University of Anbar
Engineering College
Department of Mechanical Engineering

ME 4309 - Engineering Control and Measurements

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Fourth Stage

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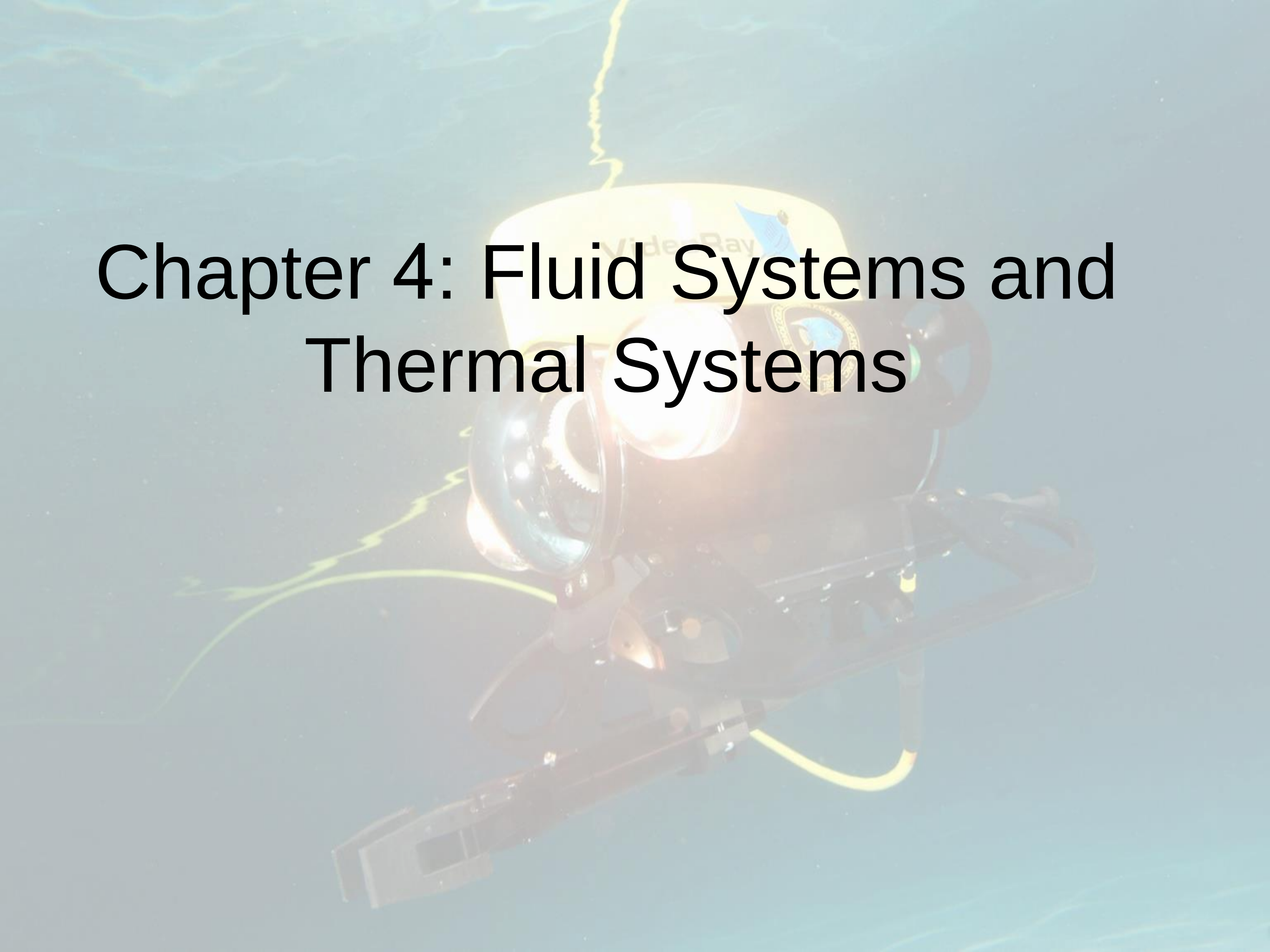
Chapter 4: Fluid Systems and Thermal Systems

