber cooling water, [kW]
T_{h1}	-Inlet temperature of heat source, [°C]	T_{h2}	-Outlet temperature of heat source, [°C]
T_{cw}	-Cooling water inlet temperature, [°C]	T_c	-Condensing temperature, [°C]
T_{cw1}	-Condenser cooling water outlet temperature, [°C]	T_{cw2}	-Absorber machine cooling water outlet temperature, [°C]
T_r	-Contrast temperature, [°C]	T_{r1}	-Inlet temperature of Chilled water, [°C]
T_{r2}	-Outlet temperature of Chilled water, [°C]	UA	-Heat transfer coefficient of condenser, [kgK-1]
x	-Liquid phase ammonia concentration, [%]	x_3	-Distillation tower inlet concentration, [%]
x_4	-Dilute solution concentration at generator outlet, [%]	x_{4a}	-Absorber outlet solution concentration, [%]
y	-Gas phase ammonia concentration, [%]		

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Paper submitted: 02.11.2024.

Paper revised: 30.12.2024

Paper accepted: 06.01.2025.