Fog Harvesting Utilizing Electrospun Interwoven Membranes

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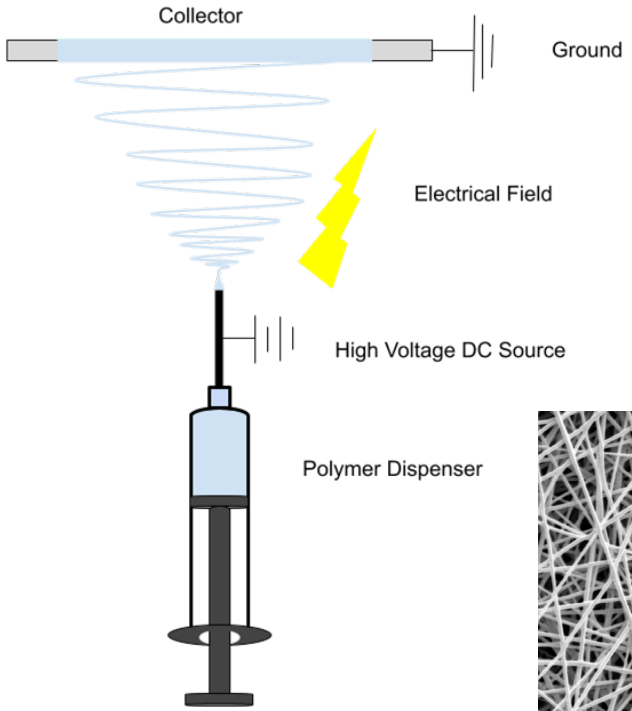
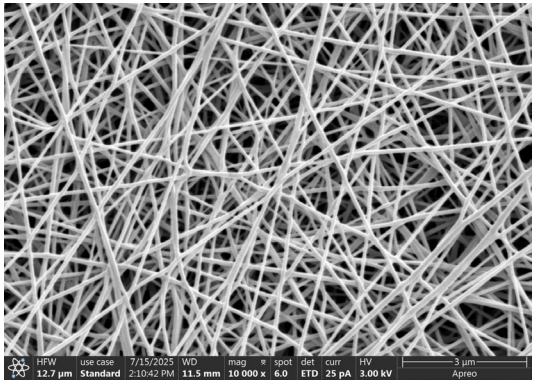
What is Electrospinning?

- Electrospinning is a clever process to produce naturally occurring nanofibers
- It uses high voltages and electric fields to extrude polymer solutions into nanofibers
- Advantages - Cost, high surface area, and tunable properties
- Typical electrospinning control parameters:
  - Voltage
  - Spinning Distance
  - Dispensing Speed
  - Solution Concentration



A typical electrospinning setup. A variety of collectors and needles can be used



Typical result

What is Fog Harvesting and Why is It Important?

- In 2024, The World Health Organization and United Nations Children's Fund (WHO/UNICEF) Joint Monitoring Programme (JMP) for Water Supply, Sanitation and Hygiene reported that ***1 in 4 people lack safely managed drinking water****
- Climate change, population growth, and urbanization contribute to water scarcity
- Fog Harvesting is currently a cheap, and sustainable water source … *but suffers from relatively low efficiency*
- Increasing the efficiency of fog collection would potentially provide a water source for regions with significant financial and geographical limitations

One of the most commonly used fog collection companies, FogQuest

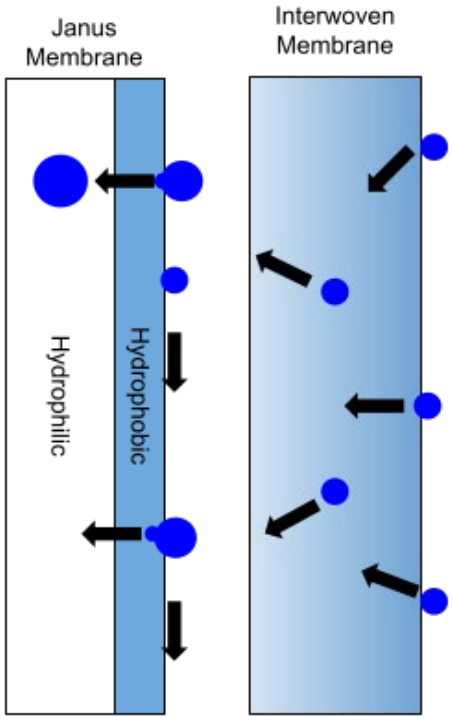
* Unicef Progress on household drinking water, sanitation and hygiene 2000-2024: Special focus on inequalities

Our Idea: Using Interwoven Membranes for Fog Collection

- Combined hydrophobic/hydrophilic membranes called ***Janus Membrane*** have shown high fog collection efficiency

