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Flow patterns and heat and mass transfer coefficients of low Reynolds number falling film flows on vertical plates: Effects of a wire screen and an additive

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ABSTRACT

The effects of the surface geometry and of a surfactant on the characteristics of LiBr–water solution falling films are experimentally investigated. Two different surfaces (flat copper plate and the same copper plate covered with a copper wire screen) are tested with four fluids (pure water and 50% lithium bromide–water solution with or without 100 ppm of 2-ethyl-1-hexanol) for Reynolds numbers from 40 to 110. Flow patterns and heat and mass transfer coefficients are discussed. Marangoni convection was observed in water-cooled LiBr–water flows resulting in significant heat and mass transfer enhancement. 2-ethyl-1-hexanol enhances heat and mass transfer in LiBr–water flows by more than a factor of two. 2-ethyl-1-hexanol in water makes copper surface strongly hydrophobic. The wire screen promotes absorption process in adiabatic conditions but hinders the process in non-adiabatic conditions by reducing the Marangoni convection induced by 2-ethyl-1-hexanol. The experimental heat and mass transfer coefficients are presented in dimensionless forms.

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Configuration de l'écoulement et coefficients de transfert de chaleur et de masse d'un film à faible nombre de Reynolds tombant sur les plaques verticales : effets d'une grille métallique et d'un additif

Mots clés : Système à absorption ; Eau-bromure de lithium ; Transfert de chaleur ; Transfert de masse ; Film tombant ; Expérimentation ; Géométrie ; Surface ; Plaque verticale ; Additifs

Nomenclature

a–d	constants in Eqs. (20) and (21)
B	constant in Eq. (12)
C	constant in Eq. (12)
C_p	heat capacity, $kJ\,kg^{-1}\,K^{-1}$
c_{1-3}	constants in Eq. (8)
D	mass diffusivity, $m^2\,s^{-1}$
g	gravity constant, $m\,s^{-2}$
h	specific enthalpy, $kJ\,kg^{-1}$
h^{fg}	latent heat of a pure species, $kJ\,kg^{-1}$
$\bar{h}$	partial specific enthalpy, $kJ\,kg^{-1}$ of a species
k	thermal conductivity, $kW\,m^{-1}\,K^{-1}$
L	absorber length, m
Le	Lewis number, $(k/\rho C_p)/D$
Nu_f	film Nusselt number, $\alpha^b/k \times (\nu^2/g)^{1/3}$
$\dot{m}$	mass flow rate, $kg\,s^{-1}$
$\dot{n}$	mass flux, $kg\,m^{-2}\,s^{-1}$
p	pressure, kPa
$\dot{Q}$	heat transfer rate, kW
$\dot{q}$	heat flux, $kW\,m^{-2}$
Pr	Prandtl number, $\mu C_p/k$
Re_f	film Reynolds number, $4\,\Gamma_s/\mu$
Sc	Schmidt number, ν/D
Sh_f	film Sherwood number, $\beta/D \times (\nu^2/g)^{1/3}$
T	temperature of solution or vapour, K
t	temperature of cooling water, K
U	average overall heat transfer coefficient, $kW\,m^{-2}\,K^{-1}$
$\bar{U}$	dimensionless heat transfer coefficient, $UL/\Gamma_s C_{ps}$
$v_{1,2}$	eigenvector components
x	absorbent mass fraction in solution
z	distance in flow direction, m

Greek symbols

α	average heat transfer coefficient, $kW\,m^{-2}\,K^{-1}$
β	average mass transfer coefficient, $m\,s^{-1}$
$\bar{\beta}$	dimensionless mass transfer coefficient, $\rho\beta L/\Gamma_s$
Γ	mass flow rate per unit perimeter, $kg\,m^{-1}\,s^{-1}$
Δh	heat of absorption, $kJ\,kg^{-1}$
Δ_T	thermal boundary layer thickness at the interface, m
Δ_x	concentration boundary layer thickness at the interface, m
δ	film thickness, m
ζ	dimensionless distance in flow direction, z/L
$\lambda_{1,2}$	eigenvalues
μ	dynamic viscosity, Pa s
ν	kinematic viscosity, $m^2\,s^{-1}$
ρ	density, $kg\,m^{-3}$
ϕ	dimensionless mass flux, $\dot{n}/\rho\beta (= x^b - x^i)$
ω	dimensionless wall heat flux, $\dot{q}^w C_{p_s}/U\Delta h [= (T^b - t) C_{p_s}/\Delta h]$

Superscripts

b	bulk solution
i	vapour–liquid interface
l	liquid
s	saturated or equilibrium
v	vapour
w	wall
*	dew point

Subscripts

o	reference condition
avg	average
bot	absorber bottom
s	solution
top	absorber top
w	cooling water

1. Introduction

Use of plate-type falling film heat exchangers is an attractive idea for small-capacity absorption machines in view of the fact that it can be made more compact, lighter and cheaper than conventional shell and tube heat exchangers (Becker, 1989; Flamensbeck et al., 1998; Estiot et al., 2006). However plate-type falling film heat exchangers are much less investigated in the field of absorption refrigeration compared with their tubular counterparts. Experimental data are rare and often inconsistent especially in the small flow rate range where falling film heat exchangers are typically designed. A small number of experimental studies have