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LiBr CONCENTRATION DISTRIBUTION IN A FALLING-FILM TYPE ABSORBER MEASURED BY A REFRACTOMETER

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ABSTRACT An experimental study of the LiBr concentration in an falling-film-type absorber was carried out to find out the optimum operating conditions for improving the heat and mass transfer in lithium bromide(LiBr)-water absorption heat pumps. An experimental apparatus for an absorber with a staggered bundle of horizontal tubes was designed, fabricated, and tested. The LiBr-water solution was extracted from the apparatus using vacuum sampling ports. The experimental results show that the difference in LiBr concentration between the inlet and the outlet of the absorber was increased by the maximum 10 percent with increasing surfactant concentration up to 3,000 ppm. The vapor absorption by the solution starts at the second row of tubes and increases gradually between the row and the fourth rows, which can be explained by the enhanced absorption thanks to the gradual decrease in the solution temperature. However the absorption of the vapor decreases from the fifth row to the end of the absorber, where the solution temperature remains relatively constant and the LiBr concentration decreases gradually.

Keywords: LiBr concentration, refractometry, surfactant, film flow rate, falling film

1. INTRODUCTION

Absorption chillers are becoming attractive since they do not use Freon gases that destroy ozone layer, and can be driven by heat. Especially, lithium bromide (LiBr)-water absorption refrigerators have been widely used as refrigeration systems for large buildings or district heating systems because lithium bromide is a stable chemical and the refrigeration efficiency is high due to the large heat of vaporization of water. Recently, the application of the absorption refrigerator has become wider, for example developing the small-sized facility for household use. Improvement of the absorber is necessary to make absorption chillers compact. For this purpose, a lot of research has been performed on the falling-film-type heat exchangers, which are widely used as an absorber in the absorption refrigerators because an absorber is the one of most important units to determine the whole size. [1-5]

In the present study, we have sought a tube type to give the maximum absorption performance. Grooved pipes are known to be effective for promoting gas absorption into falling water. Kiyota and Ousaka[1] tested for water vapor absorption with four different groove depths as well as two different knurled surfaces. The pipe with the deepest groove shows enhancement of about 1.5-1.9 in the Reynolds number range of 200-500. The knurled surfaces are not effective for the absorption, but they have better wettability at a lower flow rate and furthermore for higher knurl height, absorption increases at larger flow rate. Film thickness is measured by the contact probe method. The average film thickness curve has large undulation for deeper grooves but

it is flat for the shallow grooves.

We have performed a series of researches on the real-scale simulator for LiBr-water absorption refrigerator to investigate the optimal design conditions of falling-film-type horizontal tube heat exchangers used as an absorber and an evaporator in the real commercial refrigeration systems. Among these efforts, Chin et al. [6] proposed that the flow characteristics of the falling film on the horizontal tubes depends upon the tube geometry, for example floral tubes, and the nozzle distributors as well.

For the present study, an experimental apparatus of the real commercial size was fabricated in order to investigate the distribution of LiBr concentration and the vapor absorption. LiBr solution was extracted under the tubes from the absorber, the concentration of which was measured by a refractometer. Knowing the absorption rate of water vapor would help us to design the absorber effectively, for example, the tube distribution and so on.

For measuring the LiBr concentration in solution, a large amount of solution, approximately 100 cc, should be extracted for each measuring using the specific gravity method, which is traditionally used. This makes it difficult to measure the solution concentration at many different locations without effect on the operating condition of the absorber. Instead, some of previous studies have used an alternative measure. For example, it has been used to measure the temperature difference of cooling water and to calculate the vapor absorbed by the solution, as a replacement for the concentration difference directly. However, this result does not always represent the vapor absorption correctly.

In the present study, we measured the LiBr concentration in solution directly by refractometry to compare with the results by the indirect heat transfer measurement. Also experiments were performed at three different surfactant concentrations to evaluate the effects of the surfactant on the heat transfer as well as the LiBr concentration distribution at the absorber.

2. EXPERIMENTAL APPARATUS AND METHOD

2.1 Experimental Apparatus

An experimental apparatus for heat transfer in an absorber-evaporator unit was designed as shown in Fig. 1. This apparatus consists of an absorber-evaporator unit, a generator operated with hot water, a condenser, a solution heat exchanger, a solution pump, and instruments.

