Marangoni effect - driven salt rejection

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INTRODUCTION: A comprehensive theoretical study is conducted to explain the apparently paradoxical experimental effective transport exceeding classical diffusion by two orders of magnitude. In our study, the Marangoni effect is included at the water–air interface and it stems from spatial gradients of surface tension.

In detail this model describes the discharging process (transient behavior) of salt particles from the photothermal component of a thermal desalination device. The aim of the study is to compute the salt molar flux induced by the Marangoni convection.
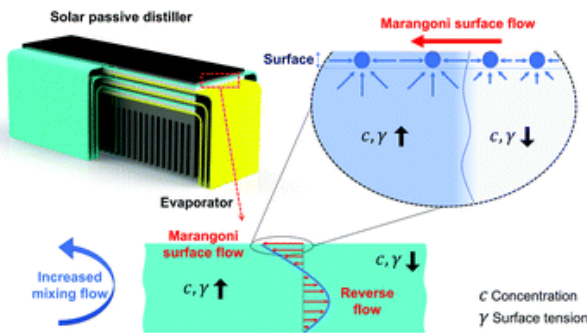

Figure 1. The Marangoni effect is found having an important role to enhance the salt rejection process in passive desalination technologies.

COMPUTATIONAL METHODS

Transport of diluted species:

$$\frac{\partial c}{\partial t} + \nabla \cdot \boldsymbol{J} + \boldsymbol{u} \cdot \nabla c = 0; \quad \boldsymbol{J} = -D\nabla c$$

Laminar flow:

$$\frac{\partial \rho \boldsymbol{u}}{\partial t} + \boldsymbol{u} \cdot \nabla(\rho \boldsymbol{u})$$

$$= \nabla \cdot \left[-p\boldsymbol{I} + \mu(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T) - \frac{2}{3}\mu(\nabla \cdot \boldsymbol{u})\boldsymbol{I} \right];$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = \boldsymbol{0};$$

$$\rho = \rho_0 + \beta c, \beta = \frac{\rho_s - \rho_0}{c_s - c_0}$$

$$\left[-p\boldsymbol{I} + \mu(\nabla \boldsymbol{u} + (\nabla \boldsymbol{u})^T) - \frac{2}{3}\mu(\nabla \cdot \boldsymbol{u})\boldsymbol{I} \right] \cdot \boldsymbol{n} = \gamma \nabla c$$

(γ concentration derivative of the surface tension)
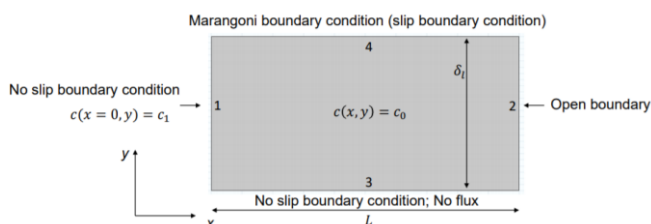

Figure 2. Simulation domain and boundary conditions employed to quantify Marangoni effect in the evaporating layer.

RESULTS: The concentration surface plots in case of classic diffusion mechanisms and Marangoni effect are shown on the left and right side of the sub-panel, respectively.
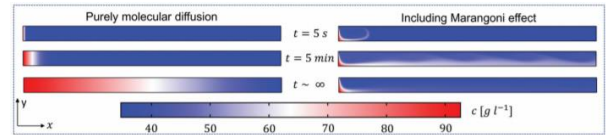

Figure 3. Transient concentration surface plots. Left side: Classical molecular diffusion (D = $1.5 \times 10^{-9}\ m^2 s^{-1}$). Right side: Including Marangoni effect.

The stationary velocity profiles that occur in the saltwater thin film at the outlet section are reported. The results show a faster mass transport process when the Marangoni effect is included in the model.
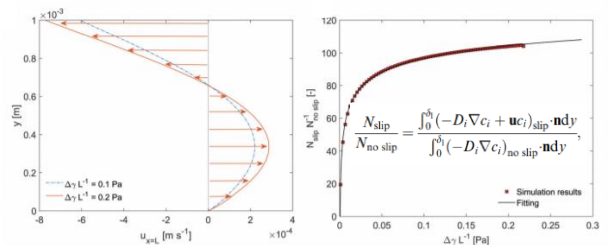

Figure 4. Left side. Stationary velocity profiles at the outlet of the domain (x = L) and in presence of an interface. Right side. Ratio between the outgoing molar flux in case of slip (N_{slip}, Marangoni effect) and no slip boundary condition ($N_{no\ slip}$), as function of the driving force.

CONCLUSIONS: Experimental results on the salt rejection process imply that the effective diffusion coefficient is more than 2 orders of magnitude larger with respect to the classic diffusion coefficient. This mismatch is explained by resorting to the Marangoni effect at the water–air interface, which originates from the spatial gradient of the salt concentration causing the surface tension gradient. This effect speeds up the discharging process of NaCl solute.

Further research has to be oriented towards optimized hydrophilic materials with anti-fouling properties and tailored capillary action to (i) feed a larger number of distillation stages with saltwater and (ii) guarantee an increased and optimal Marangoni-driven flow.

REFERENCES:

1. Eliodoro Chiavazzo, Matteo Morciano, Francesca Viglino, Matteo Fasano and Pietro Asinari. Passive solar high-yield seawater desalination by modular and low-cost distillation, NATURE SUSTAINABILITY, https://www.nature.com/articles/s41893-018-0186-x
2. Matteo Morciano, Matteo Fasano, Svetlana V. Boriskina, Eliodoro Chiavazzo and Pietro Asinari. Solar passive distiller with high productivity and Marangoni effect driven salt rejection, ENERGY & ENVIRONMENTAL SCIENCE, https://doi.org/10.1039/D0EE01440K