Increasing fog harvesting efficiency through hydrophobizing steel meshes

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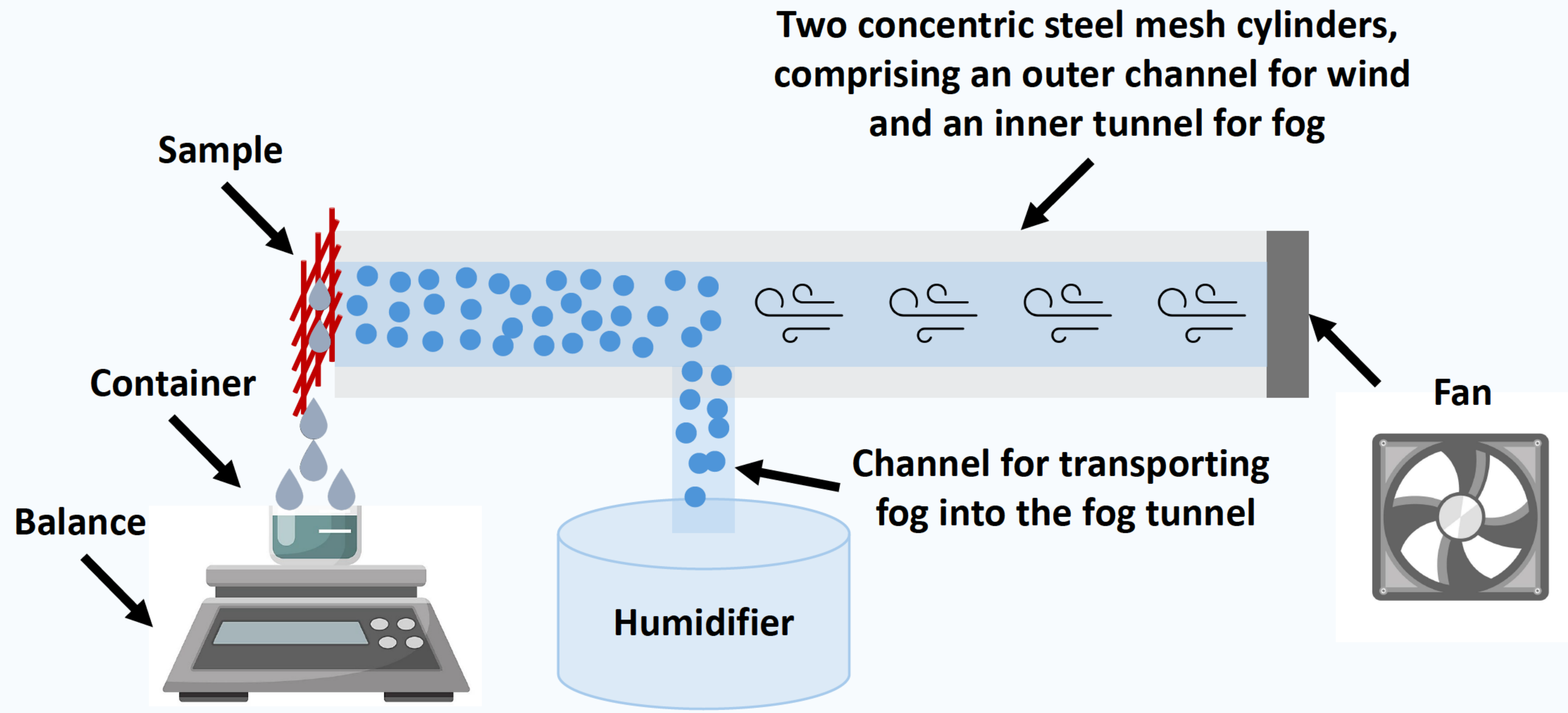
DIPSI- 17th June 2024

Contents:

- ✓WaterHaB project
  - ✓Dropen and DropenVideo
  - ✓Drop impact on meshes
  - ✓Water harvesting
- ✓Conclusion



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WaterHaB

Engineering bio-inspired atmospheric Water Harvesters through fog collection with Badgir architecture

Materials

Meshes

1. accelerate collection
2. prevent evaporation
3. reduce blockage

Engineering

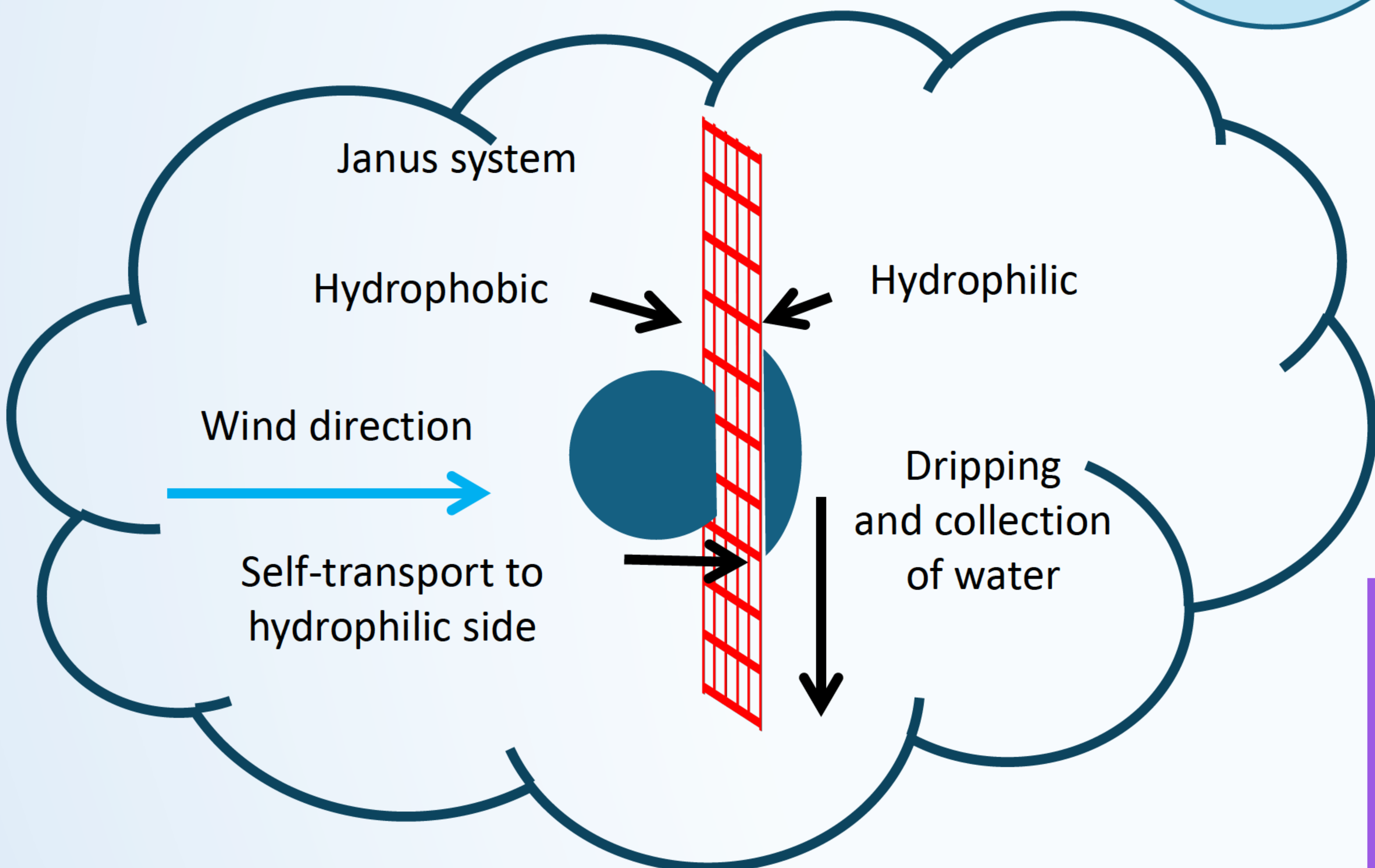
Windcatcher: "Badgir"

1. higher efficiency
2. reduced destruction
3. dew condensation

Physics

Wettability tests

1. accumulation
2. transportation



Issues:

(i) re-entrainment of collected droplets into the prevalent wind

(ii) mesh opening blockage

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la Repubblica

International award of "Le Tecnovisionarie®", 2024, Italy

la Repubblica
Milano

Quotidiano

Data 05-11-2021
Pagina 1+4
Foglio 1 / 2

La storia

La ricercatrice che ricava acqua dalla nebbia

di **Tiziana De Giorgio**

Ci lavora ogni giorno da quando, poco prima del lockdown, da Teheran è arrivata a Milano, trovando terreno fertile per la sua idea proprio nella città della "scighera". Ma l'acqua, o meglio il diritto all'acqua, è sempre stato un chiodo fisso. Sta studiando un sistema economico ed ecologico per ricavarla dalla nebbia Raziyeh Akbari, ricercatrice iraniana che dal 2020 lavora nel dipartimento di Scienza dei materiali dell'università Bicocca.

● *a pagina 4*

▲ **Alla Bicocca** Raziyeh Akbari è arrivata nell'ateneo cittadino un anno fa

Acqua dalla nebbia l'idea della ricercatrice dall'Iran alla Bicocca

"Voglio aiutare le persone che vivono nelle aree meno sviluppate del mondo". Alla base un materiale ispirato alle spine dei cactus

di **Tiziana De Giorgio**

Ci lavora ogni giorno da quando, poco prima del lockdown, da Teheran è arrivata a Milano, trovando terreno fertile per la sua idea proprio nella città della "scighera". Ma l'acqua, o meglio il diritto all'acqua, è sempre stato un chiodo fisso: «Il pensiero di aiutare le persone che vivono in aree meno sviluppate del mondo cresce con me da quando ero bambina. E cercare un modo per mettere a loro disposizione acqua pulita è la massima priorità». Sta studiando un sistema economico ed ecologico per ricavarla dalla nebbia Raziyeh Akbari, ricercatrice iraniana che dal 2020 lavora nel dipartimento di Scienza dei materiali dell'Università Bicocca. È qui, nell'ateneo milanese diventato un avamposto per la ricerca sulla sostenibilità e il clima, che porta avanti il progetto "WaterHab". Trentadue anni, una laurea e un dottorato in Fisica, Akbari ha ideato un sistema innovativo che potrebbe trasformarsi in una risorsa in tanti luoghi dove la pioggia è rara e dove manca acqua pulita anche solo per lavarsi o cucinare.

Alla base di tutto c'è un nuovo materiale ispirato alla geometria delle spine dei cactus che permette di accelerarne la raccolta dall'atmosfera e prevenire la sua evaporazione. È a questo che sta lavorando da quasi due anni Akbari, con la supervisione del professor Carlo Antonini, scienziato dei materiali, e dal collega Riccardo Ruffo, chimico. Serve a dar vita a un nuovo strumento, una specie di maglia metallica, collegata a un semplice sistema di raccolta di liquidi, che grazie a un trattamento speciale fa passare l'aria ma intrappola l'acqua.

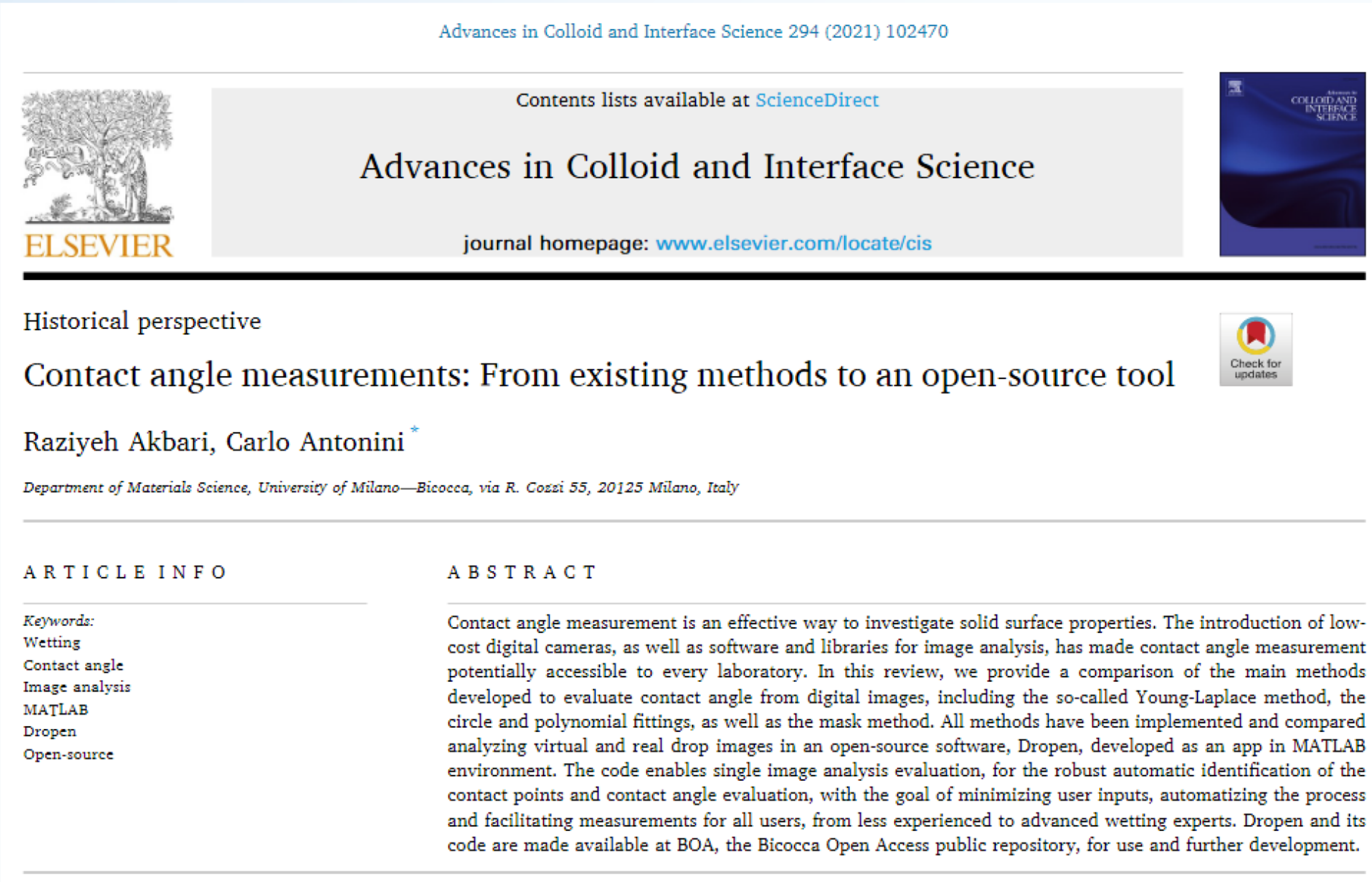
I primi WaterHab verranno inizialmente istallati sui Bagdir, le torri "acchiappavento" che si trovano sui tetti degli edifici nei de-

▲ **Raziyeh Akbari**
La ricercatrice lavora nel settore Scienza dei materiali

Lo studio in corso alla Bicocca "Sfrutto l'interazione tra liquidi e superfici"

https://milano.repubblica.it/cronaca/2021/11/05/news/acqua_dalla_nebbia_l_idea_della_ricercatrice_dall_iran_alla_bicocca-325192334/

Dropen and DropenVideo


Advances in Colloid and Interface Science 294 (2021) 102470

Contents lists available at ScienceDirect

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journal homepage: www.elsevier.com/locate/cis

