Enhancement of CO_2 Capture Absorber Performance and Improved Solvent Wetting

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PCCC-8

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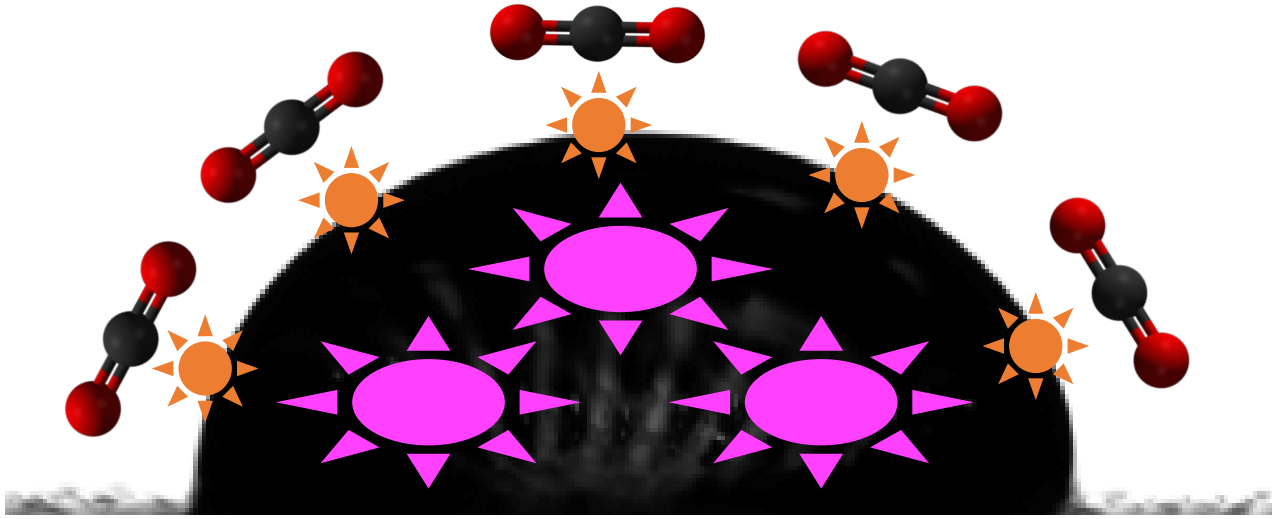
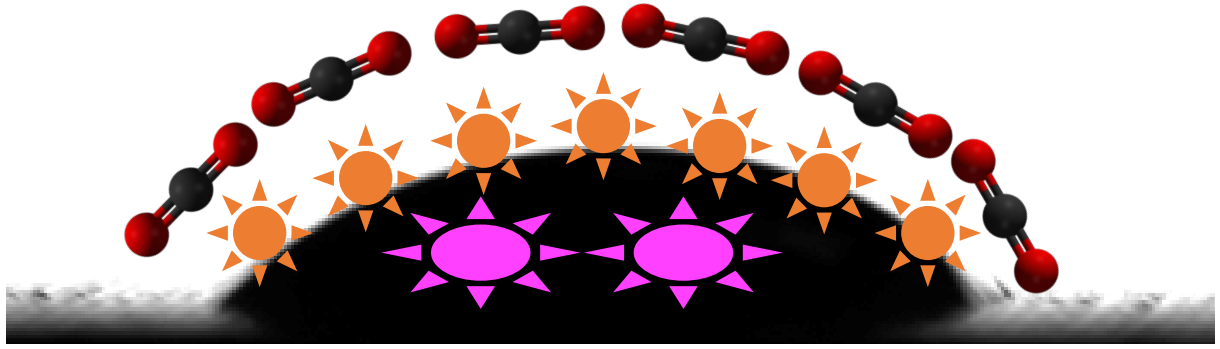
Outline

- What is Solvent “Wetting”
- Wetting with Water-Lean Solvents
- Measuring Wetting through Contact Angle
- Practical Improvements for CO_2 capture
- Conclusions

Solvent Wetting

Wettability is the preference of a liquid to be in contact with a solid surrounded by another fluid (liquid or gas). Adhesive and cohesive forces between the solid and the liquid determine the wettability.





Better wetting means more free-amine at the gas/liquid interface, less liquid hold-up, lower pressure drop, more gas volume can be treated and/or operate at a lower liquid flow rate (lower L/G), which would be useful for NGCC applications

https://www.biolinscientific.com/blog/what-is-wettability

Solvent Wetting Enhancement

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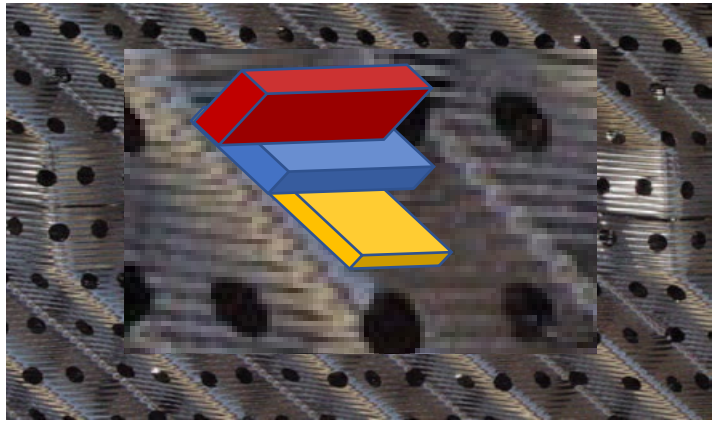
How does solvent wetting translate to CO_2 Flux?

$$- flux = A \cdot k_G \cdot (P^{g}_{CO_2} - P^{*}_{CO_2})$$

Where $k_G \propto \frac{\sqrt{D_{CO_2} \cdot k_2 \cdot [amine]}}{H_{CO_2}}$

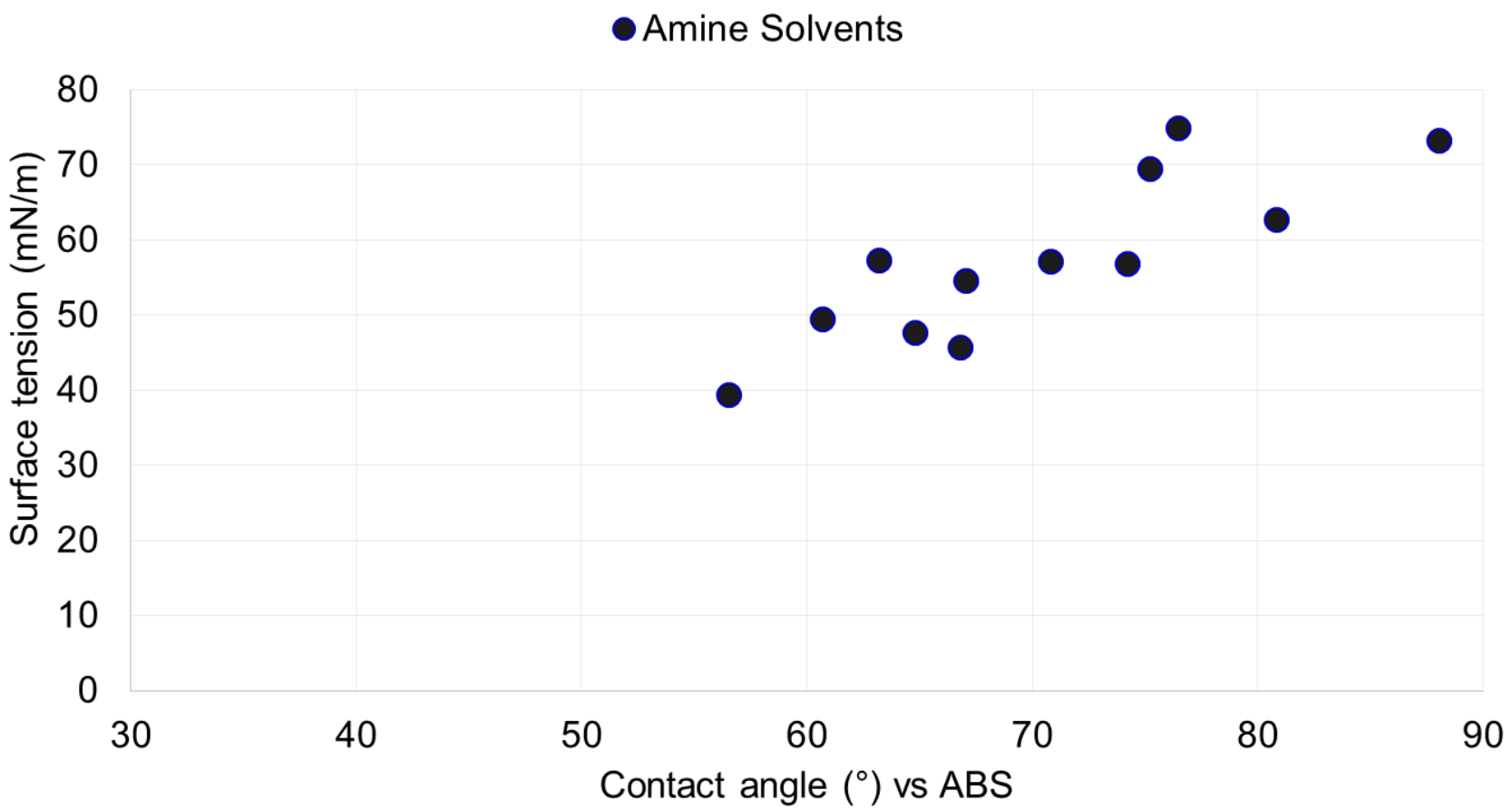


	MEA	PZ	MDEA
Rate Constant	5.94	69.21	0.004
Self-concentrated amine	1.0	3.5	~1
Calculated Kg' impact from [M]	1	1.87	~1
Calculated Kg' impact from k_2	1	3.41	0.03
Calculated Kg' Overall	**1**	**6.39**	**0.03**
Measured Mass Flux (WCC@0.1)	1	2.20	0.18

