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Heat Transfer Performance of Plate Type Absorber with Surfactant

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Abstract : Absorption chiller/heater can utilize the unused energy of the daily life waste heat, the industry waste heat, the solar energy and the earth energy. These can contribute to energy savings. But the absorption chiller/heater has a demerit that the size of absorption chiller/heater is larger than that of the vapor compression type based on same capacity. In this study, the experimental apparatus of an absorber is manufactured as a plate, which is newly applied in an absorber. The experimental apparatus is composed of a plate type absorber, which can increase the heat exchange area per unit volume and thus facilitating to deeply investigate more detail features instead of that done by the existing type, i.e., horizontal tube bundle type. The characteristics of heat transfer and refrigeration capacity are studied experimentally. The absorption enhancement by using surfactant is closely examined through the experiment and comparative figures are presented in quantitative and qualitative analysis

Key words : Absorption chiller, Chilled water, Falling film absorber, Plate type absorber, Surfactant.

Nomenclature

α : Heat transfer surface area[m²]
a : Circulation ratio of solution[-]
c : Concentration[wt%]
c_p : Constant pressure specific heat [kJ/kg.K]
D : Absorption rate of water vapor [kg/s]
G : Mass flow rate[kg/s]
h_r : Evaporation latent heat of refrigerant vapor[kJ/kg]
L : Length of plate[m]
P : Pressure[mmHg]
Q_r : Refrigeration capacity[kW]
Re : Reynolds number[-]
ΔT_{lm} : Logarithmic mean temperature difference[℃]

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Greek Letters

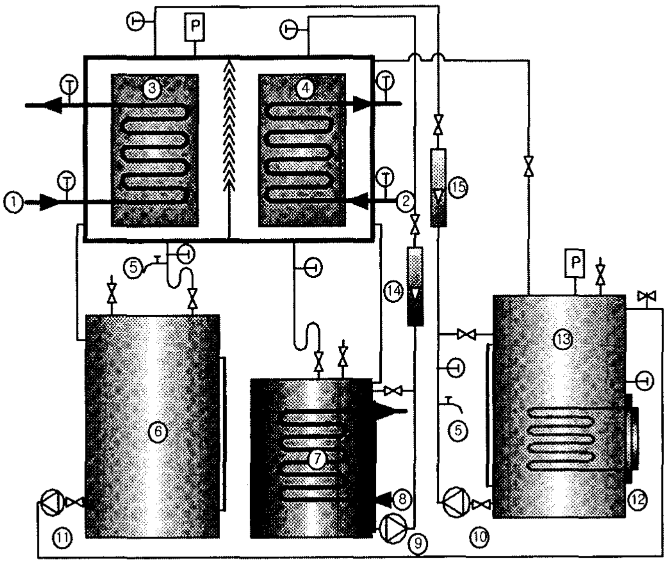
Γ : Film flow rate[kg/m.s]
ξ : Mass concentration[wt%]
μ : Dynamic viscosity[kg/m.s]

Subscripts

f : Liquid film
I : Inlet
o : Outlet
s : Solution
w : Water

1. Introduction

Now a days, refrigeration and air-conditioning devices are being widely used due to the upgraded human living standard followed by the increase of economic activities. The number of air-conditioners now in use increased sharply over the last several decades and the rate of power consumption is increasing every year. To maintain safe and secured reserved power to meet the peak power requirement, it is necessary to construct new power plants almost every year and the construction of the plants cost both time and money. But during spring and fall, the power demand is much lower than that of the summer and an equivocal energy policy occurred. It is known that, the energy consumption is reduces by (1/5~1/6) than that of the natural gas consumed in winter. On the other hand, due to the decrease in the heating demand during the summer, the national energy policy is significantly unbalanced in terms of the energy



① Cooling water ② Chilled water ③ Absorber ④ Evaporator
⑤ Sampling valve ⑥ Weak solution tank ⑦ Refrigerant tank ⑧ Chiller
⑨ Water pump ⑩ Solution pump ⑪ Solution circulation pump ⑫ Heater
⑬ Strong solution tank ⑭ Refrigerant flow meter ⑮ Solution flow meter Ⓣ Thermometer