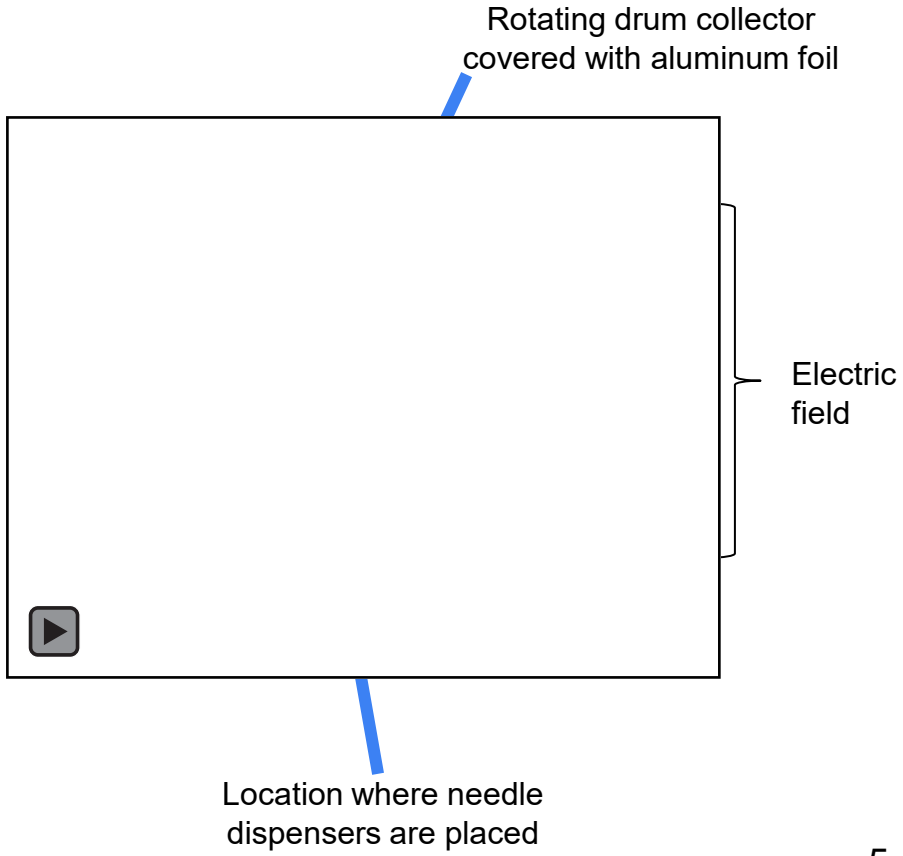
- Our goal is to create ***"Interwoven Janus Membranes"*** which would ideally increase efficiency by introducing more pathways for water to travel from the hydrophobic surface to the hydrophilic surface

- Our proposed Material System
  - Hydrophilic Material - PVA
  - Hydrophobic Material - PVDF



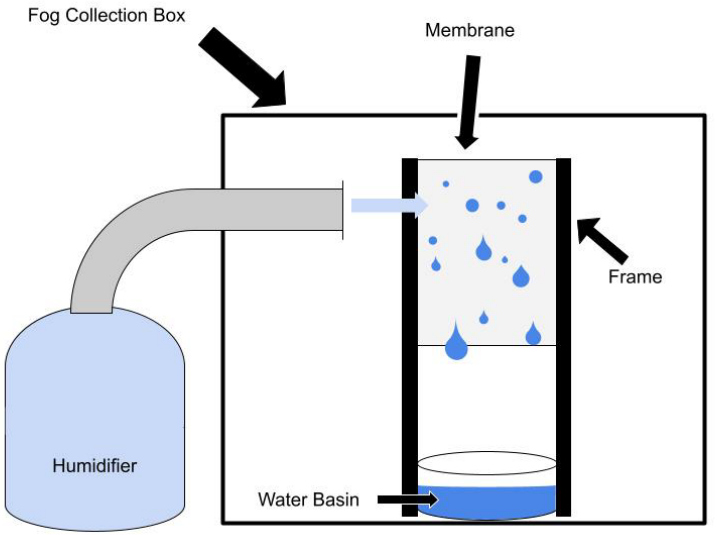
Proposed Fabrication Procedure

- Using the UofL NE300 Inovenso Electrospinning System, ***two different polymers*** can be spun simultaneously but at different feed rates.
- Adjusting the individual feed rates during spinning enables changing the amount of hydrophobic and hydrophilic material in the membrane.
- We will utilize this strategy to weave PVA and PVDF together and create an interwoven membrane



