Chemical Engineering 612

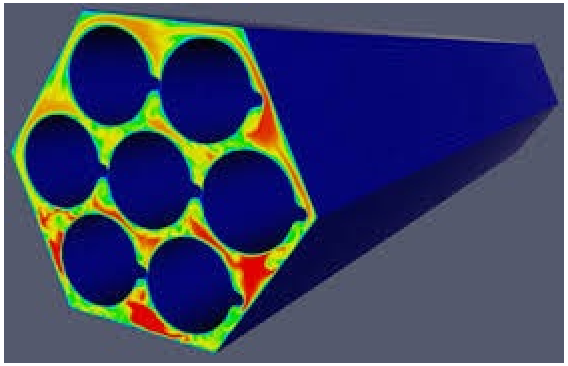
Reactor Design and Analysis

Lecture 15

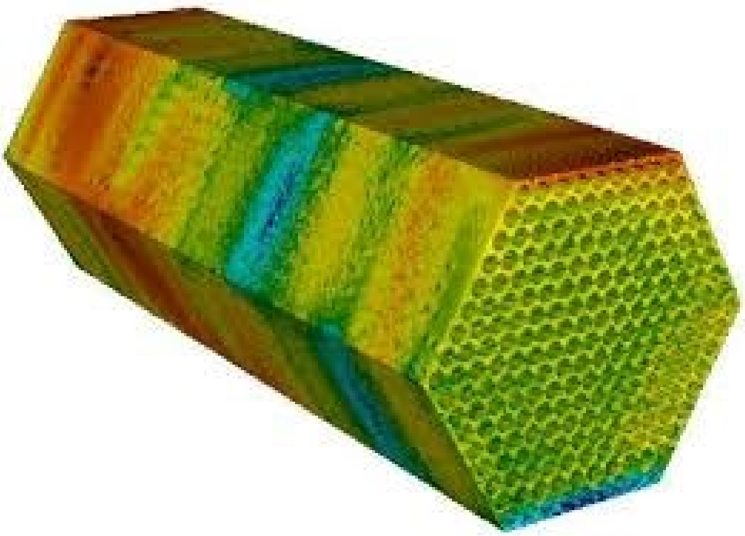
Core Hydraulic Analysis

Spiritual Thought

Flow Analysis



- Size pumps
- Evaluate Erosion
- Flow rates for heat transfer
- Core sizing/dimensions
- Vibration analysis
- Core Orificing
- Valve/component sizing

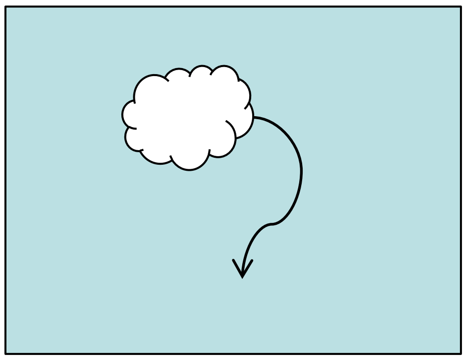


Flux

- Flux = quantity per unit area per unit time
  - Heat flux : J/m^2*s
  - Mass flux: kg/m^2*s
  - Neutron flux: $neutrons/m^2*s$
  - Momentum flux: $kg*m/s*m^2*s = kg/ms^2$
  - $\rho v = kg/m^3 * m/s = kg/m^2*s$ = mass flux
- Then the flux of any quantity per unit mass (q) is
  - .$\rho q\mathbf{v}$
    - $q = h \rightarrow J/m^2*s$ Heat flux
    - $q=1 \rightarrow kg/m^2*s$ Mass flux
    - $q=v \rightarrow kg/s*m^2*s = kg/m*s^2$ Momentum flux
- $-\rho*q*\mathbf{v}\cdot\mathbf{n}*A$ is the rate of quantity through surface A

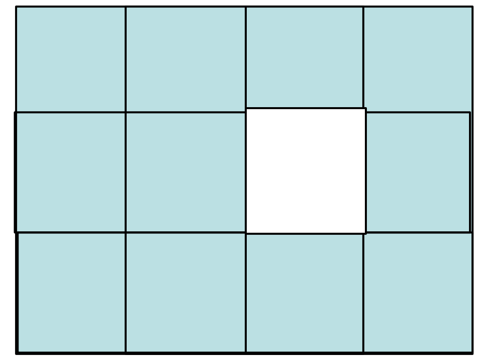
Lagrangian/Eulerian

Lagrangian



- Motion of system of **fixed mass**
- CONSERVATION LAWS
- Fluid elements move around and deform

Eulerian



- Some **fixed control volume**
- CONVENIENT FOR ENGINEERING
- Don't care about fluid elements
- Want pressure and velocity fields at a point.
  - Pressure on a wing
  - Drag on a car
  - Not the pressure of a chunk of fluid as it moves along