Low-finned copper tubes with the effective length of 1,262 mm were arranged staggered. The absorber has eight stages, and each stage consists of 30 tubes on an average; the evaporator has ten stages of tubes. The nozzle in the solution distributor over the absorber tubes was the hollow-cone spray nozzle, which gave the hollow annular distribution depending on the spray pressure and the distance from the tubes [6].

In the present apparatus, as the same as in the commercial LiBr absorption system, the spray nozzle distributor sprays the strong solution from the generator through the solution heat exchanger on the absorber tube

bundle. The solution flows down on the tube surface and absorbs the water vapor from the evaporator. The operating pressure of the unit was 8 mmHg, determined by the various parameters, for example, the inlet temperature and flow rate of the chilled water in the evaporator, those of the cooling water and so on (Table 1). The operating pressure was measured by an electronic vacuum gauge (Baratron, type 626, MKS Co.), the operating range of which is 0 to 100 mmHg (Torr).

Chilled water was supplied to be 13 degree C at the inlet of the evaporator and the cooling water temperature at the absorber inlet was set to be 30 degree C during the experiment. The weak solution that absorbed water vapor in the absorber was sent to the generator operated by hot water

Table 1. experimental conditions

Pressure of evaporator	8 mmHg
LiBr solution inlet concentration	58(±0.2) (mass %)
LiBr solution inlet temperature	63 – 64 (°C)
mass flow rate	4.2(±0.2) (m ³ /h)
Cooling water inlet temperature	30 °C
Chilled water inlet temperature	13 °C
n-octyl alcohol	0 - 3000(ppm)

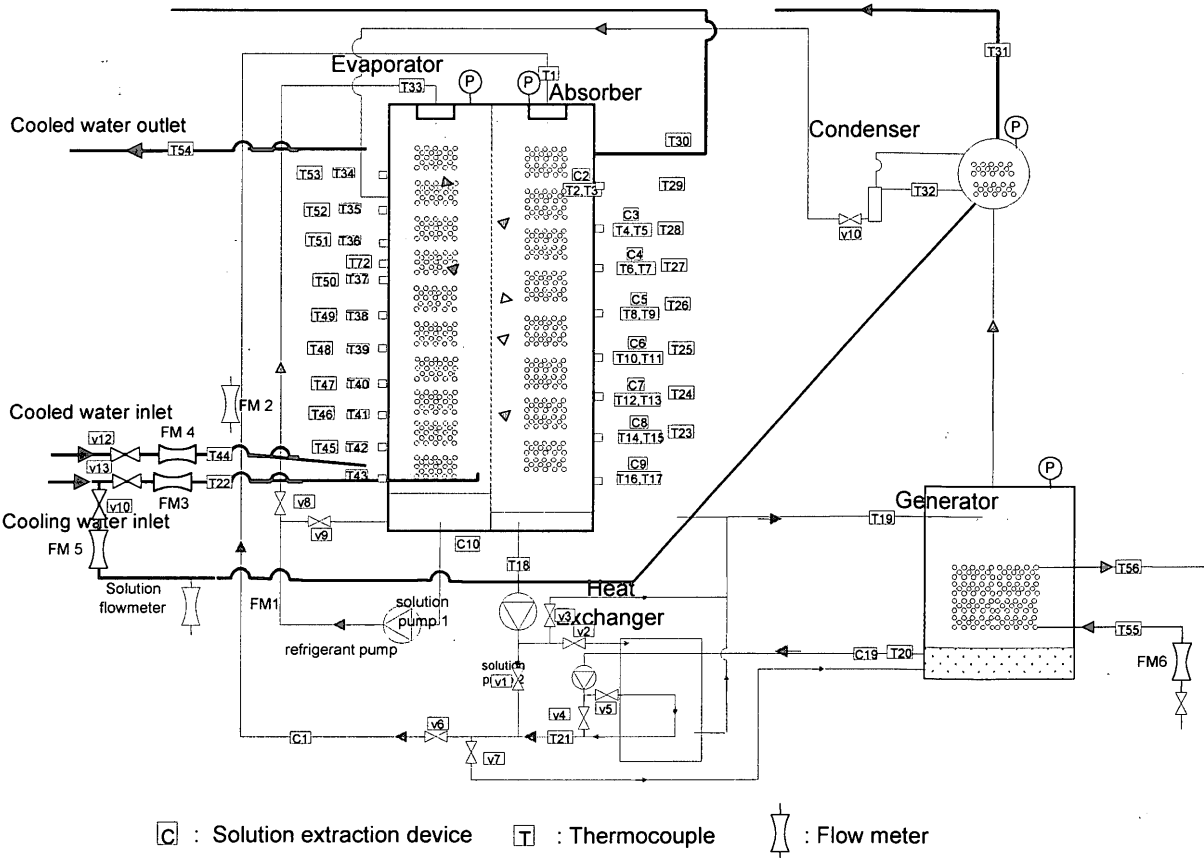


Fig. 1 Experimental apparatus

of 95 degree C and water vapor was separated from the solution to enter the condenser.

