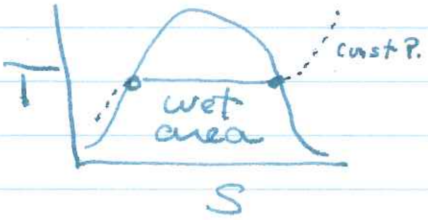
$T_{cp} = 374°C$

Return to Entropy, $S \; \frac{kJ}{K}$

$s \; \frac{kJ}{kg\,K}$

$$T\,dS = dQ\Big|_{\substack{int.\\rev.}} \qquad \int T\,dS = \int dQ$$

$$\int dS = \int \frac{dQ}{T} \qquad T(S_2 - S_1) = Q$$



1st law

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

$$\Delta KE + \Delta PE + \Delta H = Q_{1-2} - W_{cv_{1-2}}$$

$$W_{1-2} = \underset{shaft}{W_{cv}} + PdV$$

$$\cancel{\Delta H} = \cancel{\Delta U}$$

$$H = U + PV$$

$$dH = dU + d(PV)$$

$$dH = dU + PdV + V\cancel{dP} \rightarrow \text{Frequently}$$

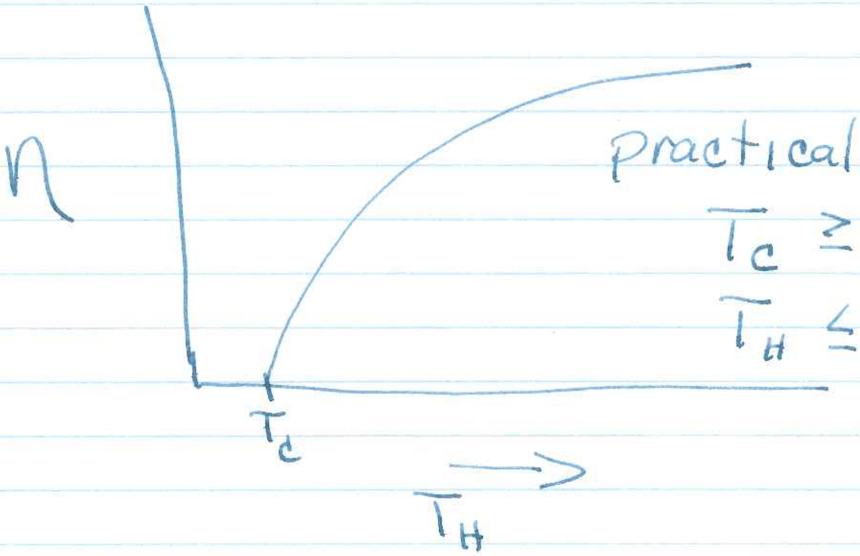
Consider a boiler or a Condenser

$$dH - VdP = dU + PdV$$

Last time

ideal Power Cycles (Carnot cycle)

$$\eta = 1 - \frac{Q_C}{Q_H} = 1 - \frac{T_C}{T_H}$$ Abs. T units



practical constraints

$T_C \geq T_{amb.}$

$T_H \leq$ structural reliability of materials

if given a system ask

A) ~~1st~~ Does it satisfy Conservation Laws

B) ~~2nd~~ Does it satisfy $2^{nd}$ Law (irreversibilities)

$$\eta \leq \eta_{max}$$

Entropy is an extensive property

$$\frac{\text{Energy}}{\text{degree}}$$

$$S \equiv \frac{kJ}{K} \quad \text{or} \quad \frac{Btu}{R}$$

SI Eng.

specific entropy

$$s = \frac{S}{m} \Rightarrow \frac{kJ}{kg\,K} \quad \text{or} \quad \frac{Btu}{lbm\,R}$$

Use same tables as $v, u, h, s$

quality affects entropy like others:

$$\begin{aligned} s &= \cancel{x s_f} + \cancel{(1-x)} s_g \\ &= s_f + x\,(s_g - s_f) \\ &= s_f + x\, s_{fg} \end{aligned}$$

