~~Grad t Wang +2 #1~~

5.79
Same Words:
2-3
4-1

The 2nd law of thermodynamics addresses the direction of a process

heat flows from hot to cold
water flows downhill, etc.

Entropy is a measure of the disorder in a system

Entropy is generated whenever irreversibilities exist (friction, directional processes).

Entropy, S $\quad \frac{\text{energy}}{\text{degree}} \quad \frac{kJ}{K}$

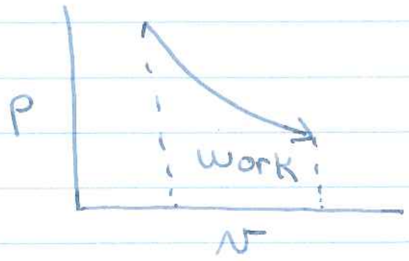
$s \quad \frac{\text{energy}}{\text{mass deg}} \quad \frac{kJ}{kg\,K}$

s evaluated like all other state properties - use tables

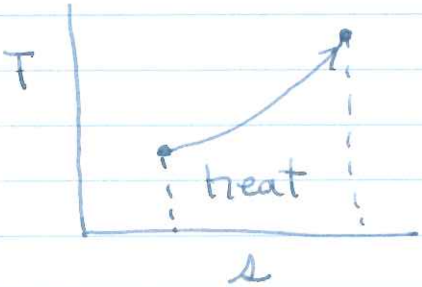
$$s = \cancel{x s_f +} (1-x) s_f + x s_g$$

flow work

$W = \int P dv$



$Q = \int T ds$



1st law

$$\cancel{\Delta KE} + \cancel{\Delta PE} + \Delta U = Q_{1-2} - W_{1-2}$$

frequently $\searrow \quad \phi \quad \searrow$

$(dQ = dU + dW)$ reversible sys.

$$dQ = T ds \qquad dW = P dV$$

$$T ds = dU + P dV$$

and/or

$$T ds = dH - V dP$$

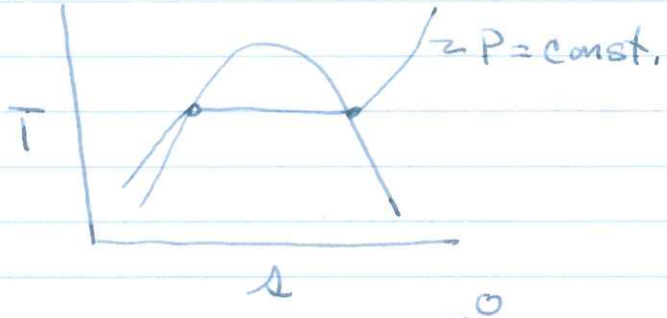
Recall $H = U + PV$ definition

$dH = dU + d(PV)$

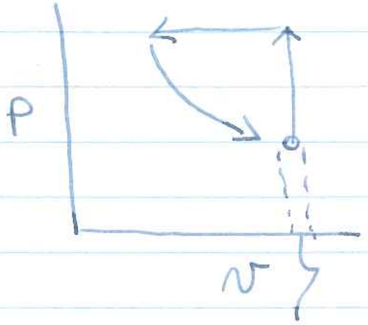
$dH = dU + PdV + VdP$

$dH - VdP = dU + PdV$

Take advantage of diagrams in analysis



$$TdS = dH - V\cancel{dP}^{\,0}$$



$$Tds = dU + P\cancel{dV}^{\,0}$$

If in a liquid region (not wet)

~ incompressible i.e. $dv = 0$

$$TdS = dU + P\cancel{dV}^{\,0}$$

and $dU = m\,du = m\,c_v dT$

$$Tds = c_v dT$$

need to move like variables

$$ds = \frac{c_v dT}{T}$$

$$\int ds = \int \frac{c_v}{T} dT$$

$s_2 - s_1 = c_v \ln(T_2/T_1)$ if c_v constant (frequently)

frequently an ideal gas assumption is reasonable.

$$T\,ds = du + P\,dv \qquad ds = \frac{du}{T} + \frac{P}{T}dv$$

$$T\,ds = dh - v\,dP \qquad ds = \frac{dh}{T} - \frac{v}{T}dP$$

$$du = c_v\,dT \qquad dh = c_p\,dT$$

$$Pv = RT \qquad \frac{P}{T} = \frac{R}{v} \Rightarrow ds = \frac{c_v\,dT}{T} + \frac{R\,dv}{v}$$

$$\frac{v}{T} = \frac{R}{P} \Rightarrow ds = c_p\frac{dT}{T} - \frac{R}{P}dP$$

integrating

$$s_2 - s_1 = \int \frac{c_v}{T}dT + R\ln(v_2/v_1)$$

$$s_2 - s_1 = \int \frac{c_p}{T}dT - R\ln(P_2/P_1)$$

Entropy balance for closed system

Change in s = amt of s transfered across bdy + amt of s generated

$$S_2 - S_1 = \int_1^2 \frac{dQ}{T} + \sigma$$

$dQ > 0$

$S_2 > S_1$

$dQ < 0$

$S_2 < S_1$

(σ dependent)