The flow rate control valves, V6 and V7 in Fig. 1, determine the circulation rate of the strong solution. The valves V4 and V5 control the inlet temperature of the strong solution of the absorber by changing the flow rate to pass the heat exchanger. The circulation rate of refrigerant (water) in the evaporator was controlled by the valve V8 and V9.

2.2 Measurement of the Temperature and the Sampling of LiBr Solution in the Absorber

Because the absorber operates at very low pressure, for example, 8 mmHg (approximately 0.01 atmospheric pressure), it is not easy to extract the solution from the absorber in operation. The sampling device was connected to the auxiliary vacuum chamber, maintained at lower pressure than the operating pressure of the absorber. Figure 2 shows the schematic diagram of the extraction device of LiBr solution from the absorber in order to measure the solution temperature and the LiBr concentration. After closing the valve V1, the solution is filled in the collecting tube and enters through the valve V2 to the pre-vacuumed T-shaped connector. The valve V4 is opened to sample 2 to 3 cc of the solution, which is very small amount compared to the specific gravity method. The LiBr concentration of the sampled solution was measured by a refractometer.

2.4 Measurement of the LiBr Concentration of the Solution Sample by a Refractometer

Refractive index of the LiBr-water mixture is a

function of the LiBr concentration and the solution temperature. LiBr concentration (ξ_i) is well approximated with the refractive index (n) and the temperature (T) by

$$\xi_i = 2.86802 n - 3.63748 + 0.000434(T - 20) \quad (1) \\ (12^\circ\text{C} \leq T \leq 40^\circ\text{C})$$

This method to measure the LiBr concentration by refractive index will be widely accepted because it is simple and needs only a few cc for measuring. The measuring range of the refractometer (R5000, Atogo Co.) is 0 to 95 percent LiBr and the accuracy is 0.01 percent.

3. EXPERIMENTAL RESULTS AND DISCUSSION

3.1 LiBr Concentration and Temperature on the Tube Stages

Figure 3 shows the measured the LiBr concentration on the tube stages to be compared to the solution temperature. In this figure, the solution temperature dropped abruptly to 44 degree C from 64 degree C at the inlet of the absorber, although the LiBr concentration did not change. This means that the LiBr solution was only cooled without vapor absorption. The LiBr concentration decreased with the similar rate from the first tube stage to the bottom (eighth) stage. The solution temperature decreased from the top to the fourth stage and it is maintained at the fifth to the bottom stage. From this result, it is obvious that the heat generation by the vapor absorption was balanced with the solution cooling by the cooling water.

