NOVEL PATTERNED SURFACES FOR IMPROVED CONDENSER PERFORMANCE IN POWER PLANTS

Professor Ranga Pitchumani

VIRGINIA TECH Advanced Materials and Technologies Laboratory

www.me.vt.edu/amtl

pitchu@vt.edu | +1 571-858-3251

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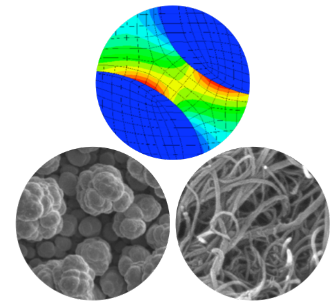
NATIONAL ENERGY TECHNOLOGY LABORATORY

AMTL Research Areas

- ❑ Advanced Materials Processing/Manufacturing
- ❑ Energy Systems
  - ❖ Fuel Cells, Solar, Thermal Power Plants
- ❑ Energy Storage
  - ❖ Thermal, Electrochemical
- ❑ Microsystems and Microfabrication
- ❑ Transport phenomena, Computational modeling
- ❑ Uncertainty Quantification, Optimization and Control

Energy



Materials Processing and Design

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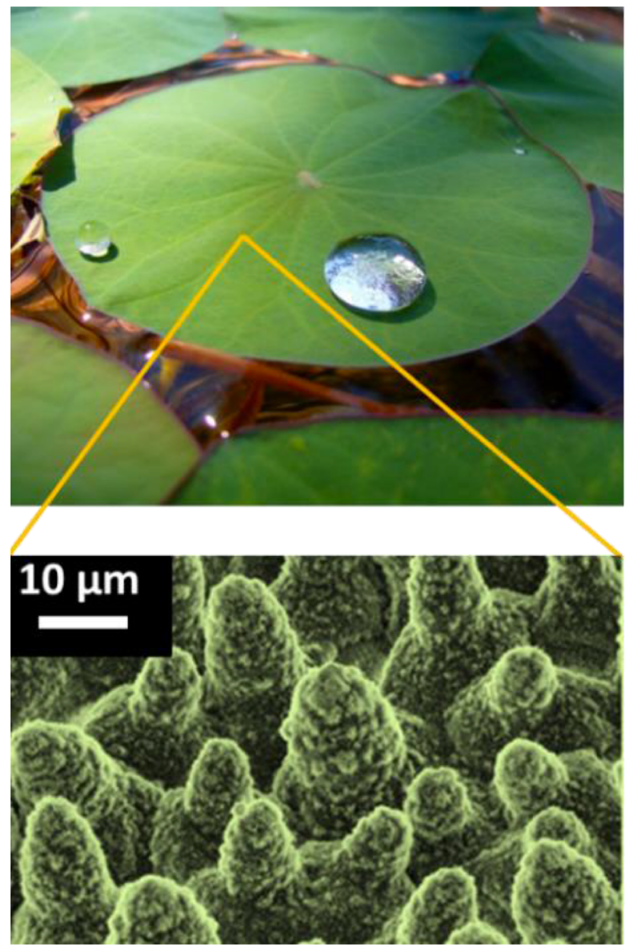
Motivation and Inspiration

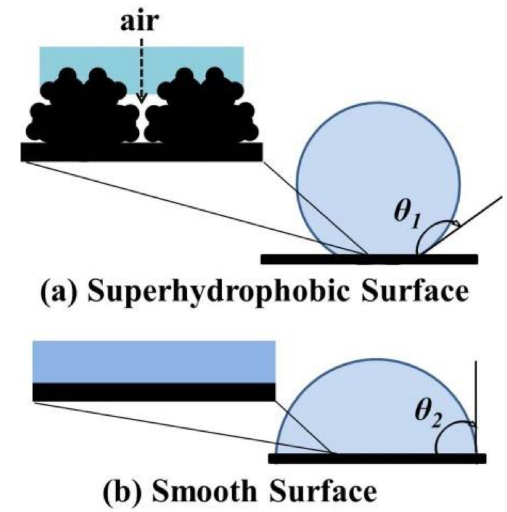
Condenser performance in a power plant is governed by two factors:

- Heat transfer on the coolant and the steam side
- Parasitic power associated with the pressure drop across the condenser unit

The overall motivation is to increase the performance of condensers in thermal power plants by addressing the two factors—specifically, increasing the heat transfer rates and reducing the pumping power.



