Research Highlights
Coating Process Fundamentals
CPF

Coating Process Fundamentals — CPF

Investigator	Expertise
Lorraine F. Francis*	Solidification, stress development, microstructure, printing
Satish Kumar*	Transport processes, interfacial phenomena, microfluidics
Marcio S. Carvalho**	Fluid mechanics, rheology, numerical methods
Alon V. McCormick	Curing, thermodynamics & kinetics, NMR, stress development
C. Daniel Frisbie	Printing processes, printed electronics
Chris W. Macosko	Rheology, polymer processing
Xiang Cheng	Colloids, polymers, rheology, visualization
Michael Tsapatsis	Zeolite and particulate coatings, membranes, separations
Wieslaw Suszynski***	Coating process experiments, apparatus, flow visualization

**Program Co-Leaders*

***Pontifica Universidade Catolica, Rio de Janeiro*

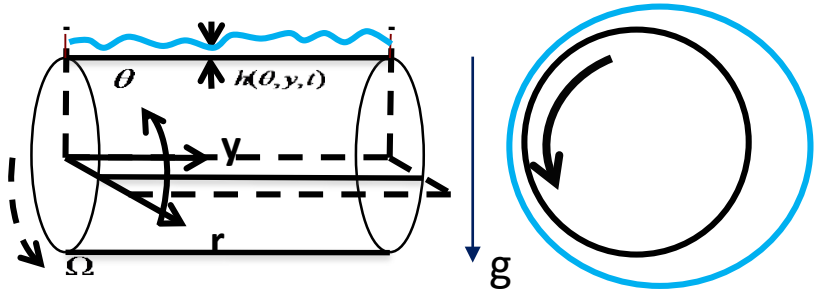
****Research Engineer and Coating Process and Visualization Laboratory Manager*

Coating of Rotating Discrete Objects with Complex Surface Geometry

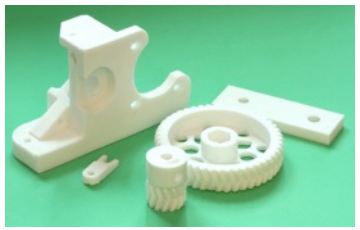
Challenge: Non-uniform coating thickness due to surface curvature

Model Problem

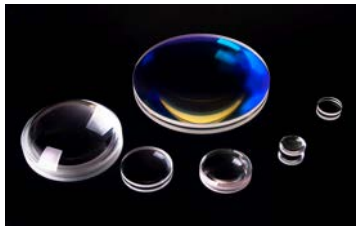
Flow of a liquid film on **rotating cylinders**



