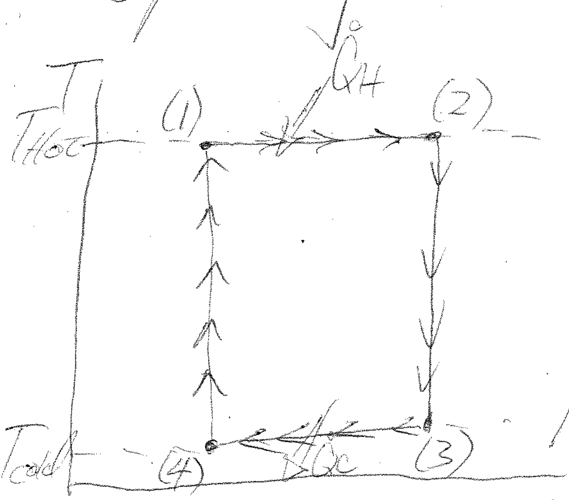
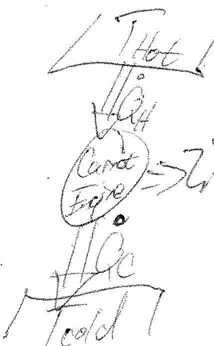
Cycles: Most feasible systems, like refrigerators would not continuously expel refrigerant or the working fluid, especially when you work hard to get a fluid with the correct properties for your system.

Up until now, we have not considered combinations of devices that bring fluids back to their original state ⇒ Cycles

- Closed cycles bring the fluid back to the original state while accomplishing a useful task like moving heat, creating work, ~~propulsion~~, etc.
- Open cycles expel fluid (usually air, sometimes water) back to the environment.

When we started the second law we introduced Ideal or reversible / Carnot heat engines, refrigerators, & heat pumps. These are actually cycles, operating between 2 thermal reservoirs. A Carnot heat engine has the following processes:





1→2) Reversible, isothermal expansion @ T_H

2→3) Reversible, ~~isothermal~~ adiabatic (isentropic) expansion from T_H to T_C

3→4) Reversible, isothermal compression @ T_C

4→1) Reversible, adiabatic compression from T_C to T_H

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The heat is provided reversibly from a constant temperature source so

$$dS = \frac{dQ}{T}\Big|_{rev} \Rightarrow Q_{1\to2} = \int_{T_1}^{T_2} T\,dS \Rightarrow Q_{1\to2} = T_H(S_2 - S_1) \Rightarrow$$

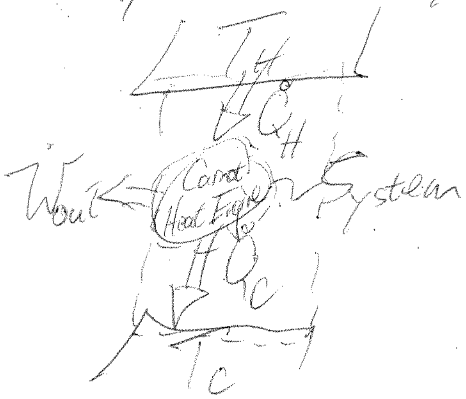
$\leftarrow$ Where $T_1 = T_2 = T_H$ = Constant

area under top line $\Rightarrow Q_{1\to2} = T_H\, m(s_2 - s_1)$

$T_3 = T_4 = T_C$ = Constant

$$Q_{3\to4} = \int_{T_3}^{T_4} T\,dS \Rightarrow Q_{3\to4} = T_C\, m(s_3 - s_4) \leftarrow \text{area under lower curve}$$

Energy Balance on Cycle: $\dot{E}_{in} = \dot{E}_{out} + \frac{dE_{stored}}{dt} \Rightarrow \dot{Q}_{H,in} = \dot{Q}_{C,out} + \dot{W}_{out} \Rightarrow \dot{W}_{out} = \dot{Q}_H - \dot{Q}_C$



so $\dot{W}_{out} = \dot{Q}_{1\to2} - \dot{Q}_{3\to4}$

the area enclosed by the cycle on a T-s diagram is equal to the power produced!!

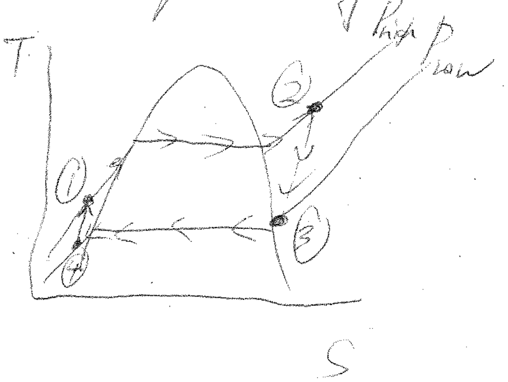
But What about the Efficiency of the cycle?