- Most solvents do not take full advantage of packing in the absorber

- Solvent physical properties can impact and potentially improve CO_2 mass transfer (diffusion resistance)

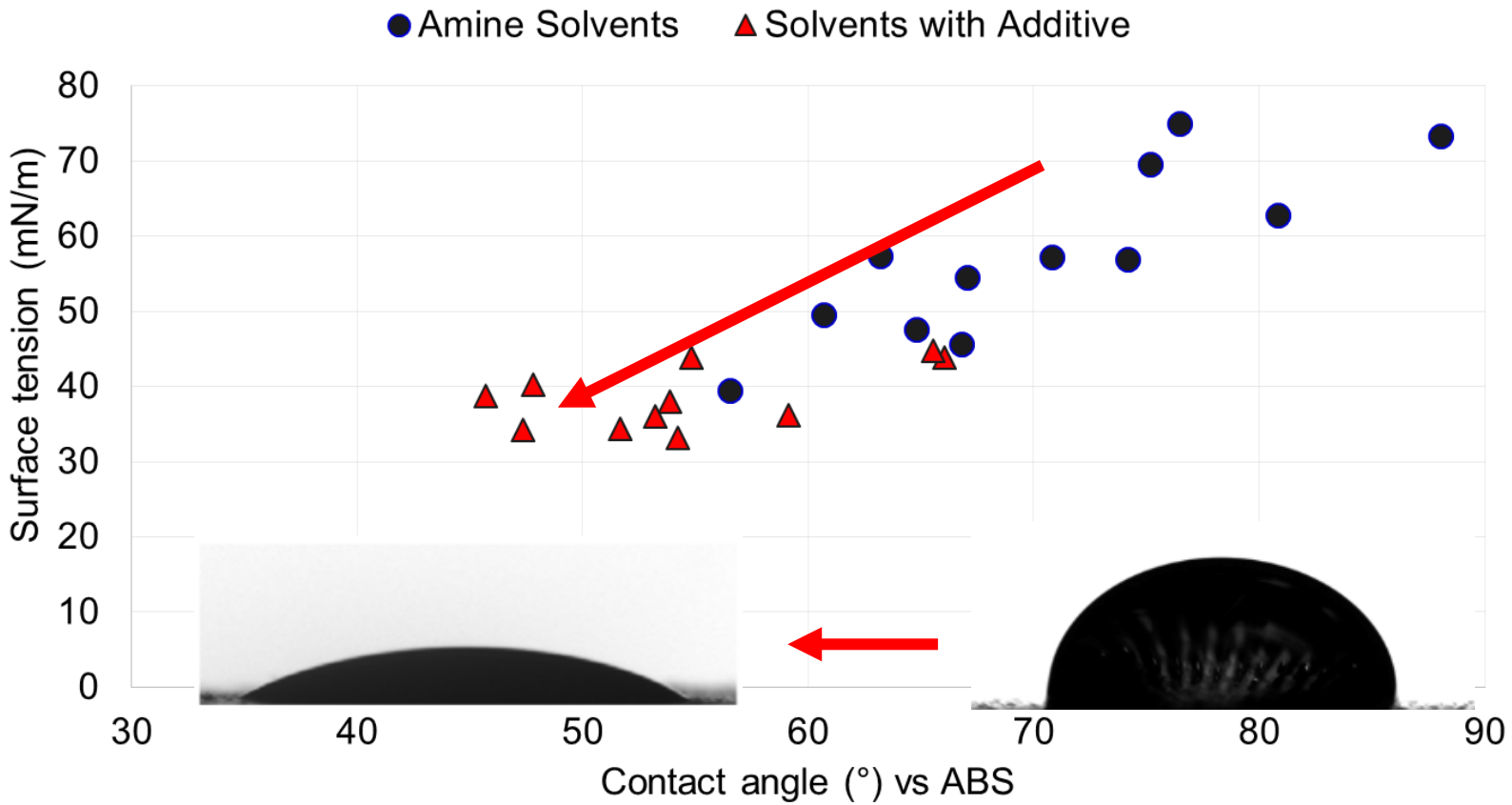
Solvent Surface Tension

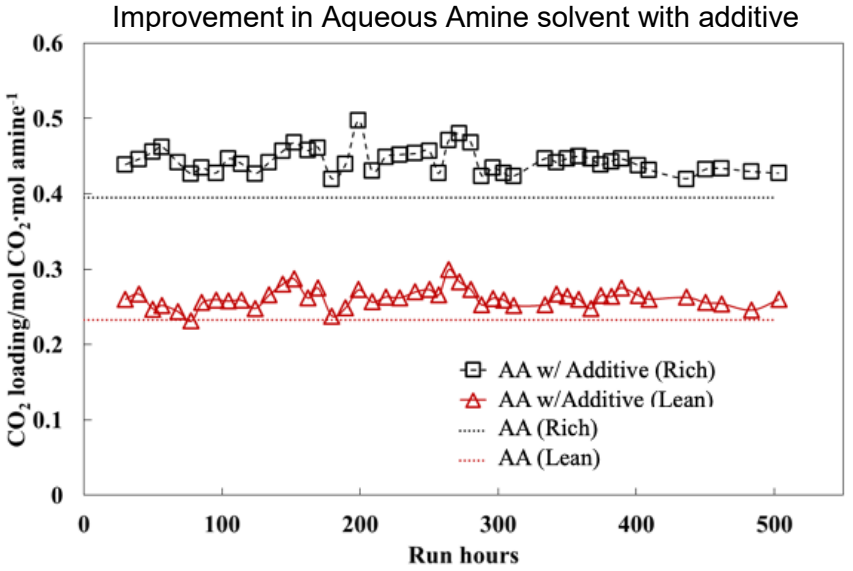


Aqueous Amines;
including Primary Amines,
Secondary Amines, and
Tertiary/Hindered Amines

The surface tension and contact angle were measured with 12 different CO_2-loaded amine solvents. The trend shows that surface tension is generally related to contact angle, and changes to surface tension can be used to change the contact angle of the solvent on the packing surface; e.g., improved wetting

Solvent Wetting Enhancement





A very small amount of surfactant-type additive (<< 0.1%) can be used to reduce the surface tension (ave. ↓30%) and contact angle (ave. ↓23%) of common amine solvents, helping to increase the wettability of these solvents on the packing surfaces. Other physical properties are unaffected by the additive, including viscosity

Water-Lean Solvents

- We use a WLS definition: < 25% water content with an inert/non-volatile co-solvent plus the active amine component

- Lower water content – lower reboiler and condenser duty

- But may have higher viscosity due to co-solvent

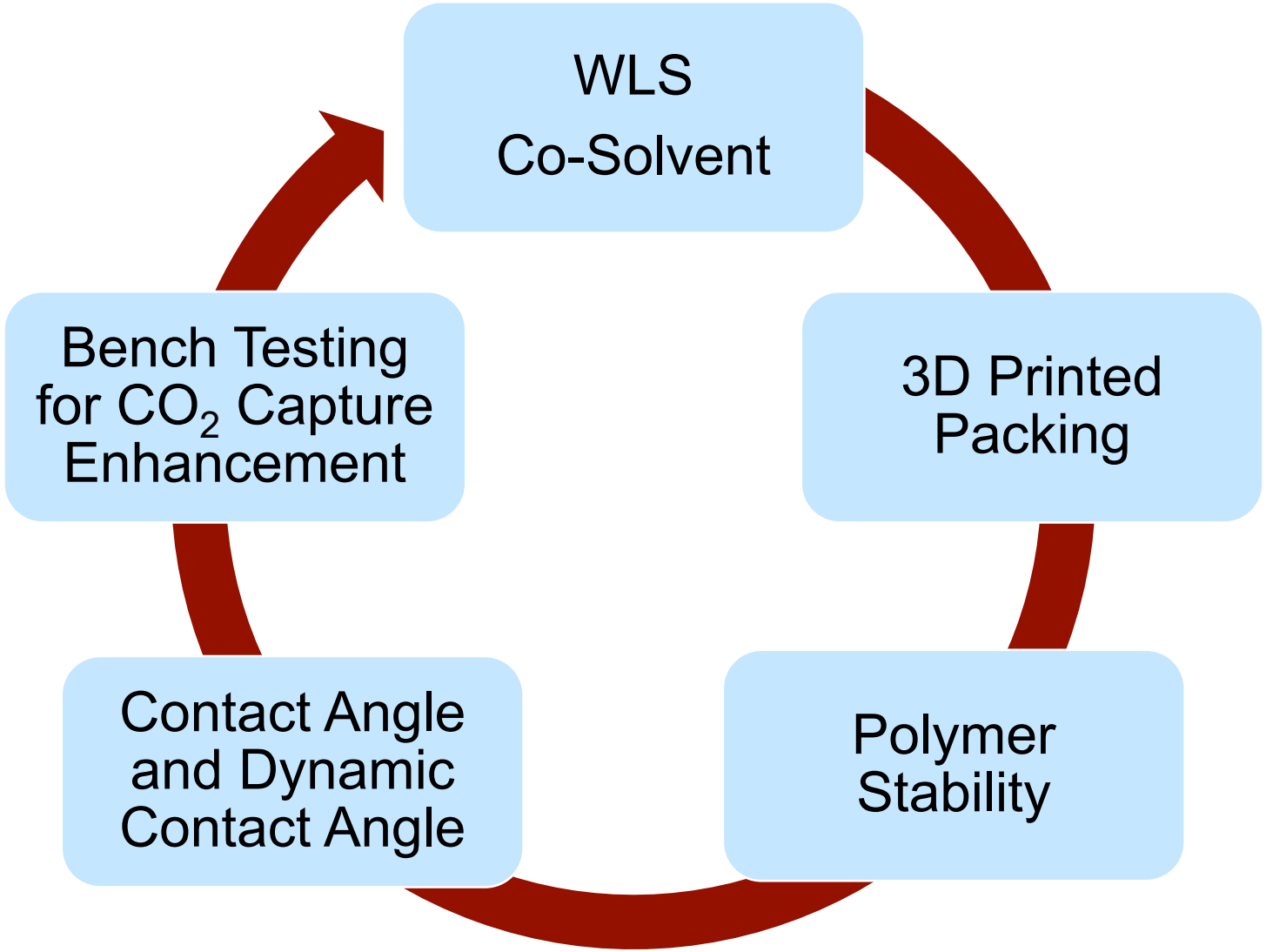
- Can also have lower *surface tension* due to presence of an organic co-solvent

