Microscale Desorption Based on Membrane Separation

Jonathan D. Thorud, Jeremy J. Siekas, James A. Liburdy, Deborah V. Pence
Department of Mechanical Engineering - Oregon State University
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Abstract

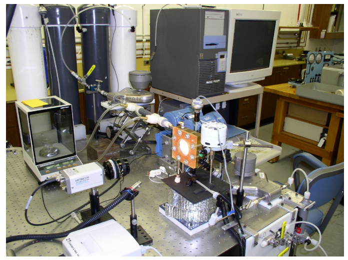
A scheme to achieve high desorption rates in a microscale system has been conceived based on the use of a hydrophobic porous membrane forming one wall of a high aspect ratio channel. To accomplish desorption, vapor is drawn through the membrane, during the addition of heat, as the binary mixture flows along the channel. The channel geometry is designed to achieve a thin film of binary mixture (lithium bromide and water) that is approximately 350 microns thick, while achieving a high membrane surface area which is approximately 3 cm x 6 cm. Vapor is drawn from the channel by creating a pressure differential across the membrane. Experiments were run varying the inlet mass flow rate, heat input, and pressure difference across the membrane, for an inlet mass fraction of 0.41. Mass fraction increases through the channel were up to 0.05. It is shown that the mass flux of vapor per mass flow rate into the channel decreases as the inlet flow rate increases, for a given heat flux. Also, the mass flux of vapor is linearly dependent on the heat input rate and not a function of inlet flow rate or pressure differential for the range of conditions studied. Images within the channel show bubble formation and desorption through the membrane under high heat flux and low inlet flow conditions.

Objectives

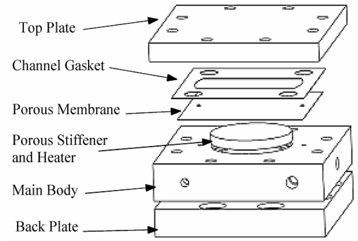
Identify parameters affecting vapor mass flow rate:

- Pressure difference across membrane
- Heat input
- Inlet mass flow rate

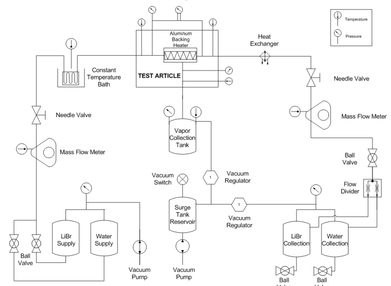
Desorber/Flow Loop Picture



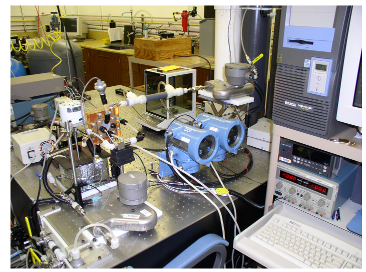
Desorber Exploded View



Flow Loop Schematic



Desorber/Flow Loop Picture



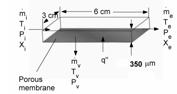
Motivation for Study

- Conventional desorbers can be inhibited by mass fraction gradients and variations in falling-film thickness
- Film resistance to mass diffusion can be decreased by decreasing the film thickness - increased diffusivity
- High transport rates are achievable with microscale energy transfer devices

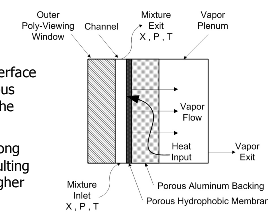
Uniqueness of Current System

- Constrained film can be oriented in any direction for operation
- Device can be operated in a reversed manner for absorption

Process Overview



- Lithium Bromide – Water mixture enters desorber at a fixed mass fraction, pressure, and temperature
- Heat is applied to the porous aluminum backing, which is transferred to the mixture
- Water vapor is formed at the membrane (liquid – vapor) interface and is drawn through the porous membrane and aluminum by the applied pressure difference
- This process in continuous along the length of the channel, resulting in an exiting mixture with a higher mass fraction



Data Reduction

Mass flow rate of vapor

$$\dot{m}_v = \left(1 - \frac{X_i}{X_e}\right)\dot{m}_i$$

Heat input to desorber

$$q = \left[\left(1 - \frac{X_i}{X_e}\right)h_v + \left(\frac{X_i}{X_e}\right)h_e - h_i\right]\dot{m}_i$$

