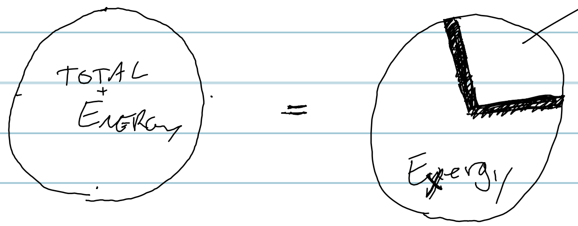
ME 332-A

Thomas STOREY

9:15 - 10:10 am Monday & WEDNESDAY
Shiley 301

Monday January 14th, 2013



Unavailable Energy
(can't be converted to work due to irreversibilities)

Chapter 7 → 1st law, ENERGY IS Always conserved

→ Exergy is potential to do work

→ Exergy may be destroyed by irreversibilities

EXERGY - max theoretical work obtainable from a system as it comes to equilibrium with environment

↳ property of system + environment

$\underbrace{T_0, P_0}_{\text{Dead STATE}}$ - Normally 1 ATM, 25°C (77°F)

$$E = \underbrace{(U - U_0)}_{\text{INTERNAL Energy - Dead State}} + P_0 \underbrace{(V - V_0)}_{\text{Work - Dead State}} - T_0 \underbrace{(S - S_0)}_{\text{Heat Transfer - dead state}} + KE + PE$$

E ↓ EXERGY ↓ Same units as Energy

Wednesday January 15, 2013

$$E = (U - U_0) + P_0(\forall - \forall_0) - T_0(S - S_0) + KE + PE$$

↳ Property of the system and the environment

→ EXERGY cannot be negative

→ EXERGY IS NOT conserved

Specific exergy:

$$e = (u - u_0) + p_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz \quad //$$

EXAMPLE

A coffee Pot with 2 Kg of water @ 100°C & 1 bar

FIND: Exergy $\quad T_0 = 20°C \quad P_0 = 1\,bar$ → Table A-2

Table A-4 WATER IN POT

$u = 2506.7$ KJ/kg

$v = 1.696$ m³/kg

$s = 7.3614$ KJ/kg K

Dead STATE Table A-2

using liquid approximations

$u_0 \approx u_{f0} = 83.95$ KJ/kg

$v_0 \approx v_{f0} = 0.0010018$ m³/kg

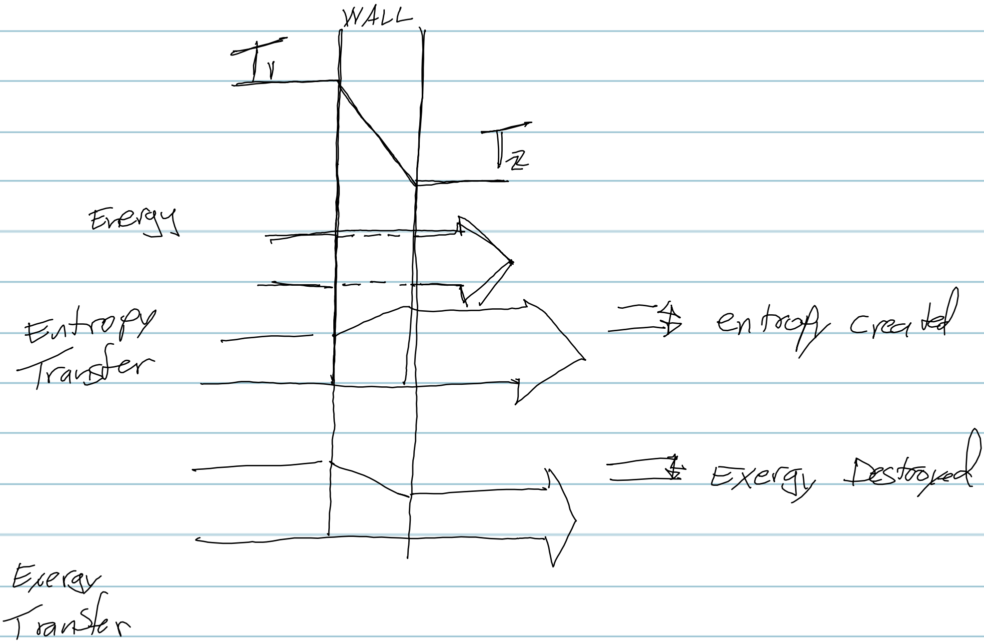
$s_0 \approx s_{f0} = 0.29666$ KJ/kg·K

$$E = m\left[(u - u_0) + P_0(v - v_0) - T_0(s - s_0)\right]$$

$$= 2\,Kg\left[(2506.7 - 83.95)\frac{KJ}{kg} + 1\,bar\left(1.696 - 0.0010018\,\frac{m^3}{kg}\right)\left(\frac{10^5 N/m^2}{1\,bar}\right) \times \frac{1\,KJ}{10^3\,N\cdot m} - (20+273)K\,(7.3614 - 0.29666)\frac{KJ}{kg\cdot K}\right]$$

$E = 1,044.5$ KJ //

	EXERGY	ENTROPY
Units:	KJ/Kg OR KJ	$KJ/Kg\,K$ OR KJ/K
	Property of System and environment together	Property of the system
	Includes other properties	Only Entropy



7.4 Closed System Exergy Balance

$$E_2 - E_1 = (U_2 - U_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)$$

EXERGY Balance

$$\underbrace{E_2 - E_1}_{\text{Exergy change}} = \underbrace{\int_1^2 \left(1 - \frac{T_0}{T_b}\right)\delta Q - \left[W - P_0(V_2 - V_1)\right]}_{\text{EXERGY TRANSFER}} - \underbrace{T_0\,\sigma}_{\text{exergy destruction}}$$

Exergy is created to create ~~enthalpy~~ entropy

$E_Q = \int_1^2 \left(1 - \frac{T_0}{T_b}\right) \delta Q$ EXERGY Associated with heat transfer

$E_W = W - P_0 (V_2 - V_1)$ " " w/ Work

$E_d = T_0 \sigma$ EXERGY Destruction (irreversibilities)

$E_2 - E_1 = E_Q - E_W - E_d$

↳ zero if no heat transfer

Homework 13 posted

Enthalpy (open-systems) $h = u + pv$

↳ flow energy (packaged for convienence, for movement)

Monday January $2 1^{ST}$, 2013

Using Exergy Balance

Example: RFGFD; Insulated Tank

$M_{air} = 0.6\,Kg$ $T_i = 20°C$ $P_i = 200\,KPa$

STATE 1

$P_1 = 200\,KPa$

$T_1 = 20°C$

STATE 2

$P_2 = 250\,KPa$

GOAL: W, ΔE, E_d

ΔE → change in exergy

E_d → Exergy destruction

$C_v = 0.72\ \frac{KJ}{Kg}\,K$ → Indicates Ideal Gas

Consv. of Mass } closed system

1st Law: $\Delta U + \cancel{\Delta KE} + \cancel{\Delta PE} = \cancel{Q} - W$

"insulated" (same)

$W = -\underset{\uparrow\,\checkmark}{m}(u_2 - \underset{\uparrow\,v}{u_1})$

2nd Law: $m(s_2 - s_1) = \cancel{\frac{Q}{T_0}} + \sigma$

"rigid tank"

Exergy: $\Delta E = m\left[(u_2 - u_1) + P_0\cancel{(v_2 - v_1)} - T_0(s_2 - s_1)\right]$

$E_d = T_0\,\sigma$

I.G.L. $P_1 V_1 = mRT$ $T_2 = \frac{P_2}{P_1} \cdot T_1$ $\therefore T_2 = 366K$ //

$P_2 V_2 = mRT$

(example continued)

$$W = -m(u_2 - u_1) = -m C_v (T_2 - T_1)$$

$$= -0.6\,\text{Kg}\left(0.72\,\frac{\text{KJ}}{\text{Kg}\,\cancel{\text{K}}}\right)(366 - 293)\,\cancel{\text{K}}$$

$$\therefore \boxed{W = -31.54\,\text{KJ}}$$

$$\Delta E = m\left[C_v(T_2 - T_1) - T_0\left(C_v \ln\frac{T_2}{T_1} + \underbrace{\cancel{R \ln\left(\frac{V_2}{V_1}\right)}}_{\text{rigid tank}}\right)\right]$$

$$= -31.54\,\text{KJ} + -0.6\,\text{Kg}(293\,\text{K})\,\frac{0.72\,\text{KJ}}{\text{Kg K}}\ln\left(\frac{306\,\text{K}}{293\,\text{K}}\right)$$

$$\boxed{\Delta E = 3.38\,\text{KJ}}$$

Now, $\sigma = m\left[C_v \ln\left(\frac{T_2}{T_1}\right)\right]$

$$Ed = T_0\,\sigma = 293\text{K} \cdot 0.6\text{Kg}\left[\frac{0.72\,\text{KJ}}{\text{Kg K}} \cdot \ln\left(\frac{366}{293}\right)\right]$$

$$\therefore \boxed{Ed = 28.16\,\text{KJ}}$$

CHECK

$$\Delta E = E_q - E_w - Ed$$

$$3.38\,\text{KJ} = -(-31.54\,\text{KJ}) - (28.16\,\text{KJ}) \quad ✓$$

paddlewheels are very irreversable

CLOSED SYSTEM - RATE FORM

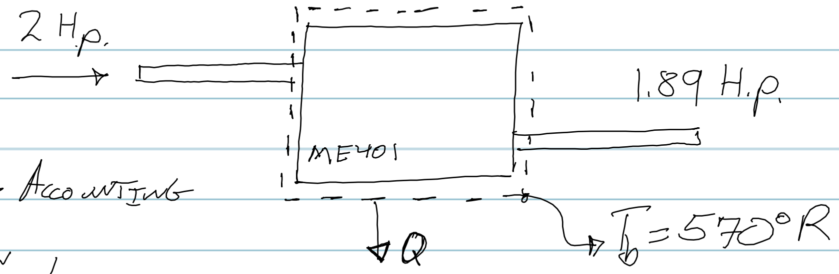
$$\frac{dE}{dt} = \underbrace{\sum_j \left(1-\frac{T_0}{T_b}\right)\dot{Q}_j}_{\dot{E}_q} - \underbrace{\left(\dot{W} - P_0\frac{dV}{dt}\right)}_{\dot{E}_w} - \dot{E}_d$$

EXERGY IN - 100%	
Ew	90%
Eq	5%
Ed	5%

} for example

$\dot{Q} = -($

EXAMPLE: GEARBOX



STEADY-STATE

FIND: Q [BTU/s], EXERGY ACCOUNTING

Consv. of Mass → Closed System $m = \text{const}$

1st Law: $\cancel{\frac{dE}{dt}} = \dot{Q} - \dot{W} \Rightarrow 0 = \dot{Q} - \dot{W}$

zero

$\dot{Q} = \dot{W}_{OUT} - \dot{W}_{in}$

2nd Law: $\cancel{\frac{dS}{dt}} = \sum_j \frac{\dot{Q}_j}{T_b} + \dot{\sigma}$

zero

EXERGY: $\cancel{\frac{dE}{dt}} = \dot{E}_q - \dot{E}_W - \dot{E}_d$

zero

⟹

$$\dot{Q} = (1.89\,hp - 2\,hp) \times \frac{2545\,BTU}{1\,hp\ \ hr} \times \frac{1\,Hr}{3{,}600\,s}$$

$$\dot{Q} = -0{,}078\,BTU/s \quad //$$

$$\dot{E}_q = \sum_j \left(1 - \frac{T_0}{T_b}\right)\dot{Q}_j$$

$$= \left(1 - \frac{530R}{570R}\right) 0{,}078\,BTU/s \Rightarrow$$

$$\dot{E}_q = 0.005\,BTU/s \quad //$$

Now,

$$\dot{E}_{W_{in}} = \dot{W}_{IN} = 2hp \times \frac{2545\,BTU}{hr\text{-}hp} \times \frac{1\,hr}{3{,}600\,s}$$

$$\dot{E}_{WIN} = 1{,}414\ BTU/s \quad //$$

$$\dot{E}_{Wout} = 1{,}336\ BTU/s \quad //$$

$$\dot{E}_d = T_0\dot{\sigma} = T_0\left(\frac{-\dot{Q}}{T_b}\right) = -\frac{530R}{570°R}\left(-0{,}078\,\frac{BTU}{s}\right)$$

$$\dot{E}_d = 0.073\,BTU/s \quad //$$

Exergy In:	1,414	This is Exergy destruction
Ew	1,336	
Eq	0,005	
Ed	0,073	✓ check

EXERGY RATE - OPEN SYSTEMS

$$\frac{dE}{dt} = \sum_j \left(1 - \frac{T_0}{T_j}\right)\dot{Q}_j - \left(\dot{W} - p_0 \frac{dV}{dt}\right) + \overbrace{\overset{\text{IN}}{\sum_i \dot{m}_i e_{fi}} - \overset{\text{OUT}}{\sum_e \dot{m}_e e_{fe}}}^{\text{New (mass flow)}} - \dot{E}_d$$

---

e_f → flow exergy

$$e_f = h - h_0 - T_0(s - s_0) + KE + PE$$

$$\frac{dE}{dt} = \sum_j \dot{E}_{qj} - \dot{W}_{cv} + \sum_i \dot{E}_{f\,in} - \sum_e \dot{E}_{f\,out} - \dot{E}_d$$

$\delta Q/t$ is entropy

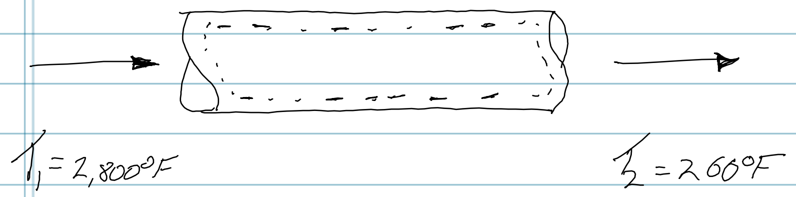
WEDNESDAY January 23rd, 2013

EXAMPLE: Steady-State combustion gas system

Cooling from 2,800°F → to 260°F (low friction pipe)
(pressure is constant)
∴ internally reversable

Treat as an ideal Gas

$$C_p = 0.25\ \mathrm{BTU}/\mathrm{lbm}\,°R \qquad T_0 = 60°F$$



EXERGY BALANCE:

$$\underbrace{\frac{dE}{dt}}_{\text{Steady}} = \dot{E}_q - \underbrace{\dot{W}_{cv}}_{\text{No Work}} + \sum \dot{E}_{f_i} - \sum \dot{E}_{f_e} - \cancel{\dot{E}_d} \rightarrow \text{internally reversable}$$

$$\frac{\dot{E}_q}{\dot{m}} = ef_2 - ef_1 = (h_2 - h_1) - T_0 (s_2 - s_1)$$

$$= C_p (T_2 - T_1) - T_0 \left(C_p \ln\left(\frac{T_2}{T_1}\right) - \underbrace{R \ln\left(\frac{P_2}{P_1}\right)}_{\text{const. Pressure}} \right]$$

enthalpy Sub

$$= 0.25 \frac{\mathrm{BTU}}{\mathrm{lb_m}\,°R} \left[(720 - 3260)°R - 520°R \ln\left(\frac{720°R}{3260°R}\right) \right]$$

$$e_q = \frac{\dot{E}_q}{\dot{m}} = -438.7\ \mathrm{BTU}/\mathrm{lbm}$$

Exergy much higher @ inlet

1st law / 2nd law

then

efficiency / exergetic efficiency

EXERGETIC Efficiency (7.6)

$$\varepsilon = \frac{E_{x\,OUT}}{E_{x\,IN}}$$

Will Vary by system

Exergetic efficiency

Used for Anything	Drinking Water	Electricity
Limited use ~~GRAY WATER~~	Gray Water	Shaft Work
Lots of work to make clean	Black Water	Heat

TURBINE:

$$\varepsilon = \frac{\dot{W}/\dot{m}}{e_{f_1} - e_{f_2}}$$

Compressor/Pump:

$$\varepsilon = \frac{e_{f_2} - e_{f_1}}{(-\dot{W}_{cv}/\dot{m})}$$

HEAT EXCHANGE: Be wary of inlets and outlets

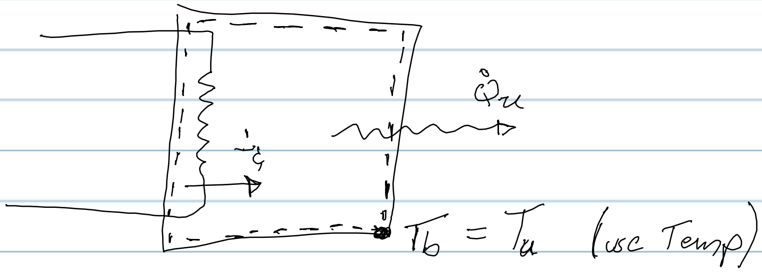
$$\varepsilon = \frac{\dot{m}_C (e_{f_4} - e_{f_3})}{\dot{m}_H (e_{f_1} - e_{f_2})}$$

HOTSIDE

COLDSIDE

Example: electric resistance heater

Process @ rate of $\dot{Q}_u$



a) Derive ε & b) Plot ε vs T from $(300 - 900)$ K

$T_0 = 20°C$

Exergy Balance: $\dot{E}_W = \dot{W}$

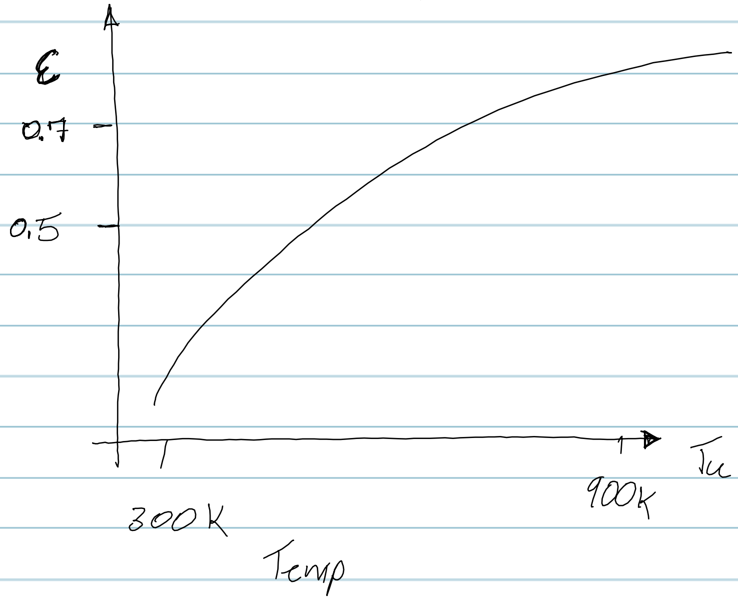
exergy out: $\dot{E}_q = \left(1 - \frac{T_0}{T_u}\right)\dot{Q}_u$

$$\varepsilon = \frac{\left(1 - \frac{T_0}{T_u}\right)\dot{Q}_u}{\dot{W}_{ele}}$$

