International Journal of Heat and Mass Transfer 100 (2016) 433–444

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ijhmt

Nu and Sh correlations for LiCl solution and moist air in plate type dehumidifier

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ARTICLE INFO

Article history:
Received 19 January 2016
Received in revised form 24 April 2016
Accepted 26 April 2016
Available online 11 May 2016

Keywords:
Dehumidification effectiveness
Lithium chloride
Liquid desiccant
Plate type dehumidifier

ABSTRACT

To cope with environmental pollution caused by rapid industrial development, international regulations such as the Montreal Protocol and the United Nations Framework Convention on Climate Change are becoming materialized day by day. As a result, interest in energy saving devices is increasing and studies are being concentrated on highly efficient refrigeration air conditioning systems. In this study, a desiccant cooling technology using a liquid desiccant of LiCl solution was researched. The plate was treated with hydrophilic coating and the wettability was improved by giving a groove shape. Consequently, a thin liquid film was maintained even with a small amount of desiccant solution, thereby increasing the stability of the liquid film and solving the scattering problem of the desiccant solution. In this study, it is found that the absorption rate increases with the increases of the liquid desiccant and air velocity and the air velocity has more significant effect on the absorption rate than the liquid desiccant solution flow. It is found that the absorption rate becomes higher with increasing the higher relative humidity and the concentration of liquid desiccant. The dehumidification effectiveness decreases greatly as the air velocity increases. Furthermore, it is concluded that the air velocity has the greatest effect on the improvement of the absorption rate and heat and mass transfer. In this experiment, Sh and Nu correlations of the air side and desiccant solution side with an error of ±25% were developed, respectively, and the absorption rate, dehumidification effectiveness and the experimental correlations were compared with other studies.

1. Introduction

The conventional vapor compressor cooling systems cause environmental pollution such as ozone layer destruction and global depletion due to the use of HCFC- and CFC-based refrigerants, and unbalanced power supply during summer due to excessive power consumption. Furthermore, owing to the depletion of energy sources, policies for diversification of energy sources, development of alternate energy sources, and promotion of more efficient use of energy are being presented [1,2]. To cope with environmental pollution caused by rapid industrial development, international regulations such as the Montreal Protocol and the United Nations Framework Convention on Climate Change are becoming materialized day by day and South Korea is also obligated by these international environmental regulations [3,4]. As a result, interest in energy saving devices is increasing and studies are being concentrated on highly efficient refrigeration air conditioning systems [5,6]. Moreover, as the subtropical area with very humid and hot summer becomes wider, the need for desiccant cooling is being emphasized at homes as well as in industries.

There are basically four types of dehumidification; cooling type dehumidification by cooling, dehumidification by compression, dehumidification by adsorption and dehumidification by absorption. Each of these four methods has distinct characteristics, and advantages and disadvantages depending on their application fields. Among them, the dehumidification by cooling is most widely used in air conditioning systems. This method is convenient in the case of cooling, but is uneconomical because it requires reheating when the solution temperature drops. Furthermore, if the dew point temperature is low, the condensate is frozen and blocks the air flow. The dehumidification by compression has large power requirement and is uneconomical if the purpose is only dehumidification. The dehumidification by adsorption which uses a solid adsorbent has lower thermal effectiveness compared to the dehumidification by absorption which uses liquid, but it can dehumidify the moist air until a very low dew point temperature. Thus, it is mainly used in the processes that require ultra-dry air. Lastly, the dehumidification by absorption uses liquid which contacts with air. If designed according to the requirements, it can

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http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.04.100
0017-9310/

Nomenclature

A	area, m^2
b	bias error, %
c_P	specific heat at constant pressure, kJ/kg K
d	diameter, m
D	diffusivity, m^2/s
h	heat transfer coefficient, kW/m^2 K
h_m	mass transfer coefficient, m/s
i	enthalpy, kJ/kg
k	thermal conductivity, kW/m K
Le	Lewis number
$\dot{m}$	mass flow rate, kg/s
N	finite value
Nu	Nusselt number
p	precision error, %
$\dot{Q}$	heat transfer rate, kW
Re	Reynolds number
Sc	Schmidt number
Sh	Sherwood number
T	temperature, °C
t	thickness of the plate, m
U	overall heat transfer coefficient, kW/m^2 K
u	experimental uncertainty
X	measurement value
$\bar{X}$	measurement mean value
x	concentration, %
ρ	density, kg/m^3
λ	absorption heat for solution, kJ/kg
μ	viscosity coefficient, kg/m-s

