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Research Article

Numerical Study on Vapor Absorption into Aqueous LiBr Solution in a Liquid-gas Ejector Using Convergent Nozzle

Rui Wang and Hongtao Gao
Institute of Refrigeration and Cryogenics Engineering, Dalian
Maritime University, Dalian 116026, China

Abstract: In this study, we have a numerical study on vapor absorption into aqueous LiBr solution in a liquid-gas ejector using convergent nozzle. A model of heat and mass transfer process in absorption of water vapor into a lithium bromide solution in liquid-gas ejector was developed. The model can predict vapor entrainment rate and mass fluxes. The effect of operating condition has been investigated. It has been observed that the absorption mass flux and the vapor entrainment rate increase as the mass flow rate of the inlet solution increases, the inlet solution concentration increases, the inlet solution temperature decreases and the absorber pressure increases. In our results, we get that the mass flux and vapor entrainment rate increases with the mass flow rate, inlet solution concentration, absorber pressure; the mass flux and vapor entrainment rate increases as the inlet solution temperature decreases; the mass flux rapidly decreases at first and slowly to zero value along flow direction.

Keywords: Ejector, lithium bromide solution, mass transfer, model

INTRODUCTION

Absorption cooling systems have been widely used in central air-conditioning refrigeration because it can make use of low-grade heat and refrigerant is safe and environmentally friendly. The absorber has a direct effect on efficiency, size of the system. To develop the absorption refrigeration, its miniaturization and efficiency improvement is very important. Most of previous model of the absorption process were focused on the plate absorber and the tuber absorber. Karami and Farhanieh (2011) developed a falling film model of absorption process of incline plate absorber. The effects of plate angle and film Reynolds number on absorption process have been investigated. The average Nusselt and Sherwood numbers, which are essential parameters to design an absorber, were correlated as a function of plate angle and film Reynolds number. Yoon *et al*. (2005) analyzed a falling film of LiBr solution of vertical plate wall cooled by water. The absorption heat and mass fluxes, the total heat and mass transfer rates and the heat and mass transfer coefficients get high values at the inlet region but decrease at the outside of the inlet region. Yigit (1999) describes a model of the absorption process in a falling film Lithium Bromide-Water absorber. The results showed that coolant side flow rate effects small on the values of mass absorbed, the outlet film temperature and also the outlet mass fraction. Inlet coolant temperature influences on the mass absorbed. Banasiak and Koziol (2009) developed a steady state mathematical model of the industrial sorption refrigeration system including two-dimensional distributions of temperature and concentration fields for heat and mass exchangers. Kyung *et al.* (2007) developed a model for absorption of water vapor into aqueous LiBr flows over a horizontal smooth tube. Kawae *et al.* (1989) performed research on effect of change of physical properties of LiBr solution and effect of operation condition on absorption mass transfer rate by numerical analysis. Killion and Garimella (2003) studied gravity-driven flow of liquid films and droplets in horizontal tube banks and found that the formation, detachment and impact of droplets and the associated waves and film disturbances can all affect the mixing of the liquid and can enhance transfer rates.

In this study the liquid-gas ejector was used in the lithium bromide absorption refrigerator in order to improve the mass transfer efficiency. In other words, LiBr solution is used as working fluid to suck the water vapor for the purpose of promoting miniaturization and efficiency improvement of lithium bromide absorption refrigerator. The present study focuses on the numerical study of the heat and mass transfer process in the liquid-gas ejector using convergent nozzle. The effects of the mass flow rate, inlet solution temperature and concentration, absorber pressure on absorption mass flux have been investigated.