The entropy change in an internally reversible process

$$ds = \frac{\delta Q}{T}\Big)_{\substack{int\\rev.}} \Rightarrow Q_{1-2} = \int_1^2 T\,ds$$

if $ds\ (+)$ then entropy increase

$$\delta Q\ (+) \Rightarrow Q_{in}$$

if $ds\ (-)$ then entropy decrease

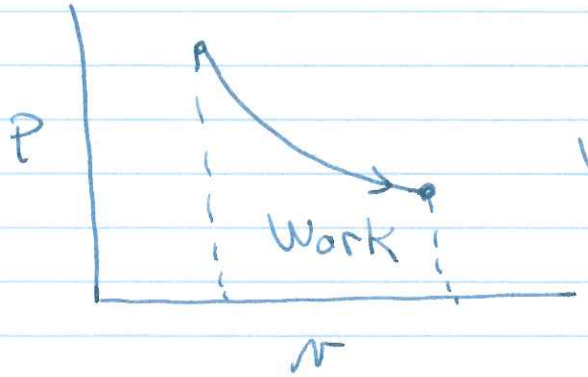
$$\delta Q\ (-) \Rightarrow Q_{out}$$

if $ds = 0$ then adiabatic

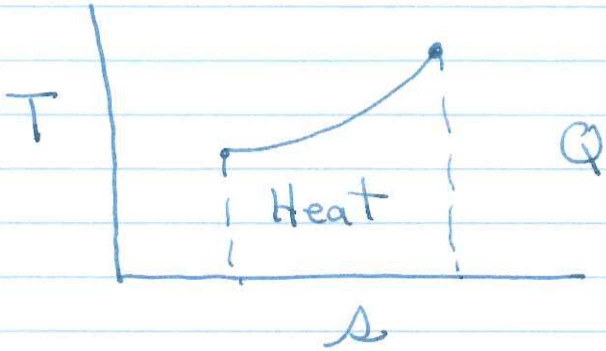
$$\delta Q = 0$$

and reversible => isentropic

Recall

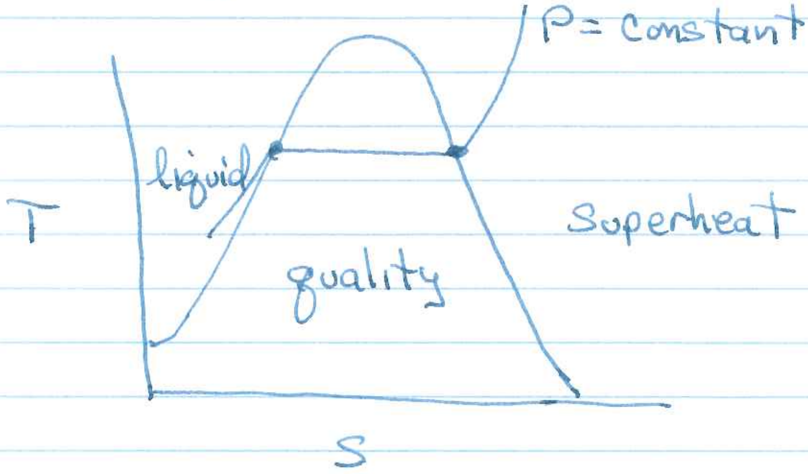


$$W = \int P\,dv$$



$$Q = \int T\,ds$$

State Diagram



Textbook has whole section (6.3) on
the Tds equations

1st Law

$$\underbrace{\cancel{\Delta KE} + \cancel{\Delta PE}}_{0} + \Delta U = \Delta Q - \Delta W$$

generally

or $$\Delta Q = \Delta U + \Delta W$$

$$\delta Q\Big|_{\substack{\text{int}\\\text{rev}}} = dU + \delta W\Big|_{\substack{\text{int}\\\text{rev}}}$$