Beilstein J Nanotechnol. 2011; 2: 152–161



$\theta > 120^{o}$ (hydrophobic)
$\theta > 150^{o}$ (superhydrophobic)

Underlying Idea

If condenser tube surfaces can be engineered to be superhydrophobic, we can enhance heat transfer performance by:

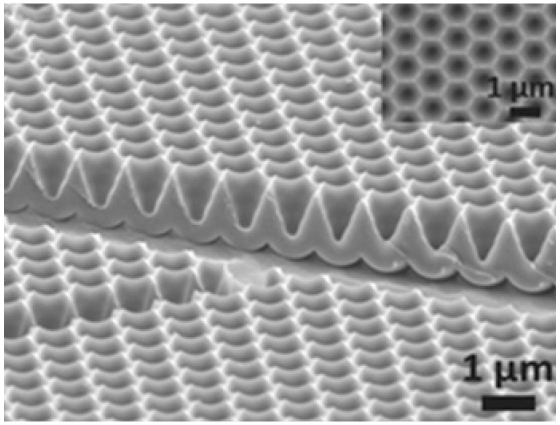
(1) promoting dropwise condensation of the steam on the shell side and eliminating flooding of the surface structure by maintaining low droplet adhesion, thus increasing condensation heat transfer coefficient;

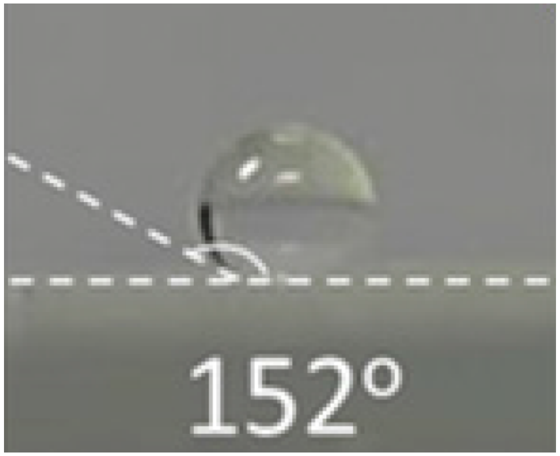
(2) accommodating higher flow rate of cooling water in the tubes for a fixed pressure drop due to reduced drag, thus improving the forced convection heat transfer coefficient and exergetic efficiency; and

(3) deterring fouling and corrosion, thereby reducing fouling resistance and improving heat transfer.

Superhydrophobic Surfaces

- Hydrophobic/Superhydrophobic surfaces are not new. Teflon® is a famous example of a hydrophobic surface.
- (Super)hydrophobic surfaces are usually created by coating a material onto a base substrate.
- A drawback is the durability of the coatings. The coating peels off at the interface and the (super)hydrophobicity is lost.
- One approach to creating superhydrophobic surfaces is through nanopatterning.
- While the approach works well on small surfaces, it is not scalable to large surfaces such as condenser tubes.





