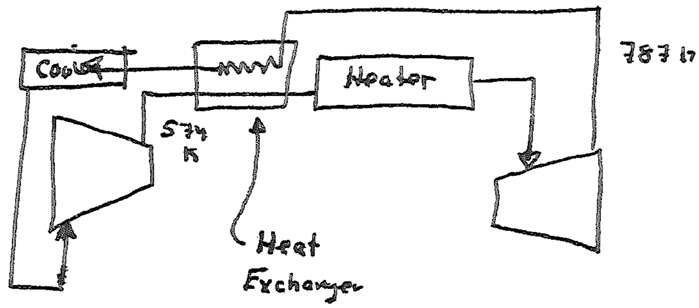


Less Q_{in} needed because some heating supplied internally.

⇒ Regeneration.

⇒ Will explore all these ideas in 323!

<u>Review</u> <u>of</u> <u>Major</u> <u>Relations</u>: ⇒ Yellow tab in summary – Know this.

Definition of entropy: $\Delta S = \int_1^2 \left(\frac{\delta Q}{T}\right)_{rev.}$

→ Can be used directly if path is internally reversible

→ If process between 1 and 2 is not reversible – must construct alternate reversible path to evaluate.

~~From definition~~

$$(S_{gen})_{system} = (S_2 - S_1)_{system} - \int_1^2 \left(\frac{\delta Q}{T}\right)_{system.}$$

$$(S_{gen})_{sys + surroundings} = (S_2 - S_1)_{system} + \frac{Q_{surr}}{T_{surr}}$$

→ Assumes surroundings are at constant T...

① Note that you have to use correct sign on Q

② Other forms include steady flow & unsteady process.

For <u>reversible</u> ($S_{gen} = 0$), adiabatic ($Q = 0$) processes – ⇒ This converts to $S_2 = S_1$ ...

⇒ Ideal pump, compressor, or turbine.

From definition of S, and first law for reversible systems ⇒ Gibbs relations.

$$Tds = du + Pdv$$
$$Tds = dh - vdP$$

Gives us a way to find ΔS from measurable props.
① Develop s values in steam tables via numerical integration.
② For ideal gas - can ~~numerically~~ analytically integrate.

2^{nd} Equation:
I.

$$(s_2 - s_1)_{sys} = \left[\int_1^2 \frac{dh}{T} - \int_1^2 \frac{v\,dP}{T}\right]$$

$$(s_2 - s_1)_{sys} = \int_1^2 \frac{C_P}{T} dT - R\ln\left[\frac{P_2}{P_1}\right]$$

⇒ For ideal gas - s depends on both P, T.

Variable C_P.

$$(S_2 - S_1)_{sys} = S_2^o - S_1^o - R\ln\left[\frac{P_2}{P_1}\right]$$

- From gas tables
- Function of T only.

For isentropic processes: $(\Delta S)_{sys} = 0$

$$\frac{P_2}{P_1} = \frac{P_{r,2}}{P_{r,1}} \qquad \frac{v_2}{v_1} = \frac{v_{r,2}}{v_{r,1}}$$

- Function of T only
- Found in Table A-~~16~~.17

⇒ For other gases that do not list P_r, v_r values (e.g. O_2, N_2), need to use S^o

Constant C_P (inerts & small ΔT)
⇒ Integrate directly

$$(S_2 - S_1)_{sys} = C_P \ln\left[\frac{T_2}{T_1}\right] - R\ln\left[\frac{P_2}{P_1}\right]$$

for convenience in some problems, a slight transformation yields.

$$(S_2 - S_1)_{sys} = C_v \ln\left[\frac{T_2}{T_1}\right] + R\ln\left[\frac{v_2}{v_1}\right]$$

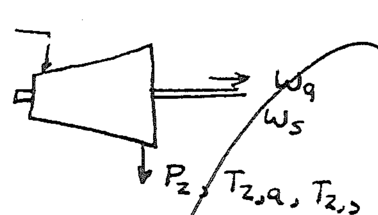
For isentropic processes $(\Delta S)_{sys} = 0$

$$\frac{T_2}{T_1} = \left[\frac{P_2}{P_1}\right]^{K-1/K} \qquad \frac{P_2}{P_1} = \left[\frac{v_1}{v_2}\right]^{K}$$

