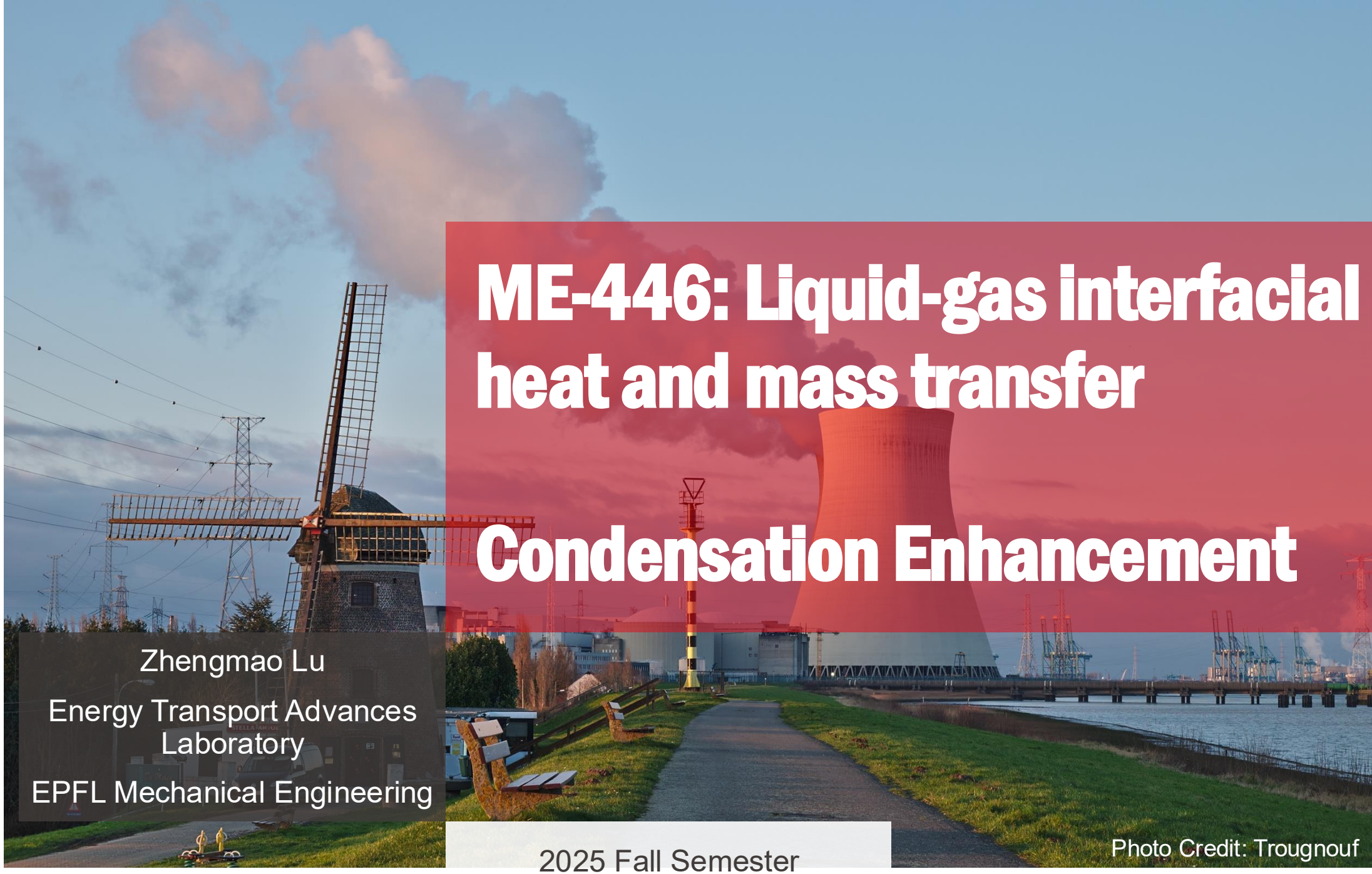


ME-446: Liquid-gas interfacial heat and mass transfer

Condensation Enhancement

Zhengmao Lu

Energy Transport Advances Laboratory

EPFL Mechanical Engineering

2025 Fall Semester

Photo Credit: Trougnouf

Last Time

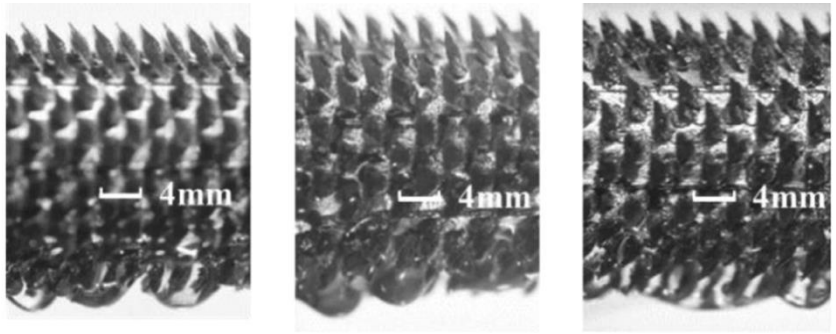
- Nucleation in condensation
- Rose’s analysis of dropwise condensation
- Nusselt’s analysis of filmwise condensation

Intended Learning Objective Today

- Typical condensation enhancement strategies
- Jumping-droplet condensation
- Design principles for lubricant infused surface
- Wicking condensation

