Review Sheet

Sunday, March 29, 2020 7:52 PM

Analysis of Control Volumes (Open System)

Flow rate $= \dot{V} = \frac{\dot{m}}{\rho} = V_{avg} \cdot A_c$

Flow Work

- work done on/by system @ inlet and exit

$W_{flow} = W_e - W_i = P_e v_e m_e - P_i v_i m_i$

pressure? specific volume mass

When matter flows, it carries energy

$\Delta E_i = \Delta m_i \cdot e_i$

$\hookrightarrow e_i = ke_i + pe_i + u_i$

Kinetic Potential Internal

$\Delta E = \Delta E_i - \Delta E_e - W_{flow}$

First Law of Thermo Applied to C.V.

$\Delta E_{cv} = m_i \theta_i - m_e \theta_e + Q - W_{sh}$

heat term flow work

where $\theta = \underbrace{u + Pv}_{\text{enthalpy}} + ke + pe = h + \underbrace{ke + pe}_{\text{usually we can ignore this}}$

$\therefore \Delta E_{cv} = m_i h_i - m_e h_e + Q - W_{sh}$

or $\dot{E}_{cv} = \dot{m}_i h_i - \dot{m}_e h_e + \dot{Q} - \dot{W}_{sh}$

Steady State Steady Flow (SSSF)

$E_{cv} = \text{const}, \ \Delta E_{sys} = 0$

$\dot{m}_i = \dot{m}_e = \dot{m}$ (no accumulation of mass)

$\dot{Q} - \dot{W}_{sh} = \dot{m}(\theta_2 - \theta_1)$

Heating Solids/Liquids at constant Pressure

$\Delta h = \Delta u$

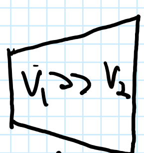
For insignificant pressure change

$\Delta h = C\Delta T + v\Delta P$

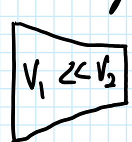
$\uparrow_{C_v \approx C_p}$

For an incompressible Liquid: $W_{pump,in} = \dot{m} v \Delta P$

Diffusers and Nozzles



Slow down fluid flow



Speed up fluid flow

Passive devices => S.S.S.F

Nozzle: increase velocity at expense of pressure } Enthalpy → KE

Diffuser: slow down velocity w/ increase in pressure } KE → Enthalpy

Turbines

- generate shaft work

convert fluid KE into shaft work ...

- nozzle accelerates fluid to push blades
- uses pressure difference to create work

For SSSF $W_{sh} - Q = \dot{m}(h_1 - h_2)$

Specific Shaft Work $\dot{w}_{sh} = h_1 - h_2$ } well insulated $Q=0$

Compressor

- opposite of turbine, takes in work to create a pressure difference
- don't insulate compressor, easier to compress a colder gas

$$W_{sh,in} = \dot{m}\,\Delta h = \dot{m}\,C_p(T_e - T_i) + q_{out}$$

Throttling Valve

- flow restricting device that causes pressure drop
  - no work is produced
- pressure drop can lead to large temperature drops
- for an adiabatic TV: $h_2 \simeq h_1$ $\quad u_1 + P_1 v_1 = u_2 + P_2 v$

Heat Exchangers

- two moving streams exchange heat w/o mixing
- heat lost by one fluid and gained by the other

Unsteady Flow, $\Delta E_{sys} \neq 0$

2nd Law of Thermo

- can't convert heat to work w/ 100% efficiency
- heat only flows from hot to cold spontaneously
- it is impossible for any device that operates on a cycle to remove heat and convert it all to work

Coefficient Of Performance (COP) of Fridges

$$\frac{\text{heat Removed}}{\text{work required}} = \text{Efficiency} \quad \Big\} \text{ often greater than } 100\%$$

$$COP_R = \frac{Q_L}{W_{in}} = \frac{Q_L}{Q_H - Q_L}$$

- air conditioners are same as fridges

Heat Pumps (AC in Reverse)

$$COP_{HP} = \frac{Q_H}{W_{in}} = \frac{Q_H}{Q_H - Q_L} = COP_R + 1$$

Electric Heaters $COP \approx 1$

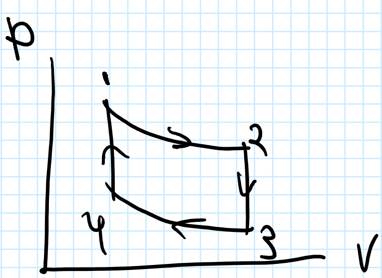
Reversible Process

- can you turn system/surrounding to original state
- needs to follow same path forwards and back

- Compression / expansion needs to be infinitely slow
- Heat transfer is by definition irreversible (unless you assume infinitesimally small temp. difference)

