Advanced Materials Research and Applications Laboratory

Cooling tower fog harvesting:
Each drop counts

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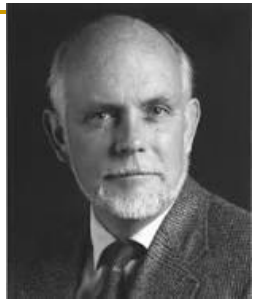
Humanity's top ten problems over the next 50 years:



Richard Smalley, Nobel Prize 1996

1. Energy
2. Water
3. Food
4. Environment
5. Poverty
6. Terrorism and War
7. Diseases
8. Education
9. Democracy
10. Population

2003: 6.5 Billion People
2050: 8-10 Billion People

Cooling tower fog…

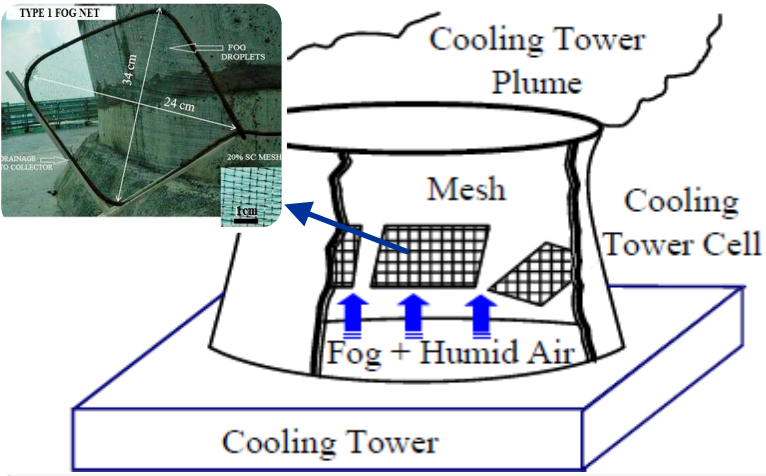
Single largest source of artificial fog ~ 1800 L/h/MW

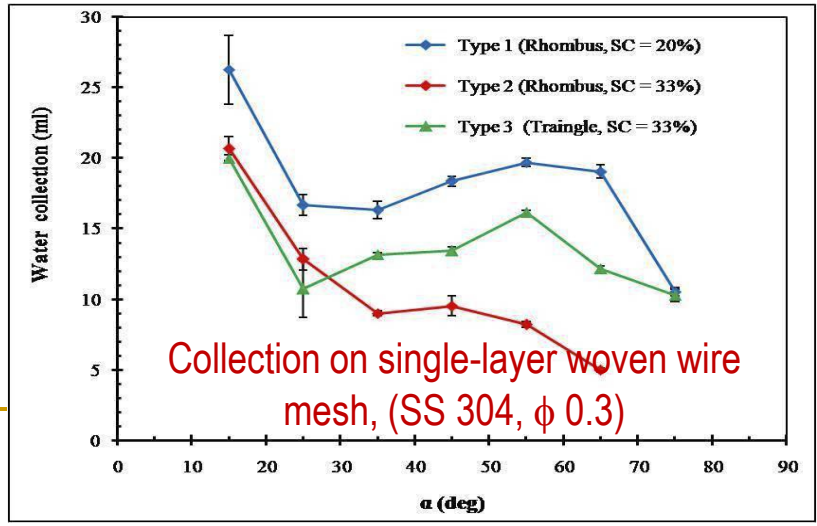
- Un-evaporated water (drift)
- Vapor
- Re-condensed fog

Problems associated with fog

- Loss of water
- Damage to electrical equipment
- Health hazard
- Visibility issues

Cooling tower fog harvester

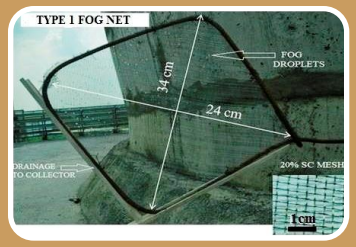




Collection: ~10.5 m^3h^{-1} for a 500 MW unit)

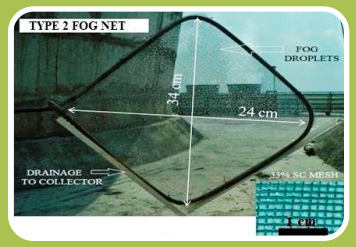
Fog collecting materials

Single-layer woven wire mesh, made of corrosion-resistant stainless steel (grade SS 304) wires of 0.3 mm diameter was used