Historical perspective

Contact angle measurements: From existing methods to an open-source tool

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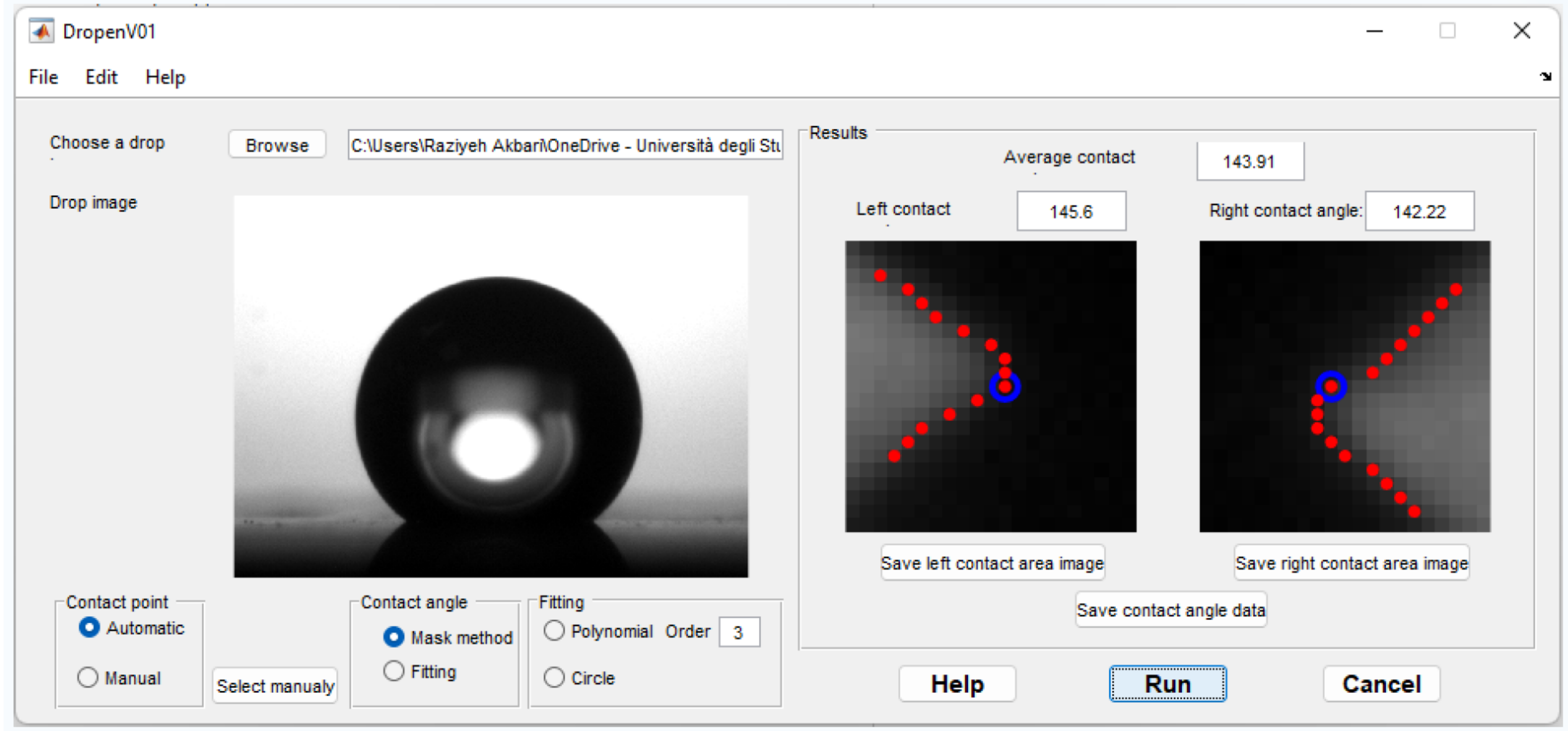
A R T I C L E I N F O

Keywords:
Wetting
Contact angle
Image analysis
MATLAB
Dropen
Open-source

A B S T R A C T

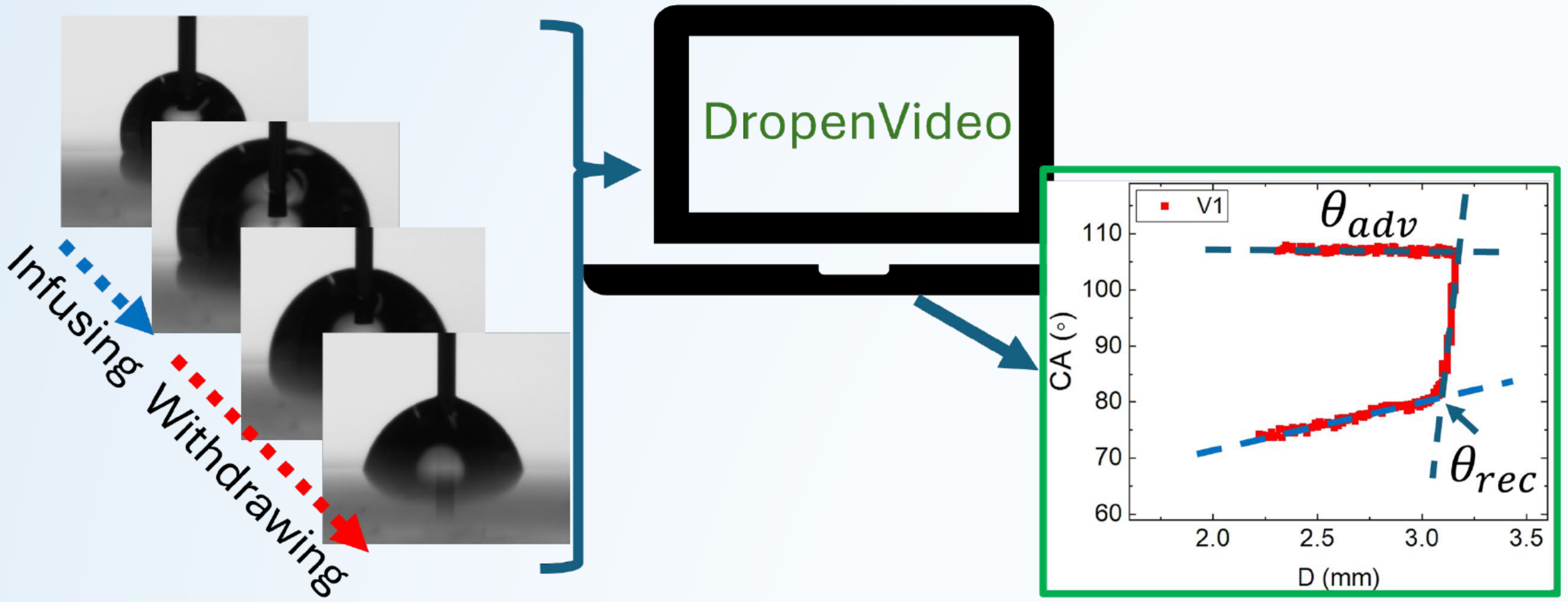
Contact angle measurement is an effective way to investigate solid surface properties. The introduction of low-cost digital cameras, as well as software and libraries for image analysis, has made contact angle measurement potentially accessible to every laboratory. In this review, we provide a comparison of the main methods developed to evaluate contact angle from digital images, including the so-called Young-Laplace method, the circle and polynomial fittings, as well as the mask method. All methods have been implemented and compared analyzing virtual and real drop images in an open-source software, Dropen, developed as an app in MATLAB environment. The code enables single image analysis evaluation, for the robust automatic identification of the contact points and contact angle evaluation, with the goal of minimizing user inputs, automatizing the process and facilitating measurements for all users, from less experienced to advanced wetting experts. Dropen and its code are made available at BOA, the Bicocca Open Access public repository, for use and further development.



R. Akbari, C. Antonini, Contact angle measurements: From existing methods to an open-source tool, ***Advances in Colloid and Interface Science,*** 294, 2021, 102470

https://doi.org/10.17632/wzchzbm58p.3

Dropen and DropenVideo



Wetting characterisation on complex surfaces by an automatic open-source tool: DropenVideo

Under review

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DIPSI 2022

DEVELOPMENT OF A ROBUST OPEN-SOURCE SOFTWARE FOR

THE AUTOMATIC ANALYSIS OF STATIC AND QUASI-STATIC CONTACT ANGLES

Raziyeh Akbari Carlo Antonini

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DIPSI- 1st July 2022

Drop impact experiments

Physics of Fluids ARTICLE pubs.aip.org/aip/pof

Outcomes from water drop impact on hydrophobic meshes

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Raziyeh Akbari (راضیه اکبری),[1,a)] Yu Wei (魏瑀),[1,2] Alberto Bagni,[1] Riccardo Ruffo,[1] Marie-Jean Thoraval (陶益壮),[2,3] Longquan Chen (陈龙泉),[4,5] and Carlo Antonini[1,a)]

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[4]School of Physics, University of Electronic Science and Technology of China, Chengdu 610054, People's Republic of China
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UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA

DIPSI 2023

Understanding water drop impact

on porous meshes for effective fog harvesting

SEFI Lab

Raziyeh Akbari

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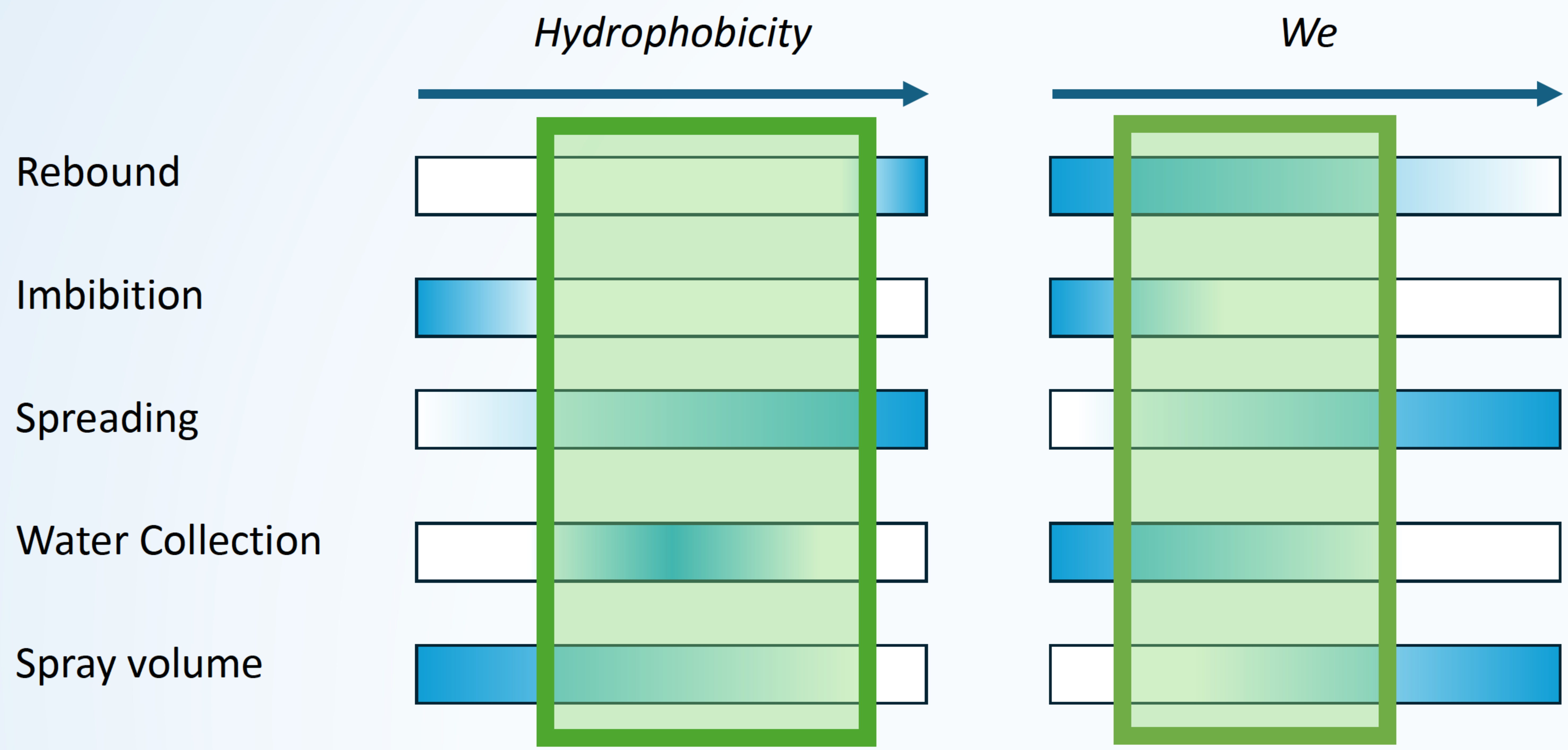
DIPSI- 16[th] June 2023

R. Akbari, Y. Wei, A. Bagni, R. Ruffo, M.J- Thoraval, L. Chen, C. Antonini, "Outcomes from water drop impact on hydrophobic meshes", **Physics of Fluids,** 36, 2024, 027137.
https://doi.org/10.1063/5.0189860

Drop impact experiments



Wind can help

$\theta_a > 140$

$10 < \Delta\theta < 20$

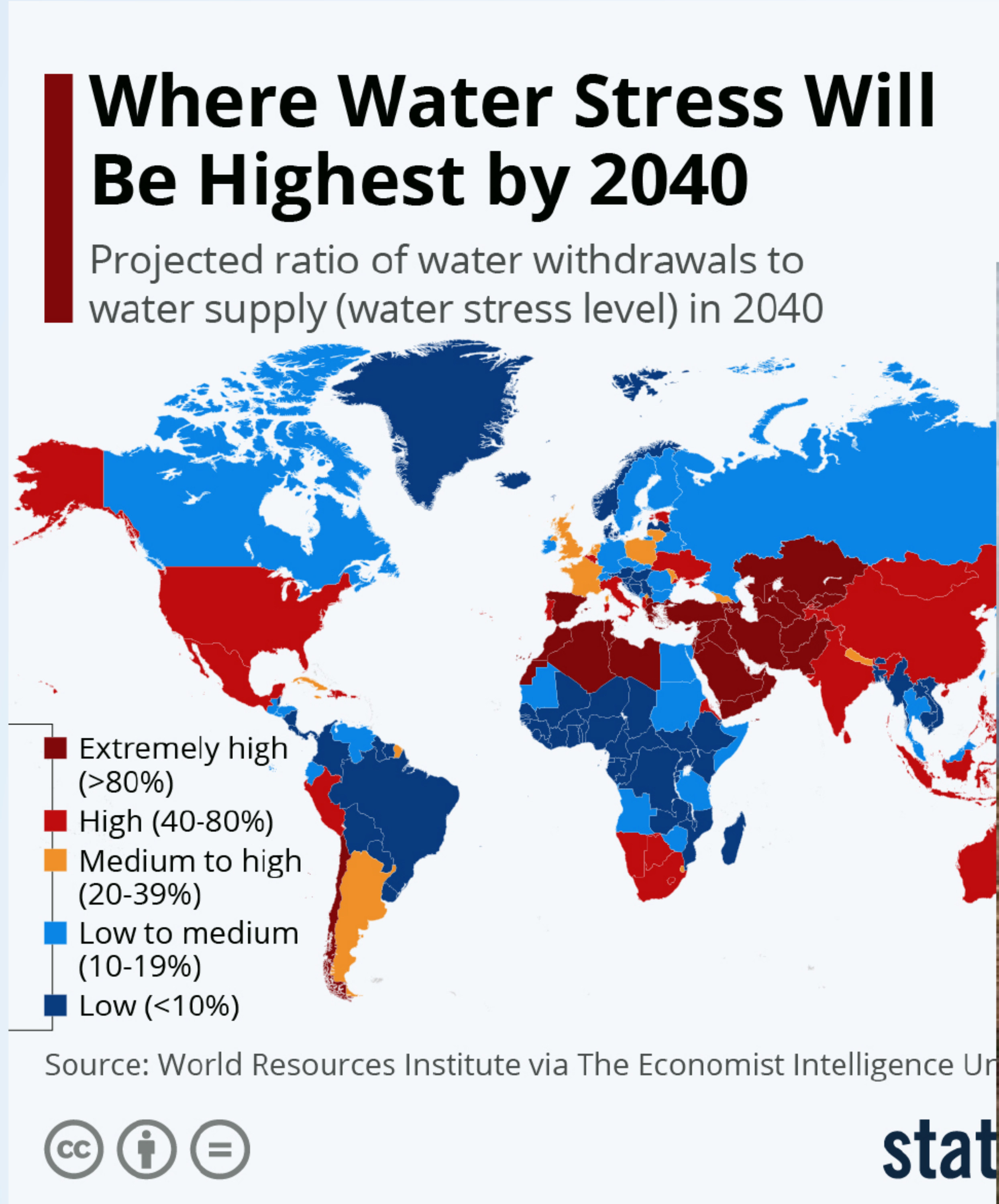
DIPSI 2023

For fog harvesting:

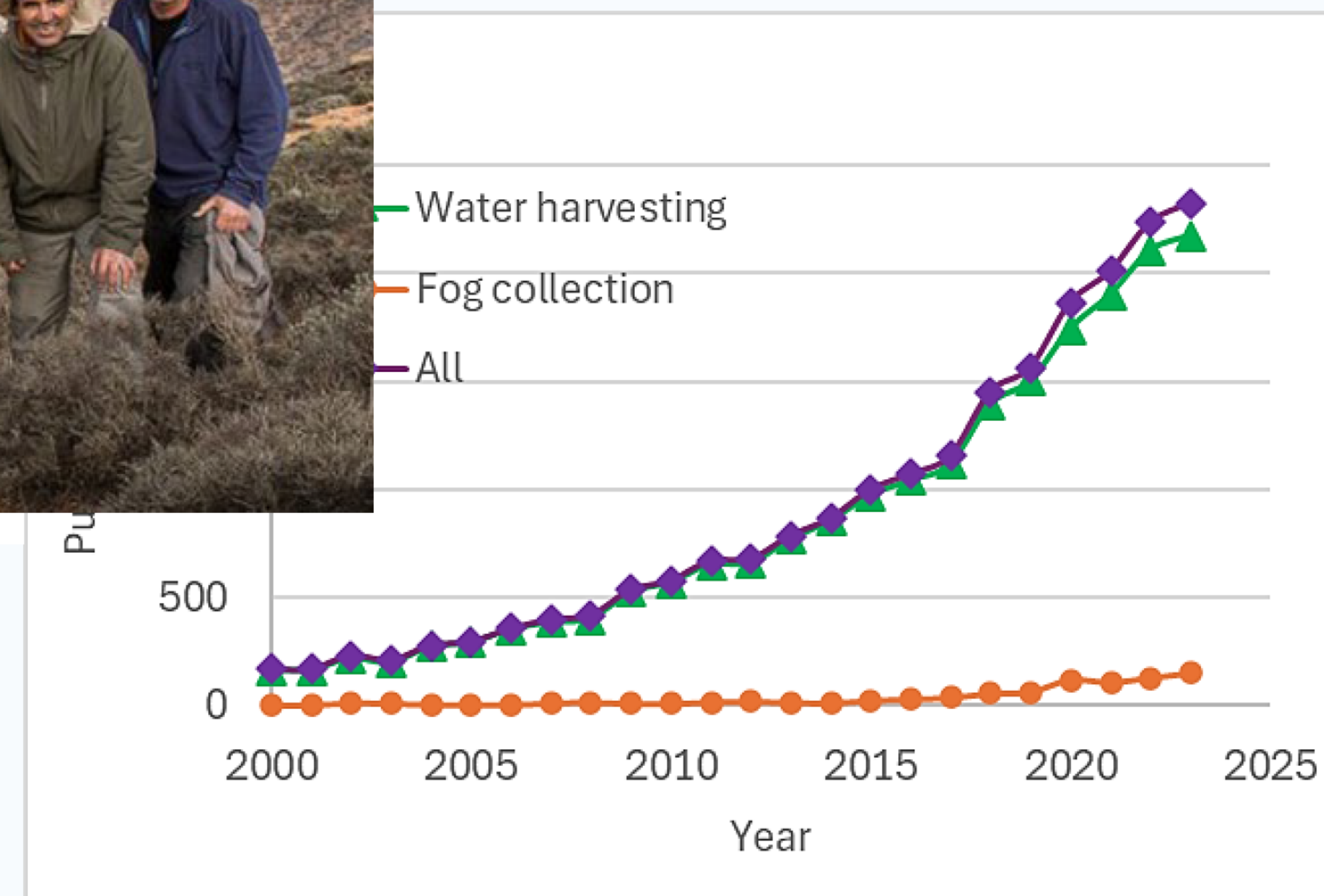
(i) Lower re-entrainment of collected drops into the prevalent wind = **No rebound**

(ii) Lower mesh blockage= **No imbibition, higher penetration, not very high spreading**

Water harvesting experiments



“Dar Si HMD“ in Morocco



RSC Advances, 13, 2023, 10273

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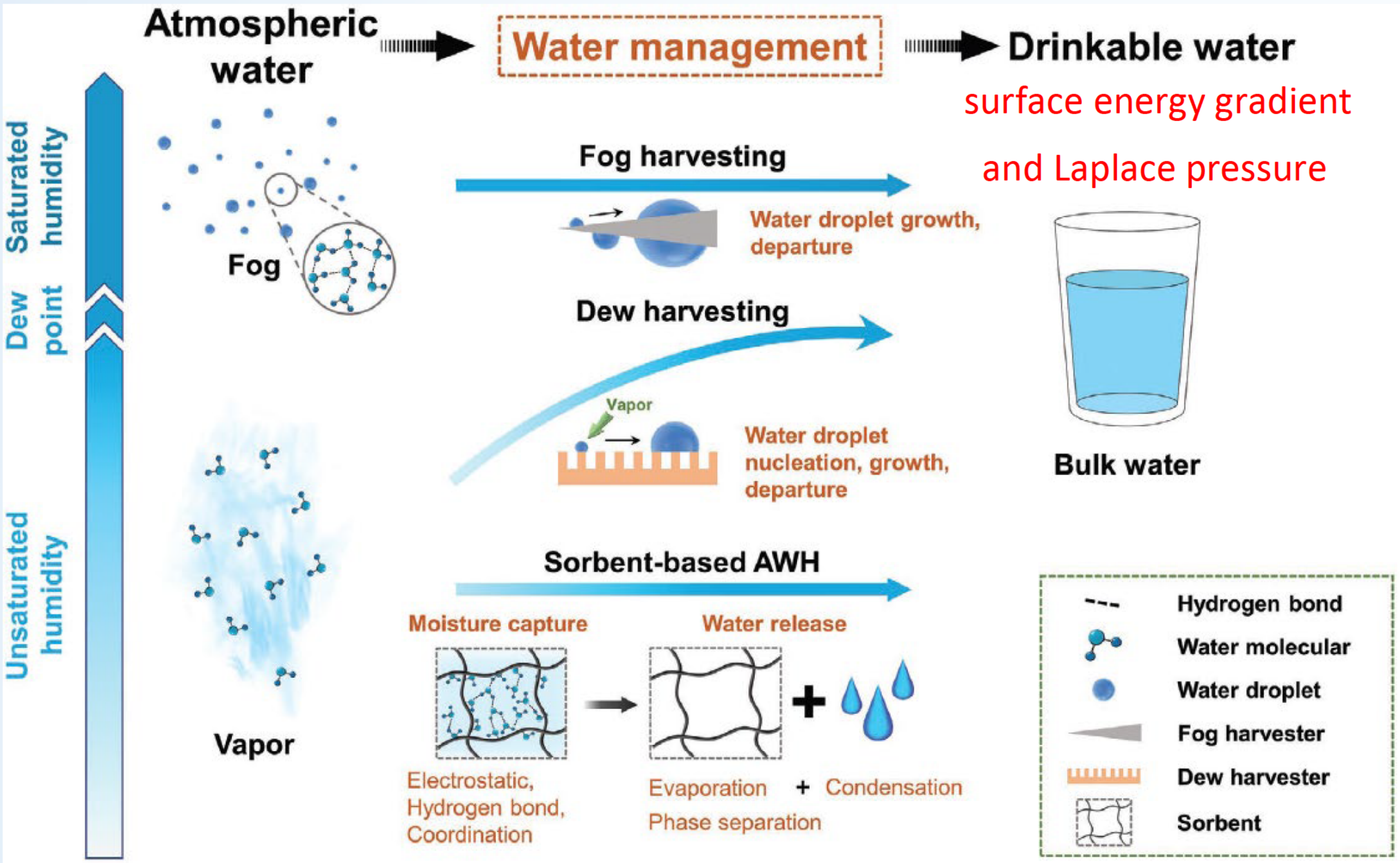
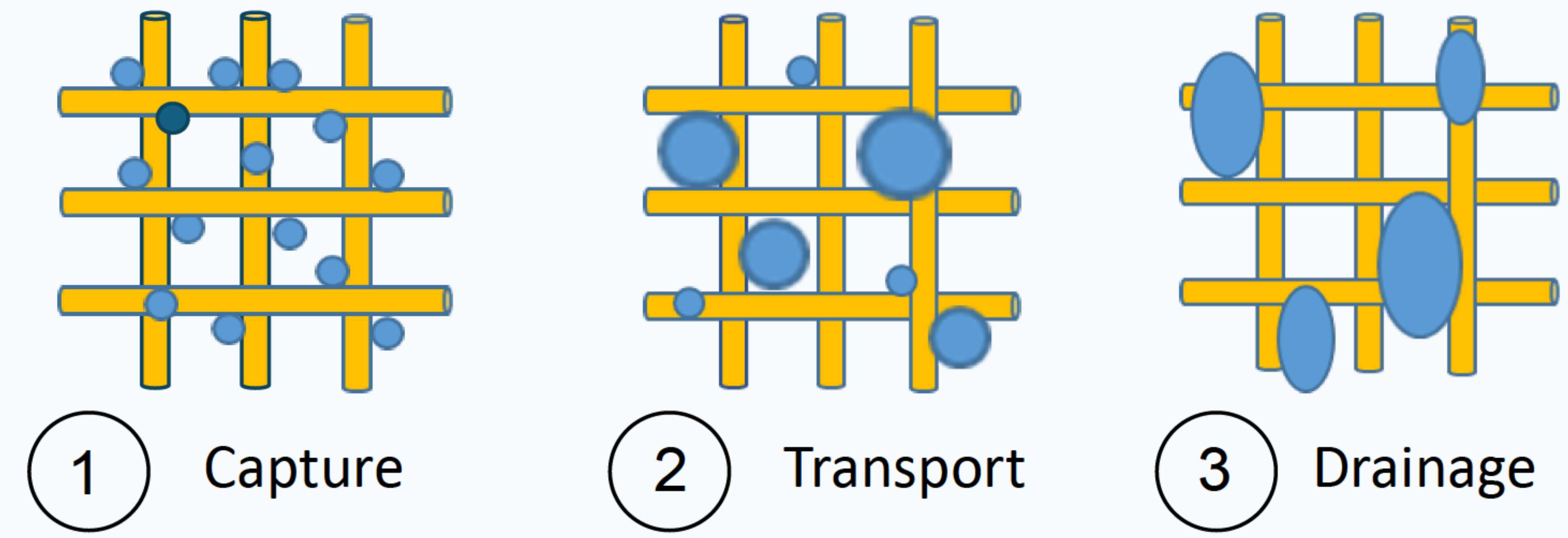
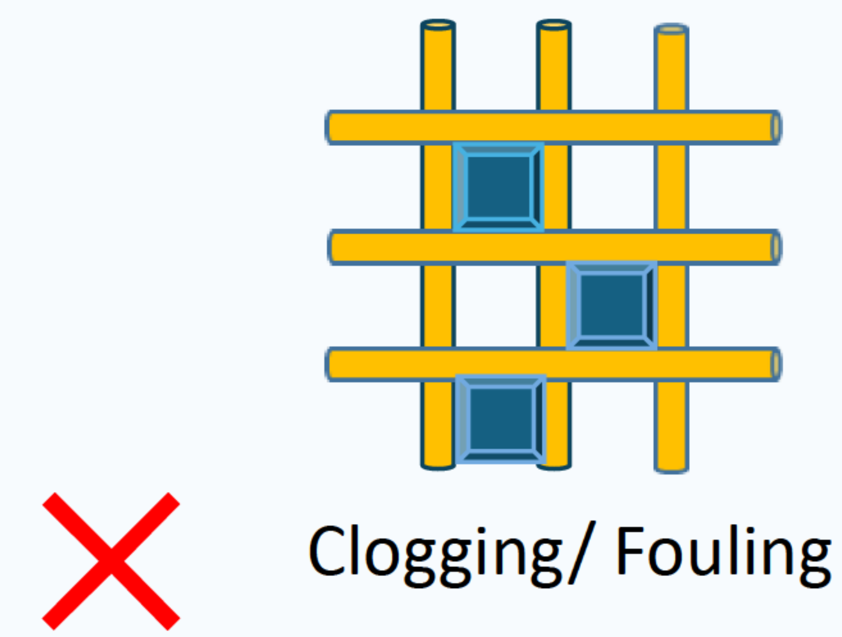
Water harvesting experiments



