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Alternate heat and mass transfer absorption performances on staggered tube bundle with M–W corrugated mesh guider inserts

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ABSTRACT

A new alternate absorption scheme of both horizontal tubular cooling absorption and mesh layer adiabatic absorption was investigated with longitudinal corrugated M–W mesh guiders inserted to the gaps of the staggered horizontal tube bundle, leading solution film flows from the lower edge of each tube to the upper edges of its lower position neighbouring tubes at both sides. The mirror symmetric M–W mesh guiders facilitate uniform distribution and dual-side exposing solution film to the vapour for adiabatic mass transfer. The VOF CFD models were established for vapour absorption with aqueous LiBr solution falling film on the alternate absorber and bare tube one. The distributions of liquid film, temperature and concentration of the solution and local heat transfer coefficient on the tube surfaces were demonstrated for both absorbers. The simulation results demonstrated that the average heat and mass transfer coefficients with the alternating absorber are respectively 33.4% and 55.4% higher than those of the bare tube one.

Performances d'absorption par transfert alterné de chaleur et de masse sur un faisceau de tubes en quinconce avec des inserts guides à mailles ondulées M-W

Mots clés : Absorbeur à LiBr aqueux ; Absorption de film tombant ; Transfert alterné de chaleur et de masse ; Guides à mailles M-W

1. Introduction

Using solar energy resources for air conditioning refrigeration in summer is a promising way to meet the energy and environment sustainable development requests (Chua et al., 2003; Sumathy et al., 2002; Xu et al., 2011). For solar energy air conditioning refrigeration, the LiBr absorption chiller is one of the applicable choices. The absorber is the largest heat exchanger in a LiBr absorption chiller. It is mainly of tube-and-shell heat exchanger, in which liquid film is distributed and falling down on the outside of horizontal tubes. The falling film on discrete tube bank is liable to uneven distribution, and the driving force of absorption will get weak due to the saturation

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Nomenclature

A	area [m^2]
C	molar concentration [mole mole^{-1}]
c_p	specific heat content [kJ kg^{-1} K^{-1}]
D	mass diffuse coefficient [m^2 s^{-1}]
F	force [N]
f	friction coefficient
h	heat transfer coefficient [W m^{-2} K^{-1}]
i	enthalpy [kJ kg^{-1}]
J	mass flux [kg m^{-2} s^{-1}]
k	mass transfer coefficient [m s^{-1}]
k_r	interface curvature
m	interface equilibrium constant
M	mass flow rate [kg s^{-1}]
n	free surface normal vector
$\hat{n}$	unit free surface normal vector
p	pressure [Pa]
S	source term
T	temperature [K or °C]
t	time [s]
U	overall heat and mass transfer coefficient [W m^{-2} K^{-1}]
u	velocity, component velocity in x direction [m s^{-1}]
v	velocity, component velocity in y direction [m s^{-1}]
x	flow direction
x_A	component A partial molar concentration in liquid phase
y	normal to the flow direction
y_A	component A partial molar concentration in vapour phase

Greek letters

Γ	solution flow rate of unit length [kg m^{-1} s^{-1}]
γ	volume fractions
δ	thickness of film [m or mm]
λ	conductivity [W m^{-1} K^{-1}]
μ	dynamic viscosity [kg m^{-1} s^{-1}]
μ_A	molar substance quantity of component A [kg kmole^{-1}]
ξ	concentration [kg kg^{-1}]
ρ	density [kg m^{-3}]

Subscripts

0	initial
A	component A [LiBr]
ab	absorption
c	concentrated solution
d	dilute solution
i	entry, tube side
l	liquid
m	mixture
o	outlet, exit
s	saturation
T	thermal
v	vapour
vl	vapour-liquid interface
w	wall

of the vapour–liquid free surface layer of the film and poor diffusion property of liquid LiBr solution. Thus, the heat and mass transfer coefficients of absorption process are usually low, which have direct impact on the performance of the entire LiBr absorption chiller. The high first-cost expense which relates to the heat transfer area of heat exchangers is one of the main obstructive factors for the popularization of LiBr absorption solar air conditioning beside crystallization and corrosion.

The extensive attentions have been drawn, and a lot of approaches have been developed by experts on heat and mass transfer enhancement of LiBr solution absorption process. These approaches include modifying the absorber structure (Cheng et al., 2003; Fujita, 1993; Genssle and Stephan, 2000; Grogori et al., 2005; Han et al., 2009; Hao et al., 2014; Isshiki and Ogawa, 1996; Kim and Ferreira, 2009; Reay, 2002), adding surfactant additives to the LiBr solution (Miller, 1999; Nakoryakov et al., 2008; Park et al., 2001; Sun et al., 2011), and optimizing the working process (Gu et al., 2005; Hu and Jacobi, 1996a, 1996b; Jeong and Garimella, 2002; Kirby and Perez–Blanco, 1994; Kyung et al., 2007a, 2007b; Marc et al., 2012; Martínez et al., 2012; Papaefthimiou et al., 2012; Selim and Elsayed, 1999; Sumathy et al., 2002). Chen et al. (2004) developed a novel LiBr absorption chiller based on plate–shell heat exchangers with dual-scale corrugation plate bundle. N'Tsoukpoe et al. (2014) investigated a LiBr–H_2O absorption process for solar heat storage with crystallization of the solution. Brunazzi and Paglianti (1998) and Sieres et al. (2009) studied respectively the mesh packing for mist eliminators and mass transfer processes in ammonia–water absorption refrigerators. Szulczewska et al. (2003) numerically studied the two-phase countercurrent flow in the geometry of the plate-type structured packing. Killion and Garimella (2001, 2003) reviewed the models of coupled heat and mass transfer in falling-film absorption and on absorption of water vapour in liquid films falling over horizontal tubes respectively. Shen and Qiao (2005) and Wang et al. (2007) studied respectively the separate heat and mass transfer absorption that the rich solution is first precooled in a heat exchanger, and then it enters an adiabatic absorber with spray and/or mesh packing to absorb steam vapour for mass transfer. As the LiBr solution is easily crystallized at rich and/or cooled condition and also the equivalent absorption heat including the latent condensation heat of coolant vapour should be transmitted and carried out from the solution to the cooling water before the adiabatic absorption process by the sensible heat of solution, which usually exceeds the safety limit and crystallization is liable to occur at the outlet of the precooler before entering the absorber, the solution circulation flow rate needs to be increased to dilute the rich solution to the moderate solution with weakened mass transfer driving force. To this point, however, if the absorption process is divided into several stages of alternative cooling absorption and adiabatic absorption, the heat and mass transfer may greatly be enhanced and the crystallization could be avoided.

The previous research results (Fujita, 1993; Jeong and Garimella, 2002; Killion and Garimella, 2001) indicate that during the vapour absorption process, the temperature increases and the concentration decreases at very thin outer-layer of the liquid