Corresponding Author: Hongtao Gao, Institute of Refrigeration and Cryogenics Engineering, Dalian Maritime University, Dalian 116026, China

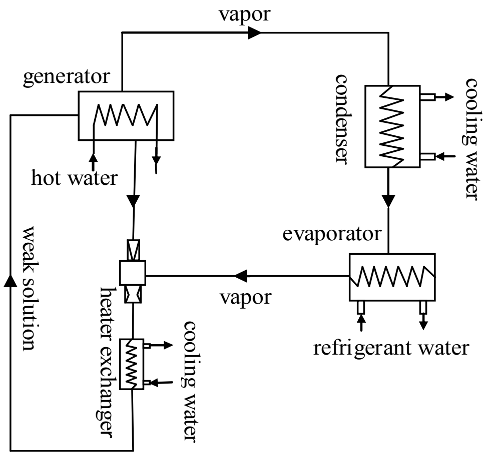

Fig. 1: The schematic diagram of experiment

EXPERIMENTAL FACILITIES

The main components of the experiment set-up shown in Fig. 1 are an absorber, a generator, a condenser, an evaporator and control and measurement devices.

The absorption refrigeration system in this study is based on single-effect absorption refrigeration cycle. The ejector-type absorber consists of an ejector and a heat exchanger. The ejector includes a nozzle (N), a mixing chamber (M) and a diffuser (D). The density and temperature of the inlet and outlet solutions can be measured by the mass flow meter. The concentrations of inlet and outlet solutions are determined, applying the water-LiBr density correlation as a function of temperature and concentration.

CFD modeling strategy: In the present study, the ejector is located so that the convergent nozzle is downward directly. The entrained vapor flows around the lithium bromide solution jet in the annular space between the solution jet and the ejector. As a result, there is no bubble formation inside the ejector. Two-dimensional ax symmetric geometry is considered with quadrilateral-meshing scheme. Lithium bromide solution as the motive fluid and water vapor as the entrained fluid are considered. Since the ejector geometry is down-flow, the gravity is taken in the positive X direction. Standard κ-ε model is used for modeling the turbulent behavior of the flow. Figure 2 shows a geometry studied and the boundary conditions used. Since the mass flow rate of lithium bromide solution through the nozzle were known, the inlet velocity is used as the boundary condition. The solution concentration at liquid-vapor interface is determined from the relation between the solution temperature and concentration in equilibrium with refrigerant vapor pressure at the interface given in McNeely (1979). The pressure profile on the centerline of the ejector with the axial locations from nozzle tip to the throat of diffuser maintained steady and it reduces rapidly to near the equilibrium pressure after the throat. Therefore, we assume the absorption process occurs from nozzle tip to the throat of diffuser.

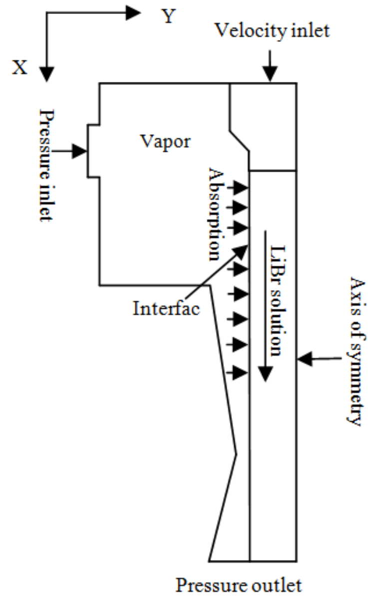

Fig. 2: The geometries of model and the boundary conditions

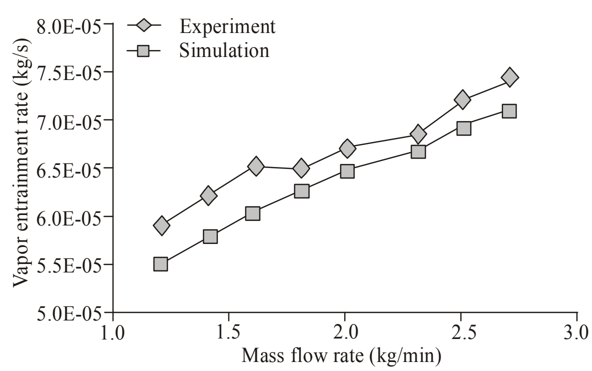

Fig. 3: Comparison of vapor entrainment rate of simulation and experiment

Table 1: Experiment conditions

Experiment conditions	Values
Inlet solution temperature	18°C
Inlet solution concentration	50.7 wt%
Inlet solution flow rate	1.2~2.7 kg/min
Evaporator temperature	5°C

Validity of the model: In Fig. 3, the vapor entrainment rates of simulation were compared with experiment values under the same condition shown in Table 1. It can be seen that a deviation of simulation value from experiment value is less than 7%.