1st law: $dE/dt = \dot{Q} - \dot{W}$

$\therefore \dot{Q} = \dot{W}$

Therefore $\varepsilon = \left(1 - \frac{T_0}{T_u}\right)$



Homework up for Next Wednesday

Units: Review

1st Law - KJ or KJ/Kg

pv $[Pa]\left[\frac{m^3}{Kg}\right]$ $\Rightarrow$ $\frac{KJ}{Kg}$

KE $V^2 \left[\frac{m^2}{s^2}\right]$ $\Rightarrow$ KJ/Kg

2nd Law $\frac{KJ}{KgK}$

Monday January 28th, 2013

Chapter 8 -

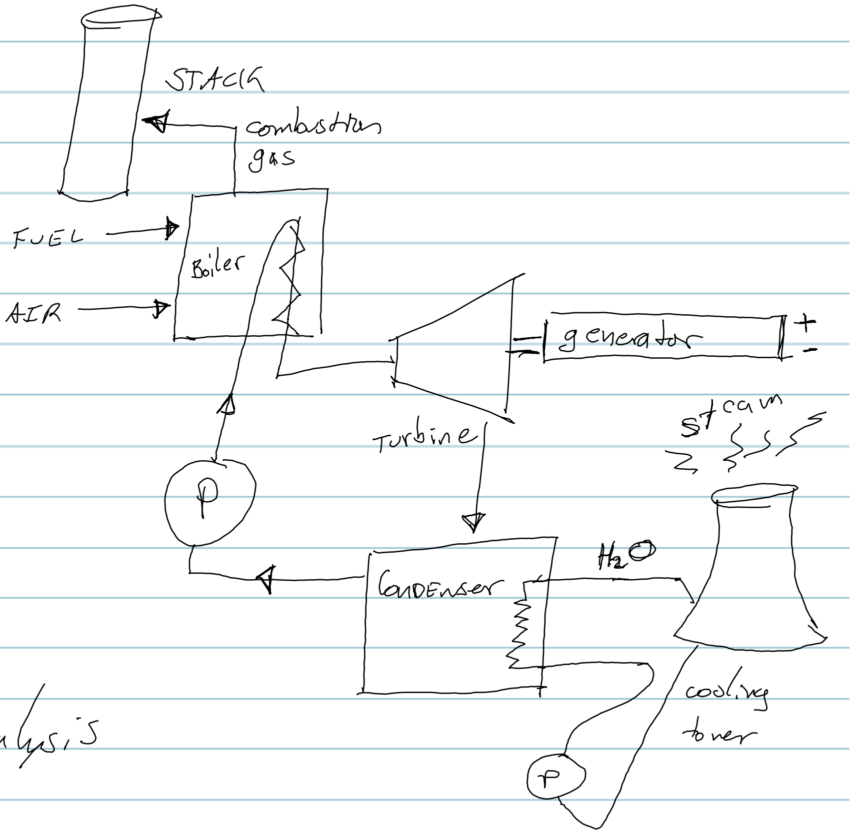
Power (generation)

48.5% coal

22% Nat gas

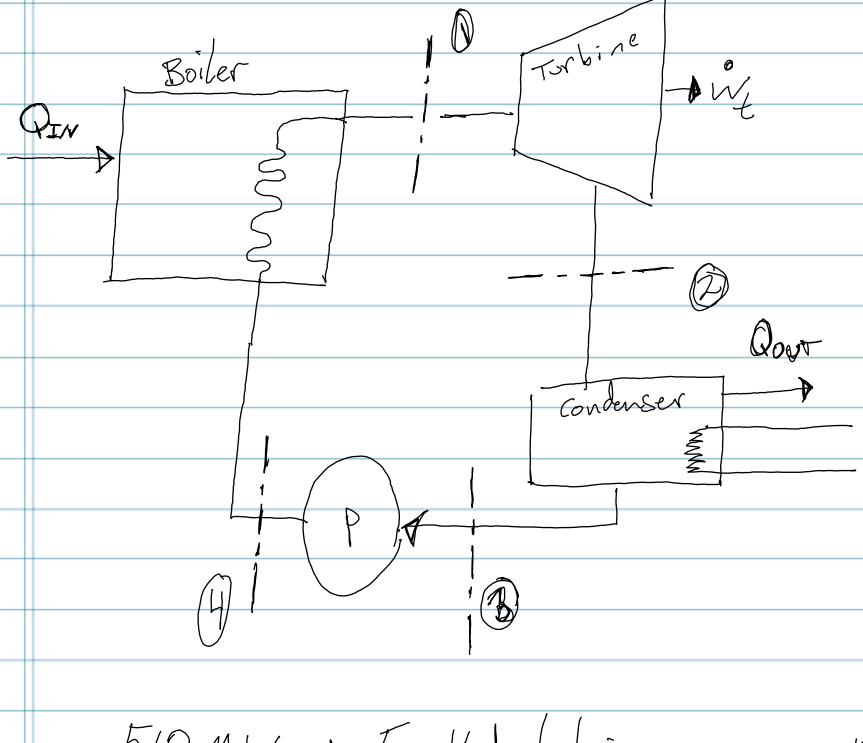
5.8% Hydroelectric

2.5% renewable



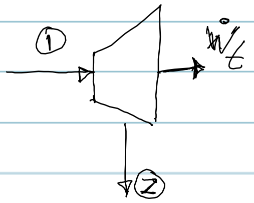
- Most Plants use Water as working fluid.

- Make Simplifications for Analysis



510 MW → 5 Hydroelectric 125MW → Wind System

TURBINE

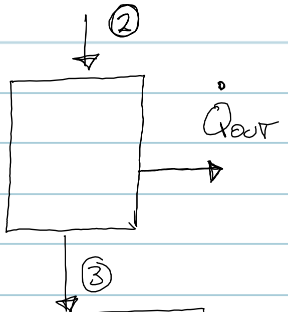


open system.

$$\underset{\text{steady}}{\frac{dE}{dt}} = \underset{\text{none}}{\dot Q} - \dot W + \dot m\left(h_1 + \frac{v_1^2}{2g} + gz_1\right) - \dot m\left(h_2 + \underbrace{\frac{v_2^2}{2g} + gz_2}_{\text{gone}}\right)$$

$$\boxed{\frac{\dot W_t}{\dot m} = h_1 - h_2}$$

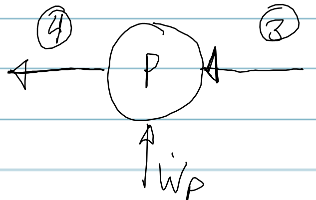
CONDENSER



$$\underset{\text{steady}}{\frac{dE}{dt}} = (-\dot Q_{OUT}) - \overset{\text{No work}}{\dot W} + \dot m\left(h_1 + \frac{v^2}{2g} + gz_2\right) - \dot m\left(h_2 + \underbrace{\frac{v_2^2}{2g} + gz_2}_{\text{NONE}}\right)$$

$$\boxed{\frac{\dot Q_{OUT}}{\dot m} = (h_2 - h_3)}$$

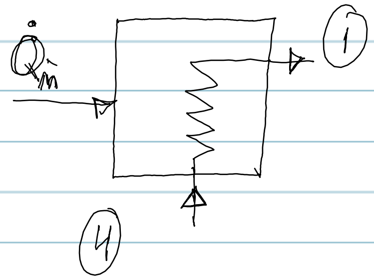
Pump



steady, no Q

$$\boxed{\frac{\dot W_p}{\dot m} = h_4 - h_3}$$

BOILER



$$\boxed{\frac{\dot Q_{IN}}{\dot m} = h_1 - h_4}$$

Efficiency

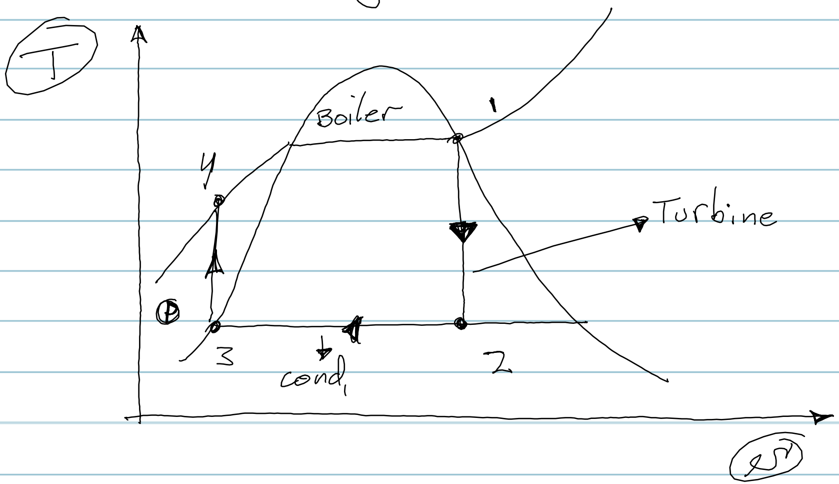
$$\eta = \frac{\text{what we get out}}{\text{what we put in}} = \frac{\dot{W}_{cyc}}{\dot{Q}_{IN}} = \frac{\frac{\dot{W}_t}{\dot{m}} - \frac{\dot{W}_p}{\dot{m}}}{\dot{Q}_{IN}/\dot{m}}$$

So;

$$\eta = \frac{(h_1 - h_2) - (h_4 - h_3)}{(h_1 - h_4)}$$

Back Work Ratio: $= \frac{\dot{W}_p/\dot{m}}{\dot{W}_t/\dot{m}} = \frac{(h_4 - h_3)}{(h_1 - h_2)}$

Ideal Rankine Cycle



1→2: isentropic expansion

2→3: Heat transfer in condenser @ Constant Pressure

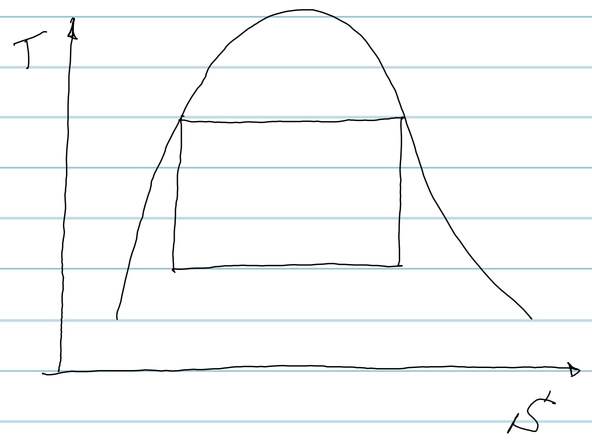
3→4: isentropic compression in pump

4→1: Heat Transfer to fluid in boiler at Constant pressure

Carnot Cycle:

→ But this is never full liquid

This is for reference



Since we assume it's ideal (isentropic)

$$\left(\frac{\dot{W}_p}{\dot{m}}\right)_{\substack{\text{INT}\\ \text{REV}}} = \int_3^4 v\,dp \approx \boxed{v_3\left(P_4 - P_3\right)} \quad //$$

→ Assume liquid

→ Irreversibility in Turbine (EXPANSION)

$$\eta_T = \frac{\dot{W}_t/\dot{m}}{\left(\dot{W}_t/\dot{m}\right)_s} = \frac{h_1 - h_2}{h_1 - h_{2s}}$$

h_2 → (real) (off to the side)

h_{2s} → $s_1 = s_2$ (ideal) vertical

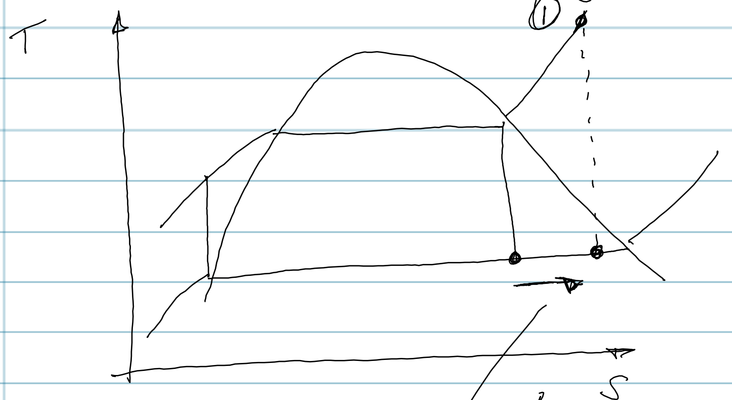
→ LOSSES IN PUMP

$$\eta_p = \frac{\left(\dot{W}_p/\dot{m}\right)_s}{\dot{W}_p/\dot{m}} = \frac{h_{4s} - h_3}{h_4 - h_3} \quad //$$

8.3 Superheat

- low Quality in Turbine Can Damage Turbine (piting on blades)

$x = 90\%$ or higher @ exit



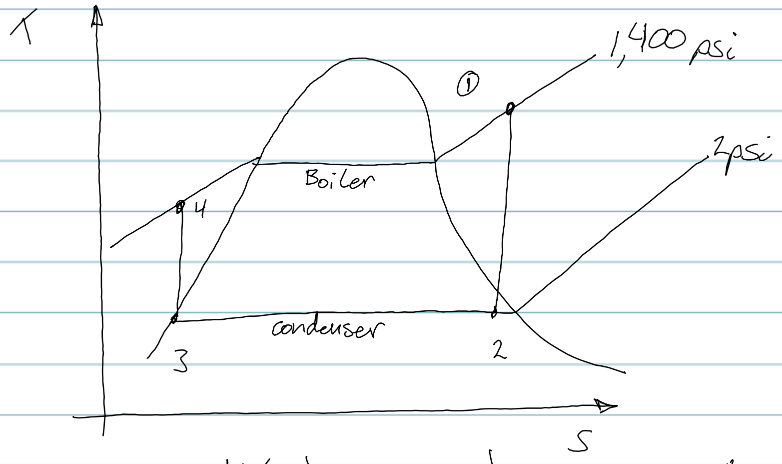
→ higher quality @ exit (longer turbine life)

- Possible for state 2 to be super heated

- Limited by (T) → can't melt turbine blades (practical upper limit)

Boiler w/ super-heating = Steam generator

EXAMPLE: Ideal Rankine + Superheat



$\dot{W} = 1 \cdot 10^9 \ \frac{BTU}{hr}$

FIND: a) $\dot{m}$ (lb/hr) d) $\dot{m}_{cw}$ [lb/hr]

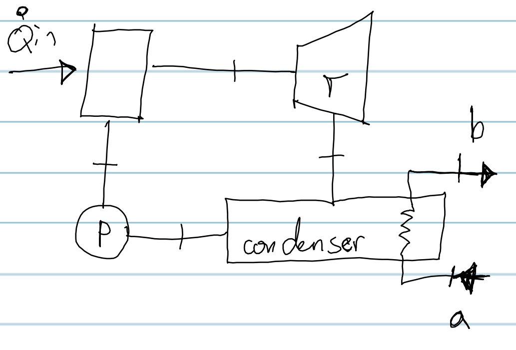
b) $\dot{Q}_{in}$ [BTU/hr]

c) η

STATE	P(psi)	T [°F]	x	h [BTU/lbm]	s [BTU/lbm °R]
1	1,400	1000°F		1493.5	1.6094
2	2		0.822	934.29	$s_2 = s_1$
3	$P_3 = P_2$		$x = 0.0$	94.02	
4	$P_4 = P_1$			98.22	$s_3 = s_4$

just this column is for look-ups

State 3: $v_3 = 0.01623 \ ft^3/lb_m$



Fluids & Thermo (last week to Mischa)

Wednesday January 30th, 2013

Example (continued)

1st Law By Component

TURBINE $\dot{W}_T = \dot{m}(h_1 - h_2)$

PUMP $\dot{W}_P = \dot{m}(h_4 - h_3)$

Steam Generator ☆ → $\dot{Q}_{IN} = \dot{m}(h_1 - h_4)$

Condenser $0 = \dot{m}(h_2 - h_3) + \dot{m}_{cw}(h_a - h_b)$

↑ ☆

Whole System:

☆ ↗ $\eta = \frac{\dot{W}_{cyc}}{\dot{Q}_{in}}$ $\dot{W}_{cyc} = \dot{W}_t - \dot{W}_p$

$$\frac{\dot{W}_t}{\dot{m}} = (1493.5 - 934.29)\frac{BTU}{lbm} = 559.21\ BTU/lbm$$

$$\frac{\dot{W}_p}{\dot{m}} = (98.22 - 94.02)\frac{BTU}{lbm} = 4.19\ BTU/lbm$$

$$\frac{\dot{W}_{cyc}}{\dot{m}} = (559.21 - 4.19)\frac{BTU}{lbm} = 554.93\ BTU/lbm$$

$$\text{So}\quad \dot{m} = \frac{\dot{W}_{cyc}}{(\dot{W}_{cyc}/\dot{m})} = \frac{1\times10^9\ \frac{BTU}{hr}}{554.93\ BTU/lbm} = 1.80\times10^6\ \frac{lbm}{hr}\ //$$

$$\dot{Q}_{IN} = \left(1.80\times10^6\ \frac{lbm\ \cancel{BTU}}{hr}\right)(1493.5 - 98.22)\frac{BTU}{lbm} = 2.51\times10^9\ \frac{BTU}{hr}\ //$$

Now; $\eta = \frac{\dot{W}_{cyc}}{\dot{Q}_{in}} = \frac{10^9 \text{ BTU/hr}}{2.51 \times 10^9 \text{ BTU/hr}}$ $\eta = 0.398$ //

