Oct. 13/17
Thermal

Specific Heats

Two kinds of specific heat - one at C_v (cons. volume), one at C_p (cons. pressure)

$$\begin{cases} C_v = (\delta u / \delta T)_\vartheta \longrightarrow du = C_v\,dt \\ C_p = (\delta h / \delta T)_P \longrightarrow dh = C_p\,dt \end{cases}$$

$Q - W = \Delta V$
$\vartheta = c$
$\therefore Q = \Delta U$

Joule : $u = u(T)$ For ideal gas

Initial temp $= T_1$
Final temp $= T_2$
→ experiment by Joule.

$$Q - \cancel{W}^{\,0} = \Delta U$$
$$\cancel{Q}^{\,0} = \Delta U \qquad \boxed{U_1 = U_2}$$

$$h = u + P\vartheta$$
$$h = u + \underbrace{RT}_{\text{const.}}$$
$$\therefore h = h(T)$$

① $u = u(T)$
② $h = h(T)$

$\Delta u = u_2 - u_1$ (table)
$\Delta u = \int_1^2 c_v(T)\,dT$
$\Delta u \simeq C_{v,\,avg}\,\Delta T$

$$\left.\begin{array}{l} \Delta u = C_{v,\,AVG}\,\Delta T \\ \Delta h = C_{p,\,AVG}\,\Delta T \end{array}\right\}$$

SP. Heat relations :

$$\left.\begin{array}{l} h = u + P\vartheta \\ h = u + RT \end{array}\right\} \text{(where } P\vartheta = RT\text{)}$$

$$dh = du + d(RT) \longrightarrow dh = du + R\,dT$$
$$C_p\,dT = C_v\,dT + R\,dT$$
$$C_p\,\cancel{dT} = (C_v + R)\,\cancel{dT}$$
$$C_p - C_v = R \longrightarrow \text{gas const.}$$
$$(C_p > C_v)$$

Ratio of specific heats :

γ or $K = C_p/C_v$

For solids or liquids : only one sp. heat

$C_p = C_v = C$

$$\boxed{Q = mc\Delta t}$$

$h = u + Pv$

$dh = du + P\cancel{dv}^{\,0} + v\,dP$

$$\boxed{v = C \quad dh = du + v\,dP} \rightarrow \Delta h = \Delta u + v\Delta P \rightarrow \text{Solid or liquid}$$

Solid : $v\Delta P$ is negligible

$\therefore \Delta h = \Delta u = C_{v,avg}\,\Delta T$

Liquid : 1 const. P process $\rightarrow$ heaters

$P = C \quad \Delta h = \Delta u + v\cancel{\Delta P}^{\,0}$

$\Delta h = \Delta u$

2. const T process ($T = c$)

Examples 4-8, 4-12, 4-13

4-8) $\cancel{Q}^{\,0} - W = \Delta U$ | $W_{sh,in} = \Delta U = m\Delta u = m(u_2 - u_1)$

$-(-W_{sh,in}) = \Delta U$ | $= m\,C_{v,avg}(T_2 - T_1)$

$W_{sh} = \dot{W}_{sh}\,\Delta t$

$= 0.02\text{ hp} \times \frac{30}{60}\text{ h} \times \left(\frac{2545\text{ btu/h}}{1\text{ hp}}\right)$

$1\text{ hp} = 550\text{ ft lbf/s}$

(4-8, cont.)

$C_v \cong 0.753$ Btu/lbm °F $\longrightarrow$ $25.45 = 1.5 \times 0.753 \times (T_2 - 80)$

$\therefore T_2 = 102.5\,°F$

b) $\frac{P_1 \cancel{V_1}}{T_1} = \frac{P_2 \cancel{V_2}}{T_2}$ $\therefore P_2 = \frac{P_1}{T_1} \times T_2 = \left(\frac{50}{80+460}\right)(102.5+460)$