Lagrangian Solution

- Differential Analysis
- Solution at any point in space
- Produce vector/scalar fields
  - Pressure
  - Velocity
  - Enthalpy
- CFD
- Common in Licensing, beyond class scope
- For concept reactors, use Eulerian approach

Eulerian Solution

- Utilize Reynolds Transport Theorem:

$$\frac{dB_{sys}}{dt} = \frac{d}{dt}\int_{CV} \rho b \, dV + \int_{CS} \rho b \vec{v} \cdot \vec{n} \, dA$$

  - Recall that any property can be B_{sys}
    - Mass – Continuity Equation
    - Momentum – Force Vector Balance
    - Energy – Mechanical Energy Balance

Governing Equation

- $0 = \frac{d}{dt}\int_{CV} \rho\, dV + \int_{CS} \rho \vec{v} \cdot \vec{n}\, dA$
- $\sum \vec{F} = \frac{d}{dt}\int_{CV} \rho \vec{v} dV + \int_{CS} \rho \vec{v}\vec{v} \cdot \vec{n}\, dA$
- $\frac{dQ}{dt} + \frac{dW}{dt} = \frac{d}{dt}\int_{CV} \rho(u + \frac{1}{2}v^2 + gz)dV + \int_{CS} \rho(u + \frac{1}{2}v^2 + gz)\vec{v} \cdot \vec{n} dA$

- Combined, these give integral view of fluid dynamics, useful in reactor design

Mechanical Energy Equation

$$\frac{fLv^2}{2D}$$

- Can be viewed as multiple components of energy balance for control volume:
  - Gravity
  - Stagnation (acceleration)
  - Pressure difference
  - Friction
  - Shaft work

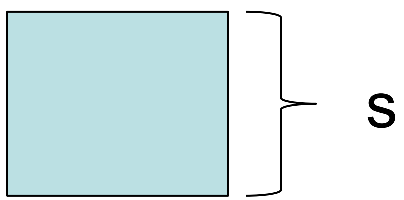
$f_{lam} = 57/Re$

Colebrook $$\frac{1}{\sqrt{f}} = -2\log\left(\frac{\epsilon/D}{3.7} + \frac{2.51}{Re\sqrt{f}}\right)$$

Haaland $$\frac{1}{\sqrt{f}} = -1.8\log\left[\frac{6.9}{Re} + \left(\frac{\epsilon/D}{3.7}\right)^{1.11}\right]$$

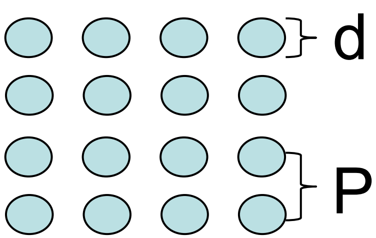
Non-circular flow regions

- Non-circular flow
  - Hydraulic Diameter, $D_e = \frac{4A}{P_w}$
  - f_{lam} = shape specific
  - f_{turb} ~ round tube f