39.8%

So;

$$0 = \dot{m}(h_2 - h_3) + \dot{m}_{cw}(h_a - h_b)$$

$h_a = 28.08$ BTU/lbm A2E $h \approx h_f$

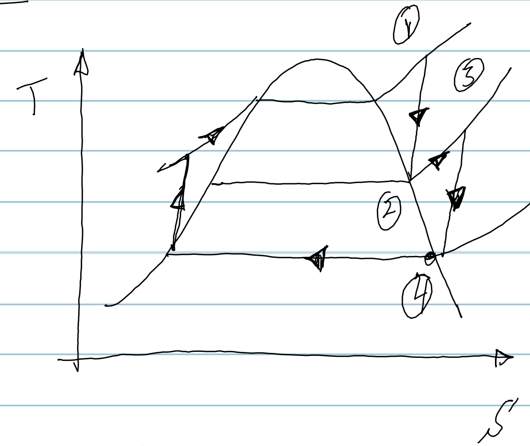
$h_b = 44.09$ " "

Lastly;

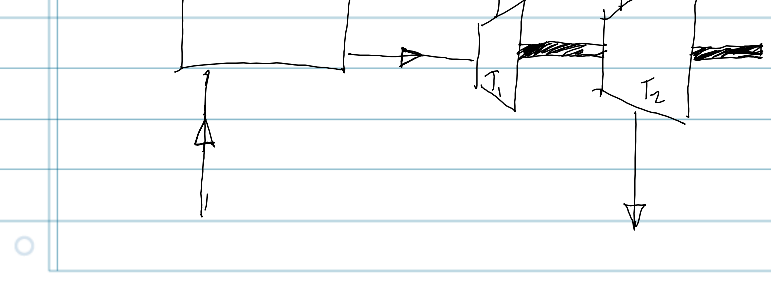
$$\dot{m}_{cw} = \frac{\dot{m}\,(h_2 - h_3)}{(h_b - h_a)}$$

$$\boxed{\dot{m}_{cw} = 9.45 \times 10^7 \text{ lbm/hr}}$$ //

REHEAT:



This further improves the quality of the exit



T_1 = high-pressure turbine

T_2 = low-pressure turbine

These two turbines are optimized

Now we must include both turbine stages

$$\dot{W}_t = \dot{W}_{t_1} + \dot{W}_{t_2}$$

Turbine(s)

$$\dot{W}_t = \dot{m}(h_1 - h_2) + \dot{m}(h_3 - h_4)$$

Pump

$$\dot{W}_p = \dot{m}(h_6 - h_5)$$

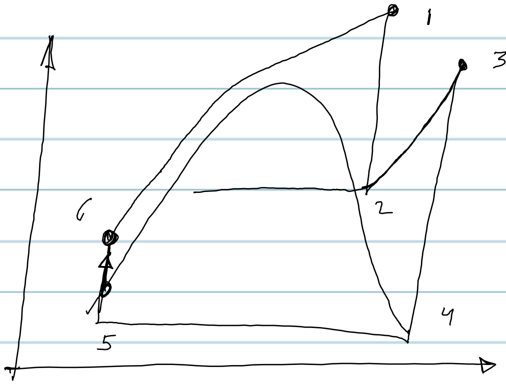
$$\dot{W}_{cycle} = \dot{W}_t - \dot{W}_p = \dot{m}\left[(h_1 - h_2) + (h_3 - h_4) - (h_6 - h_5)\right]$$

$$\dot{Q}_{IN} = \underbrace{\dot{m}(h_1 - h_6)}_{\text{steam generator}} + \underbrace{\dot{m}(h_3 - h_2)}_{\text{Reheat}}$$

$$\eta_{cycle} = \frac{\dot{W}_{cyc}}{\dot{Q}_{in}} = \frac{(h_1 - h_2) + (h_3 - h_4) - (h_6 - h_5)}{(h_1 - h_6) + (h_3 - h_2)}$$

Super critical—

Does not Use a traditional boiler:



Over 22.1 MPa / 3200 Psi

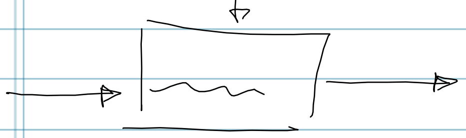
$\eta = 35\%$
$(\leq 40\%)$

$\eta \leq 50\%$

8.4 REGENERATION

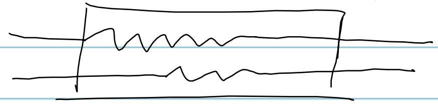
→ Use regenerative Feedwater Heaters to improve efficiency

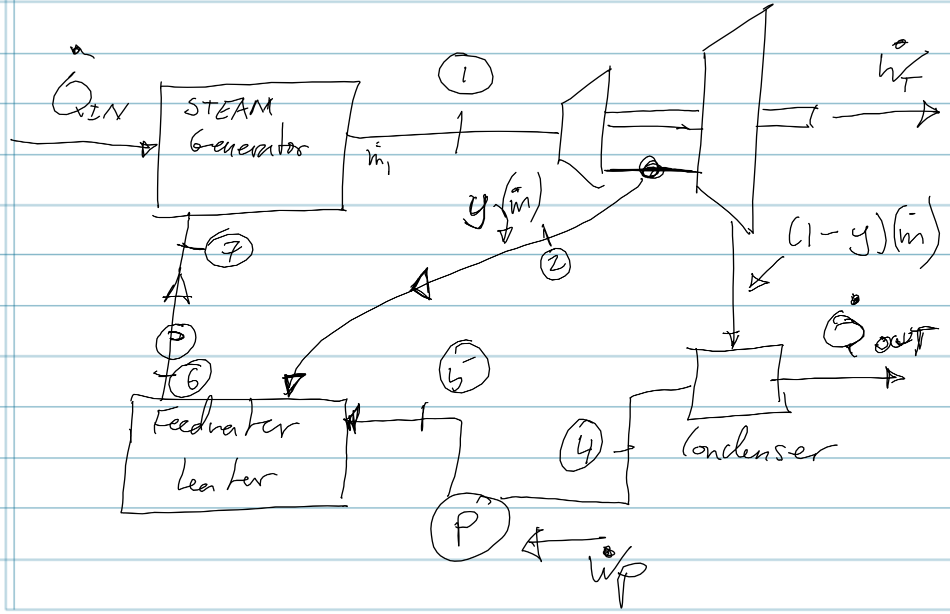
open Feedwater Heater



closed F.H.

heat exchanger



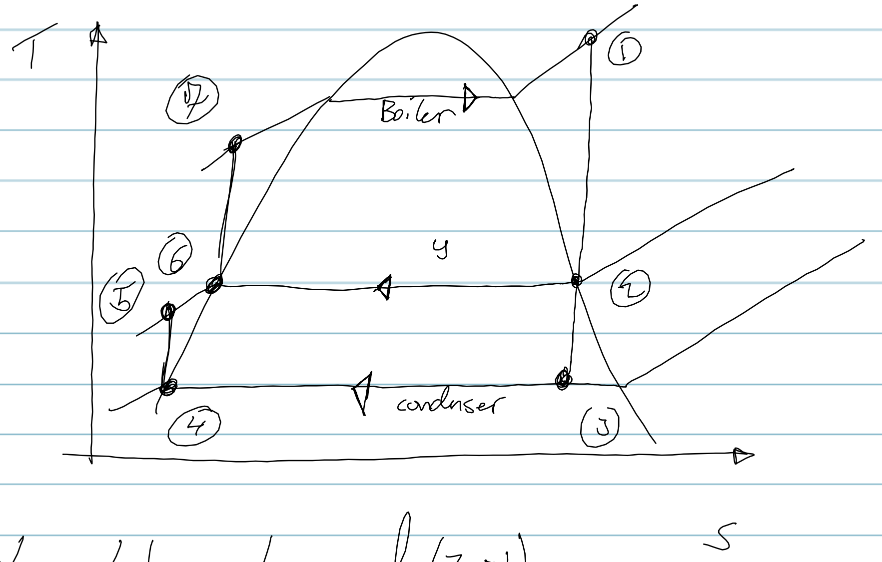


$$y = \frac{\dot m_2}{\dot m_1}$$

$$1-y = \frac{\dot m_3}{\dot m_1}$$

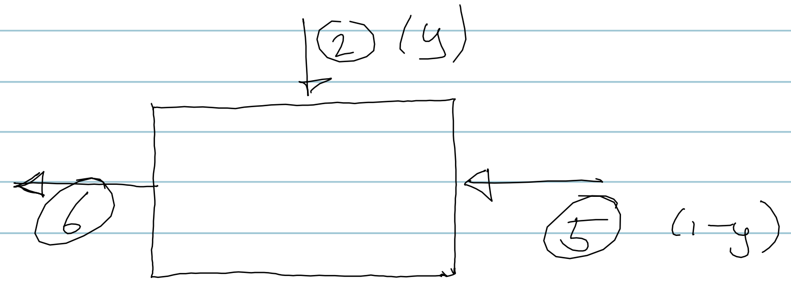
→ Mini Project Due

Monday, February 4th, 2013 → Turn in Quiz by 5 p.m. of Tar Day
(Next Monday & Wednesday)



→ less heat input required (7 → 1)
(rather than a → 1)
→ Reduces boiler fuel needed

→ vertical line



1st Law: Feedwater heater

$$0 = y h_2 + (1-y) h_5 - h_6$$

$$y = \frac{h_6 - h_5}{h_2 - h_5} \quad //$$

1st Law: Turbine

$$\dot{W}_t = \dot{m}_1 (h_1 - h_2) + \dot{m}_3 (h_2 - h_3)$$

$$\frac{\dot{W}_t}{\dot{m}_1} = (h_1 - h_2) + (1-y)(h_2 - h_3) \quad //$$

Pumps: 1st Pump:

$$\dot{W}_p = \dot{m}_1 (h_7 - h_6) + \dot{m}_3 (h_5 - h_4)$$

$$\frac{\dot{W}_p}{\dot{m}_1} = (h_7 - h_6) + (1-y)(h_5 - h_4)$$

Steam Generator:

$$\frac{\dot{Q}_{in}}{\dot{m}_1} = h_1 - h_7 \;//$$

Condenser: $\dot{Q}_{OUT} = \dot{m}_3 (h_3 - h_4)$

$$\dot{Q}_{out} / \dot{m}_1 = (1-y)(h_3 - h_4)$$

$$\eta = \frac{\dot{W}_{cyc}}{\dot{Q}_{IN}} = \frac{\dot{W}_t - \dot{W}_p}{\dot{Q}_{in}}$$

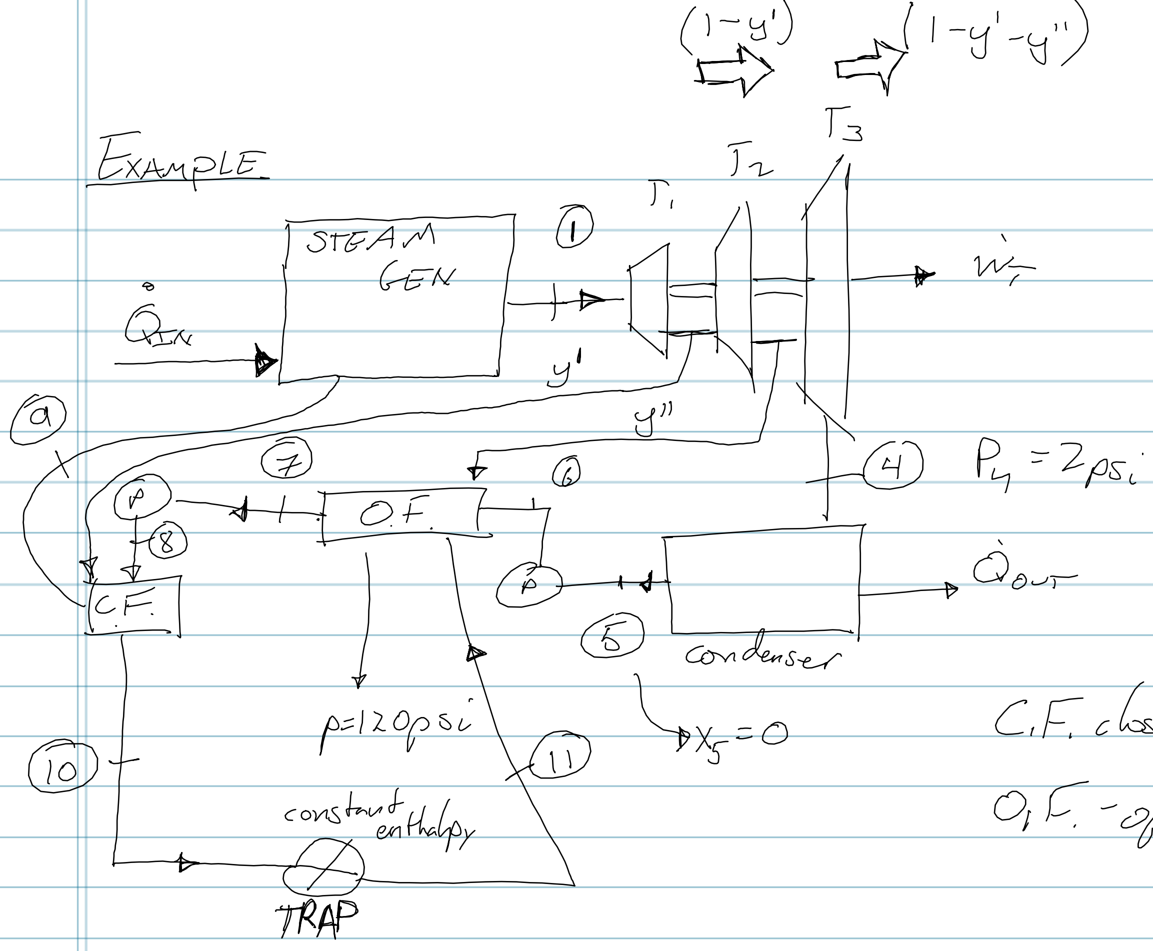
Open Feedwater

Closed Feedwater 8.4.2

Multiple Feedwater 8.4.3.

↳ occurs w/ multi stage turbines

EXAMPLE



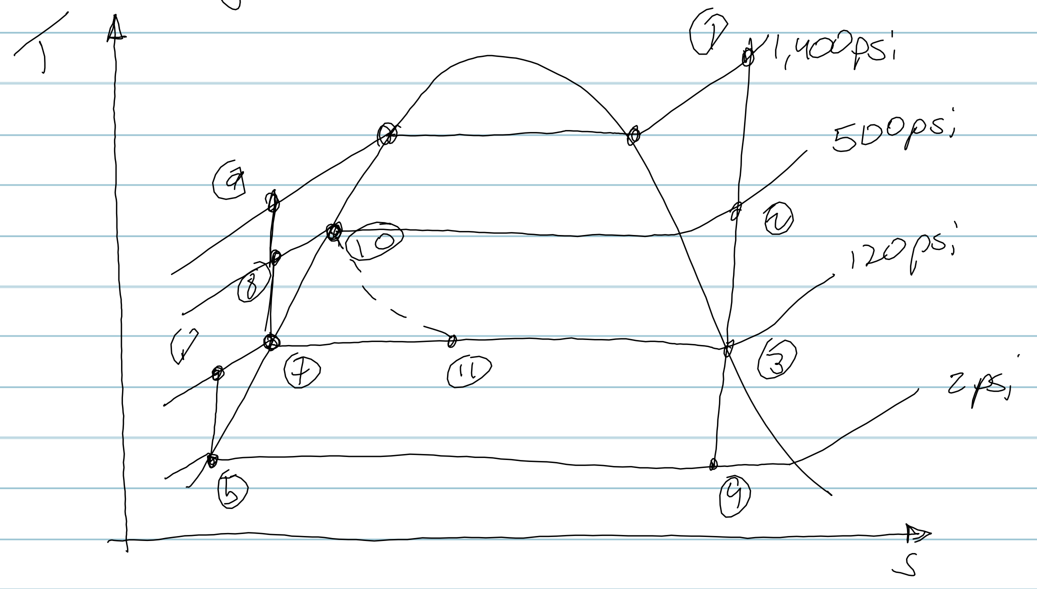
C.F. closed Feedhtr

O.F. - open Feedheater

$P_1 = 1{,}400 psi$ $\quad x_7 = 0$

$T_1 = 1{,}000°F$ $\quad x_{10} = 0$

We have enough info to sketch T-S diagram



FIND: a) $\dot m_1$

b) $\dot Q_{in}$

c) η

STATE	P [psi]	T [°F]	h [BTU/lbm]	s [BTU/lbm°R]	x
1	1,400	1000			
2	500				
3	120				
4	2				
5	$P_5 = P_4$		94.02		$x_5 = 0$
6	$P_6 = P_3$		94.37 $(h_6 \approx h_5 + v_5(P_6 - P_5))$		
7					$x_7 = 0$
8	$P_8 = P_1$		3169.4 $(h_8 \approx h_7 + v_7(P_8 - P_7))$		
9	$P_9 = P_1$	477.07	$h_9 \approx h_{f9}$		
10	$P_{10} = P_2$				
11	$P_{11} = P_3$		$h_{11} = h_{10}$		

Now; 1st law for each component

T_1 $\quad \dot W_{T_1} = \dot m_1 (h_1 - h_2)$

T_2 $\quad \dot W_{T2} = \dot m_1 (1 - y')(h_2 - h_3)$

T_3 $\quad \dot W_{T3} = \dot m_1 (1 - y' - y'')(h_3 - h_4)$

P_1 $\quad \dot W_{P_1} = \dot m_1 (1 - y' - y'')(h_6 - h_5)$

P_2 $\quad \dot W_{P2} = \dot m_1 (h_8 - h_7)$

STEAM Generator

$$\dot Q_{IN} = \dot m_1 (h_1 - h_9)$$

closed F.W.

$$0 = \cancel{\dot Q} - \cancel{\dot W} + \dot m_1 (h_8 - h_9) + \dot m_1 y' (h_2 - h_{10})$$

whole thing

Open F.W.

$$0 = \dot Q - \dot W + \dot m_1 y'' h_3 + \dot m_1 (1 - y' - y') h_6 + \dot m_1 y' h_{11} - \dot m_1 h_7 \quad //$$

Wednesday February 6th, 2013 (example continued)

⟹ (continued)

$$\eta = \frac{\dot{W}_{cyc}}{\dot{Q}_{in}}$$

Solve for $\dot{m}_1$

$$\dot{W}_{cyc} = \dot{m}_1(h_1 - h_2) + \dot{m}_1(1-y')(h_2 - h_3) + \dot{m}_1(1-y'-y'')(h_3 - h_4) - \dot{m}_1(1-y'-y'')(h_6 - h_5) - \dot{m}_1(h_8 - h_7)$$

$$\dot{m}_1 = \frac{\dot{W}_{cyc}}{\left\{(h_1-h_2)+(1-y')(h_2-h_3)+(1-y'-y'')(h_3-h_4)-(1-y'-y'')(h_6-h_5) - (h_8-h_7)\right\}}$$

Need $y' + y''$ → write 1st law for each heater to find mass fractions

$$y' = \frac{(h_9 - h_8)}{(h_2 - h_{10})} = \ldots = 0.159$$

$$0 = y'' h_3 + (1 - 0.159 - y'') h_8 + (0.159) h_{11} - h_7$$

$\therefore y'' = 0.145$

So;

$\dot{m}_1 = 2.23 \times 10^6$ lb/hr

$\dot{Q}_{in} = 2.3 \times 10^9$ BTU/hr

Q.