Condensation Enhancement

Finned Tube Condenser



Gu *et al.*, *International Journal of Heat and Mass Transfer* 2020

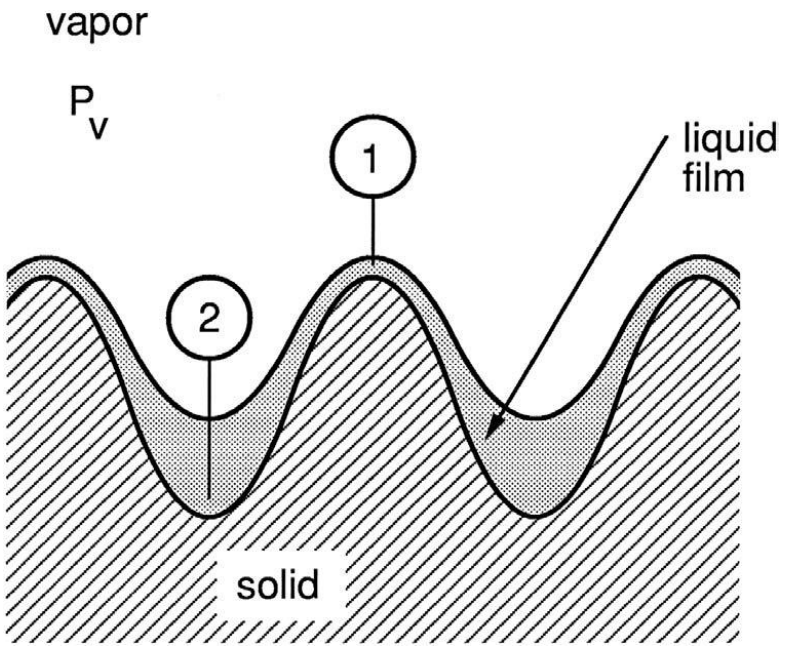
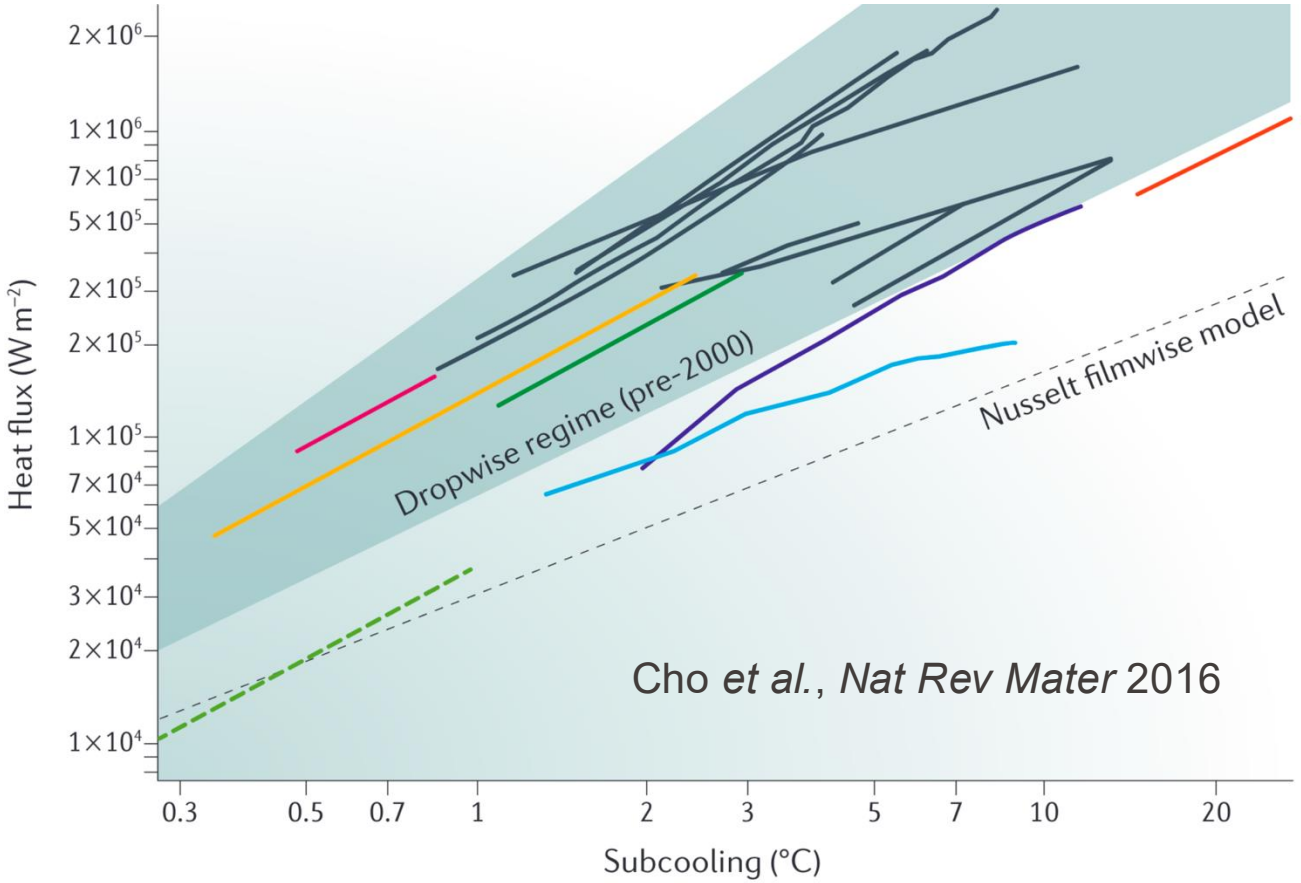
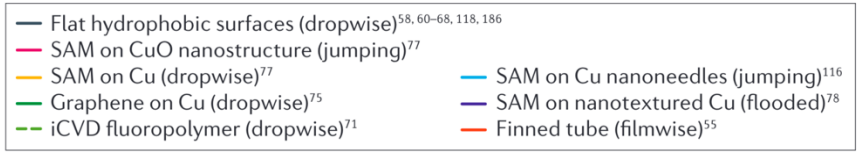


FIGURE 9.26 in Carey

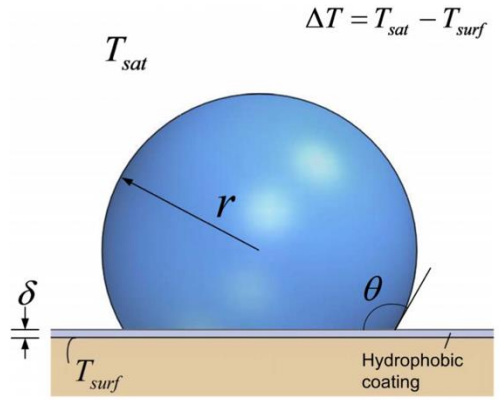
Increase condensation heat transfer area

