UWE Bristol

Thermodynamics & Fluids

UFMEQU-20-1

FLUIDS

Lecture 4: Fluid Machines

Today's Lecture

- Pump Characteristics
  - Pressure Rise vs. Flow rate
- Pipe Characteristics
- Matching Pump and Pipe Characeristics
- Efficiency
- Example

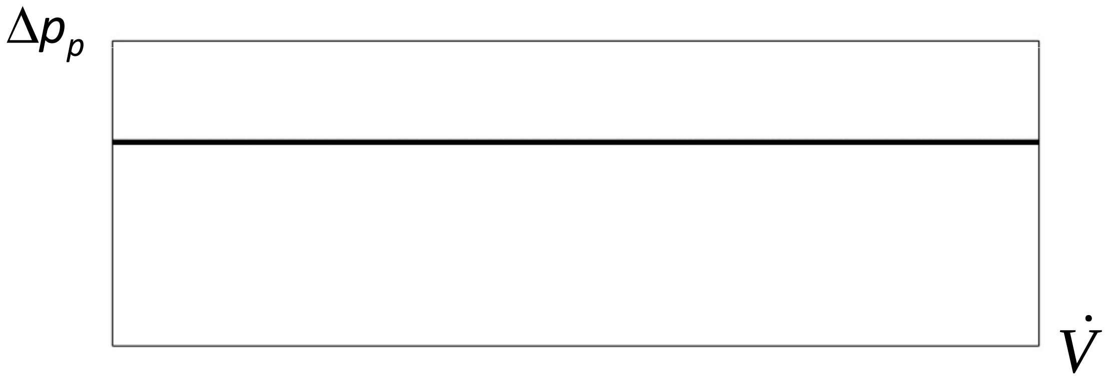
Fluid Machines

- A fluid machine either:
  - Takes energy from the flow:
    - e.g. Turbine, hydraulic motor, hydraulic actuator

  - Gives energy to the flow:
    - e.g. Pump, compressor

Machine Characteristics: Pump

- Characteristic is relationship between pressure rise, Δp_p against flow rate
- Simplest: pressure rise constant:



- Unrealistic: $\Delta p_p \times \dot{V}$ = Power
- If Δp_p is constant with any flow rate, power = infinity

Machine Characteristic: Pump

- Alternative characteristic:
  - We know that efficiency is defined as:

$$\eta = \frac{\text{Power to the flow}}{\text{Power consumption}} = \frac{\Delta p_p \dot{V}}{P}$$