Subscripts

a	air
abs	absorption
c	coolant
da	dry air
i	inlet
int	interface
o	outlet, outside
s	lithium chloride solution

simultaneously satisfy the required temperature and humidity conditions. However, this method is generally used when a low dew point is required because the desiccant must be regenerated and restored. If a liquid desiccant is used, it is easy to increase the contact area with air and is appropriate for a large-sized dehumidifier. The required conditions for liquid desiccant are no corrosiveness, low equilibrium vapor pressure, low viscosity, and chemical stability.

The liquid desiccant cooling technology is an open absorption-type cycle that can simultaneously process both the latent and sensible heat of air using a liquid desiccant solution, and has the advantage of being able to use low-temperature heat sources such as district heating feed water, industrial waste heat, and solar energy which are under 80 °C. The liquid desiccant cooling technology has excellent stability because the entire process is carried out in the atmospheric pressure and excellent heat and mass transfer capacity because the liquid desiccant solution directly contacts with air. Furthermore, it can remove air pollution with the sterilization effect of the liquid desiccant. However, the commercialization of liquid desiccant cooling technology is being delayed due to a few problems. It becomes more difficult to dehumidify to a low humidity as the ambient air increases, and the liquid desiccant solution may be polluted by foreign matters in air because it directly contacts with air. In addition, if the corrosive desiccant is lost or flows into the system due to scattering, it can lead to serious problems. As a large contact area between air and desiccant is required for efficient dehumidification of air, the conventional dehumidifiers and regenerators mainly use a packed bed and a tube bundle. However, this type of dehumidification system supplies an excessive amount of desiccant solution to increase the surface wettability. As the liquid desiccant has a thick liquid film, it has lower heat and mass transfer performance, and the liquid desiccant is scattered by the flowing air due to the unstable surface of liquid film.

In this study, to solve the problems of the existing dehumidifiers, a liquid dehumidification system that uses a plate-type dehumidifying heat exchanger with grooves on the surface was fabricated. This grooved plate-type dehumidifying heat exchanger has excellent wettability and can maintain a thin liquid film even if a small amount of liquid desiccant. Therefore, due to the improved stability of liquid film, the scattering problem of the liquid desiccant can be solved and the heat and mass transfer capacity is enhanced. The final objectives of this study are to develop experimental Nusselt and Sherwood number correlations of liquid desiccant solution and moist air, and to compare the experimental results with the numerical results. The experimental correlations can be used for the practical design of plate type dehumidifier with LiCl solution.

2. Experiment system

2.1. Structure of plate-type dehumidifying heat exchanger

Fig. 1 shows the shape of the plate-type dehumidifying heat exchanger used in this study. This heat exchanger was fabricated using the heat-resistant ABS (XR-474), considering the temperature and corrosiveness of the regenerated heat source during the regeneration process, and is composed of top header, bottom header, and flat tube. This plate-type dehumidifying heat exchanger has the size of 5 mm in depth, 200 mm in length, and 600 mm in height. The top header was designed to evenly distribute the liquid desiccant solution (LiCl solution) on the vertical plate, and the bottom header was designed to collect the liquid desiccant after the dehumidification process and to send it to the regeneration tank. The geometric details of the plate type dehumidifier are summarized in Table 1. The plate surface has grooves which allow the liquid desiccant flow while maintaining a thin liquid film, and hydrophilic coating treatment for improvement of the wettability of the lithium chloride solution. The acrylic epoxy resin, thinner and alumina oxide powders (average diameter of 50 μm) are mixed together with the weight ratio of 1:0.5:0.35 and embrocated on the surface of the grooved plate. The grooved plate with the surface treatment is dried within an oven at 90 °C for 90 min. After then, sulfonic resin solution with colloid silica and water is mixed together with the weight ratio of 1:1 and embrocated again on the surface of the grooved surface. The grooved plate with the second surface treatment is dried again within the oven at 90 °C for 90 min. Fig. 2 shows the SEM image of the multi-porous hydrophilic surface treatment on the plane plate.