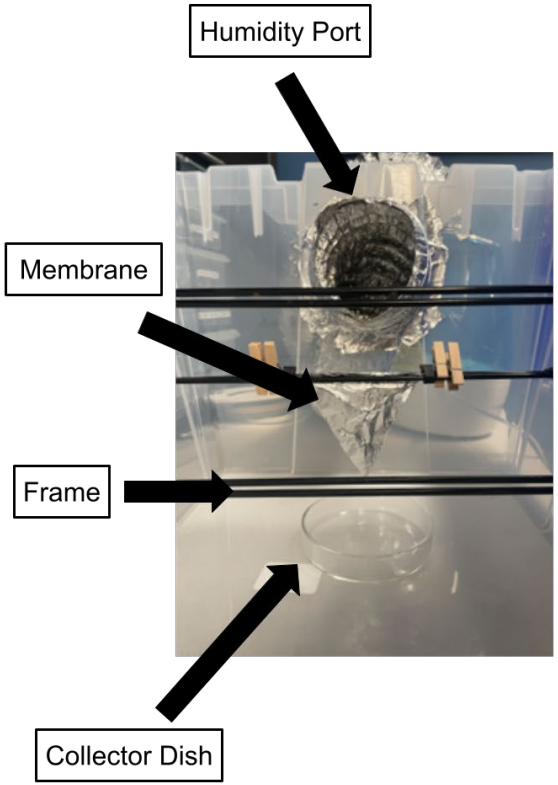
Custom Fog Collection Test Setup

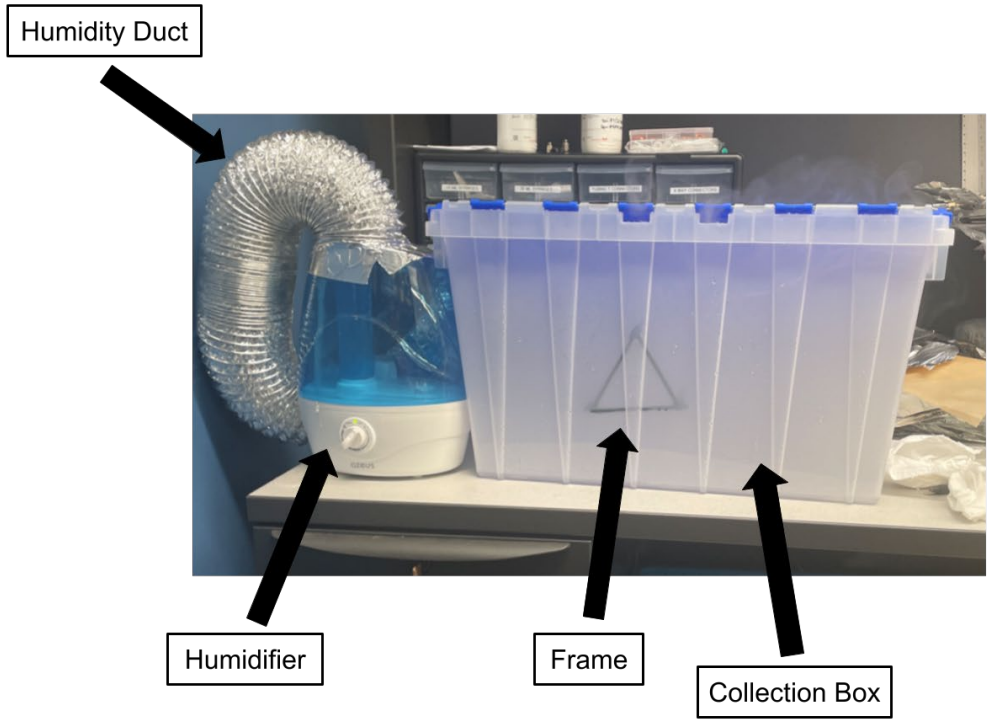
- An efficient Fog collector has a high collection rate and low retention rate
- To test the membranes, a humidifier will simulate fog for 1.5 hours
- The membranes are designed to drip water into a collection basin, this is collected water
- Some water will be retained within the membrane, and is more difficult to utilize



Fog collection testing setup; at lab scale a humidifier can be used to generate “fog”. It is currently in the process of being built and tested.