Table 2: Operating conditions

Parameters	Nominal	Range
Inlet solution temperature	40°C	38~42°C
Inlet solution flow rate	2.7 kg/min	1.2~2.7 kg/min
Inlet solution concentration	60 wt%	58~62 wt%
Absorber pressure	1 kPa	0.875~1.145 kPa

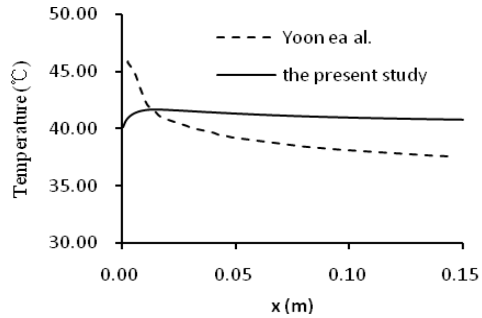

Fig. 4: Comparation of temperature profiles of present study with previous investigations

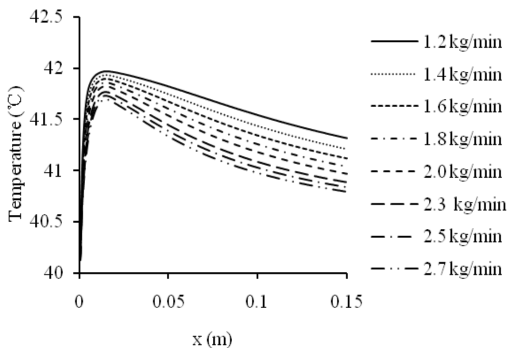

Fig. 5: Interface temperature profiles

RESULTS

The nominal conditions and the investigated ranges of the present study are summarized in Table 2.

Concentration and temperature distributions: The interface temperature profile is compared with that of Yoon *et al*. (2005) in Fig. 4. The temperature profile of the present study increases rapidly at first and slowly decreases along the flow direction, however, the one of Yoon's study decreases rapidly and slowly along the flow direction. Yoon's study focuses on the study of the combined heat and mass transfer process in a vertical plate absorber which is cooled by cooling water, therefore, even if the water vapor is absorbed, the temperature still decreases as the x increases. In present study, there is no cooling water in absorption process and the cooling water cools the solution after the absorption process, as seen in Fig. 1. Thus, the temperature increases at first as the vapor is absorbed.

Figure 5 presents the interface temperature distribution along the flow direction. The interface temperature increases rapidly the first and then

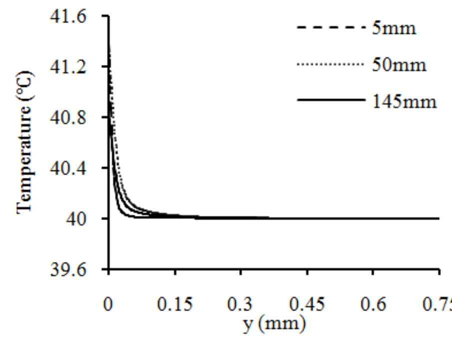

Fig. 6: Temperature profiles across-flow

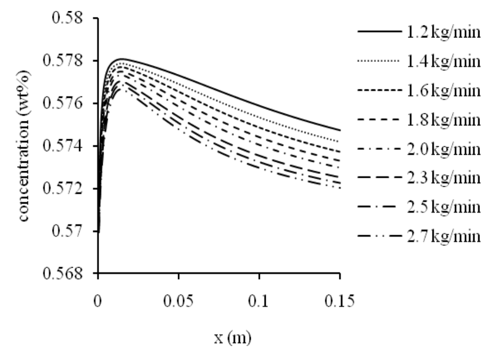

Fig. 7: Concentration profiles

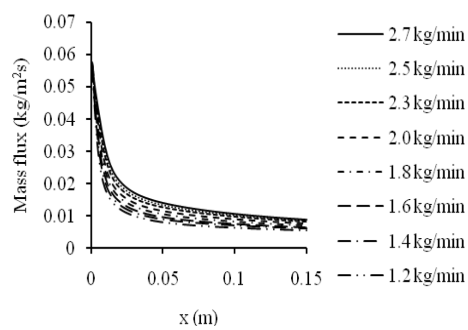

Fig. 8: Effect of mass flow rate on absorption mass flux

decreases slowly. The heat of absorption releases at interface and it transfers from the interface to the bulk. When the mass flow rate is high, the heat is rapidly taken away by the solution. Therefore, at the same location, the temperature decreases as the mass flow rate increase.