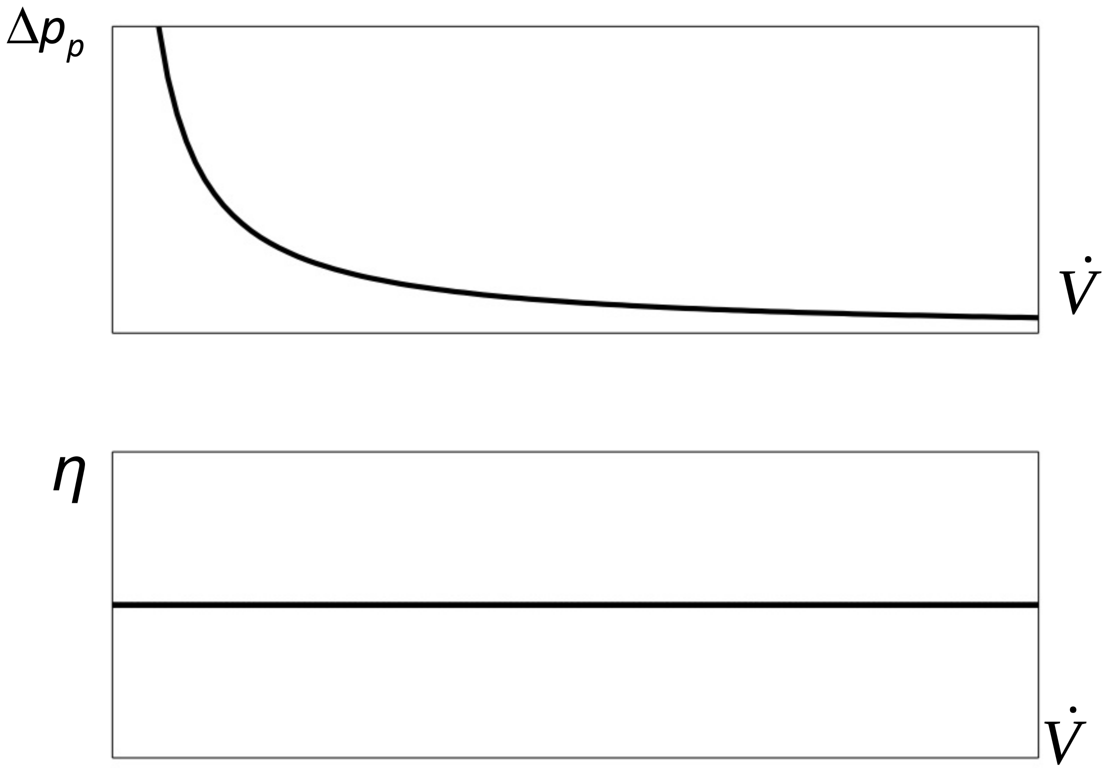
  - Rearranging

$$\eta = \frac{\Delta p_p \dot{V}}{P} \rightarrow \Delta p_p = \frac{\eta P}{\dot{V}}$$

  - Therefore (assuming Power and efficiency are constant):

$$\Delta p_p = \frac{\text{constant}}{\dot{V}}$$

Machine Characteristic: Pump



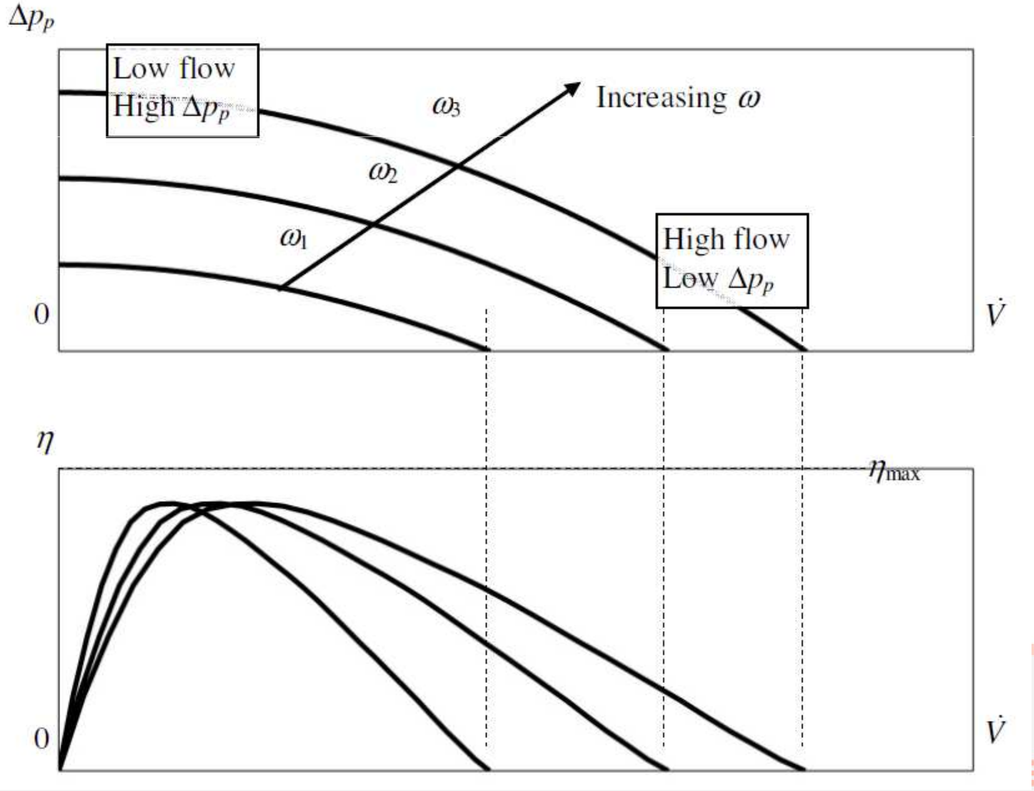
Unrealistic: η is not constant

- normally optimised for particular flow rate and rotational velocity.

