3.044 MATERIALS PROCESSING

LECTURE 15

Pilkington Sheet Glass Process

Pour molten glass on a liquid, let it settle/flatten and then let it cool

· higher ρ than glass $\rightarrow \rho_{\text{glass}} = 2500\,\frac{\text{kg}}{\text{m}^3}$

· liquid temperature $\rightarrow$ between $T_{\text{rigid}} \sim 550°\text{C}$ and $T_{\text{working}} \sim 900°\text{C}$

· immiscible

Answer: Liquid Metal

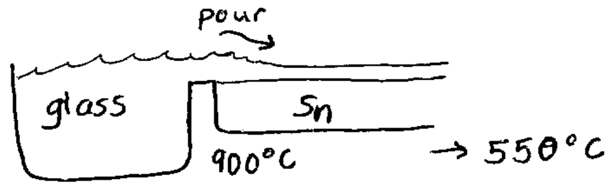
Sn (tin) $\rightarrow \rho_{Sn} = 7000\,\frac{\text{kg}}{\text{m}^3}$

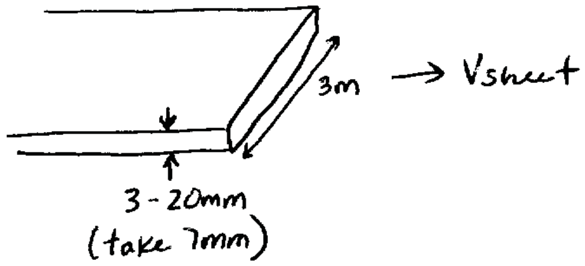
The velocity of the sheet is determined by economic input:

$\Rightarrow$ need 750 tonnes/day to compete with block casting and grinding

$$\boxed{V_{\text{sheet}} = 10\,\frac{\text{m}}{\text{min}}}$$

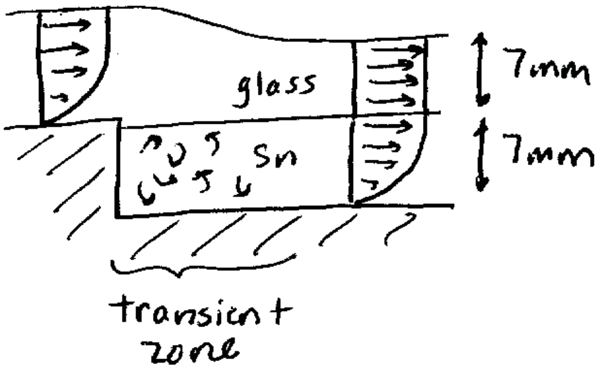
Date: April 9th, 2012.





Two Physical Goals

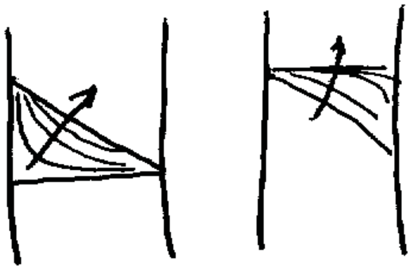
1) Fluid Flow → flat, stable film, level glass
2) Heat Transfer → cool to 550°C from 900°C



Fluid Flow:

$$\rho_{\text{glass}} = 2500\,\frac{\text{kg}}{\text{m}^3}$$
$$\mu_{\text{glass}} = 10^2\,\text{Pa}\cdot\text{s}$$
$$\rho_{\text{Sn}} = 7000\,\frac{\text{kg}}{\text{m}^3}$$
$$\mu_{\text{Sn}} = 3\times 10^{-}3\,\text{Pa}\cdot\text{s}$$

How long does it take to remove the transient? How long does it take to get to steady-state?



In Diffusion:

$$\underbrace{\tau}_{\substack{\text{dimensionless}\\\text{time}}} = \frac{\alpha t}{L^2} = 1$$

$$\tau = \frac{\overbrace{\nu}^{\substack{\text{kinematic}\\\text{viscosity}}} \quad t}{L^2}$$

$$t_{ss} = \frac{L^2}{\left(\frac{\mu}{\rho}\right)}$$

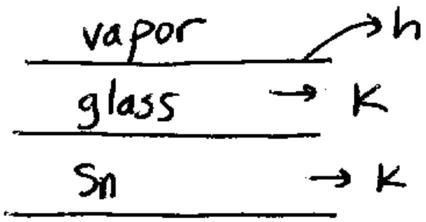
For glass:

$$L = 0.007\,\text{m}, \quad \mu = 10^2\,\text{Pa}\cdot\text{s}, \quad \rho = 2500\,\frac{\text{kg}}{\text{m}^3}$$
$$\Rightarrow t_{ss} = 0.0001\,\text{s}$$