Steps in fog collection



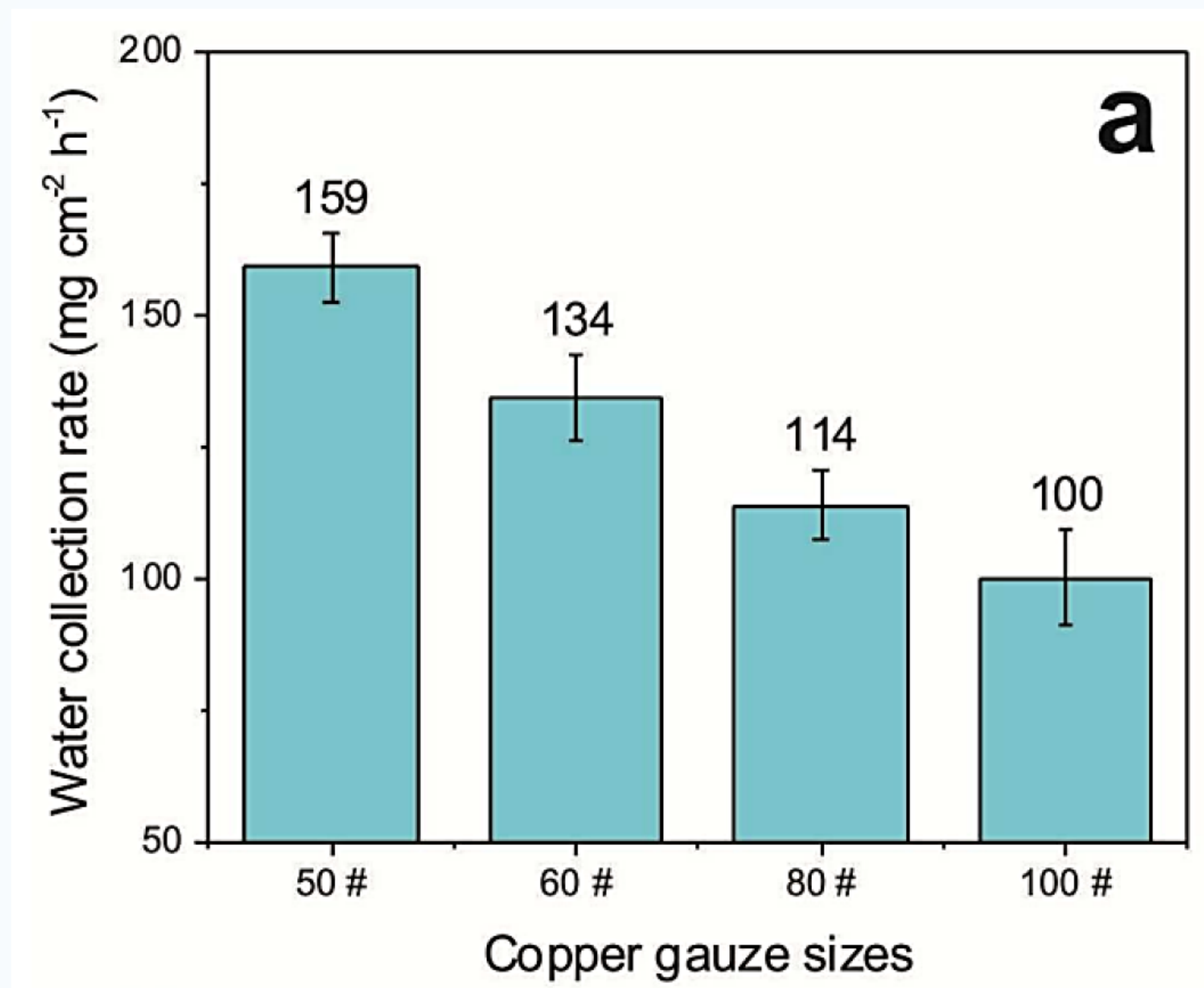


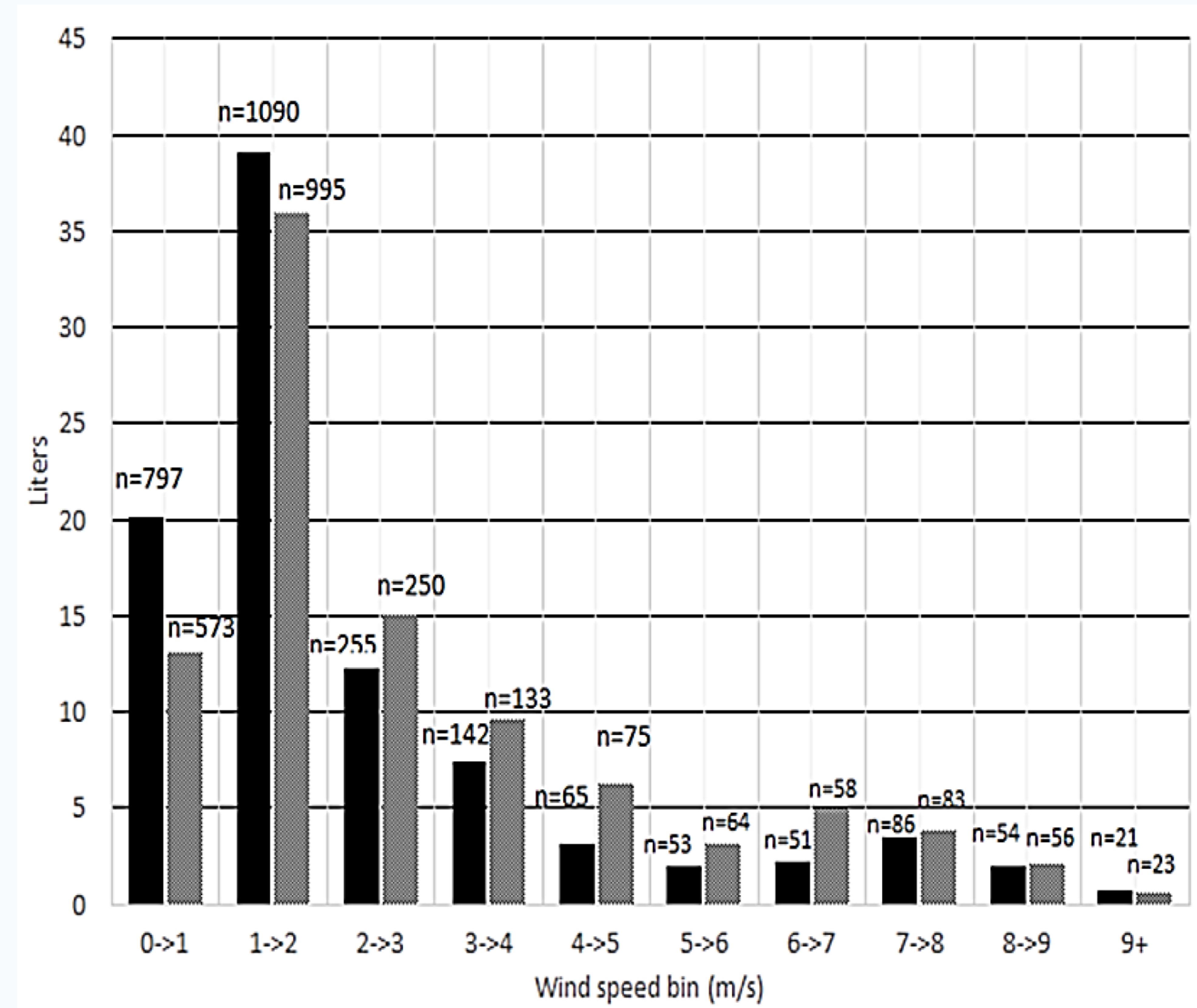
Water harvesting experiments

Fog characteristics

Wind speed

Mesh dimensions and surface characteristics

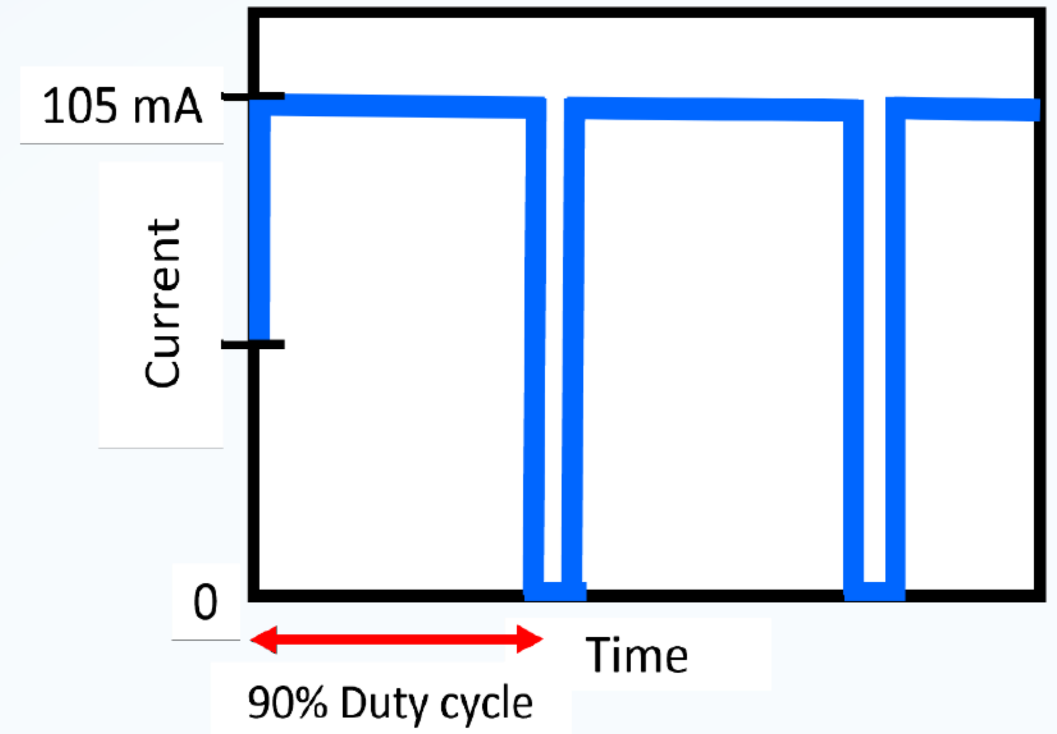




Journal of Materials Chemistry A, 37, 2015, 18963.
Aerosol and Air Quality Research (AAQR), 18.1, 2018, 270.

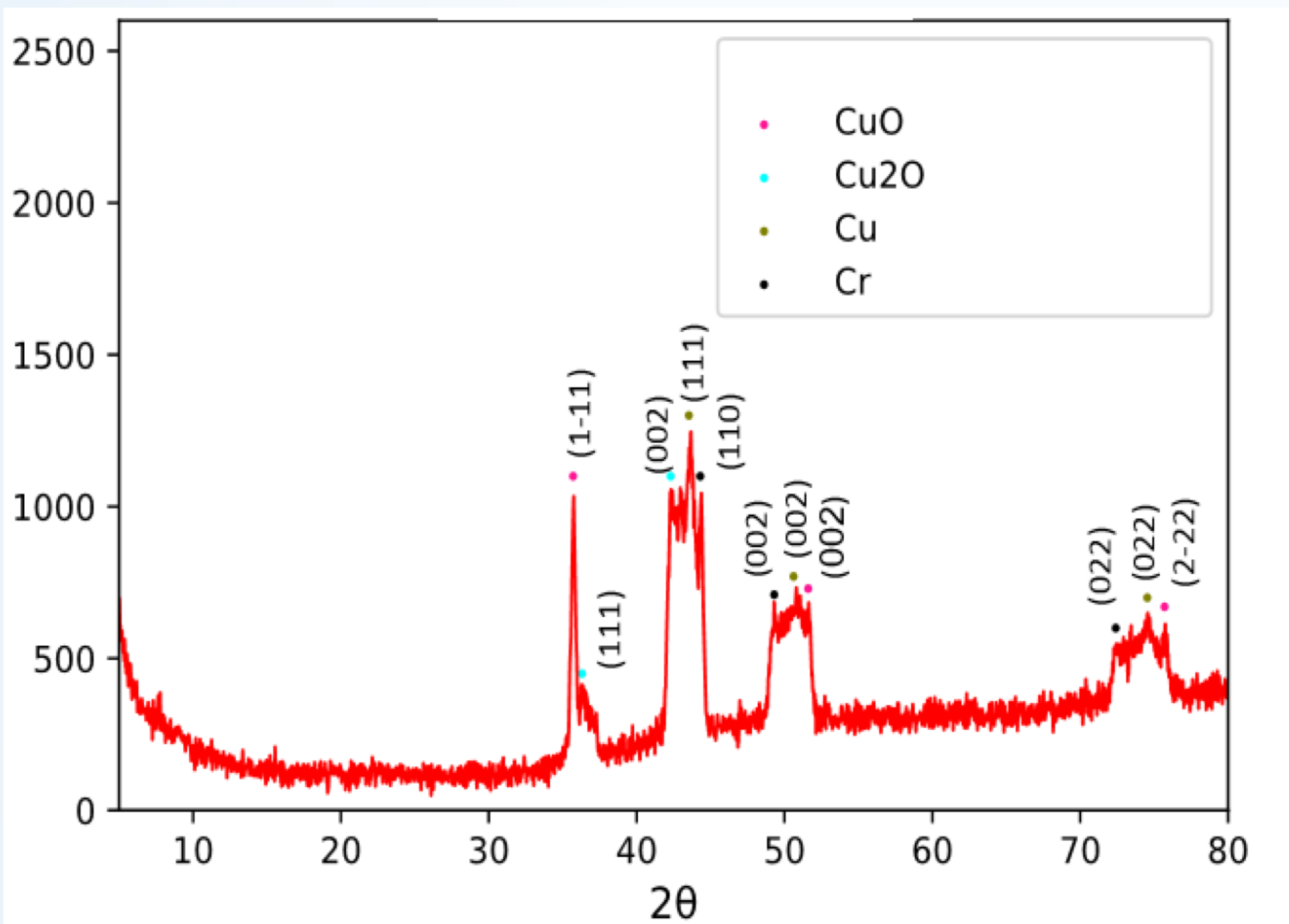
Water harvesting experiments

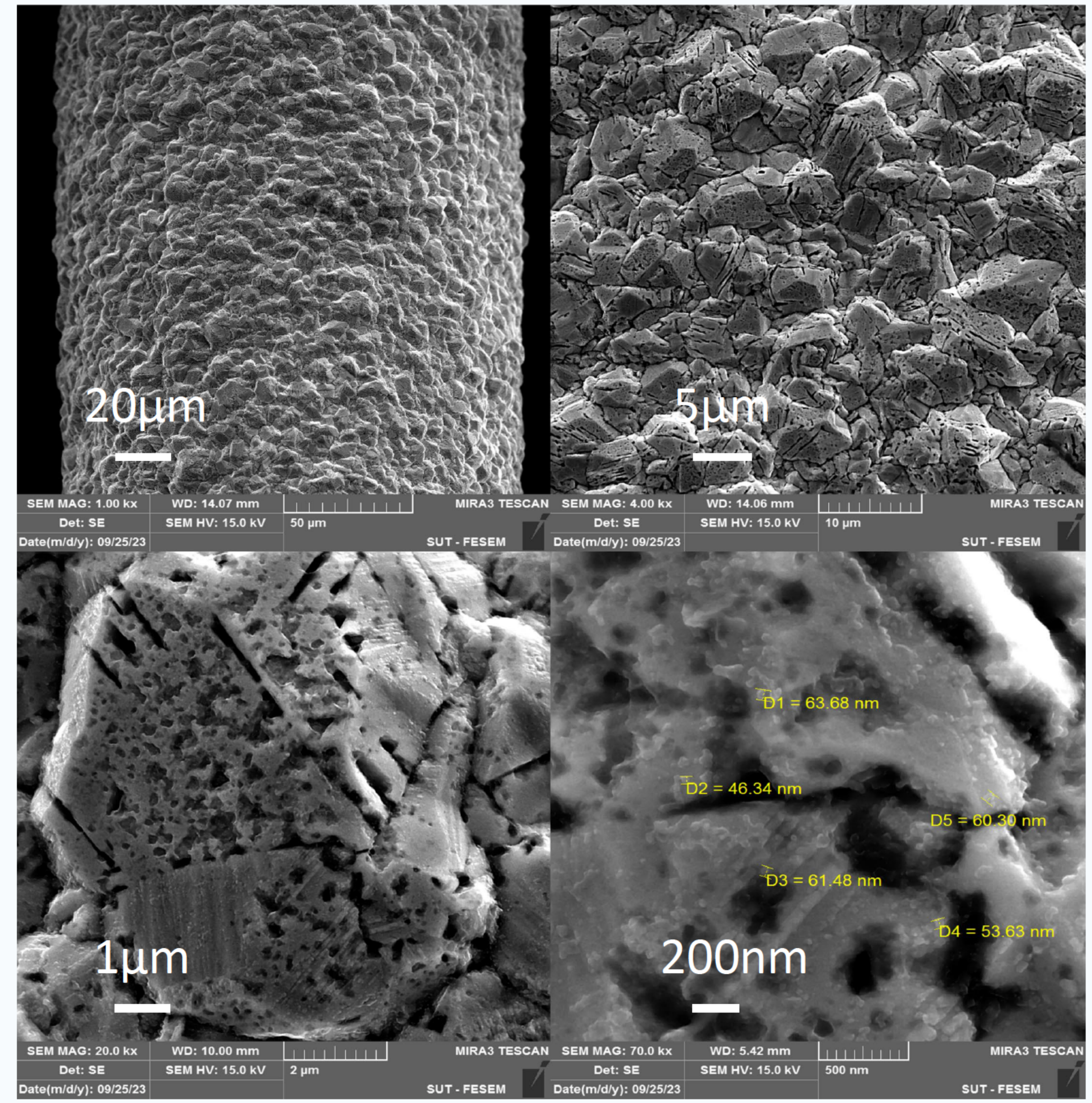
Pulsed electrodeposition of Cu on Steel meshes



Surface modification:

30 ml Ethanol + 2 ml TEOS + 2 ml HMDS + 3 ml DI



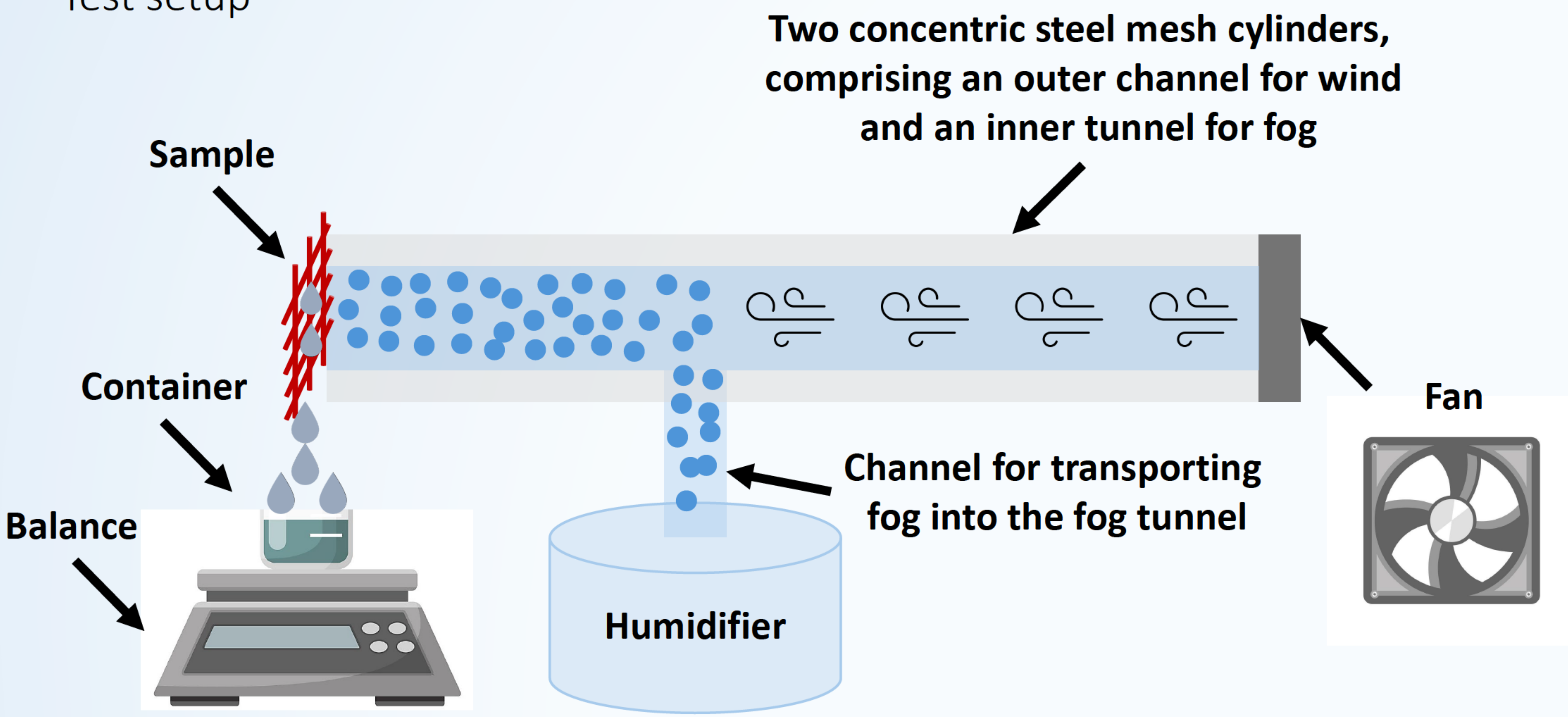


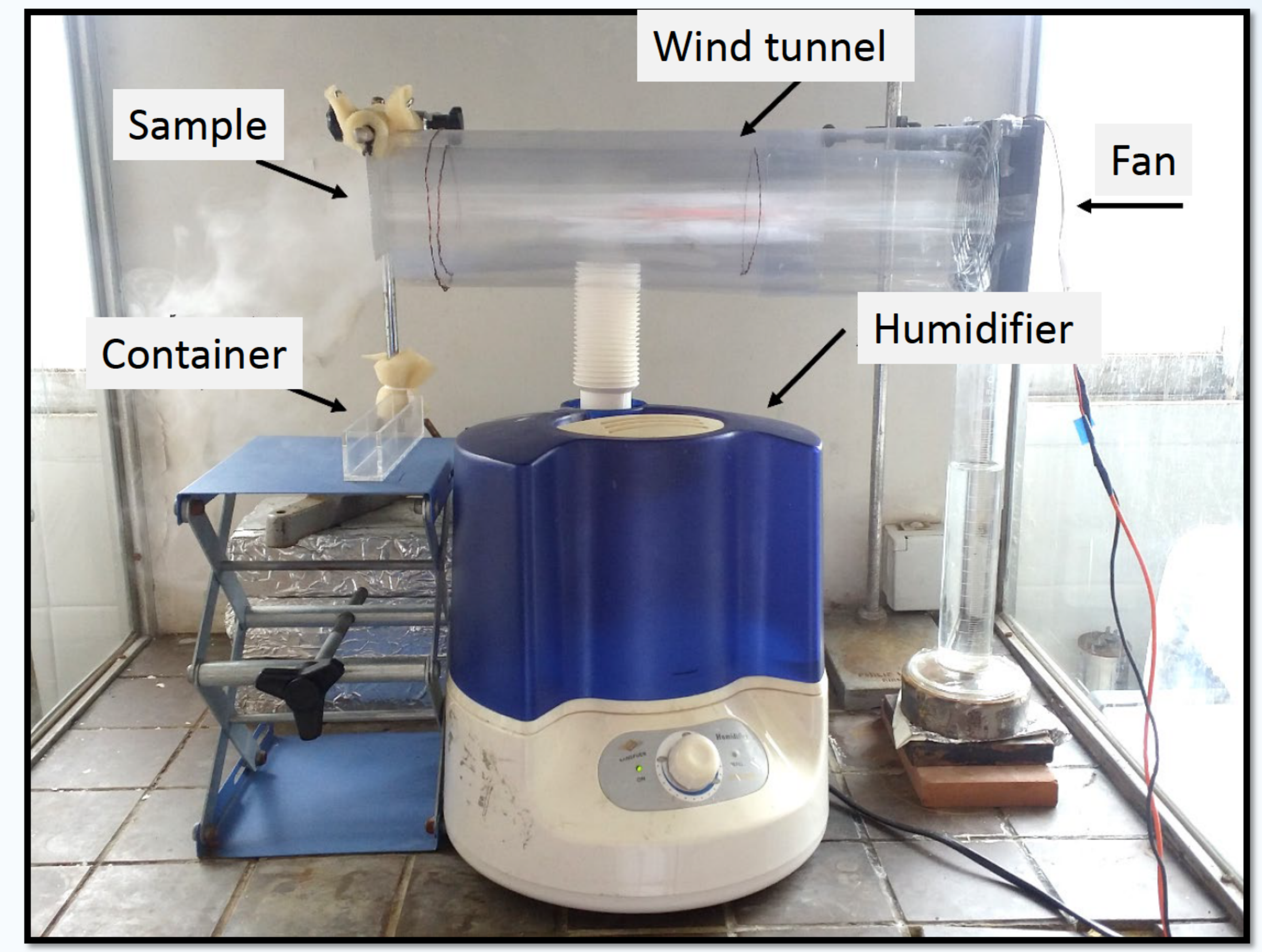
Tetraethoxysilane (TEOS)

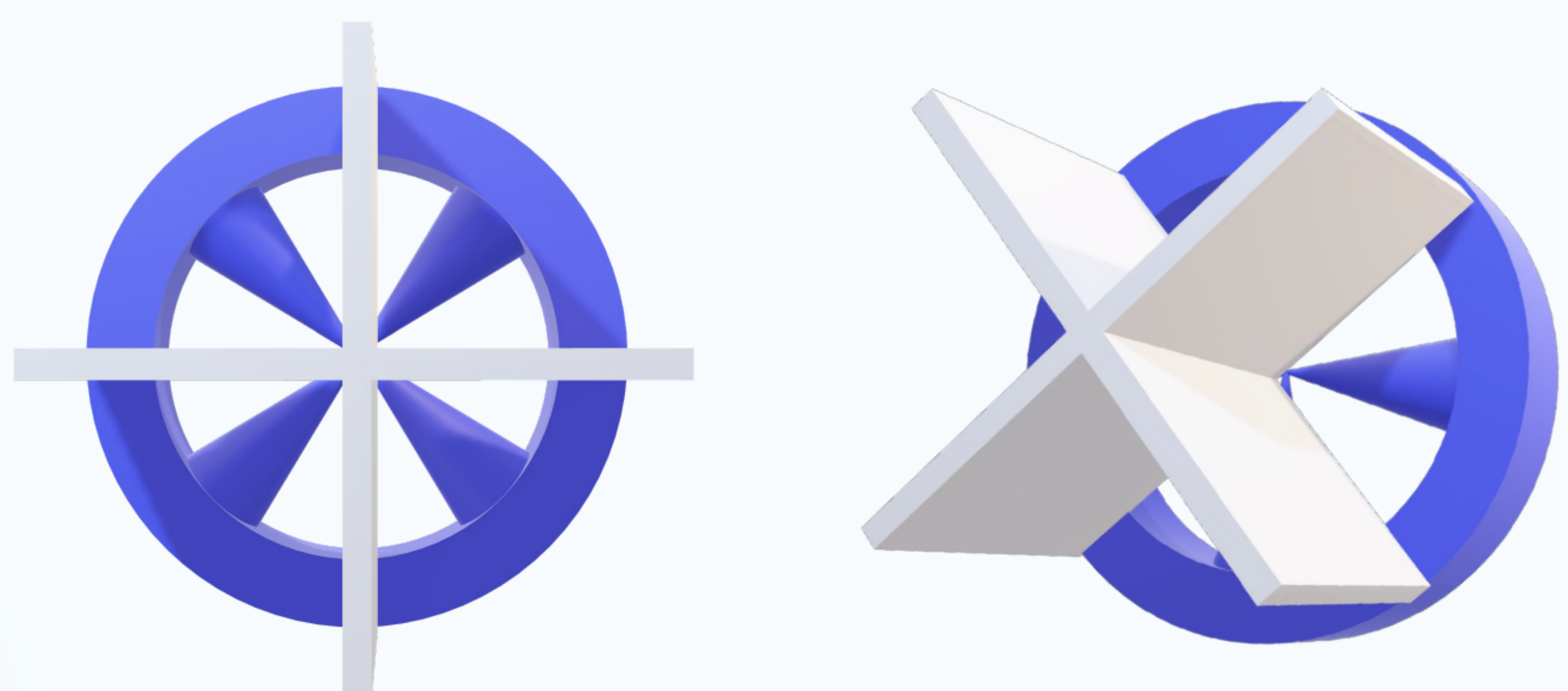
Hexamethyldisilane (HMDS)