Uncertainties

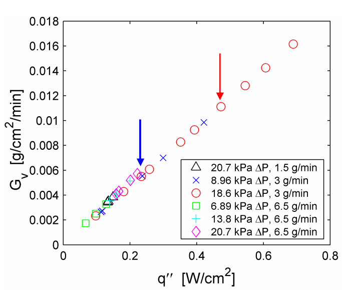
TEST CASES:	20.7kPa, 1.5g/min 6.89kPa, 6.5g/min 13.8kPa, 6.5g/min 20.7kPa, 6.5g/min	8.96kPa, 3g/min 18.6kPa, 3g/min
ρ_i [kg/m³]	0.64	0.60
ρ_e [kg/m³]	0.64	0.63
$\dot{m}_i$ [g/min]	0.19	0.11
$T_{thermocouples}$ [°C]	0.25	0.25
$T_{mass\ flow\ meter}$ [°C]	0.1	0.1
P [kPa]	0.345	0.345
P_{drop} [kPa]	0.050	0.050

Typical Calculated Variable Uncertainties:
- Mass Fraction Change = 0.27 %
- Vapor Mass Flux = 7.6 %
- Heat Input = 6.9 %

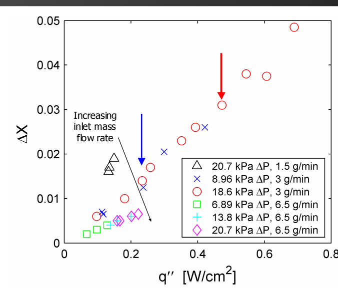
Results

- Channel height = 350 μm
- Max vapor mass flow rate = 0.297 g/min
- Max heat input = 11 W
- Inlet mass flow rate range = 1.5 to 6.5 g/min

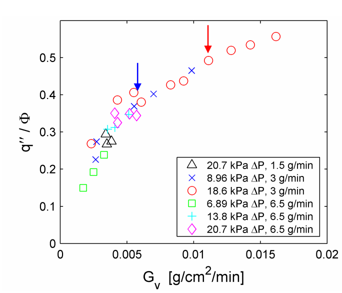
TEST CASES:	20.7kPa, 1.5g/min 6.89kPa, 6.5g/min 13.8kPa, 6.5g/min 20.7kPa, 6.5g/min	8.96kPa, 3g/min 18.6kPa, 3g/min
Inlet Mass Fraction	0.415	0.410
Inlet Pressure [kPa]	44.1	42.5
Inlet Temp [°C]	89.5	88.5



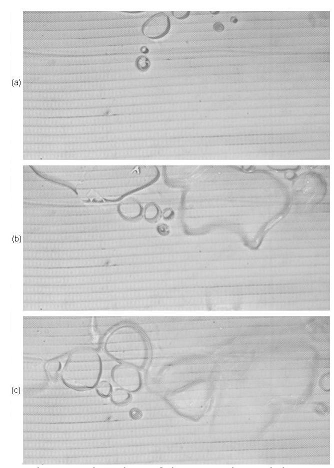
Vapor mass flux vs. Calculated heat input flux



Mass fraction change vs. Calculated heat input flux



Calculated heat flux to power input flux vs. Vapor mass flux



Photographs taken of the microchannel during (a) the onset of nucleate boiling (0.24 W/cm2), (b) higher heat input (0.30 W/cm2), and (c) the highest heat input (0.44 W/cm2), for the 8.96 kPa ΔP, 3 g/min test case.

Boiling Transition (3 g/min case):
0.24 W/cm2 for ΔP = 8.96 kPa
0.48 W/cm2 for ΔP = 18.6 kPa

Future Areas of Study

- Investigate desorption under variations in the inlet mass flow rates and pressure difference across membrane
- Determine effect of channel height on the vapor mass flux and mass fraction gradients in channel
- Identify vapor mass fluxes and heat input requirements for different inlet mass fractions
- Determine effects of boiling on desorption rates and heat input requirements
- Study binary boiling behavior at different sub-atmospheric pressures
- Develop a hydrophobic porous structure to replace the membrane-aluminum structure
- Use the constrained thin film for absorption

Conclusions

- Vapor mass flux varies linearly with heat input
- Lower inlet mass flow rates result in higher mass fraction changes
- Pressure difference across membrane has little effect on vapor mass flux, but does influence the point at which nucleation/boiling occurs in the channel
- Transition to boiling in desorber is not detrimental to vapor mass flux rates