Fig. 1 Schematic diagram of experimental apparatus

demand and energy supply. The practical uses of absorption cooling and heating have been devised in order to assist solving difficulties related to excessive power consumption in peak hours and environmental pollution. Absorption heating and cooling applications driven by gas is highly effective to provide heating in winter and cooling in summer utilizing an absorption chiller/heater. The absorption chiller/heater is a system that can be operated by solar energy, recycled heat and heat from liquid or gas fuel using environment friendly working fluids such as water or ammonia. In Korea, the absorption chiller/heater, which has a capacity of more than 30RT and uses H_2O/LiBr as a refrigerant/absorbent has been developed for commercial purposes. To make the absorption chiller/heater competent to vapor compression system for the middle and low capacity residential and commercial uses, it highly imperative to improve performance as well as to decrease the size of the whole system. Also, the researches in this arena have strongly being progressed [1~5]. In fact, absorber is one of the most important part in any cooling/heating system and that improving of absorber performance and decreasing of absorber size play vital role on the whole absorption machines. The absorber transfer coefficients are low due to the relatively ineffective mass transfer processes on the liquid side. One effective technique to augment the absorber transfer coefficients involves the addition of a surfactant additive called Octal Alcohol (2-ethyl-1-hexanol). Using octal alcohol can increase transfer performance in absorber design by as much as two times but system effects such as pressure drop and non-absorbable gas effect usually limit the effectiveness of the additive in bundles to much more modest gains[6]. Plate type heat exchangers are used to exchange heat between liquids which itself utilizes corrugated surfaces and thus provide secondary flow and mixing to produce high heat transfer performance[7]. Researches in the relevant field are getting considerable attention[8].

In this study, besides using the surfactant to improve the absorption of vapor into the falling film of LiBr solution, the focus was also given on the packaging of absorber. The utilization of plate-type heat exchanger will make it easier to layout the absorber in the absorption system and to reduce the size of the whole system. For application purposes, the performance of plate-type absorber using LiBr solution as working fluid was studied experimentally under different operating conditions.

2. Experimental apparatus and method

2.1 Experimental apparatus

Fig. 1 shows the schematic diagram of experimental apparatus used in this study; it is composed of absorber, evaporator, strong solution tank, generator, weak solution tank, refrigerant tank, heater and tubes along with other peripherals for the connection of apparatus. For easy observation of the fluid flowing situation in the absorber, one side of absorber is mounted with a large glass plate and the other side with the cooling water part. Between the cooling water and LiBr solution, the heat transfer copper plate made by different geometric configurations are placed. To make sure that the LiBr solution flows smoothly, a solution distributor is mounted in the absorber. A cooling tower is used to remove heat from condensation and absorption process. The digital pressure sensor at the top of generator and the digital manometer at the top of the absorber are installed to measure high and low pressures respectively. Cooling water is supplied to absorber from constant temperature bath of 2HP/5kW grade and that of the chilled water from 3HP/8kW. Sheath type thermocouples are installed to measure the temperatures of water and solution at every inlet and outlet of absorber, evaporator, generator and tanks whereas sample valves are used for measuring the solution concentrations at the inlet and outlet of the absorber and gear pumps are utilized for maintaining constant flow rate of refrigerant and solution. Fig. 2 shows the plate used as plate type heat exchanger. The size of plate is 400mm in width and 600mm in length. Table 1 shows the experimental conditions.

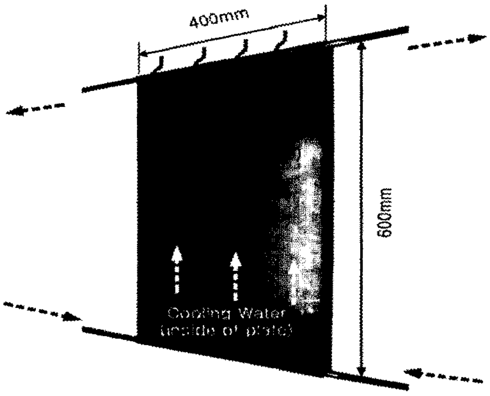


Fig. 2 Heat exchanger of plate absorber

Table 1 Experimental conditions

Pressure of Absorber P (kPa)		1.2
LiBr Solution	Inlet Temperature Tsi (℃)	49
	Inlet Concentration *Csi* (wt%)	60
	Film Reynolds Number *Ref*	6~35
Cooling Water	Inlet Temperature *Twi* (℃)	32
	Flow rate (ℓ/min)	18

2.2 Experimental method

Although batch type experiment is difficult to continue operating for longer time and that the size of each component of the system is required to be larger to increase the operating time of the system, still the experiment was progressed in batch type due to its several superiority over the sequential type. In batch type, the operation of the system is simple, experimental conditions like the variation of temperature, concentration and flow rate of solution, pressure of absorber etc can be maintained as required and therefore one can grasp about the effects of absorption phenomenon with considerable ease. This experiment is divided into processes of establishment of experimental conditions, measurement of performance and generation of solution to perform the experiment in stable state. In the test section, vacuum situation is created through vacuum pump to maintain proper experimental conditions. Refrigerant is cooled at refrigerant tank by chilled water to saturation temperature corresponding to experimental pressure so that the pressure in evaporator remain unaffected by the refrigerant vapor pressure in refrigerant tank.