Water harvesting experiments

Test setup







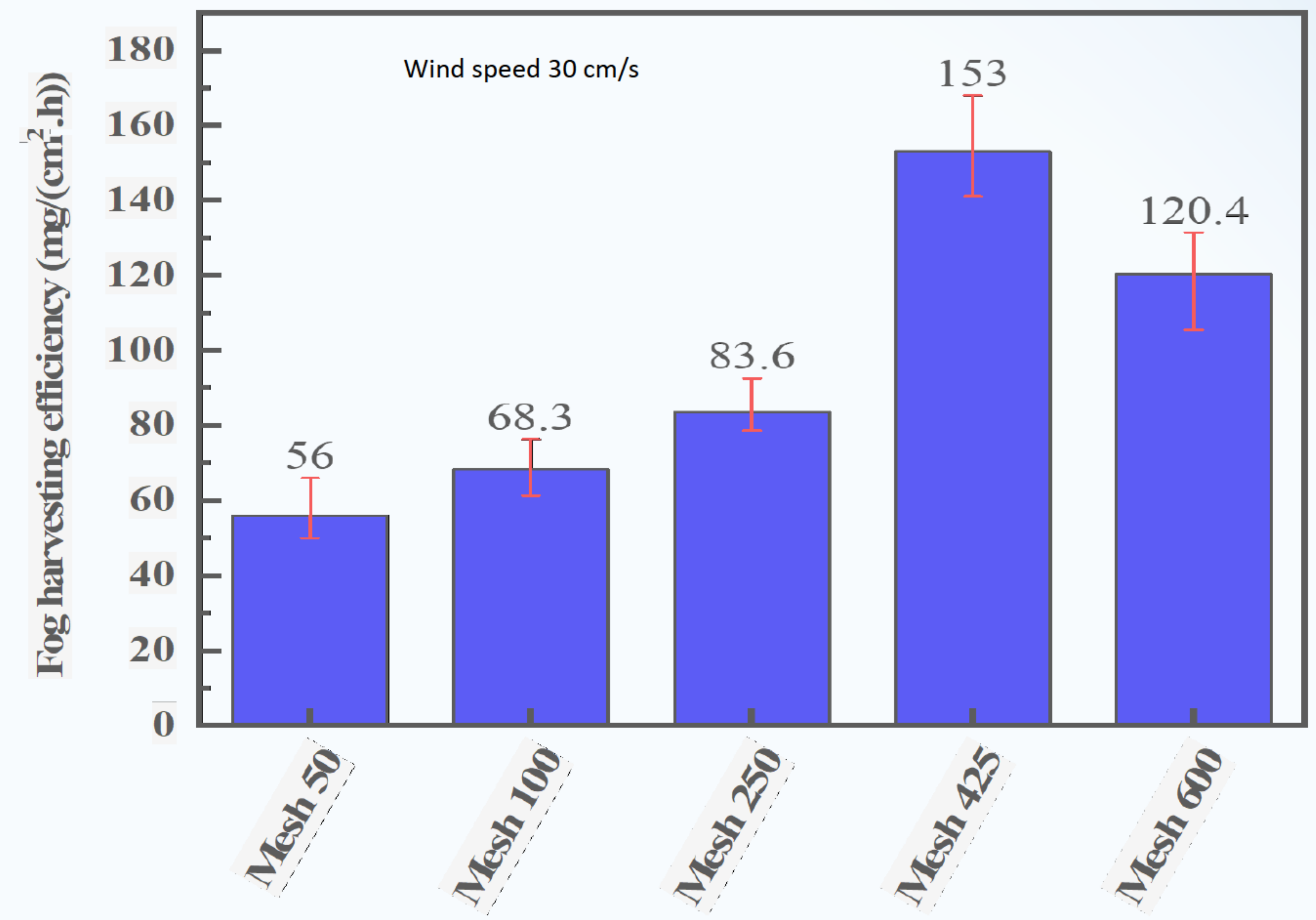
To reduce vorticity in air flow

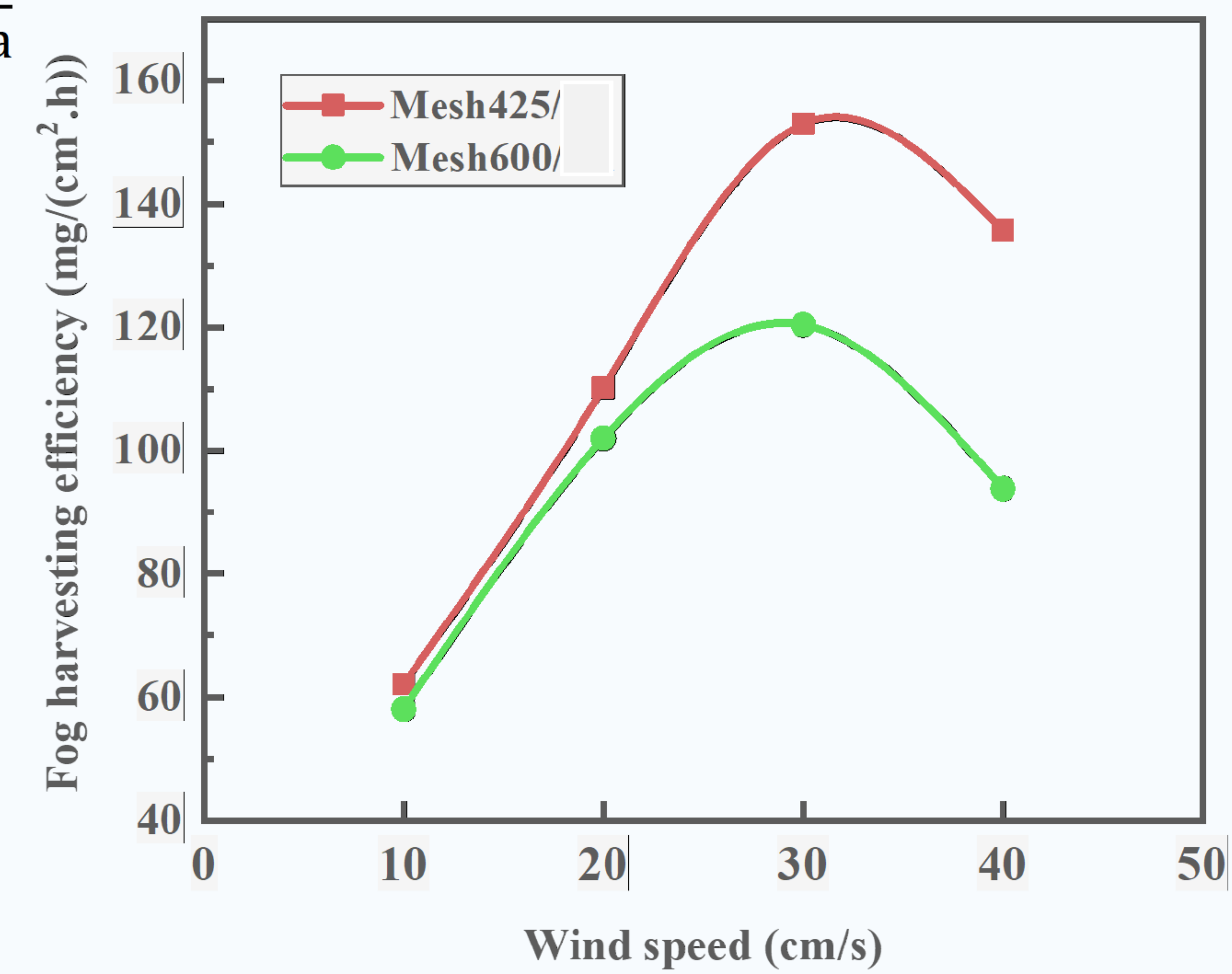
Water harvesting experiments

Control experiments

- At least 5 times of repetition of each experiment
- ~ 1-2 hours of experiment
- ~ 350 g evaporated water by humidifier during each experiment
- → the amount of collected water < 10% of evaporated water by humidifier

$$\text{Fog harvesting efficiency} = \frac{\text{amount of collected water}}{\text{test duration} \times \text{mesh surface area}}$$





Fog flow rate (ml/h)	210
Fog droplet size (μm)	< 20
Mesh surface area (cm^2)	3×3
Temperature (°C)	33 ± 3
Humidity (%)	90 ±5
Test duration (hours)	1

Label	Wire (μm)	Opening (μm)	Mesh number
Mesh 50	50	50	#240
Mesh 100	50	100	#160
Mesh 250	120	250	#60
Mesh 425	150	425	#40
Mesh 600	180	600	#30

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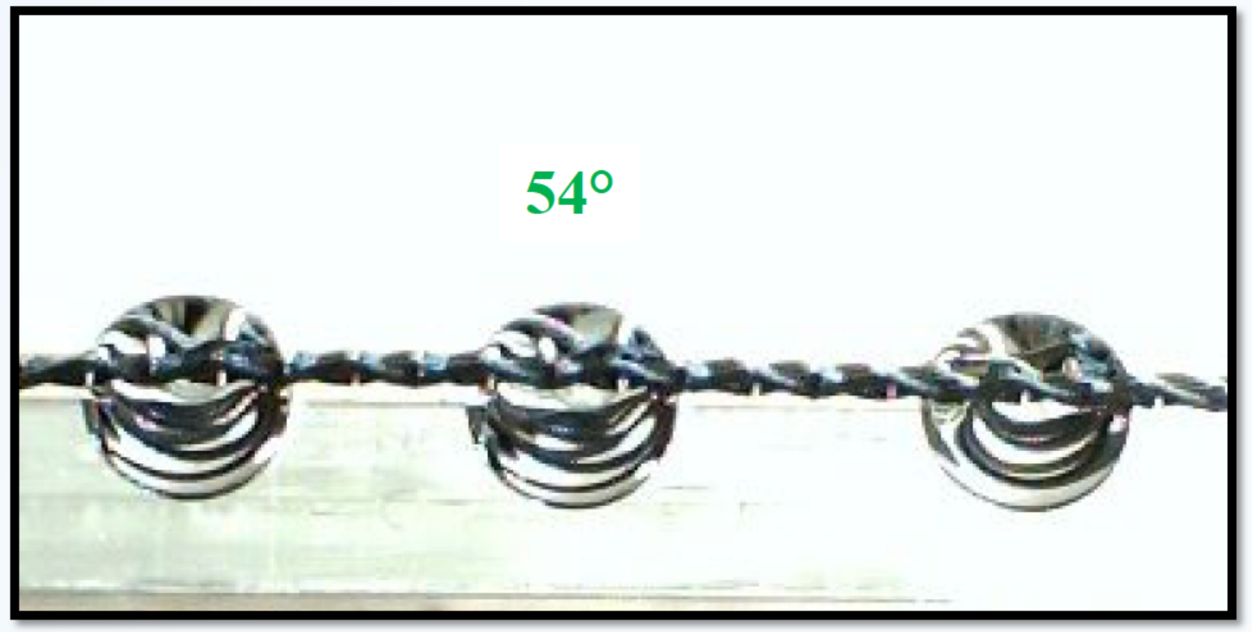
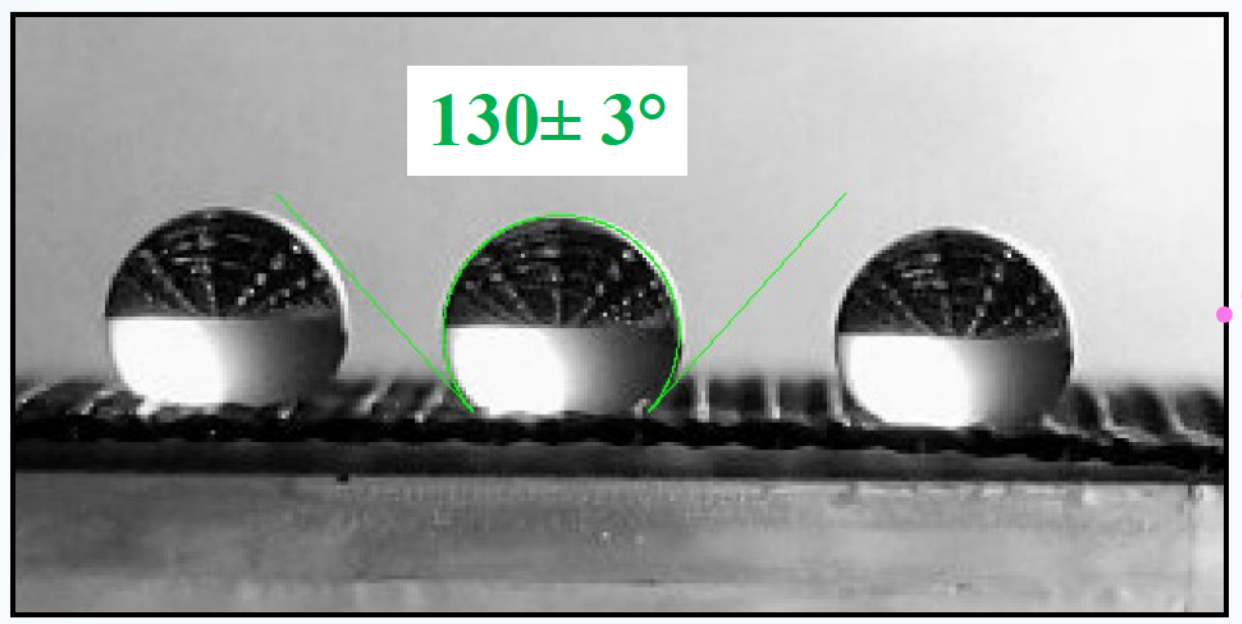
Water harvesting experiments