Know $\Delta W = PdV$

and

$$\delta Q\Big|_{\substack{\text{int}\\\text{rev}}} = TdS$$

Then:

$$Tds = dU + PdV$$

Recall enthalpy $H = U + PV$

$h = u + Pv$

$$dH = dU + d(PV) = dU + PdV + VdP$$

chain rule

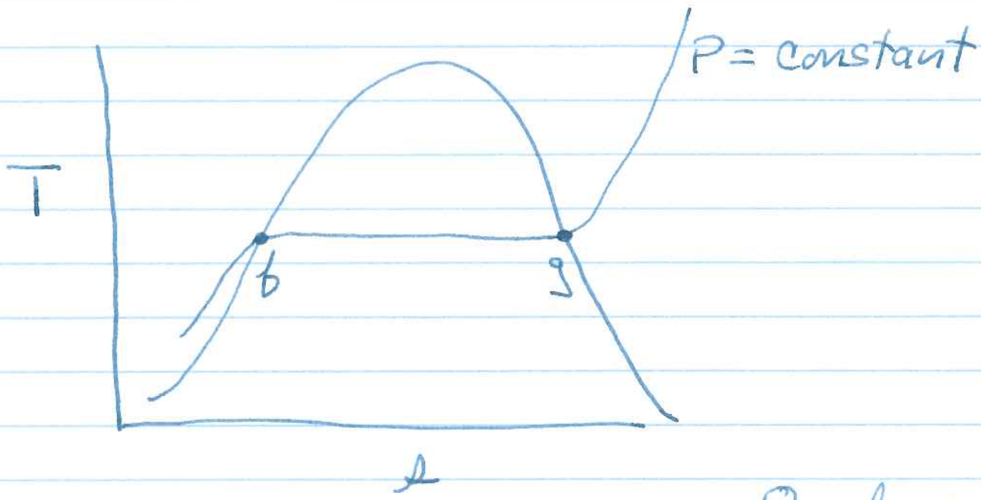
or

$$dU + PdV = \overbrace{dH - VdP}$$

$$T\,dS = dH - V\,dP$$

Similarly $T\,ds = dh - v\,dP$ specific basis

Consider a T-s diagram



$$T\,ds = dh - v\,\cancelto{0}{dP}$$ along Const P line

in which case

$$\int_f^g T\,ds = \int_f^g dh$$

$$T(s_g - s_f) = h_g - h_f$$

if one moves to the liquid region of the diagram, then incompressible

$$T\,ds = du + P\cancelto{0}{dv}$$

and $$du = c_v\,dT$$

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

$$s_2 - s_1 = c_v \ln(T_2/T_1) \text{ if}$$

$c_v$ is constant

Consider $\Delta s$ for ideal gases

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

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

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

$$Pv = RT$$

$$\frac{P}{T} = \frac{R}{v}$$

$$\frac{v}{T} = \frac{R}{P}$$

$$ds = c_v \frac{dT}{T} + R\frac{dv}{v}$$

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

integrating

$$s(T,v)_2 - s(T,v)_1 = \int_{T_1}^{T_2} c_v \frac{dT}{T} + R\ln(v_2/v_1)$$

$$s(T,P)_2 - s(T,P)_1 = \int_{T_1}^{T_2} c_p \frac{dT}{T} - R\ln(P_2/P_1)$$

if $c_p$ + $c_v$ constants

$$s_2 - s_1 = c_v \ln(T_2/T_1) + R\ln(v_2/v_1)$$

$$s_2 - s_1 = c_p \ln(T_2/T_1) - R\ln(P_2/P_1)$$

# Entropy Balance for a closed system

$$\text{Change in entropy within system during some time interval} = \text{net amt. of entropy transferred across bdy during t} + \text{amt. of entropy produced w/in system}$$

$$s_2 - s_1 = \int_1^2 \frac{\delta Q}{T} + \sigma$$

$\delta Q > 0$ (in)

$s_2 > s_1$

$\delta Q < 0$ (out)

$s_2 < s_1$

(depends on $\sigma$ too)

$\sigma > 0$ irreversibilities

$\sigma = 0$ no. irr

$\sigma < 0$ impossible