- Using an organic co-solvent may lead to favorable surface interactions with polymers

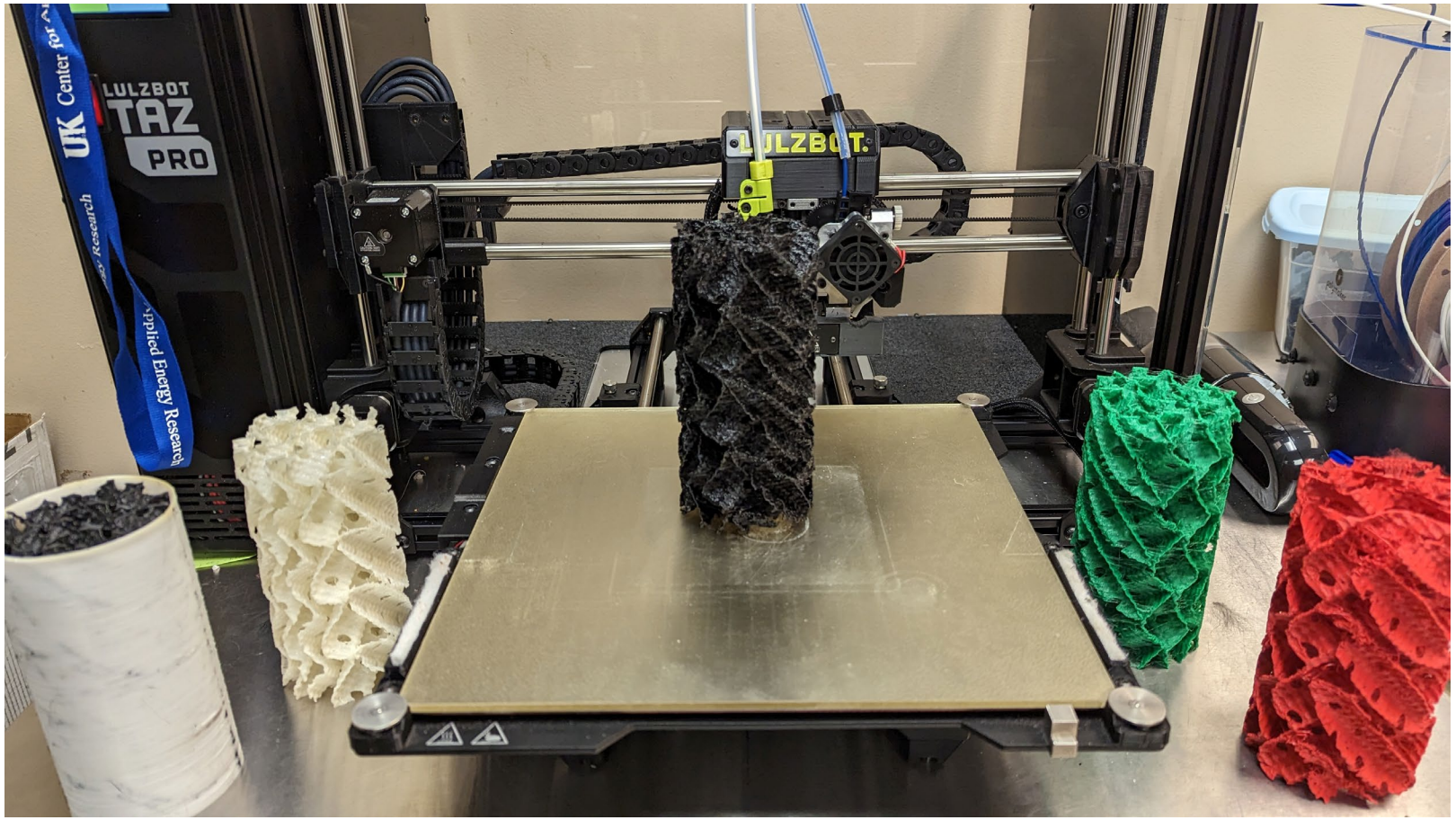
Co-Solvent Class	Example
Alcohols	1-Octanol[1,2]
Diols	1,4-Butanedoil[1]
Glycols	Ethylene Glygol[1,2]
Glycol Ethers	Diethylene glycol ethyl ether[1]
Other Organics	N-methyl-pyrrolidone[2]

[1]Chowdhury et al., *IJGGC*, 2020, 103081; [2]Wanderley et al., *Sep. Purif. Technol.* 2021, 118193

Improved Solvent Wetting



Solvent Compatibility



3D Printing Polymers

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Material	*Color*	*Brand*	*Coupon Name*	*Stability (60°C)*
Polyethylene terephthalate glycol (PETG)	Blue	Polymaker	PETG-Blue	
PETG	Clear	Polymaker	PETG-Clear	
Polylactic acid (PLA)	White	Polymaker	PLA	
Nylon	Black	Polymaker	CoPA	
Nylon	Black	3DXTech	Nylon	
Nylon	Green	Kodak	Nylon -Green	
Nylon	Red	MatterHackers	Nylon - Red	
Polyvinyl butyral (Copolyester)	Orange	Polymaker Polysmooth	Polysmooth	
Polycyclohexylenedimethylene Terephthalate glycol (PCTG)	Clear	Essentium	PCTG	
High Impact Polystyrene (HIPS)	Pink	Closed Lopped Plastics	HIPS	
Acrylonitrile butadene sytrene (ABS)	White	IC3D	ABS	
Eastman Amphora AM3300 3D Polymer (nGen)	Purple	ColorFabb	nGen	
Dow OBC (Olefin Block Copolymer)	Silver	Dow	OBC	
PP (Polypropylene)	Clear	Ultimaker	PP	
EVOLV3D OBC (Olefin Block Copolymer)	Blue	3DXTech/Dow	OBC -Blue	
CarbonX (PP + Carbon Fiber)	Black	3DXTech	CFPP	
PC +PBT (polycarbonate polybutylene terephthalate)	White	Polymaker	PC+PBT	
Cooling Tower PP	Clear	-	CT PP	
PVC	Clear	-	PVC	

Unstability: Glycol Ether Co-Solvent

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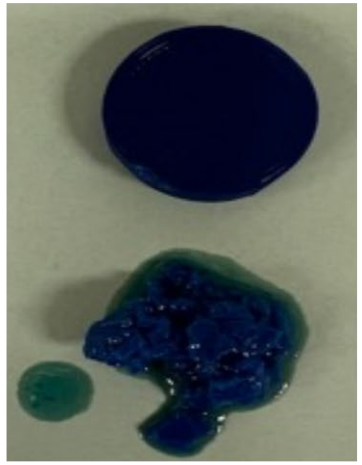
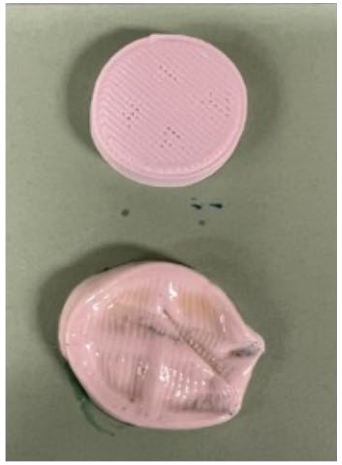
PLA