Carnot Cycle

- reversible heat engine, best performance out of all heat engines



2 reversible adiabatic
2 reversible isothermal

$$\frac{Q_L}{T_L} = \frac{Q_H}{T_H} \quad \text{and} \quad \ln\left(\frac{V_1}{V_2}\right) = \ln\left(\frac{V_4}{V_3}\right)$$

$$\eta_{carnot} = 1 - \frac{T_L}{T_H}$$

Entropy
- disorder, randomness, a measure of freedom
- a numeric quantity

$$\left.\begin{array}{l} ds = \left(\frac{\delta Q}{T}\right)_{Rev} \quad \left[\frac{kJ}{K}\right] \end{array}\right\} \text{extensive property}$$

- entropy of CL? → go to saturated table @ temp
- for mixture use quality to get weighted average

Entropy change in Ideal Gas

isochoric + isothermal = total change

$$S_2 - S_1 = C_v \ln\left(\frac{T_2}{T_1}\right) + R \ln\left(\frac{V_2}{V_1}\right)$$

$$C_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right)$$

Entropy change of Incompressible Substance

$$S_2 - S_1 = C \ln\left(\frac{T_2}{T_1}\right)$$

Entropy change due to Carnot Cycle = 0

In an Irreversible Process:

$dS = \frac{\partial Q}{T} + \partial S_g$ } — Entropy generated

Entropy increases as you go from solid → Liquid → gas

increased freedom / Entropy involves adding a lot of heat

Isentropic Process → No entropy change (adiabatic + reversible)

↳ well insulated turbine

↳ fast compression

Entropy in temperature-dependent C_p/C_v

$$s_2 - s_1 = s_2^\circ - s_1^\circ - R\ln\left(\frac{P_2}{P_1}\right)$$

$$\left(\frac{P_2}{P_1}\right) = \frac{P_r(T_2)}{P_r(T_1)}, \qquad \frac{V_2}{V_1} = \frac{V_r(T_2)}{V_r(T_1)}$$

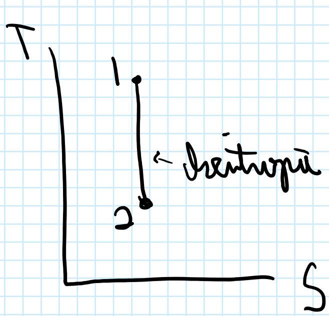
Entropy Increase Principle

- entropy of universe is always increasing

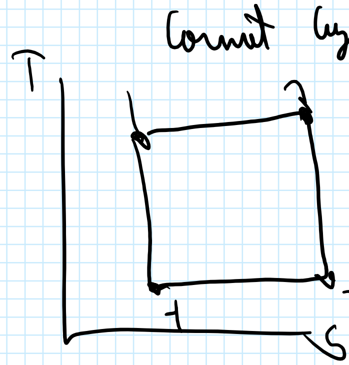
$$\Delta S = \frac{\delta Q}{T} + \Delta S_{gen} \qquad \dot{S}_{in} = \dot{S}_{out} + S_{gen}$$

For a non adiabatic system, S_{sys} may decrease but overall total entropy must be increasing (system + environment)

T-S diagram



Carnot Cycle



(a box)

Area under T-S curve

is heat interaction = Q

Entropy in C.V.

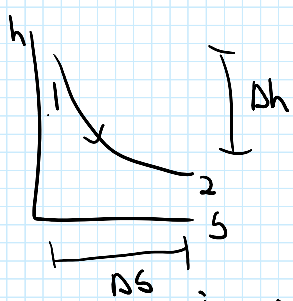
- mass entering / exiting system carries entropy

$$\Delta S_{cv} = \underbrace{\frac{Q}{T}}_{\text{entropy transfer by heat}} + \underbrace{m_i s_i - m_e s_e}_{\text{entropy transfer by mass}} + S_{gen}$$

For SSSF $\quad S_{gen} = \dot{m}(s_e - s_i) - \underbrace{\int \frac{\delta Q}{T}}_{0 \text{ for adiabatic SSSF}}$

h-s diagrams

- have both enthalpy (1st law) and entropy (2nd law)



$$\dot{Q} - \dot{W} = \dot{m}(h_e - h_i)$$

$$\dot{S}_{gen} = \dot{m}(s_e - s_i) - \int \frac{\delta Q}{T}$$

For an adiabatic reversible process, it curves to the right

Best Performance for a turbine is reversible (no entropy change)

- what if not reversible?

$$\eta_T = \frac{\text{Actual Work}}{\underset{\leftarrow \text{max possible}}{\text{Isentropic Work}}} = \frac{W_a}{W_s} \Bigg\} \text{Isentropic efficiency of a turbine} = \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

For a compressor

$$\eta_c = \frac{\text{Isentropic Work Input}}{\quad} = T_{2s} - T_1$$

For a compressor

$$\eta_c = \frac{\text{Isentropic Work Input}}{\text{Actual Work Required}} = \frac{T_{2s} - T_1}{T_{2a} - T_1}$$

Isentropic Nozzle efficiency

$$\eta_n = \frac{\text{Actual KE @ Exit}}{\text{Isentropic KE @ Exit}} = \frac{h_{2s} - h_1}{h_{2a} - h_1} \approx \frac{T_{2s} - T_1}{T_{2a} - T_1}$$