DTU

47201 Engineering thermodynamics

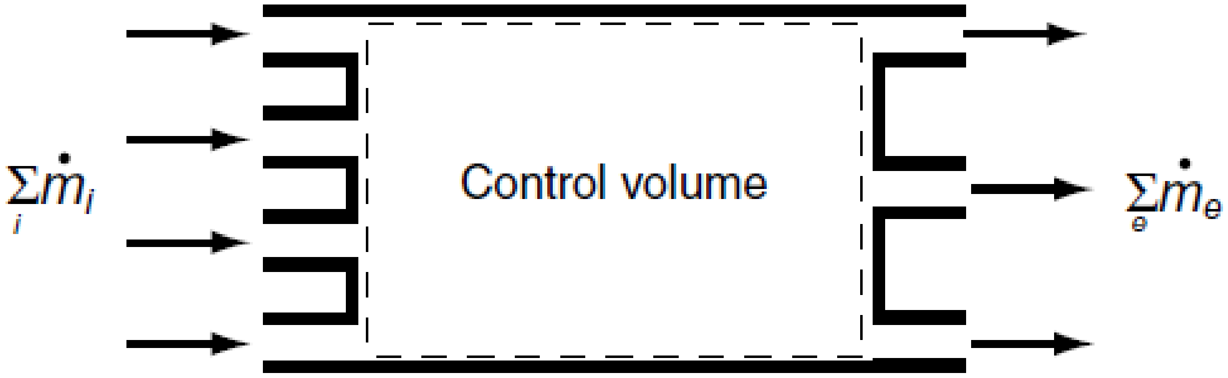
Lecture 3b: First law for open systems (Ch 4.13-4.16)

Open systems – multiple inlets and outlets

For systems with multiple inlets and outlets, it is just a matter of performing the same analysis on each stream. For steady state:

$$\sum_{i=1}^{\#inlets} \dot{m}_{in,i}\left(h_{in,i} + \frac{1}{2}v_{in,i}^2 + gz_{in,i}\right) + \sum_{i=1}^{\#\,heat\ terms} \dot{Q}_i + \sum_{i=1}^{\#\,work\ terms} \dot{W}_i =$$

$$\sum_{i=1}^{\#outlets} \dot{m}_{out,i}\left(h_{out,i} + \frac{1}{2}v_{out,i}^2 + gz_{out,i}\right) + \sum_{i=1}^{\#\,heat\ terms} \dot{Q}_{out} + \sum_{i=1}^{\#\,work\ terms} \dot{W}_{out}$$



When to use c_v or c_p *(section 4.10)*

- When we deal with state variables, often we only care about the internal energy or enthalpy at the end of some process. In this case, we can use c_v if we are looking at the internal energy and c_p when looking at the enthalpy. For an ideal gas, c_v is a function only of temperature.
  - Using the definition of enthalpy $h = u + Pv$ and substituting the ideal gas law for the pressure and specific volume gives
  $$h = u + R\,T$$
  - Then using the definition of c_p
  $$c_p = \frac{\partial h}{\partial T} = c_v + R$$

- So for an ideal gas, c_p is also a function only of temperature. However, for most other fluids, c_p and c_v are a function of both temperature and pressure and possibly other fields.

- For example, for an incompressible liquid $c_p(T) = c_v(T) = c(T)$ (Eq. 4.86)