$\eta = 0.435$ ↗ Better

39.8% ↗

8,5 other Aspects

- → Other working fluid
  - → Fluid properties
  - → Different boiling point (vapor dome shape)
  - ↳ a.k.a. Organic Rankine Cycles
    - ↳ Hydrocarbon
    - ↳ Ammonia
    - ↳ Refrigerants

8.5,2 Cogeneration

Produce electricity & (Steam <u>or</u> heat)

- ↳ Manufacturing (electricity & steam)
- ↳ District Heating (different from cogeneration)

Dirk

Main Boiler of 12

↳ for Steam (Melting)

Building heat, domestic hot water cookin

Fire tube boiler → 3

200hp Summer
400hp
800hp Winter

Inputs: 1. H_2O
2. Fuel Source → 1) Nat gas → cheap
3. Electricity → 2) # fuel oil (b/c company can cut nat. gas)

Main Danger: Water in the "sight" glass

10,000 gallon Tank (fuel)

200 gallons/hour @ 100%
800hp

Steam → to campus

condensate

80% Back

Larger Demand in the Morning.

H_2O → treat (H_2O softener)

loss:
evap pump
vented
to atmosphere

H.T. loss w/ mineral collection

↳ W/G/S/ Melting

Rated @ 15psi
Small

Big @ 150

Take out 99% of water

Then treat w/ sulfites → oxygyn savange

Corrosion is quicker w/ O_2 (pockets)

E. A. Tank → pumps → Boiler

3 pass boiler / 4 pass

Safety valves on boiler

working pressure (Trim)

{ old 150 lb Boiler
{ new 15 lb boiler

} auto open?
} close, pressure release valve

1963 drop because lighter volume

Not continuous feed v/s continuous feed

2002 800h.p. Solenoid valve electronic — electronic valve

Newest Boiler 400h.p. 2009

Controls:
incoming air temp
H_2O in boiler temp

running efficiency p=13.6 lbs

84% eff

5% O_2

Inc air 661 F

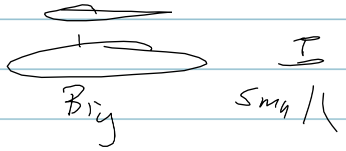
H_2O = 242°F

Fuel mix
↳ actuator
air
↳ actuator

Motor
↳ variable speed
↓
or fuel for
oil to
control RPM

Adjusting Manually
↳ all through range of fire

Dual Valves



Heat exchanger to heat building

On long lines of steam use drip legs
↳ low point to
drain condensate
↓
b/c flashing
Push H_2O into bend
or valve etc.

warming water for irrigation from slab

Wednesday, February 13th, 2013

Chapter 9 - Gas Power Systems

2.5L 2009 VW Jetta (Gas)

2.0	Fuel Economy	29 MPG	Power 170hp	177 ft-lb
		34 MPG	115	125 lb
	Diesel	41	140	~~125~~ 236
		42	140	236

$\frac{5\text{ miles}}{\text{gallon}}$

$\frac{29\text{ miles}}{1\text{ gallon}}$

$10{,}000\text{ miles} \times \frac{1\text{ gallon}}{29\text{ miles}} \times \frac{\$4.00}{1\text{ gallon}}$

$10{,}000\text{ miles} \times \frac{1\text{ galon}}{41\text{ miles}} \times \frac{\$4.00}{1\text{ gallon}}$

low g/m = \$1,379.00

high/g m = \$975.609

\$400
per 10,000 miles

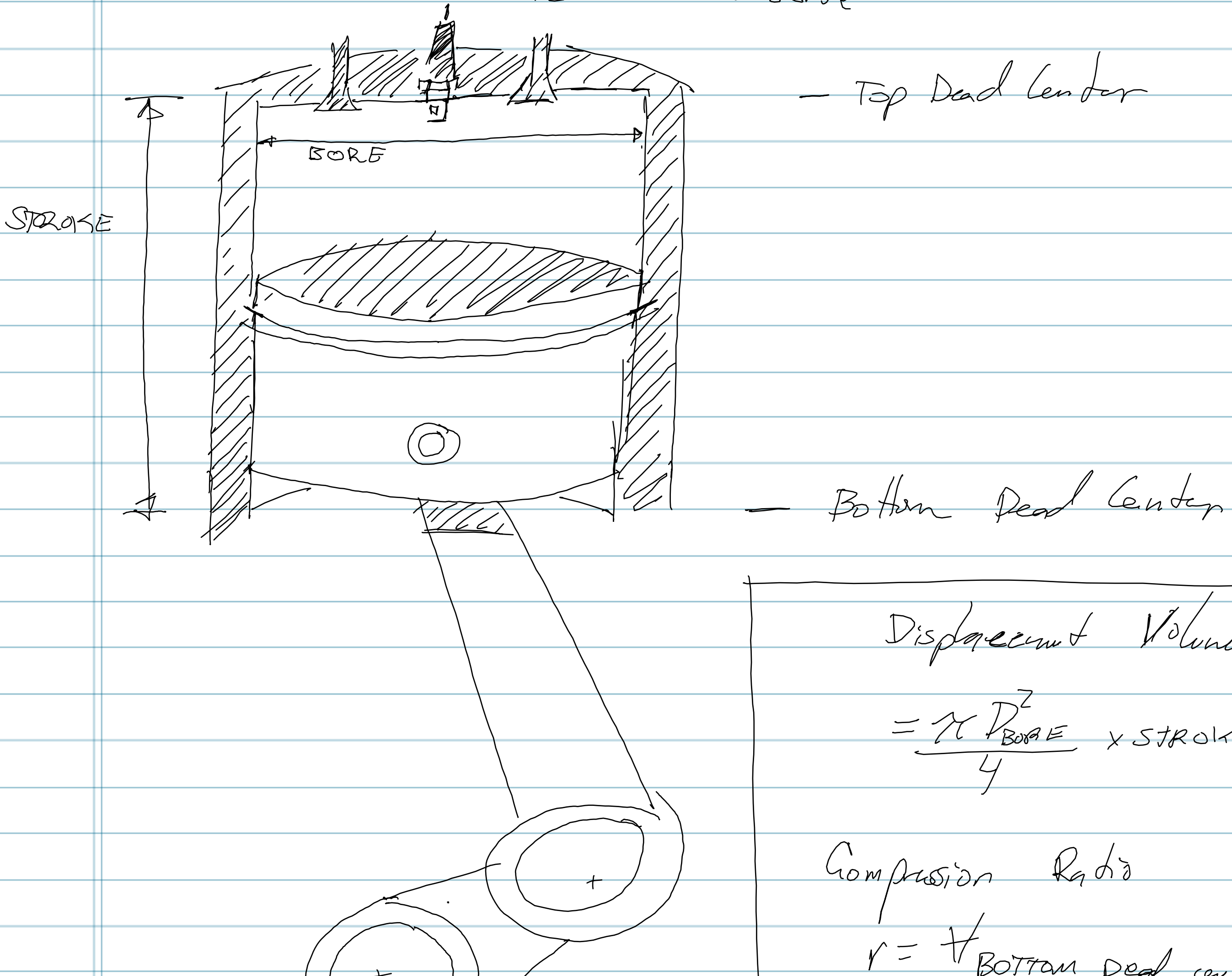
\$4,000 100,000 mi

Spark Ignition: ("GAS")

- power ~300Hp
- Light, low cost for cars

Compression Ignition: ("Diesel")

- Typically higher fuel economy (eff)
- More Power Possible



Displacement Volume

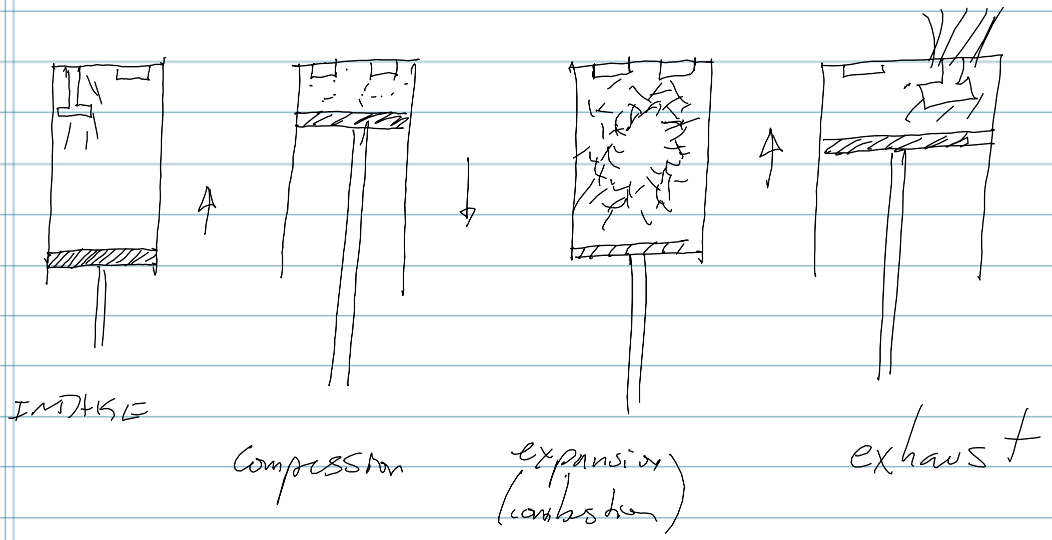
$$= \frac{\pi D_{BORE}^2}{4} \times STROKE$$

Compression Ratio

$$r = \frac{V_{BOTTOM\ Dead\ center}}{V_{TOP\ D.C.}}$$

4 stroke engine → Four strokes for every 2 spins of the Motor.

①



Mean effective Pressure (Mep)

$$M_{EP} = \frac{\text{Network for 1 cycle}}{\text{Displacement volume}}$$

(measure of performance, it is a theoretical pressure

9.1 Air Standard Analysis

Simplifications for modeling an I.C. engine w/o combustion.

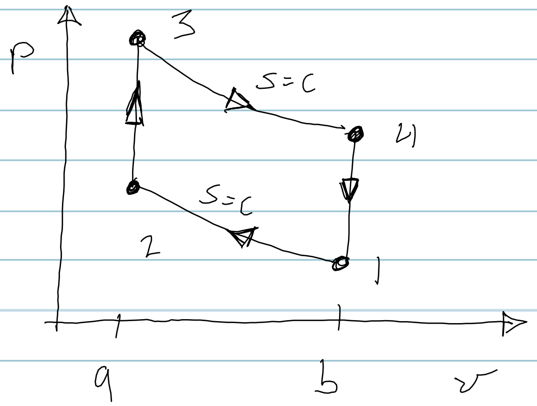
- → air is an ideal gas
- → combustion treated as heat transfer
- → everything is internally reversible
- → No intake/exhaust process

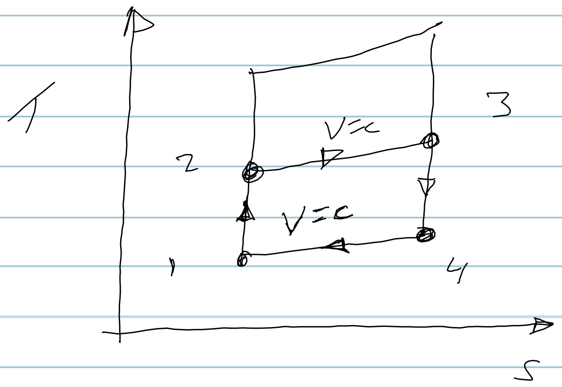
Cold air standard analysis

- Same as air standard
- constant specific heats

Recall Ideal Gas Relations (Table 9.1)

9.2 Air-Standard Otto Cycle





1 → 2: Isentropic compression (BDC → TDC)

2 → 3: Constant volume heat addition

3 → 4: Isentropic expansion

4 → 1: Constant Volume heat rejection

Open Book, No NOTES

Monday February 18th, 2013   Exam 1 Wednesday

↳ Rankine

Watch ideal gasses ← ↳ Exergy

Homework due Wednesday

Exam Review

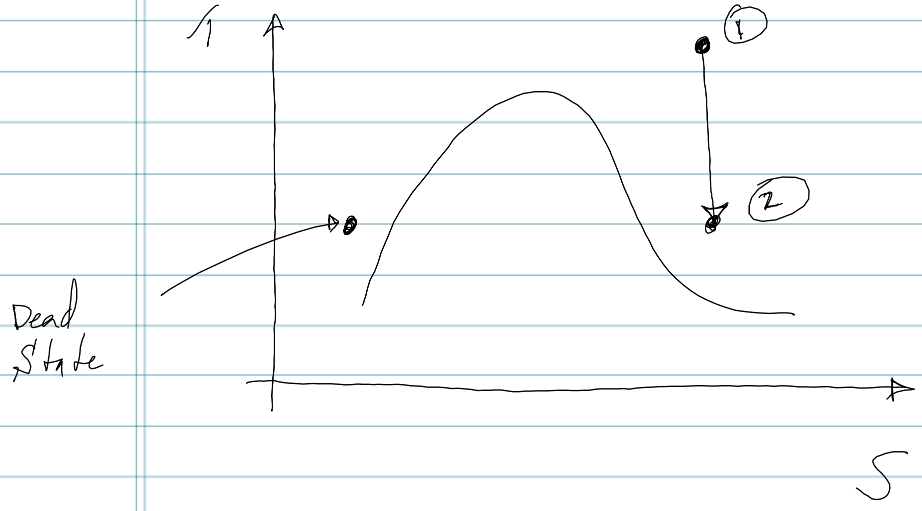
Chapter 7 → Exergy max theoretical work obtainable from overall system as it comes to equilibrium with envirnmt

$e = (u-u_0) + P_0(v-v_0) - T_0(s-s_0) + KE + PE$

$e_f = (h-h_0) - T_0(s-s_0)$

Dead State: $T_0 = 25\,^\circ C$ ($77\,^\circ F$)

$P_0 = 1\,atm$



CLOSED SYSTEM (constant mass)

$$\underbrace{E_2 - E_1}_{\text{Exergy Change}} = E_q - E_w - E_d$$

$$E_q = \int_1^2 \left(1 - \frac{T_0}{T_b}\right) \delta Q$$

$$E_W = W - P_0 (V_2 - V_1)$$

$$E_d = T_0 \sigma$$

Open System

Boundary Temp

$$\frac{dE}{dt} = \sum \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j - \left(\dot{W}_{cv} - P_0 \frac{dV}{dt}\right) + \sum \dot{m}_i e_{fi} - \sum \dot{m}_e e_{fe} - \dot{E}_d$$

2nd law efficiency (exergetic)

$$\varepsilon = \frac{\text{Exergy Out}}{\text{Exergy In}}$$

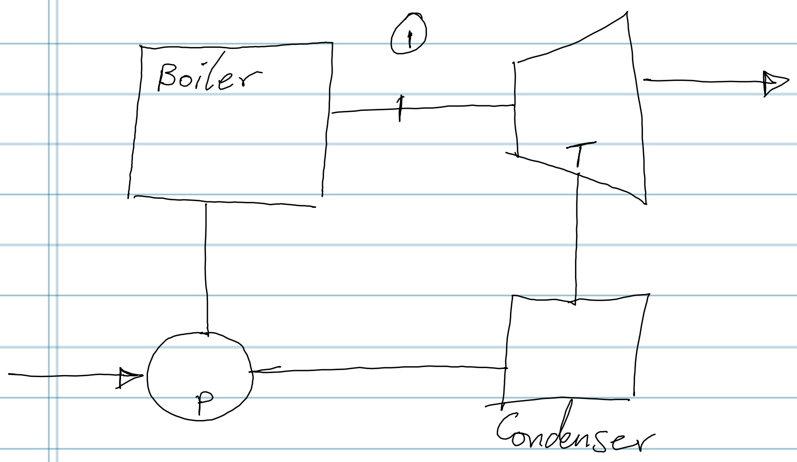
Exergy Accounting

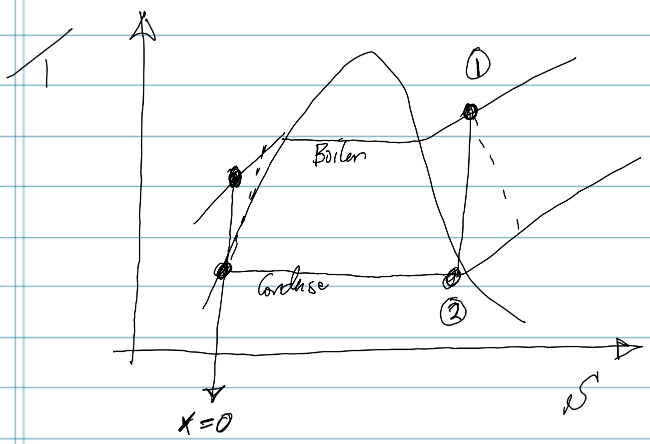
Exergy In

EXERGY OUT

EXERGY Destruction

Chapter 8 Rankine Cycle





STRATEGY

1. T-S diagram, draw and fix states
2. Conservation of energy for each component
3. Conservation of energy for whole system
   ↳ $\eta = \frac{W_T - W_P}{Q_{in}}$

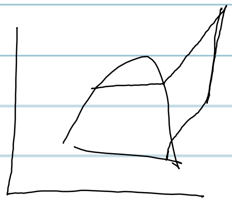
Isentropic efficiencies

$$\eta_t = \frac{h_1 - h_2}{h_1 - h_{2s}} \qquad \eta_p = \frac{h_{4s} - h_3}{h_4 - h_3}$$

