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Measurement of absorption rates in horizontal-tube falling-film ammonia-water absorbers

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ABSTRACT

Heat and mass transfer in a horizontal-tube falling-film ammonia-water absorber was investigated. A tube bank consisting of four columns of six 9.5 mm nominal OD, 0.292 m long tubes was installed in a shell that allowed heat and mass transfer measurements and optical access for flow visualization. This absorber was installed in a test facility consisting of all the components of a chiller, fabricated to obtain realistic operating conditions at the absorber to account for the influence of the other components in the system. Tests were conducted over desorber solution outlet concentrations of 5–40% for three nominal absorber pressures of 150, 345 and 500 kPa, for solution flow rates of 0.019–0.034 kg s^{-1}. Measurement and analysis techniques, heat transfer rates, and solution- and vapor-side heat and mass transfer coefficients are described. Trends in heat and mass transfer coefficients are discussed, highlighting the effects of solution flow rate and concentration, and absorber pressure.

Mesures des taux d'absorption des absorbeurs à ammoniac / eau aux tubes horizontaux à film tombant

Mots clés : Absorption ; Film tombant ; Transfert de chaleur ; Transfert de masse ; Ammoniac ; Eau

1. Introduction

The global climate change issue has focused renewed attention on the use of absorption heat pumps, which are environmentally sound and energy-efficient alternatives to CFC-based, ozone-depleting space-conditioning systems. The heat-driven absorption systems, particularly those employing the more advanced cycles such as the Generator-Absorber-Heat Exchange (GAX) cycle (Garimella et al., 1996; Engler et al., 1997) could offer higher source efficiencies than corresponding vapor compression systems in the heating mode, and when powered by waste heat, offer the potential to be part of an

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Nomenclature

A	Area (m^2)
Ar	Archimedes number
Cp	Specific heat ($kJ\ kg^{-1}\ K^{-1}$)
C_T	Total molar concentration ($kMol\ m^{-3}$)
d	Diameter (m)
D	Binary diffusion coefficient ($m^2\ s^{-1}$)
g	Acceleration due to gravity ($m^2\ s^{-1}$)
Ga	Galileo number
h	Specific enthalpy ($kJ\ kg^{-1}$)
k	Conductivity ($W\ m^{-1}\ K^{-1}$)
L	Length (m)
LMTD	Log Mean Temperature Difference
M	Molar mass ($kg\ kMol^{-1}$)
$\dot{m}$	Mass flow rate ($kg\ s^{-1}$)
N	Number
Nu	Nussel tnumber
$\dot{n}$	Molar flux ($kMol\ m^{-2}\ s^{-1}$)
P	Pressure (kPa)
Pe	Peclet number
Pr	Prandtl number
Q	Heat Duty (kW)
q	Quality
R	Thermal resistance ($K\ W^{-1}$)
Re	Reynolds number
R_R	Resistance ratio
R_W	Wall resistance
Sc	Schmidt number
Sh	Sherwood number
T	Temperature (°C)
U	Overall heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
x	Mass concentration
$\tilde{x}$	Molar concentration
z	Mass concentration of condensing flux
$\tilde{z}$	Molar concentration of condensing flux

Greek symbols

α	Heat transfer coefficient ($W\ m^{-2}\ K^{-1}$)
β	Mass transfer coefficient ($m\ s^{-1}$)
Δ	Difference
δ	Film thickness (m)
$\dot{\Gamma}$	Mass flow rate per unit length per side of tube ($kg\ m^{-1}\ s^{-1}$)
μ	Dynamic viscosity ($kg\ m^{-1}\ s^{-1}$)
ν	Kinematic viscosity ($m^2\ s^{-1}$)
ρ	Density ($kg\ m^{-3}$)
σ	Surface tension ($N\ m^{-1}$)

Subscripts

1, 2	Species 1 or 2
Abs	Absorber
C	Coolant
concentrated	Concentrated solution
cond	Condenser
coolant	Coolant fluid
dilute	Dilute solution
drip	Drip tray
drop	Droplet
fg	Phase change
ID	Inner diameter
in	Inlet
int	Interface
l	Liquid/solution
latent	Latent heat
OD	Outer diameter
out	Outlet
pool	Solution pool
R	Ratio
Ref	Refrigerant
sen	Sensible heat
sol	Solution
T	Total
t	Tube
v	Vapor

overall integrated energy system that provides building cooling, heating, and power. The absorber, in which refrigerant vapor is absorbed into the dilute solution with the release of a substantial amount of heat of absorption, governs the viability of the entire cycle and has been referred to as the “bottleneck” in the absorption heat pumps (Beutler et al. 1996). However, a lack of understanding of this inherently complicated process has led to the use of poor designs employing inappropriate and often grossly expensive and oversized heat and mass exchangers. The ammonia-water fluid pair (unlike the LiBr/H_2O fluid pair) has a volatile absorbent, thus presenting both heat and mass transfer resistances across the respective temperature and concentration gradients in both the liquid and vapor phases. The highly non-ideal ammonia-water fluid pair releases a considerable amount of heat of absorption at the vapor-liquid interface that must be transferred across a liquid film into the coolant. Some of this heat released at the interface is also transferred to the vapor, depending on the local temperature differences. Furthermore, at different regions in the overall absorption process, particularly over the wide concentration and temperature range of cycles such as the GAX cycle, the local concentrations in the bulk and interface liquid and vapor phases could be such that species are desorbed into the vapor phase, rather than being absorbed.

Absorption is a complex, coupled heat and mass transfer phenomenon governed by liquid and vapor phase saturation conditions, operating pressures and component geometry. The various driving potentials and local gradients inherent in these phases can be quite different at conditions close to saturation and those that involve subcooling of the incoming liquid solution. The inlet subcooling characteristic of the dilute solution entering an absorber that is part of an operational heat pump system introduces considerable confounding influences that make it challenging to isolate the contribution, to absorption, of the corresponding equilibrium conditions, and those due to the subcooling. Many studies in the literature have