In the process of performance measurement, temperature at the inlet and out let of absorber and the solution flow rate are measured when strong solution flows as liquid film through spilling on plate from the top of the absorber. The evaporated refrigerant is absorbed to flowing down solution in absorber and the non-evaporated refrigerant flows again in refrigerant tank. The solution weaken by absorption of refrigerant is accumulated in weak solution tank and the solution concentration is measured by sampling valve. Cooling and chilled water are carried respectively to absorber and evaporator through water pump of constant temperature bath while absorption solution and refrigerant are flown as counter flow. The flow rates at the inlet of evaporator and absorber are taken while the cycle comprising of the cooling water that gains heat in absorber and chilled water that loses heat in evaporator are kept moving by adjusting the temperature in the constant temperature bath. The solution temperature at the inlet and outlet of absorber and absorber plate are measured in 5 parts.

In the solution generating process, all the weak solution is carried to the strong solution tank, circulated there by strong solution pump followed by heating by heater (3kW) at generator and then the refrigerant in the heated weak solution is separated. Thus the strong solution is generated and the separated refrigerant is carried to evaporator by pressure difference and accumulated to refrigeration tank and is cooled and condensed by cooling water in evaporator.

The absorbent solution and refrigerant flow rates are set to specified values by adjusting the respective flow control valves while watching the flow meters. Then the absorption experiment is started. The absorbent solution behavior is observed while temperatures and flow rates were being monitored. When the absorber operation is stabilized, the temperature, concentration and flow rate data obtained at each specified point are processed by a data logger and a personal computer and stored on floppy disk.

3. Calculation Method

An absorption model was established to evaluate heat transfer in an absorption process. The heat added to cooling water in the absorber can be written as

$$Q_{co} = G_{co} c_p (T_{c,co} - T_{c,ci}) \tag{1}$$

The heat of absorption solution given by the difference between inlet and outlet at the absorber can be expressed as

$$Q_s = G_{si} h_{si} - G_{so} h_{so} \tag{2}$$

Here, solution enthalpy of inlet and outlet hsi, hso can respectively be defined as follows

$$h_{si} = h(T_{si}, \xi_{si}) \quad (3)$$

$$h_{so} = h(T_{so}, \xi_{so}) \quad (4)$$

Refrigeration capacity Q_r of this apparatus can be written as

$$Q_r = Q_{co} - Q_s \quad (5)$$

The overall heat transfer coefficient K can be written as

$$K = \frac{Q_{co}}{\Delta T_{lm} \cdot a} \quad (6)$$

where the heat transfer area a and LMTD ΔT_{lm} is respectively defined by equation (7) and (8)

$$a = \pi d_0 L \quad (7)$$

$$\Delta T_{lm} = \frac{\{(T_{Asi} - T_{Acoo}) - (T_{Aso} - T_{Acoi})\}}{\ln\{(T_{Asi} - T_{Acoo})/(T_{Aso} - T_{Acoi})\}} \quad (8)$$

The film Reynolds number and the mass flow rate to solution flow rate per unit length is respectively determined as

$$\mathrm{Re}_f = \frac{4\Gamma_s}{\mu_{si}} \quad (9)$$

$$\Gamma_s = \frac{G_{si}}{2L} \quad (10)$$

4. Experimental results and discussion

4.1 Characteristics by surfactant concentration

To measure the characteristics namely heat flux, overall heat transfer coefficient and refrigeration capacity with respect to surfactant concentration, experiment was conducted under the the experimental conditions given in table 1. The absorption heat flux with a variable surfactant concentration is showed in Fig. 3. It is evident from this figure that as surfactant concentration increases, absorption heat flux increases as well. It can further be claimed that the heat flux is increasing nearly monotonically up to concentration level 3000 ppm but the increase is rather slow for even higher