Figure 6 presents the cross-flow temperature in case of x = 5, x = 50 and x = 145 mm, respectively. In the figure, the y = 0 and y = 0.75 mm mean, respectively the liquid-vapor interface and the axis of symmetry. The temperature reduces rapidly from the interface to the axis of symmetry. The temperature decreases rapidly at first and then slowly along the y direction.

Figure 7 shows the interface concentration distribution along the flow direction. The trend of the interface concentration with the flow direction is similar

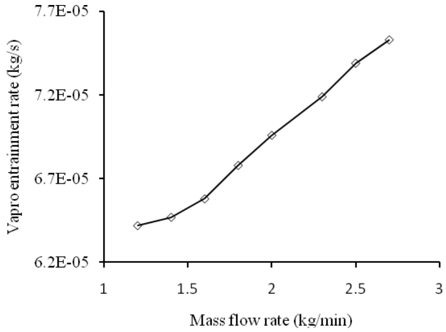

Fig. 9: Effect of mass flow rate on vapor entrainment rate

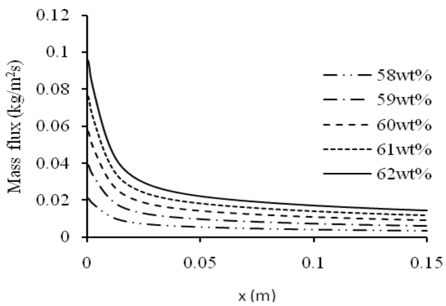

Fig. 10: Effect of inlet solution concentration on absorption mass flux

with the interface temperature. The higher mass flow rate, the higher gradient of the concentration at the interface, the more absorbed vapor. Thus, at the same location, the concentration decreases as the mass flow rate increases.

Effect of mass flow rate on absorption mass flux and vapor entrainment rate: Figure 8 shows the effect of mass flow rate on absorption mass flux at a solution concentration of 60 wt% and at eight different mass flow rates. At the convergent nozzle outlet, the mass fluxes are almost equal. As the mass flow rate increases, the velocity increases. Thus, the gradient of the concentration at the interface increases and the absorption capacity increases. Therefore, the absorption mass flux increases with the mass flow rate.

Figure 9 shows how the mass flow rate affects the vapor entrainment rate at a solution concentration of 60 wt% and a solution temperature of 40°C. A vapor entrainment rate increase of about 17% is observed from a mass flow rate change of 1.2 to 2.7 kg/min, respectively.

Effect of inlet solution concentration on absorption mass flux and vapor entrainment rate: Figure 10 illustrates the effect of inlet solution concentration on absorption mass flux at a solution temperature of 40°C and at five different solution concentrations. As the concentration of LiBr solution increases, the vapor pressure of solution decreases and the mass transfer driving force increases. Therefore the mass flux increases as the inlet solution concentration increases.