Promoting Dropwise Condensation



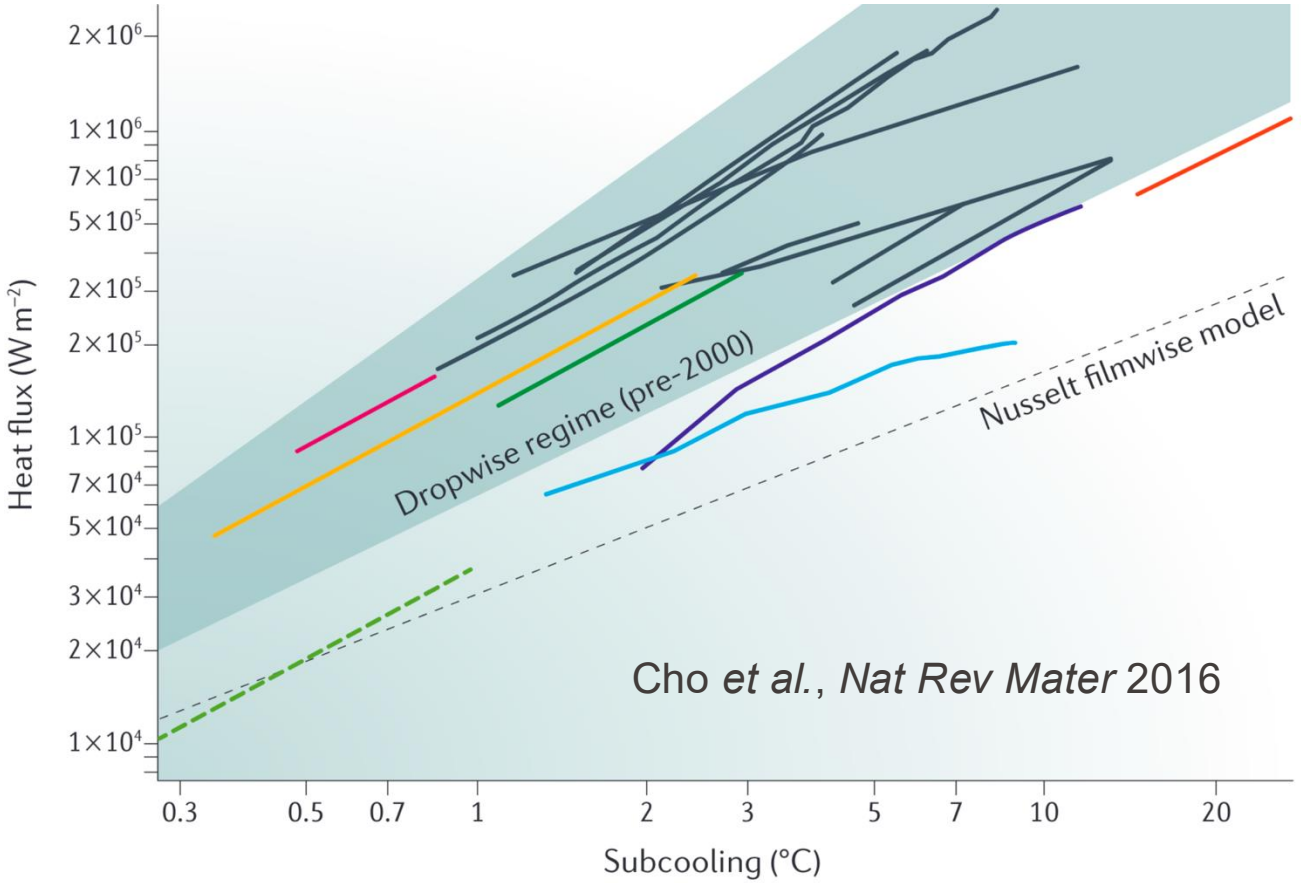


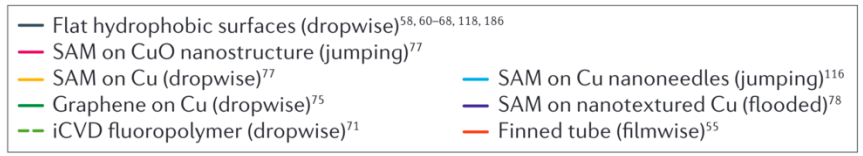
Flat Hydrophobic Coating



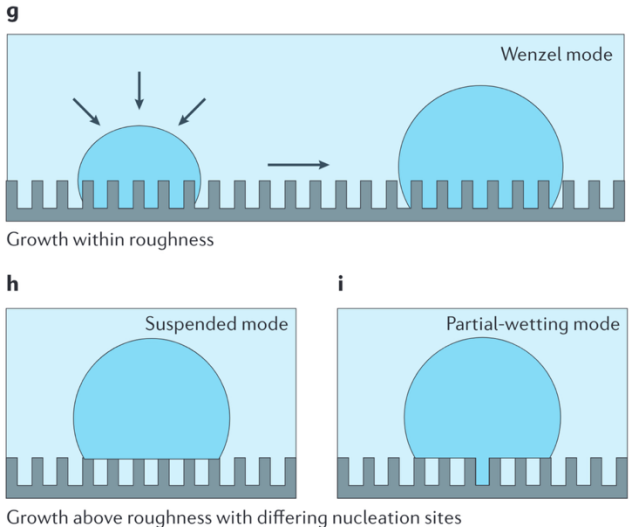
- Increase contact angle and decrease contact angle hysteresis