$\sigma > 0$ irreversibilities

$\sigma = 0$ reversible

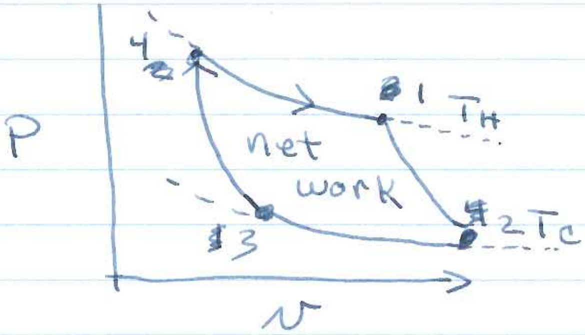
$\sigma < 0$ impossible

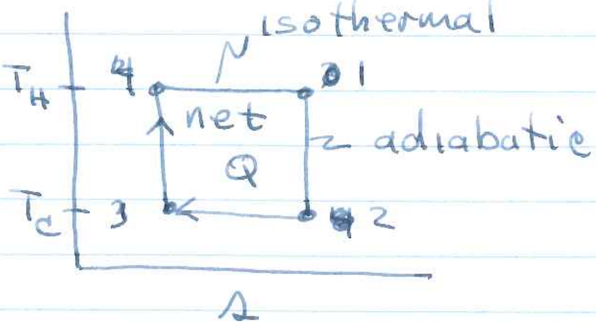
* a Carnot Cycle is defined as

4 reversible processes: two adiabatic processes alternated w/ two isothermal processes.

* Control Volume (open system)

$$\frac{dS}{dt} = \sum \frac{d\dot{Q}}{T} + \sum_{in} \dot{m}s - \sum_{out} \dot{m}s + \dot{\sigma}_{cv}$$





Process

~~1 -> 2~~ 3 -> 4 : gas compressed adiabatically from T_c to T_H

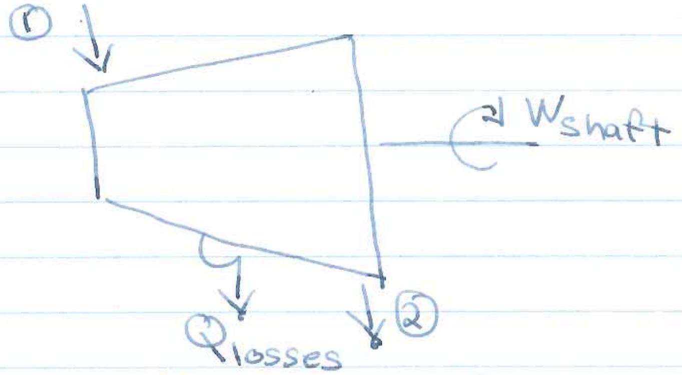
~~2 -> 3~~ 4 -> 1 : gas expands isothermally receiving Q_H from reservoir at T_H

~~3 -> 4~~ 1 -> 2 : gas expands adiabatically from T_H to T_c

~~4 -> 1~~ 2 -> 3 : gas compresses isothermally to initial state releasing Q_c to reservoir at T_c

Consider:

Air enters a turbine



$P_1 = 400\ kPa$ $\qquad$ $P_2 = 100\ kPa$

$T_1 = 970\ K$ $\qquad$ $T_2 = 670\ K$

heat (Q) is lost from turbine surface a $T_{sur.\,Avg} = 315\ K$

$\dot{Q} \sim 30\ kJ/kg$ of air flowing

assume ideal gas $c_p = 1.1\ \frac{kJ}{kg\,K}$

1st law $\quad 0 = \dot{Q} - \dot{W}_{cv} + \dot{m}(h_1 - h_2)$

$$\frac{\dot{W}_{cv}}{\dot{m}} = \frac{\dot{Q}_{cv}}{\dot{m}} + (h_1 - h_2) = \frac{\dot{Q}_{cv}}{\dot{m}} + c_p(T_1 - T_2)$$

$$\frac{\dot{W}_{cv}}{\dot{m}} = -30\ \frac{kJ}{kg} + 1.1\ \frac{kJ}{kg\,K}(970 - 670) = 300\ \frac{kJ}{kg}$$

[redacted]

2nd law

$$\underset{ss}{0} = \frac{\dot{Q}_{cv}}{T} + \dot{m}(s_1 - s_2) + \dot{\sigma}_{cv}$$

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = -\frac{\dot{Q}_{cv}}{\dot{m}T} + \underset{\substack{\downarrow \\ \text{ideal gas const } c_p}}{(s_2 - s_1)}$$

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = \frac{-\dot{Q}_{cv}/\dot{m}}{T_b} + c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln P_2/P_1$$

$$R = 8.314 \frac{kJ}{kmol\,K} \frac{1}{28.97} \frac{kmol}{kg} = .287 \frac{kJ}{kg\,K}$$

$$\frac{\dot{\sigma}_{cv}}{\dot{m}} = -\frac{(-30\,kJ/kg)}{315\,K} + \left[1.1 \ln\left(670/970\right) - .287 \ln\left(\frac{100}{400}\right)\right] \frac{kJ}{kg\,K}$$

$$= 0.086 \frac{kJ}{kg\,K} \quad \text{entropy generation}$$

if T_b smaller (ie bdy further away
$\dot{\sigma}$ larger (same $\dot{Q}$
smaller T_b)