Basics in Process Design

Pressure in pipe systems
- Block flow diagrams
- Calculate flows from mass and energy balances
- Rough sizing of equipment for:
  - storage
  - preprocessing
  - reaction
  - separation,
  - heat exchange
  - transport
- Instrumentation
- Cost estimates
Today

- Factors influencing pressure in pipes
- Modelling
- Local pressure
- System curve
- Typical questions
- Example
Factors influencing pressure drop in pipes

- Height difference, inlet and outlet pressure, flow velocity
- Pipe length, pipe diameter, surface roughness, pipe fittings, configuration
- Fluid density and viscosity
Modelling

- Draw a diagram of the pipe system
- Divide the pipe system into logical sections
- Note what is known and unknown (flow velocity/ inlet pressure/ outlet pressure/ pressure drop/ pipe length/ pipe diameter/ pipe parts/ height differences/ densities/ viscosities/ pipe data ...)

- For each section:
  - Outlet pressure = inlet pressure – pressure drop

\[
p_{out} = p_{in} + \rho \cdot g \cdot (z_{in} - z_{out}) + \Delta p_{\text{pump}} - \frac{1}{2} \cdot \rho \cdot w^2 \cdot \sum \zeta
\]
Local pressure

- Pressure at each section boundary
- Plotted against pipe length

- Fluid might change phase if pressure too low → could change flow calculations
- Can the pipe handle the pressure?
System curve

- Necessary pressure increase or decrease in pipe system for certain flows
- Can be used with pump curves or valve curves

\[ \Delta p_{pump} = p_{out} - p_{in} - \rho \cdot g \cdot (z_{in} - z_{out}) + \frac{1}{2} \cdot \rho \cdot w^2 \cdot \sum \zeta \]
Typical questions

- inlet pressure, outlet pressure, pipe system and fluid properties → flow in pipe
- flow, outlet pressure, pipe system and fluid properties → inlet pressure
- flow, outlet pressure, inlet pressure and fluid properties → pipe system

- Iterative solution – guess, calculate, check, guess better, calculate ....
Flow velocity

The graph shows the total price (€) against flow velocity (m/s), with different line colors representing the cost of pumping, the cost of pipe, and the total cost.
Example

- Pump ammonia from synthesis to storage tank
- Inlet pressure 3 bar, temperature -33°C
- Outlet 30 m higher than inlet and 200 m away
- Pipe size? Necessary pressure increase in pump at different volume flows
- Ammonia properties? Pipe roughness?
  - http://www.peacesoftware.de/einigewerte/nh3_e.html
  - http://www.engineeringtoolbox.com/ammonia-d_971.html
\[ \Delta P_{pump} = P_{out} - P_{in} + \rho g (z_{out} - z_{in}) + \frac{1}{2} \rho \omega^2 \Sigma \]

\[ P_{in} = 3 \text{ bar} = 300 \text{ kPa} \]

\[ P_{out} = 1 \text{ bar} = 100 \text{ kPa} \]

\[ z_{in} = 0 \text{ m} \]

\[ z_{out} = 30 \text{ m} \]

\[ \omega = 2 \text{ m/s} \]

\[ \rho = 681 \text{ kg/m}^3 \]
\[ \omega = \frac{V}{4 \pi} \]
\[ V = \frac{m}{S} = \frac{450 \text{ ton}}{681 \text{ ton/m}^3} = \frac{1000 \text{ m}^3}{681 \text{ m}^3} = 1.47 \times 10^{-3} \text{ m}^3 \]
\[ \lambda = \frac{\pi d^2}{4} \]
\[ d = \sqrt{\frac{4 \cdot \frac{m}{S}}{\pi \cdot \omega}} = \sqrt{\frac{4 \cdot 1.47 \times 10^{-3} \text{ m}^3}{\pi \cdot 2 \text{ m/h}}} = 0.0697 \text{ m} \]
\[ d = 70 \text{ mm} \rightarrow \omega = 1.988 \text{ m/s} \]
\[ \sum y = \frac{l}{h} \cdot \frac{a}{\alpha} \]

\[ \Rightarrow \frac{y}{l} = 0.01 \left( \frac{10^6}{\text{Re}} + 18.7 \left( \frac{1000k}{a} \right) \right) \]

\[ \text{Re} = \frac{\omega \cdot d \cdot g}{\eta} = \frac{\omega \cdot g}{\eta} \]

\[ = \frac{1.988 \times 0.07 \times 681}{258.98 \times 10^6} \]

\[ = 365927 \]

\[ > 2300 \]

\[ k = 0.05 \text{mm} \]
\[ h_d = 0.01 \left( \frac{10^6}{365 \times 27} + 18.7 \left( \frac{1000 \cdot 0.05 \text{mm}}{70 \text{mm}} \right) \right) \]

\[ \approx 0.01989 \]

\[ \Sigma h = 0.01989 \cdot \frac{200 \text{m}}{0.05 \text{m}} + 1.1 + 0.5 + 2 \cdot 0.5 \]

\[ = 59.4 \]
\[ \Delta P_{\text{pump}} = 100 \text{kPa} - 300 \text{kPa} \\
+ 681 \frac{\text{kg}}{\text{m}^3} \cdot 9.81 \frac{\text{m}}{\text{s}^2} \left(30 \text{m} - 0 \text{m}\right) \\
+ \frac{1}{2} \cdot 681 \frac{\text{kg}}{\text{m}^3} \cdot \left(1.988 \text{m/s}^2\right)^2 \cdot 59.4 \\
\frac{\text{Pa}}{1000 \text{Pa/kPa}} \\
\Delta P_{\text{pump}} = 80.3 \text{kPa} \]
Questions?