$$\Delta u = \int_{T_1}^{T_2} c\,dT$$

$$\Delta h = \int_{T_1}^{T_2} c\,dT + \int_{v_1}^{v_2} v\,dP \quad Eq\ (4.88)$$

Methodology for solving thermodynamics problems

1. Carefully review the problem statement and what is known.

2. Choose the system.

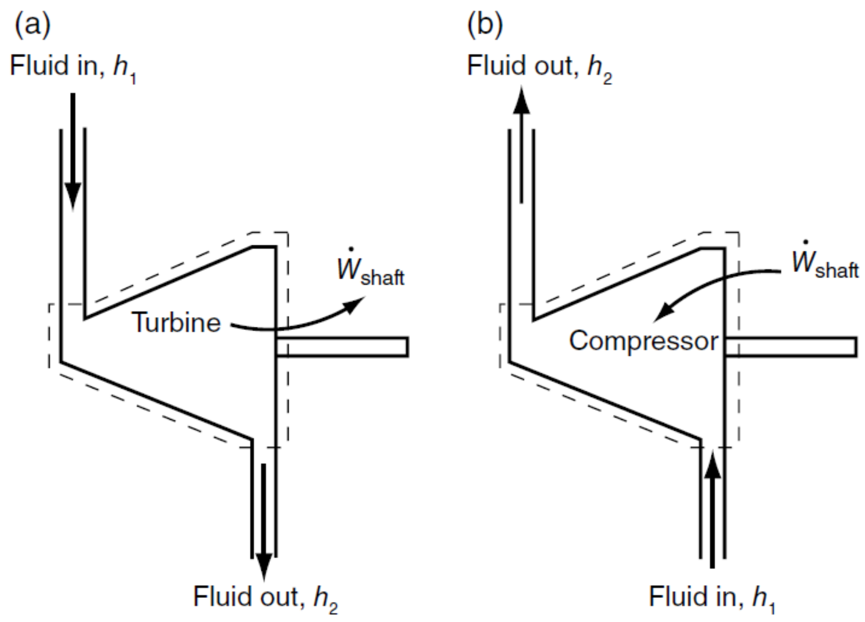
3. Apply a mass balance on the chosen system

4. Apply an energy balance on the chosen system

Steady Flow Devices – Turbines and Compressors

Turbine :
device that uses a high energy fluid flow to turn a shaft (output work)

Compressor :
A device that increases the pressure (and temperature) of a gas (requires work input)



The first law energy balance for a turbine

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{out}$$

If Q=0 (Thermal insulated)
$z_2 = z_1$ and $V_2 = V_1$;

$$\dot{W}_{shaft} = \dot{m}\,(h_{out} - h_{in})$$

Calculated from C_p

Steady Flow Devices – Pumps

A pump refers to a device that increase the elevation or pressure of a liquid, while a compressor increases the pressure or elevation of a gas.

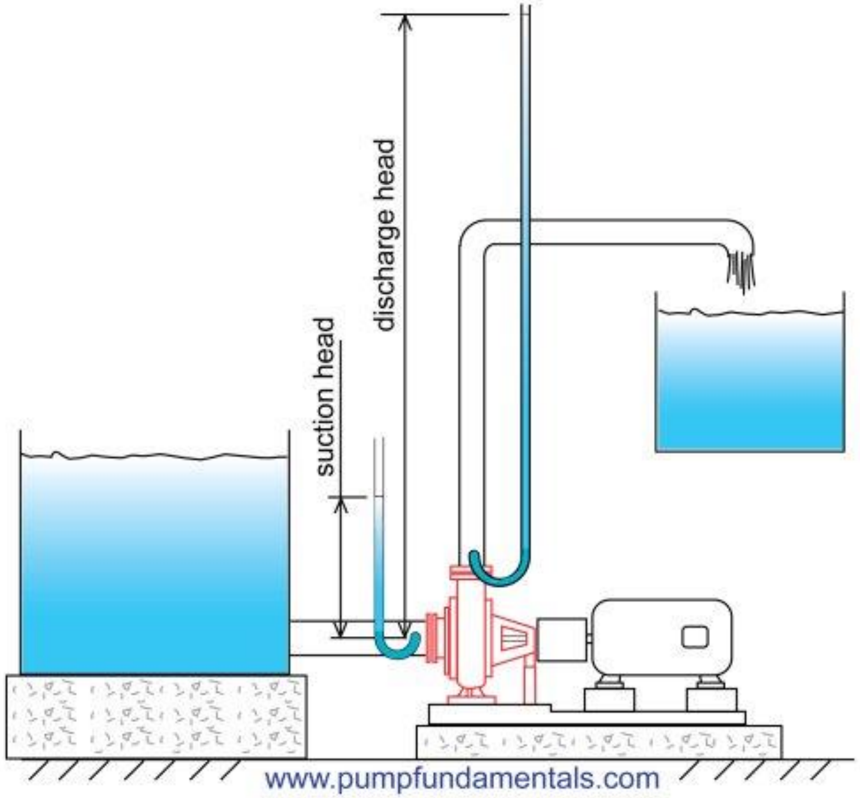
So for a pump, we assume an incompressible liquid