Condensation Enhancement

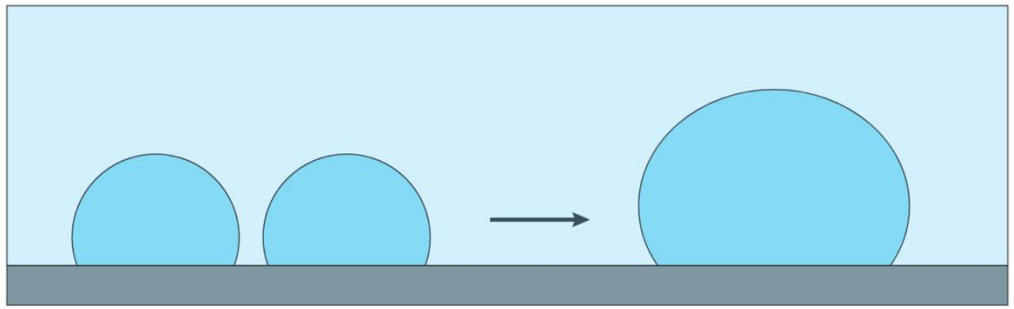




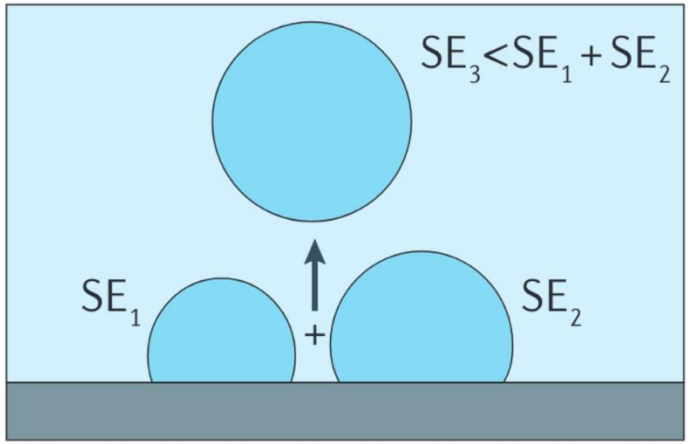
Surface Structure + Hydrophobic Coating



Jumping Droplet Condensation



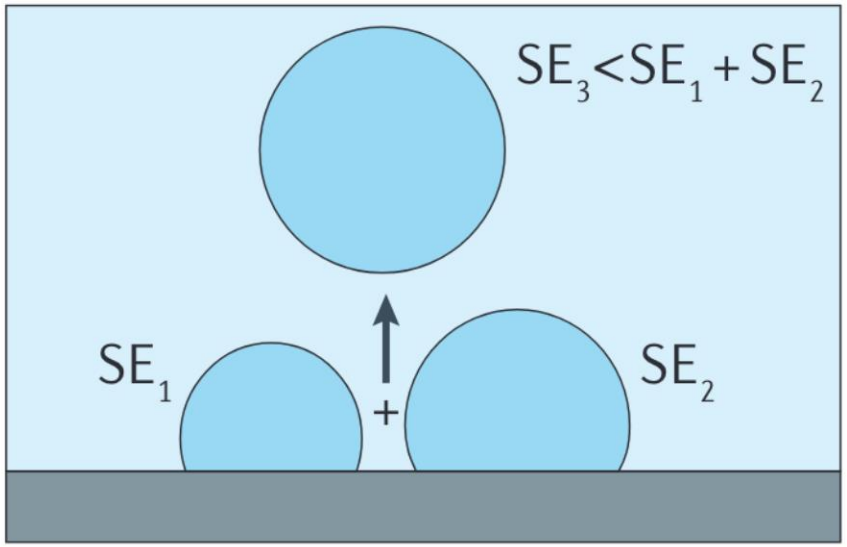
Coalescence



Coalescence departure

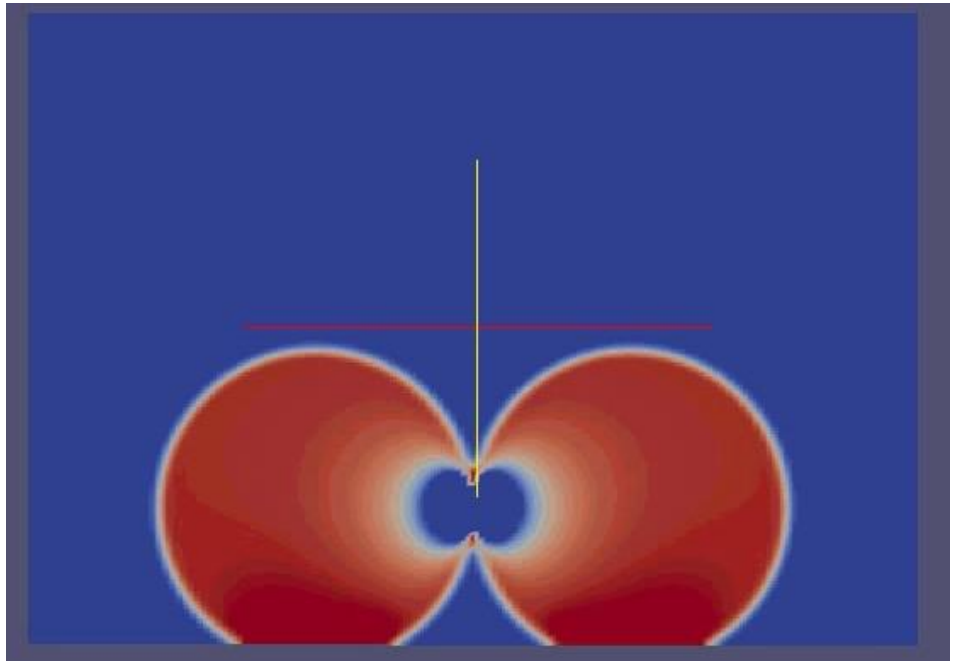
https://doi.org/10.1103/PhysRevLett.103.184501

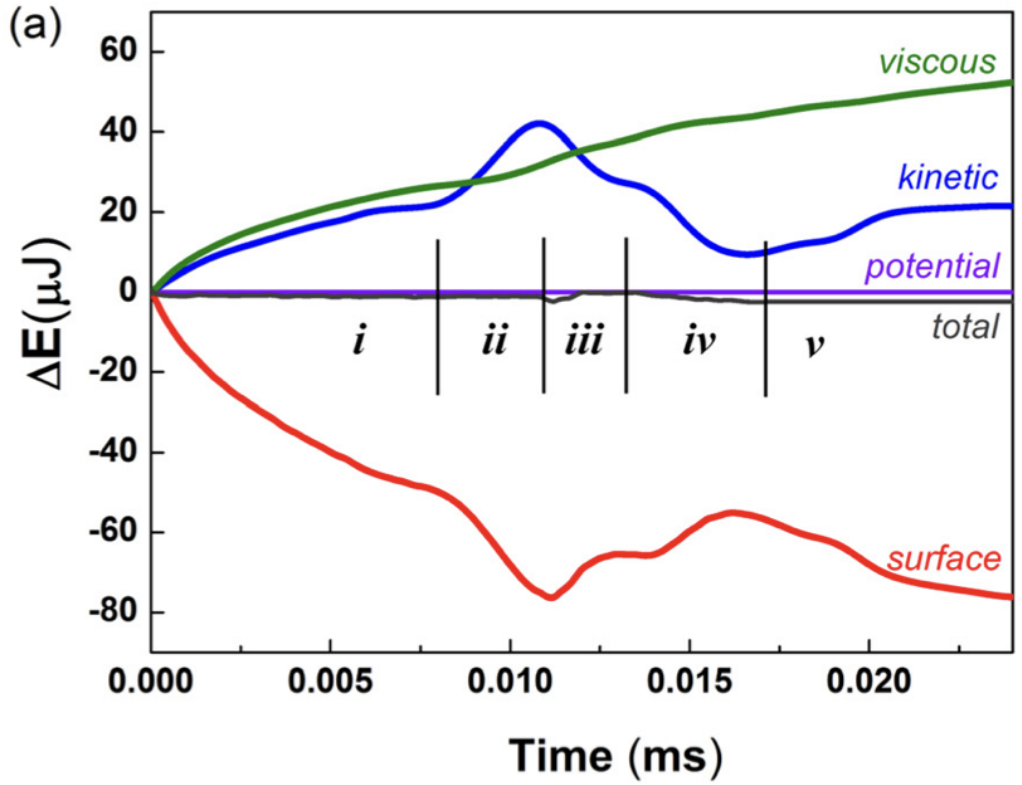
Jumping Droplet Condensation



Coalescence departure

Jumping Droplet Condensation





Appl. Phys. Lett. 103, 161601 (2013)

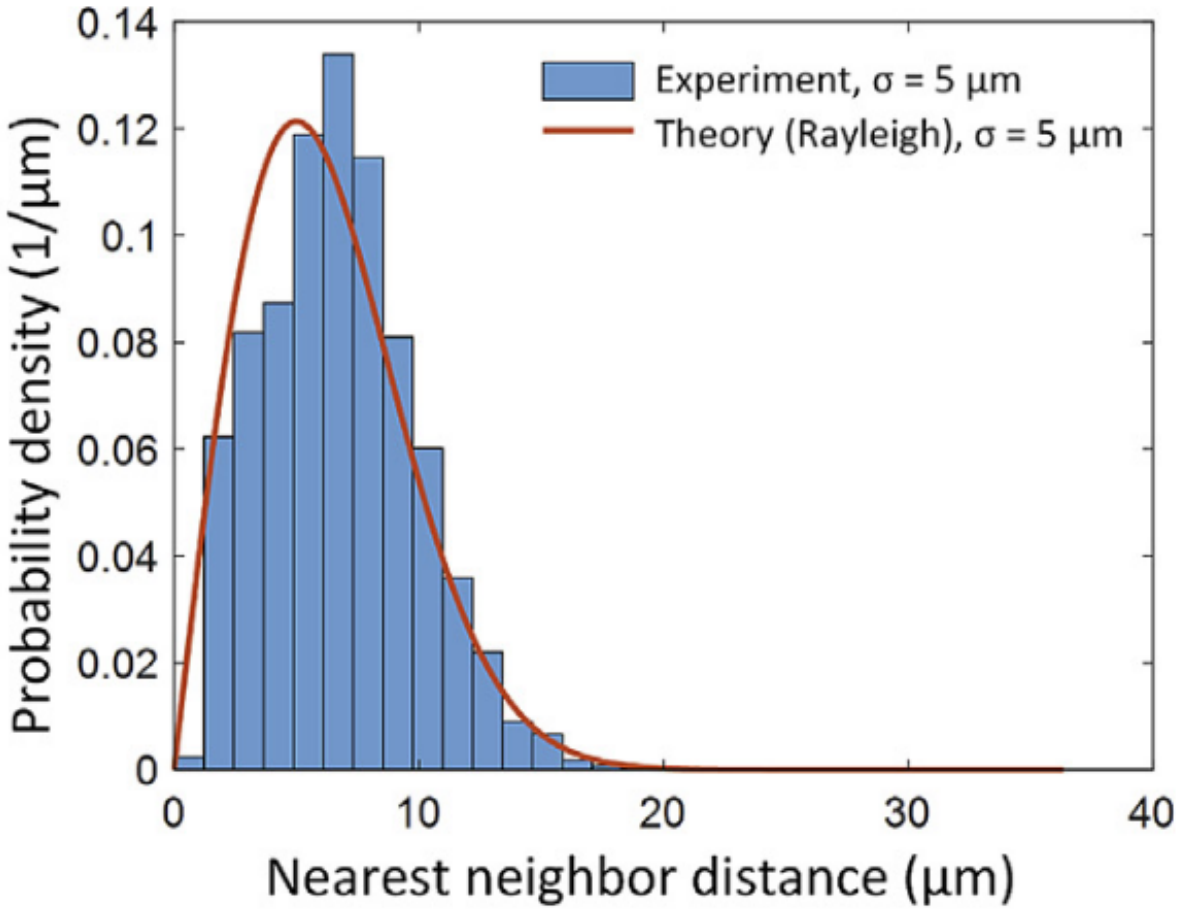
Distribution of Droplet Radii in Dropwise Condensation