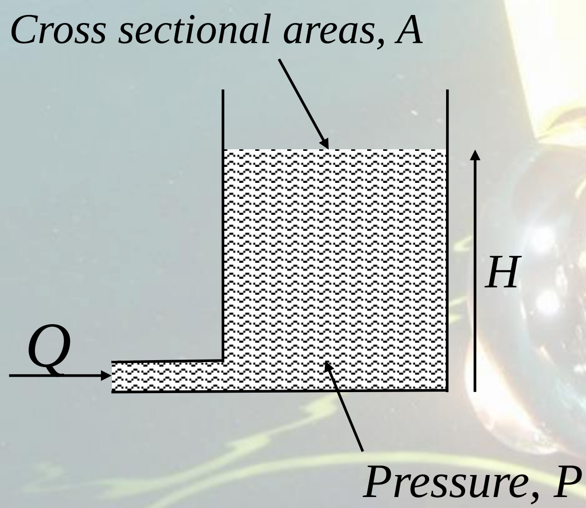


Fluid Systems

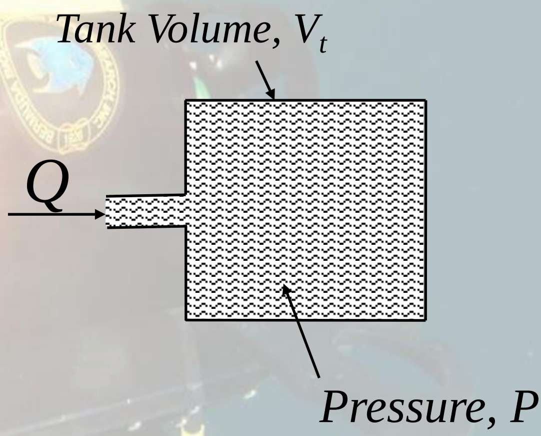
- Pressure, P (Pa)
- Flow Rate, Q (m^3s^{-1})