Coatings 2018, 8(2), 47
doi:10.3390/coatings8020047

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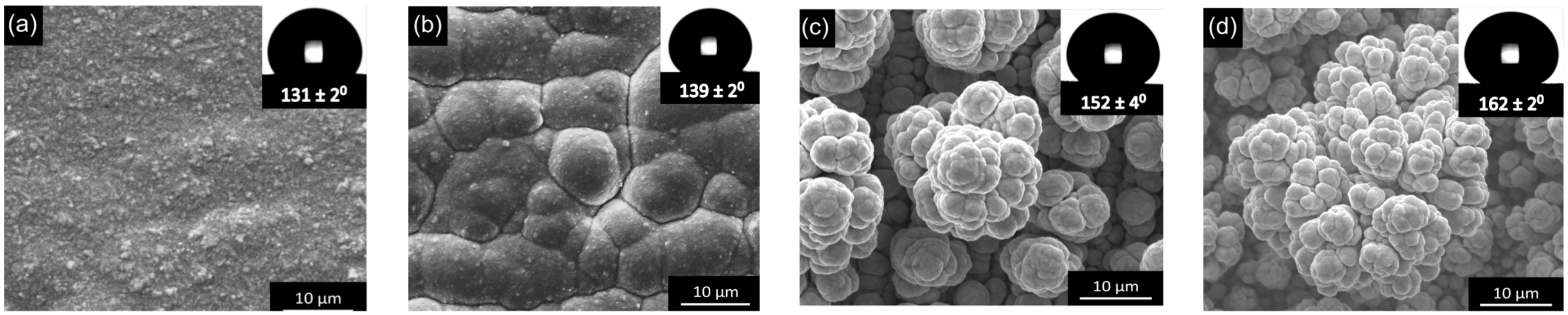
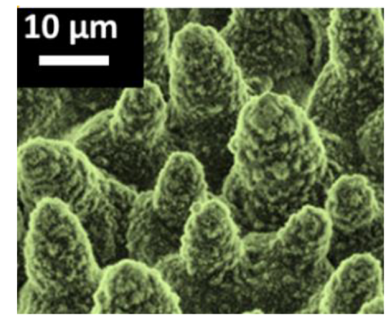
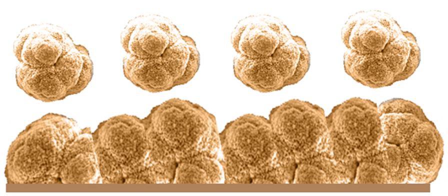
Superhydrophobic Surfaces via Electrodeposition





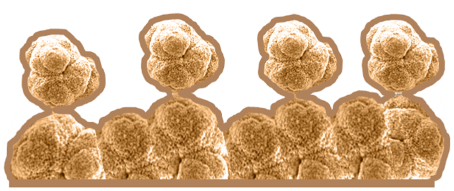
(a)

Cauliflower-shaped structures form on the deposit surface when a high overpotential is applied;



(b)

With increasing time or increasing overpotential, the branches appear detached from the surface;



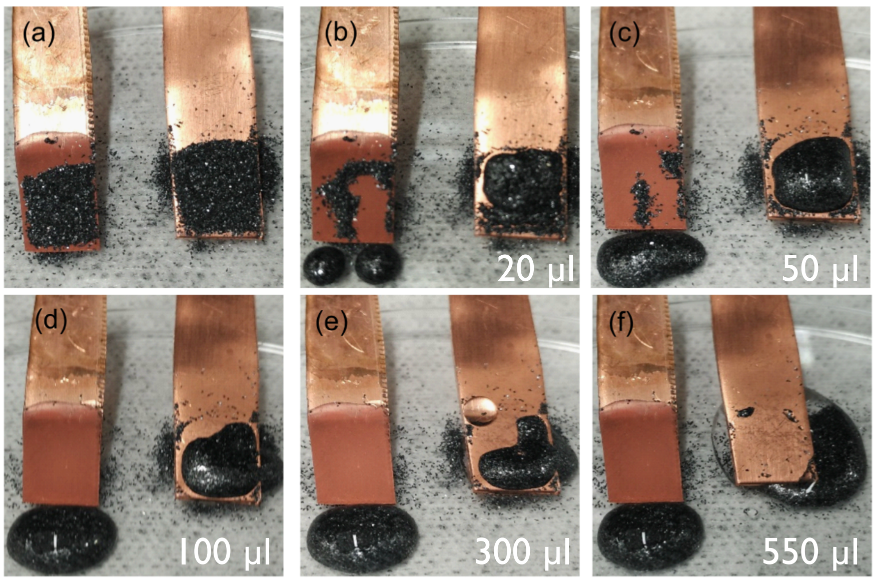
(c)