Imposed Surface Topography & Complex Cross-section Shape



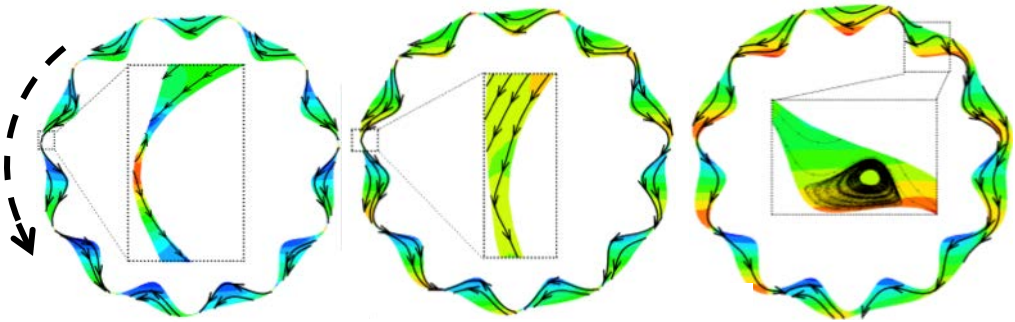
3D Printed Parts



Lens

Patterned Cylinders

Reverse Flows

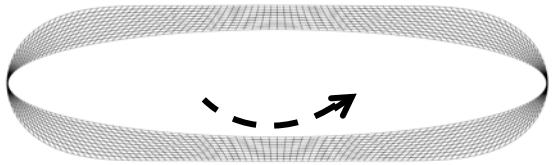


Increasing Film Thickness

Trapping of liquid may be detrimental to coating quality

Slender Cylinders

Increasing Rotation Rate



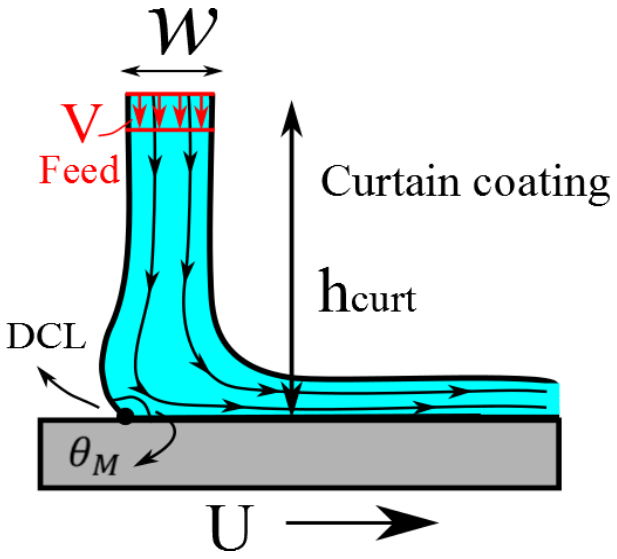
Film Rupture

Liquid Shedding

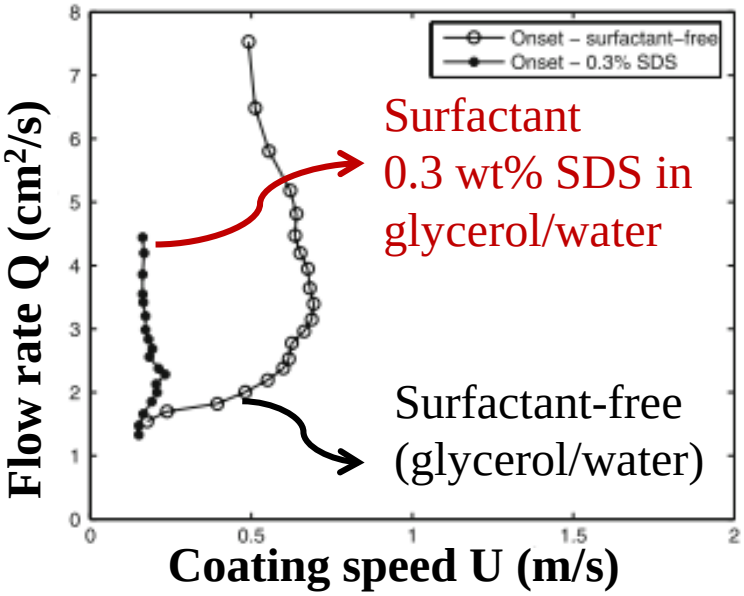
Smooth coatings will likely require simultaneous rotation and drying

Weihua Li (Kumar)

