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 open heat engines, refrigerators, & heat pumps. These are actually cycles operating between 2 thermal reservoirs. A Carnot heat engine has the following processes:

1. Reversible isothermal expansion @ T4
2. Adiabatic compression
3. Reversible isothermal expansion from T4 to Tc
4. Reversible isothermal compression @ Tc
5. Reversible, adiabatic compression from Tc to T4
The heat is provided reversibly from a constant temperature source so $T_2 = T_1 = T_H = \text{Constant}$

\[ dS = \frac{dQ}{T_H} \Rightarrow Q_{1\to 2} = \int_{T_1}^{T_2} T \, dS \Rightarrow Q_{1\to 2} = T_H (S_2 - S_1) \Rightarrow \]

Area under line $\Rightarrow Q_{1\to 2} = T_H \cdot (S_2 - S_1)$

\[ T_3 = T_4 = T_c = \text{Constant} \]

\[ T_3 \to 4 = \int_{T_3}^{T_4} T \, dS \Rightarrow Q_{3\to 4} = T_c \cdot \ln \left( \frac{S_3}{S_4} \right) = \text{area under lower curve} \]

Energy Balance on Cycle: $E_{in} = E_{out} + dE_{shaft} \Rightarrow Q_H = Q_{out} + W_{out} \Rightarrow T_c = \dot{Q} - \dot{W}$

So $W_{out} = \dot{Q} - \dot{W}$

The area enclosed by the cycle on a $T$-$S$ diagram is equal to the power produced $W$.

But What about the Efficiency of the Cycle?

\[ \eta = \frac{\text{What you want}}{\text{What you paid}} \Rightarrow \eta = 1 - \frac{Q_{3\to 4}}{Q_{1\to 2}} \Rightarrow \]

\[ \eta = 1 - \frac{T_c \cdot \ln \left( \frac{S_3}{S_4} \right)}{T_H \cdot \ln \left( \frac{S_2}{S_1} \right)} \Rightarrow \eta = 1 - \frac{T_c}{T_H} \text{ Same as before} \]
It's difficult (even impossible) to keep a process isentropic, but we can keep fluids nearly isothermal. How? Change the phase (as shown on the T-s diagram earlier).

It's not quite this easy though. Even small changes in inequality have big change 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 these processes out of the 2-phase region. What do components look like?

Example: Vapor Power cycle has net power 100 MW, \( P_2 = 8 \text{ MPa} \), \( T_2 = 500^\circ \text{C} \), \( x = 0 \), \( P_f = 8 \text{ kPa} \). 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) AS Turbine, \( P_{\text{pump}} = 0 \)
Step 1: For solving Cycles: Make a Table

<table>
<thead>
<tr>
<th>Step</th>
<th>Process</th>
<th>P(kPa)</th>
<th>T(°C)</th>
<th>X(%)</th>
<th>h(\text{kg})</th>
<th>s(\text{kg})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Boiler</td>
<td>-P₂</td>
<td>41.75</td>
<td>=</td>
<td>\text{Sub}</td>
<td>181.89</td>
</tr>
<tr>
<td>2</td>
<td>Turbine</td>
<td>8,000</td>
<td>500</td>
<td>=</td>
<td>\text{Super}</td>
<td>3399.5</td>
</tr>
<tr>
<td>3</td>
<td>Condenser</td>
<td>41.509</td>
<td>= P₄</td>
<td>0.803</td>
<td>2040</td>
<td>173.84</td>
</tr>
<tr>
<td>4</td>
<td>Pump</td>
<td>8</td>
<td>41.509</td>
<td>=</td>
<td>0.0</td>
<td>173.84</td>
</tr>
</tbody>
</table>

Step 2: For Cycles: Analyze Components

Part A: Heat transfer to Boiler: Energy Balance: \( E_{in} = E_{out} + W_{net} \)

\[ Q_{1a} = \dot{m}(h_{1a} - h_{2}) \]

\[ Q_{B} = \dot{m}(h_{2} - h_{3}) \]

What's \( \dot{m} \)?

We have net cycle power: \( W_{net} = W_{Turb} - W_{Pump} \)

\[ W_{Turb} = \dot{m}(h_{2} - h_{3}) \]

\[ W_{Pump} = \dot{m}(h_{2} - h_{4}) \]

\[ W_{net} = \dot{m} h_{2} - \dot{m} h_{4} \]

\[ \dot{m} = \frac{W_{net}}{h_{2} - h_{4}} \]

\[ \dot{m} = \frac{100 \text{ MW}}{3399.5 - 173.84} \]

\[ \dot{m} = 99.617 \text{ kg/s} \]

\[ Q_{B} = 99.617 \times (3399.5 - 181.89) \]

\[ Q_{B} = 320.527 \text{ kW} \]

Part B: Cycle Efficiency

\[ \eta = \frac{W_{net}}{Q_{B}} \]

\[ \eta = \frac{100 \text{ MW}}{320.527 \text{ MW}} \]

\[ \eta = 0.312 = 31.2\% \]