PCTG

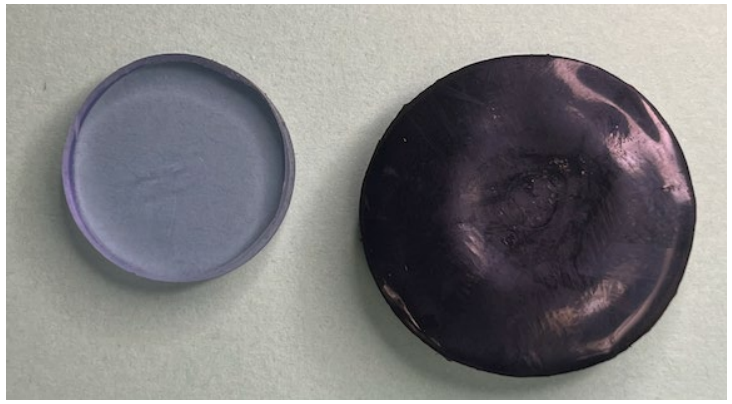
PETG



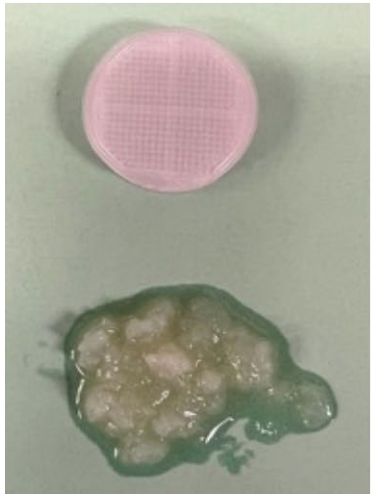
ABS



PVC



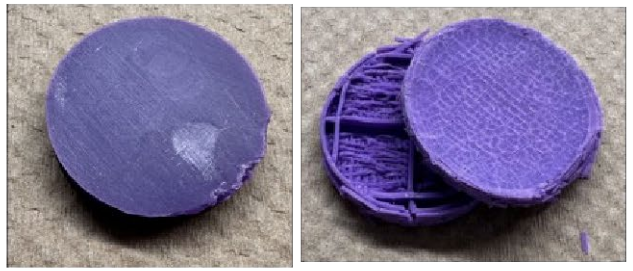
PETG-Clear



HIPS

Polysmooth

nGen



Stable : Glycol Ether Co-Solvent

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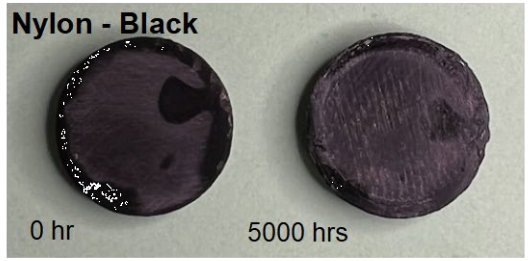
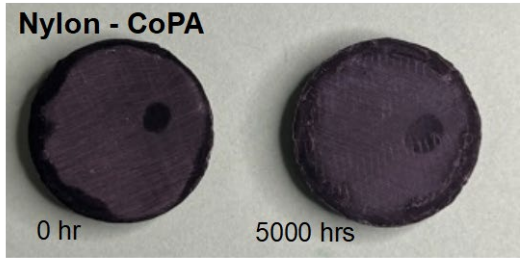
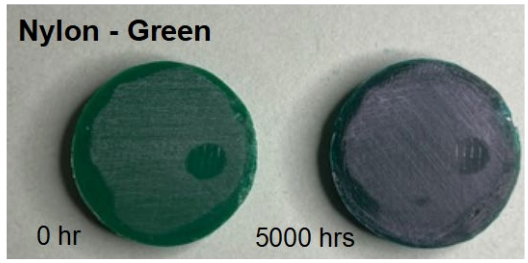
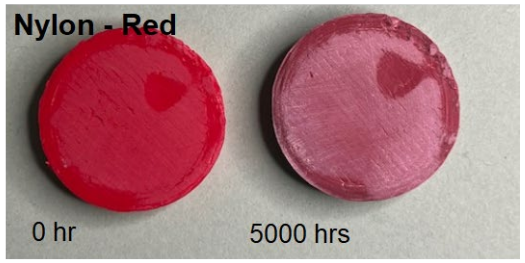
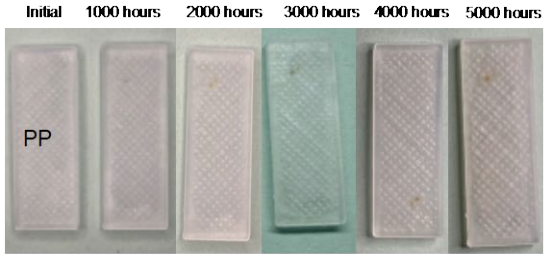
Nylon, PP, Olefin Stability after 5000 hrs