Fog Collection Setup

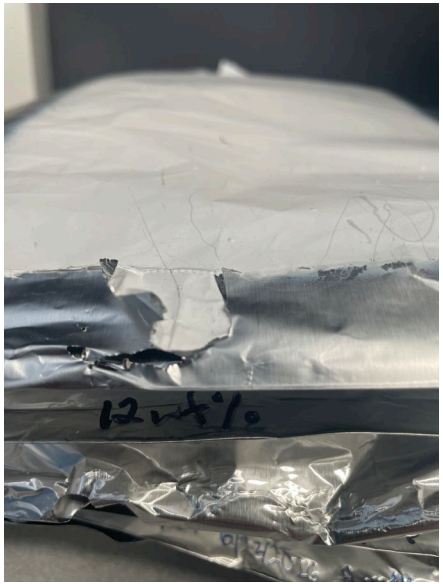




Spinning and Testing

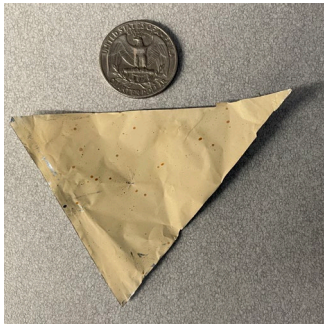
- **Solutions:**
  - 18wt% PVA in RO water
  - 15wt% PVDF in DMF
- The membranes also must undergo crosslinking, to ensure the hydrophilic material does not dissolve
- The efficiency of the interwoven membranes will be compared to standard Janus membranes and a pure hydrophilic membrane
- 3 samples of each type of membrane were electrospun for 3 hours and tested for 1.5 hours

Completed fog collection setup, before fog is turned on

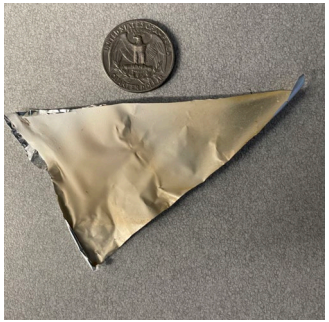


A sample of hydrophilic membrane, before crosslinking

Electrospun Membranes

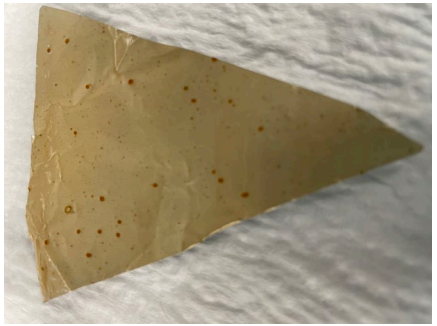


Hydrophilic membrane - Dry

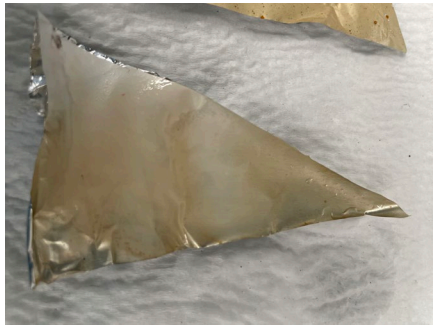


Standard Janus - Dry

Interwoven Janus - Dry



Hydrophilic membrane - Wet

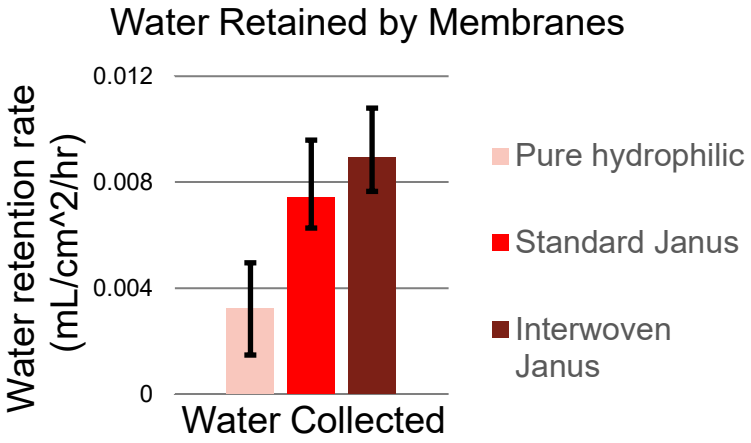


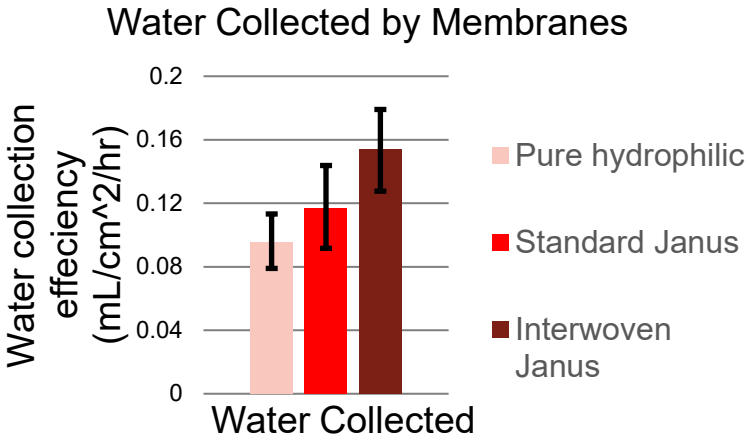
Standard Janus - Wet

Interwoven Janus - Wet

Results of Fog Collection

- The interwoven Janus membranes demonstrated an average collection efficiency of **0.15mL/cm^2/hr**
- However, interwoven Janus showed a **20.3% higher water retention rate** compared to standard Janus membranes
- Retained water cannot be used, and may affect water collection
- Despite increasing retention rate, interwoven Janus membranes increased **average collection efficiency by 31.5%**





Conclusion

- The electrospinning process still provides difficulties in utilizing interwoven membranes and obtaining consistent results

- However, electrospun interwoven Janus membranes **increased the water collection efficiency by 31.5%** and **increased water retention rate by 20.3%**

- The increase in both water collection and water retention in the interwoven Janus membranes suggests the membrane may experience the highest fog collection efficiency after being fully saturated

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Thank you
Any Questions?