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{out}$$

$$\dot{W}_{shaft} = \dot{m}\left[\left(h_2 - h_1\right) + g\left(z_2 - z_1\right)\right].$$

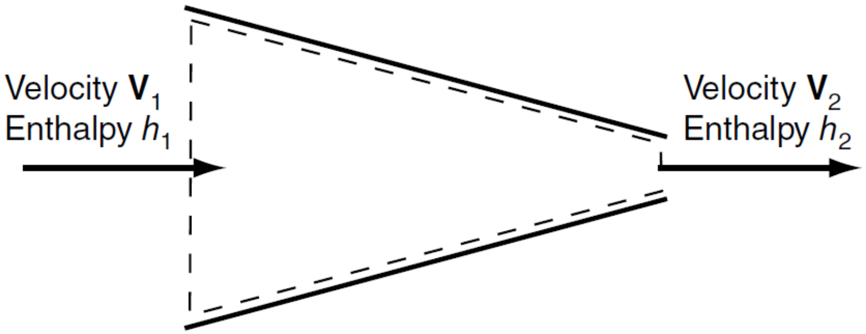
$$h_2 - h_1 = c\left(T_2 - T_1\right) + v\left(P_2 - P_1\right)$$

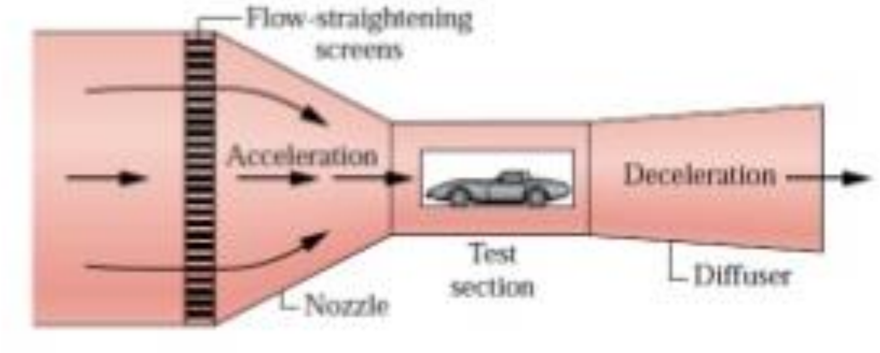
$$\boxed{\dot{W}_{\text{shaft}} = \dot{m}\left[v\left(P_2 - P_1\right) + g\left(z_2 - z_1\right)\right].}$$



Steady Flow Devices – Nozzles and Diffusers

Nozzle: device to accelerate gases before expelled





Diffuser = "reverse operation" of nozzle

The first law energy balance for a nozzle:

$$\dot{Q}_{in} + \dot{W}_{in} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{in} = \dot{Q}_{out} + \dot{W}_{out} + \dot{m}\left(h + \frac{V^2}{2} + gz\right)_{out}$$

$$\mathbf{V}_2 = \sqrt{2\left(h_1 - h_2\right)}.$$

No potential energy changes, no heat transfer, no work, and V2>>V1

Problems 3b

4.76

4.77

4.80

4.81

Problems 3b with solutions

4.76 Power to compressor is 140 kW

4.77 502.2

4.80 369 C

4.81 644.6 kW