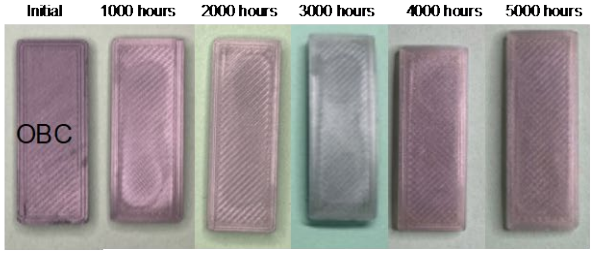


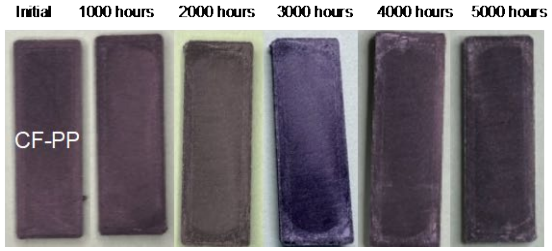


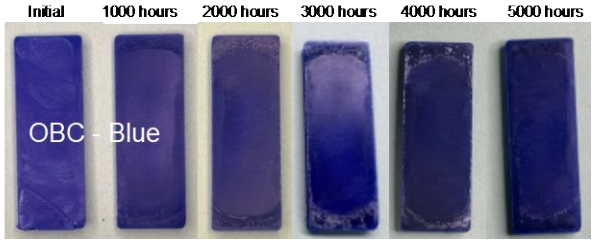


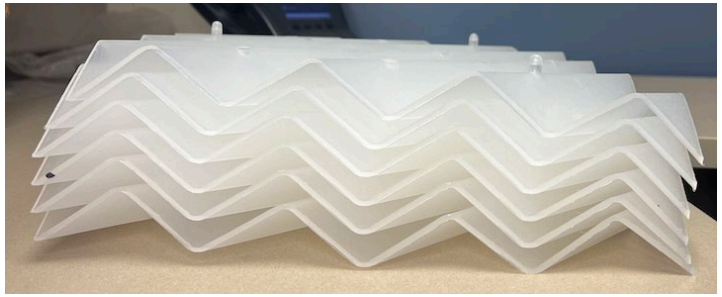


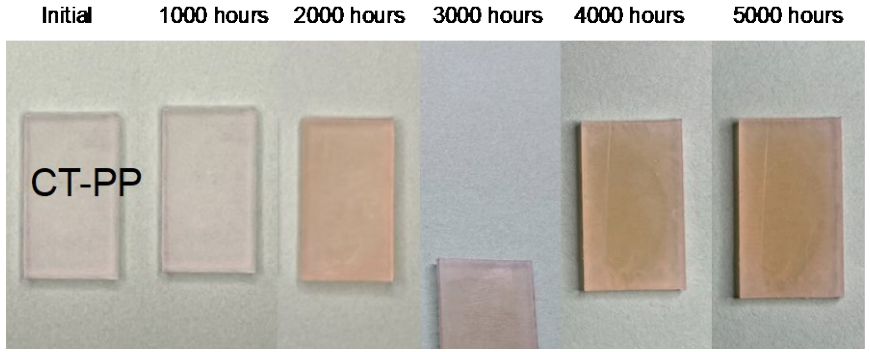












3D Printing Polymers w/ WLS

PCCC-8

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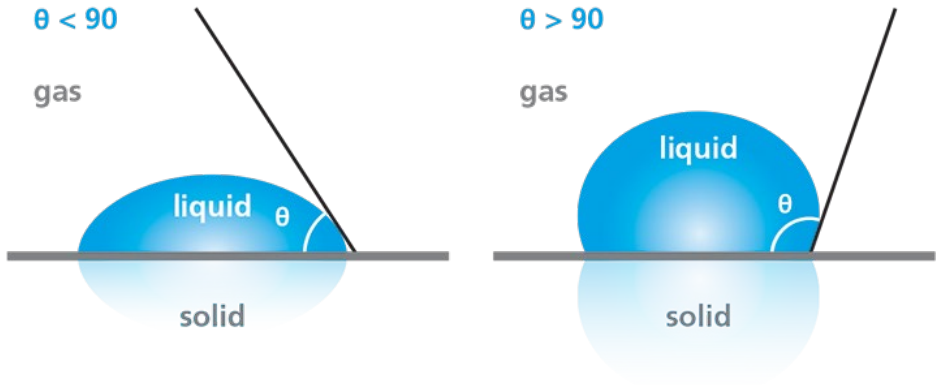
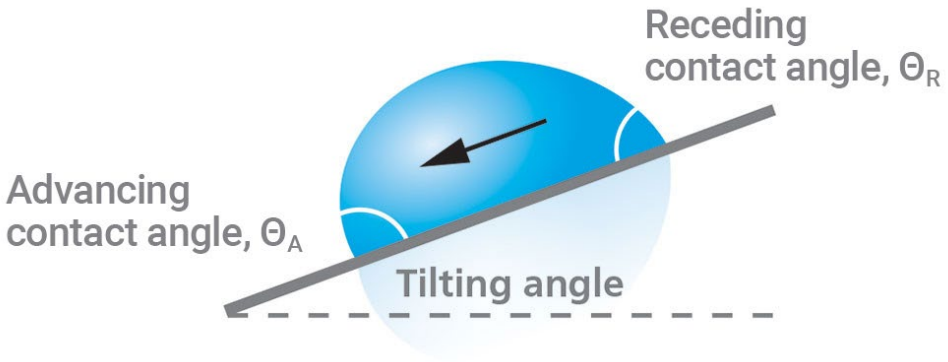
PETG	Clear	Polymaker	PETG-Clear	< 1000 hrs
Polylactic acid (PLA)	White	Polymaker	PLA	< 1000 hrs
Nylon	Black	Polymaker	CoPA	> 5000 hrs
Nylon	Black	3DXTech	Nylon	> 5000 hrs
Nylon	Green	Kodak	Nylon -Green	> 5000 hrs
Nylon	Red	MatterHackers	Nylon - Red	> 5000 hrs
Polyvinyl butyral (Copolyester)	Orange	Polymaker Polysmooth	Polysmooth	< 1000 hrs
Polycyclohexylenedimethylene Terephthalate glycol (PCTG)	Clear	Essentium	PCTG	< 1000 hrs
High Impact Polystyrene (HIPS)	Pink	Closed Lopped Plastics	HIPS	< 1000 hrs
Acrylonitrile butadene sytrene (ABS)	White	IC3D	ABS	< 1000 hrs
Eastman Amphora AM3300 3D Polymer (nGen)	Purple	ColorFabb	nGen	< 1000 hrs
Dow OBC (Olefin Block Copolymer)	Silver	Dow	OBC	> 5000 hrs
PP (Polypropylene)	Clear	Ultimaker	PP	> 5000 hrs
EVOLV3D OBC (Olefin Block Copolymer)	Blue	3DXTech/Dow	OBC -Blue	> 5000 hrs
CarbonX (PP + Carbon Fiber)	Black	3DXTech	CFPP	> 5000 hrs
PC +PBT (polycarbonate polybutylene terephthalate)	White	Polymaker	PC+PBT	< 1000 hrs
Cooling Tower PP	Clear	-	CT PP	> 5000 hrs
PVC	Clear	-	PVC	Its complicated

Contact Angle





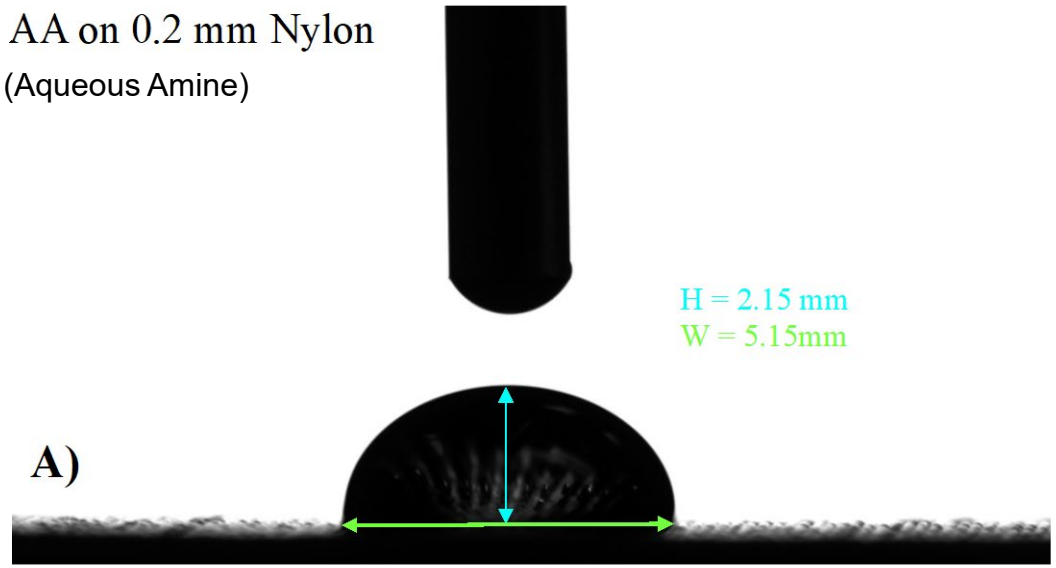
Static Contact Angle measures the bulk repulsive/attractive interactions between the surface and a liquid (solvent)

Dynamic Contact Angle will measure the advancing and receding contact angle, and will replicate the downward flow of the solvent on the absorber packing and better describe the actual wetting profile of the packing

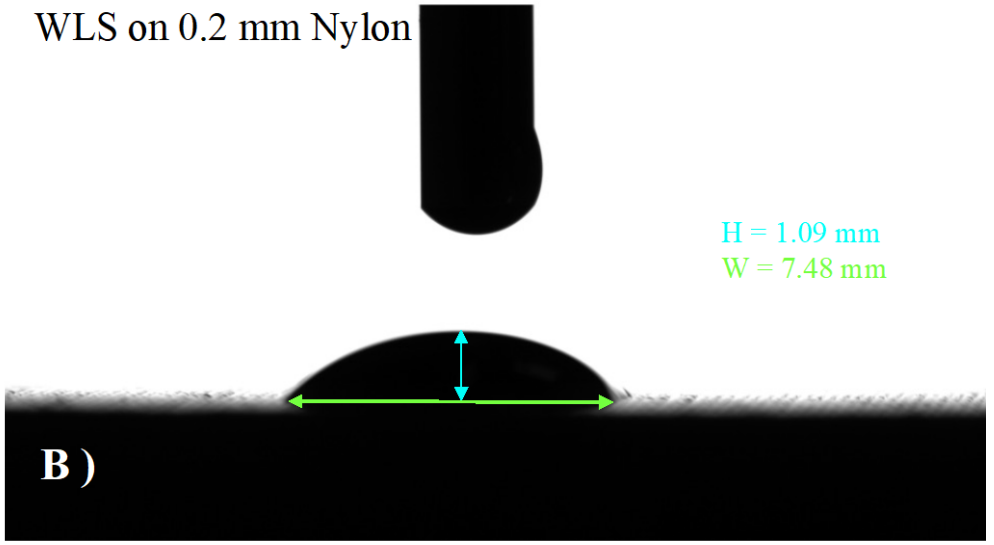
https://www.nanoscience.com/techniques/tensiometry/contact-angle-measurements-and-wettability/

Static Contact Angle

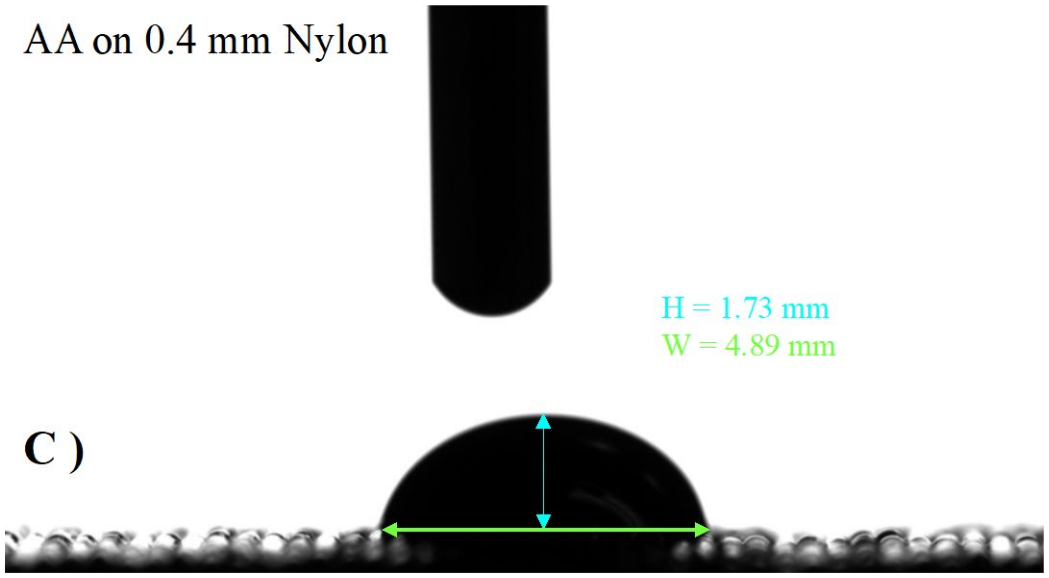
AA on 0.2 mm Nylon
(Aqueous Amine)