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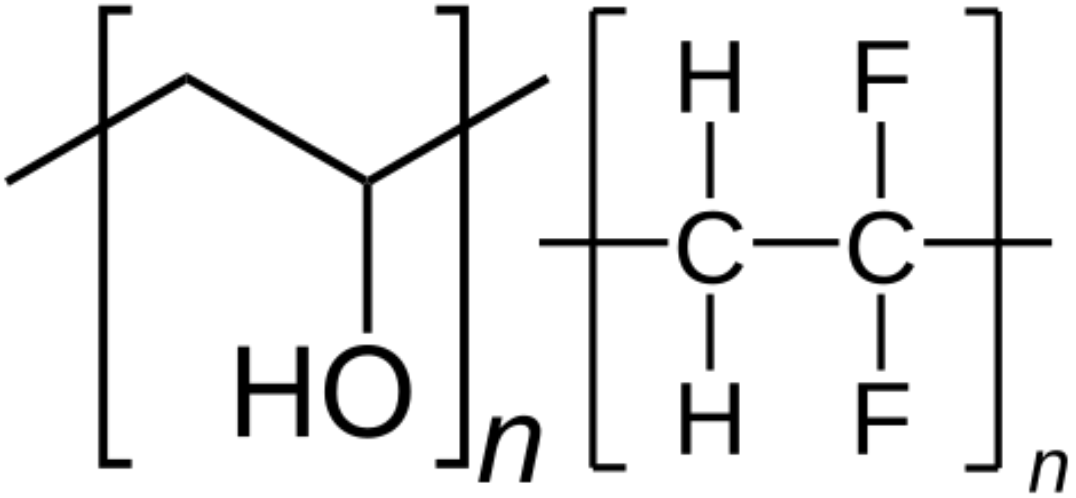
Spinning Parameters

- Solutions
  - PVA Solution: 18wt% in RO water
  - PVDF Solution: 15wt% in DMF
- Spinning
  - Distance: 100mm
  - Drum Speed: 300rpm
  - Homogeneity: 80mm @ 20mm/s
  - Nozzle Type: Hybrid
  - Total Time: 3 hours
- Spinning order: Layers
  - PVA → Interwoven → PVDF

	Hydrophilic	Standard Janus	Interwoven Janus
Flow Rate: PVA	0.45ml/hr	0.45ml/hr	0.45ml/hr
Flow Rate: PVDF	0ml/hr	8ml/hr	8ml/hr
Voltage	37kV	36kV	36kV
Nozzles	1	1	2
Time: PVA	3 hrs	1.5 hrs	1 hr
Time: Interwoven	0 hrs	0 hrs	1.5 hrs
Time: PVDF	0 hrs	1.5 hrs	0.5 hrs

Spinning Solutions

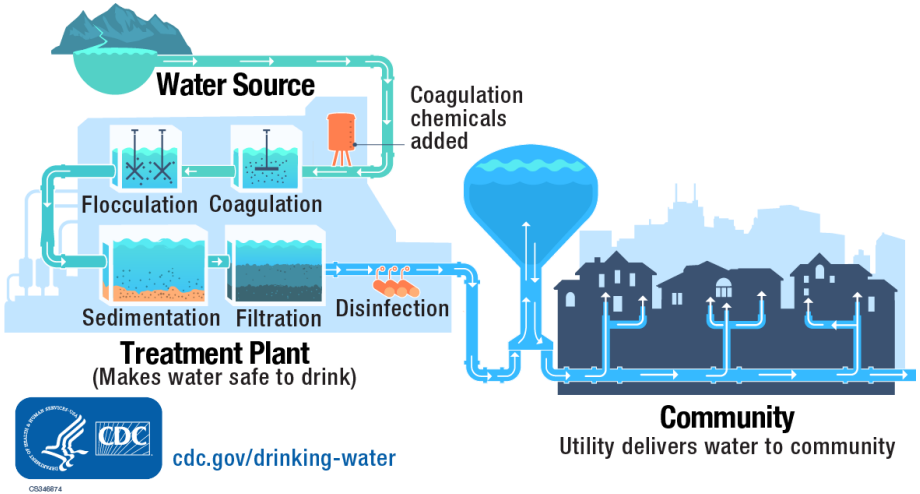
- Two polymers were used for this experiment:
  - Hydrophilic PVA
  - Hydrophobic PVDF
- PVA (Polyvinyl Alcohol) was chosen because it is nontoxic, affordable, and has been previously studied
- PVA solutions can be made with water as a solvent