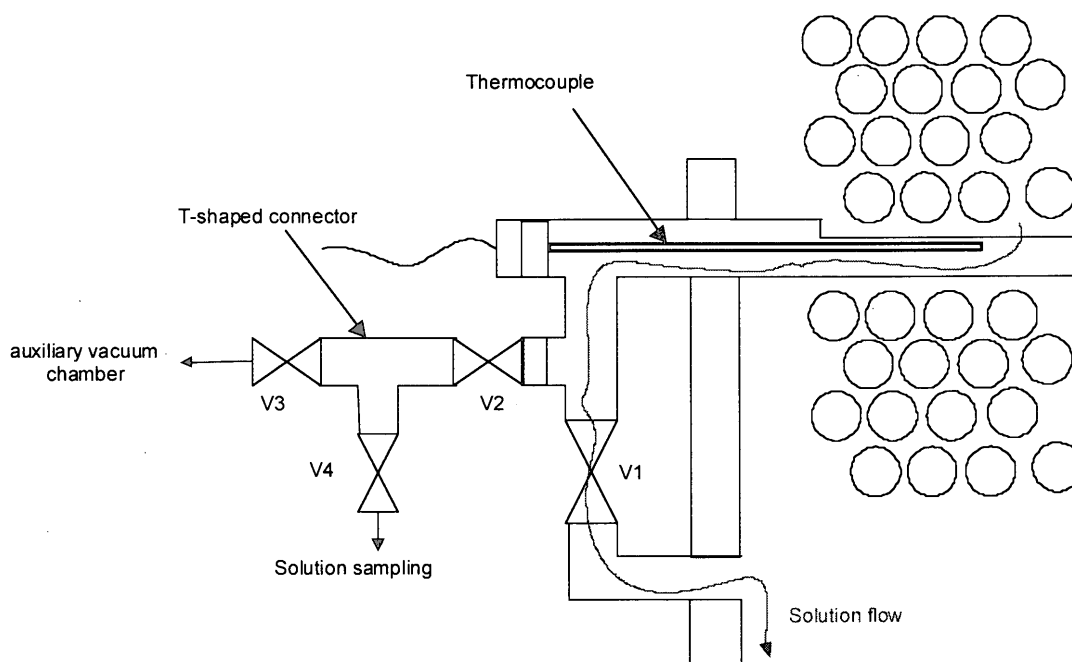


Fig. 2 LiBr-solution extraction device

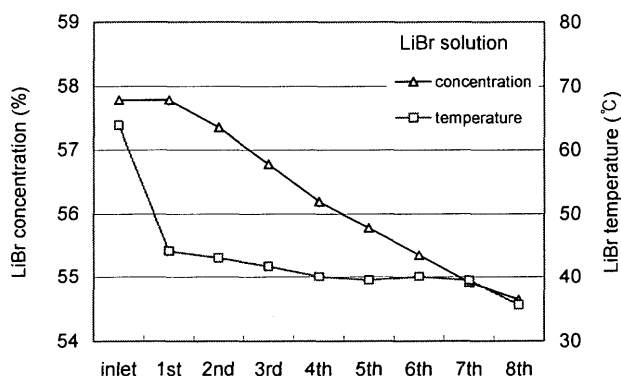


Fig. 3 Variation of solution concentration and temperature on staggered absorption tubes

In Fig. 3, because the LiBr concentration decreased with a similar rate, the vapor absorption of each stage seems to be the same. However, the vapor absorption, calculated from the LiBr concentration and temperature, varied a lot as shown in Fig. 4.

Figure 4 shows the distribution of the vapor absorption over the tube stages. In this figure, the vapor absorption, based on the difference in LiBr concentration, increases within the second to the fourth stage but it decreases gradually afterwards. These results suggest that the absorption ability of the LiBr solution increases with decrease in temperature between the second and the fourth stage and that the vapor absorption decreases with the decreasing LiBr concentration because the solution temperature is maintained constant.

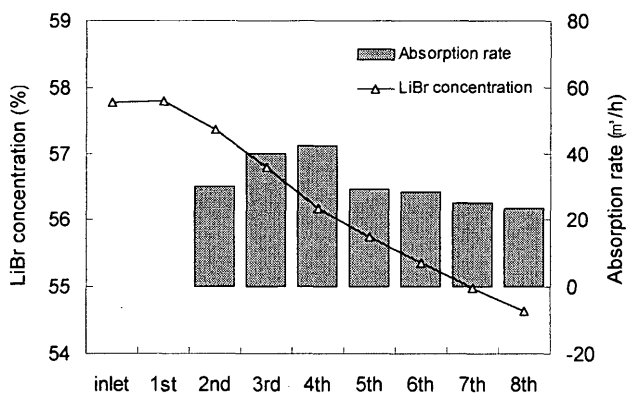


Fig. 4 Variation of solution concentration and absorption rate on staggered absorber tubes

Figures 5 and 6 illustrate the distribution of the solution concentration over the tubes by surfactant addition.

At first, fig. 5 shows the results by changing the amount of the surfactant added. The surfactant concentration was varied from 0 to 3,000 ppm, which seems too high compared to the previous studies [2, 3]. This concentration of the surfactant was calculated based on the amount of surfactant added to the total amount of the solution before the start-up of the system. During the operation, however, the surfactant concentration at the absorber tubes could be a

lot lower than these values because part of the surfactant added would be condensed in the system, especially in the condenser. We are planning to measure the surfactant concentration of the solution in the absorber in operation later. Before adding the surfactant, the LiBr concentrations at the inlet and the outlet of the absorber were 58.3% and 55.4%, respectively. These concentrations became lower with increasing the surfactant addition and finally 56.4% and 54.2%, respectively, with 3,000 ppm. Meanwhile, the total amount of the vapor absorbed into the solution did not change much. This means that the average LiBr concentration became lower with surfactant addition. These results suggest that with the surfactant addition the absorbing ability of the solution in the absorber could increase and the LiBr solution concentration at the outlet of the absorber decreased, while the LiBr concentration at the generator outlet did not return back to the design concentration because the constant supplying heat in the generator. Therefore, the evaporator-absorber reaches at a new equilibrium condition with the lower average LiBr concentration in the absorber.