For tin:

$$L = 0.007\,\text{m}, \quad \mu = 3 \times 10^{-}3\,\text{Pa}\cdot\text{s}, \quad \rho = 7000\,\frac{\text{kg}}{\text{m}^3}$$
$$\Rightarrow t_{ss} = 114\,\text{s}, V_{\text{sheet}} = 10\,\frac{\text{m}}{\text{min}}$$

$$\boxed{\text{Length of travel to achieve steady state: } \approx 20\,\text{m}}$$



Heat Transfer:

$$\text{Vapor/glass interface:} \quad h = 10\,\frac{\mathrm{W}}{\mathrm{m^2K}}$$

$$\text{Glass:} \quad k = 1.7\,\frac{\mathrm{W}}{\mathrm{mK}}, \quad L = 0.007\,\mathrm{m}$$

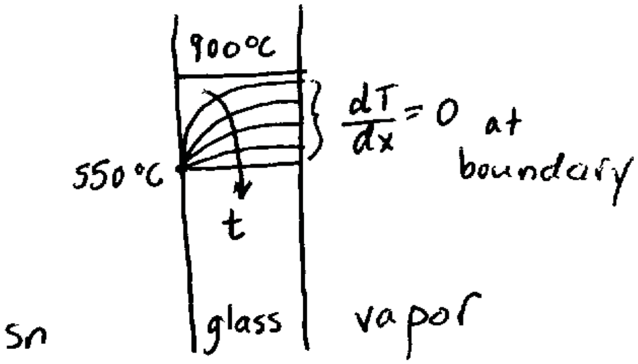
$$\text{Bi:} \quad \frac{hL}{k} = 0.04$$

Bi is **Low!** conduction is **rapid** in glass and convection is **slow**

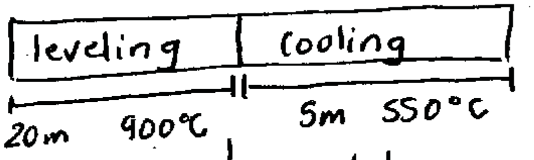
$$\text{Tin:} \quad k = 35\,\frac{\mathrm{W}}{\mathrm{mK}}$$

Compare the resistances of glass and Sn: resistance of Sn is low → Sn is a great heat sink

How long does it take to cool?



$\tau = 1$
$t \approx 15 - 30\,\text{sec}$



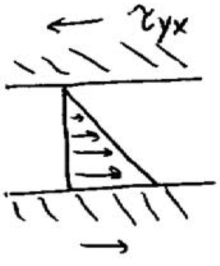
↳ cant have a step function of T from 900°C to 550°C so length must increase

Summary of Fluid Flow

$$\frac{\partial \bar{v}}{\partial t} = \nu \nabla^2 \bar{v} + \frac{\bar{F}}{\rho} - \frac{\nabla P}{\rho}$$
$$\frac{\partial v_x}{\partial t} = \nu \frac{\partial^2 v_x}{\partial y^2} + \frac{F_x}{\rho} - \frac{1}{\rho}\frac{\partial P}{\partial x}$$

Navier-Stokes Equation: solve this with boundary conditions → laminar flow

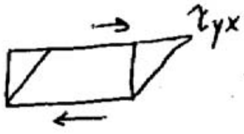
Fluids can transfer momentum to solids



Fluid Flow: $\tau_{yx} = -\eta \frac{\partial v_x}{\partial y}$

$\leftrightarrows$ is ⊕ stress

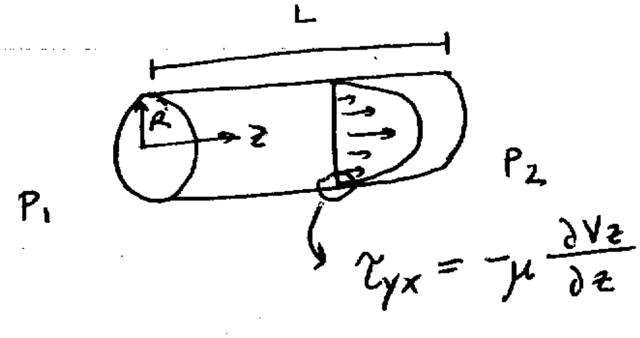
opposite sign convention



Solid Mechanics: $\tau_{yx} = \frac{F}{A}$

$\rightleftarrows$ is ⊕ stress

Fluid Flow in a Pipe:



Pipe:

$$V_x = \frac{\Delta P}{4L\mu}\left(R^2 - r^2\right)$$

At the wall:

$$\tau_{yx} = -\mu \left.\frac{\partial V_z}{\partial r}\right|_{r=R}$$

Stress on the Inner Pipe Wall:

$$\tau_0 = \frac{\mu\Delta P}{4L\mu}2R = \frac{\Delta P \cdot R}{2L}$$

Kinetic Force: (drag force, total force exerted by the fluid on the solid)

$$\begin{aligned} F_k &= \int_A \tau dA \\ &= \frac{\Delta P R}{2L} 2\pi R L \\ &\boxed{F_k = \Delta P \pi R^2} \end{aligned}$$

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Spring 2013

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