Additional Topics

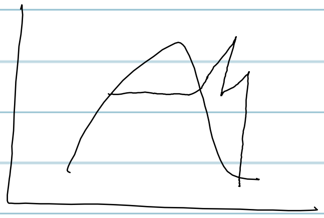
☐ Super-heating

Push to higher T



☐ Reheat

Pass Back through
Boiler

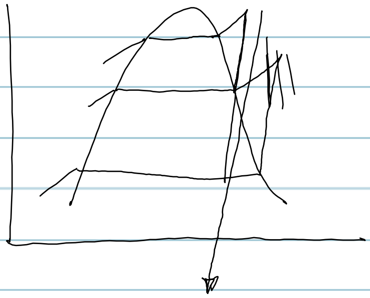


☐ Super-critical

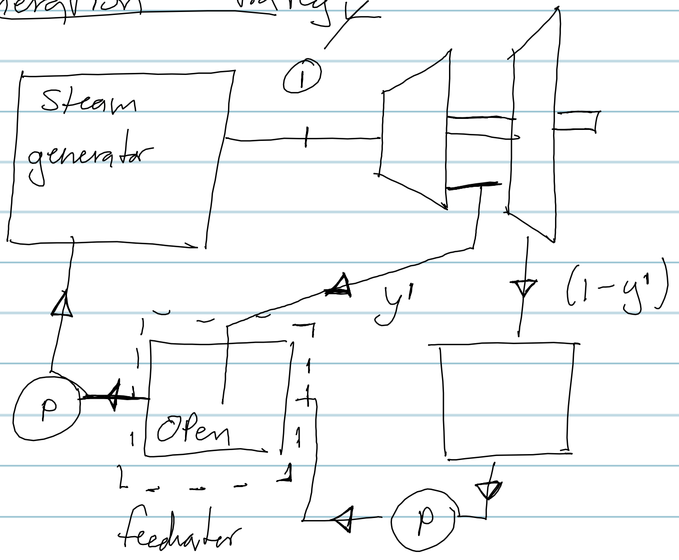
↳ higher P, T cycle

☐ Regeneration

Feedwater heaters
- closed
- open



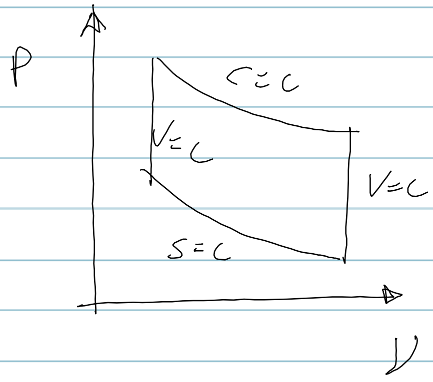
Regeneration Strategy

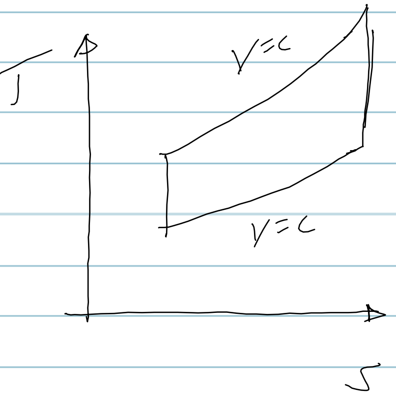


y' → mass fraction

To solve for y, use Control Volume around heaters

Air Standard OTTO cycle





$\frac{W_{12}}{m} = u_2 - u_1$ $\frac{Q_{23}}{m} = u_3 - u_2$

$\frac{W_{34}}{m} = u_3 - u_4$ $\frac{Q_{41}}{m} = u_4 - u_1$

$$\frac{W_{cyc}}{m} = \frac{W_{34} - W_{12}}{m} = (u_3 - u_4) - (u_2 - u_1)$$

$$\eta = 1 - \left(\frac{u_4 - u_1}{u_3 - u_2}\right)$$

TABLE A-22 ☆

$v_r(T)$ - relative volume (Temperature dependent)

We use idealgas/isentropic

$$\frac{v_2}{v_1} = \left[\frac{RT_2}{p_r(T_2)}\right]\left[\frac{p_r(T_1)}{RT_1}\right]$$

So IF $s_1 = s_2$

$$\frac{v_2}{v_1} = \frac{v_{r_2}}{v_{r_1}} \qquad \text{Equation } (6.42)$$

relative volume

For OTTO Cycle

$$v_{r_2} = v_{r_1}\left(\frac{V_2}{V_1}\right) = \frac{v_{r_1}}{r} \leftarrow \text{compression Ratio}$$

where $r = \frac{V_1}{V_2} = \frac{V_4}{V_3}$

$$v_{r_4} = v_{r_3}\left(\frac{V_4}{V_3}\right) = r\, v_{r_3}$$

Cold air STANDARD (Constant C_p)

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{K-1} = r^{K-1}$$

So $\eta = 1 - \left(\frac{1}{r^{K-1}}\right)$

$$\frac{T_4}{T_3} = \left(\frac{v_3}{v_4}\right)^{K-1} = \frac{1}{r^{K-1}}$$

$K = 1.4$ for air

$\frac{C_p}{C_v}$ → Tabulated, don't calculate

"Fully Reversible" → No exergy destruction

Wednesday, February 27th, 2013

Project, 5 peer-reviewed Journals, Thermodynamics Topic

1 paragraph + 2 citations → Due After Break

Ref Works → Sign-Up

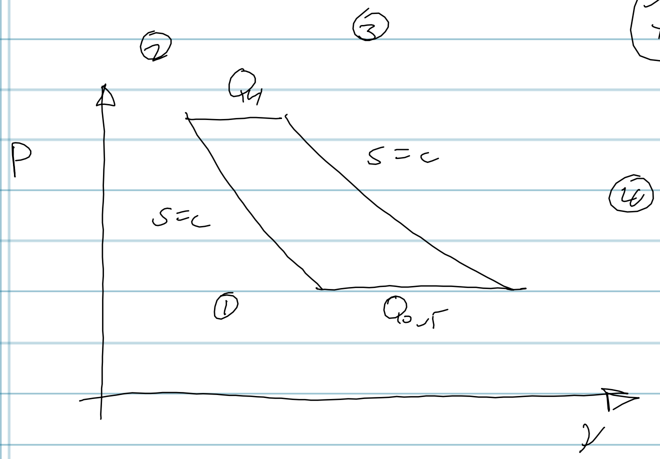
Engineering Village → Good Search, optimization
and launchpointing and optimization

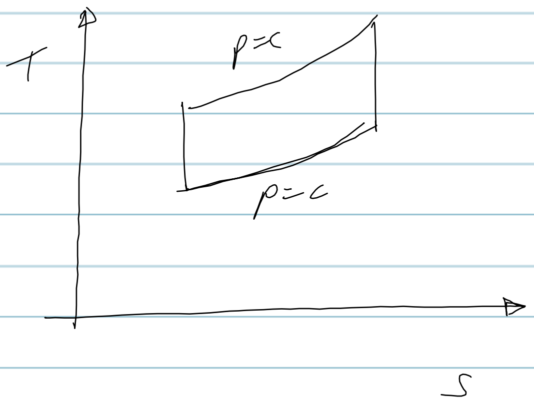
UP Illiad → same as pilots → use school address.

→ electronnically delivered articles (30 days to expire)

→ can download to local

Monday March 4th, 2013 ☐ Homework #7 Due Friday (7p.m. Under-Door)





1st Law for Each Component:

$$\frac{W_t}{m} = h_3 - h_4 \qquad \frac{Q_{in}}{m} = h_3 - h_2$$

$$\frac{\dot{W}_c}{m} = h_2 - h_1 \qquad \frac{\dot{Q}_{out}}{m} = h_4 - h_1$$

$$\eta = \frac{W_{cyc}}{Q} = \frac{W_t - W_c}{Q_{in}} = \frac{(h_3 - h_4) - (h_2 - h_1)}{(h_3 - h_2)}$$

B.W.R:

$$\frac{W_c}{W_t} = \frac{h_2 - h_1}{h_3 - h_4}$$

Typically 40% - 80%

For Isentropic Processes

$$P_{r_2} = P_{r_1}\left(\frac{P_2}{P_1}\right)$$

$$P_{r_4} = P_{r_3}\left(\frac{P_4}{P_3}\right) = P_{r_3}\left(\frac{P_1}{P_2}\right)$$

COLD AIR STANDARD

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}$$

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{K-1}{K}} = T_3\left(\frac{P_1}{P_2}\right)^{K-1/K}$$

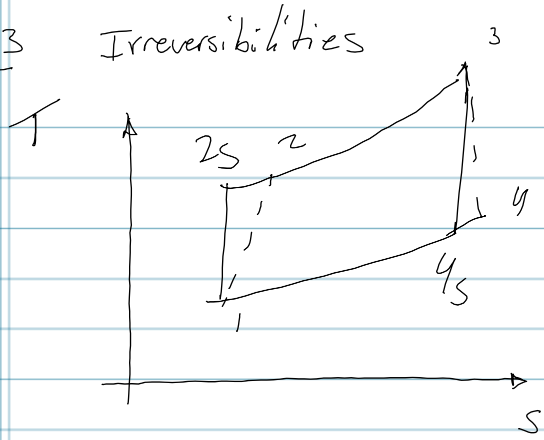
$$\eta = \frac{(h_3 - h_4) - (h_2 - h_1)}{(h_3 - h_2)}$$

$$= \frac{C_p(T_3 - T_4) - C_p(T_2 - T_1)}{C_p(T_3 - T_2)}$$

$$= 1 - \frac{T_2 - T_1}{T_3 - T_2}$$ (Factor/Algebra)

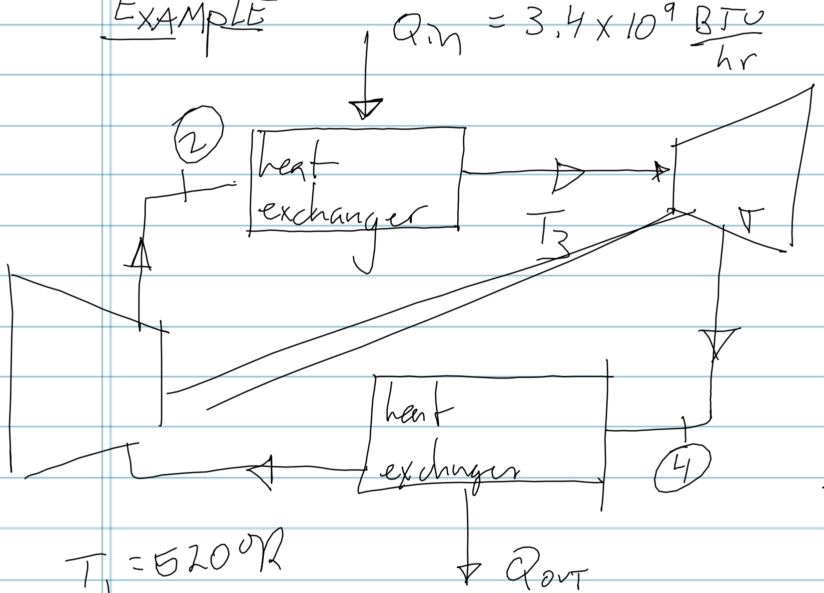
$$= 1 - \frac{1}{\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}}}$$

9.6.3 Irreversibilities



$$\eta_t = \frac{h_3 - h_4}{h_3 - h_{4s}} \qquad \eta_c = \frac{h_{2s} - h_1}{h_2 - h_1}$$

EXAMPLE



$T_3 = 3000°R$

$\frac{P_2}{P_1} = 14$

$T_1 = 520°R$

FIND: $\eta =$

$\dot{m} =$

$\dot{W}_{NET} =$

STATE	Temperature	h [BTU/lbm]	P_r
1	520°R →	124,27 →	1,2141
2	1092,5°R ←	790,68 ←	17,0058
3	3,000°R →	790, 68 →	941,4
4	←	←	67.24

STATE 2

$$P_{r_2} = \left(\frac{P_2}{P_1}\right) P_{r_1}$$

$$= (14) \cdot 1.2147$$

$$P_{r_2} = 17.0058 \;//$$

STATE 4

$$P_{r_4} = \left(\frac{P_4}{P_3}\right) P_{r_3} = \left(\frac{1}{14}\right) \cdot 941.4$$

$$= 67.24$$

$$\eta = 1 - \frac{Q_{out}/m}{Q_{in}/m} = 1 - \frac{h_4 - h_1}{h_3 - h_2}$$

$$= 1 - \frac{'' \quad ''}{'' \quad ''}$$

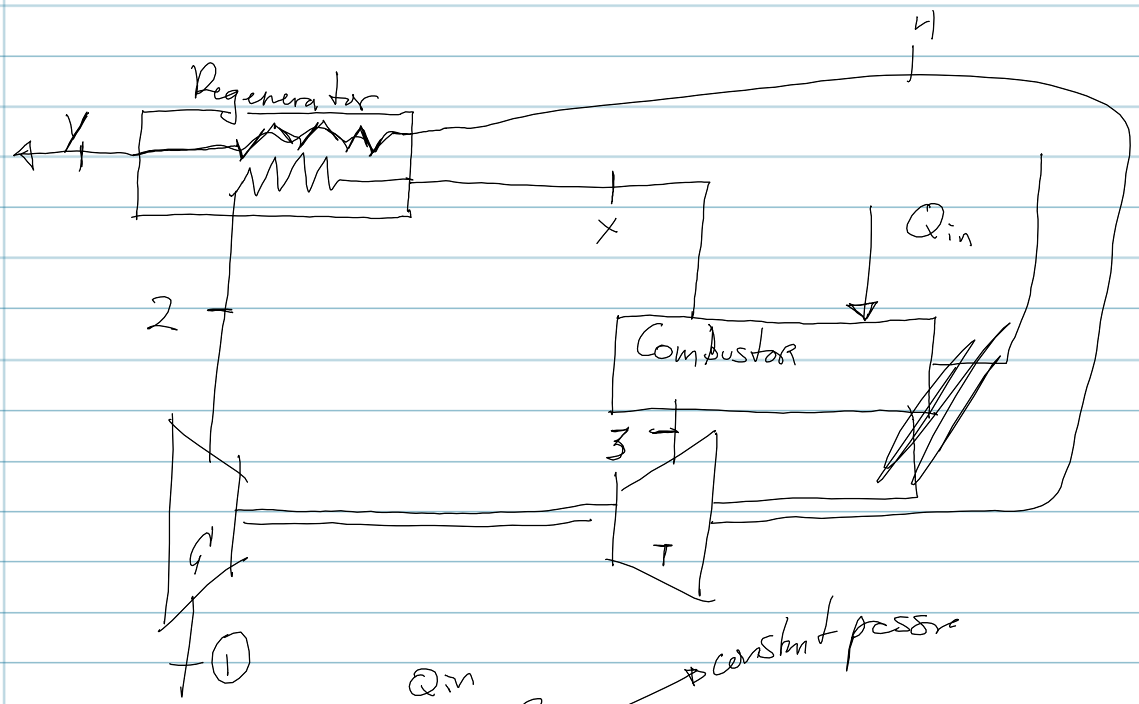
$$= 0.498 = 50\% \;//$$

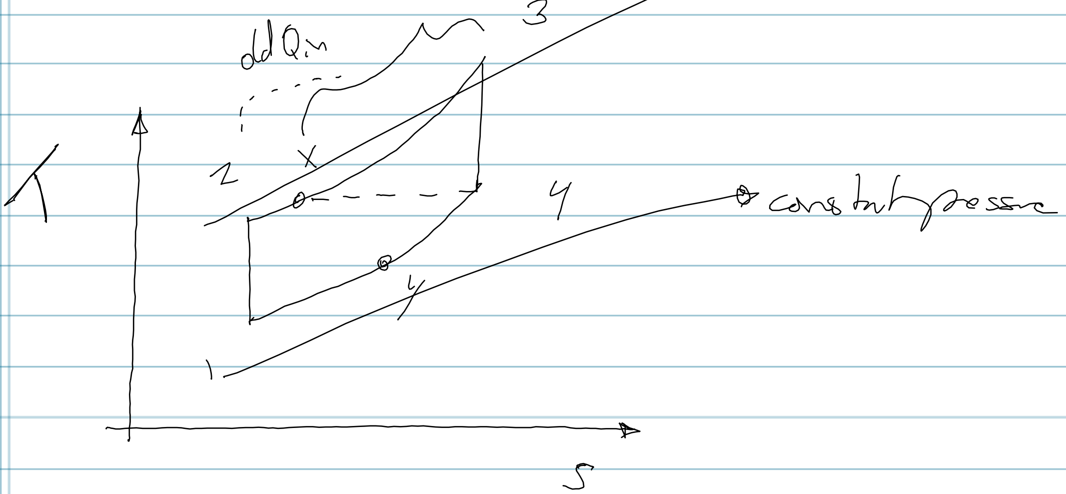
$$Q_{in} = \dot{m}(h_3 - h_2) \quad \therefore \quad \dot{m} = 6.45 \times 10^6 \frac{lb}{hr}$$

$$\dot{W}_{cyc} = \dot{m}\left[(h_3 - h_4) - (h_2 - h_1)\right]$$

$$= 1.693 \times 10^9 \;BTU/hr \;//$$

9.7 Regenerative Gas Turbines





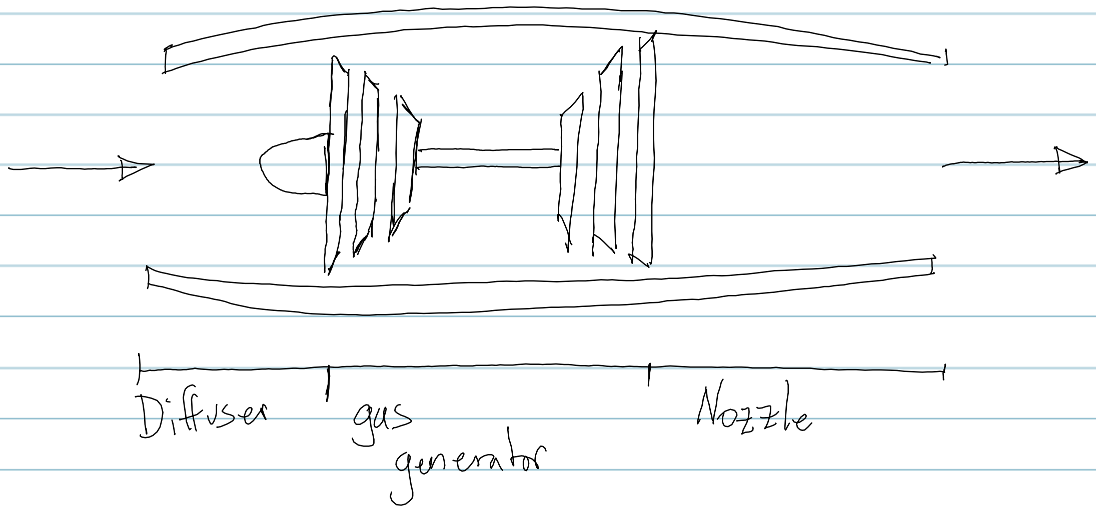
Regenerator effectiveness

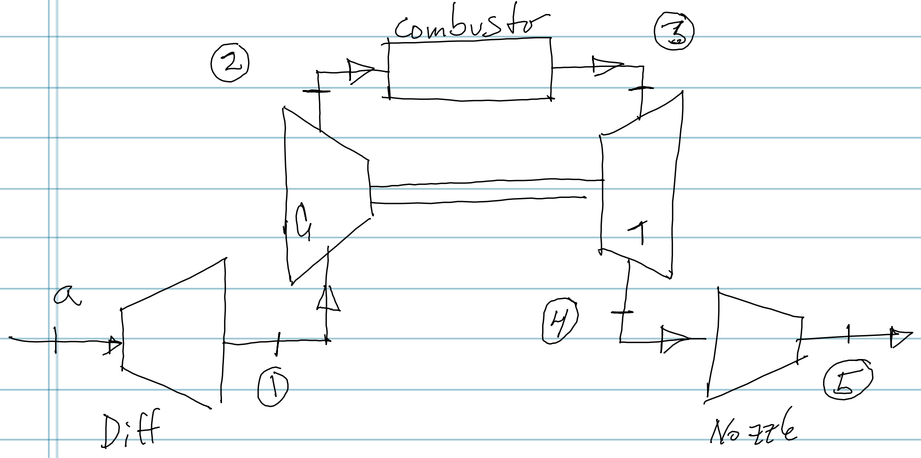
$$\eta_{Reg} = \frac{h_x - h_2}{h_4 - h_2}$$

