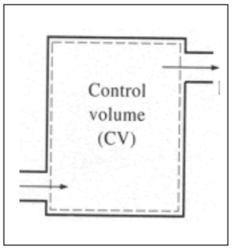
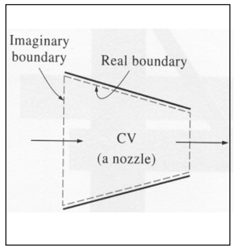
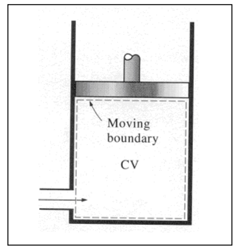
Analysis of Control Volumes

- A water heater, a car radiator, a turbine, and a compressor are examples of control volumes.







Conservation of Mass Principle

- Mass, like energy, is a conserved property, and it cannot be created or destroyed.

$$\begin{pmatrix}\text{total mass}\\ \text{enetering}\\ \text{CV}\end{pmatrix} - \begin{pmatrix}\text{total mass}\\ \text{leaving}\\ \text{CV}\end{pmatrix} = \begin{pmatrix}\text{net change in}\\ \text{mass within}\\ \text{CV}\end{pmatrix}$$

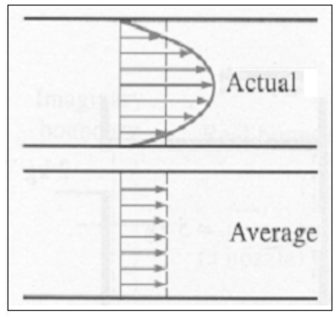
$$\boxed{\sum m_i - \sum m_e = \Delta m_{CV}}$$

where $\begin{cases} i & \text{inlet,} \\ e & \text{exit,} \\ CV & \text{Control Volume.} \end{cases}$

Mass & Volume Flow Rates

Mass flow rate:

$$\dot{m} = \int_A \rho \upsilon_n dA = \rho \upsilon_{av} A$$

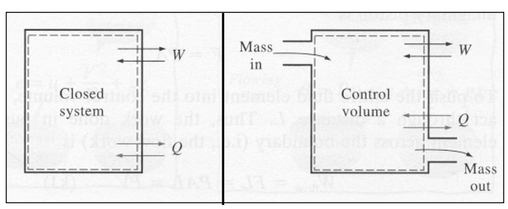


Volume flow rate:

$$\dot{V} = \int_A V_n dA = V_{av} A$$

$$\dot{m} = \rho \dot{V} = \frac{\dot{V}}{\upsilon}$$

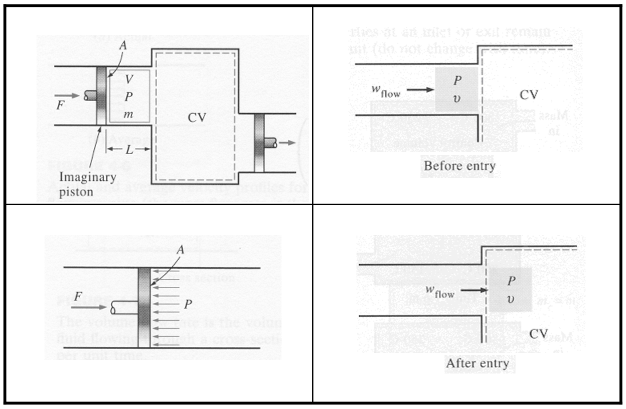
Conservation of Energy Principle



$$\begin{pmatrix} \text{total energy} \\ \text{crossing bounday} \\ \text{as heat and work} \end{pmatrix} + \begin{pmatrix} \text{total energy} \\ \text{of mass} \\ \text{entering CV} \end{pmatrix} - \begin{pmatrix} \text{total energy} \\ \text{of mass} \\ \text{leaving CV} \end{pmatrix} = \begin{pmatrix} \text{net change} \\ \text{in energy} \\ \text{of CV} \end{pmatrix}$$

$$Q - W + \sum E_{in,mass} - \sum E_{out,mass} = \Delta E_{CV}$$

Flow Work



Flow Work

Force applied on the fluid element:

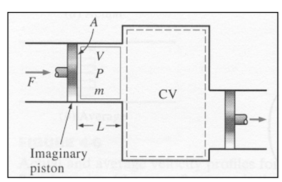
$$F = PA$$

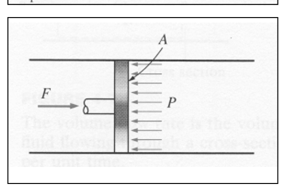
Work done on the fluid element:

$$W_{flow} = FL = PAL = PV$$

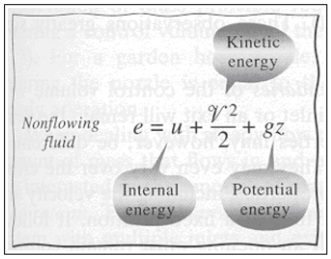
Flow work per unit mass:

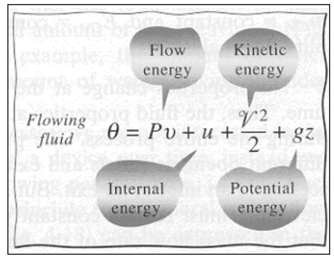
$$w_{flow} = Pv$$





Total Energy





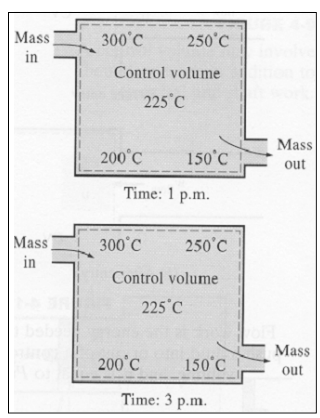
$$e = u + ke + pe = u + \frac{v^2}{2} + gz$$

$$\theta = h + ke + pe = h + \frac{v^2}{2} + gz$$

- By using the enthalpy, one does not need to be concerned about the flow work

Steady-State Flow Process

1) No properties (intensive or extensive) within the control volume change with time.
2) No properties change at the boundaries of the control volume with time.
3) The heat and work interactions between the system and its surroundings do not change with time.



Conservation of Mass

$$\begin{pmatrix}\text{total mass entering}\\ \text{CV per unit time}\end{pmatrix} = \begin{pmatrix}\text{total mass leaving}\\ \text{CV per unit time}\end{pmatrix}$$

$$\sum \dot{m}_i = \sum \dot{m}_e \quad \text{(kg/s}$$

For ***single stream*** devices:

$$\dot{m}_1 = \dot{m}_2 \quad \text{(kg/s)}$$

$$\rho_1 \upsilon_1 A_1 = \rho_2 \upsilon_2 A_2$$

$$\frac{1}{\upsilon_1} V_1 A_1 = \frac{1}{\upsilon_2} V_2 A_2$$

Conservation of Energy

$$\begin{pmatrix}\text{total energy crossing}\\ \text{boundary as heat and}\\ \text{work per unit time}\end{pmatrix} = \begin{pmatrix}\text{total energy transported}\\ \text{out of CV with mass}\\ \text{per unit time}\end{pmatrix} - \begin{pmatrix}\text{total energy transported}\\ \text{into CV with mass}\\ \text{per unit time}\end{pmatrix}$$

$$\dot{Q} - \dot{W} = \sum \dot{m}_e \theta_e - \sum \dot{m}_i \theta_i$$

$$\dot{Q} - \dot{W} = \underbrace{\sum \dot{m}_e \left(h_e + \frac{\mathcal{V}_e^2}{2} + g z_e\right)}_{\text{for each exit}} - \underbrace{\sum \dot{m}_i \left(h_i + \frac{\mathcal{V}_i^2}{2} + g z_i\right)}_{\text{for each inlet}}$$

Conservation of Energy

For ***single stream*** devices:

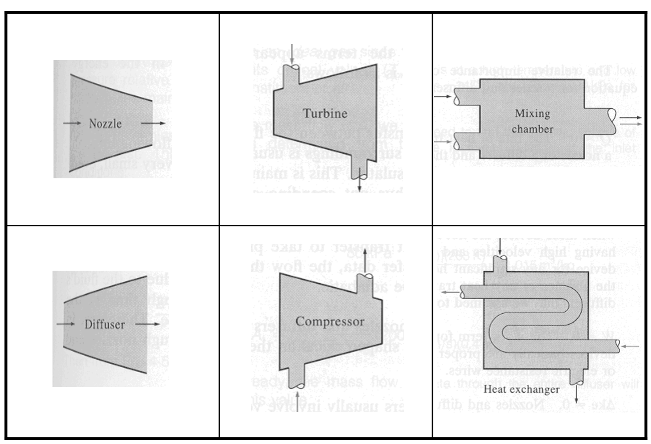
$$\dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{\mathcal{V}_2^2 - \mathcal{V}_1^2}{2} + g(z_2 - z_1)\right] \quad \text{(kW)}$$

$$q - w = h_2 - h_1 + \frac{\mathcal{V}_2^2 - \mathcal{V}_1^2}{2} + g(z_2 - z_1) \quad \text{(kJ/kg)}$$

For negligible change in the fluid kinetic and potential energy:

$$q - w = \Delta h \quad \text{(kJ/kg)}$$

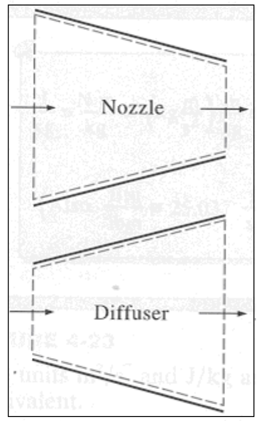
Steady Flow Engineering Devices



Nozzles & Diffusers

- $\dot{Q} \approx 0$
- $\dot{W} \approx 0$
- $\Delta ke \neq 0$
- $\Delta pe \approx 0$

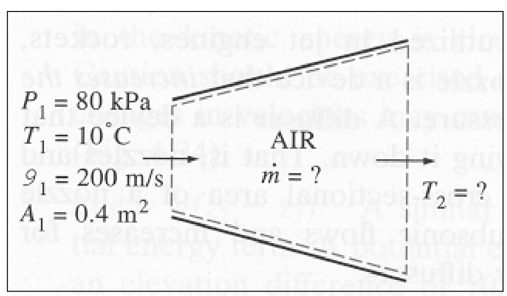
$$\cancelto{0}{q} - \cancelto{0}{w} = \Delta h + \Delta ke + \cancelto{0}{\Delta pe}$$



Example

Determine

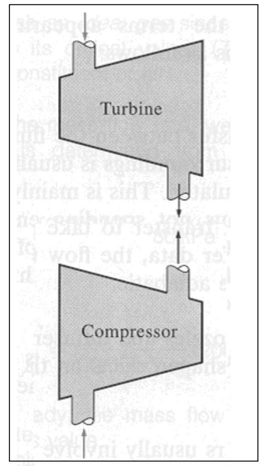
- (a) the mass flow rate of the air and
- (b) the temperature of the air leaving the diffuser.



Turbines & Compressors

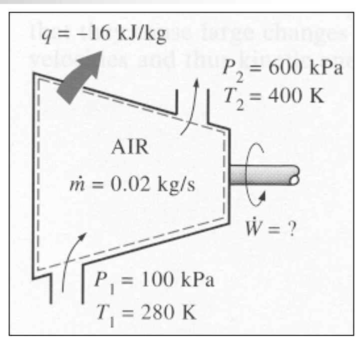
- $\dot{Q} \approx 0$
- $\dot{W} \neq 0$
- $\Delta ke \approx 0$
- $\Delta pe \approx 0$

$$\overset{0}{\cancel{q}} - w = \Delta h + \overset{0}{\cancel{\Delta ke}} + \overset{0}{\cancel{\Delta pe}}$$



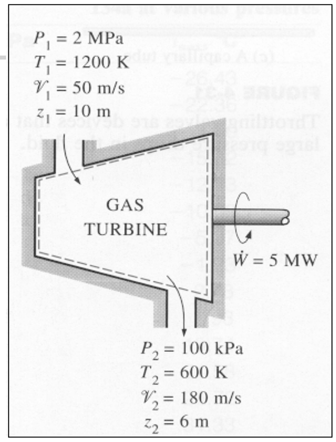
Example

- Assuming the changes in kinetic and potential energies are negligible, determine the necessary power input to the compressor.