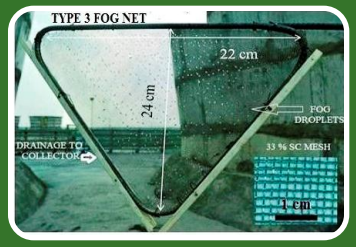
Type 1

- *SC* = 20% - rhombus frame
- Fog net of surface area 0.0814 m^2



Type 2

- *SC* = 33% - triangular frame
- Fog net of surface area 0.0814 m^2



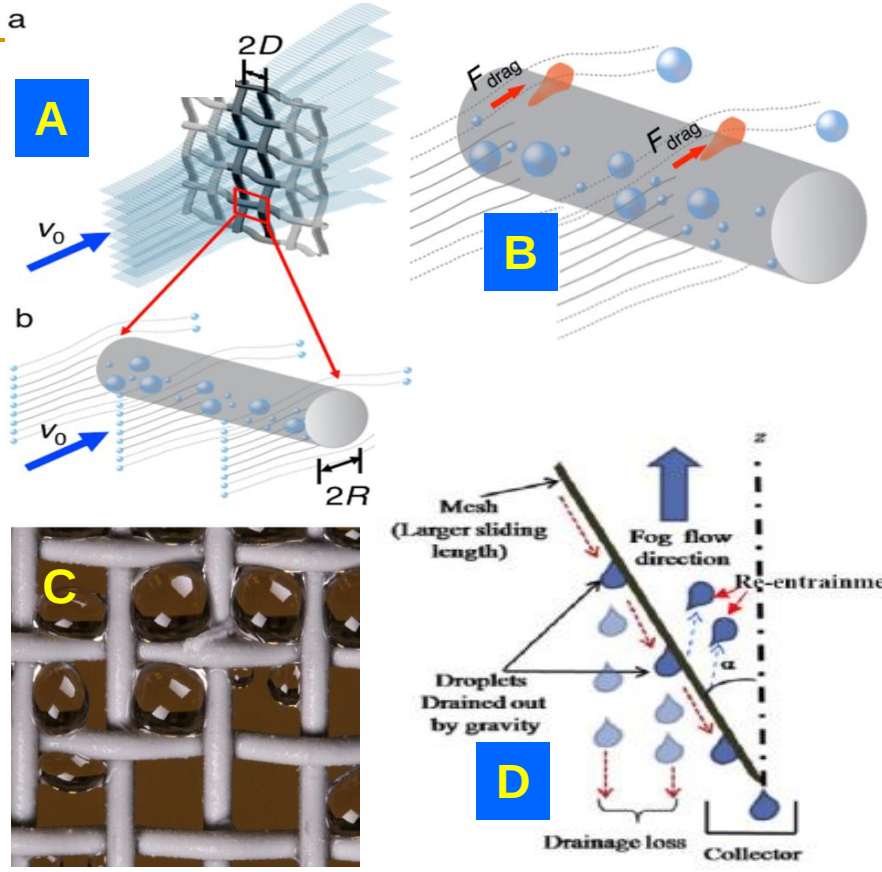
Type 3

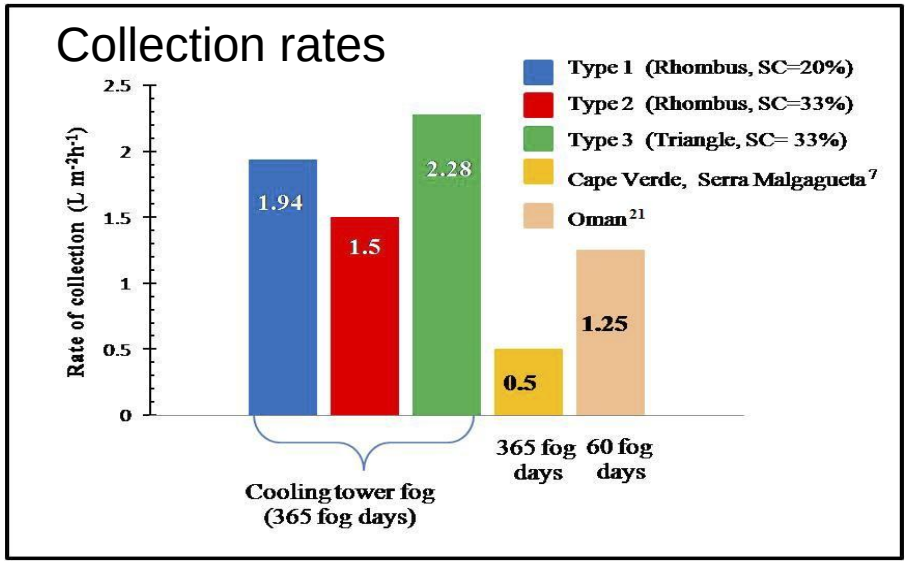
- *SC* = 33% - triangular frame
- Fog net of surface area 0.0525 m^2

 # SC is the fraction of area covered by the fibers in a mesh

Current challenges

- Poor collection efficiency
  - A. Bypassing of fog stream
  - B. Re-entrainment
  - C. Flooding of pores
  - D. Premature dripping
- Durability of fog nets





Desired mesh property

- Better aerodynamic efficiency
- High adhesion
- Low sliding angle
- Durability of surface finish

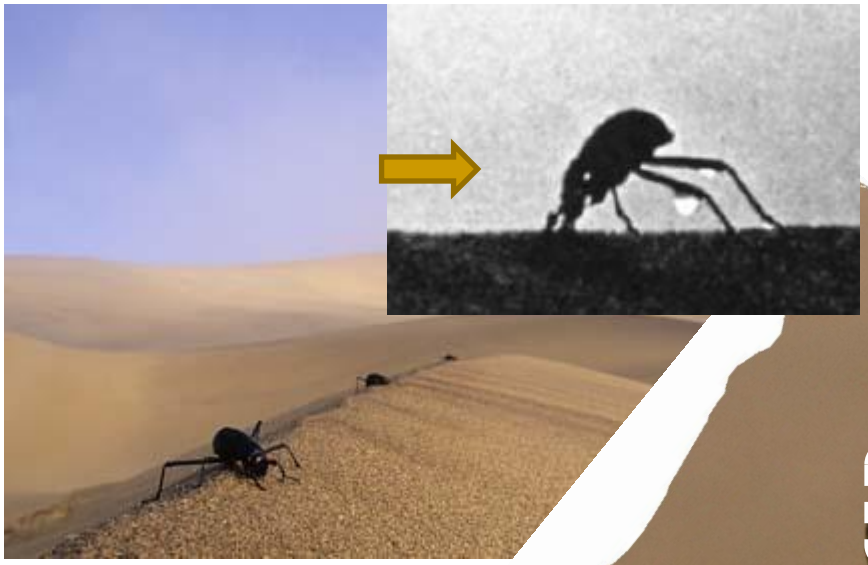
- Park *et al., Langmuir,* 29 (2013) 13269
- Ghosh *et al*, Energy, 89(2015) 1018