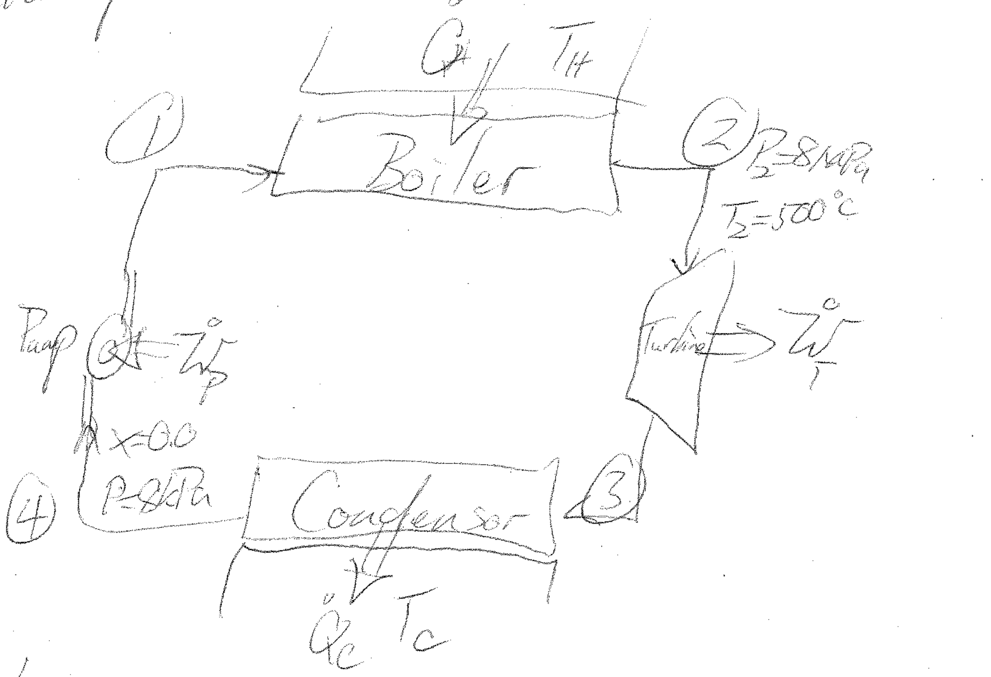
$$\eta_{carnot} = \frac{\text{What you want}}{\text{What you payed}} = \frac{\dot{W}_{net}}{\dot{Q}_H} \Rightarrow \frac{\dot{Q}_{1\to2} - \dot{Q}_{3\to4}}{\dot{Q}_{1\to2}} = 1 - \frac{\dot{Q}_{3\to4}}{\dot{Q}_{1\to2}} \Rightarrow$$

$$\Rightarrow \eta_{carnot} = 1 - \frac{T_C\, \dot{m}(s_3 - s_4)}{T_H\, \dot{m}(s_2 - s_1)} \Rightarrow \underline{\eta_{carnot} = 1 - \frac{T_C}{T_H}}$$ Same as before

- It's difficult (even impossible) to keep a process isentropic, but we can keep fluids nearly isothermal. How? Change the phase (→ draw vapor dome on T-s diagram earlier)

→ It's not quite this easy though. Even small changes in quality have big changes in properties making it difficult to engineer components that change the pressure of 2-phase fluids: pumps don't work well with cavitation, turbines don't work well with water. ⇒ the solution is to move those processes out of the 2-phase region: What do components look like?





Example: Vapor Power cycle has net power 100MW, $P_2 = 8MPa$, $T_2 = 500°C$, $x_4 = 0.0$, $P_4 = 8kPa$. Assume components are ideal.

Find: A) Rate of Heat transfer, B) Thermal Efficiency of cycle

Assumptions: 1) SS, 2) $\Delta P_{Boiler \,\&\, Condenser} = 0$, 3) $\Delta S_{Turbine \,\&\, Pump} = 0$

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Step 1 for solving Cycles: Make a Table

REFPROP

	State	T (°C)	P (kPa)	x (-)	h ($\frac{kJ}{kg}$)	s ($\frac{kJ}{kg\text{-}K}$)
	1	41.751	$=P_2$	Sub	181.89	$=S_4$
Boiler →						
	2	500	8,000	Super	3399.5	6.7266
Turbine →						
	3	41.509	$=P_4$	0.803	2040	$=S_2$
Condenser →						
	4	41.509	8	0.0	173.84	0.59249
Pump →						

Step 2 for Cycles: Analyze Components

Part A. Heat transfer to (from) Boiler: Energy Balance: $\dot{E}_{in} = \dot{E}_{out} + \cancel{\frac{dE_{stored}}{dt}} \Rightarrow \dot{Q}_{in} + \cancel{\dot{W}_{in}} + \dot{m}_{in}\left(h_{in} + \cancel{\frac{V_{in}^2}{2}} + \cancel{gz_{in}}\right)$

$= \cancel{\dot{Q}_{out}} + \cancel{\dot{W}_{out}} + \dot{m}_{out}\left(h_{out} + \cancel{\frac{V_{out}^2}{2}} + \cancel{gz_{out}}\right)$

$\dot{Q}_{in} = \dot{m}(h_{out} - h_{in}) \Rightarrow \dot{Q}_B = \dot{m}(h_2 - h_1)$ what's $\dot{m}$?

We have net cycle power: $\dot{W}_{net} = \dot{W}_{Turb} - \dot{W}_{Pump} \Rightarrow \dot{W}_{net} = \dot{m}(h_2 - h_3) - \dot{m}(h_1 - h_4) \Rightarrow$

$$\Rightarrow \frac{\dot{W}_{net}}{(h_2-h_3)-(h_1-h_4)} = \dot{m} = \frac{100{,}000\ kW}{(3399.5-2040)-(181.89-173.84)} \Rightarrow \dot{m} = 99.617\ \frac{kg}{s}$$

$$\dot{Q}_B = 99.617\ \frac{kg}{s}\,(3399.5 - 181.89) \Rightarrow \boxed{\dot{Q}_B = 320{,}527\ kW}$$

Part B Cycle Efficiency?: $\eta_{Rankine} = \frac{\text{What we want}}{\text{What we payed}} \Rightarrow \frac{\dot{W}_{net}}{\dot{Q}_B} = \frac{100\ MW}{320.5\ MW} \Rightarrow$

$$\eta_{Rankine} = 0.312 = \boxed{31.2\%}$$