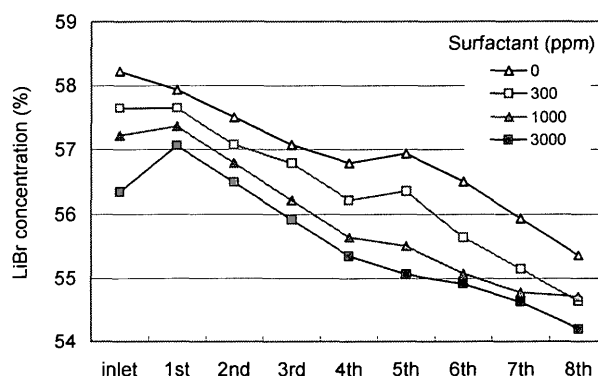


Fig. 5 Effect of surfactant addition on solution concentration variation

In addition, the LiBr solution concentration increased between the inlet (56.4%) and the first stage of tubes (57%) instead of decrease by the absorption for the graph in case of 3,000 ppm in surfactant concentration. This phenomenon was due to the "flashing" that the water vapor in the solution was vaporized when the LiBr solution entered with the concentration lower than the equilibrium.

Figure 6 is the result when adding the surfactant but also increasing the heat supply to the generator in order to maintain the same operating conditions of the absorber as the case without surfactant including the inlet solution concentration as 58%. Comparing the two cases, the LiBr concentration at the absorber outlet was varied from 55.3% (the concentration difference 2.9%) without surfactant, to 54.7% with 3,000-ppm-surfactant (the concentration difference was 3.1%). This shows the increase in the concentration difference in the absorber with enhancing the absorption ability. The vapor absorption, proportional to the concentration difference, could be increased by 8 percent. However, the enhancement was lower than the expectation based on the findings that the system performance would be enhanced about 15 percent with addition of surfactant. This might be due to the fact that the inlet solution concentration was lower in the case with surfactant than that without it.

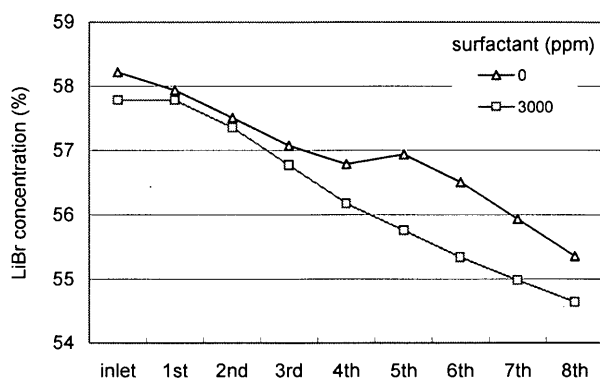


Fig. 6 Variation of solution concentration with and without surfactant

In figures 5 and 6, we could also find that the LiBr concentration was rather increased between the fourth and the fifth stage and there is no known explanation for this behavior yet. However, we could guess that the increase in the film thickness was prominent on these locations, as shown in reference [6]. The finding that this behavior did not be found with higher surfactant addition supports the explanation because the film was maintained to be thin over the whole tubes by the surfactant effect.

4. CONCLUSION

(1) With the surfactant addition up to 3,000 ppm of the initial solution, the vapor absorption in the absorber, proportional to the concentration difference, increases about 8 percent from the result without surfactant.

(2) When the LiBr solution entered with the concentration lower than the equilibrium, the "flashing" phenomenon that the water vapor in the solution was vaporized and the LiBr solution concentration increased between the inlet and the first stage of tubes.

(3) The LiBr solution was only cooled without vapor absorption at the first stage. The vapor absorption increases within the second to the fourth stage because the absorption ability of the LiBr solution increases with decrease in temperature between the second and the fourth stage. However, it decreases gradually afterwards with the decreasing LiBr concentration because the solution temperature is maintain constant.

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7. NOMENCLATURE

n	refractive index
T	solution temperature

Greek symbols

ξ_i	LiBr concentration
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