Namib desert: one of the most arid desert on earth

Average annual rainfall: 2 – 200 mm
Average annual temperature: 9 – 20 ^{o}C

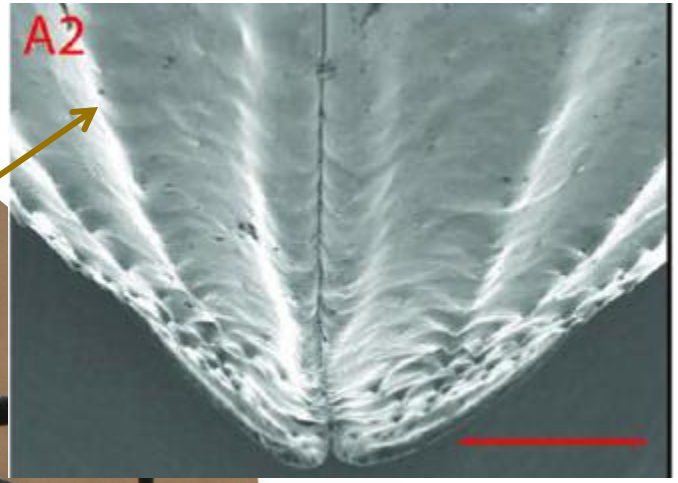
Morning fog: 60 – 200 days in a year
Water droplet : 1 – 40 μm

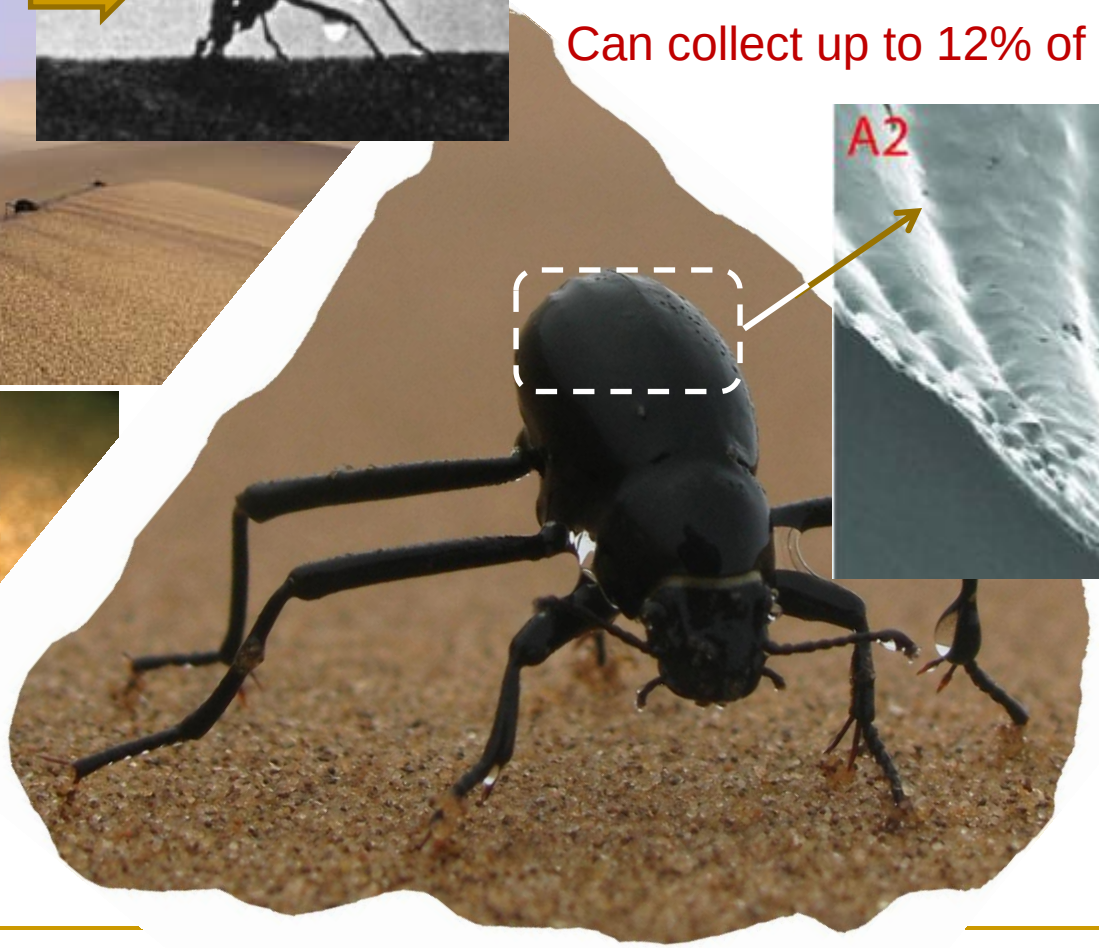
Surface roughness and water collection…



Namib Desert Beetle: *Fog basking beetle*
Onymacris unguicularis

Can collect up to 12% of their body weight!