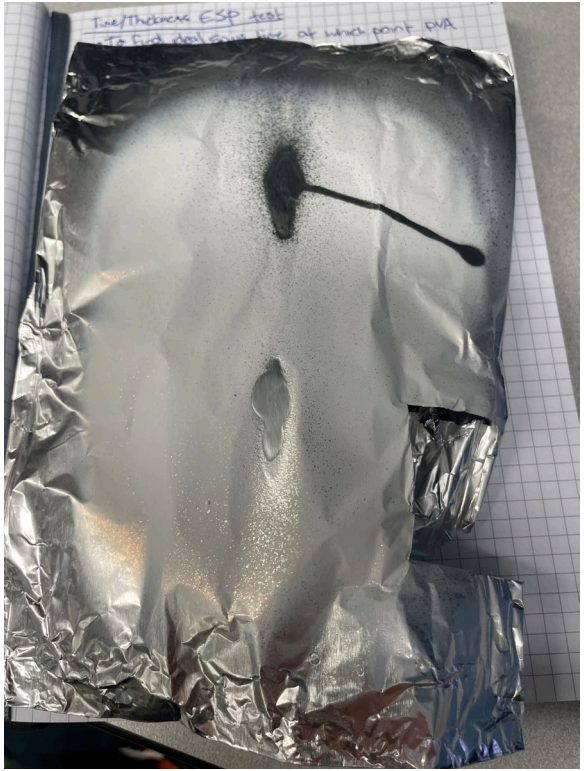


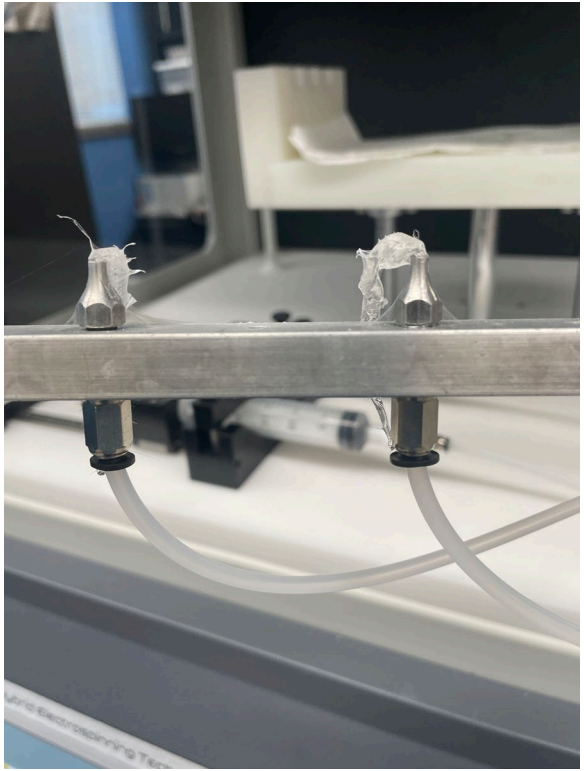
- PVDF (Polyvinylidene Fluoride) was chosen due to being nontoxic, affordable, and mechanically strong
- PVDF solutions can be made with DMF as a solvent

What about pollutants in the air?

- Due to air pollution, fog collection does not simply provide clean water
- It is still necessary to filter and clean the water
    - Filtering and cleaning water is expensive, and another barrier to reducing water scarcity
    - Some filtration, like sediment filtration may be less necessary

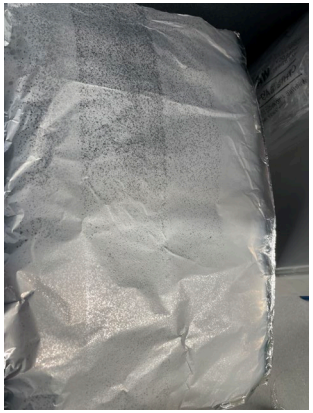
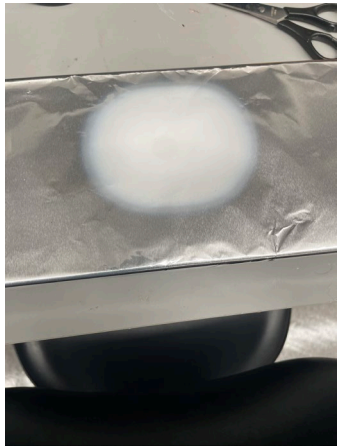