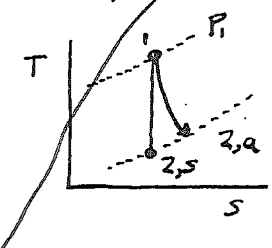
$$\frac{T_2}{T_1} = \left[\frac{v_1}{v_2}\right]^{K-1}$$

$$K = C_P / C_v$$

Compressor and Turbine efficiency:

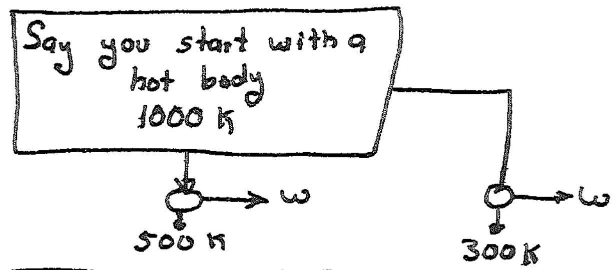


$$\eta_T = \frac{\text{actual } w}{\text{isentropic } w} = \frac{h_1 - h_{2,a}}{h_1 - h_{2,s}} < 1$$



Real η ⇒ Think of some useful work being lost to friction
⇒ Less work comes out because exiting fluid is hotter.

Chapter 7 - Availability/Irreversibility -



Environment is at 300 K, 100 KPa

- You know you can extract work by placing a cycle between the two. How can you get the most?

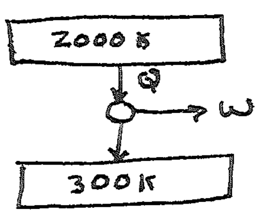
(1) Cycle must be reversible.

(2) Body must finish in equilibrium with the environment.
~~⇒ Dead State~~

⇒ Hotter, and you could still get more work.
⇒ Body cannot go colder because heat cannot be rejected from a cold body to a hot body.

⇒ Body finishing in equilibrium with environment is called the "dead state."

⇒ So, for our gas turbine example



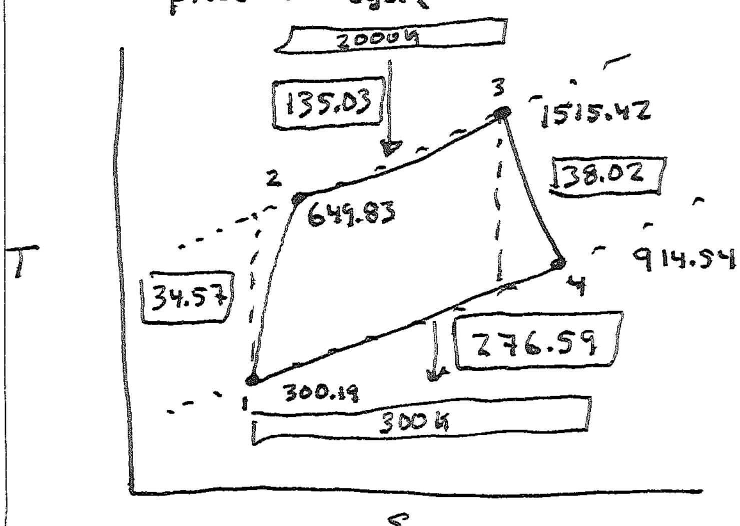
$$\eta = 1 - \frac{T_L}{T_H} = 85\%$$

So 85% of the heat in the furnace is <u>available</u> for conversion to work.

For the case where we had $\eta_c, \eta_T < 1$, $\eta = 29\% \Rightarrow 85 - 29 = 56\%$ of the available work was wasted.

How to find this? <u>Irreversibility</u> $= I = T_o S_{gen}$ ← Environmental Temperature.

= work missing due to specific piece of cycle



Add them up:

		%
W_{net} =	251.24	34.2
I_{1-2} =	34.57	4.7
I_{2-3} =	135.03	18.4
I_{3-4} =	38.02	5.2
I_{4-1} =	276.59	37.6
W_{max} =	735.45	100

$$\eta = \frac{735.45}{865.54} = 85\%$$

⇒ Carnot.

$$I_{1-2} = T_0 S_{gen} = T_0\left[S_2 - S_1 + \cancel{\frac{Q_{surr}}{T_{surr}}}^{\,0}\right]$$

— Where from?