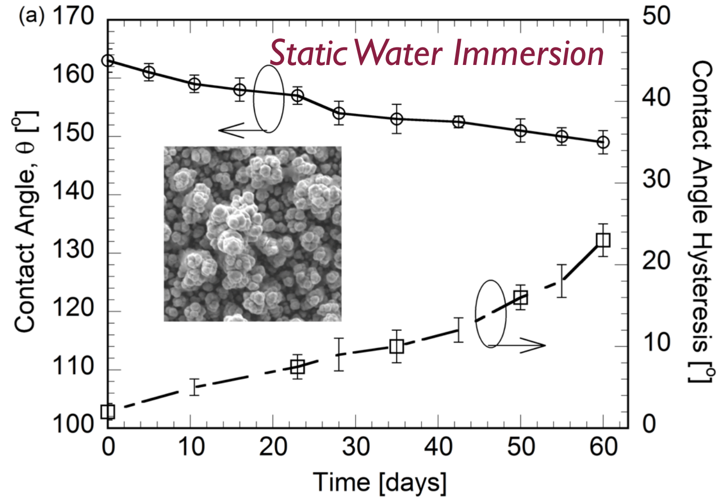
The branches are reattached to the surface by depositing an additional thin layer of metal at a low overpotential (0.15V) for a short time

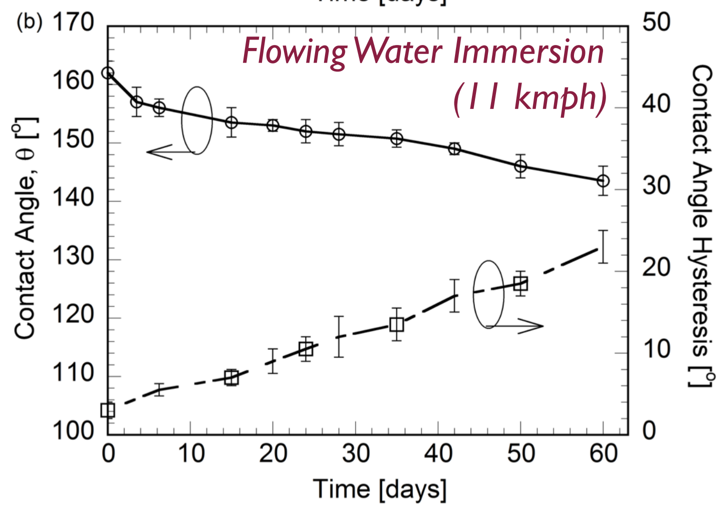
- Novel process for producing superhydrophobic metallic coatings based on electrodeposition.
- Coating is integrally formed on the base metal substrate, eliminating issues of interfacial failures.
- Electrodeposition is a widely used process in the industry and can be used on large as well as small surfaces.
- The process is potentially suited for creating superhydrophobic surfaces on condenser surfaces.