Dynamic Wetting Failure and Hydrodynamic Assist in Curtain Coating

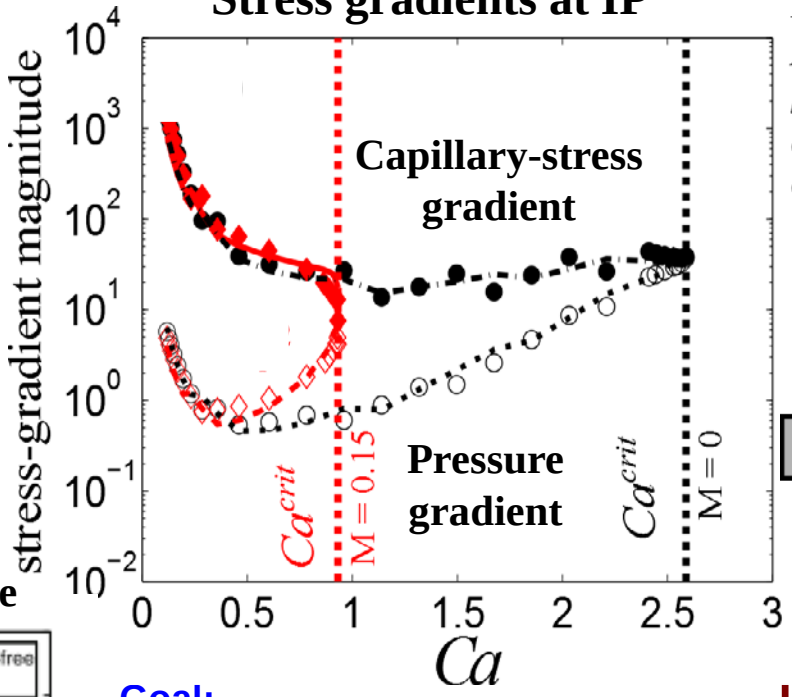


Surfactant promotes wetting failure



Marston et al., *Exp. Fluids* 46 (2009) 549

Stress gradients at IP



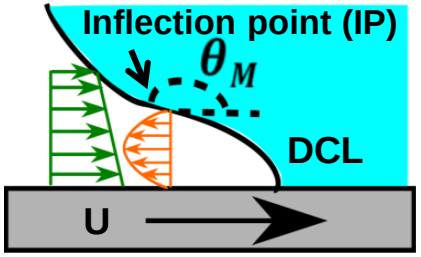
Marangoni number

$M = (\sigma_0 - \sigma_m)/\mu_{liq}U$

μ_{liq}: liquid viscosity

σ_o: surface tension of solvent

σ_m: surface tension of solution



Wetting failure occurs when capillary forces cannot pump air away → Ca^{crit}

Goal:

Understand how surfactants influence wetting failure and hydrodynamic assist in curtain coating

Results:

- Marangoni stresses (surface-tension gradients) promote the onset of wetting failure in curtain coating
- Marangoni stresses are a possible mechanism for the experimental observations reported by Marston et al.

Chen-Yu Liu (Kumar and Carvalho)

C.-Y. Liu, E. Vandre, M. S. Carvalho, and S. Kumar, J. Fluid Mech. 808, 290 (2016).

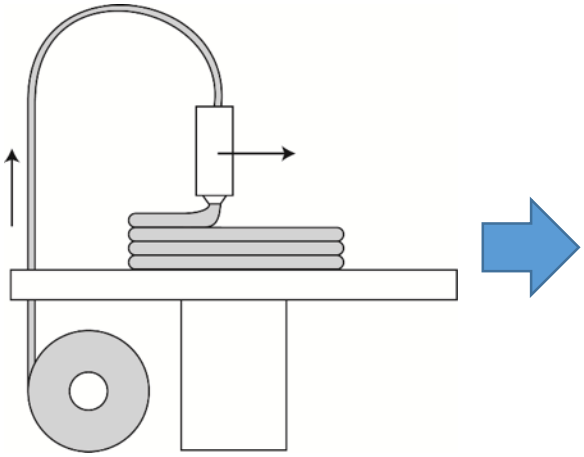
Dynamics of Capillary-Driven Flow in 3D Printed Open Microchannels

Objectives

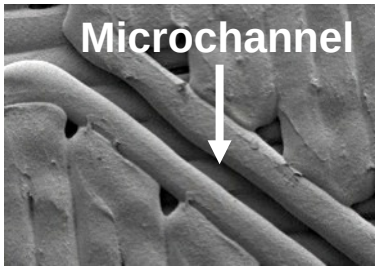
- Fabricate open microchannels with 3D printing
- Understand flow dynamics in 3D printed microchannels

Key Results

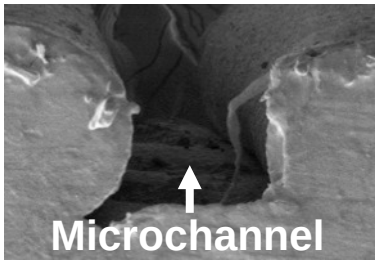
- Open microchannels can be readily printed but are rough and irregular
- 3D printed surface causes unique contact line motion and flow dynamics
- Surface roughness lowers capillary filling velocity



