Investigation of Simultaneous Heat and Mass Transfer Characteristics of Air Cooled Absorber Chillers

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Abstract

In pure heat transfer, specifications of effectiveness, fluid properties, and flows enable calculation of the heat exchanger area. In case of absorption, a simultaneous heat and mass transfer governs the performance of the absorber. The exchange of mass across the liquid-vapour interface involves the generation of heat. The heat effects associated with the mass exchange increase the temperature, which affects the equilibrium state of the pressure and composition and in turn affects the mass. The combined interaction of all these factors makes the absorption process very difficult to analyse and predict. A study of simultaneous heat and mass transfer was therefore conducted on air-cooled vertical falling film absorber to better understand the mechanisms driving the heat and mass transfer processes. Absorption experiments were conducted on air-cooled absorber with thermal duty of 8 kW at various solution concentrations, at various absorber pressures, and with various concentrations of LiBr-water solution. Hence, this study presents the experimental data on the heat and mass transfer process in the absence of heat and mass transfer additive.

Keywords

Absorption, air-cooled absorber, LiBr-water, simultaneous heat and mass transfer

I. Introduction

Absorption refrigeration cycle has been increasingly considered as one of the most prospective alternatives for electricity-powered compression refrigeration cycle. In the past few years, rapid expansion in the use of electricity-powered air conditioning in big cities has been a strong reason for the occurrence of electricity demand peaks in the summer and winter seasons. In order to relieve inconsistency between electric supply and demand, heat driven absorption refrigeration is pretty promising. Absorption refrigeration systems can be driven either by low-grade heat such as solar energy, geothermal energy, waste heat, and so on, or by high-grade heat such as those driven by natural gas, oil, steam, and so forth. In addition, CFC, HCFC and HFC refrigerants widely used in vapour compression refrigerators and heat pumps are gradually phased out, because these working substances not only contribute to stratospheric ozone depletion, but also cause global warming. Virtually all absorption chillers use lithium bromide and water as the absorption fluids. Research has shown LiBr to be one of the best absorption working fluids because it has a high affinity for water, releases water vapour at relatively low temperatures, and has a boiling point much higher than that of water. The heart of the chiller is the absorber, where a process of simultaneous heat and mass transfer occurs as the refrigerant water vapour is absorbed into the falling film of aqueous LiBr. The more water vapour absorbed into the falling film, the larger the chillers capacity for supporting comfort cooling. It is popular fact that water cooled absorption heat pumps supply cooling and heating for large buildings, but it is advisable to develop air-cooled absorption systems for small buildings such as villas. As compared to the water-cooled absorption systems, air-cooled absorption systems, dispense with the cooling tower, cooling water pump, cooling water piping, etc. It has great advantages such as low construction, installation, no special machine rooms, increased ease of handling and enhanced level of reliability [1]. On the other hands, the advantages in human health and application in areas lack of water source are remarkable. However, in order to get the driving force for heat transfer between air and water/solution, the absorber and condenser temperature for the air-cooled system is generally increased from 50 to 55 °C, about 10 °C higher than that of the water-cooled system. Therefore, the solution concentration is 5-8% higher and the temperature of the high pressure generator is about 50 °C higher than that for the water-cooled system [2]. So it causes boost of temperature, concentration and pressure in the generators, increase in the risk of crystallization and acceleration of corrosion. Some theoretical or experimental studies are devoted to the invention of new cycle modes, selection of new working fluids and enhancement of heat and mass transfer process in the absorber so as to solve the above mentioned problems. GRI analysed and tested such an absorber, and found it to enhance mass-transfer rates significantly, with the potential to improve overall absorber performance. This work was documented in 1995, and found no evidence of further work applying this approach to air cooled LiBr chillers [3-4]. Kurosawa and Fujimaki conducted experiments to improve heat and mass transfer characteristics in an air-cooled absorber with an ideal counter flow heat exchanger. The absorber outlet temperature was obtained lower than that of the cooling air at the outlet. However, an air-cooled absorber with four spray pumps and its configuration was more complicated. Lee et al. evaluated performance of H_2O+LiBr+LiI+$LinO_3$+LiCl solution as a new working fluid for an air-cooled absorption chiller [5]. Lower crystallization temperature was found at the same conditions compared with that of LiBr-water solution. Kim et al. developed three different working fluids LiBr + H_2N (CH_2) OH + H_2O, LiBr+ HO $(CH_2)_3OH$ + H_2O, LiBr + $(HOCH_2CH_2)_2NH$ + H_2O for air-cooled absorption cycles. Three solutions were found to be operated safely at high absorber and condenser temperature. However, several additional considerations about the necessity of the rectifier, high viscosity, corrosion and heat and mass transfer characteristics were not considered. In case of vertical falling-film absorber, the strong solution is distributed along the inner walls of vertical tubes that carry the water vapour from the evaporator. The Yazaki introduced the concept of vertical falling film absorption using new solution chemistry with 8 refrigeration ton unit. Yazaki found that it was necessary to use internally enhanced tubes to wet the inner tube walls completely and to enhance mass transfer. GRI/Battelle reported good results with vertical falling-film absorbers when tested in sub-scale sections. However, full-scale components yielded reduced performance [6]. Kiyota, et al, at Tokushima University, through analysis and experimental work, concluded that air cooling of a vertical falling-film absorber will require about three times the heat-transfer surface compared to water cooling of the same absorber design.