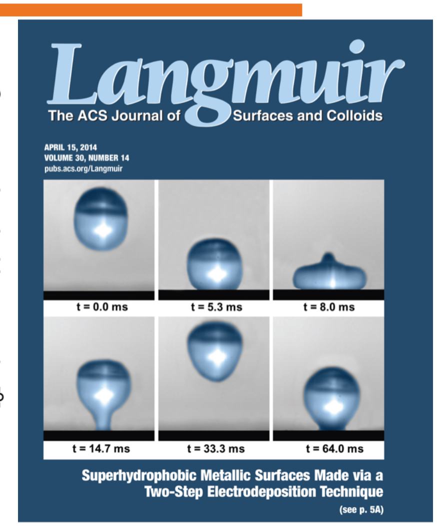
Preliminary Results

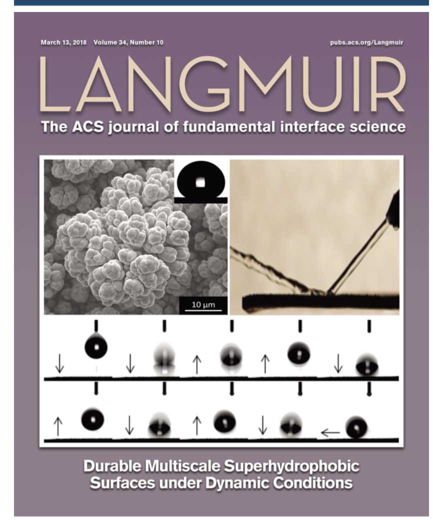
Reduced Fouling



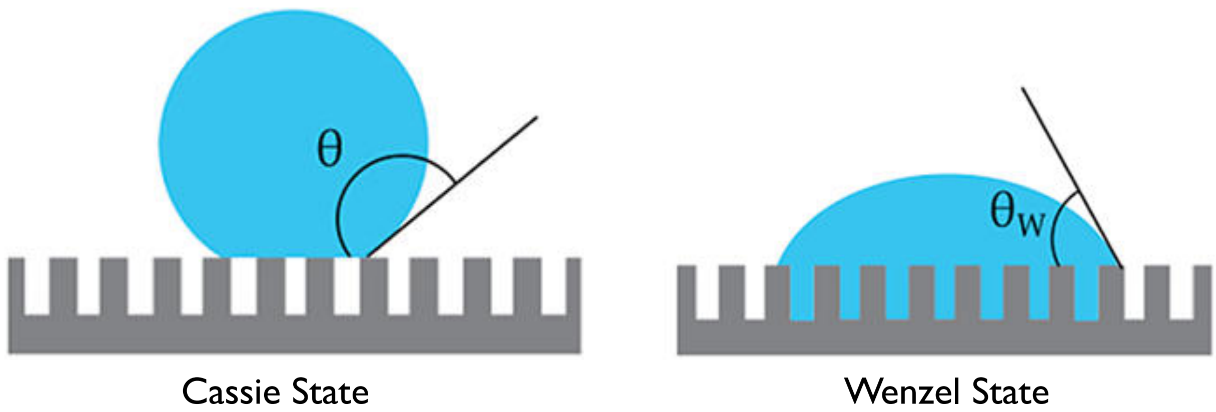




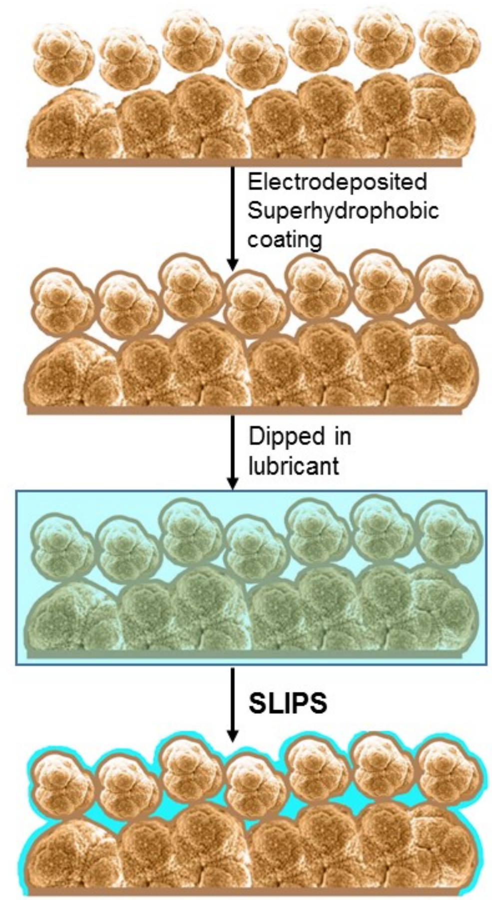




SLIPS Coatings



- Superhydrophobic coatings may transition from the Cassie state to a Wenzel state resulting in loss of superhydrophobicity.
- In our studies, we have demonstrated excellent stability over extended period of months.



- To enhance the durability of coatings further, we are planning to explore fabrication of *slippery liquid infused porous surfaces* (SLIPS)