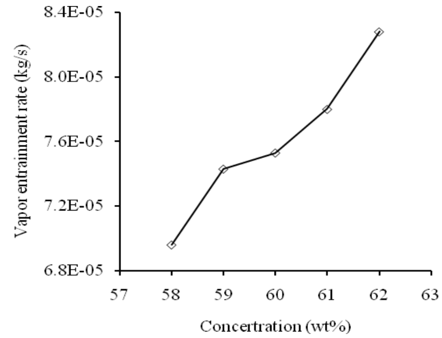

Fig. 11: Effect of inlet solution concentration on absorption mass flux

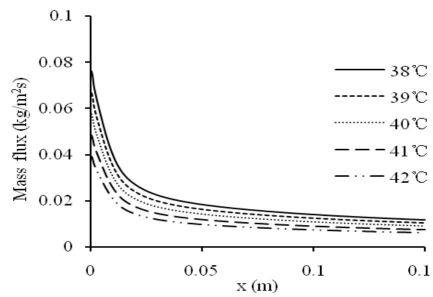

Fig. 12: Effect of inlet solution temperature on vapor entrainment rate

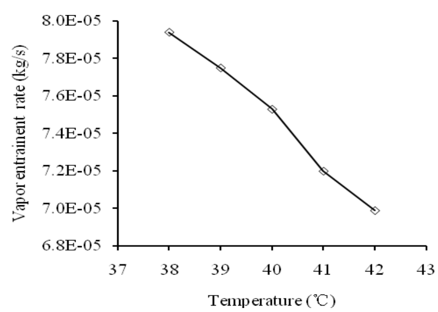

Fig. 13: Effect of inlet solution temperature on vapor entrainment rate

Figure 11 represents the vapor entrainment rate versus the inlet solution concentration. The vapor entrainment rate increases with the inlet solution concentration. The range of vapor entrainment rate is 6.96×10^{-5} -8.3×10^{-5} kg/s.

Effect of inlet solution temperature on absorption mass flux and vapor entrainment rate: Figure 12 shows the effect of inlet solution temperature on absorption mass flux at the solution concentration of 60 wt% and five different solution temperatures. As the inlet solution temperature decreases, the vapor pressure of solution decreases and the driving force increases. It causes the mass flux to increases as the inlet solution temperature decreases.

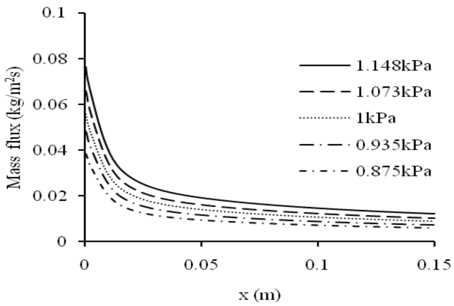

Fig. 14: Effect of absorber pressure on vapor entrainment rate

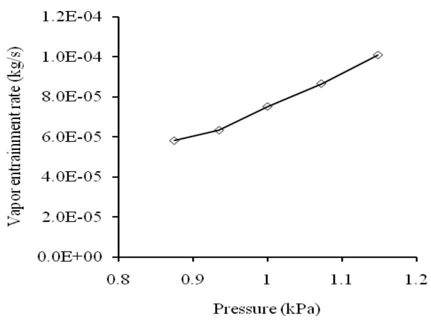

Fig. 15: Effect of absorber pressure on vapor entrainment rate

The resulting reduction in the mass transfer driving force decreases the vapor entrainment rate, as seen in Fig. 13. At a temperature of 38°C, the vapor entrainment rate is about 7.94×10^{-5} kg/s, whereas it is about 7×10^{-5} kg/s when the temperature is 42°C.

Effect of absorber pressure on absorption mass flux and vapor entrainment rate: Figure 14 shows the effect of the absorber pressure on absorption mass flux at the solution temperature of 40°C, the solution concentration of 60 wt% and five different absorber pressures. The higher is the absorber pressure, the greater is the potential for vapor transfer to the LiBr solution. Consequently, the mass flux increases with the absorber pressure.

Results in Fig. 15 show the influence of the absorber pressure on the vapor entrainment rate. The vapor entrainment rate increases about 4.5×10^{-5} kg/s when the absorber pressure is increased from 0.875 to 1.148 kPa.

CONCLUSION

Liquid-gas ejector was applied to absorption refrigerator to enhance mass transfer efficiency and a model was developed to analyze the experimental results. The predicted vapor entrainment rate matched well with the experimental value. The conclusions are as follows:

- The mass flux and vapor entrainment rate increases with the mass flow rate, inlet solution concentration, absorber pressure.
- The mass flux and vapor entrainment rate increases as the inlet solution temperature decreases.
- The mass flux rapidly decreases at first and slowly to zero value along flow direction.

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