Example

1. Compare Δh, Δke, and Δpe
2. Determine the work done per unit mass of hot gases
3. Calculate the mass flow rate of the steam

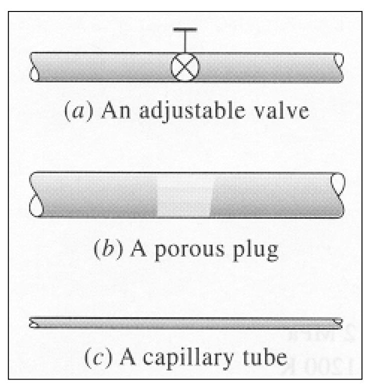


- Gases can be treated as air

Throttling Valves

- ⇨ $\dot{Q} \approx 0$
- ⇨ $\dot{W} \approx 0$
- ⇨ $\Delta ke \approx 0$
- ⇨ $\Delta pe \approx 0$

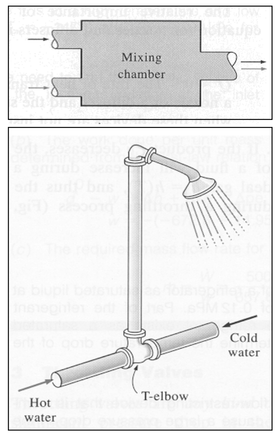
$$h_2 \approx h_1$$



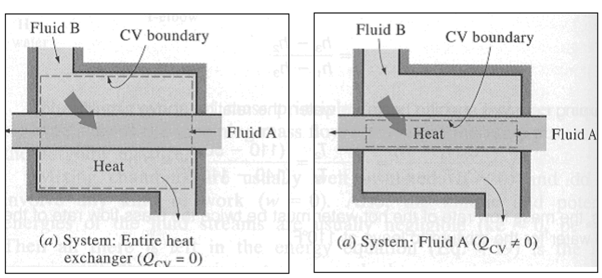
Mixing Chambers

- $\dot{Q} \approx 0$
- $\dot{W} = 0$
- $\Delta ke \approx 0$
- $\Delta pe \approx 0$

$$h_2 \approx h_1$$



Heat Exchangers



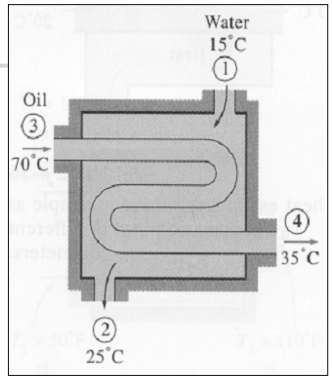
- $\dot{W} = 0$
- $\Delta ke \approx 0$
- $\Delta pe \approx 0$

- Heat transfer associated with a heat exchanger may be zero or nonzero depending on how the system is selected.

Example

- Neglecting any pressure drops, determine:

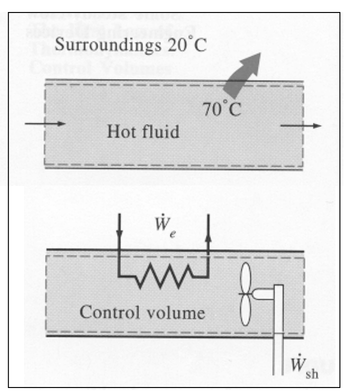
1. Mass flow rate of the cooling water required, and
2. Heat transfer rate from the engine oil to water.



Pipe & Duct Flow

- ⇨ $\dot{Q} \neq 0$
- ⇨ $\dot{W} \neq 0$
- ⇨ $\Delta ke \approx 0$
- ⇨ $\Delta pe \neq 0$

$$\dot{Q} - \dot{W} = \dot{m}(\Delta h + \Delta ke^{\nearrow 0} + \Delta pe^{\nearrow 0})$$



Example

- If heat is lost from the air in the duct to the surroundings at a rate of 200 W, determine the exit temperature of air.