bettertogether

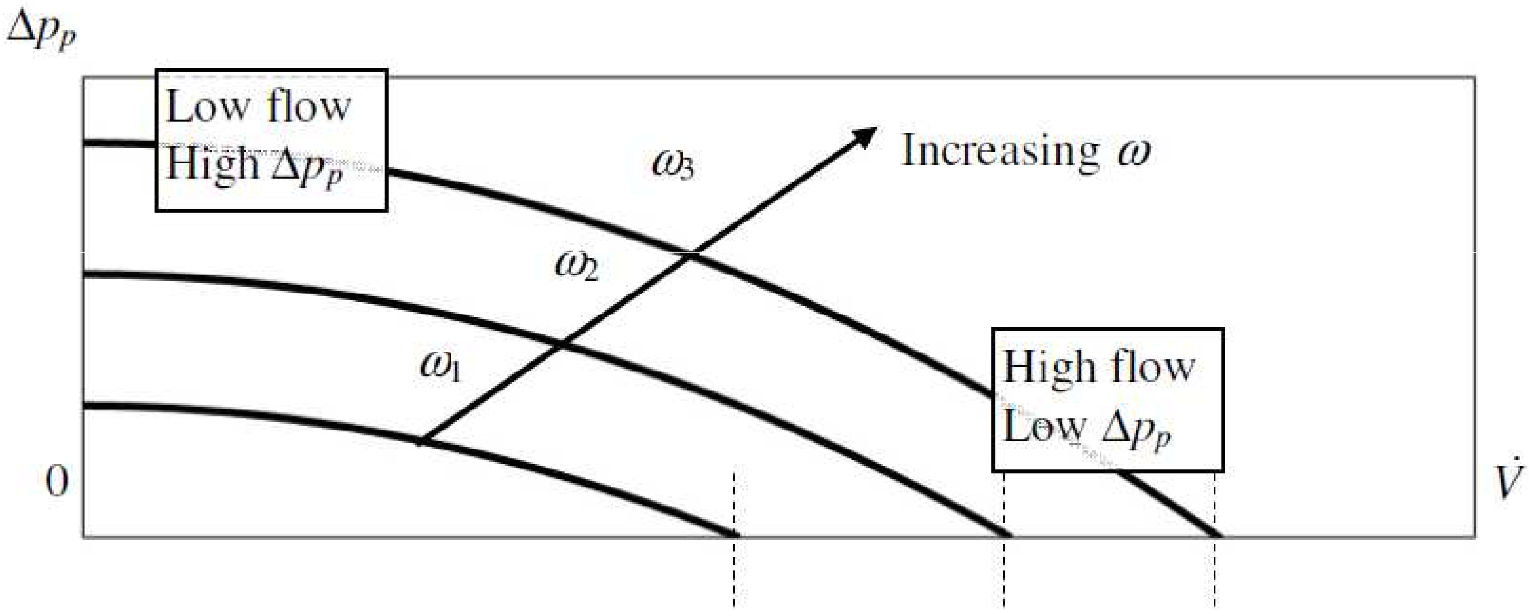
Machine Characteristic: Pump

- Power input can also be varied
  - Pump characteristic now:



Machine Characteristic: Pump

- **Pump Characteristic**

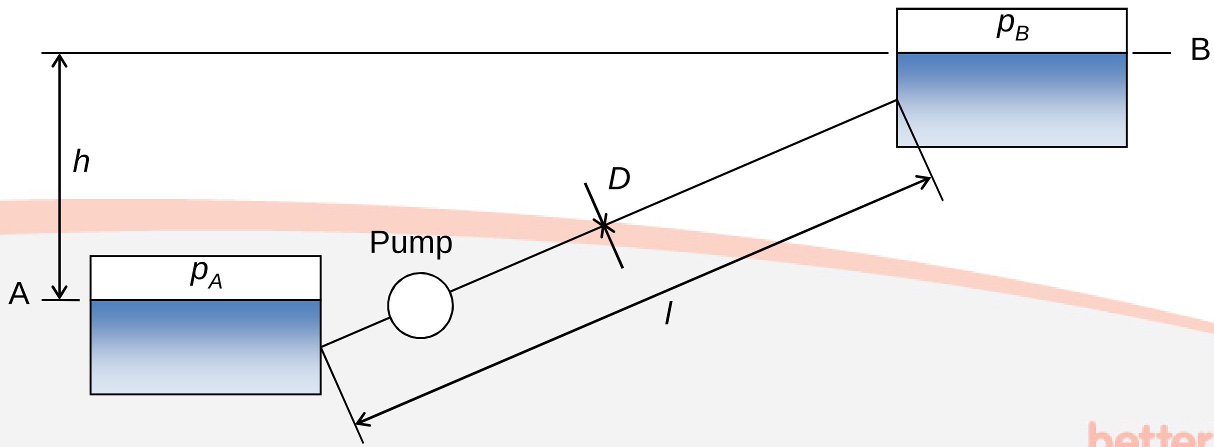


$$\Delta p_p = A_1 - A_2 \dot{V}^2$$

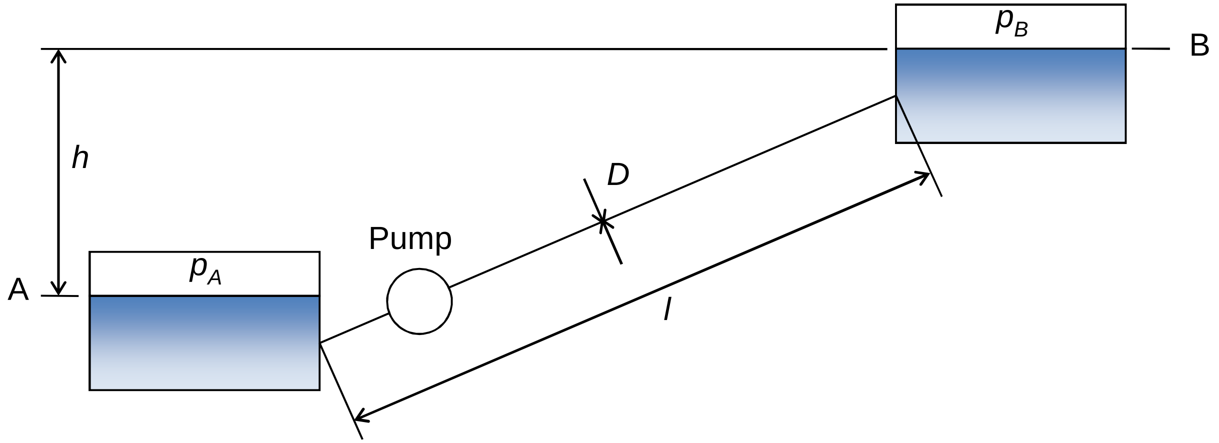
A_1 and A_2 are constants specific to pump

Machine Operation

- Analysis of machine in which pump is operating
- Allows us to find the operating point (what flow rate)
- For example



Machine Operation



- Pump has to overcome:
  - Hydrostatic pressure (ρgh)
  - Pressure difference ($p_A - p_B$)
  - Losses due to friction and minor losses
- Need to use Bernoulli's equation:

$$p_A + \frac{1}{2}\rho c_A^2 + \rho g z_A + \Delta p_p = p_B + \frac{1}{2}\rho c_B^2 + \rho g z_B + \Delta p_L$$

Machine Operation

- A and B are reservoirs, so c_A and c_B are zero:

$$p_A + \frac{1}{2}\rho c_A^2 + \rho g z_A + \Delta p_p = p_B + \frac{1}{2}\rho c_B^2 + \rho g z_B + \Delta p_L$$

$$p_A + \rho g z_A + \Delta p_p = p_B + \rho g z_B + \Delta p_L$$

$$\Delta p_p = (p_B - p_A) + \rho g (z_B - z_A) + \Delta p_L$$

$$\Delta p_p = (p_B - p_A) + \rho g h + \Delta p_L$$

- Pressure loss (excluding minor losses!):

$$\Delta p_L = \frac{fL}{D}\frac{1}{2}\rho c^2 = \frac{8 fL\rho}{\pi^2 D^5}\dot{V}^2$$