- Probability density function

$$A(r) = \frac{r^{-2/3}}{3r_{max}^{1/3}} \qquad r_{max} = K_3\sqrt{\frac{\sigma}{\rho g}} \qquad \text{for } r_e < r \leq r_{max}$$

$$h_{dc} = \frac{1}{\Delta T_t}\int_{r_e}^{r_{max}} \frac{q_d}{2\pi r^2} A(r)dr$$

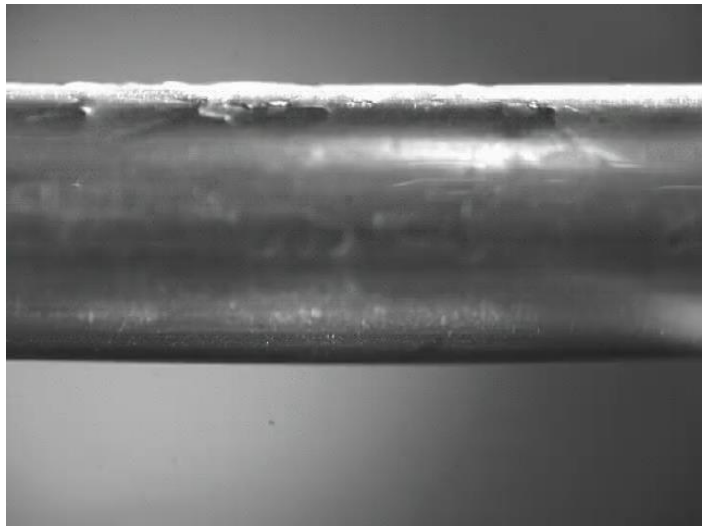
Distribution for Jumping Droplet Condensation



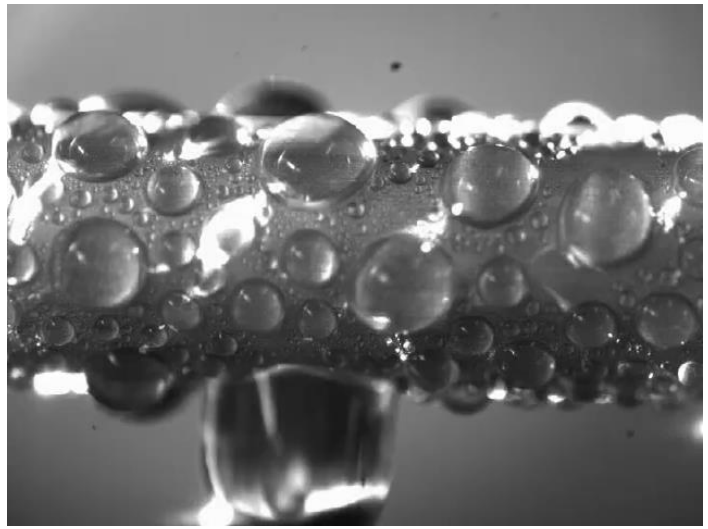
- Since contacting neighboring droplet will cause jumping removal, droplet radius should be around half the nearest neighbor distance
- Jumping-droplet mode will result in smaller average droplet sizes on the surface and better heat transfer