$$T_0(S_2 - S_1) = T_0\left[S_2^\circ - S_1^\circ - R\ln\frac{P_2}{P_1}\right] = 300K\left[2.4781 - 1.70203 - \left(0.287\,\tfrac{KJ}{Kg\cdot K}\right)\ln\left(\frac{10}{1}\right)\right]$$

$$I_{1-2} = 34.57 \text{ KJ/Kg}$$

$$I_{2-3} = T_0 S_{gen} = T_0\left[S_3 - S_2 + \frac{Q_{surr}}{T_{surr}}\right]$$

$$= T_0\left[S_3^\circ - S_2^\circ - \cancel{R\ln\frac{P_3}{P_2}}^{\,0} + \frac{h_2 - h_3}{T_{surr}}\right]$$

$$= (300K)\left[3.362 - 2.4781 + \frac{(647.83 - 1515.42)}{2000}\right] = 135.03 \text{ KJ/Kg}$$

May 29

$$I_{3-4} = T_0\left[S_4^\circ - S_3^\circ - R\ln\frac{P_4}{P_3} + \cancel{\frac{Q_{surr}}{T_{surr}}}^{\,0}\right]$$

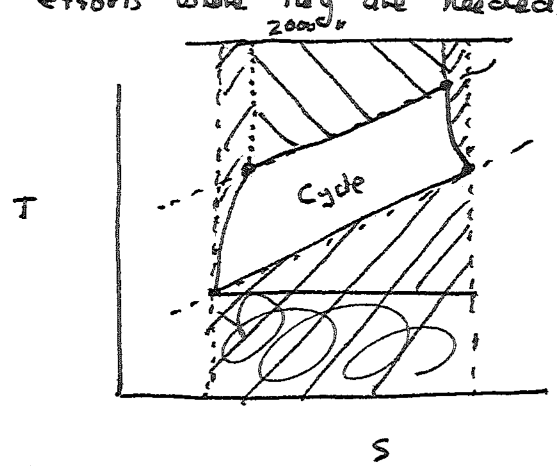
$$= (300K)\left[2.8279 - 3.362 - (0.287)\ln\left[\frac{1}{10}\right]\right] = 38.02 \text{ KJ/Kg}$$

$$I_{4-1} = T_0\left[S_1^\circ - S_4^\circ - \cancel{R\ln\frac{P_1}{P_4}}^{\,0} + \frac{h_4 - h_1}{T_{surr}}\right]$$

$$= (300K)\left[1.70203 - 2.8279 + \frac{914.54 - 300.19}{300K}\right] = 276.59 \text{ KJ/Kg}$$

- So the nice thing about an irreversibility calculation is that it shows where the missing work is lost, and allows you to focus efforts where they are needed.

Graphically:



Four kinds of missing work.