Machine Operation

- Substituting:

$$\Delta p_p = \left(\left(p_B - p_A\right) + \rho g h\right) + \left(\frac{8 fL\rho}{\pi^2 D^5}\right) \times \dot{V}^2$$

Static lift (not dependent on flow rate)

C_1

Flow rate dependent term

C_2

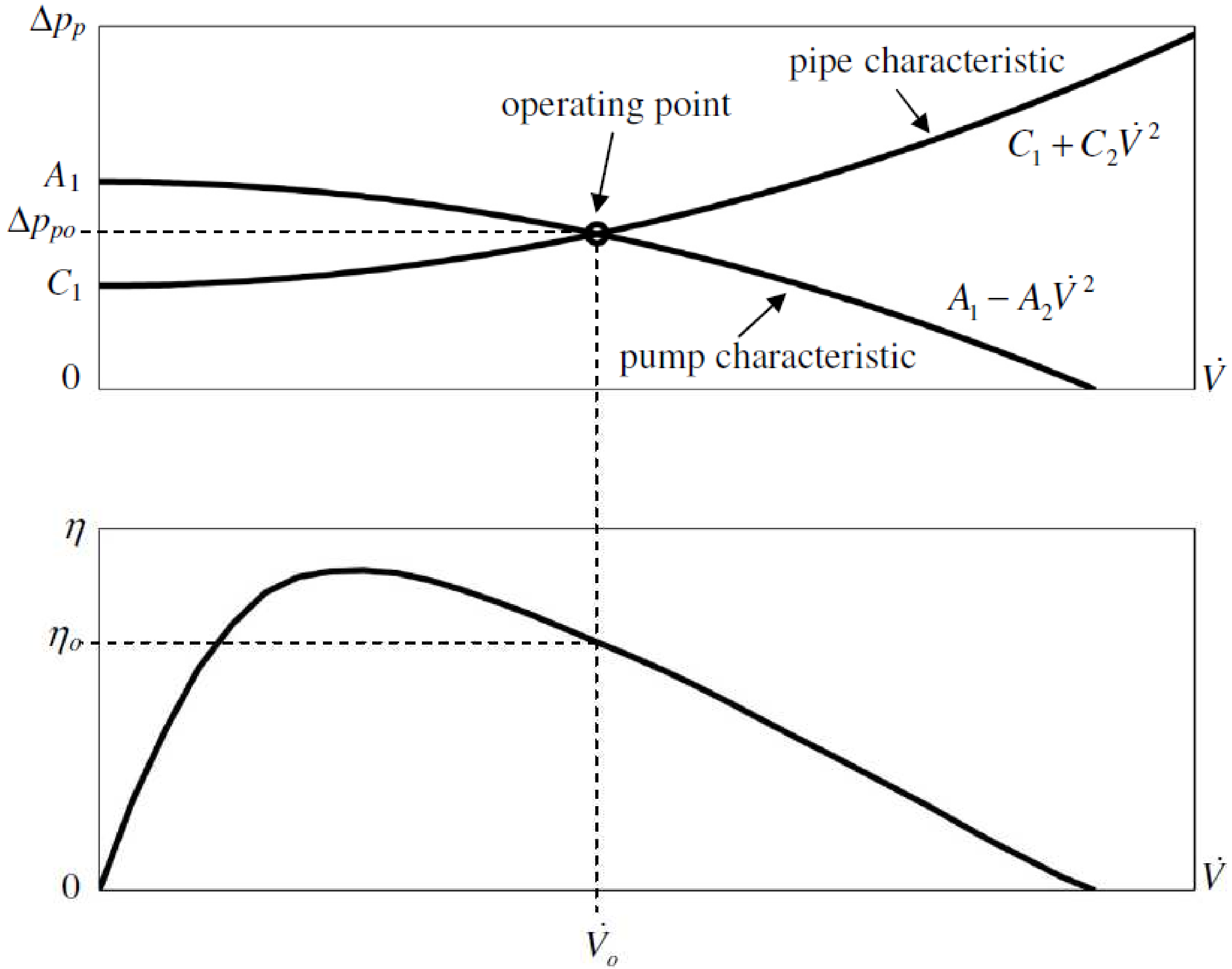
- **Pipe characteristic:** $$\Delta p_p = C_1 + C_2 \dot{V}^2$$