Different Condensation Mode

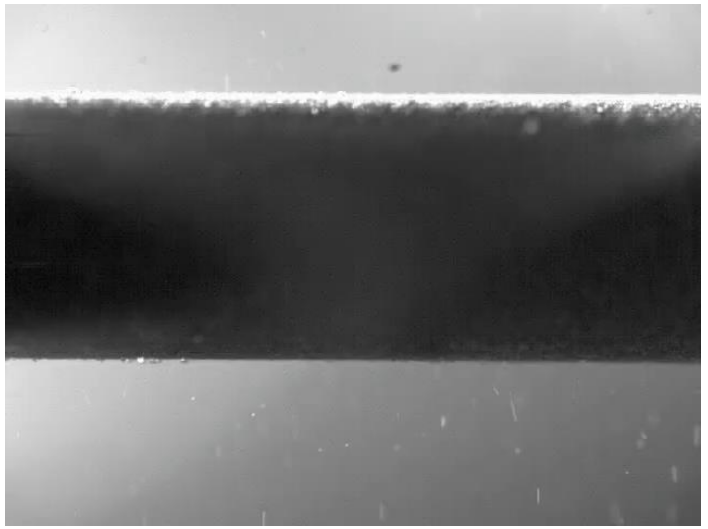
Superhydrophobic surface



Filmwise condensation



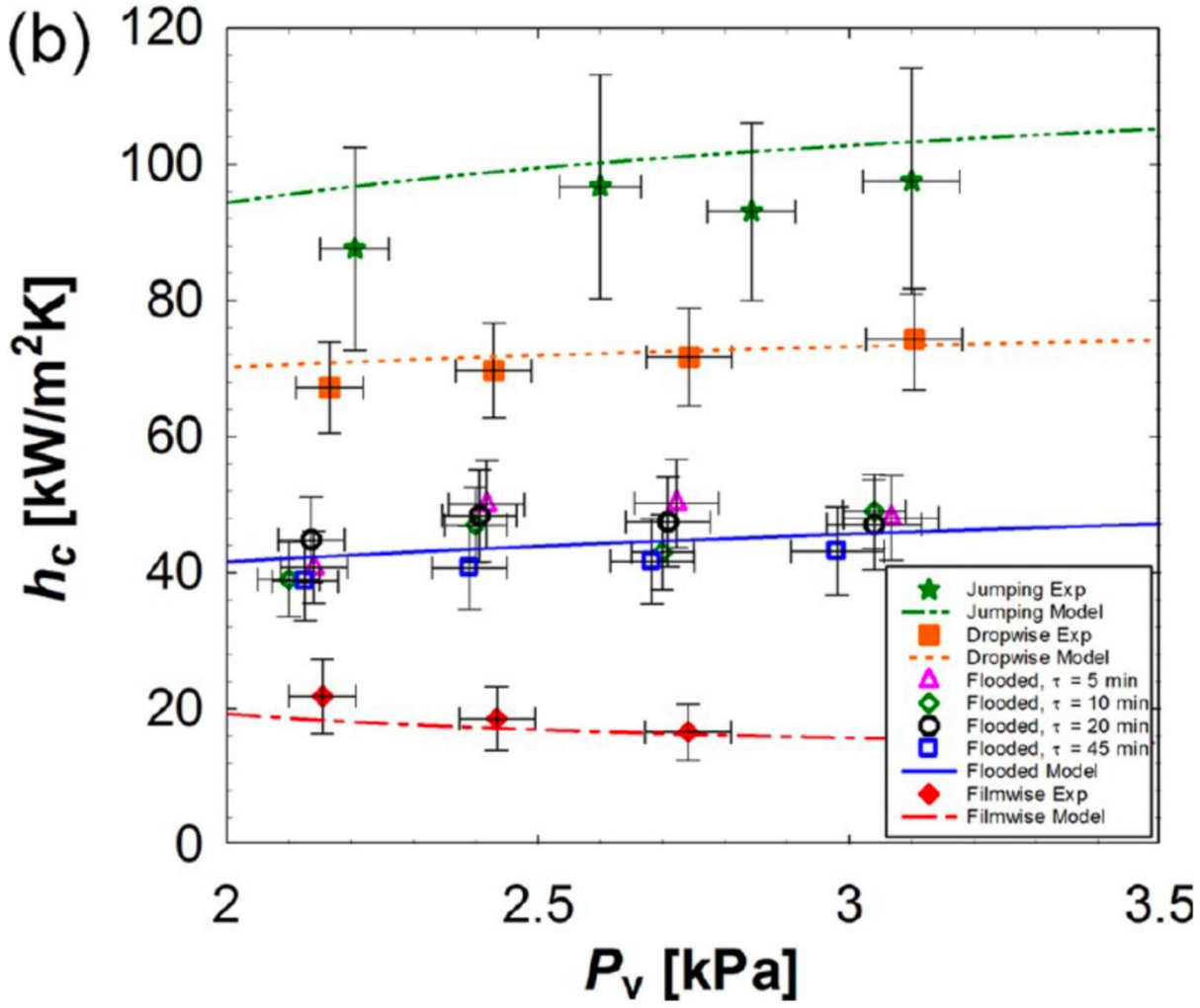
Dropwise condensation



Jumping-droplet condensation

Miljkovic *et al.*, *Nano Lett.* (2013)

Heat Transfer Enhancement



Jumping-droplet

>

Dropwise

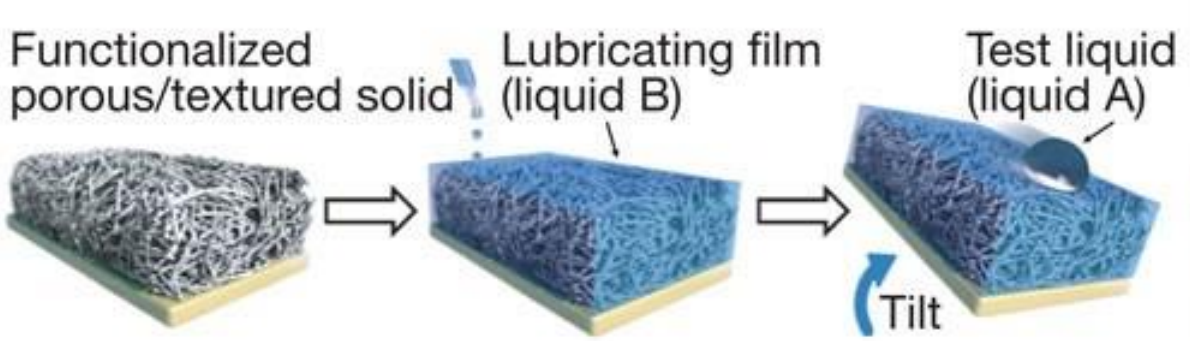
>

Filmwise

Nano Lett. 2013, 13, 179−187

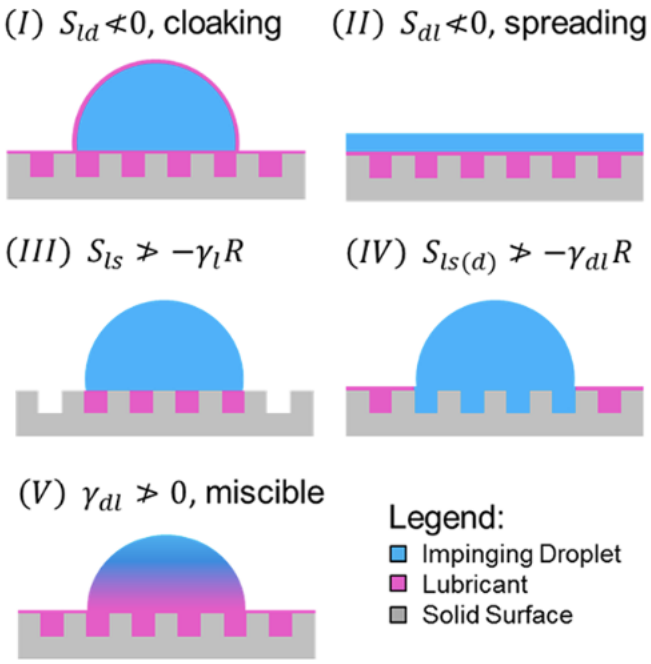
How About Low Surface Tension Fluids

Lubricant Infused Surface (LIS)



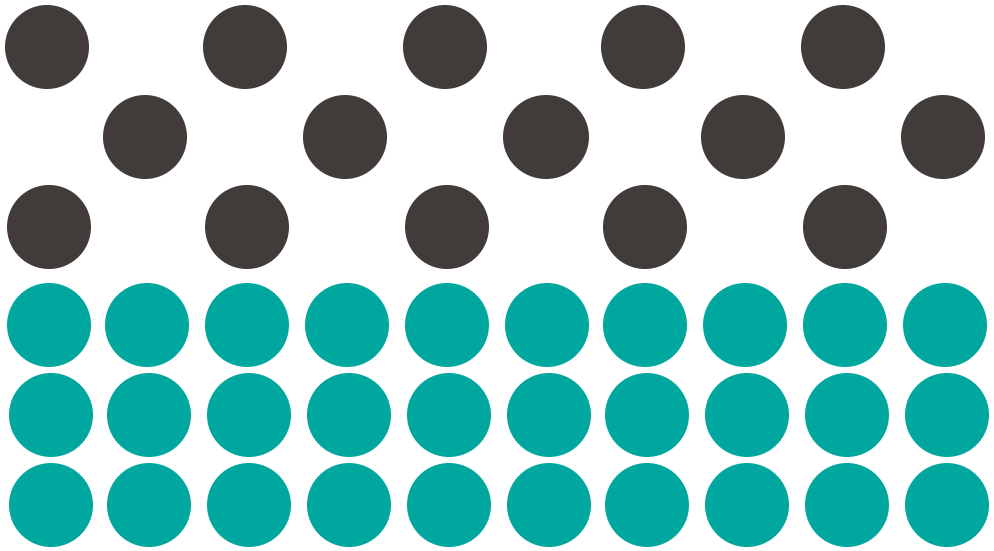
Nature volume 477, pages 443–447 (2011)

How to Design LIS



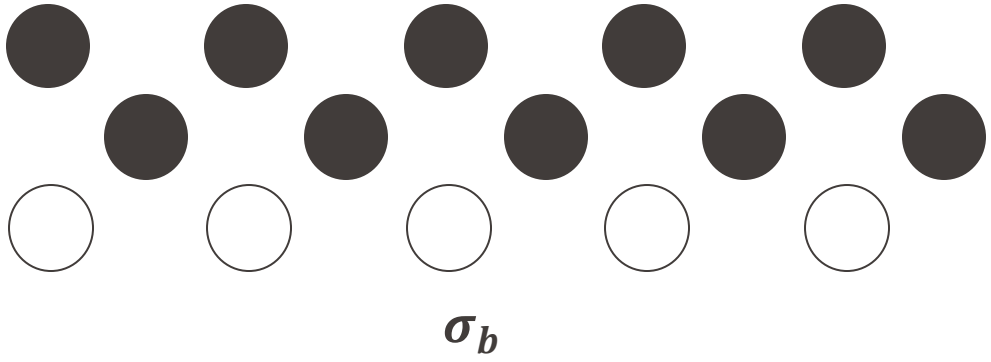
ACS Appl. Mater. Interfaces2017, 9, 42383−42392