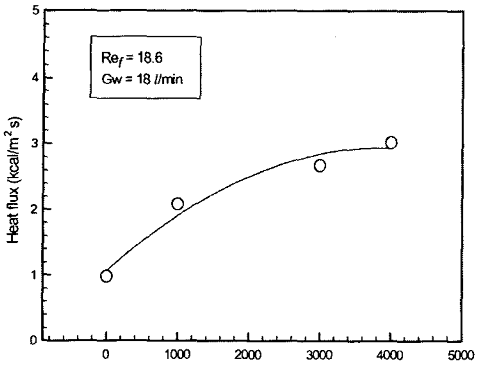


Fig. 3 Absorption heat flux by surfactant concentration

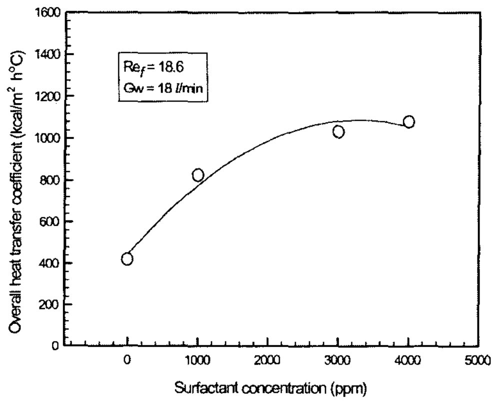


Fig. 4 Overall heat transfer coefficient by surfactant concentration

concentration level than 3000 ppm. Overall heat transfer coefficient of plate absorber, K by the surfactant concentration is given in Fig. 4. From this figure, we can claim that overall heat transfer coefficient increases as surfactant concentration increases until 3000 ppm. The value of K at 3000 ppm is 1032 kcal/m^{2}h^{0}C. For any further increase in the concentration level of surfactant, the rate of increase of the overall heat transfer coefficient is low. Refrigeration capacity of plate absorber, Qr by surfactant concentration is given next in Fig. 5. This figure indicates that Refrigeration capacity increases with increasing surfactant concentration until 3000 ppm and has a slower increasing trend for any higher concentration of surfactant. The refrigeration capacity found at 3000 ppm is 3878 kcal/h.

4.2 Comparisons by solution flow rate

Comparative results with and without surfactant for the heat flux, overall heat

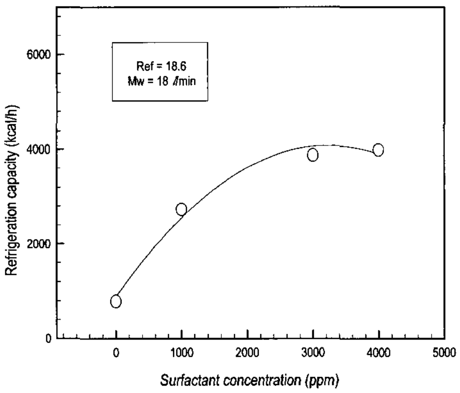


Fig. 5 Refrigeration capacity by surfactant concentration

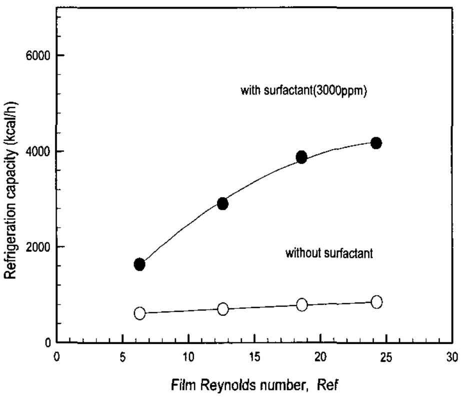


Fig. 6 Refrigeration capacity by solution flow rate

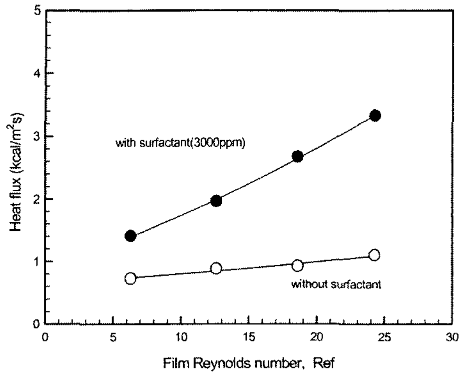


Fig. 7 Heat flux of plate observer by solution flow rate

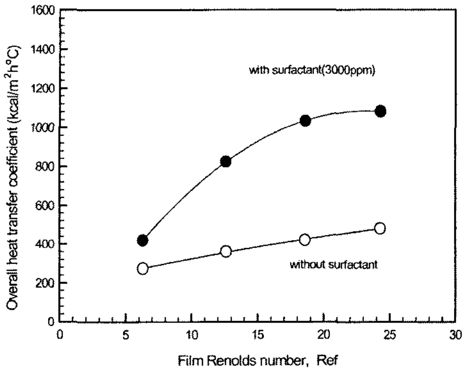


Fig. 8 Overall heat transfer coefficient of plate observer by solution flow rate

transfer coefficient and refrigeration capacity with a variable solution flow rate have been included next under the same experimental conditions defined in table 1. Refrigeration capacity of plate absorber Q_r by solution flow rate is given in Fig. 6. Refrigeration capacity increases steadily with increasing solution flow rate when surfactant was used. The capacity found at 18 ℓ/min is 3878 kcal/h. But the increase of refrigeration capacity without surfactant is very low indeed.