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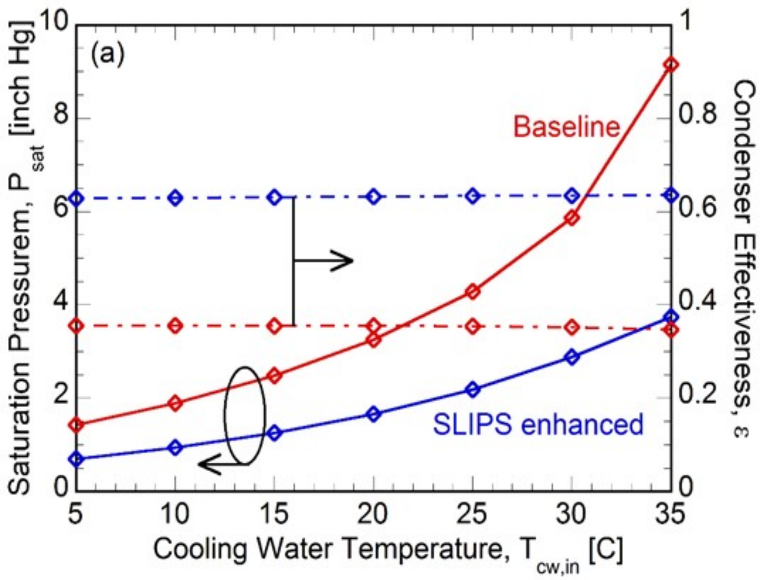
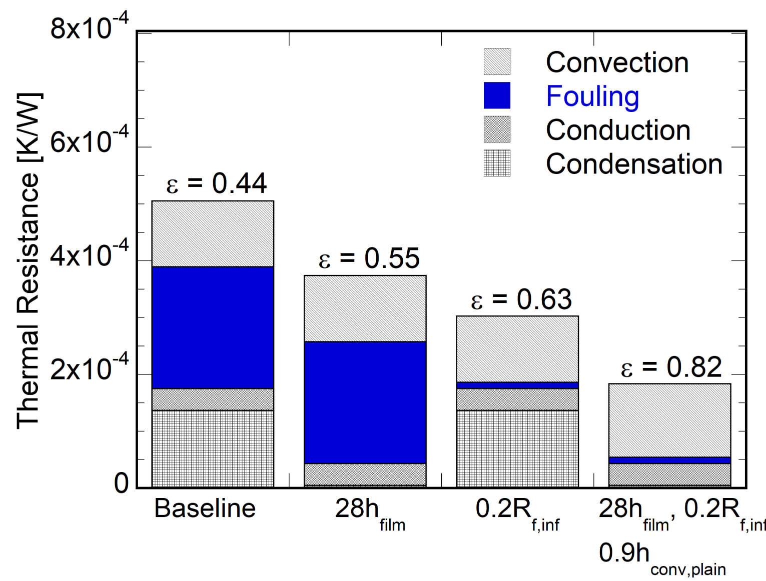
Anticipated Benefits





- By promoting dropwise condensation (28x over film condensation), reducing drag (by an anticipated 15-20%), and reducing fouling resistance, the overall condenser and power plant efficiency are enhanced.
- The enhancement is especially significant during summer when the cooling water temperature is high, as observed by the reduced condenser pressure with Superhydrophobic/SLIPS surface.
- The results suggest that the overall condenser heat exchanger effectiveness can be increased by 1.75 to 1.9 times for cooling water temperature of 5–35 C.
- This results in a reduction in the condenser pressures by 0.7–5.5-inch Hg from the baseline as the temperature ranges from 5–35 C.

Planned Work: Overview

- Investigate fabrication and characterization of Superhydrophobic and SLIPS surfaces on different materials, to systematically elucidate influence of fabrication parameters on the resulting surface texturing performance, and from these studies derive optimal material and process parameter combinations that lead to best performance in power plant condenser applications.
- Conduct studies to characterize and demonstrate performance improvements as follows:
  - Systematically characterize the condensation heat transfer performance on the *steam-side* of Superhydrophobic/SLIPS tubes and plates for a range of operating conditions, and develop correlations.
  - Systematically characterize drag reduction and convective heat transfer improvements on the cooling water flow *inside* the Superhydrophobic/SLIPS tubes and plates for a range of practical operating conditions, demonstrate performance improvements, and develop correlations.
  - Conduct accelerated fouling and corrosion testing of the Superhydrophobic/SLIPS surfaces to demonstrate improved fouling and corrosion resistance over a range of practical operating environments. The results will be used to quantitatively correlate coating life-time or cleaning intervals and operating conditions.
- Develop a cost/system performance model of a Superhydrophobic/SLIPS enhanced condenser heat exchanger and optimize system design for least payback period and maximum exergetic efficiency.
- Demonstrate a laboratory scale prototype of Superhydrophobic/SLIPS enhanced tube bundle at turbine condenser design conditions.