From Week 2



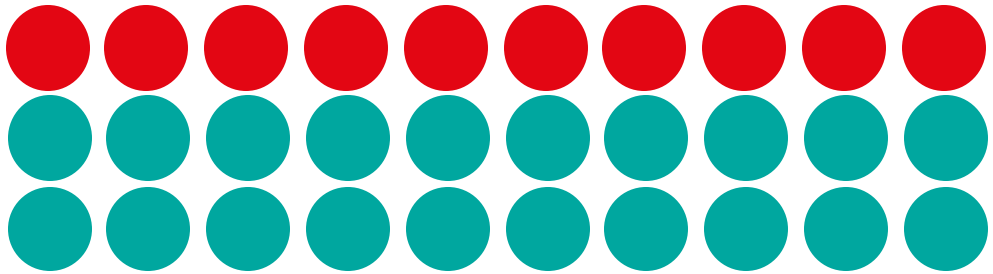
σ_{ab}

w_{ab}



σ_b

σ_a



$$\sigma_{ab} = \sigma_a + \sigma_b - w_{ab}$$

w_{ab} depends on intermolecular interactions

van Oss, Chaudhury, and Good (vOCG Model)

Langmuir 1992,8, 2877-2879

$$\gamma_A^{tot} = \gamma_A^{LW} + 2\sqrt{\gamma_A^+ \gamma_A^-}$$

$$\gamma_{AB}^{tot} = \gamma_A^{LW} + \gamma_B^{LW} - 2\sqrt{\gamma_A^{LW}\gamma_B^{LW}} + 2\sqrt{\gamma_A^+\gamma_A^-} + 2\sqrt{\gamma_B^+\gamma_B^-} - 2\sqrt{\gamma_A^+\gamma_B^-} - 2\sqrt{\gamma_B^+\gamma_A^-}$$

Phenomenological, Lifshitz-van der Waals component + polar component

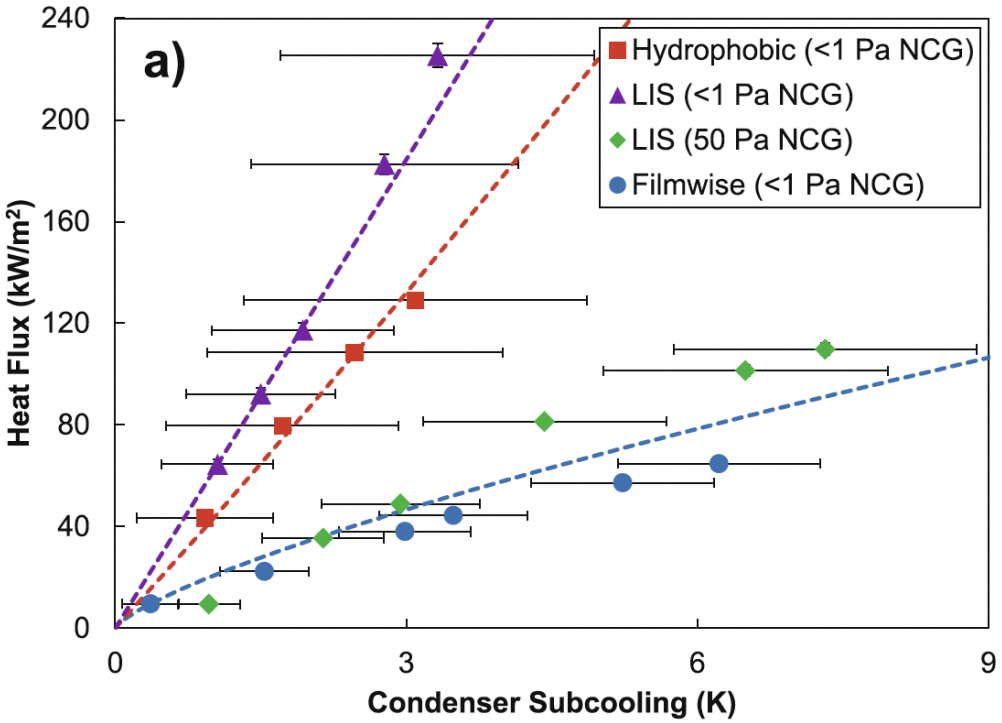
Metallic interactions not considered

Condensation Experiment

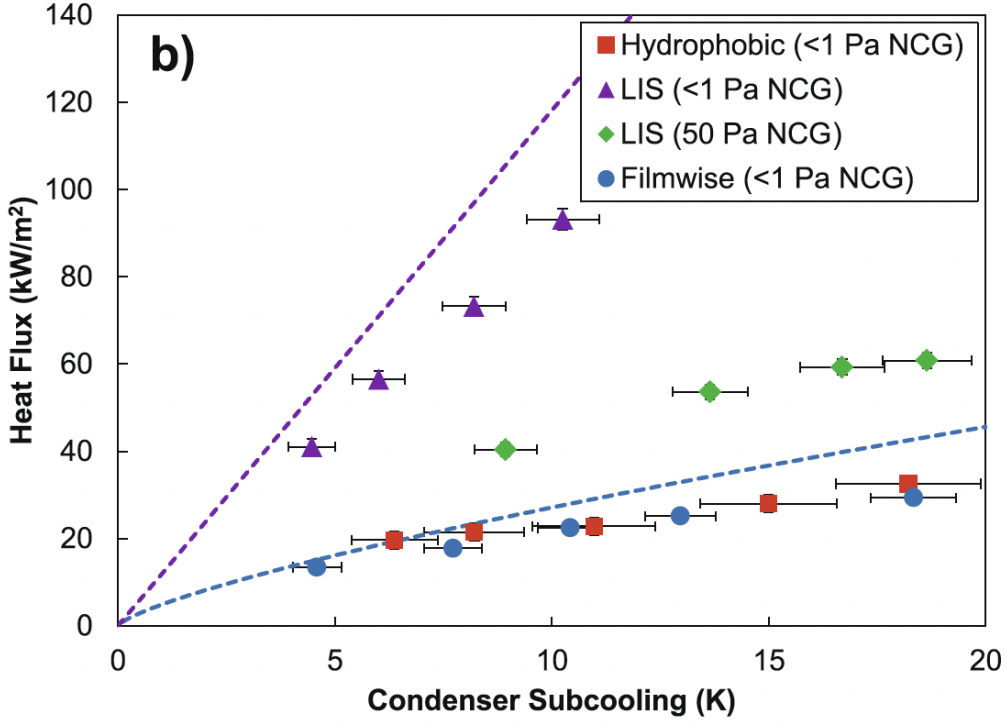
	Water (72 mN/m)	Toluene (28 mN/m)
Regular hydrophobic		
LIS		

Heat Transfer Enhancement

Water (72 mN/m)