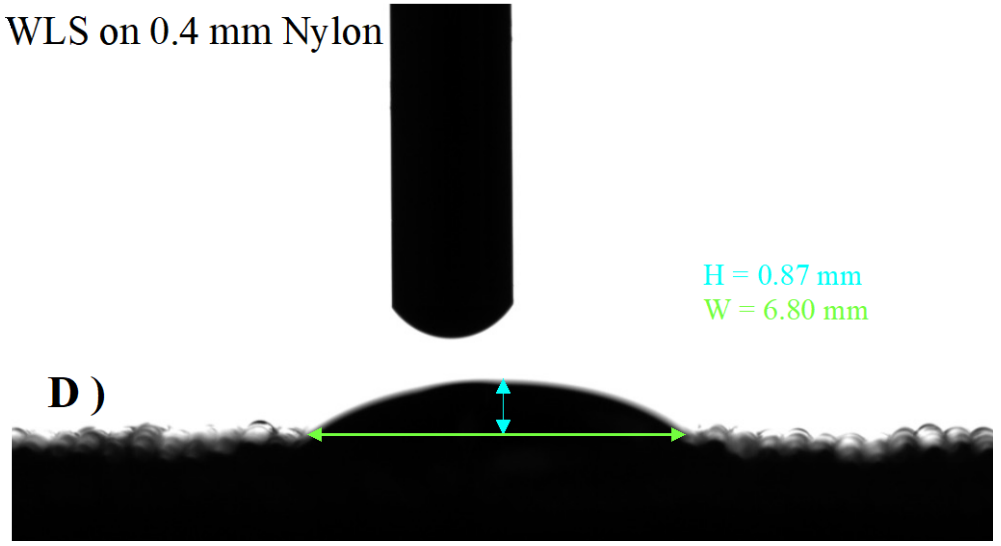
WLS on 0.2 mm Nylon



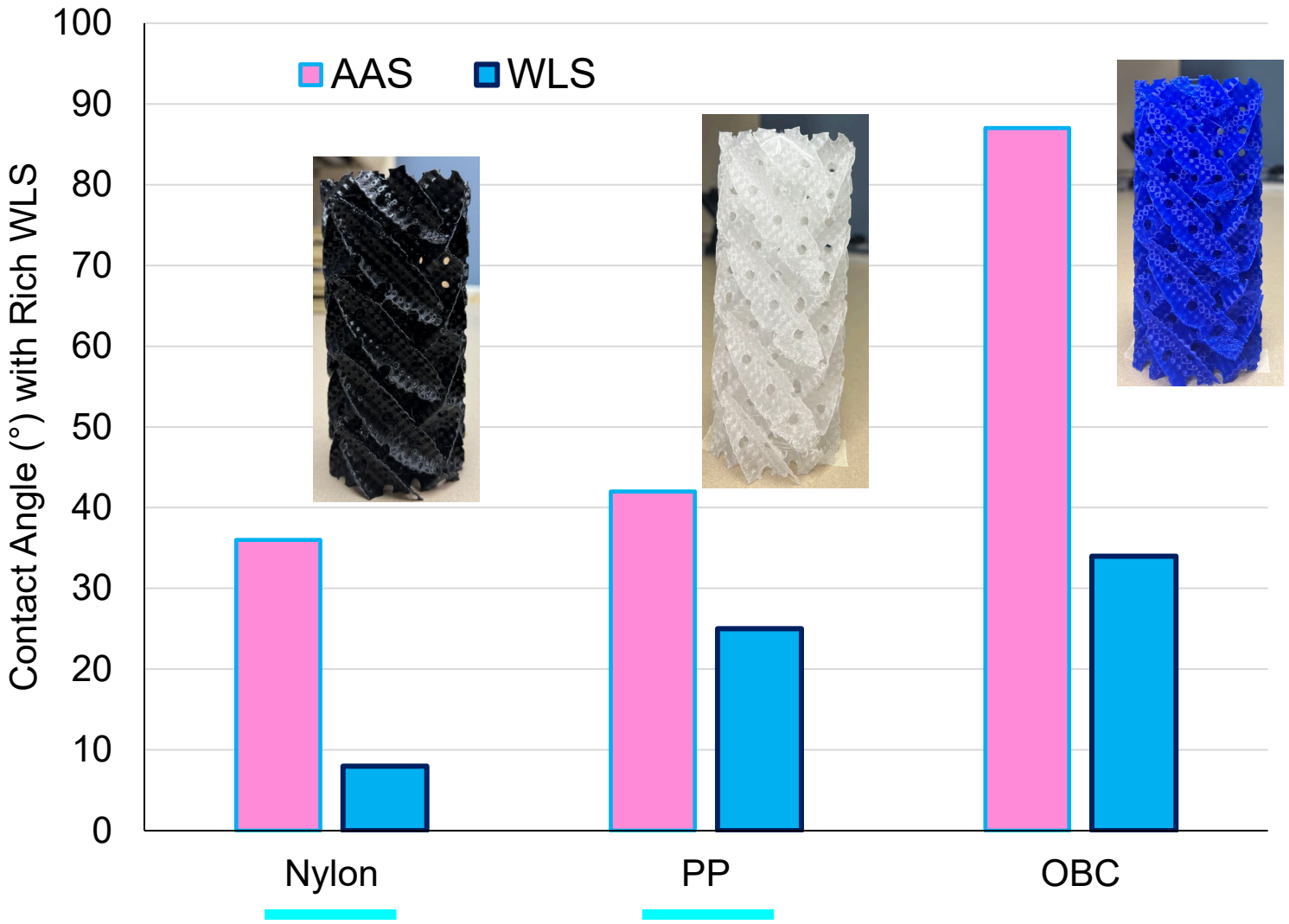
AA on 0.4 mm Nylon

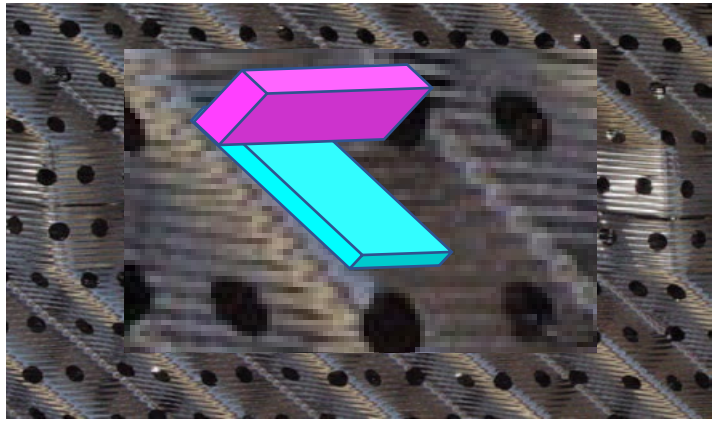


WLS on 0.4 mm Nylon

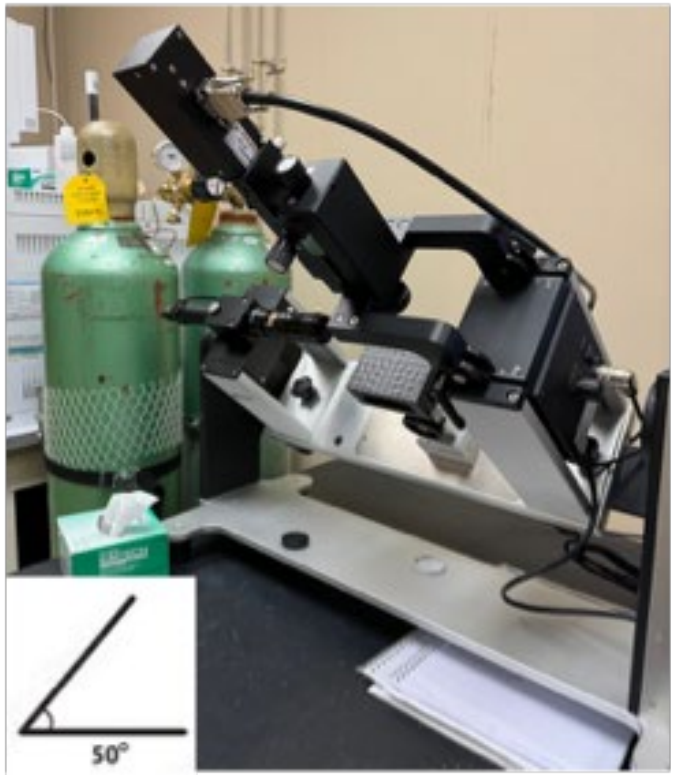


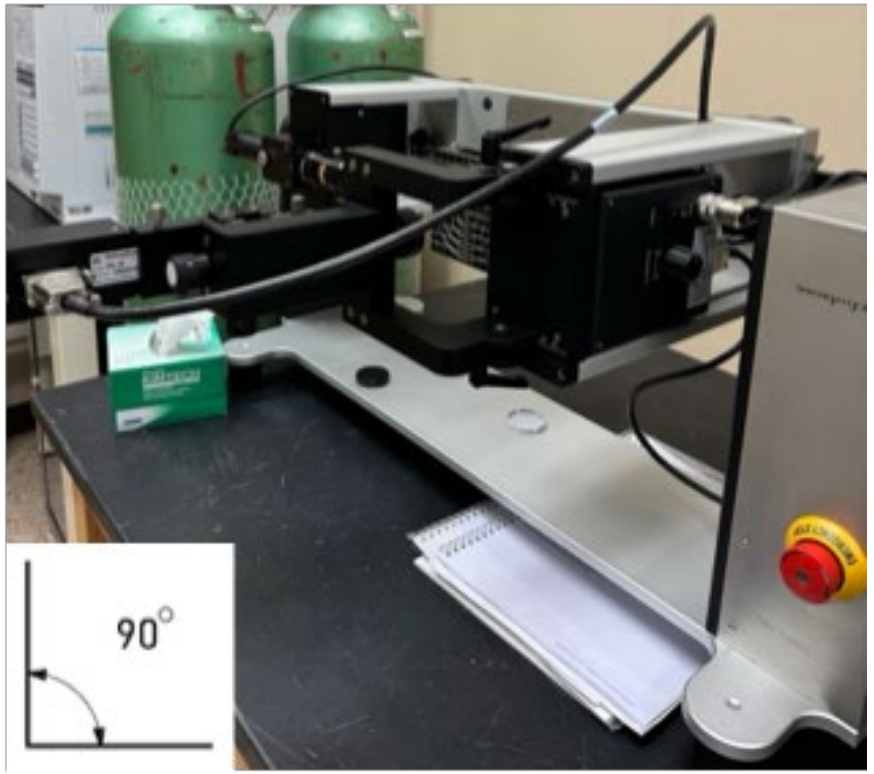
Wetting Profile at Rich C/N





Dynamic Contact Angle

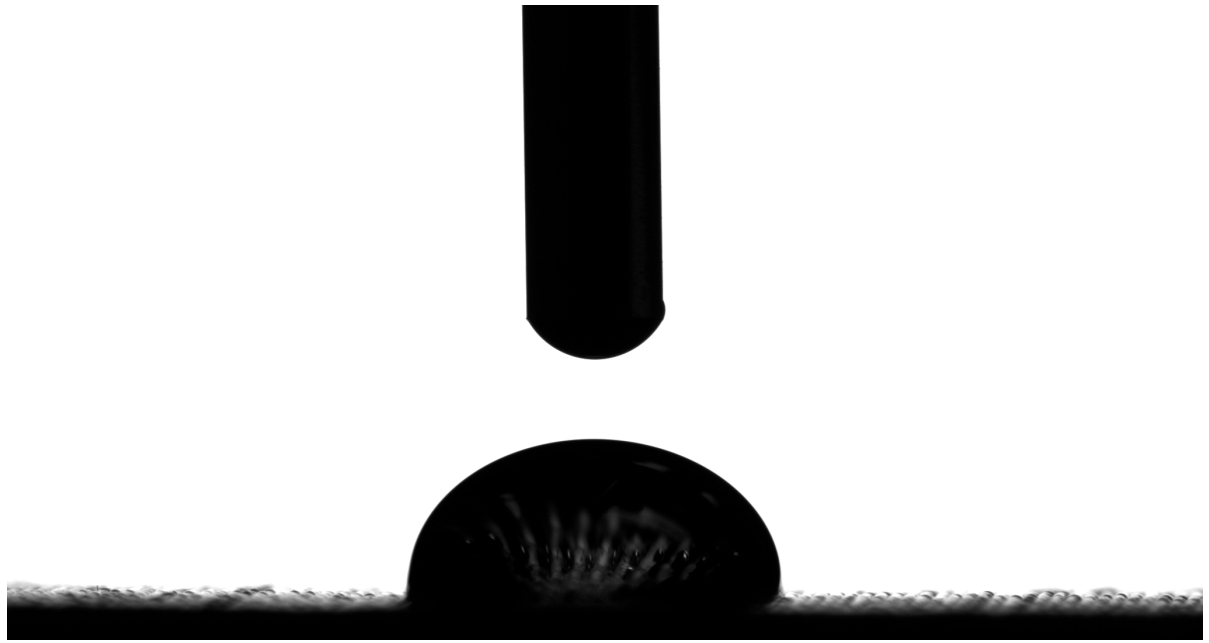




DataPhysics OCA 15EC Tensiometer with titling base in start position, tilted at 50º and 90º.