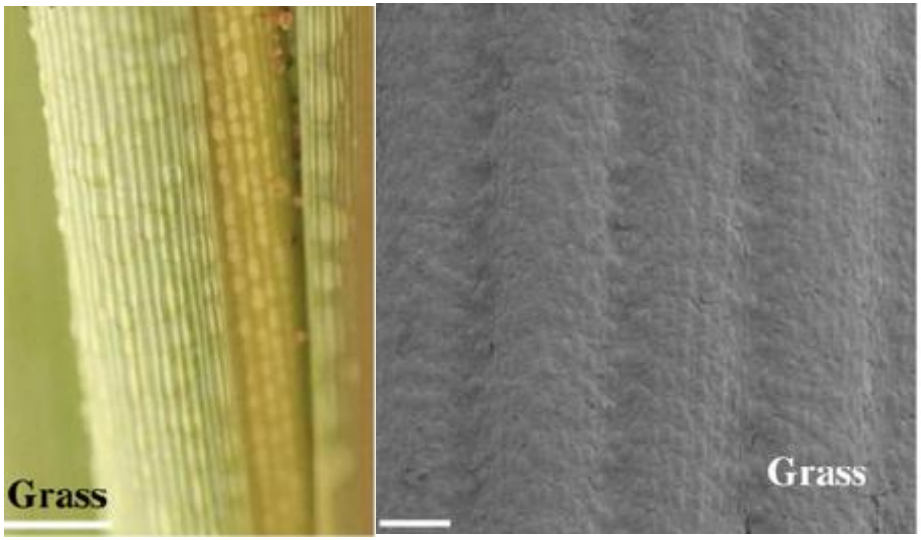


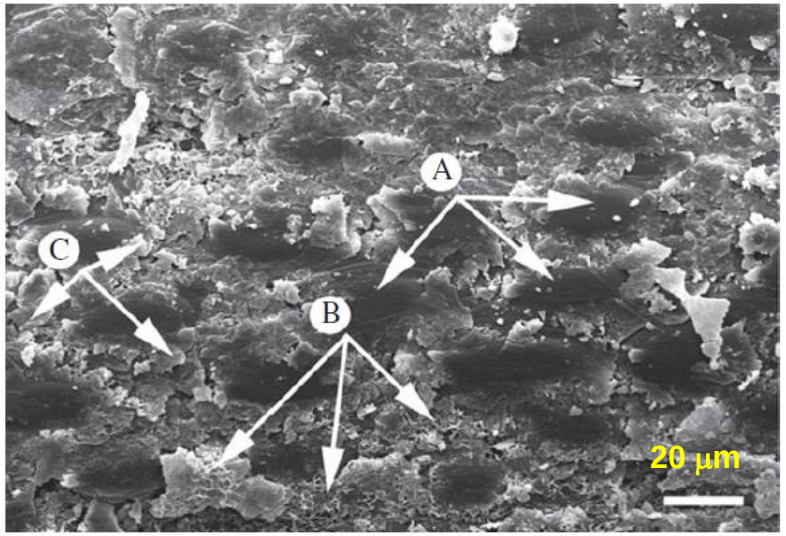
Hamilton and Seely, Nature, 262 (1976) 285

Nørgaard and Dacke, Frontiers in Zoology 7 (2010) 1

Surface roughness and water collection…

- *Stipagrostis sabulicola (Bushman grass)*
- Longitudinal grooves (30 – 80 μm) and ridges (100 – 150 μm)
- Prickle hair, micro-crystalline silica, putative wax on surface
- Collection up to 4 – 5 L per fog event (~5 L/m^2/day)