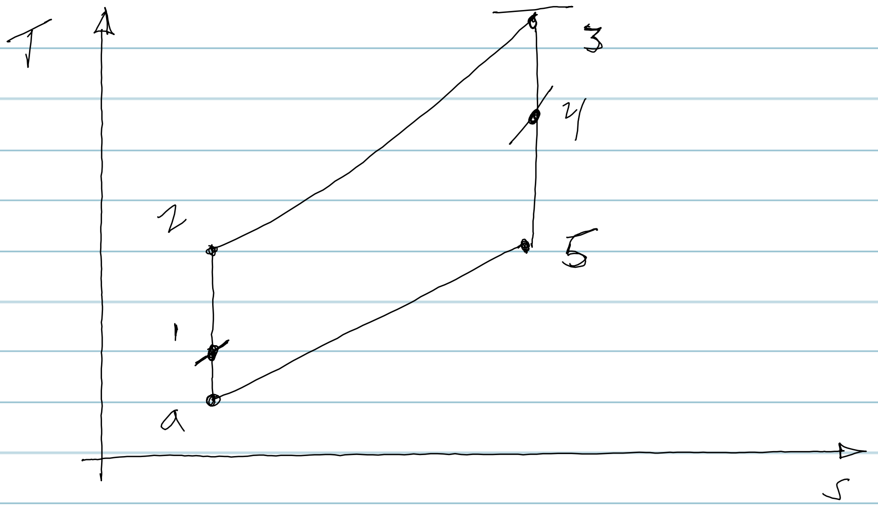
Typically 60-80%

$$Q_{in} = h_3 - h_x \quad //$$

Monday March 18th, 2013







EXAMPLE

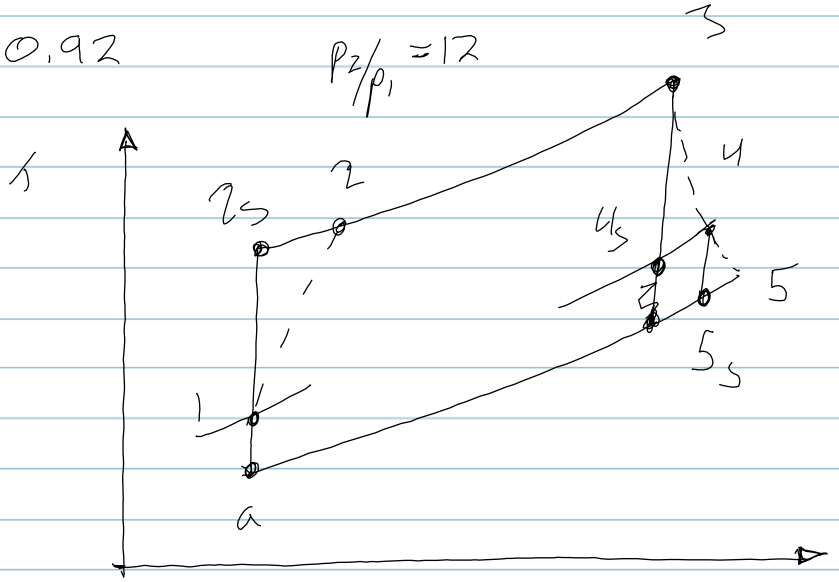
Givens: $\dot{m} = 85\ lb/s$ $\quad V_a = 750\ ft/s$ $\quad T_a = 420°R$

$V_1 = 0$ $\quad P_a = 9\ psi$

$\eta_c = 0.88$ $\quad T_3 = 2400\ °R$ (high Temps)

$\eta_T = 0.90$ $\quad P_5 = 9\ psi$

$\eta_N = 0.92$ $\quad P_2/P_1 = 12$



STATE	T [°R]	h [BTU/lbm]	P_r	P [psi]
a	420	100.32	0.5760	9
1		111.55	0.83492	13.05
2				
2s				
3	2400	617.22	367.6	
4				
4s				
5				
5s				

STATE 1

1^{st} Law Diffuser ✓ ✓

$$0 = \left(h_a + \frac{V_a^2}{2}\right) - \left(h_1 + \cancelto{0}{\frac{V_1^2}{2}}\right)$$

$$h_1 = 100.32\ BTU/lbm + \frac{750\,ft^2}{s} \cdot \frac{1\,lbf\ s^2}{32.2\,lb_m\,ft} \cdot \frac{1\,BTU}{778\,ftlbf}$$

$$h_1 = 111.55\ BTU/lbm \ //$$

$$P_1 = \left(\frac{Pr_1}{Pr_a}\right) P_a = \left(\frac{0.83442}{0.5760}\right) \cdot 9psi = 13.05psi$$

STATE 2

$$Pr_{2s} = Pr_1\left(\frac{P_2}{P_1}\right) = 10.019\ psi\ //$$

$$h_{2s} = 227.29\ BTU/lbm\ //$$

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1} \qquad So; \quad h_2 = h_1 + \frac{h_{2s} - h_1}{\eta_c}$$

$$h_2 = 243.07\ BTU/lbm$$

$$P_2 = 12 \cdot P_1$$

$$P_2 = 156.6\ psi$$

STATE 4

TURBOJET $\frac{\dot{W}_c}{\dot{m}} = \frac{\dot{W}_T}{\dot{m}}$

$$h_2 - h_1 = \eta_T (h_3 - h_{4s})$$

$h_{4s} = 471.09$ BTU/lbm //

$P_4 = \left(\frac{P_{r_{4s}}}{P_{r_3}}\right)(P_3)$ so $P_4 = 57.61$ psi

STATE 5

$P_{r_{5s}} = P_{r_4}\left(\frac{P_5}{P_4}\right) = 151.24\left(\frac{9}{57.61}\right)$

$P_{r_5} = 23.627$

NOTE: $\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}}$

$h_4 = h_3 - \eta_T (h_3 - h_{4s}) = 485.7$ BTU/lbm //

Now; $\dot{Q}_{IN} = \dot{m}(h_3 - h_2) = 1.45 \times 10^8$ BTU/hr //

$\dot{W}_C = \dot{m}(h_2 - h_1) = 4.025 \times 10^7$ BTU/hr //

1st Law Nozzle $0 = \left(h_4 + \underbrace{\frac{V_4^2}{2}}_{\text{zero}}\right) - \left(h_{5s} - \frac{V_{5s}^2}{2}\right)$

$\Longrightarrow$

$$V_{5s}^{2} = 2\left(h_4 - h_{5s}\right) \times \frac{778\ \text{ftlb}}{\text{BTU}} \Big/ \frac{32.2\ \text{ft}}{\text{s}^2}$$

$$V_{5s} = 3131.93\ \text{ft/s}$$

$$\eta_N = 0.92 = \frac{V_5^{2}}{V_{5s}^{2}} \;//$$

$$\text{Now;}\ V_5 = 3{,}004\ \text{ft/s} \;//$$

WEDNESDAY March 20th, 2013

Semester Map

Power Systems

- Vapor Power (Rainkine)
- Gas Power
  - OTTO
  - DIESEL
  - BRYTON
- Property Exergy

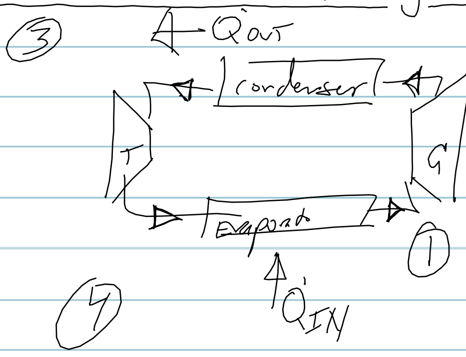
HVAC systems

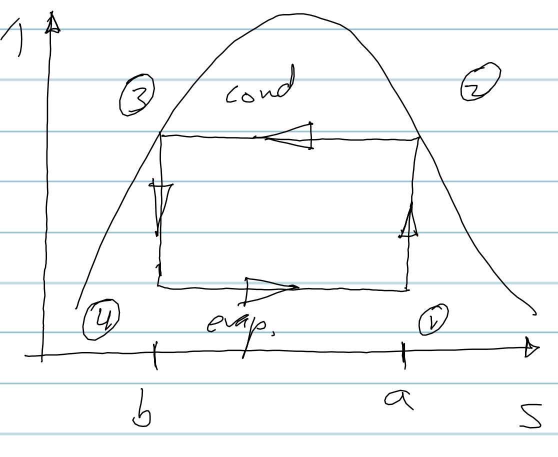
- Vapor refrigeration
- Heat Pumps
- Psychrometrics (water/air mixtures)

Chapter 10

New objective: Rather than $\dot{W}$ we are focused on $\dot{Q}$

10.1.1 Carnot refrigeration cycle





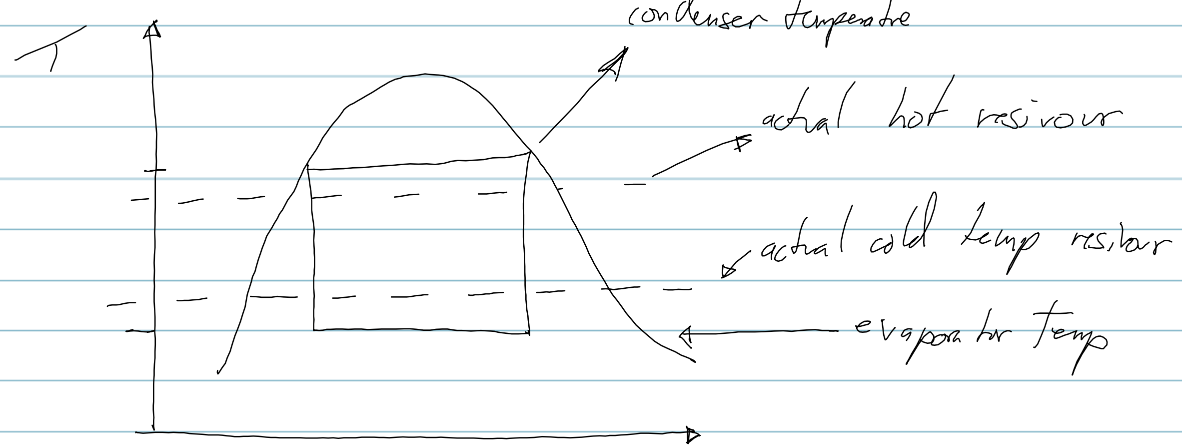
Coefficient of performance

$$\beta = \frac{\dot{Q}_{IN}}{\dot{W}_{cycle}}$$

$$= \frac{\dot{Q}_{IN}}{\dot{W}_C - \dot{W}_T} = \frac{T_c\,(s_a - s_b)}{(T_H - T_c)\,(s_a - s_b)} = \frac{T_c}{T_H - T_c} \;//$$

$$\beta_{max} = \frac{T_C}{T_H - T_C}$$

REAL Systems:

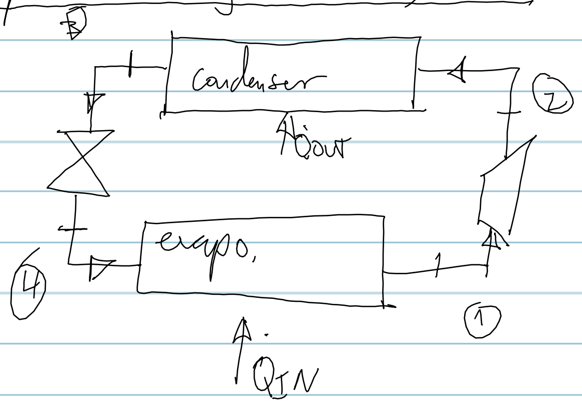


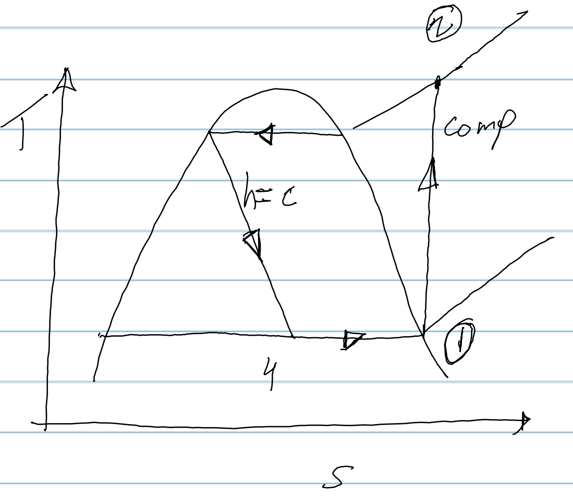
☐ In practice we need ΔT to create $\dot{Q}$
this makes β ↓

☐ We would rather not compress vapor-liquid mix (wet compression)
so we shift 1-2 to the right

☐ from 3 to 4, low quality mix, produces very little work, instead
we use a throttling valve

Actual Vapor Refrigerator System





Analysis

1st Law Evaporator:

$$\frac{\dot{Q}_{IN}}{\dot{m}} = h_1 - h_4 \longrightarrow \text{"refridgeration capacity"}$$

Compressor: $\frac{\dot{W}_c}{\dot{m}} = h_2 - h_1$

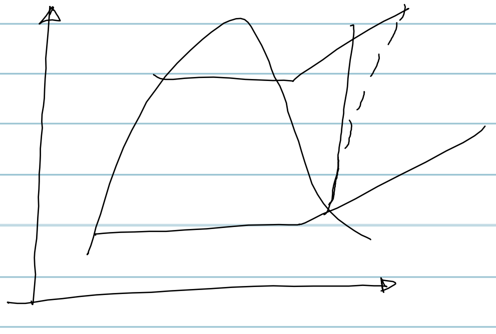
Condenser: $\frac{\dot{Q}_{out}}{\dot{m}} = h_2 - h_3$

Valve (no W, NOR Q) so $h_4 = h_3$

$$B = \frac{\dot{Q}_{IN}/\dot{m}}{\dot{W}_c/\dot{m}} = \frac{h_1 - h_4}{h_2 - h_1}$$

Irreversabilities

$$\eta_c = \frac{h_{2s} - h_1}{h_2 - h_1}$$



HVAC Nomenclature

Tons of Refrigeration → amount of cooling cabability of 1 ton of ice

1 Ton of refrigeration = 200 BTU/min
= 211 KJ/min

EER (energy efficiency ratio)

→ When outside Temp is 95°F

$$EER = \frac{\dot{Q}_{IN}\ [BTU/hr]}{\dot{W}_{IN}\ [W]} = COP\ 3{,}413 = \beta \cdot 3{,}413$$

↑ Unit Conversion

SEER (seasonal energy efficiency ratio)

→ Total cooling over a season (BTU) compared to energy consumption (Watt-hours)

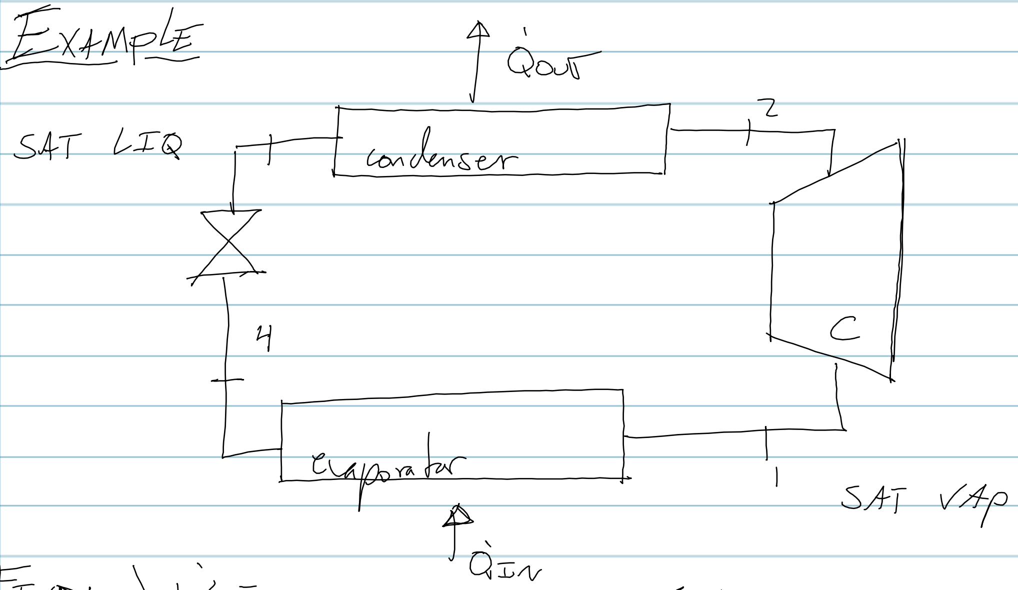
Typically $EER \approx 0.875\, SEER$ //

As of 2006; all residential air-conditioners have $SEER \geq 13$

Monday March 25th, 2013

Exam Next Wednesday
↳ Chapter 9 (no dual cycles)
↳ (practice exam)