Dynamic Contact Angle - Nylon

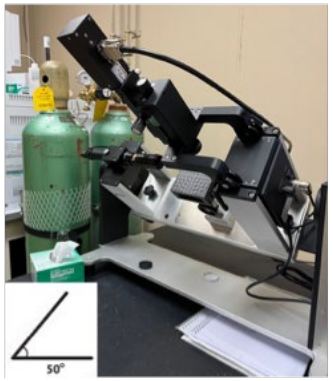
AA

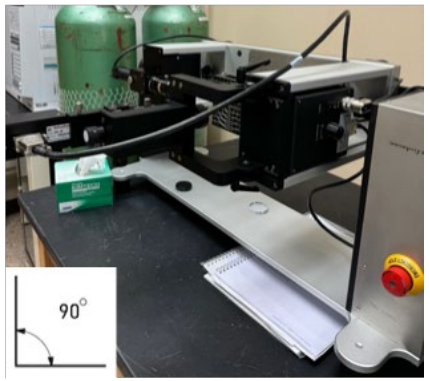


Roll off angle = 90 º

WLS

Roll off angle = 50 º

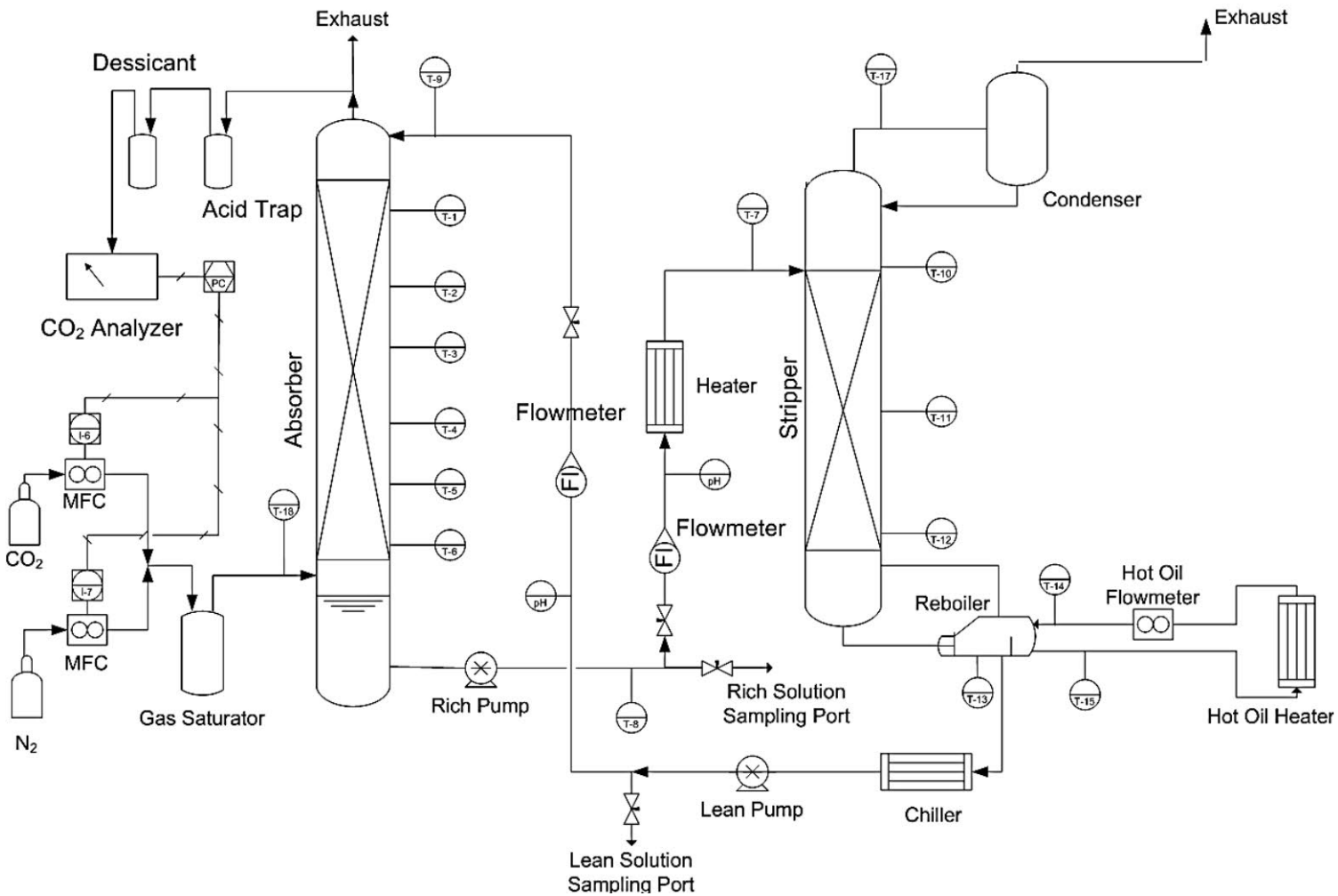




A lower roll-off angle indicates a lower resistance to movement and a greater tendency for droplets to roll off the surface and is a function of surface wetting and solution viscosity.

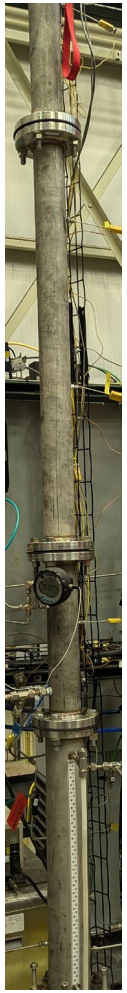
A good DCA range is greater than 45° but less 90°.

