Supporting Information

Energy Efficiency and Performance Limiting Effects in Thermo-Osmotic Energy Conversion from Low-Grade Heat

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SUPPORTING DISCUSSION

Vapor Transport in a Deaerated System. Membranes operating under vacuum will demonstrate unique transport behavior. Because the mean free path increases substantially with a lower air pressure in the pores, even membranes with pore sizes as large as 500 nm will operate in the Knudsen transport regime.[1–3] Models for transport through vapor-gap membranes under vacuum also include a small contribution from viscous transport through the pore. The permeability of a membrane operating in Poiseuille or viscous flow is expressed as[2]

$$B_w^V = \frac{r^2 P_m \varepsilon}{8\eta_w RT\tau\delta} \tag{S1}$$

where r is the membrane pore radius, P_m is the average pressure in the membrane pore, ε is the membrane porosity, η_w is the viscosity of water vapor, R is the ideal gas constant, T is the temperature, τ is the tortuosity, and δ is the thickness.

The permeability of the membrane under vacuum is calculated as the sum of the Knudsen permeability (eq 7 of the main text) and the permeability of the membrane under viscous flow (eq S1). In most cases, the viscous contribution is relatively low. For example, in a 100 μm thick membrane with a 400 nm pore size, the Knudsen permeability is 5.60×10^{-6} kg m^{-2}s^{-1}Pa^{-1}, whereas the viscous permeability is 0.47×10^{-6} kg m^{-2}s^{-1}Pa^{-1}.

REFERENCES

(1) Schofield, R. W.; Fane, A. G.; Fell, C. J. D. Gas and Vapour Transport through Microporous Membranes. II. Membrane Distillation. *J. Memb. Sci.* **1990**, *53*, 173–185.

(2) Khayet, M. Membranes and Theoretical Modeling of Membrane Distillation: A Review. *Adv. Colloid Interface Sci.* **2011**, *164*, 56–88.

(3) Winter, D.; Koschikowski, J.; Ripperger, S. Desalination Using Membrane Distillation: Flux Enhancement by Feed Water Deaeration on Spiral-Wound Modules. *J. Memb. Sci.* **2012**, *423–424*, 215–224.

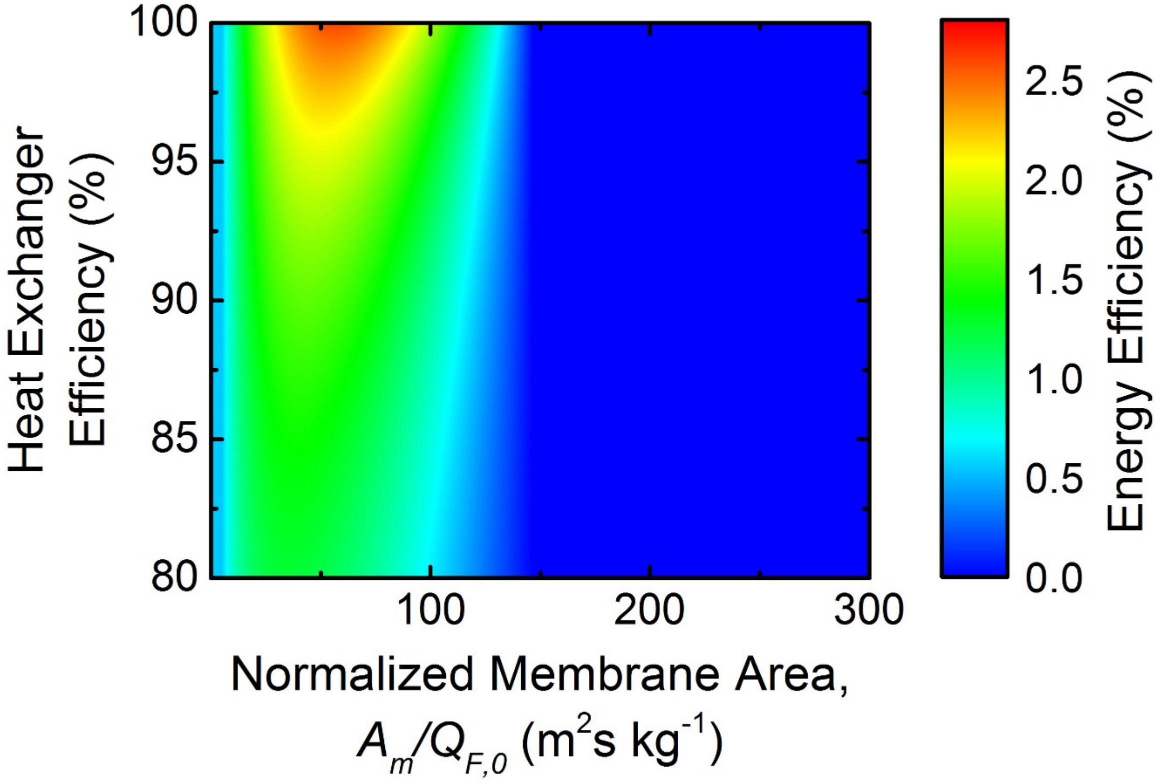

Figure S1. Energy conversion efficiency as a function of the heat exchanger efficiency and normalized membrane area (membrane area, A_m, divided by the initial feed flow rate, $Q_{F,0}$). The heat source temperature is 60 °C and the heat sink temperature is 20 °C. The hydraulic pressure difference between the two streams is 20000 kPa (200 bar), and balanced flow rates are assumed. The membrane permeability coefficient, B_w, is 1×10^{-6} kg m^{-2}s^{-1}Pa^{-1}; the thermal conductivity of the membrane, K_m, is 0.04 W m^{-1}K^{-1}; the heat transfer coefficient, h, on both sides of the membrane is 5000 W m^{-2}K^{-1}; and the thickness is 100 μm.