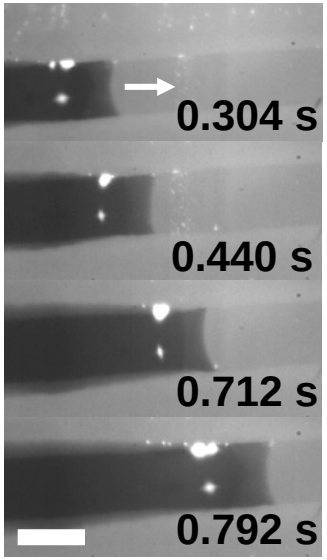
3D printing procedure



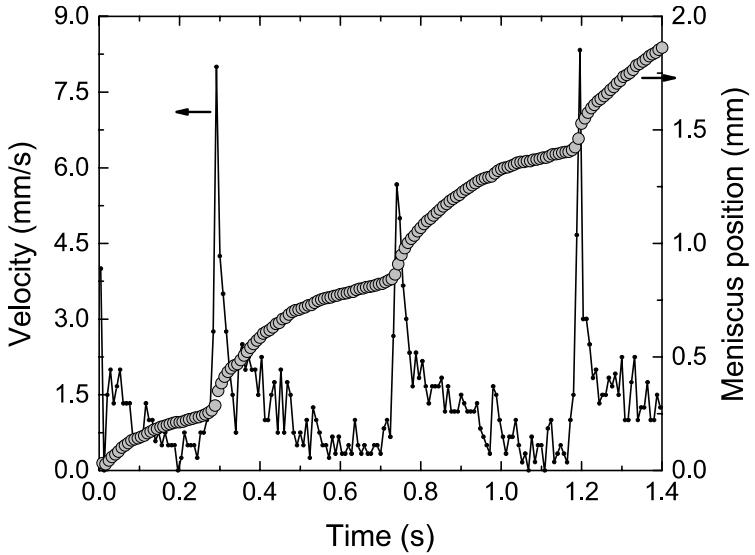
Top view



Cross section



Scale bar: 200 μm



Robert Lade (Francis, Macosko)

* Lade et al. *Langmuir* **2017**, *33*, 2949–2964

Pulsed Irradiation for High-Throughput Curing Applications

Objective

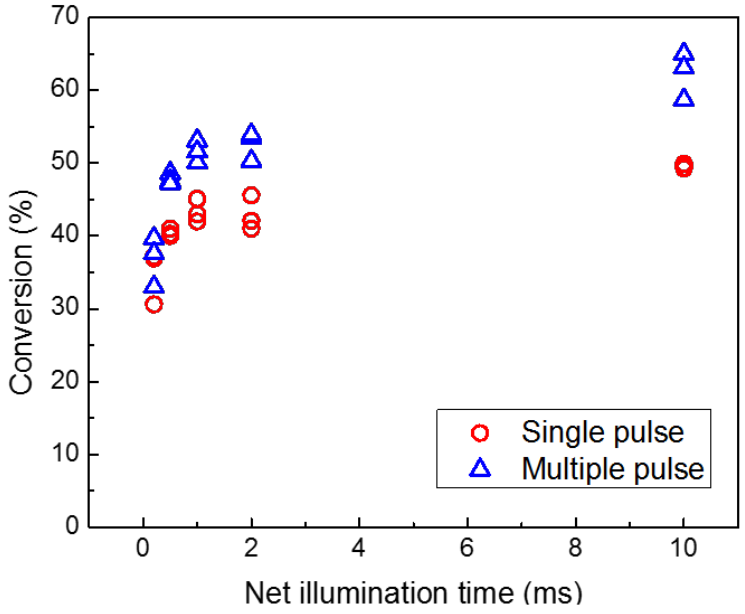
✓ Investigate curing kinetics of acrylate coatings under intense pulsed light (IPL)