$(°F + 460 = R)$

(4-12) $C_i = 0.45$ kJ/kg·°C | heat lost by iron

$C_w = 4.18$ kJ/kg·°C | = heat gain by water

$mC(T_2 - T_1)$

Iron = 80 °C For iron $\Delta T = (80 - T)$

Water = 25°C For water $\Delta T = (T - 25)$

$50 \times 0.45 \times (80 - T) = 500 \times 4.18 \times (T - 25)$

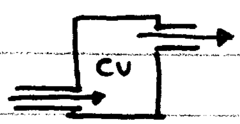
$\therefore T = 25.6\,°C$

Oct. 5/17 Thermo

Mass + Energy Analysis of Control Volumes (chap. 5)

obj:
1) Development of conservation of mass principle
2) Apply conservation of mass to steady and unsteady flow.
3) Apply 1st law of thermodynamics in system and control volume
4) Identify energy carried by mass flow
5) Energy balances for steady flow devices

Conservation of mass:
1) Closed system → System
2) open system → Control volume



$m_{in} - m_{out} = \cancel{[d/dt]}\, m_{cv}$

For steady flow: $m_{in} = m_{out}$

$m_{sys} = const$

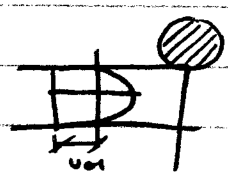
$[d/dt]\, m_{sys} = 0$

Conservation of Energy
1) Sys → $Q - W = \Delta U$
2) CV → $E_{in} - E_{out} = \cancel{d/dt}\, E_{cv}$

For steady flow $\boxed{E_{in} = E_{out}}$

$\mathcal{V} \rightarrow$

Vol Flow rate



$\mathcal{V} = V_{av} A_c$

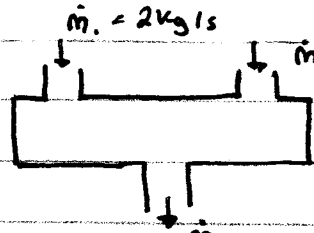
$\rho = m/\mathcal{V} = \dot{m}/\dot{\mathcal{V}}$

$\dot{m} = \dot{\mathcal{V}} \times \rho$

$\dot{m} = \rho V_{Av} A_c$

(continuity eq'n)

Mass balance for steady flow processes



$\sum_{in} \dot{m} = \sum_{out} \dot{m}$

$\dot{m}_3 = \dot{m}_1 + \dot{m}_2$

$= 5 kg/s$

$m_1 = m_2$

$\rho_1 V_1 A_1 = \rho_2 V_2 A_2$

$\rho \to$ Avg, $A \to$ cross sectional area

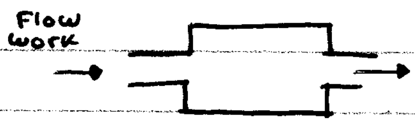
Special Case : incompressible Flow

$\dot{m} = \underset{\hookrightarrow \text{const.}}{\rho} A V = \text{const.}$

$\therefore AV = \text{const.}$

$\sum_{in} \dot{V} = \sum_{out} \dot{V} \;;\; \dot{V} = \text{const.}$

Flow work and Energy of a Flowing Fluid



$w_{Flow} = P\upsilon = P/\rho$

Non-Flowing Fluid : $e = u + V^2/2 + gz$

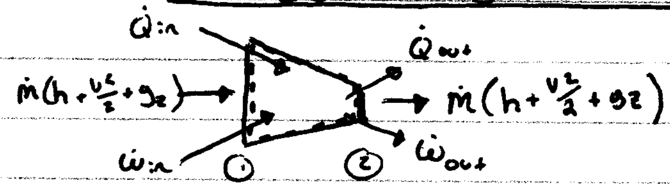
Flowing Fluid : $\theta = u + P\upsilon + V^2/2 + gz$

(remember $h = u + P\upsilon$)

$\therefore \theta = h + \frac{V^2}{2} + gz$

$E_{Flow} = m\theta \qquad \dot{E}_{Flow} = \dot{m}\theta$

Energy analysis of Steady Flow systems :



Energy :

1) Q or $\dot{Q}$

2) W or $\dot{W}$

3) E_{Flow} or $\dot{E}_{Flow}$

$\dot{E}_1 = \dot{E}_2$

$$\left.\begin{aligned} &\dot{Q}_{in} + \dot{W}_{in} + \sum_{in} \dot{m}(h + V^2/2 + gz) \\ &= \dot{Q}_{out} + \dot{W}_{out} + \sum_{out} \dot{m}(h + V^2/2 + gz) \end{aligned}\right\} \to \begin{aligned} &\dot{Q}_{in} - \dot{Q}_{out} = \dot{Q}_{net\text{-}in} \to \dot{Q} \\ &\dot{W}_{out} - \dot{W}_{in} = \dot{W}_{net\,out} \to \dot{W} \end{aligned}$$