Fluid flow store

Open reservoir



Pressurised tank



$$Q = C_f \frac{dP}{dt}$$

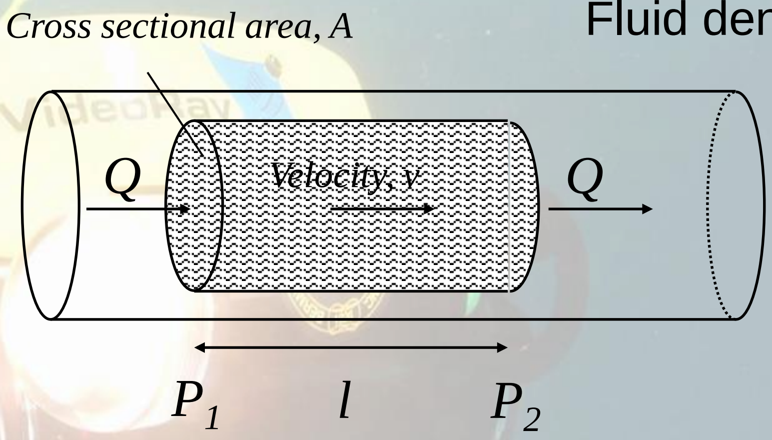
$$P = \frac{1}{C_f} \int Q dt$$

C_f – fluid capacitance

Fluid effort store

Fluid density, ρ

Fluid flow in a pipe



Force, $F = A(P_2 - P_1) = AP_{21}$

From Newton's laws: *F* = *ma*

$$F = \rho A l \frac{dv}{dt}$$

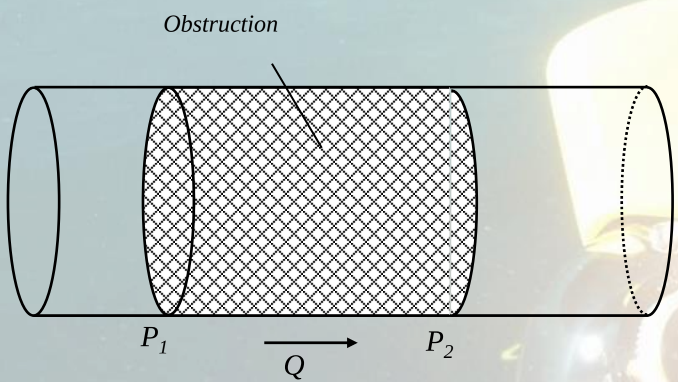
$$P = \frac{F}{A}$$

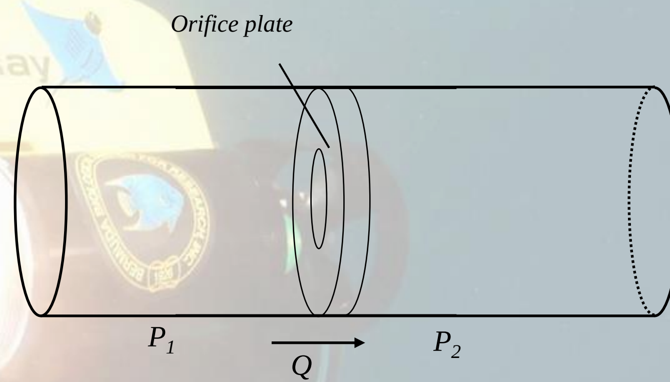
$$Q = vA$$

$$P_{12} = L_f \frac{dQ}{dt} \qquad Q = \frac{1}{L_f} \int P_{12}\, dt$$

Fluid inertance, $L_f = \dfrac{\rho l}{A}$

Fluid Dissipator



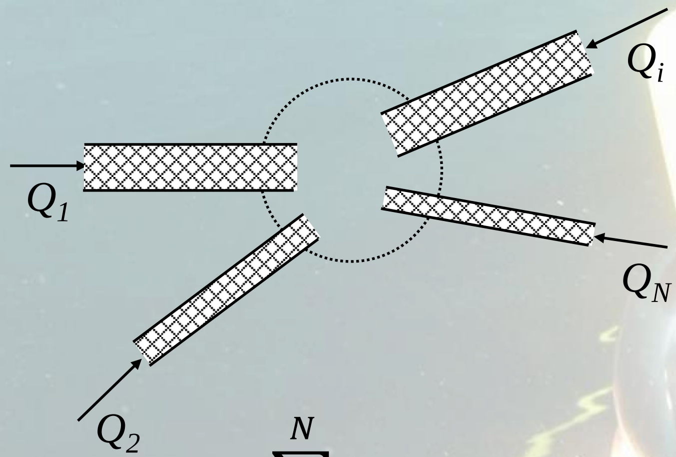


$$P_{12} = R_f Q$$

R_f – fluid resistance

In reality, the fluid resistance relationship is highly nonlinear and complex. This is a linear approximation

Fluid system interconnection rules

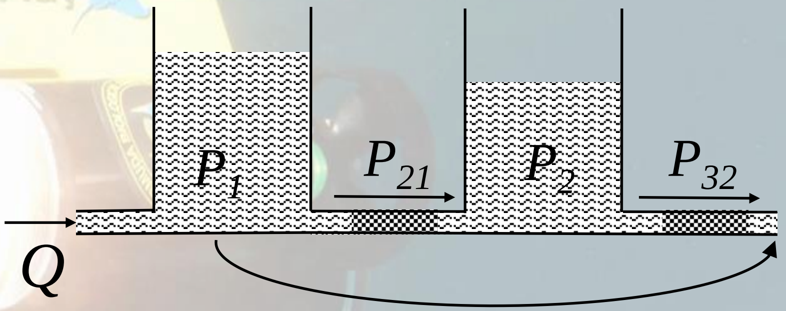


$$\sum_{j=1}^{N} Q_j = 0$$

Sum of flows at a junction equals zero (no leaks allowed)