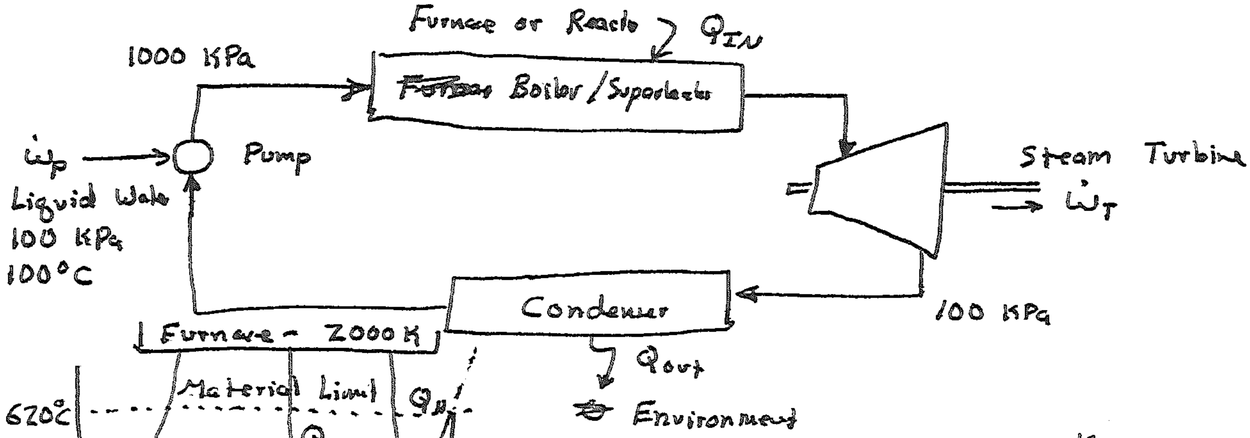
Reed - 6
Ruiz - 13

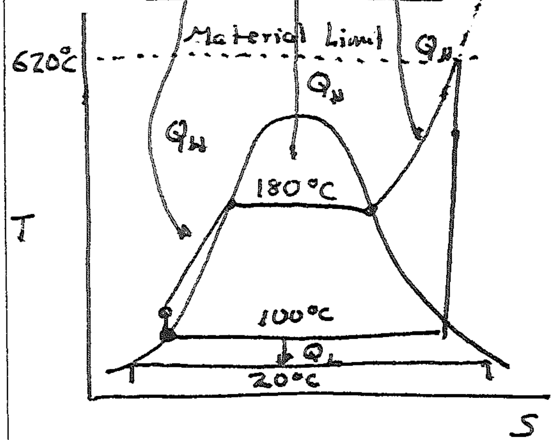
⟹ Key points:
- Dead state
- Availability
- Irreversibility --- How to calculate.

⟹ Reading: 7.1; 7.2, 7.7.

Now, lets talk qualitatively about some other critical cycles.

Rankine Cycle... Steam ~~or Nuclear~~ Power plant





$\Longrightarrow$ Steam Locomotive η = 10%
how to improve.

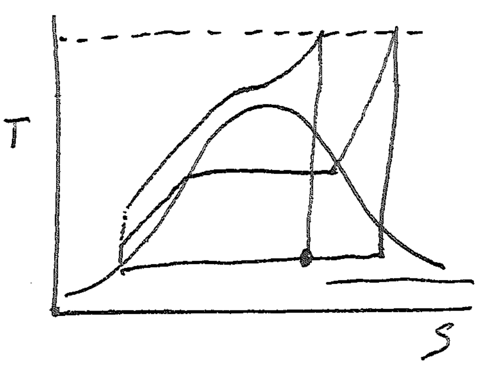
$\Longrightarrow$ Irreversibilities Q_H, Q_L.

$\Longrightarrow$ How to reduce Q_L - Irreversibility?

$\Longrightarrow$ Decrease condenser pressure to sub-atmospheric - no problem!

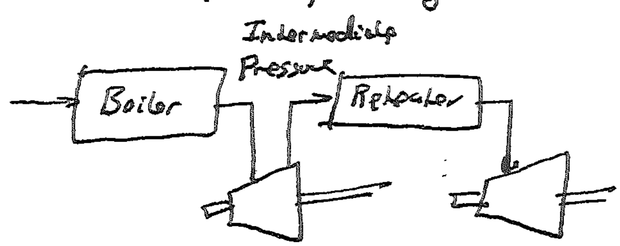
$\Rightarrow$ 30°C = 4.2 KPa

Q_H $\Rightarrow$ Increase upper cycle pressure



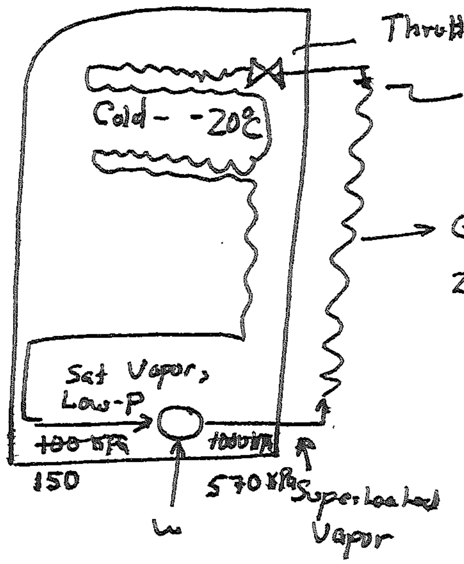
- Higher Temperature for Q_H
- Low quality turbine exit.

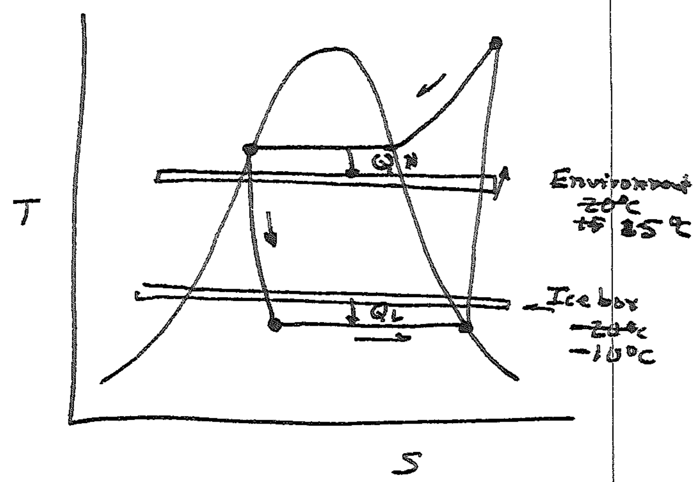
$\Rightarrow$ Solution is to ~~reheat~~ expand partially and reheat.