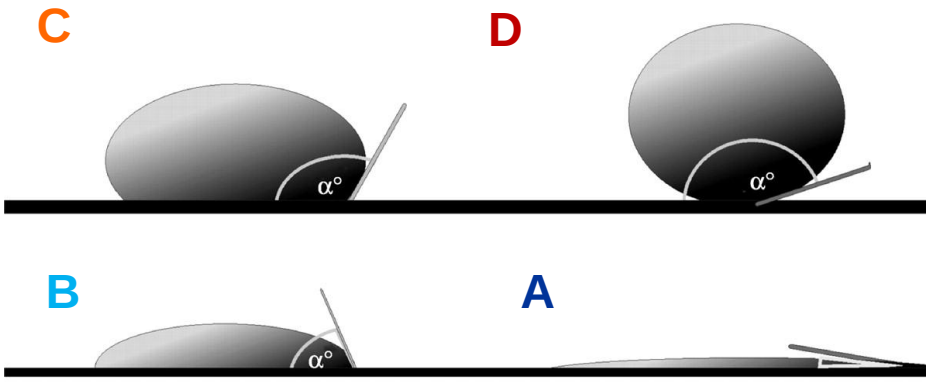
θ_a ~ 98°, θ~ 77°, θ_r~ 56°

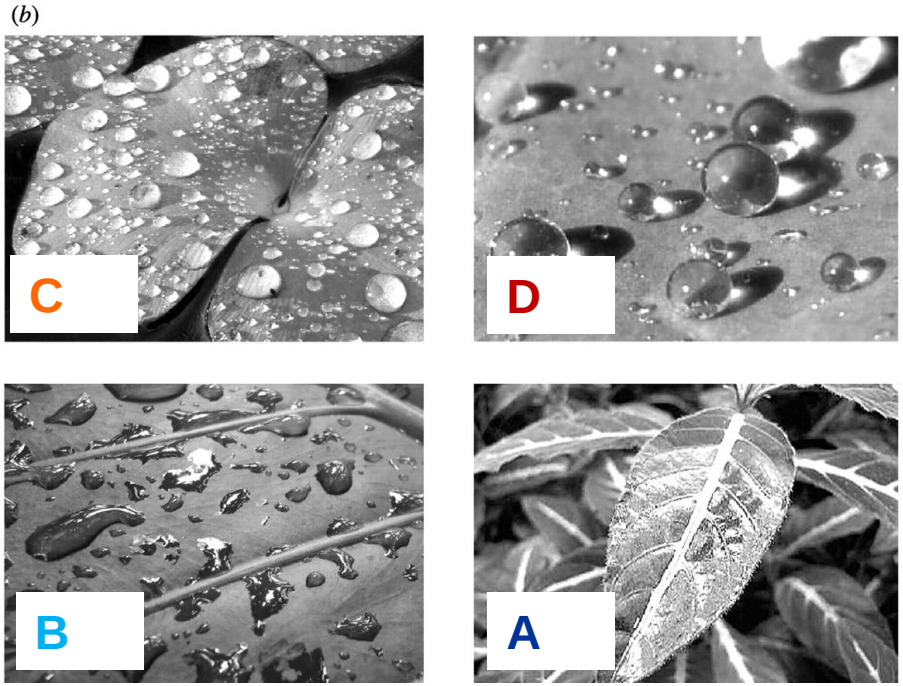
Roth-Nebelsick et al., J. Royal Society Interface, 9 (2012) 1965

What we are currently working on …

- To develop an efficient fog collector for water recovery from power plant cooling tower plumes.
- Objective
  - Develop, through laboratory experiments, a prototype of wettability-engineered metal mesh for rapid fog collection with high overall collection efficiency
  - Characterize mesh performance
  - Optimize collection efficiency

Surface wettability…





A: 0° <θ< 20°: Superhydrophilic

B: 20° <θ< 90°: Hydrophilic

C: 90° <θ< 150°: Hydrophobic

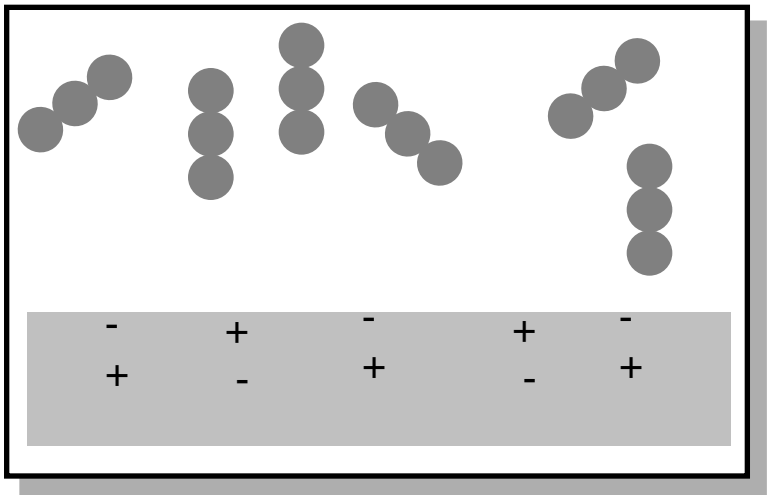
D: 150° <θ< 180°: Superhydrophobic

Superhydrophobic surfaces generally offer low hysteresis, and easy “roll-off”

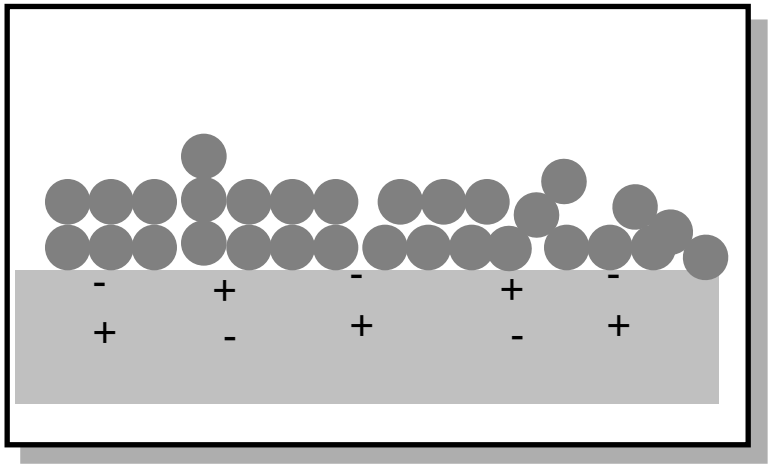
Surface tailoring - hydrophobization

Decrease wetting of water/ increase contact angle:
Attach/produce non polar groups on surfaces to *cover polar bulk material*

- Materials
  - Teflon, fluorinates
  - Silicone
  - Non polar polymers
- Processes
  - (dip) Coating
  - Plasma deposition
  - Vapour deposition
  - Adhesive coating