For compressible fluids, sum of all mass flows at a junction equals zero

$$\sum_{j=1}^{N} m_j = 0$$

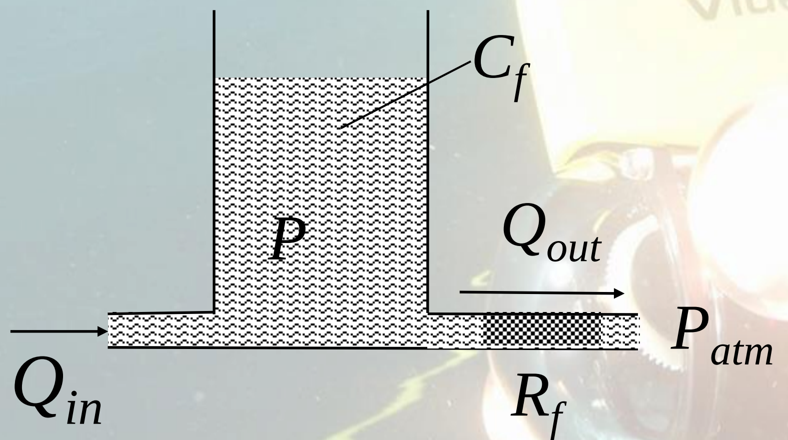


$$P_{31}=P_{21}+P_{32}$$

$$\sum_{j=1}^{N-1} P_{j,j+1} = 0$$

Sum of pressure differences around a loop equals zero

Fluid system Example



Assume P_{atm} is zero

$$Q_{out} = \frac{P - P_{atm}}{R_f} = \frac{P}{R_f}$$

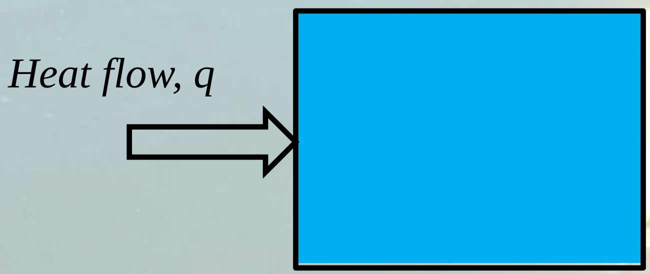
$$\frac{dP}{\mathrm{d}t} = \frac{1}{C_f}[Q_{in} - Q_{out}]$$

$$\frac{dP}{\mathrm{d}t} = \frac{1}{C_f}\left[Q_{in} - \frac{P}{R_f}\right]$$

Thermal Systems

- Heat flow rate, q (Watts)
- Temperature, T (Kelvin)
  - Can also use Heat (Joules) – but we will stick to temperature

Thermal Flow Store



Heat stored in material

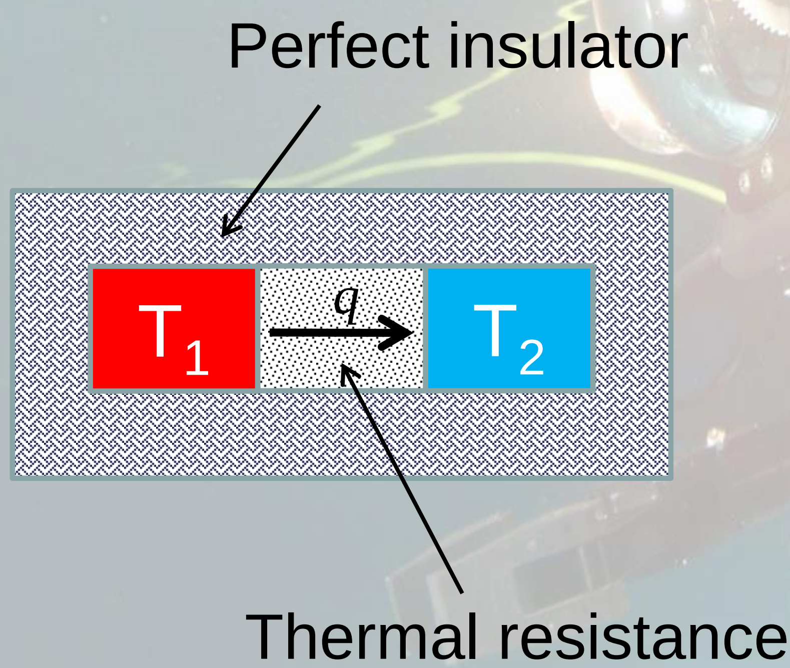
$$q = mC_P \frac{dT}{dt}$$

$$T = \frac{1}{mC_p} \int q \, dt$$

m – body mass (kg),
C_p – specific heat capacity of material ($Jkg^{-1}K^{-1}$)

Thermal Dissipator

- Heat loss occurs through conduction, convection and radiation
- Convection and radiation are nonlinear so we will stick to conduction



$$q = \frac{\sigma_c A}{l}(T_1 - T_2)$$

σ_c – thermal conductivity
A – cross sectional area
l – length of the object

Interconnection rules

- Sum of heat flows into a thermal junction equals zero
- Sum of temperatures around a loop equals zero

Summary

- To control a system we have to understand its behaviour
- Mathematical models are useful in understanding and predicting system behaviour
- Real systems are very complex

Summary

- We have to simplify them in order to get usable models
  - Linear
  - Single input , single output
  - Time invariant
  - Low order
- Take care that simplifications do not make the model invalid
- Lumped element (mass, spring, damper or RLC) models can be converted into mathematical form fairly easily. Solving the equations can be harder!