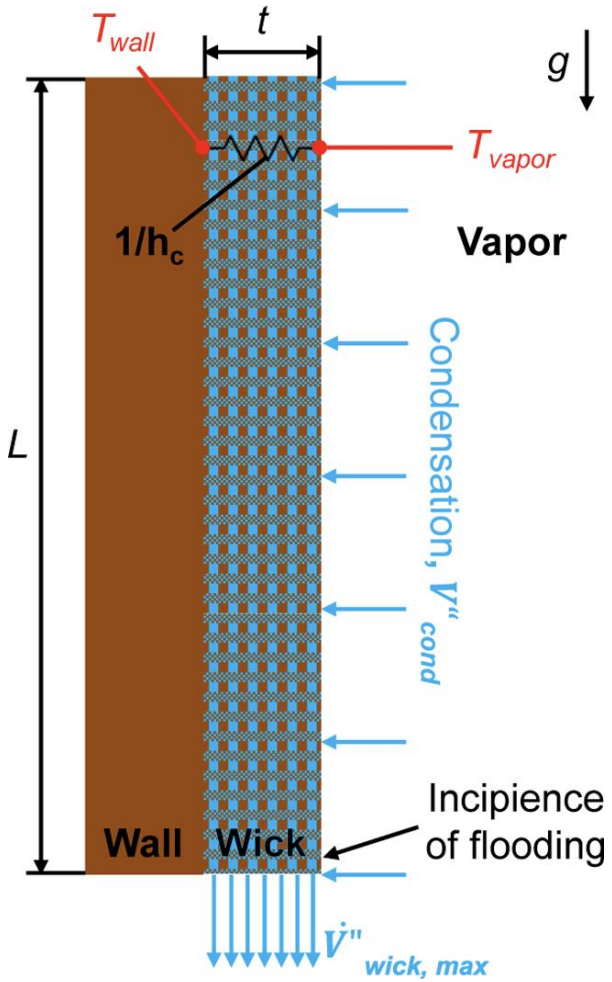
Toluene (28 mN/m)



Preston, D.J. et al. Sci Rep 8, 540 (2018)

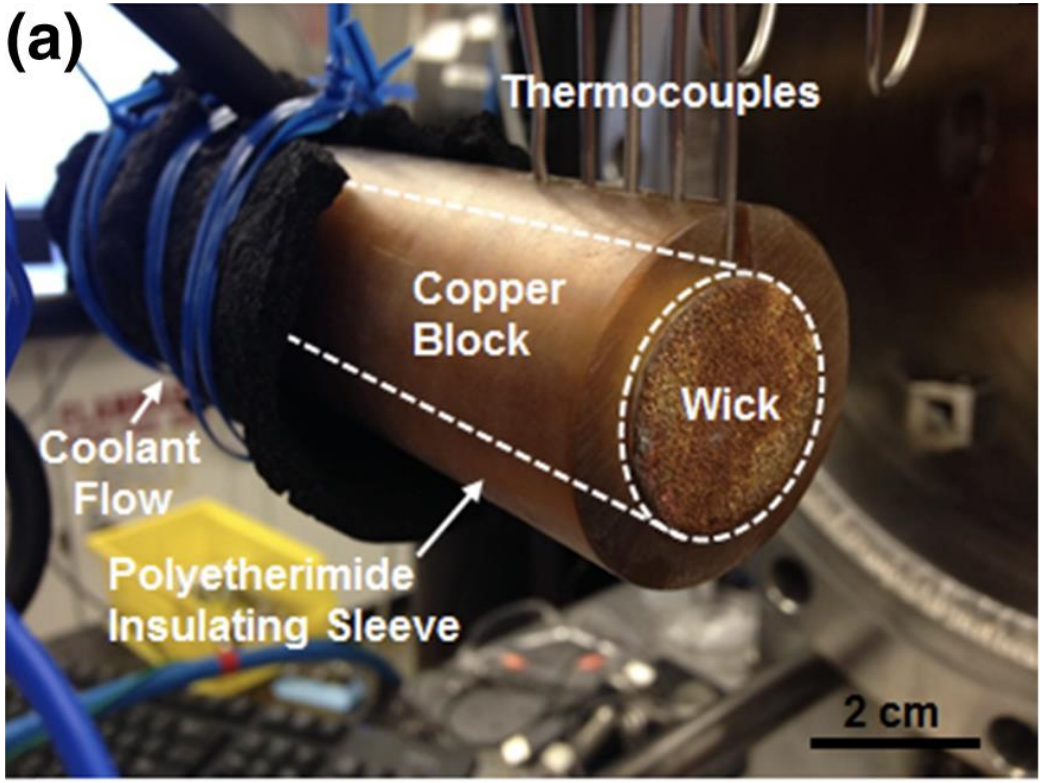
Note the effect of NCG (non-condensable gases)

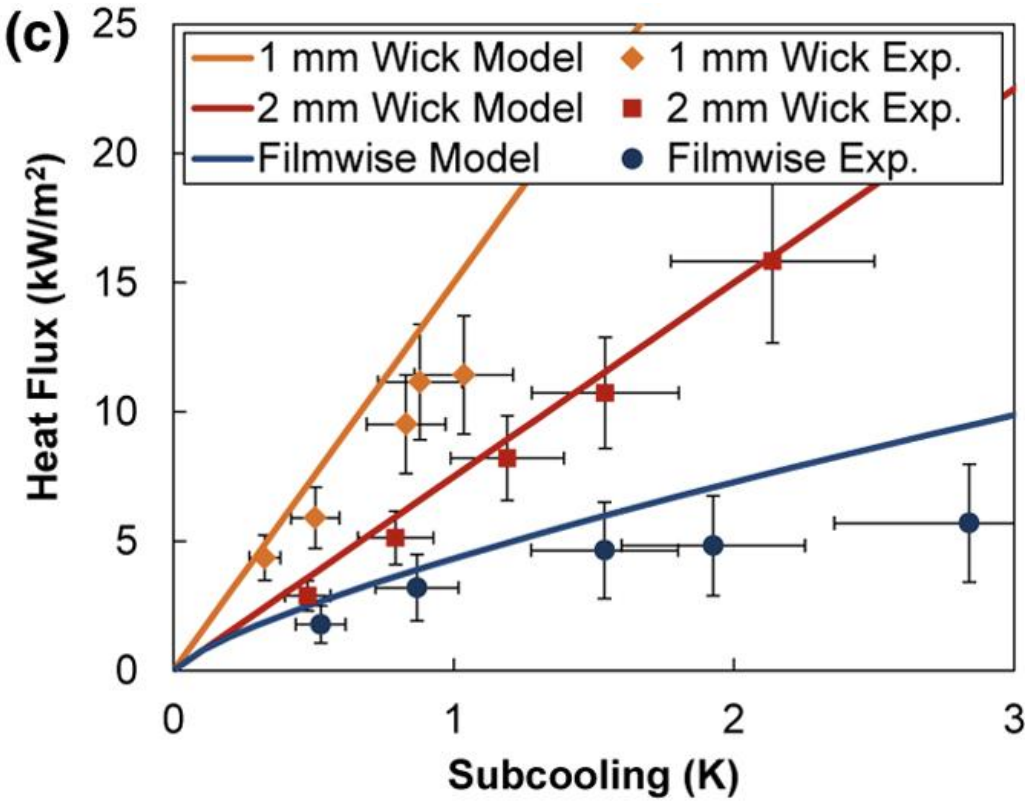
Wicking Condensation



Langmuir 2018, 34, 4658−4664

Experimental Results





Langmuir 2018, 34, 4658−4664