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Nanofibrous membrane-based absorption refrigeration system

Rasool Nasr Isfahani, Karthikeyan Sampath, Saeed Moghaddam*

Department of Mechanical and Aerospace Engineering, University of Florida, Gainesville, FL 32611, USA

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ABSTRACT

This paper presents a study on the efficacy of highly porous nanofibrous membranes for application in membrane-based absorbers and desorbers. Permeability studies showed that membranes with a pore size greater than about one micron have a sufficient permeability for application in the absorber heat exchanger. Membranes with smaller pores were found to be adequate for the desorber heat exchanger. The membranes were implemented in experimental membrane-based absorber and desorber modules and successfully tested. Parametric studies were conducted on both absorber and desorber processes. Studies on the absorption process were focused on the effects of water vapor pressure, cooling water temperature, and the solution velocity on the absorption rate. Desorption studies were conducted on the effects of wall temperature, vapor and solution pressures, and the solution velocity on the desorption rate. Significantly higher absorption and desorption rates than in the falling film absorbers and desorbers were achieved.

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Système frigorifique à absorption à membrane à base nano-fibreuse

Mots clés : Système à absorption ; absorption à base de membrane ; Membrane à base de désorption ; Nano-fibres ; Conditionnement d'air ; Bromure de lithium

1. Introduction

Absorption refrigeration systems (ARSs) are fundamentally attractive for our future energy economy because they can harness low quality heat energy for cooling. Their use is particularly attractive in combined heating, cooling, and power (CCHP) systems in which the ARS is powered

by waste heat. Recent advancements in solar-thermal collectors have also enhanced the prospect of solar-cooling using ARSs.

The existing ARSs employ large heat exchangers, which are both bulky and expensive. The high initial cost of the system as well as its operational and maintenance needs have limited the use of ARSs to large facilities. Development of more

* Corresponding author. Tel.: +1 352 392 0889.

E-mail address: saeedmog@ufl.edu (S. Moghaddam).

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Nomenclature

\bar{d}_p	membrane mean pore diameters (m)
K_m	absorption coefficient ($\text{kg m}^{-2} \text{s}^{-1} \text{Pa}^{-1}$)
\dot{m}_{sol}	solution flow rate (kg h^{-1})
M	molecular weight (kg mol^{-1})
\dot{N}	molar flow rate (mol s^{-1})
P	pressure (Pa)
P_v	vapor pressure (Pa)

P_s	solution pressure (Pa)
$P_{s,w}$	solution water vapor pressure (Pa)
R	universal gas constant ($\text{J mol}^{-1} \text{K}^{-1}$)
T	temperature ($^{\circ}\text{C}$ or K)
T_w	wall temperature ($^{\circ}\text{C}$ or K)
T_{sup}	wall superheat temperature ($^{\circ}\text{C}$ or K)
ε	membrane porosity
∇P	pressure gradient across the membrane

compact, inexpensive, and robust systems for small-scale applications could expand the absorption systems use. In this study, the potential of a new heat exchanger configuration for development of compact small-scale systems is explored. The new approach enables fabrication of the system heat exchangers in a plate-and-frame configuration that is inherently more compact than the current shell-and-tube heat exchangers.

Depending on the choice of working fluid pairs, absorption systems are classified into ammonia–water and lithium bromide–water (LiBr–water) systems. This study is focused on the LiBr–water system in which water is used as the refrigerant and a LiBr–water solution is used as the absorbent. In a conventional LiBr–water ARS, water vapor is absorbed into the solution while it is sprayed on a cooled tube bank. Hydrodynamics of the falling liquid over the tubes (governed by the gravitational and shear forces) dictates the liquid film thickness and velocity. These two parameters along with the tube surface temperature determine the water absorption rate and thus the absorber heat exchanger surface area and size. In the existing configuration, the solution film thickness and velocity cannot be independently controlled. To enhance the absorption rate through controlling these two parameters, the solution can be mechanically constrained in microchannels by a porous hydrophobic membrane. The water vapor then

passes through the membrane and is absorbed into the solution at the vapor–solution interface (cf. Fig. 1a). The design of a membrane-based absorber is provided in Fig. 1b. Because the solution is constrained, its thickness can be reduced and run fast to minimize the mass boundary layer thickness. Furthermore, reducing the solution film thickness lowers the thermal resistance between the vapor–solution interface and the cooling wall. These effects enhance the absorption rate.

Implementation of thin solution films can also enhance the desorption process (cf. Fig. 2) through reduction of the resistance water molecules encounter when they diffuse out of the solution. This process is simply the opposite of the absorption process discussed above. Also, it is known that the growth rate of bubbles is slow in the LiBr solution (Nakoryakov et al., 1998) because of the low water diffusion coefficient. The bubbles growth rate is an order of magnitude slower than in pure water, where the bubble growth is heat transfer limited. Thus, a significant surface superheat temperature is required to grow the bubbles large enough to depart from the heat transfer surface (the buoyancy force should overcome the surface tension forces during the departure process). At moderate temperatures, bubbles remain on the surface and impede the heat transfer process. Flow boiling of the solution in thin microchannels can potentially alleviate this issue, since drag forces can remove small bubbles from the surface.

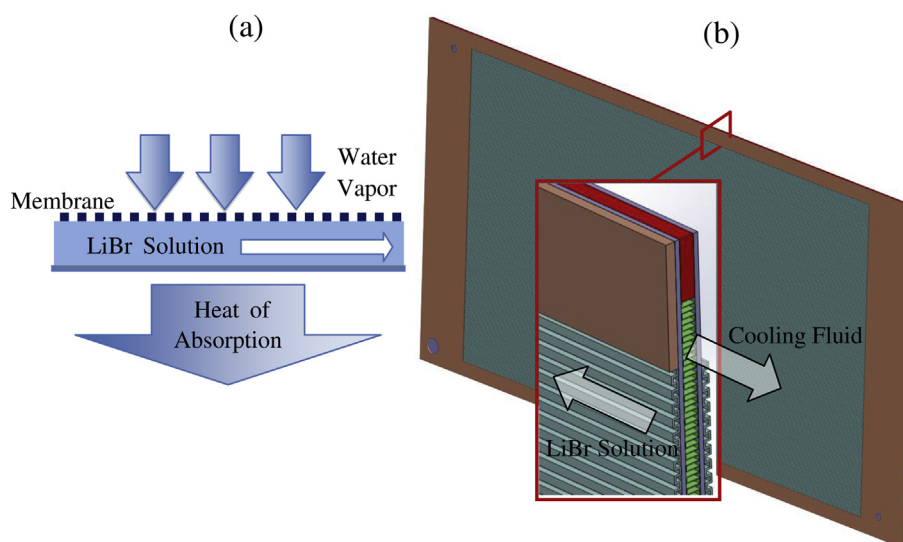


Fig. 1 – (a) Schematic representation of a constrained solution flow in absorber (b) A design of a membrane based absorber (membrane is not shown on the water–LiBr flow channels).

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