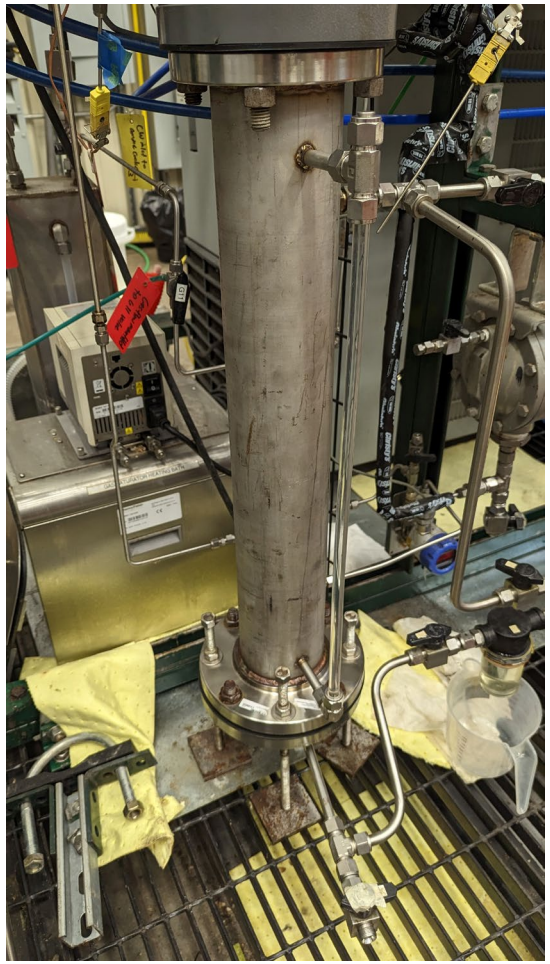
Bench Testing – Packing + WLS



Bench Testing – Packing + WLS

3D Printing of PP and Nylon packing





<u>Testing Conditions:</u>

72” packing height

3” packing diameter

250Y geometry

5M amine target

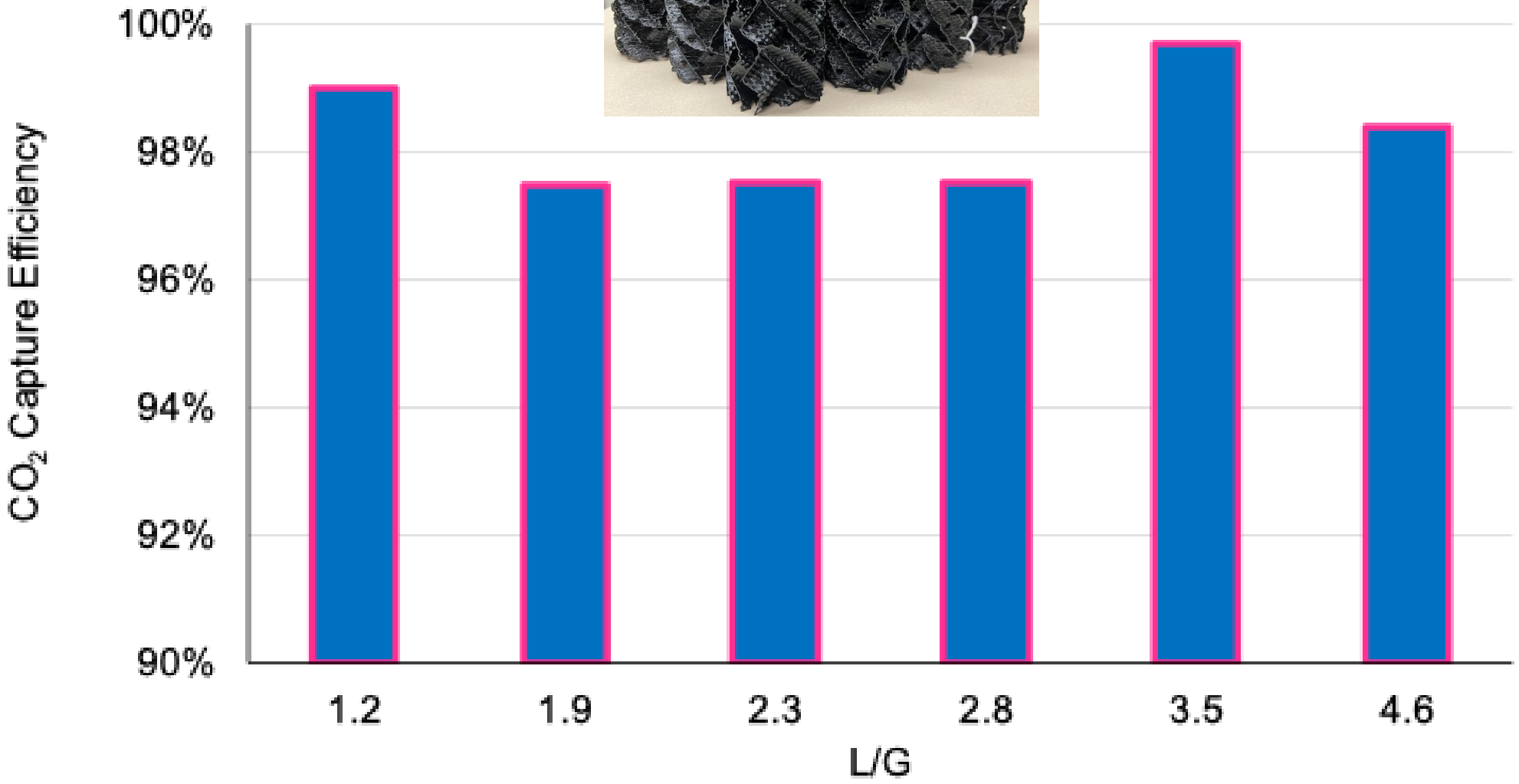
Water content ~25%

4% CO_2 (NGCC)

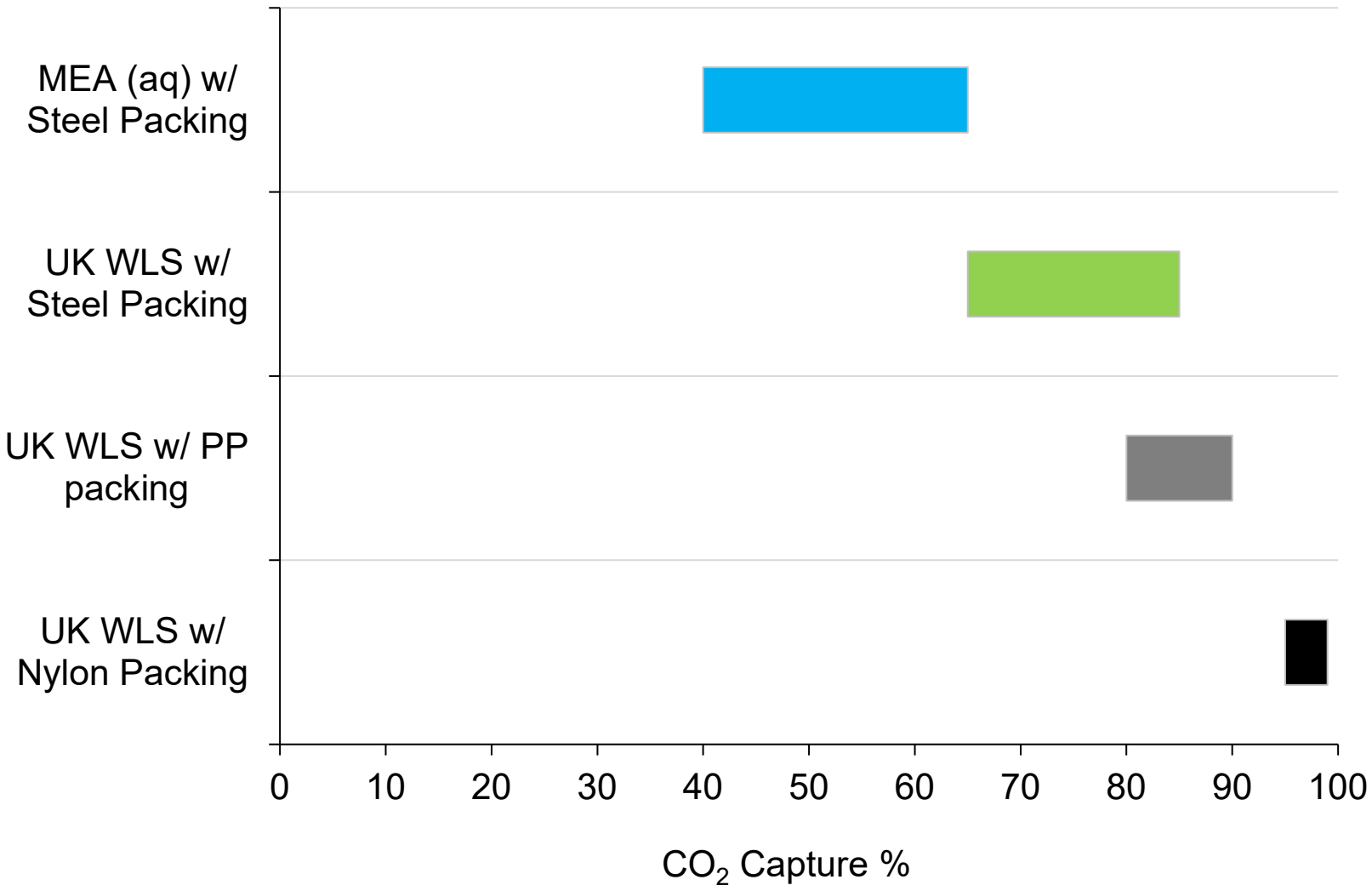
L/G was main variable

Bench Testing - PP

Bench Testing - Nylon



Bench Testing – Summary



Solvent Wetting (sCA)

Poor (> 30°)

Good (> 20°)

Good (> 20°)

Excellent (< 10°)

Conclusions

- Water-lean solvents can have better wetting when compared to common aqueous amine solvents as measured through static and dynamic contact angles

- 3D printed polymer packing can have favorable wetting profiles when combined with water-lean solvents

- Combination of WLS and polymer packing surfaces can have practical improvements for CO_2 capture

Acknowledgements

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Thompson Lab

Keemia Abad
Moushumi Sarma