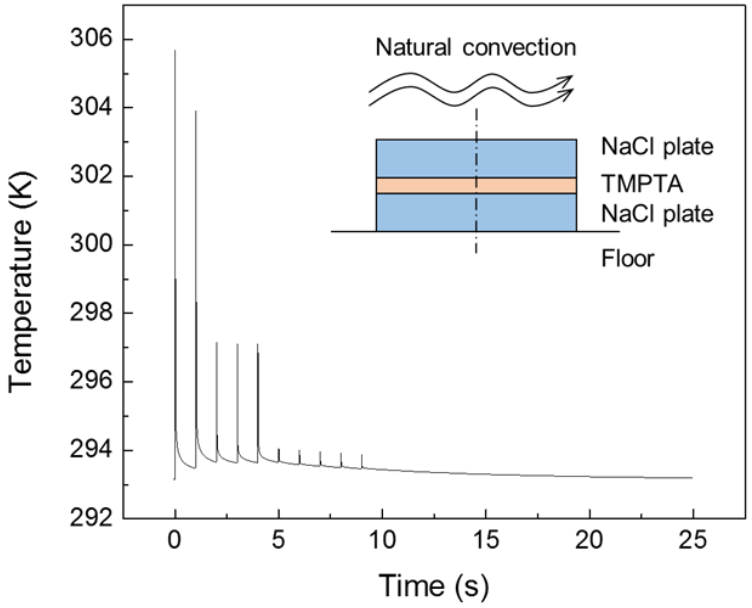
Results

✓ Limiting conversion depends on the irradiation dose, but not the irradiation dose rate

✓ Curing completes within a few milliseconds with a controlled single pulse

✓ Ambient-temperature cure and low photoinitiator loading are attained





Yuyang Du (Francis, McCormick)

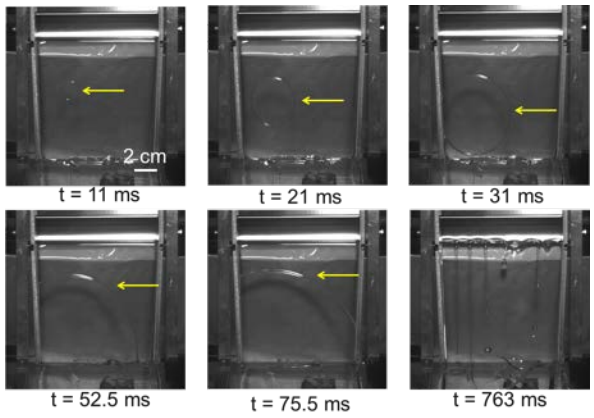
*Du, Y.; Williams, B. A. *et al*. *Prog. Org. Coat.* **2017**

Effect of Rheological Properties on Curtain Coating

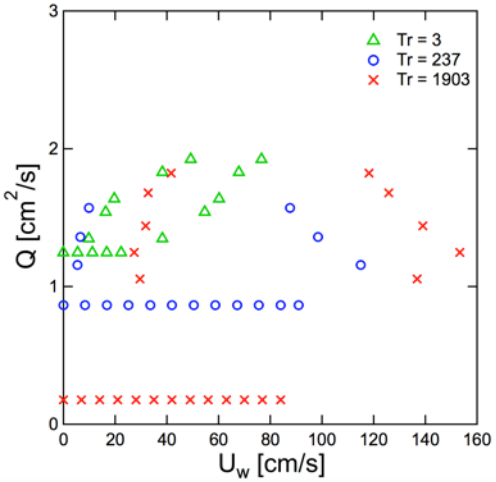
Goal: Study the effect of rheological properties on liquid curtain stability and coating window

Method: Rheological characterization, high speed flow visualization and model.