In this work the enhancement of heat and mass transfer approach was chosen i.e. vertical falling film absorber. The vertical tube is better suited for the both experimental and analytical studies of the coupled heat and mass transfer processes occurring within the absorber. The experimental set-up is developed for absorber duty of 8kW and experimentation was performed to investigate the effects of solution concentration, solution flow and absorber pressure on the absorption performance to study the simultaneous heat and mass transfer characteristics fallowing the text of this paper.

II. Experimental Set-Up

The air cooled absorber for thermal duty of 8kW using lithium-bromide/water solution consists of a vertical tube bundle of 31 tubes having 16mm outer diameter and length 1000mm, having 12 fins per inch. Concentrated absorbent solution (≈62 %) from the high temperature generator through the solution heat exchanger and is fed to distribution nozzles. This solution falls in each of the absorber tubes. Concentrated absorbent has an affinity to water. Hence the vaporized refrigerant from the high temperature generator is absorbed. Due to this absorption the vacuum in the absorber is maintained at a low pressure. The Concentrated absorbent becomes diluted. During this dilution the heat of dilution is generated. This increases the temperature of the absorbent solution. This high temperature absorbent solution heats the air being forced on the absorber tubes. As it loses its heat to the air it is able to absorb more refrigerant vapour and gets further diluted (≈58 %). The variables considered for the parametric study of the absorber performance were the cooling air temperature, the absorber pressure, the solution flow rate and the inlet solution concentration.

III. Theoretical Aspects

The parameters selected to asses the absorber performance were: concentration of the solution, the absorber thermal load, overall heat transfer coefficient.

Assuming the steady state, the mass and concentration balances for the test section are described by the following equations:

$$G_{conc} + G_{ref} = G_{dil} \quad (1)$$

$$G_{ref} \cdot C_{ref} + G_{conc} \cdot C_{conc} = G_{dil} \cdot C_{dil} \quad (2)$$

Assuming no heat losses at the test section, the heat balance equation is expressed as,

$$Q_{tot} = G_{ref} \cdot h_{ref} + G_{conc} \cdot h_{conc} - G_{dil} \cdot h_{dil} \quad (3)$$

The total heat transfer rate is calculated from the mass flow rate and the temperature difference of the coolant:

$$Q_{cw} = G_{cw}\ C_p\ (T_{cw2} - T_{cw1}) \quad (4)$$

The overall heat transfer coefficient is defined by the following equation:

$$Q_{abs} = H\ (A_o\ LMTD) \quad (5)$$

The overall mass transfer coefficient can be given as:

$$M = H_m A_o (C_{EX} - C_{EQ}) \quad (6)$$

The concentration of the solution at the absorber inlet x_{conc} and outlet x_{dil} should be measured by equilibrium chart for aqueous lithium bromide solutions.