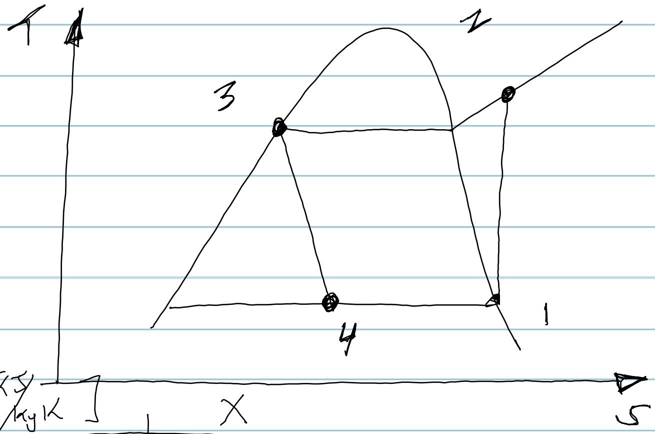
EXAMPLE



FIND: a) $\dot{W}_c =$

b) $\dot{Q}_{IN} =$ [tons]

c) β



STATE	P[Bar]	h [kJ/kg]	s [kJ/kgK]	X
1	2	241.3	0.925^3	SAT. vapor
2	8	269.92	$s_2 = s_1$	
3	8	93.4^2		
4	2	$h_3 = h_4$		

$$\dot{W}_c = \dot{m}(h_2 - h_1) = \frac{7\,kg}{min}(269.92 - 241.3)\frac{kJ}{kg} \times \frac{1\,min}{60\,s}$$

$$= 3.34\,kW \,//$$

$$\dot{Q}_{IN} = \dot{m}(h_1 - h_4) = \quad \times \frac{1\,TON}{211\,kJ/min} = 4.91\ TONS \,//$$

$$\beta = \frac{(h_1 - h_4)}{(h_2 - h_1)} = \quad = 5.17 \,//$$

10.3 Refrigerants

- $T_C + T_H$
- Toxcisity, cost, global warming
- Compressor Type

WEDNESDAY March 27th, 2013

EXAM Review

Monday April 8th, 2013

→ Papers Due Monday
(by Mid-night)
(down @ Mid-night)

→ Wednesday (Turn in H.W.
No class)

10.4 Cascade and Multi-stage systems

Cascade → link 2 or more systems together to reach lower temperatures

Figure 10.9 (pg 605)

$$\beta = \frac{\text{GET OUT}}{\text{PUT IN}} = \frac{\dot{Q}_{IN}}{\dot{W}_{CA} + \dot{W}_{CB}}$$

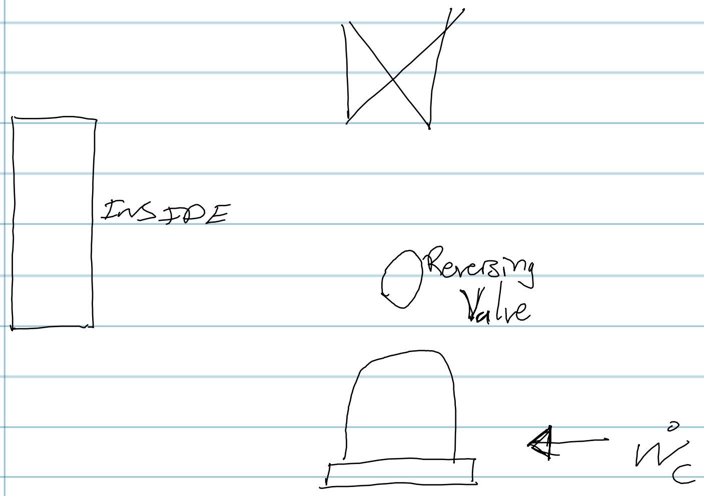
INTER-Cooling → Reduce Compressor Work
Using Flash Chamber

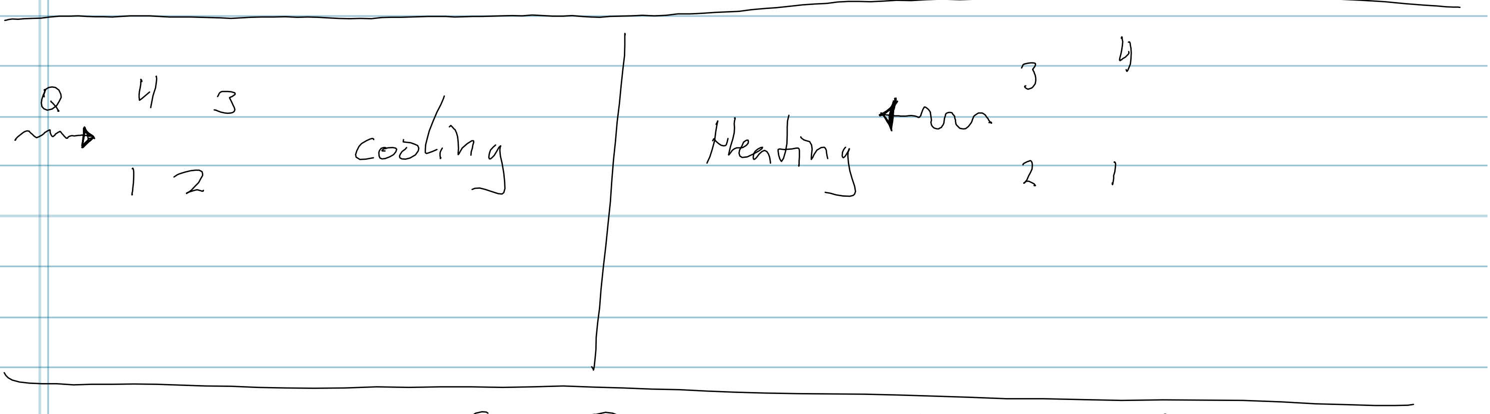
10.5 Absorption Refrigeration

Figure 10.11 pg 607

10.6 Heat Pumps

→ Figure 10.13 pg 609





$$\gamma = \frac{\text{GET OUT}}{\text{PUT IN}} = \frac{h_2 - h_3}{h_2 - h_1}$$ (heating mode)

$$\gamma_{max} = \frac{T_H}{T_H - T_C}$$

Refrigerants

R 1 3 4 a $= CH_2FCF_3$

(# of Carbon Atoms − 1) → 1

(# of flourine atoms) ← 4

(# hydrogen Atoms + 1) ← 3

a → "form of molecule"

- 700 Series, (last two digits are atomic weight)

702	H_2
718	H_2O
729	AIR
744	CO_2

R12 Chlorofloro carbon

ODP: Ozone Depletion Potential

GWP: Global Warming Potential

	ODP	GWP	
R-22	0,05	1700	(Phasing out)
R-134a	0	1300	
R-410a	0	1725	
R-12	1	8500	(Phased out 1996)
R-152a	0	120	
R-1234yf	0	4	

10.7 Gas Refrigeration Systems

Figure 10.15 pg 612

$$\beta = \frac{\dot{Q}_{in}/\dot{m}}{\dot{W}_c/\dot{m} - \dot{W}_t/\dot{m}} = \frac{(h_1 - h_4)}{(h_2 - h_1) - (h_3 - h_4)}$$

Monday April 15th, 2013

(Skipping Chapter 11)

Chapter 12 → Ideal Gas Mixture and Psychrometric Applications

$$n_i = \frac{m_i}{M_i}$$

→ mass of i [lbm] or [kg]

→ Molecular weight [kg/kmol) or [lbm / lbmol]

# of moles

$$\text{Total mass} = \sum_{i=1}^{j} m_i$$

Mass fractions :

$$mf_i = \frac{m_i}{m}$$

$$1 = \sum_{i=1}^{j} mf_i$$

$$n = n_1 + n_2 + \dots + n_j = \sum_{i=1}^{j} n_i$$

$$y_i = \frac{n_i}{n}$$ Mole Fractions (y)

total mass →

total moles →

$$\frac{m}{n} = M \quad \text{OR} \quad M = \sum_{i=1}^{j} y_i M_i$$

Example

1 Kmol of air

$$\left.\begin{array}{lll} 0.708 & \text{Kmol} & N_2 \\ 0{,}2098 & \text{Kmol} & O_2 \\ 0{,}00930 & \ldots & Ar \\ 0.00034 & \ldots & CO_2 \end{array}\right\} y_i$$

	y_i	M_i
N_2	0.7808	28.01
O_2	0.2095	32.00
Ar	0.0093	39.94
CO_2	0.00034	44.01

$M_i \longrightarrow$ appendix $\frac{Kg}{Kmol}$

$$M_{air} = (0.7808 \cdot 28.01) + (0.2095 \cdot 32.00)$$

$$+ \ldots + \ldots$$

$$M_{air} = 28.96 \ Kg/Kmol$$

12.2 Relating p, V, and T for Ideal Gas mixtres

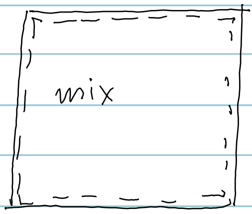
Dalton model → assumes gasses do not interact
→ each component has a partial pressure

$$p_i = \frac{n_i \bar{R} T}{V}$$ Partial Pressure

$$\frac{p_i}{p} = \; = \frac{n_i}{n} = y_i \quad \text{or} \quad p_i = y_i p$$

12.3 Evaluating U, H, S and Specific Heats

closed system



$U = \Sigma U$

$H = \Sigma H$

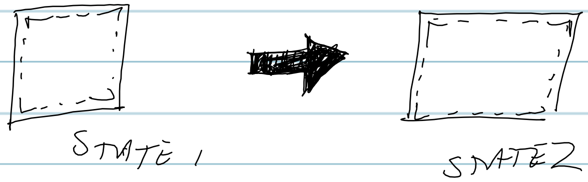
$$\boxed{\begin{aligned} \bar{u} &= \sum y_i \bar{u}_i \\ \bar{h} &= \sum y_i \bar{h}_i \end{aligned}}$$

$$\bar{c}_v = \sum y_i \bar{c}_{vi}$$

$$\bar{c}_p = \sum y_i \bar{c}_{pi}$$

$$\bar{s} = \sum y_i \bar{s}_i \quad //$$

12.4 Analyzing Systems Involving MIXTURES



$$\Delta \bar{u} = \sum y_i \left[\bar{u}_i(T_2) - \bar{u}_i(T_1) \right]$$

$$\Delta \bar{h} = \sum y_i \left[\bar{h}_i(T_2) - \bar{h}_i(T_1) \right]$$

$$\Delta s = \sum y_i \left[\bar{s}_i(T_2, p_2) - \bar{s}_i(T_1, p_1) \right] \quad //$$

$$\Delta s_i = s^{\circ}(T_2) - s^{\circ}(T_1) - \bar{R} \frac{p_{i2}}{p_{i1}}$$

$$\frac{p_{i2}}{p_{i1}} = \frac{p_2}{p_1} = \text{constant composition}$$

$$\Delta \bar{u} = \bar{c}_v (T_2 - T_1)$$

$$\Delta \bar{h} = \bar{c}_p (T_2 - T_1)$$

$$\Delta \bar{s} = \bar{c}_p \ln \frac{T_2}{T_1} - \bar{R} \ln \frac{p_2}{p_1}$$

Example

mix of 5 lb_m of Oxygen &

2 lb_m of Argon

Compressed from: 20 lb_f/in^2 80°F

To: 80 lb_f/in^2 240°F

Can this process be adiabatic

	$m\,(lb_m)$	$M\,[lb_m/lb_{mol}]$	$n_i = m/M$	$y_i = n_i/n$
O_2	5	32.0	0.156	0.757
A_r	2	39.94	0.05	0.243
			Σ: 0.206	

$$\frac{0.156}{0.206}$$

Consv of Mass:

$m = const$

1st law: $Q \to 0$ assumption

$$\Delta U = W$$

2nd law:

$$\Delta S = \cancel{\Sigma \frac{Q}{T}} + \sigma$$

positive → possible

negative → impossible

$$\sigma = \Delta S = n_{O_2}\left[\bar{s}_{O_2}(T_2, p_2) - \bar{s}_{O}(T_1, P_1)\right]$$

s°

$$+ n_{AR}\left[\bar{s}_{Ar}(T_2\ p_2 - \ldots\right.$$

$\ldots$

c_p

We will use s°

$$= n_{O2}\left[s^{o}(T_2) - s^{o}(T_1) - \bar{R}\ln\left(\frac{P_2}{P_1}\right)\right]$$

$$+ n_{AR}\left[c_{p_{ar}}\ln\left(\frac{T_2}{T_1}\right) - \bar{R}\ln\left(\frac{P_2}{P_1}\right)\right]$$

$= -0.143\ \text{BTU}/{}^{o}R \quad - 0.07$

$= -0.213\ \text{BTU}/{}^{o}R \implies$ Process cannot be adiabatic

Wednesday April 17th, 2013

Last H.W. Due Next Wednesday

E.C. Due Monday of Finals Week

12.5 Psychrometric Principles

Humidity ratio

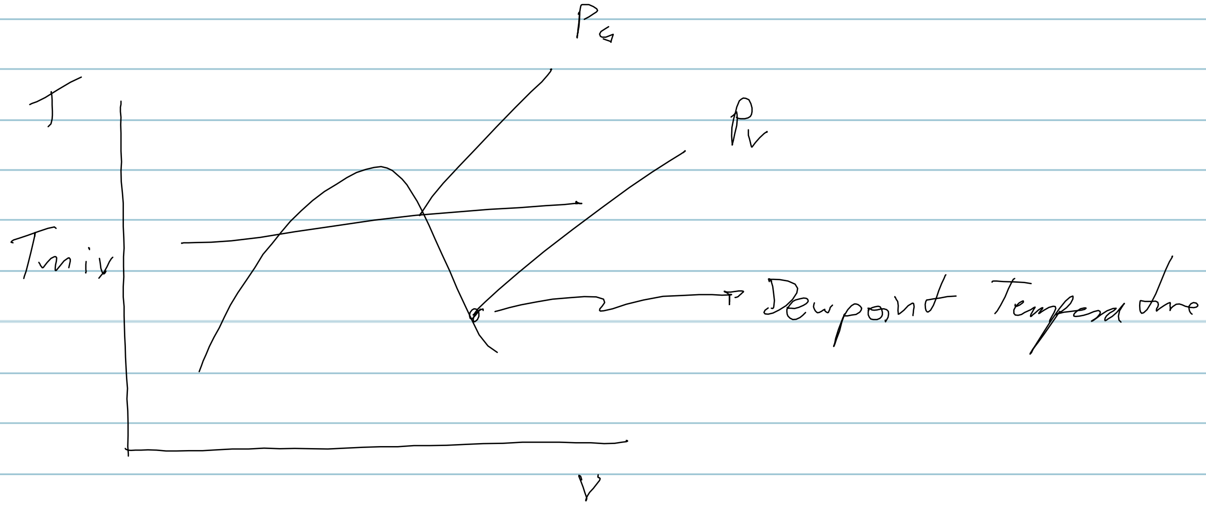
$$\omega = \frac{m_v}{m_a}$$

m_v → mass of vapor

m_a → mass of Dry Air

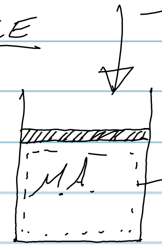
ϕ is relative humidity

$$\phi = \left.\frac{p_v}{p_g}\right|_{T,p} \qquad \frac{\text{mole fraction of } H_2O \text{ in mix}}{\text{'' '' in sat mix}}$$



Dew point Temperature → Temp. at which condensation begins if mix is cooled at constant pressure

EXAMPLE



$p = 100\ KPa$

moist air @ $T = 30°C$

$P_v = 2.33\ KPa$

GOALS: ω, ϕ

$$p = p_v + p_a \quad So; \quad P_a = 97.66\ KPa$$

$$T_{SAT}(P_v = 2.339\ Kpa) = 20°C \quad A\text{-}2$$

$$\phi = \frac{P_v}{P_g(30°C)} = \frac{2.339\ KPa}{4.246\ KPa} = \boxed{56.1\ \%}$$

We use ideal gas law on water vapor now (usually not recommended)