Wettability

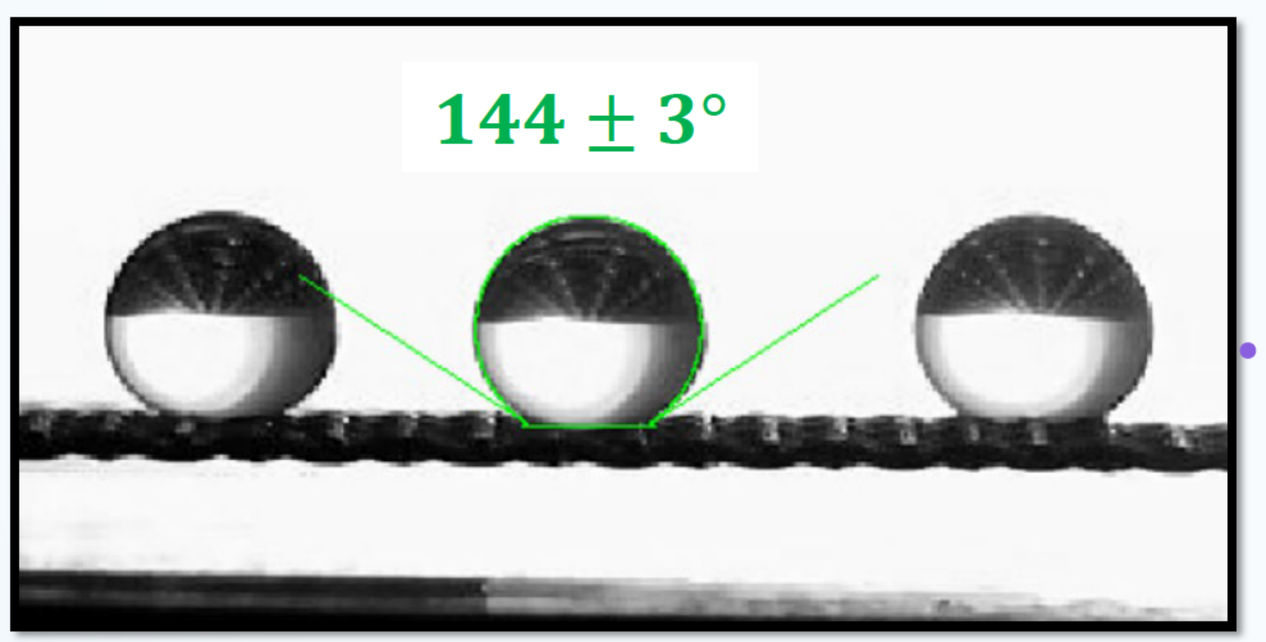
Steel mesh

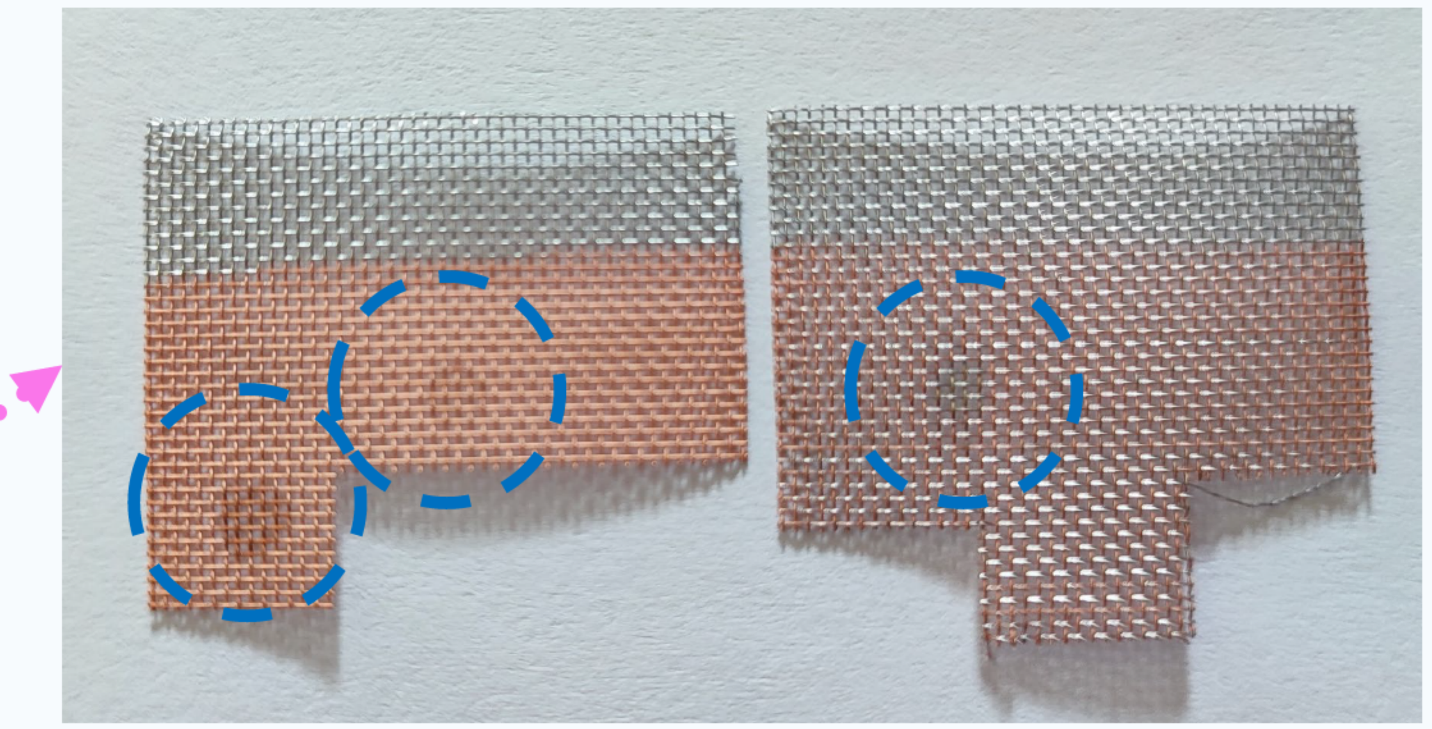


Cu coated mesh

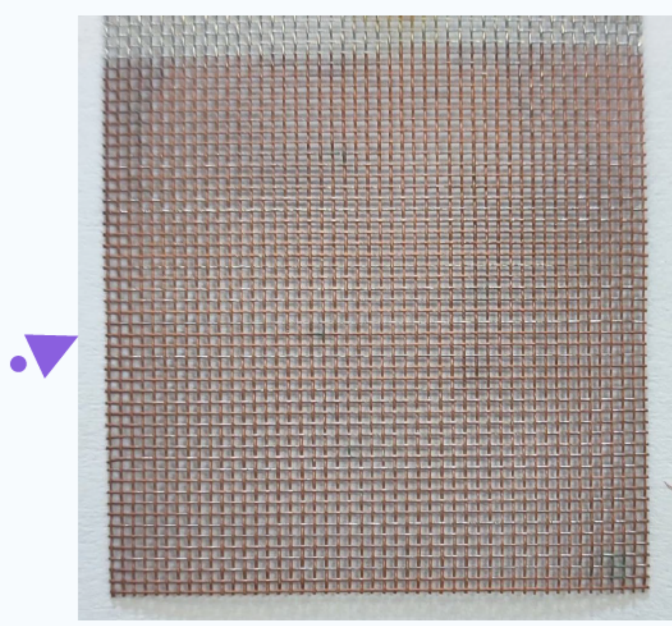


Si/Cu coated mesh

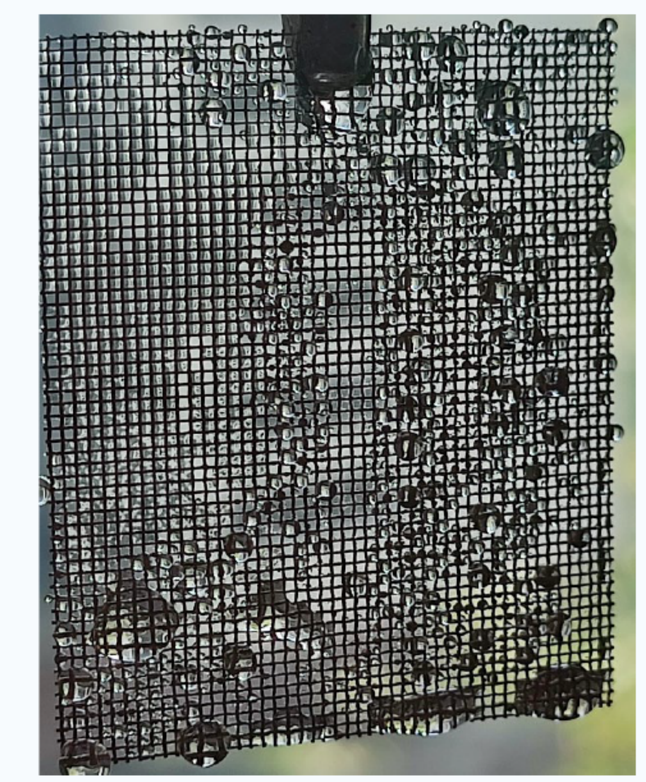




After wettability experiment



After wettability experiment



After 2 hours of fog collection experiment

Water harvesting experiments

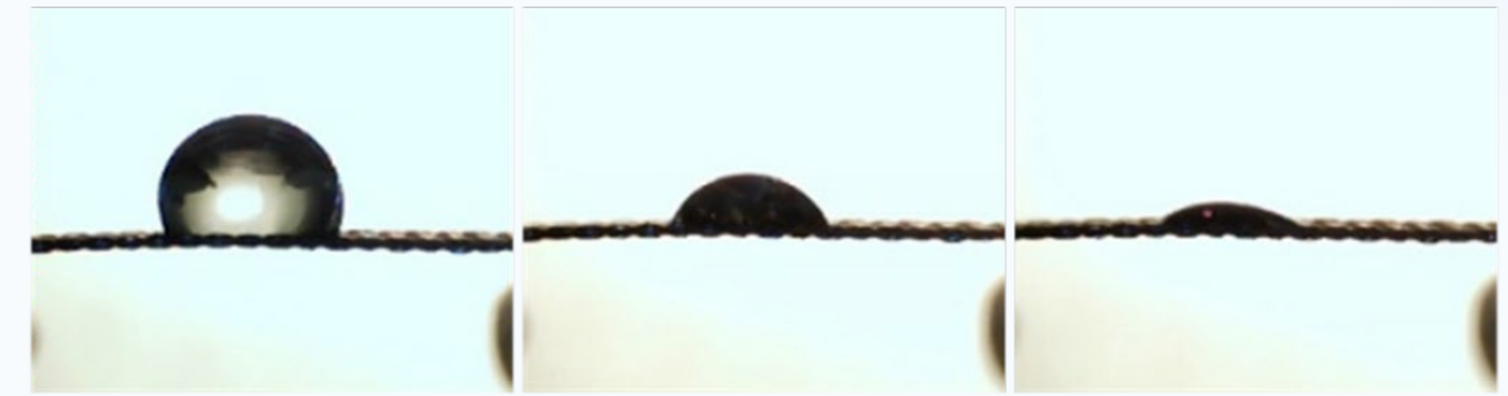
Wetting durability

Samples	Wetting durability of dry sample	Wetting durability of prewetted sample
Steel mesh	5 s	0 s
Cu coated mesh	3 min	0 s
Si/Cu coated mesh	> 4 hours	The sample cannot be wetted.

Cu coated mesh

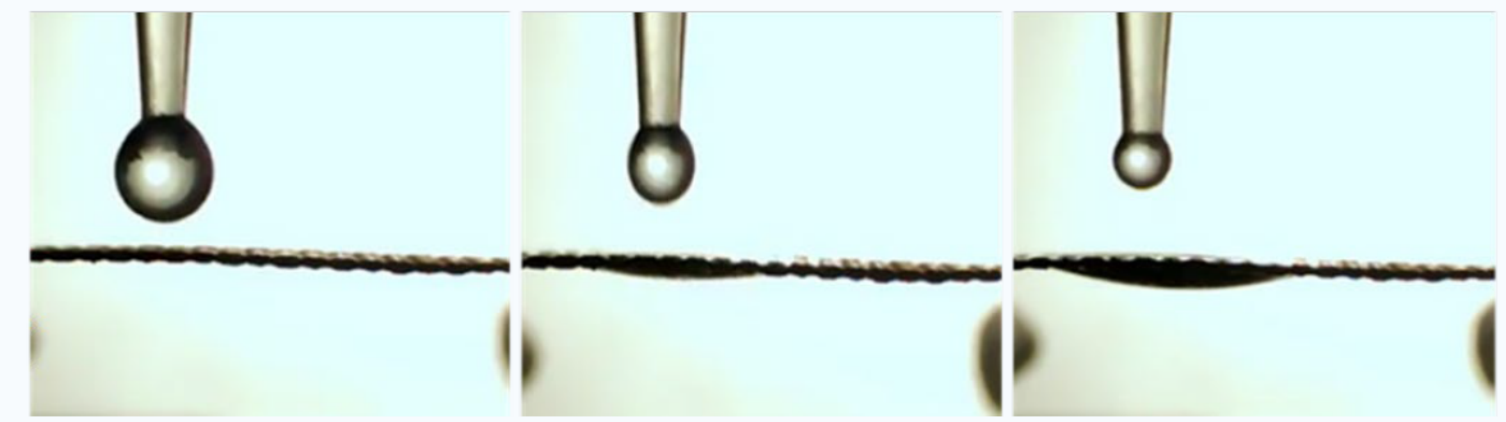
t= 1 min 120 min 160 min

Dry sample



t= 0 ms 10 ms 20 ms

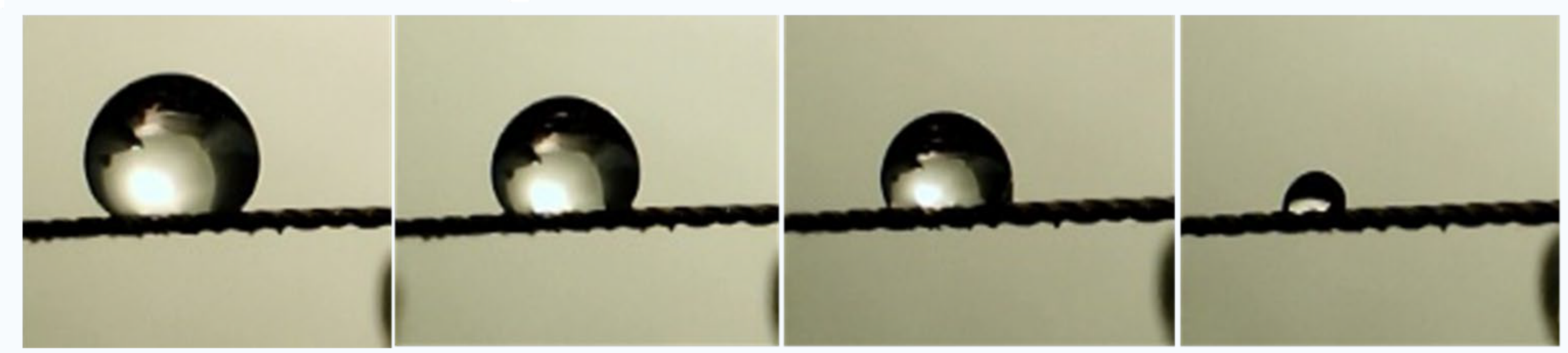
Prewetted sample



Si/Cu coated mesh

t= 1 min 1 h 2 h 4 h

Dry sample



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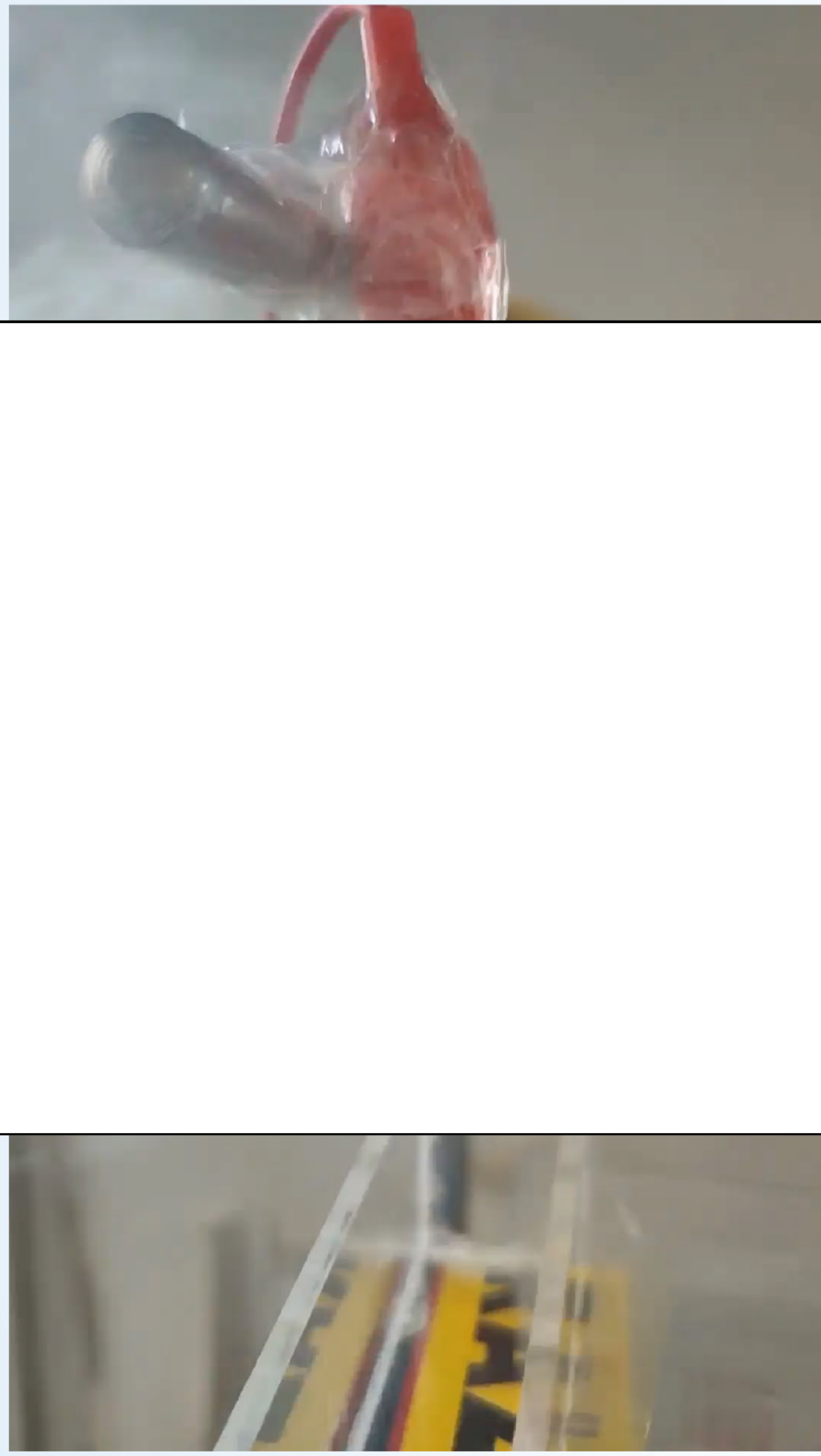
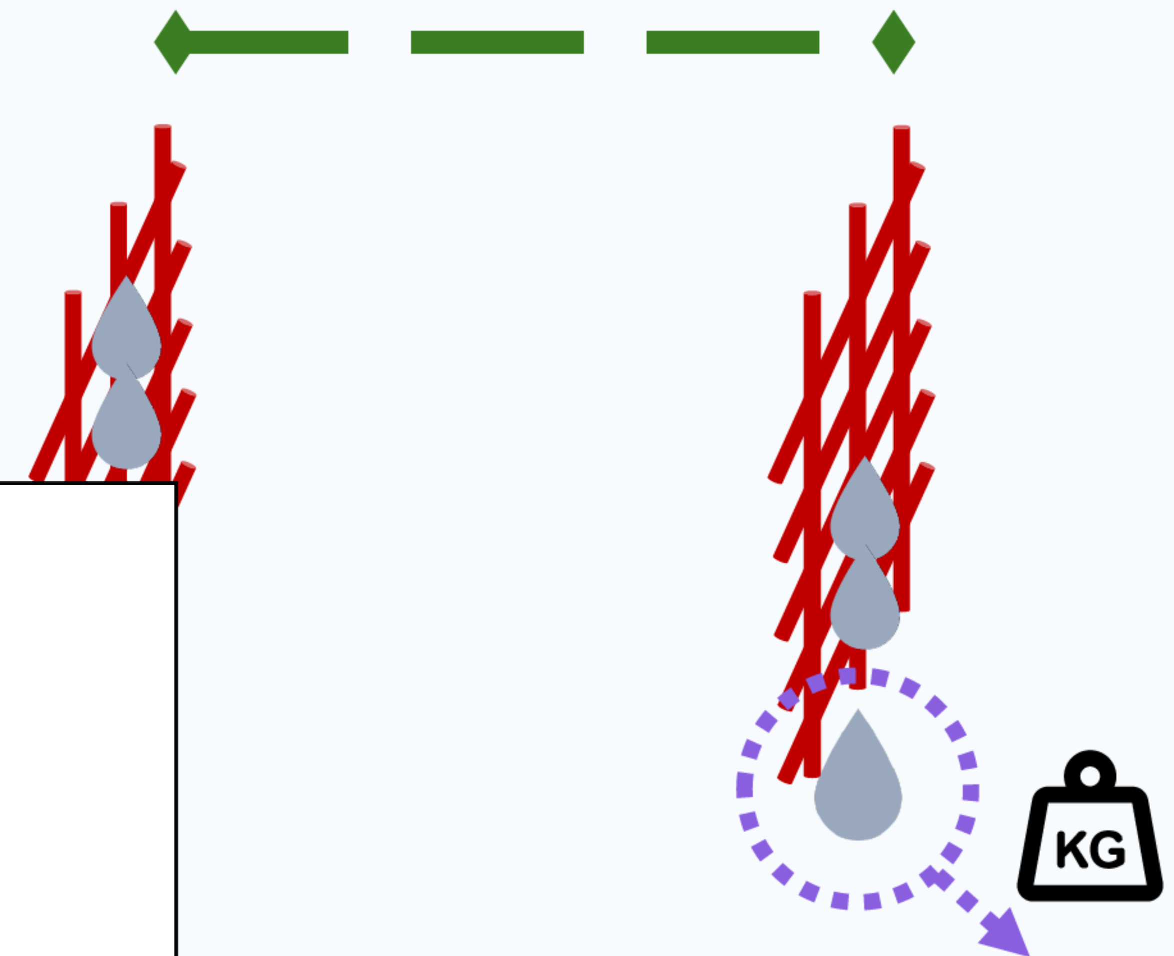
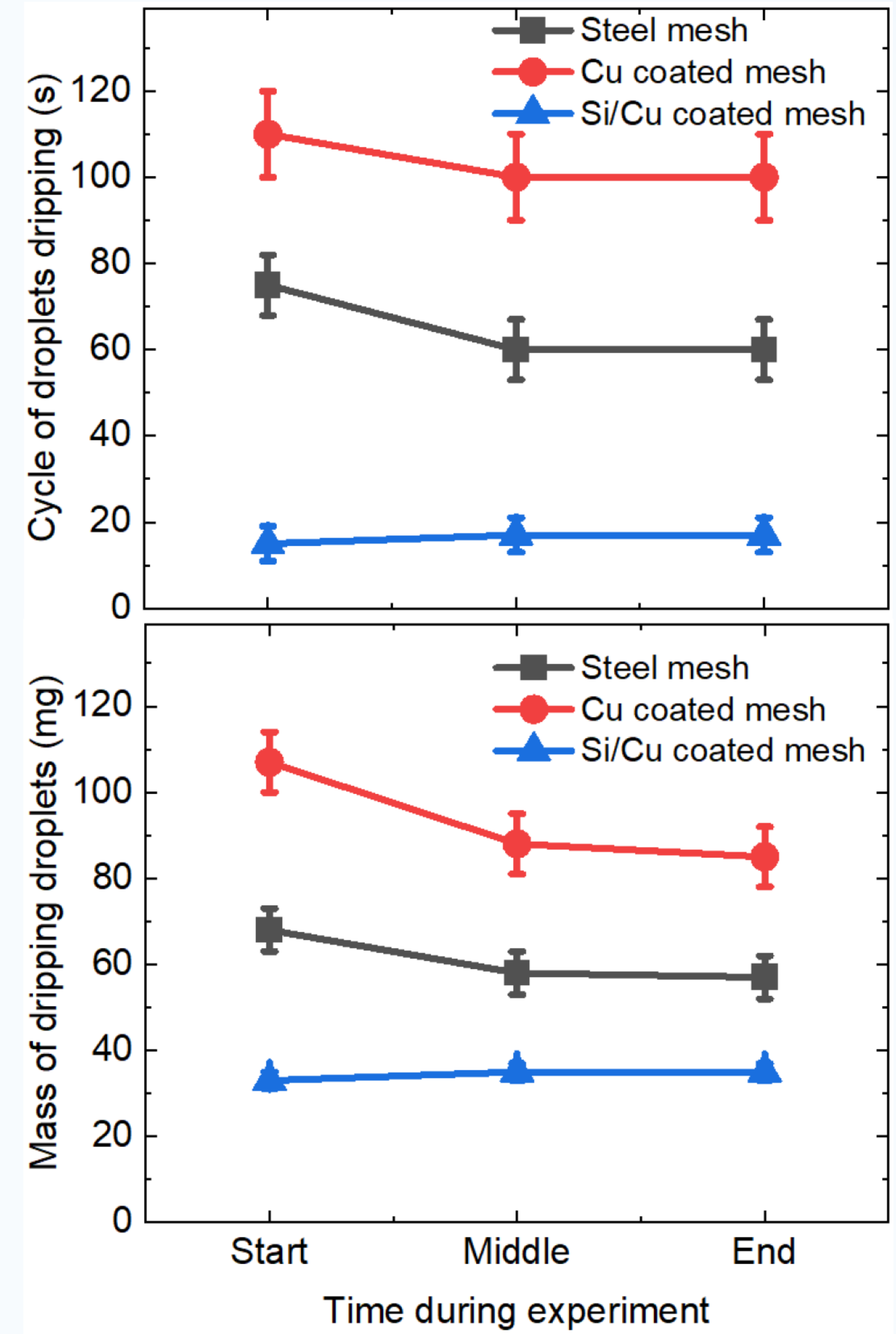
Water harvesting experiments

