Hydraulic Analysis of Liquid Surface First Walls

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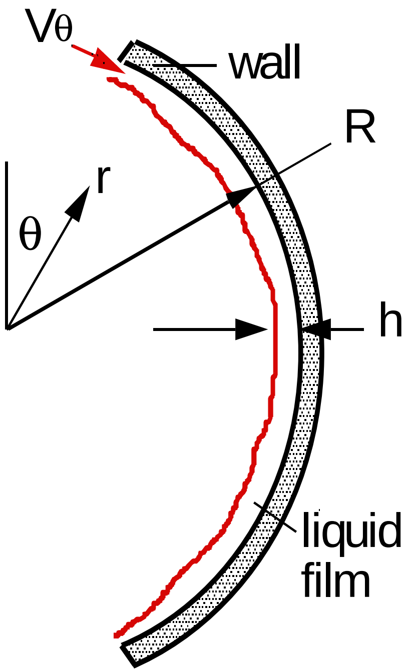
Convective Liquid Layer

- 1D "Shallow water" (R >> h) equations in cylindrical geometry

$$\frac{d\left(hV_\theta\right)}{d\theta} = 0 \quad \text{(continuity)}$$

$$\frac{V_\theta^2}{R} = \frac{1}{\rho}\frac{dp}{dr} + g\cos\theta \quad \text{(r - mom)}$$

$$\frac{V_\theta}{R}\frac{dV_\theta}{d\theta} = -\frac{1}{\rho R}\frac{dp}{d\theta} + g\sin\theta - F_{friction} \quad (\theta\text{ - mom})$$



- Final equations

$$V_\theta = q_o / h$$

$$p(r,\theta) = \left(\rho V_\theta^2 / R - g\rho\cos\theta\right)(r-h)$$

$$\frac{dh}{d\theta} = \frac{-Rgh^3\sin\theta + Rh^3F_{friction}}{gh^3\sin\theta + q_o^2}$$

h	≡	thickness
p	≡	pressure
V_θ	≡	velocity
q_o	≡	flowrate
r,θ	≡	cyl.coord
R	≡	arc radius
g	≡	accel.gravity

Friction Terms for Lithium in Toroidal B Field

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- Velocity will be laminarized by MHD if:

$$\frac{\mathrm{Ha}_T\ \beta}{\mathrm{Re}} > 7\times 10^{-3}$$

- Velocity will be inviscid "Hartmann" flow if:

$$\mathrm{Ha}_T\ \beta^2 > 50$$

$\mathrm{Ha}_T \equiv B_T w \sqrt{\dfrac{\sigma}{\rho\nu}}$

$\mathrm{Re} \equiv V_\theta h/\nu$

$\beta \equiv h/w$

$w \equiv$ width

$\sigma \equiv$ elect.cond.

$\rho \equiv$ density

$\nu \equiv$ kin.visc.

- The friction term for laminarized, inviscid Hartmann velocity profiles in insulated channels is:

$$F_{friction} = \frac{2\nu q_o\ \mathrm{Ha}_T}{hw^2}$$

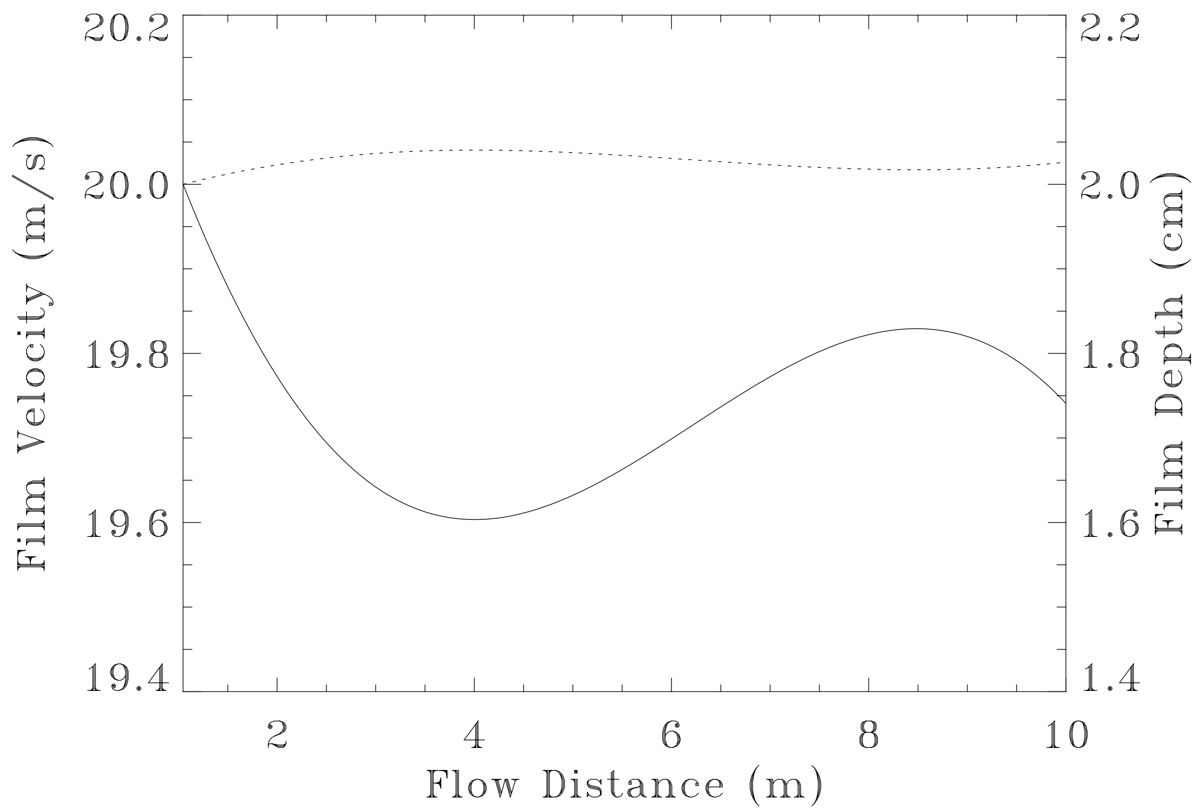
- The friction term for laminarized, parabolic velocity profiles is:

$$F_{friction} = \frac{3\nu q_o}{h^3}$$

Lithium Flow Profiles

- V,h remain constant over 10 m flow

B = 6 T
w = 2 m
h_o = 2 cm
V_o = 20 m/s

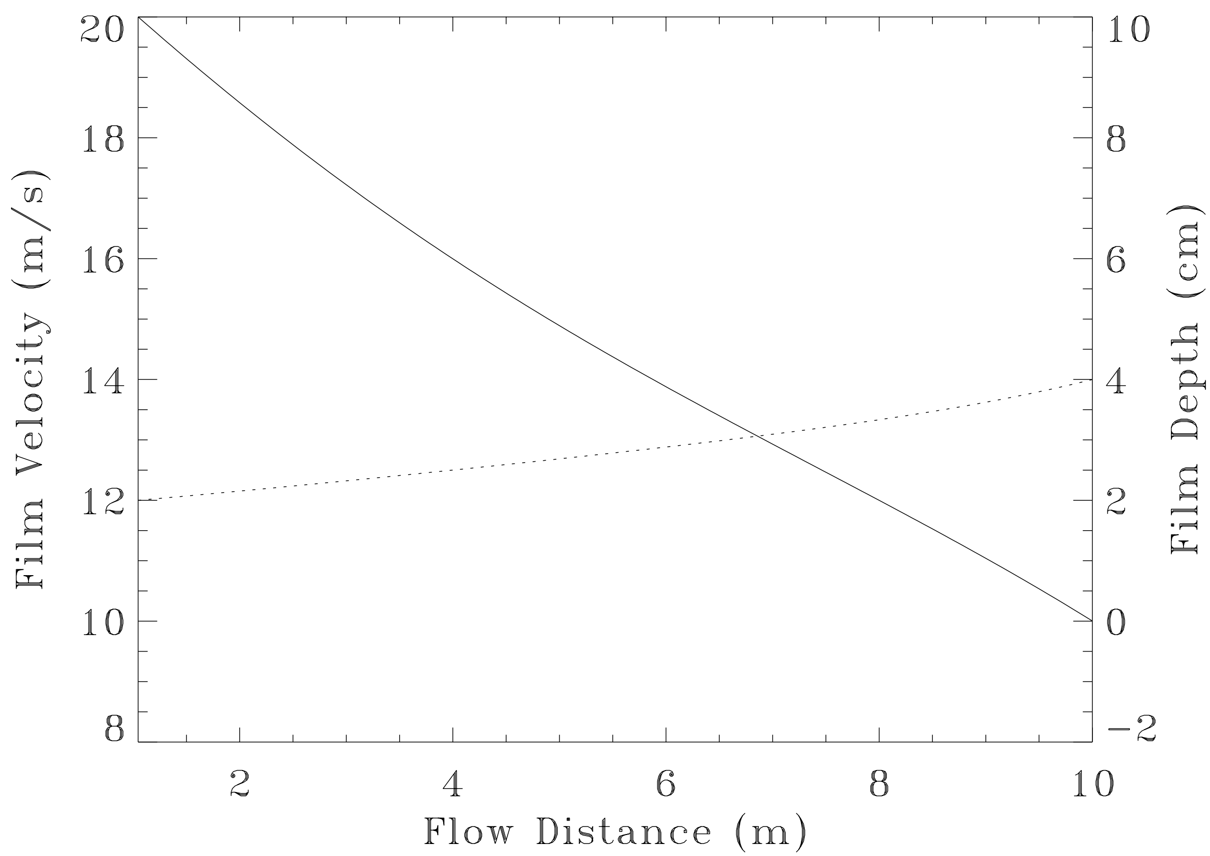


- Flow remains adhered by centrifugal acceleration 10x gravity

Effect of Reduced Channel Width on Lithium Flow Profile

- Flow is slowed to ½ original velocity

B = 6 T
w = 1 m
h_o = 2 cm
V_o = 20 m/s



Turbulent Friction Terms for Flibe

- Velocity profile for flibe will be turbulent
- Turbulent friction term using the Darcy-Weisbach formula for non-circular open channels gives:

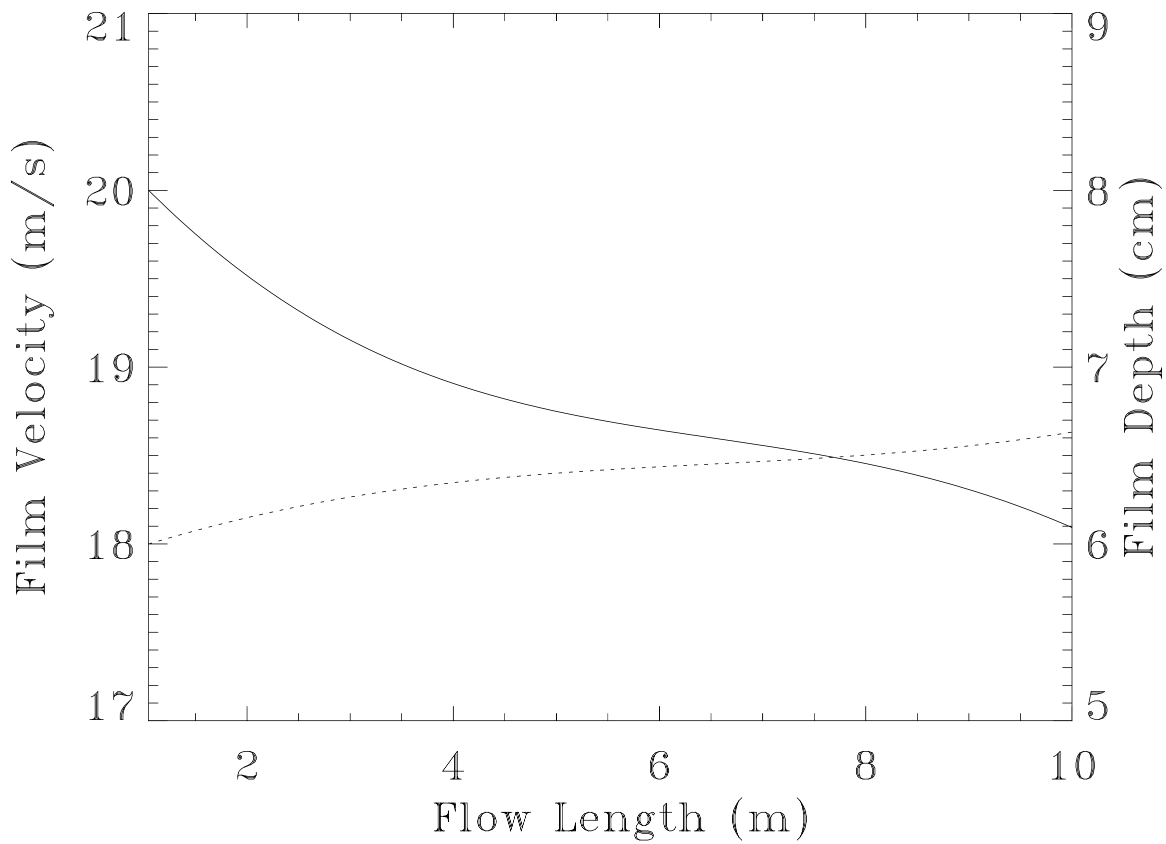
$$F_{friction} = \frac{f q_0^2}{8h^3}$$

- friction factor (f) for smooth pipes $\frac{1}{\sqrt{f}} = 2\log(\mathrm{Re}\sqrt{f}) - 0.8$
- From tables, f = 0.018 for slightly rougher pipes

Flibe Flow Profiles

- h increases slightly due to friction force, causing drop in velocity

h_o = 6 cm
V_o = 20 m/s
f = 0.018



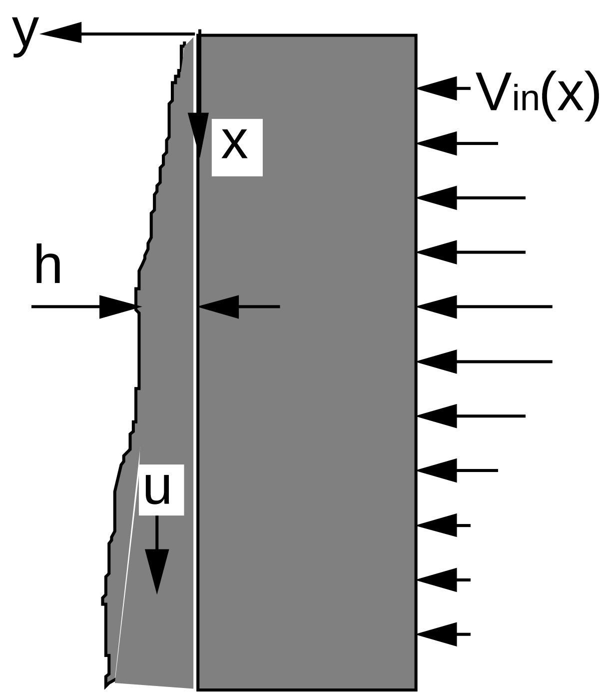
- Flow remains adhered by centrifugal acceleration 10x gravity

Liquid-Filled Porous WallConcepts

- Flow equations with porous feed in cartesian geometry

$$\frac{d(uh)}{dx} = v_{in}(x)$$

$$\frac{d(u^2 h)}{dx} = gh - v_{in}u - 3uv/h$$



- Velocity is low, flow is laminar

- Results:
  Lithium: possible to generate 0.5 mm film over 1-2 m modules moving at ~1 m/s.
  This will in some some convection polodially.

Lithium Flow Profile over Porous Substrate

v_{in} = 0.5 mm/s