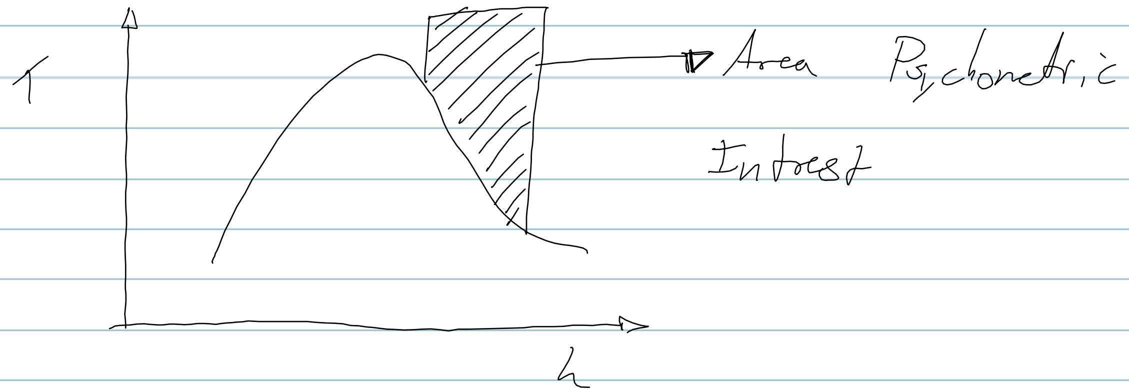
$$\omega = \frac{m_v}{m_a} = \frac{M_v P_v \cancel{V/RT}}{M\ P_a \cancel{V/RT}} = \frac{18.016}{28.97}\left(\frac{P_v}{\underbrace{P - P_v}_{P_a}}\right)$$

$$= 0.662\left(\frac{P_v}{p - p_v}\right)$$

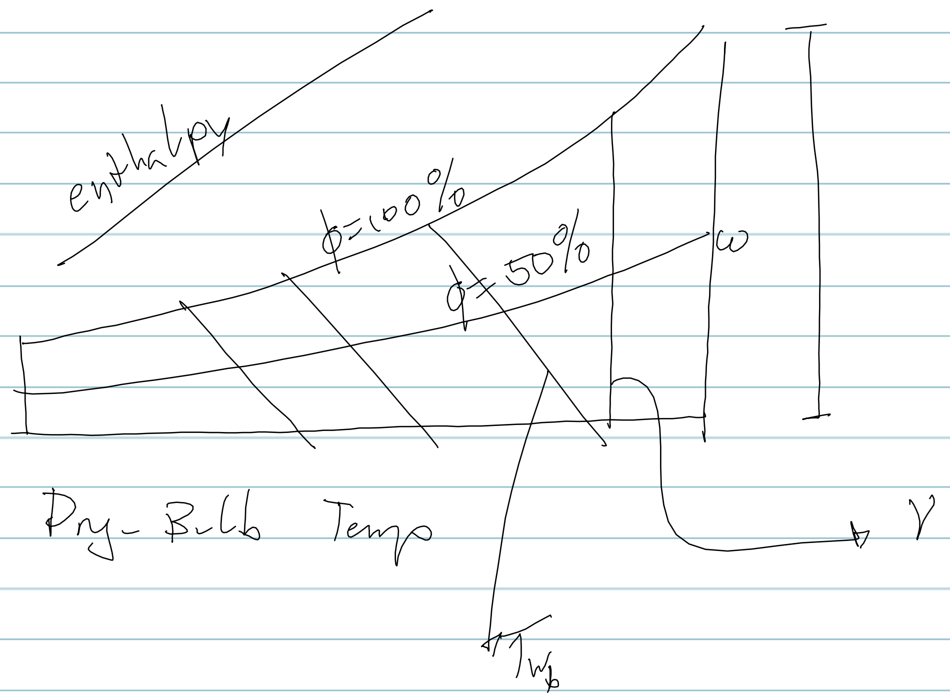
$$\omega = 0.0149\ \frac{kg\ vapor}{kg\ dry\ air}$$

12.6 Wet & Dry Bulb Temperatures

Sling psychrometers & Aspirating psychometer
↳ used to find humidity ratio



We use Figure 12.9 → Psychrometric chart



MIXTURE ENTHALPY

$$H = H_a + H_v = m_a h_a + m_v h_v$$

$$\frac{H}{m_a} = h_a + \frac{m_v}{m_a} h_v = h_a + \omega h_v$$

$$\frac{H}{m_a} = h_a \, \omega h_v \longrightarrow \text{Tabulated Form}$$

on A-9E

Examples

a) $T_{DP} = 65^\circ F$ $\phi = 60\%$ $T_{WB} = 70^\circ F$

↳ constant pressures are ⟷ horizontal

b) $T = 80^\circ F$ $\phi = 70\%$

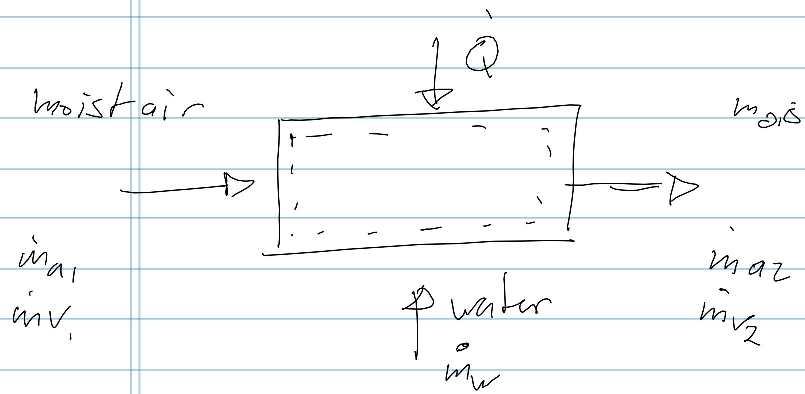
$\omega = 0.021$ $h =$

$T_{WB} = 72$

Monday Apr 22nd, 2013

- → Exam Review Wed
- → Final Exam Next thursday
  - ↳ study guide posted
  - ↳ practice exam posted
  - ↳ 3 Questions
- → last homework due Wednesday
- → Extra Credit Due Next Monday

12.8 Analyse air conditioning Process



Consv of Mass: $0 = \dot{m}_{a1} + \dot{m}_{v1} + \dot{m}_w - \dot{m}_{a2} - \dot{m}_{v2}$

NOTE: $\dot{m}_w + \dot{m}_{v1} = \dot{m}_{v2}$

Also,

$$w_1 = \frac{\dot{m}_{v1}}{\dot{m}_{a1}} = w_2 = \frac{\dot{m}_{v2}}{\dot{m}_{a2}}$$

So, $m_w = -\dot{m}_{v1} + \dot{m}_{v2}$

$$\dot{m}_w = \dot{m}_a(w_2 - w_1)$$

1^ST Law:

$$\cancel{\frac{dE}{dt}} = \dot{Q} - \cancel{\dot{W}} + \sum \dot{m}_i h_i - \sum \dot{m}_e h_e$$

$$0 = \dot{Q} + \dot{m}_{a_1} h_{a_1} + \dot{m}_{v_1} h_{v_1} + \dot{m}_w h_w - \dot{m}_{a_2} h_{a_2} - \dot{m}_{v_2} h_{v_2}$$

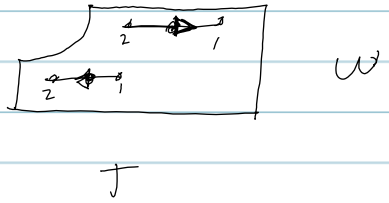
$$h \approx h_g(T)$$

$\dot{m}_{v_1} = \omega_1 \dot{m}_{a_1}$ $\dot{m}_{v_2} = \omega_2 \dot{m}_{a_2}$

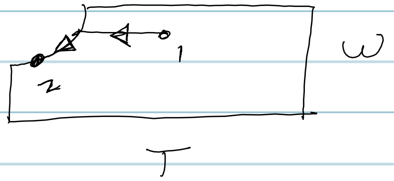
$$0 = \dot{Q} + \dot{m}_a \underbrace{\left(h_{a_1} + \omega_1 h_{g_1}\right)} + \dot{m}_w h_w$$
$$- \dot{m}_a \underbrace{\left(h_{a_2} + \omega_2 h_{g_2}\right)}_{\text{psych Chart}}$$

→ this this the enthalpy from chart

Pure Heating or Cooling

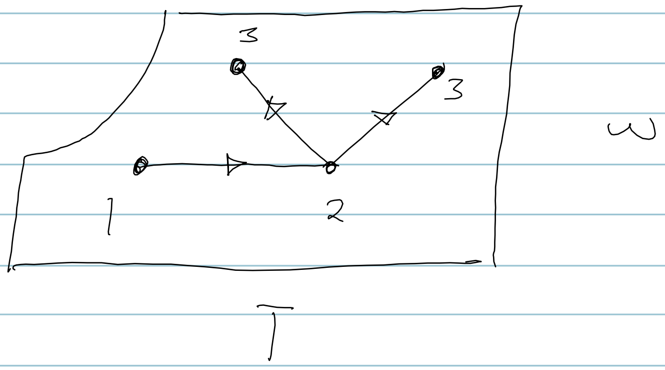


Dehumid & Cooling



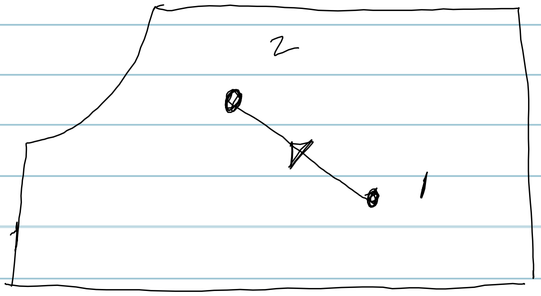
Heating & humidification

(more info needed on 3; is it hot or cold vapor being added)



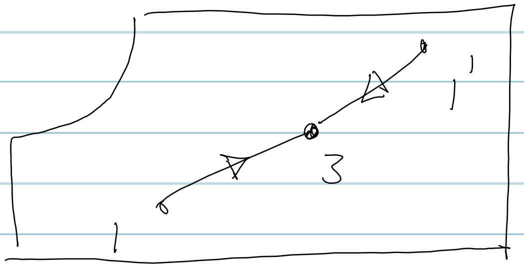
Adiabatic humidification

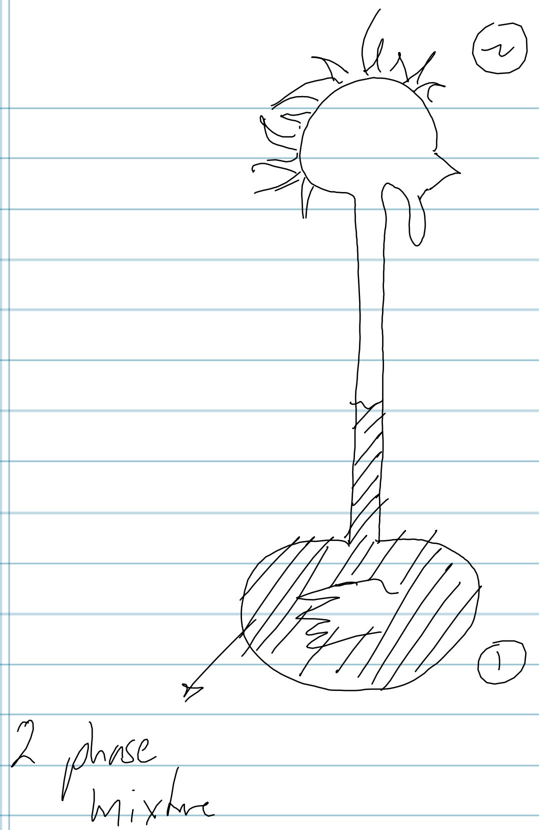
(Evaporative Cooling)



T_{WB} = constant

Adiabatic Mixing





- Water evaporates on head
- Temp of head decreases

Pressure decreases

- When pressure ② lower than P_1

Liquid Rises

Wednesday April 24th, 2013

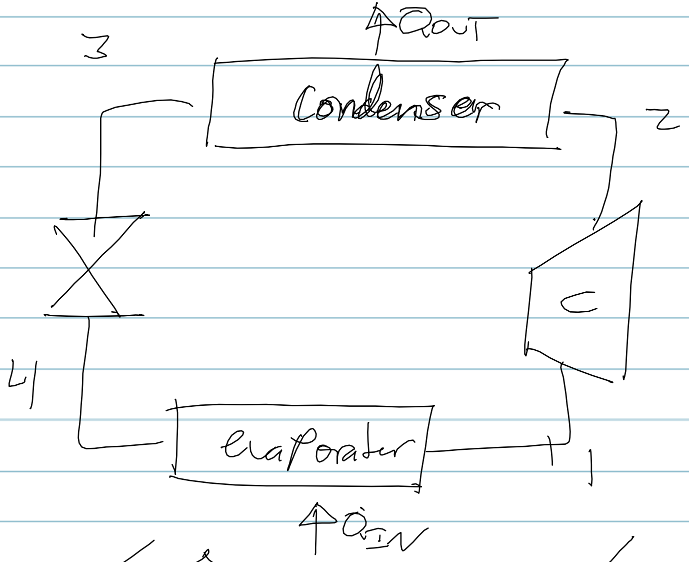
Schedule
- Final Exam Next Thursday
- Extra Credit Due Monday

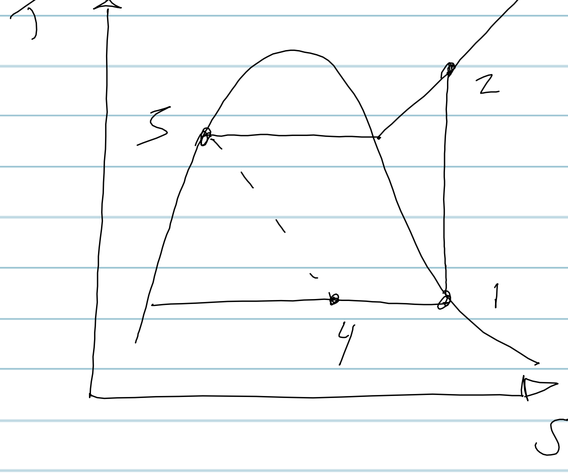
A/C Refrige
- psy & I.G.

Chapter 10

EXAM Review
Ch 10 & Ch 12
-3 PROBS

Vapor Compression Refrigeration





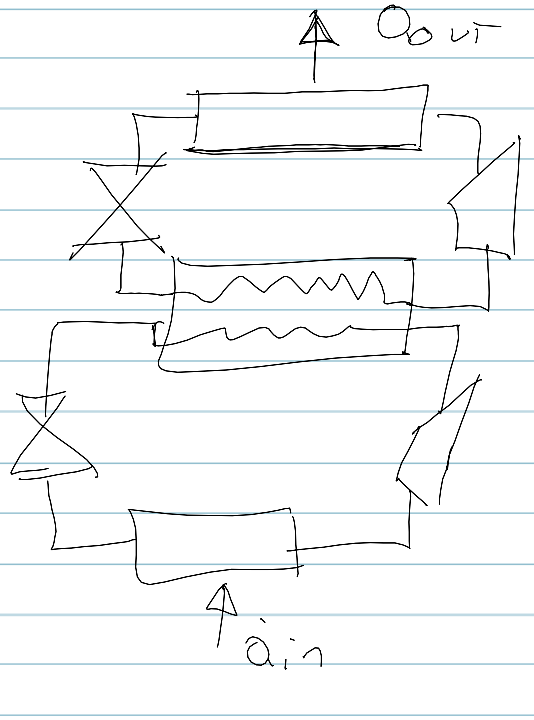
Capacity → $\dot{Q}_{IN}$

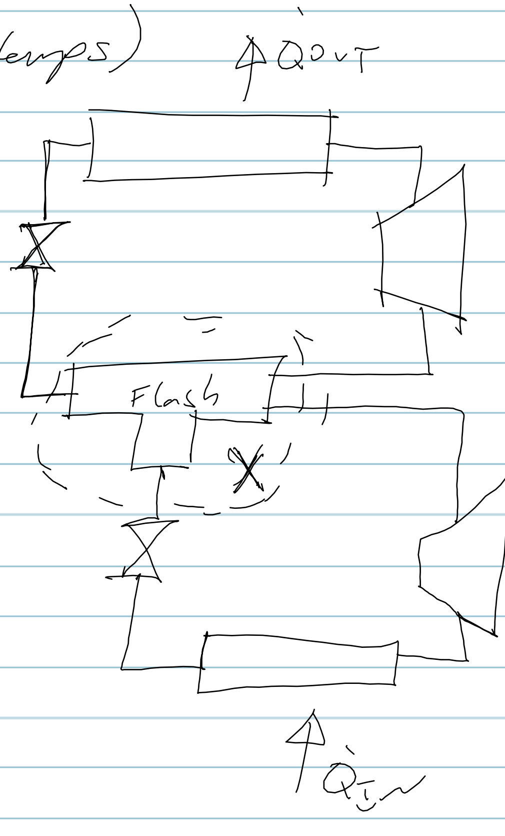
1 Ton Refrigeration $= 200 \frac{BTU}{min} = 211 \frac{kJ}{min}$

COP → coef. of. perform

$$\beta = \frac{\text{we get}}{\text{cost}} = \frac{\dot{Q}_{IN}}{W_c}$$

Cascade System (to lower temps)



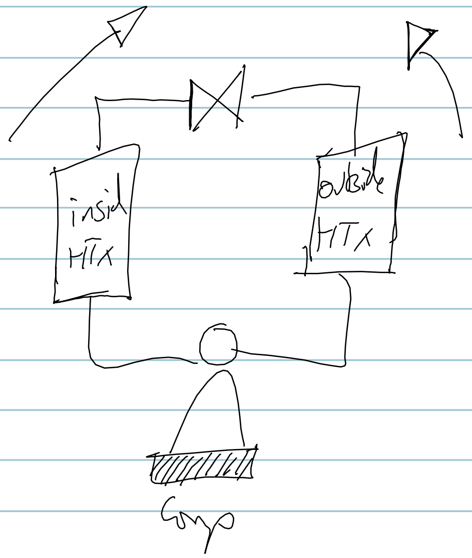


- Absorbtion Cycles
- Brayton cycles (air)

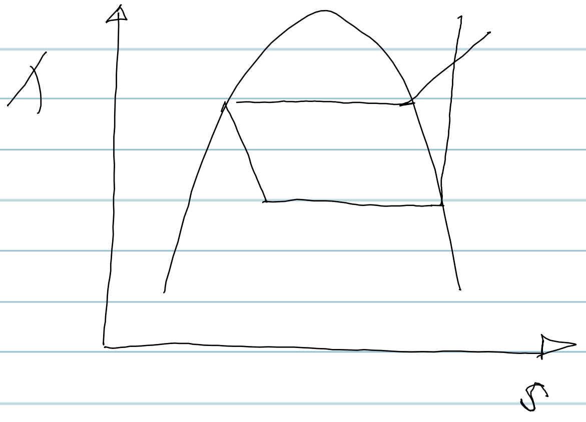
Heat Pumps

Same components

$$\gamma = \frac{\text{get}}{\text{cost}} = \frac{\dot{Q}_{out}}{\dot{W}_c}$$



Be sure to go to & From T-s diagrams



Chapter 12

Ideal Gas MIXTURES

of moles → $n = \frac{m}{M}$

mole fraction → $y_i = \frac{n_i}{n}$

mass fraction → $mf_i = \frac{m_i}{m}$

Properties:

on a per mole basis

$$\bar{u} = \sum y_i \bar{u}_i$$

$$\bar{h} = \sum y_i \bar{h}_i$$

$$\bar{s} = \sum y_i \bar{s}_i$$

+ 1st & 2nd laws apply as before

Psychrometrics:

Relative Humidity: $\phi = \frac{P_v}{P_g}$

Vapor partial pressure

saturated pressure

$$\phi = \frac{y_v}{y_{v,sat}}$$

Humidity ratio

$$\omega = 0.622\left(\frac{P_v}{P - P_v}\right)$$

P_{TOTAL}