non polar groups: e.g. C_4F_8



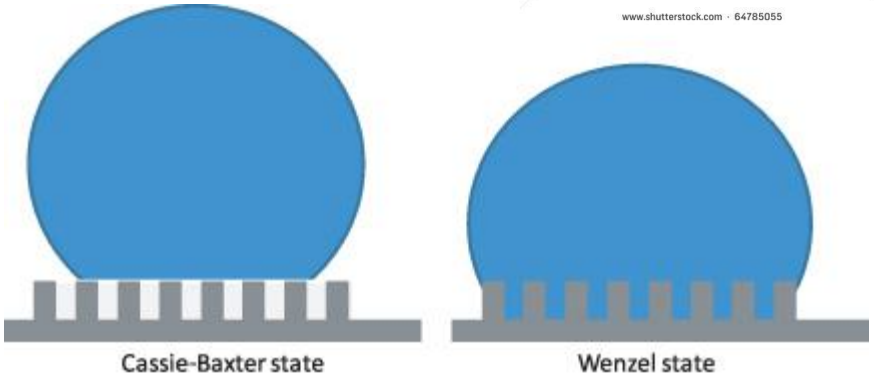
Surface texture

- Wenzel state

$$\cos\theta_{\text{rough}} = r\cos\theta_{\text{smooth}}$$

- Cassie Baxter State

$$\cos\theta^* = -1 + (1-\phi_s)\cos\theta$$

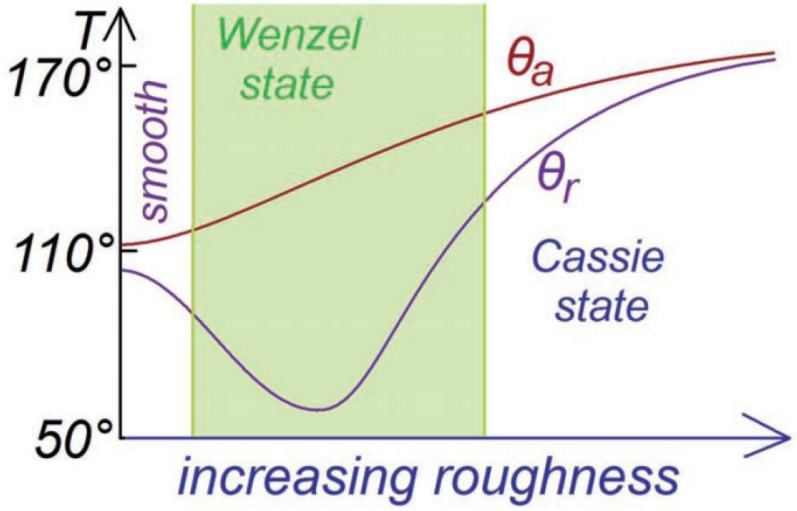


- Cassie state more stable when:

$$\theta_Y > \theta_c,\ \cos(\theta_c) = -\frac{1-f}{r-f}$$

f = Solid fraction,

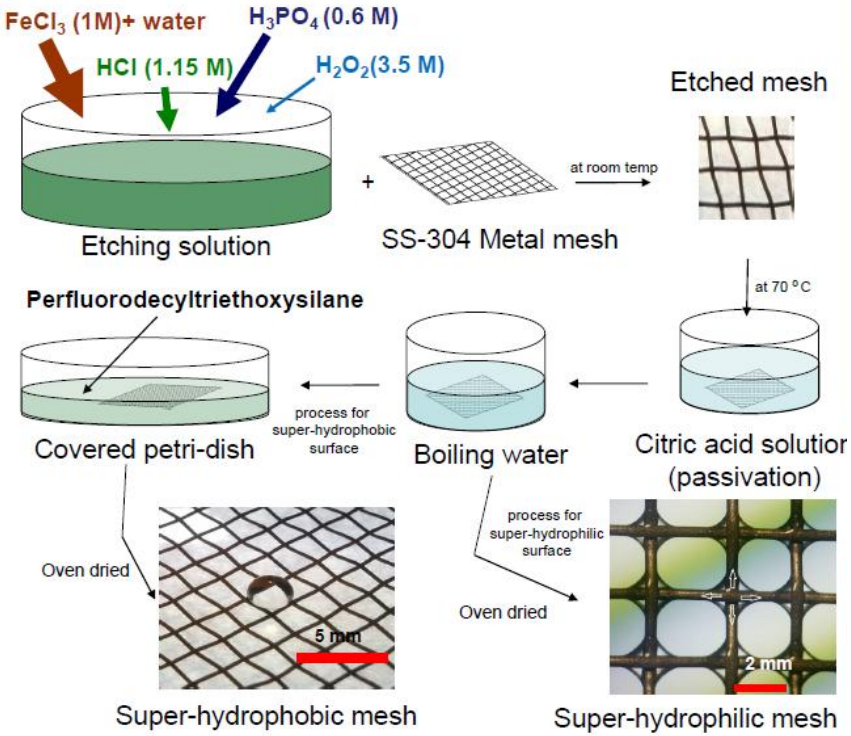
r = Surface roughness ratio (>1)