Did not Cover P 86

Other cycle - basic refrigeration





- Why use a throttle? Why not a turbine ... get some work back.
  - ⇒ Complexity.
  - ⇒ Expanding liquids complex.

- What makes a refrigerant good?
  - Low-P side > 1 atm, so you don't leak air in.
  - Non-reactive, non-toxic.

- R-12 → CF_2Cl_2
  - Inert in troposphere
  - Reaches stratosphere

$$CF_2Cl_2 \xrightarrow{h\nu} CF_2Cl + Cl\cdot$$

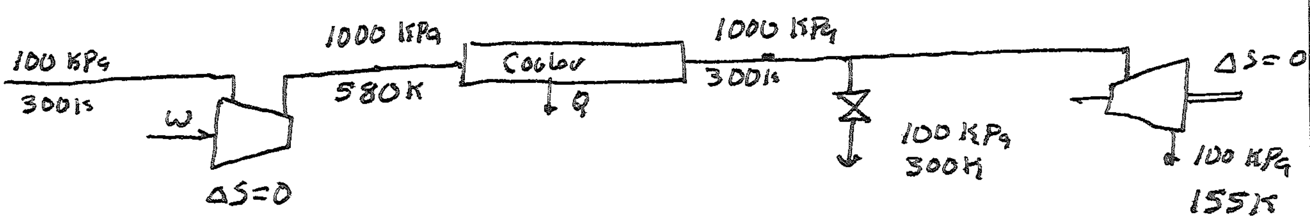
Cycle:

$$\cdot Cl + O_3 \longrightarrow ClO + O_2$$
$$O + ClO \longrightarrow O_2 + Cl\cdot$$

Many O_3's destroyed by a single Cl.
→ Why its so insidious.

R134a → More likely to break down in troposphere.

Air Refrigerator? Airlines so don't carry heavy working fluid.



On airlines ⇒ - Take air off engine compressor
- Cool
- Expand through turbine.

⇒ Friday - ~~Final + CE~~ Review, Final + Class evaluations. (No. 2 pencil).

Early Ch. Concepts u (vs. h) $W_{1-2} = \int F \times \text{displacement} = \int_1^2 P\,dV$

May 31

Q_{1-2}: Final: Comp, but No. Ch. 7 (will see this later).

⇒ Frequent complaint – too many equations. ⇒ Think in terms of a system.

First Law:

⇒ For process occuring between fixed end points Start ① End ②

$$Q - W = \sum m_e\left[h_e + KE_e + PE_e\right] - \sum m_i\left[h_i + KE_i + PE_i\right] + \left[m_2u_2 - m_1u_1\right]_{cv}$$

Cons. of Mass: $\sum m_i - \sum m_e = (m_2 - m_1)_{cv}$

⇒ Common sense lots of times.

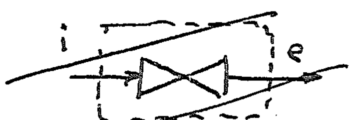
⇒ For a flow process at a particular point in time:

$$\dot{Q} - \dot{W} = \sum \dot{m}_e\left[h_e + KE_e + PE_e\right] - \sum \dot{m}_i\left[h_i + KE_i + PE_i\right] + \frac{d}{dt}\left[mu\right]_{cv}$$

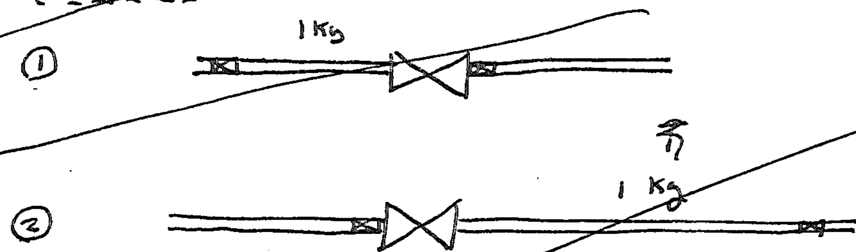
Cons. of Mass: $\sum \dot{m}_i - \sum \dot{m}_e = \frac{dm_{cv}}{dt}$

Key points: Difference between <u>i/e</u> and 1/2

Difference between u and h.



by simplification $h_i = h_e$.