IV. Experimental Absorption Test Results

In this work, to start the testing the independent parameters of flow, concentration and pressure is established. Flow rate was the easiest variable to change, and therefore the effects of other variable were tested for concentrated mass flows ranging from 106 to 127 kg/h (Re numbers of 150-400). The load is defined as the heat removed from the absorber by the coolant; it is plotted in fig.1. The increase in a load is directly related to the mass of vapour absorbed into the falling film; it is plotted in fig. 2. The more vapour absorbed, the greater the capacity of a chillers evaporator. Absorber load then is a good indicator of system performance, although the mass absorbed is the important variable. The data are separated and plotted in fig. 3a and fig. 3b to better indicate the effects of absorber pressure and concentration. Pressure and concentration both have the strong effects on the mass absorbed. Testing at 62 wt% LiBr showed the mass absorbed to increase as the pressure was increased from 15 to 17 mm Hg. Similar increases in mass absorbed were observed when the concentration was increased from 60 to 62 wt% LiBr fig. (3b). The driving force for mass transfer through the vapour-liquid interface can be expressed as the difference between the partial pressure of water vapour in the vapour phase and the vapour pressure of water-salt solution at a given temperature and concentration. Obviously, the driving force increases with an increase in the absorber pressure. The driving force would also increase as the concentration of LiBr increases. The higher the LiBr concentration, the lower the partial pressure and therefore the greater the driving force for mass transfer in turn increasing the mass absorbed and the load. Hence, the plots shown in following fig.s are consistent with absorption theory. However, once the vapour has been absorbed, the driving force is liquid-side-controlled because of the high resistance to mass diffusion. After absorption, the mass transfer driving force is defined in terms of the difference in concentration between the interface and the bulk of film. The higher the bulk concentration of LiBr, the larger this liquid-side driving force and the more mass absorbed into the bulk. Fig. (4) shows how the thermal load increases with the absorber pressure. For testing at 60 wt% concentration, a decrease in a coolant temperature caused the increase in a mass absorbed to nearly double fig. (5a). The absorber thermal load shows a similar trend as it can be observed in fig. (5b)

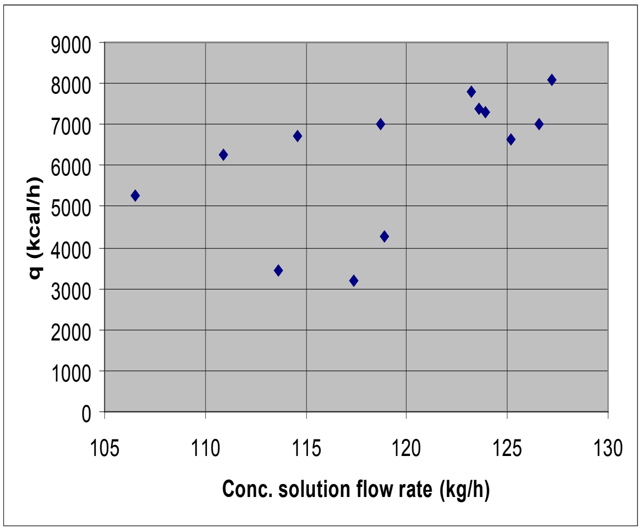

Fig.1 : Absorber Load Vs Falling Film Mass Flow Rate

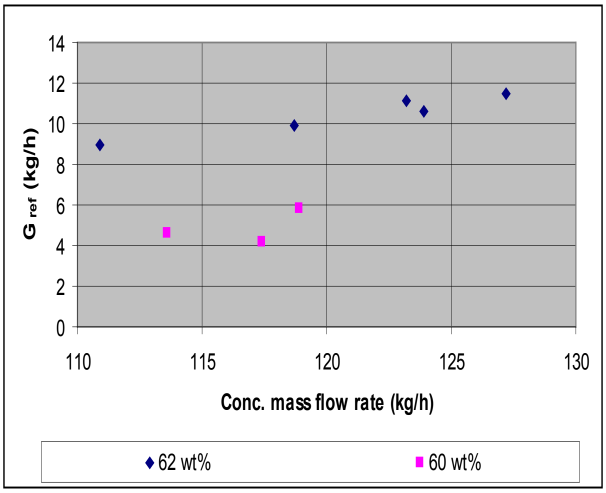

Fig. 2 : Mass absorbed as a function of concentration and falling film mass flow rate