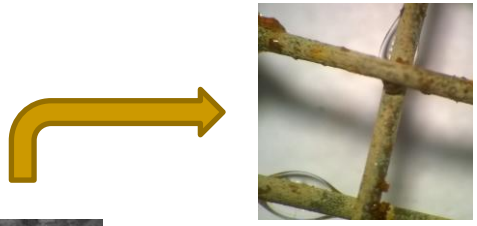


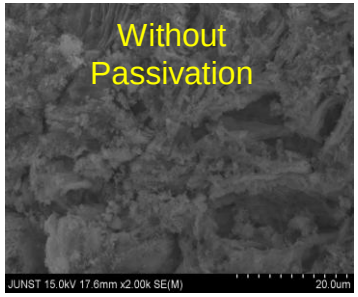
Wettability Engineering of Metal Mesh

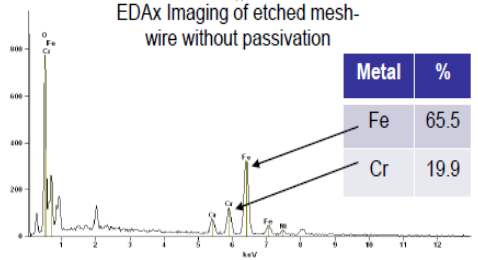
Wettability-engineered fog nets

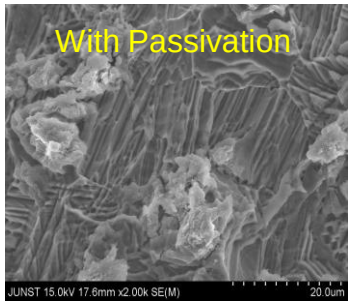
Wet chemical route: facile and scalable

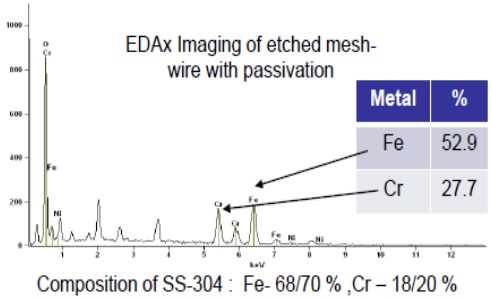




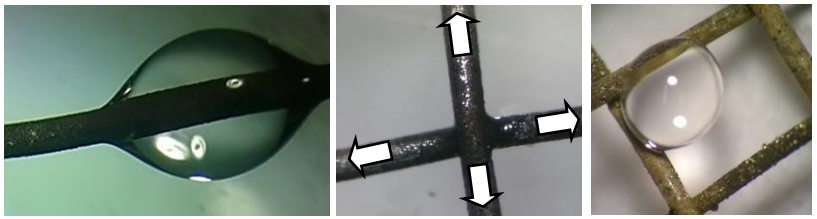




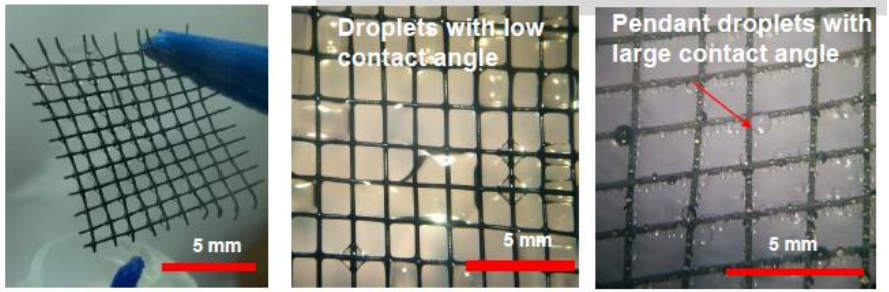




Composition of SS-304 : Fe- 68/70 % ,Cr – 18/20 %



HPL SHPL SHPB

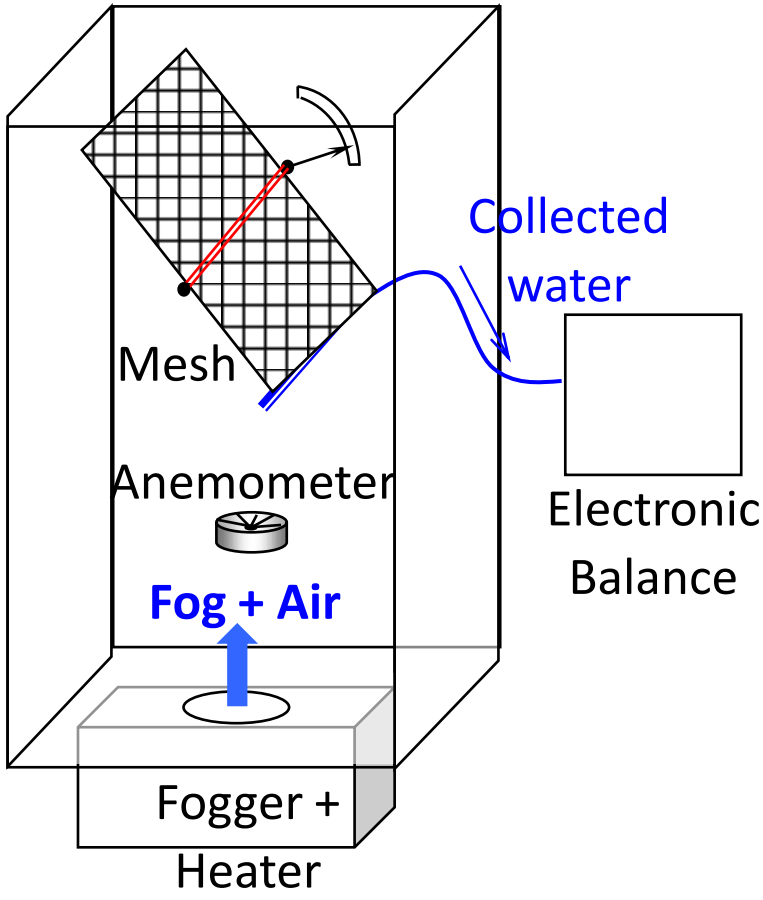


As received mesh Superhydrophilic mesh Superhydrophobic mesh

Behavior of fog droplets deposited on the meshes.