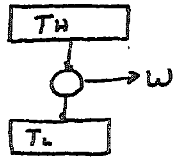
Treat as closed system.

$\cancel{Q}^{0} - W = m(u_e - u_i)$

$\frac{W}{m} = P_e v_e - P_i v_i$

$0 = (u_e + P_e v_e) - (u_i + P_i v_i) \Rightarrow h_e = h_i$ ⇒ If you understand this, you understand the origin of h.

2nd Law: Clausius Inequality $\oint \frac{\delta Q}{T} \le 0$



Maximum Work Power Cycle
Minimum Work Heat Pump.

Entropy.

$$(S_{gen})_{sys} = (S_2 - S_1)_{sys} - \int_1^2 \left(\frac{\delta Q}{T}\right)_{sys}$$

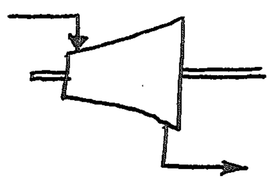
$$(S_{gen})_{sys+surr} = (S_2 - S_1) + \frac{Q_{surr}}{T_{surr}} \quad \text{(assumes } T_{surr} = \text{const).}$$

$S_{gen} \ge 0$ for any real process

$S_{gen} = 0$ for a reversible process

$S_{gen} < 0$ for an impossible process.

~~Adiabatic~~ Take a turbine



If we call it reversible and adiabatic

Reversible means $S_{gen} = 0$
Adiabatic means $Q = 0$ $\Big\} \Rightarrow S_2 = S_1$

Note that it is possible to have ~~an~~ a reversible, non-adiabatic turbine.

Find	$S_2 - S_1$	If $S_2 = S_1$
Steam	Tables.	Tables.
Air Vary C_p	$S_2^o - S_1^o - R \ln \frac{P_2}{P_1}$	$\frac{P_{r,2}}{P_{r,1}} = \frac{P_2}{P_1}$ (also v_r) or $S_2^o = S_1^o + R \ln \frac{P_2}{P_1}$
Const C_p	~~$S_2^o - S_1^o$~~ $C_p \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$	$\frac{T_2}{T_1} = \left[\frac{P_2}{P_1}\right]^{K-1/K}$

~~Gp Mixes & Humidification ⇒ Nothing on Final ⇒ Specialized areas. Later courses.~~

~~Cycles: Nothing new other than repeated application of above.~~

~~$\eta = 1 - \frac{Q_{out}}{Q_{in}}$~~

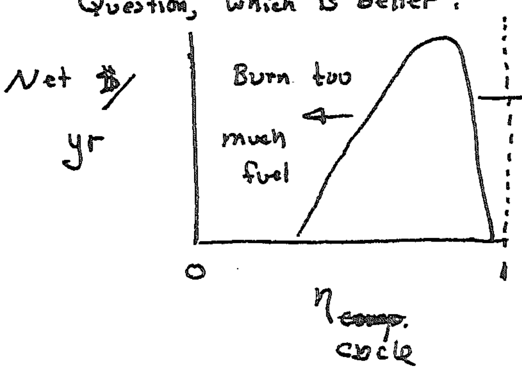
$W = Q_{in} - Q_{out}$.

Efficiency is key, but η costs. In real engineering, you are trying to optimize use of resources. ⇒ Measure is cost.

Gas turbine cycle: Basic cycle ⇒ cycle efficiency = 45.7 %

Same cycle, but $\eta_{comp} = 80\%$, $\eta_{turbine} = 85$ } $\eta_{cycle} = 29\%$

Question, which is better?



What goes on here? → Equipment costs too much.
(fuel savings won't offset)

⇒ Role of engineering design is to use the technical stuff to find the economic optimum.

⇒ Finals similar to other exams,
⇒ Will post tentitive class standing over weekend Glass case MEB.
⇒ Audit for errors.
⇒ Final: Mon: 8:30-10:20 here!
– In Sat. all day.
⇒ Evaluation:

- Participation Vol. / omit items you don't want to answer.
- No names.
- Won't see until its all over.
- No. 2 pencil only.

⇒ Good luck on all finals!

THE END