Single stream:

$$q - w = (h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) + g(z_2 - z_1)$$

$$q - w = \Delta h + \Delta ke + \Delta pe$$

$$q = \frac{\dot{Q}}{\dot{m}} \quad \text{and} \quad w = \frac{\dot{W}}{\dot{m}}$$

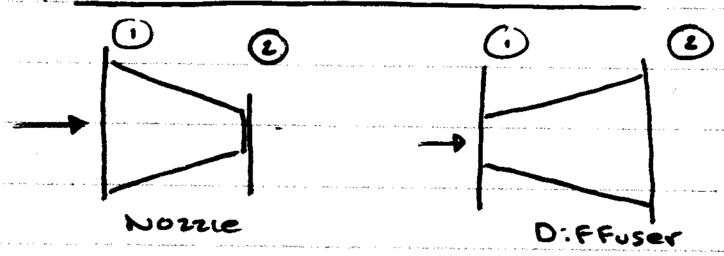
For Δke and $\Delta pe \simeq 0$

$$q - w = \Delta h$$

Some steady flow engineering devices

1) Nozzles and diffusers
2) Turbines and compressors
3) Throttling valves
4a) Mixing chamber
4b) Heat Exchanger
5) Pipe and Duct Flow

1) Nozzles + Diffusers



$$\dot{m}\left(h_2 + \frac{V_2^2}{2} + gz_2\right) = \dot{m}\left(h_1 + V_1^2/2 + gz_1\right)$$

$$h_2 - h_1 = \frac{V_1^2}{2} - \frac{V_2^2}{2} + \cancel{\left[gz_1 - gz_2\right]} \to 0$$

For nozzle : $V_2 \gg V_1$ $\qquad h_1 - h_2 = +ve$

$\therefore h_2 < h_1$

For diffuser $V_2 \ll V_1$ $\qquad h_2 - h_1 = +ve$

$\therefore h_2 > h_1$

2) Compressors and turbines

↳ Pump, fan ↳ diesel - engine turbine

or gas turbine

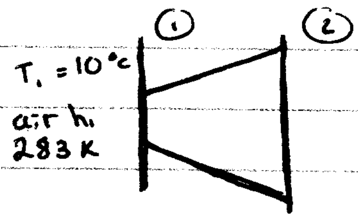
or hydroelectric

or steam

$$\cancel{\dot{Q}}^{\,\emptyset} - \dot{W} = \dot{m}\left(h_2 + V_2^2/2 + g z_2\right) = \dot{m}\left(h_1 + V_1^2/2 + g z_1\right)$$

$$-\left(\dot{W}_{out} - \dot{W}_{in}\right) = \dot{m}\left[(h_2 - h_1) + \left(\frac{V_2^2 - V_1^2}{2}\right) - g(z_2 - z_1)\right]$$

Example 5-4 (from textbook):



① air → ideal gas

$$P\upsilon = RT$$

$$\upsilon_1 = \frac{RT}{P_1} = \frac{(0.287\ kJ/kg.K)(10 + 273\ K)}{(80\ kPa)}$$

$$= 1.015\ m^3/kg$$

a) $\dot{m} = \rho_1 A_1 V_1$

$$= 1/\upsilon \times (0.4\ m^2) \times (200\ m/s)$$

$$= 78.8\ kg/s$$

$\dot{E}_{in} = \dot{E}_{out}$

↳ $\dot{Q}$, $\dot{W}$, $\dot{m}\left(h + \frac{V^2}{2} + gz\right)$

$$\dot{m}(h_1 + V_1^2/2) = \dot{m}(h_2 + V_2^2/2)$$

$$h_2 = h_1 + V_1^2/2$$

$$V_2 \ll V_1 \rightarrow V_2 \cong 0$$

$$h_2 = h_1 + V_1^2/2$$

↳ from table

$$h_1 @ 283\ K = 283.14\ kJ/kg$$

$$h_2 = 283.14 + \frac{200^2}{2}$$

$$h_2 = 303.14\ kJ/kg \qquad T_2 = 303\ K$$