Operating Point

- Two equations for Δp_P:
  - For pump characteristic: $$\Delta p_p = A_1 - A_2 \dot{V}^2$$
  - For pipe characteristic: $$\Delta p_p = C_1 + C_2 \dot{V}^2$$
  - Operating point is where these two are equated:

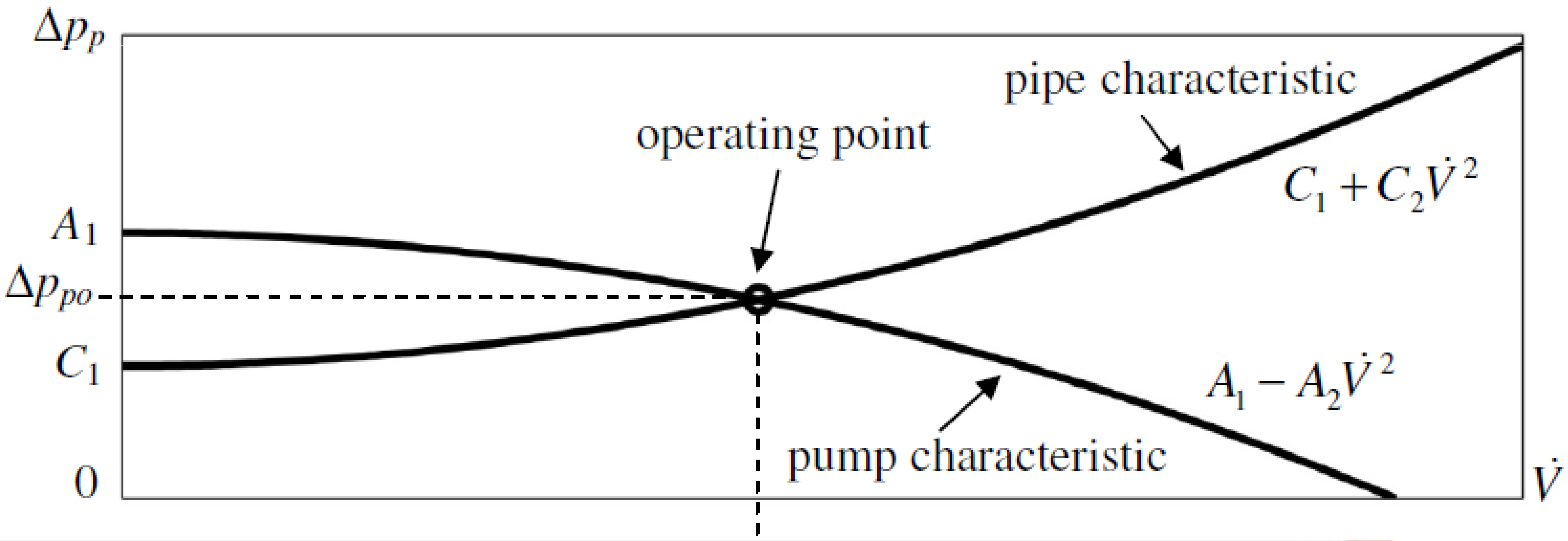
$$A_1 - A_2 \dot{V}^2 = C_1 + C_2 \dot{V}^2$$

Operating Point



Operating Point

- By equating Pipe and Pump Characteristics, flow rate at operating point can be found.



Example

- On visualiser

Summary

- Pump characteristic given by: $\Delta p_p = A_1 - A_2\dot{V}^2$

- Pipe characteristic given by: $\Delta p_p = C_1 + C_2\dot{V}^2$
  - C1 is static lift: $(p_A - p_B) + \rho g h$
  - C2 is flow dependent term: $\dfrac{8 fL\rho}{\pi^2 D^5}$ (Note: this excludes minor losses!)

- Flow rate can be found by equating equations: $A_1 - A_2\dot{V}^2 = C_1 + C_2\dot{V}^2$

Summary

- Some key things to remember:
  - Efficiency

$$\eta = \frac{\text{Power to the flow}}{\text{Power consumption}} = \frac{\Delta p_p \dot{V}}{P}$$

  - Sometimes pump and pipe characteristic are given as **head** (watch out!):

$$H = \frac{p}{\rho g}$$