The Flow of Thin Liquid Film Past Obstructions

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SEL Seminar
What’s going on?
Common applications of obstructions in thin liquid films

- Lubrication
- Spin-coating
- Shelter in lava flow
Why build a separate facility?
Real-life analogy: flow around bridge pylon/pillar
### Obstructions

<table>
<thead>
<tr>
<th>Flow</th>
<th>Circle</th>
<th>Triangle</th>
<th>Square</th>
<th>Hexagon</th>
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<td><img src="image" alt="Circle" /></td>
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- **Material:** FormLabs Gray Pro resin
- **Parametric Study**
  - Sizes: 5, 10, 15 mm (1.25%, 2.5%, 3.75% of channel width)
  - Incline angle: 30, 45, 60 degrees
  - Flow Rates: 20, 40, 60 g/s
  - Geometry shapes
### Obstructions - Time averaged images

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- **Material:** FormLabs Gray Pro resin
- **Sizes:** 5, 10, 15 mm (1.25%, 2.5%, 3.75% of channel width)
- **Shown:** 60 g/s, 30 deg incline angle, 15 mm obstructions
Obstructions – Takeaways

- No dry patch
- No obvious change in downstream film thickness
- A wake profile exists

Next steps:
- Increase obstruction size
- Measure wake profile film thickness
Plate Obstructions

- Material: Acrylic
- Parametric Study
  - Widths: 25 – 105 mm @ 5 mm increments
  - Incline angle: 30, 45, 60 degrees
  - Flow Rates: 20, 40, 60 g/s
Plate Obstructions – Two regimes

Experimental procedure

1. Stop flow
2. Install obstruction
3. Restart flow
4. Downstream film ruptures
5. Spray water on dry patch immediately downstream of the obstruction
6. Record whether the dry patch recovers (rewets)
Plate Obstructions – Two regimes

Experimental procedure

Stop flow
↓
Install obstruction
↓
Restart flow
↓
Downstream film ruptures
↓
Spray water on dry patch immediately downstream of the obstruction
↓
Record whether the dry patch recovers (rewets)

Recovers

Does not recover
Plate Obstructions – Regime map V1

Incline Angle | Flow Rate [g/s] | Plate Width [mm] |
--------------|----------------|-----------------|
              | 20  | 25  | 30  | 35  | 40  | 45  | 50  | 55  | 60  | 65  | 70  | 75  | 80  | 85  | 90  | 95  | 100 | 105 |
60 deg        | 60  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
45 deg        | 60  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
30 deg        | 60  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

*: Wetting issues at 20 g/s
Tends to be dry
Quasi-stable between wet and dry
60 deg Plate Obstruction
Plate Width (20mm – 90mm)
Plate Obstructions – Wet/Dry boundary

\[ x = -\frac{r}{3} \left( \frac{1 - 3 \cos^2(\psi)}{\sin^3(\psi)} - 1 \right), \quad y = r \frac{\cos(\psi)}{\sin^2(\psi)} \]

\[ r = m f_2(\theta_s) \frac{L_c^2}{\sin(\alpha)} \frac{U_c}{\Gamma}, m = 0.23 \]

\[ f_2(\theta_s) = \frac{(1 - \cos(\theta_s))^4}{\theta_s - \sin(\theta_s) \cos(\theta_s)} \]

\[ \theta_s \approx 21^\circ \]

Boundary location is a function of:
- \( \theta_s \), **contact angle** between water and incline pane
- \( L_c = \sqrt{\frac{\sigma}{\rho g}} \), capillary length (**surface tension**, **density**)
- \( U_c = \frac{\sigma}{\mu} \), capillary velocity (**surface tension**, **viscosity**)
- \( \alpha \), **incline angle** wrt horizontal
- \( \Gamma \), **flow rate** per unit **film width** (~0.1E-3 m²/s)
What now...?

- Redo regime map with cleaner water and more diligent glass cleaning (algae growth and small smudges)
- Test more acrylic obstructions of different shapes
- Formulate a non-dimensional number to help predict which regime a configuration belongs to
- Test in the annular flow facility with refrigerant (very low contact angle with glass <1°)
White Resin
$\theta_s \approx 64^\circ$

Gray Pro Resin
$\theta_s \approx 80^\circ$