The comparative picture of heat flux of plate absorber by solution flow rate is given in Fig. 7. With surfactant, we can probably say from this figure that heat flux is almost directly proportional to the film Reynolds number. But the increase of heat flux without surfactant is rather slow. At a flow rate of 18 ℓ/min, the heat flux is 2.67, which is more than two times the figure found without surfactant. Overall heat transfer coefficient of plate absorber by solution flow rate is given in Fig. 8. Heat transfer coefficient with surfactant increases steadily up to *Ref* = 18 and the value of K there is 1032 kcal/m^{2}h℃ which is more than two times the corresponding figure without surfactant as well. The change in overall heat transfer coefficient while flow rate exceeds 18 ℓ/min is not remarkable.

5. Conclusion

Following conclusions can be drawn based on results of batch type absorption experiment of plate absorber using standard design capacity of 1RT.

- The heat flux, Overall heat transfer coefficient and the Refrigeration capacity of the plate absorber increased nearly monotonically while the surfactant concentration was increasing up to 3000 ppm but the increasing rate of the heat flux was rather slow in case of even higher concentration level than 3000 ppm. The value of overall heat transfer coefficient was 1032 kcal/m^{2}h℃ and that of the Refrigeration capacity was 3878 kcal/h both at surfactant concentration of 3000 ppm. Any further increase in the concentration level of surfactant slowed down the rate of the overall heat transfer coefficient and the refrigeration capacity.
- Refrigeration capacity, heat flux and overall heat transfer coefficient of plate absorber increased steadily with increasing solution flow rate when surfactant was used. The refrigeration capacity found at 18 ℓ/min is 3878 kcal/h. But the increase of refrigeration capacity without surfactant was very slow (620-858 kcal/h). The numerical figure of heat flux is 2.67 kcal/m^{2}s, which is more than two times the corresponding figure without surfactant. Overall heat transfer coefficient at the design condition was also found to be more than two times the corresponding value of K without surfactant. The variation in overall heat transfer coefficient with flow rate exceeding 18 l/min is not remarkable.
- Refrigerating capacity, heat transfer rate and heat flux increased significantly after adding the surfactant. But in the case of adding the surfactant over the

concentration of 3,000ppm, the increasing rates for all quantities were very low. The refrigerating capacity was lower without surfactant but with surfactant, RT was even more than our expectation.

Acknowledgement

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References

[1] Naoyuki Inoue, *"Practical Studies on Absorbers in Japan"*, Refrigeration Engineering Division EBARA Corporation, pp,119, 1988.

[2] J. I. Yoon and T. Kashiwagi, *"Characteristics of heat and mass transfer for a falling film type absorber with insert spring tubes"*, Transaction of the KSME, Vol. 19, No .6, pp. 1501-1509, 1995.

[3] I. Morioka and M. Kiyota, *"Absorption of water vapor into a lithium bromide water solution film falling along a vertical plate"*, Transaction of the Japan Society of Mechanical Engineering, Vol.53, No. 485, pp. 236-240, 1987.

[4] T. Kashiwagi, Y. Kurosaki and I. Nikai, *"Heat and mass diffusions in the absorption of water vapor by aqueous solution lithium bromide"*, Transaction of the JAR, Vol. 1, No.1, pp.89-98, 1984.

[5] J. I. Yoon, H. K. Oh and T. Kashiwagi, *"Characteristic simulation of the waste-heat utilization absorption cycles"*, Trans. of the JAR, Vol. 12, No. 1, pp. 43-52, 1995.

[6] Keith E. H., Reinhard R., Sandford A.K., Absorption Chillers and Heat pumps , CRC Press, Inc.

[7] Ralph L. W., Principles of Enhanced Heat Transfer , John Wiley & Sons, Inc.

[8] M. M. A. Sarker, J. I. Yoon et al., Heat transfer performance of Plate absorber with surfactant, Proceedings of the Int. Symposium on Combustion Engine and Marine Engineering, pp. 365-371, 2003.