Water harvesting using Si/Cu coated mesh





low rate (ml/h)	210
roplet size (μm)	< 20
speed (cm/s)	30
Mesh surface area (cm^2)	3×3
Temperature (°C)	33 ± 3
Humidity (%)	90 ±5
Test duration (hours)	2



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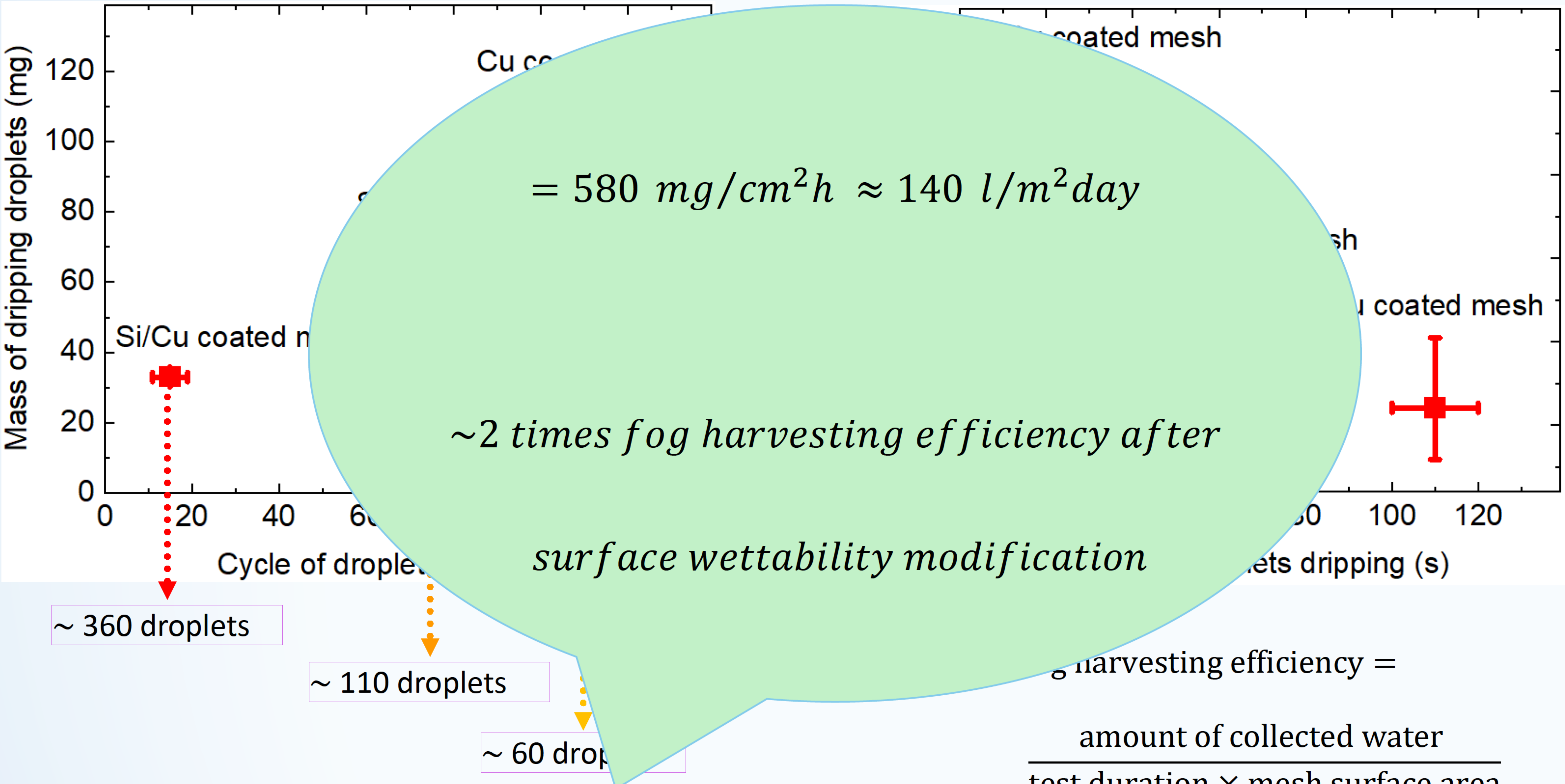
Water harvesting experiments



$$= 580\ mg/cm^2h\ \approx 140\ l/m^2day$$

$\sim 2\ times\ fog\ harvesting\ efficiency\ after\ surface\ wettability\ modification$

…harvesting efficiency =

$$\frac{\text{amount of collected water}}{\text{test duration} \times \text{mesh surface area}}$$

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Discussion

Reference	Wettability	Chamber (Open/Close)	Temperature	Hu…	Distance	Fog flow …h)	Wind speed (cm/s)	Fog harvesting Efficiency $(l/m^2 day)$
J. Mater. Chem. A, 3, 2015, 18963	Hydrophobic/ hydrop…						12	38
Nanoscale, 9, 2017, 14620	Superhy… hy…							48
Macromol. Mater. Eng., 302, 2017, 1600387	Super…							19
J. Mater. Chem. A, 7, 2019, 5426								67
Front. Phys., 9, 2021, 680641								420
Prog. Org. Coat., 171, 2022, 107016								87
Present study							**30**	**140**

$$12\ l/m^2\ day \xrightarrow[modification]{Wettability} \times 2 = 24\ l/m^2\ day$$

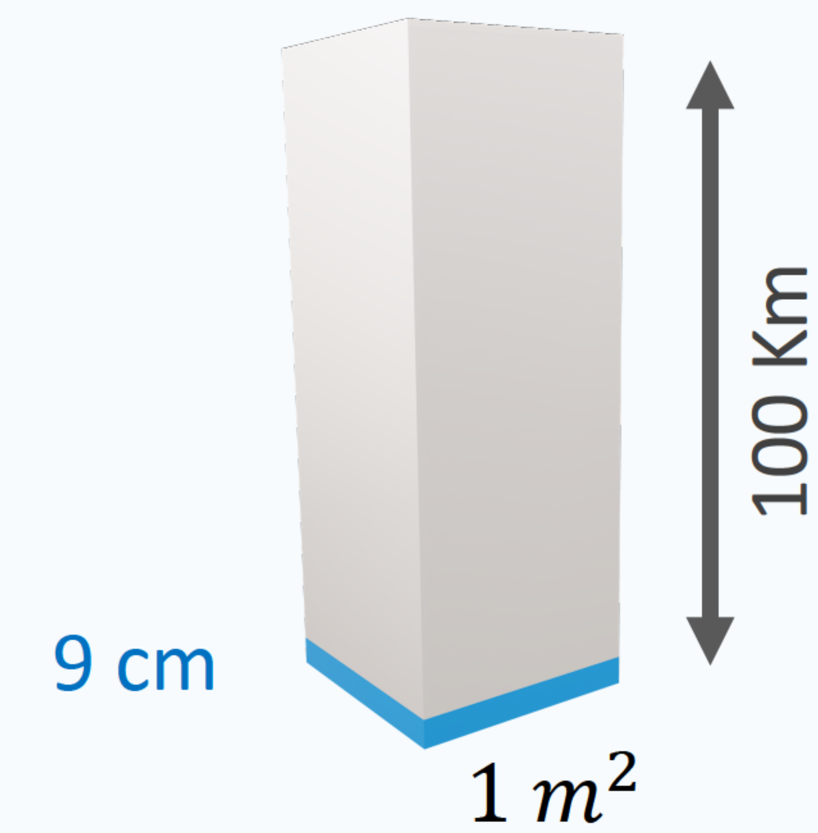
$$8\ l/person\ day\ \ potable\ water \Longrightarrow 60 \times 55\ cm^2$$

$$100\ l/person\ day\ water \Longrightarrow 2 \times 2\ m^2$$

The maximum amount of atmospheric water …

Available atmospheric water in California coast in 201… …ay

Maximum efficiency in installed fog collection systems: in … $l/m^2 day$



https://earthobservatory.… …/global-maps/MYDAL2_M_SKY_WV
International Journal of Lo… …on Technologies, 15, 2020, 253.
Renewable and Sustainable Energy Reviews, 29, 2014, 52.
Atmospheric and Climate Sciences, 02, 2012, 525.
https://www.faa.gov/aircraft/air_cert/design_approvals/small_airplanes/icing_protection_systems/faa_documents/media/acereportar-00-30.pdf
Philosophical Transactions of the Royal Society A, 378, 2020, 20190444.

Conclusions:

- ❖ The Cu-coated surface absorbs fog droplets after multiple-drop impact and significantly reduces drainage.
- ❖ A silica thin layer is vital for continuous and efficient fog collection.
- ❖ The Silica-Cu mesh increases fog harvesting efficiency by 100%.

Future Plan:

- ➢ Janus meshes approach
- ➢ Fabrication of hydrophilic-hydrophobic patterns on the surface
- ➢ Large scale fog harvesting experiments

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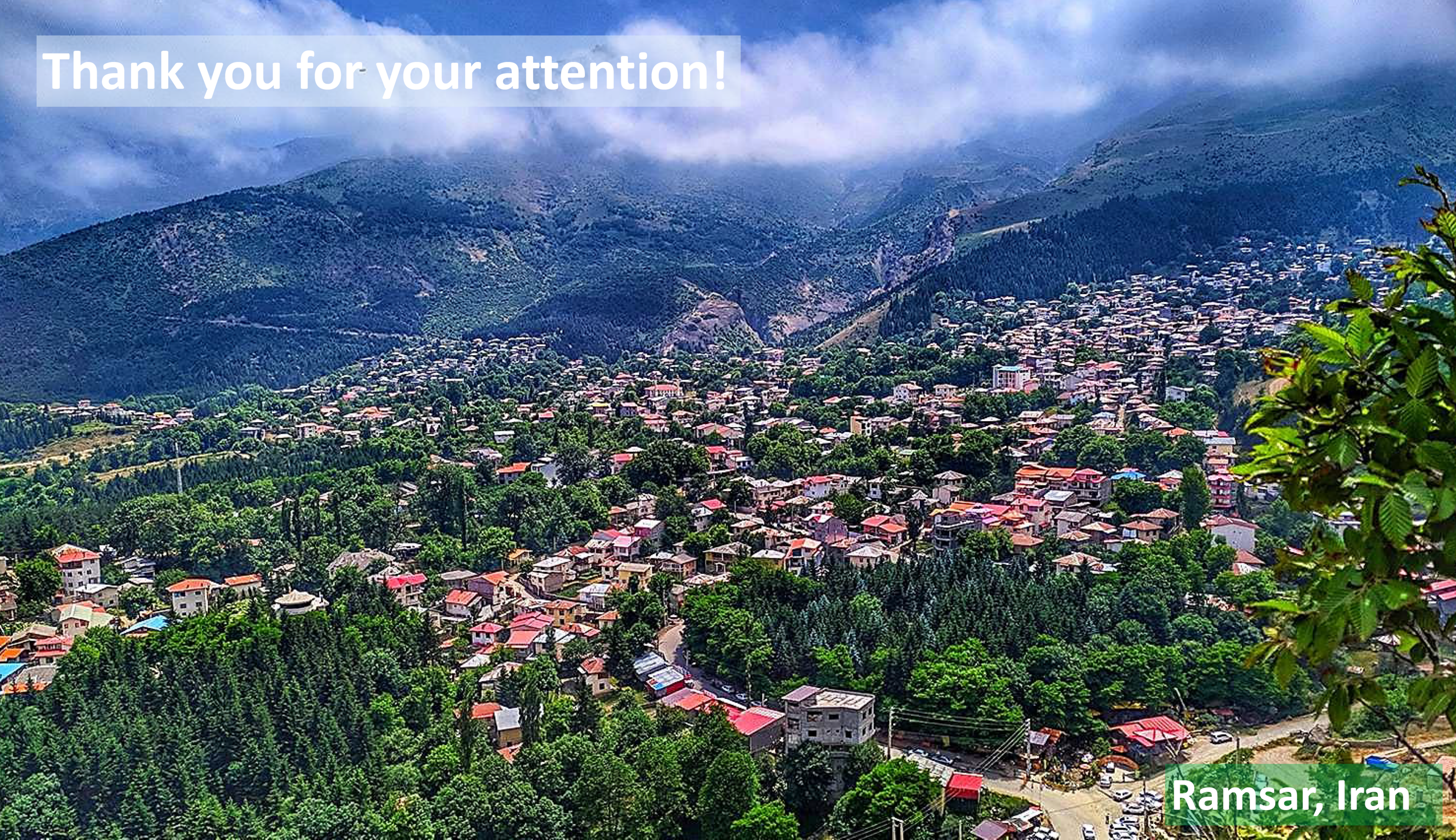
Thank you for your attention!
Ramsar, Iran