$$D_e = \frac{4A}{P_w} = \frac{4s^2}{4s} = s$$

f_{lam} =57/Re



$$D_e = \frac{4A}{P_w} = \frac{4\left(P - \frac{\pi}{4}D\right)}{\pi D}$$

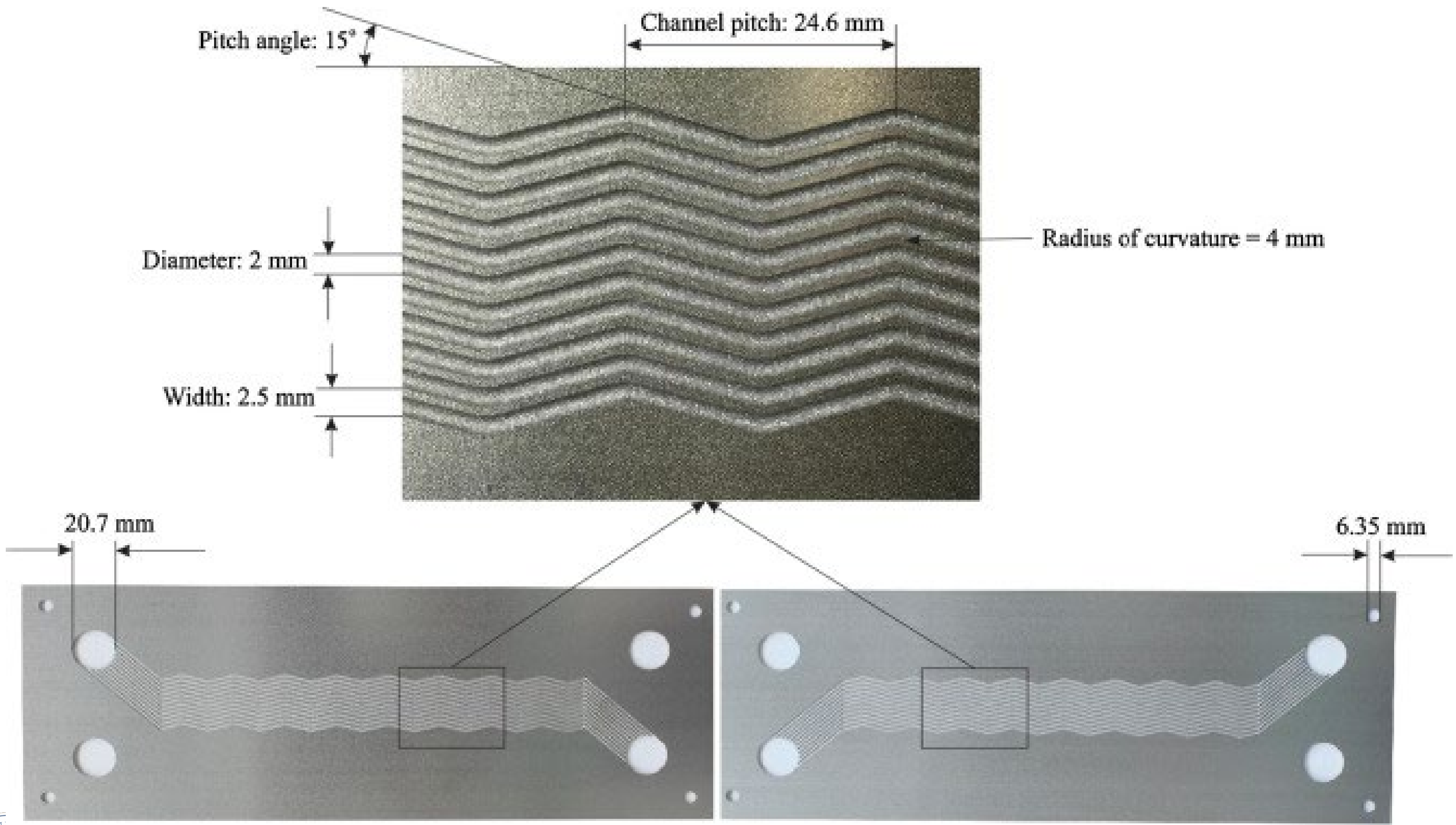
$$f = \frac{C_{fL(or\,T)}}{Re^n}$$

n = 1, laminar, n = 0.18, turbulent

Tube Bundle Friction

- Lam - $C_{fL} = a + b_1\left(\frac{P}{D} - 1\right) + b_2\left(\frac{P}{D} - 1\right)^2$
  - For edge and corners, P/D replaced by W/D
- Turb - $Re_{De} = 10^4 \rightarrow \frac{f}{f_{ct}} = 1.045 + 0.071\left(\frac{P}{D} - 1\right)$
- - $Re_{De} = 10^5 \rightarrow \frac{f}{f_{ct}} = 1.036 + 0.054\left(\frac{P}{D} - 1\right)$
  - OR $C_{fT} = a + b_1\left(\frac{P}{D} - 1\right) + b_2\left(\frac{P}{D} - 1\right)^2$
  - Coefficients found in Tables 9.5 and 9.6 of Nuclear Systems I
  - Add contributions from spacer grids and mixing vanes

PCHEs



Pitch angle: 15°
Channel pitch: 24.6 mm
Radius of curvature = 4 mm
Diameter: 2 mm
Width: 2.5 mm
20.7 mm
6.35 mm

Entrance Region Effects

- Velocity profile develops here
  - $\frac{z}{D_e} = 0.05Re$ (laminar)
  - $\frac{z}{D_e} = 25 - 40$ (turbulent)
- Characterized by higher f (flow acceleration)
- Exists for most flow disruptions Sensors far from orifices, obstructions, etc.