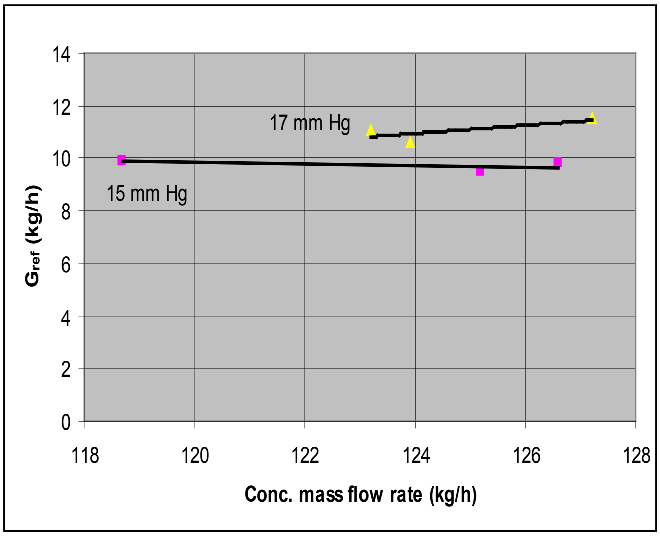

Fig. 3a : The Effect of Absorber Pressure for 62 wt% LiBr

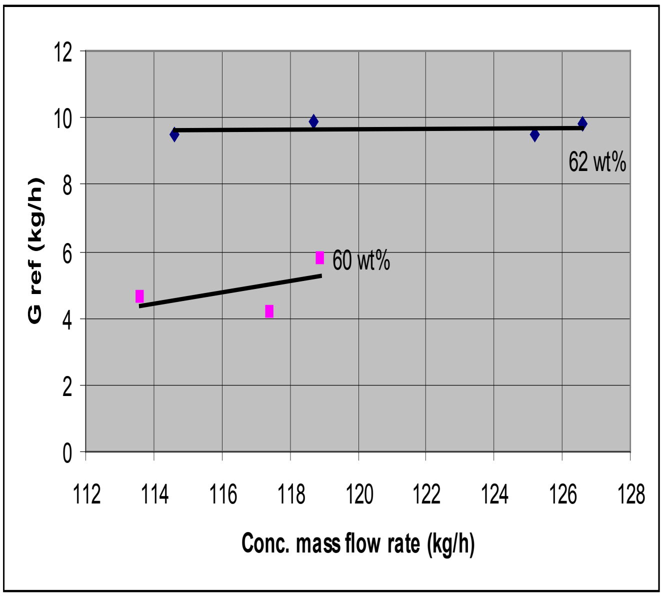

Fig. 3b : The effect of concentration for 17 mm of Hg

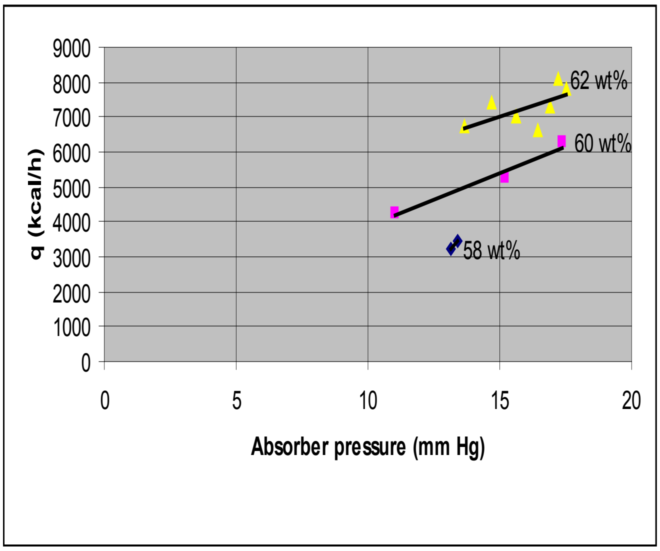

Fig. 4 : Effect of concentration and pressure on absorber thermal load

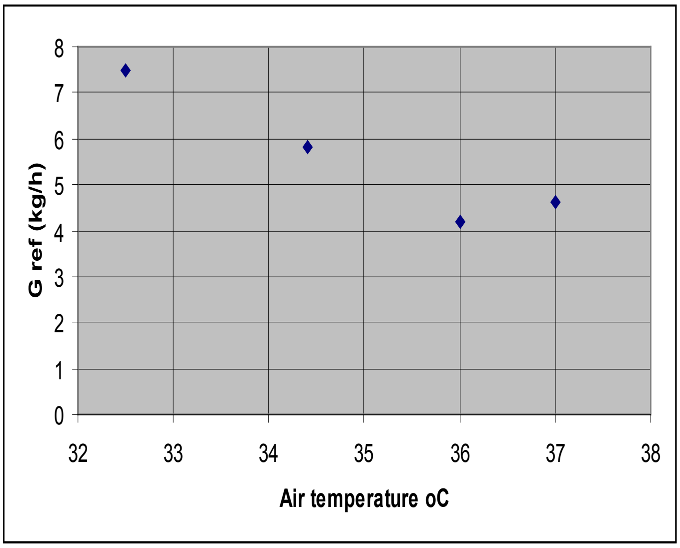

Fig. 5a: Effect of Air Temperature on Mass Absorption

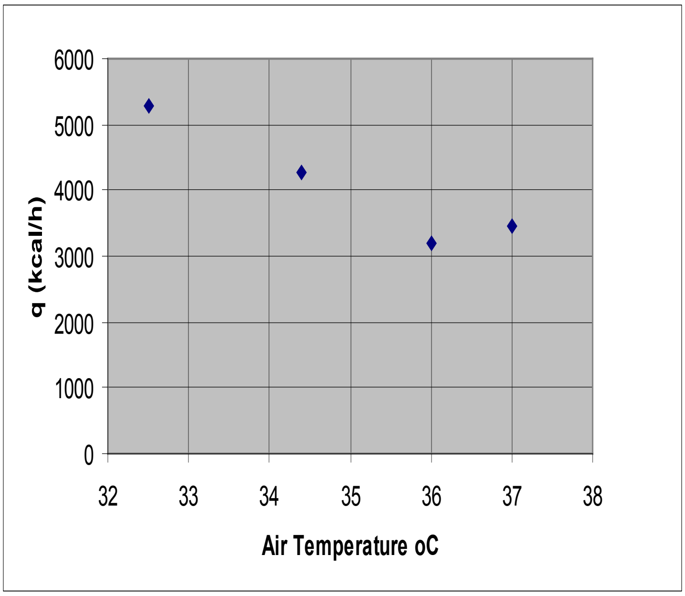

Fig. 5b: Effect of air temperature on absorber thermal load

V. Conclusion

Experimental data for falling film absorption are sparse. The dearth of experimental data strongly suggested the need for a combined experimental and analytical approach to the absorption phenomena. The data must be free of confounding issue of non-condensable and must provide information in the operating ranges of present day equipment.

The experimental set-up is developed and experiments are conducted on vertical tube bundle having 16mm outside diameter and 1000mm in length to investigate simultaneous heat and mass transfer characteristics. Simultaneous heat and mass transfer has strong pressure, concentration, and temperature effects. The total heat transfer rate increases with the solution flow rate and solution temperature. The intensified mixing and wetting seem to improve the heat and mass transfer. Hence, this study investigates complex heat and mass transfer process and contains useful information for guiding the development of an air-cooled vertical column absorber.

VI. Nomenclature

Symbol	Descriptive	SI Unit
A	Area	m^2
C	Concentration of Absorbate	% wt
C	Specific heat	kJ/kg-K
G	Mass flow rate	kg/h
Hm	Overall mass Transfer coefficient	m/s
H	Overall heat transfer coefficient	J/m^{2}Ks
Q	Heat transfer rate	J/s

Subscripts

cw	Coolant
EQ	Equilibrium
EX	Exit
1	Inlet
2	Outlet
conc	Concentrated
dil	Diluted
ref	Refrigerant vapour

VII. Acknowledgement

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