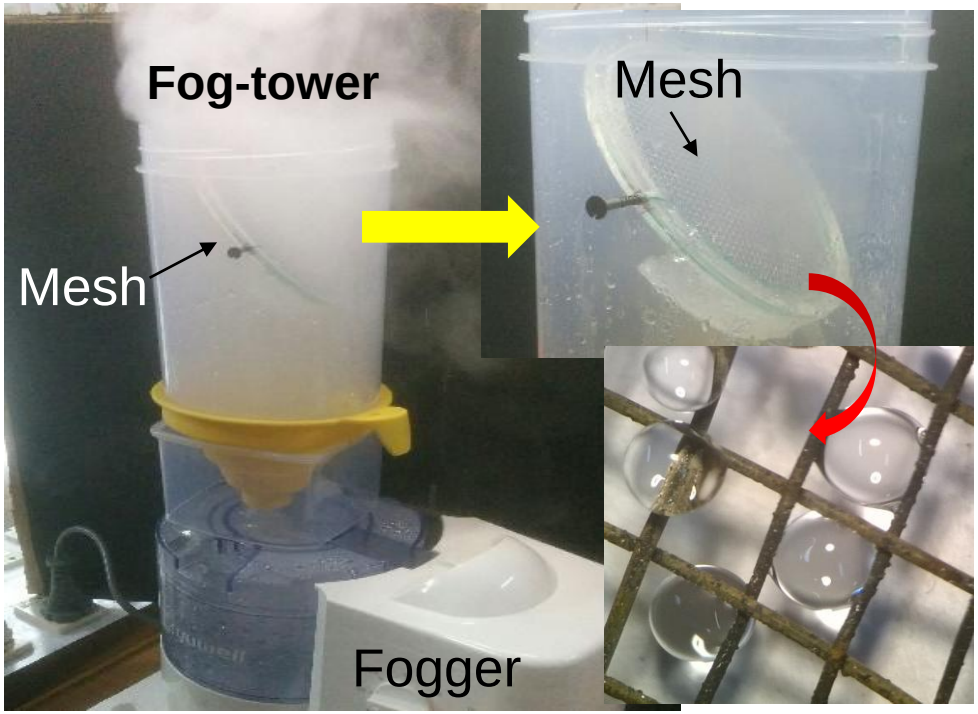
Fog tunnel experiments…

- Development of a fog harvesting test bench
- Development of wettability-tuned metal mesh
- Miniature prototype fog-harvesting setup
- Performance characterization of the prototype



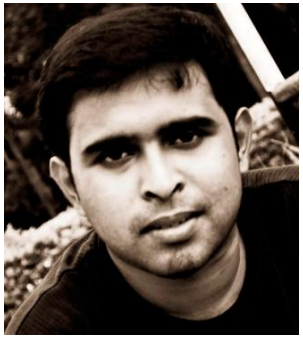
What else can we do in this regard by harnessing the capillary force to our advantage?

Team JU



The fog team:

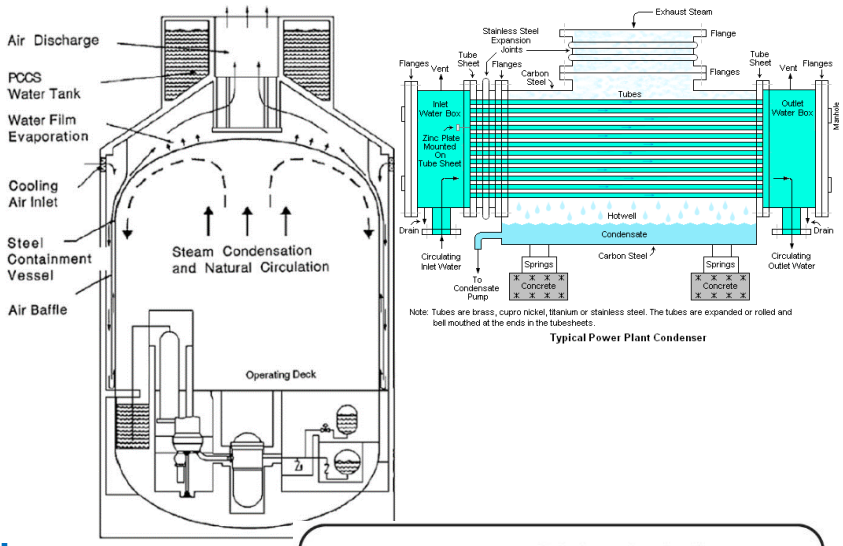
Ritwick Ghosh (PhD Student)
Priya Singh (UG Student)
Chandrima Patra (UG Student)

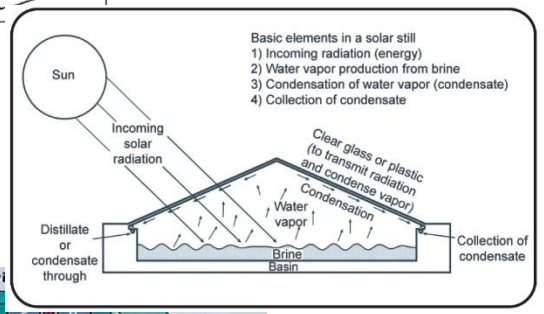


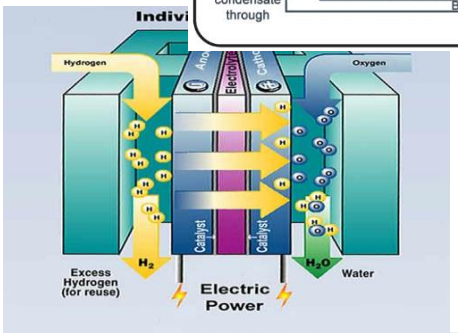
Seed grant from **JU-TEQIP (II)** and support for participating at the International Engineering Sourcing Show (IESS-VII), 2018, Chennai

Broader motivation

- Enhancing DWC
  - Condensers and FW Heaters in power plants
  - Passive containment cooling in nuclear reactors
  - Solar desalination plants
- Water management in fuel cells
- Condensate removal in HVAC
- **Water/fog harvesting**
- **Atmospheric water capture**







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