Time/Thickness ESP test

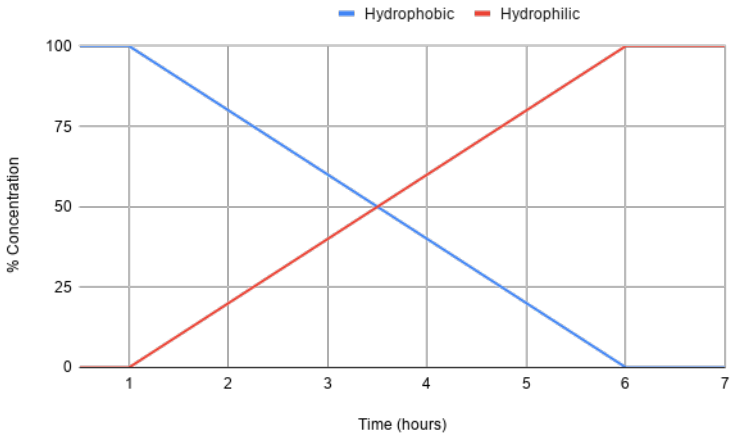


Electrospinning So Far

- Two needle electrospinning presents unique difficulties
- Optimizing the parameters is essential in creating good electrospun membranes

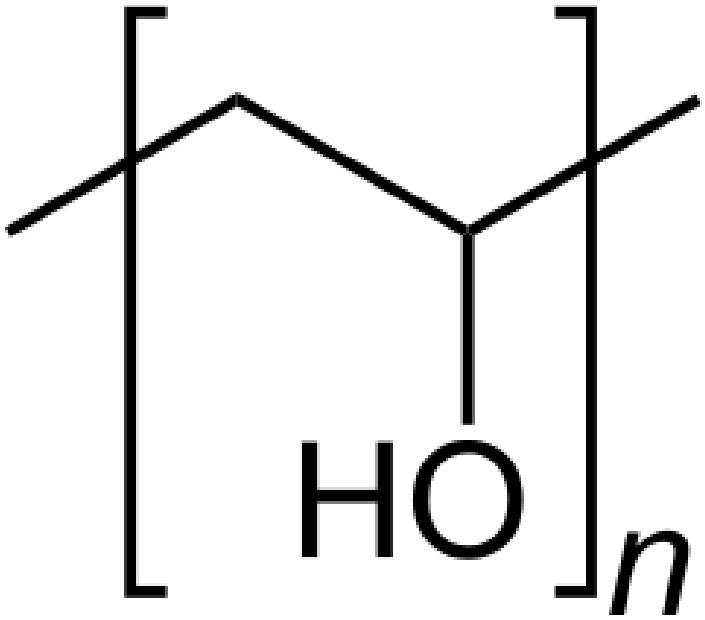

Hydrophobic
Hydrophilic


Hydrophobic
Hydrophilic
100
75
50
25
0
% Concentration
1
2
3
4
5
6
7
Time (hours)

PVA

- Polyvinyl Alcohol
- Hydrophilic
- Biocomptible
- PVA is water soluble, meaning that a spinning solution can easily be made
- Previous work in this lab has studied PVA, and serve as a basis for PVA spinning in this study.

INSERT IMAGE FOR PVA



PVDF

- Polyvinylidene fluoride
- Hydrophobic
- Resistance to UV damage
- Resistance to microbial damage
- PVDF will be dissolved in DMF to create the spinning solution
- PFAS (forever chemical), meaning that other potential Hydrophobic materials should be considered

