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Microchannel component technology for system-wide application in ammonia/water absorption heat pumps

Srinivas Garimella[a,*], *Matthew D. Determan*[a], *J. Mark Meacham*[b], *Sangsoo Lee*[c], *Timothy C. Ernst*[d]

[a] *Sustainable Thermal Systems Laboratory, George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, 801 Ferst Drive, Atlanta, GA 30332, USA*
[b] *OpenCell Technologies, 311 Ferst Dr. Atlanta, GA 30332-0100, USA*
[c] *University of Nevada, Reno Mechanical Engineering, Mail Stop 312, Reno, NV 89557, USA*
[d] *Advanced Engineering Division, Cummins Inc. 1900 McKinley Avenue, Columbus IN 47201, USA*

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ABSTRACT

A novel miniaturization technology for binary-fluid heat and mass exchange was developed and numerous components were fabricated for demonstration as different parts of an ammonia/water absorption heat pump. Short lengths of microchannel tubes are placed in an array, with several such arrays stacked vertically. The ammonia/water solution flows in falling film/droplet mode on the outside of the tubes while coupling fluid flows through the microchannels. Coupling fluid heat transfer coefficients are extremely high due to the use of microchannel tubes. Effective vapor–solution contact on the absorption side minimizes heat and mass transfer resistances. This concept addresses all the requirements for absorber design in an extremely compact geometry. The technology is suitable for almost all absorption heat pump components (absorbers, desorbers, condensers, rectifiers, and evaporators) and for a wide range of binary-fluid processes. The development of several components for absorption and desorption at different capacities using this technology is reported here.

Technologie des composantes des minicanaux à appliquer aux systèmes à pompe à chaleur à absorption à ammoniac/eau

Mots clés : Absorption ; Miniaturisation ; Transfert de chaleur ; Transfert de masse ; Microcanal ; Film tombant

* *Corresponding author*. Tel.: +1 404 894 7479.
E-mail address: sgarimella@gatech.edu (S. Garimella).
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Nomenclature

a	wetted area ratio
A	area (m^2)
C	concentration ($mol\,m^{-3}$)
c_p	specific heat ($J\,kg^{-1}\,K^{-1}$)
$\tilde{c}_p$	molar specific heat ($J\,mol^{-1}\,K^{-1}$)
D	diameter (m)
h	enthalpy ($J\,kg^{-1}$)
LMTD	log-mean temperature difference (K)
m	mass flow rate ($kg\,s^{-1}$)
M	molar mass ($kg\,mol^{-1}$)
Nu	Nusselt number
$\dot{n}''$	molar flux ($mol\,m^{-2}\,s^{-1}$)
Pe	Péclet number
Pr	Prandtl number
$\dot{Q}$	heat transfer rate (W)
R	thermal resistance ($K\,m^2\,W^{-1}$)
Re	Reynolds number
T	Temperature (°C)
U	overall heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
x	ammonia mass fraction
$\tilde{x}$	ammonia mole fraction
$\tilde{z}$	condensing flux ammonia mole fraction

Greek symbols

α	heat transfer coefficient ($W\,m^{-2}\,K^{-1}$)
β	mass transfer coefficient ($m\,s^{-1}$)
δ	film thickness
ϕ	heat transfer correction parameter

Subscripts

a	ammonia
abs	absorbing
bulk	bulk
c	coolant
i	in
int	interface
l	liquid
o	out, outside
s	solution
SP	single pass
T	total
v	vapor
w	water, wall

1. Introduction

International interest in the global climate change problem has focused renewed attention on the development of novel thermal systems that reduce the environmental impact of energy consumption in the space-conditioning, chemical processing and other energy-intensive industries. One response to this problem is the use of absorption heat pumps, which are environmentally sound and energy-efficient alternatives to CFC-based, ozone-depleting space-conditioning systems. These thermally activated systems are powered by recuperated waste heat or can be gas-fired, as opposed to the high-grade electrical energy required for vapor compression systems, thus resulting in high source-energy-based efficiencies. They also have fewer moving parts. The principle of operation is as follows: thermal energy is used to boil a refrigerant from a concentrated refrigerant-absorbent solution in a desorber at high pressure. The refrigerant is condensed using ambient air as the heat sink, and expanded to a low pressure across a valve. At this low pressure, the refrigerant is cold enough to effect space-conditioning as it evaporates in the evaporator, thus cooling room air. The evaporated refrigerant is combined with the dilute solution in an absorber releasing the heat of absorption, from where it is pumped back in liquid form to the generator, which requires orders of magnitude less electrical energy than the energy required for compression of the refrigerant vapor in conventional systems. This thermodynamic cycle can also be run in the heating mode in winter, with the evaporator coupled to the outdoor air to withdraw heat from the ambient, and the condenser and absorber coupled to the indoor air to provide space heating. Thus, these thermodynamically attractive absorption systems have been implemented in large commercial applications.

Various investigators have focused on increasingly complex thermodynamic cycles to obtain incremental improvements in the theoretical coefficients of performance (COPs). For example, Garimella et al. (1996) and Engler et al. (1997) have reported high cooling and heating mode COPs for the generator absorber heat exchange (GAX) Heat Pump cycle over a wide range of ambient conditions. Double-effect (Gommed and Grossman, 1990; Garimella et al., 1992; McGahey et al., 1994) and triple-effect cycles (DeVault and Marsala, 1990; Grossman et al., 1994; Ivester and Shelton, 1994; Garimella et al., 1997) were also investigated and showed the potential for high COPs. Even 4-effect absorption chillers (Grossman et al., 1995) and other multiple-effect absorption cycles (Ziegler and Alefeld, 1994) have been investigated to achieve high COPs. However, the increased cycle complexity also results in the need for numerous heat exchangers and control systems. The performance potential of these advanced cycles cannot be realized without practically feasible and economically viable compact heat exchangers, which represents one of the biggest hurdles to commercialization. The development of such heat and mass exchangers has proved to be challenging, and has in fact hindered the adoption of absorption technology as a viable space-conditioning option. This is particularly true for the small-capacity residential market, where the lack of compact, inexpensive component designs for binary-fluid (refrigerant-absorbent) heat and mass transfer represents a crucial hurdle.

In thermally activated absorption heat pumps, the absorber, in which refrigerant vapor is absorbed into the dilute solution with the release of the heat of absorption, governs the viability of the entire cycle and has been referred to as the