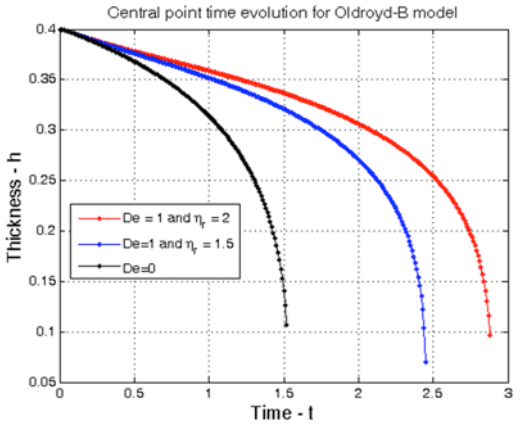
High speed visualization of curtain breakup



Curtain coating window for Newtonian and viscoelastic liquids



Evolution of a perturbation in a Newtonian and viscoelastic liquid sheet



Main Result:

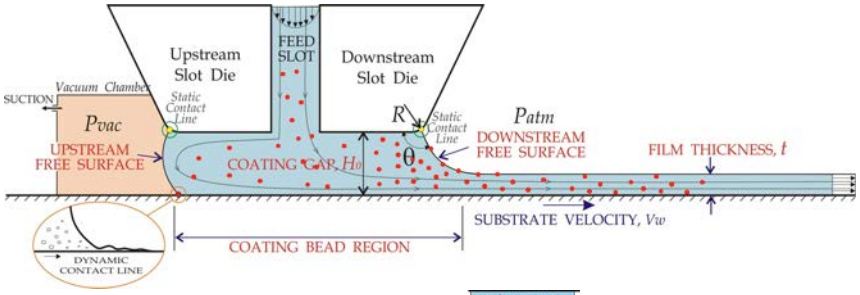
Effect of rheological properties on the different failure mechanism in curtain coating;

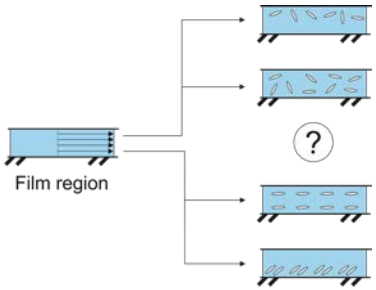
Show how liquid formulation may be adjusted to optimize curtain coating process.

A. M. Karim, W. Suszynski, L. F. Francis and M. S. Carvalho, AIChEJ, sub., 2016.

Alireza Karim (Francis and Carvalho)
Marisa Bazzi (Carvalho)

Slot Coating of Particulate Suspension





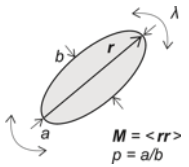
Goal: Evaluate effect of particle concentration and size on process limits and particle distribution and orientation on the coated film.

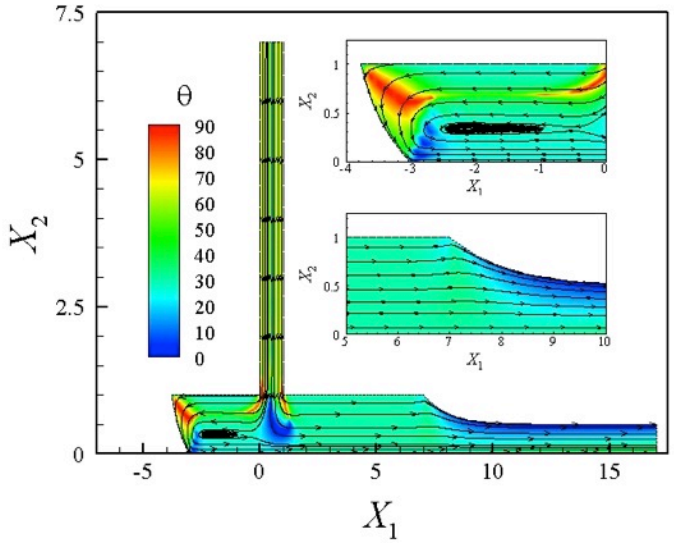
Method: Solve the Navier-Stokes equations for free surface flows coupled with particle concentration and conformation transport equations using the finite element method

Main Result:

Accurate prediction of process limits of particle suspension coating.

Effect of flow conditions on particle distribution and alignment on coated film.





Reboucas, Siqueira, Souza Mendes and Carvalho, JNNFM, vol.234, 2016
I. Siqueira, R. Reboucas and M.S. Carvalho, JNNFM, vol.243, 2017
I. Siqueira, R. Reboucas and M.S. Carvalho, AIChE J, in print, 2017

R. Reboucas and I. Siqueira (Carvalho)