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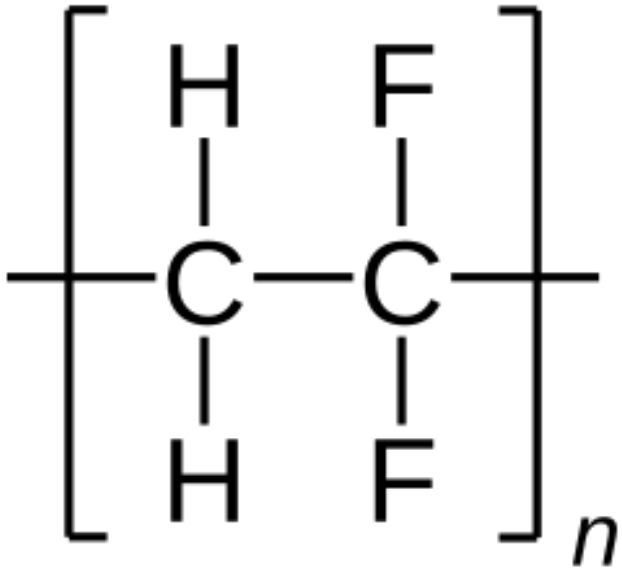
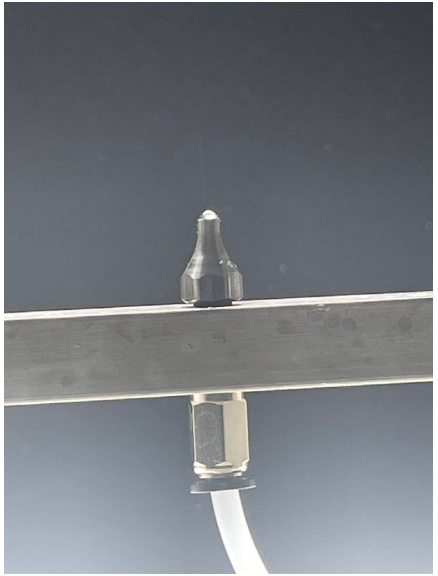
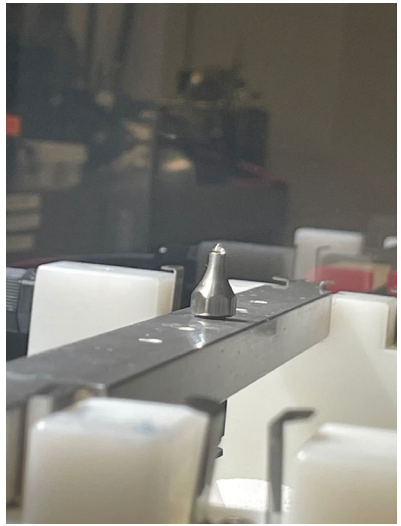
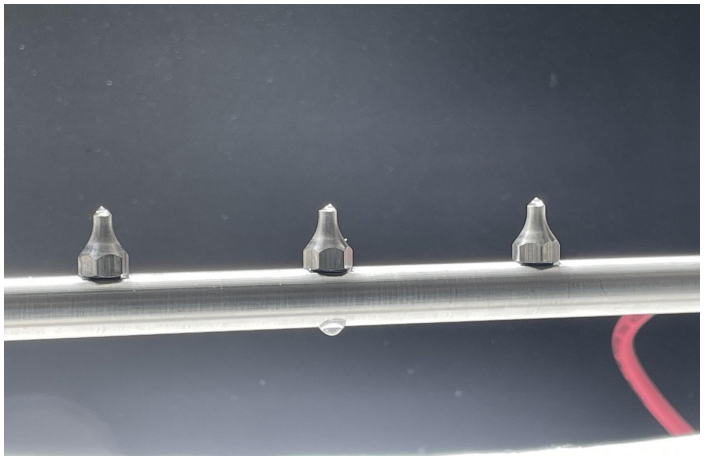
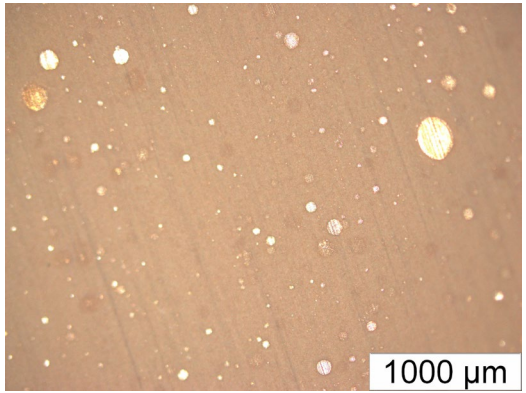
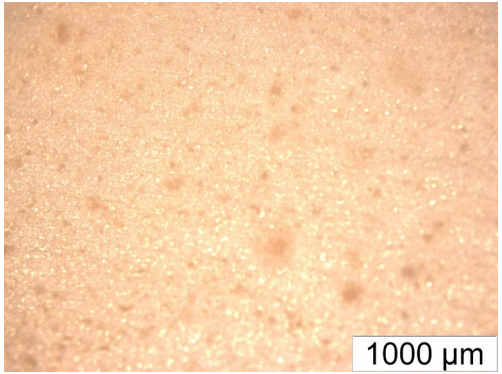









1000 µm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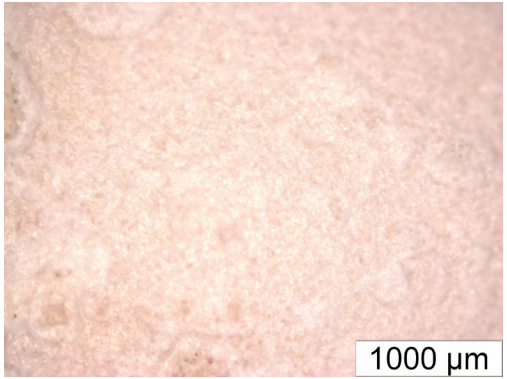
1000 µm

Other types of nets used for fog collection