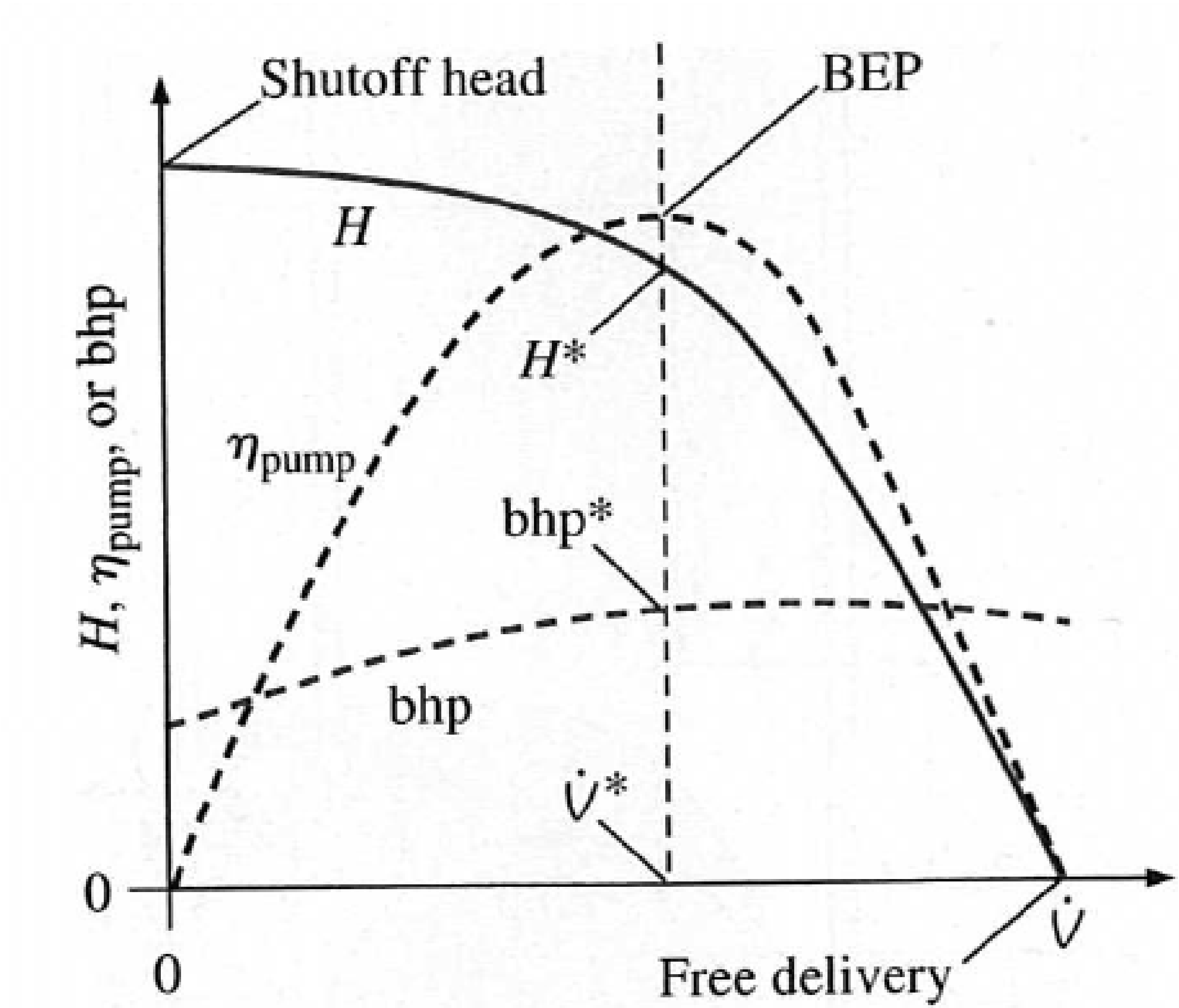
Flow Networks

- Pipe Networks composed of single pipes
- Pipes is series
  - Constant $\dot{V}$, additive ΔP
  - Type I – find ΔP
  - Type II – find $\dot{V}$
- Pipes in parallel
  - Constant ΔP, additive $\dot{V}$
  - Type I
  - Type II
  - Type III – Find D

Sample Problem

- Calculate the pressure drop across a bare-rod core assembly (no spacer grids or mixing vanes) for a closed stainless steel square assembly with 264 tubes in square configuration, P/D = 1.13, D = 0.34 in, L = 10 ft, S = 6.531 in $\dot{m} = 100$ kg/s water.

Pump Curve Schematic



Pump Operation Curves

- Piping system requires a given **V** and a given H.

$$H_{req} = \frac{P_2 - P_1}{\rho g} + \frac{v_2^2 - v_1^2}{2g} + (z_2 - z_1) + H_{loss}$$

  - H_{loss} is friction and minor losses, etc.
- Pump has a corresponding **V** and H.
- These **must match**, forming the operating point.
  - This may not be the best efficiency.
- Select a pump so that the best efficiency point (BEP) occurs at the operating point.
- Generally oversize the pump a bit
  - higher flow for given H_{req}
  - or Higher H_{avail} for given flow
  - Add a valve after pump → raises H_{req} to match H_{avail} for given flow
  - Somewhat wasteful, but offers control.
  - Also may increase efficieny. (But higher efficieny may not compensate for extra work wasted in the valve (see example 14.2)