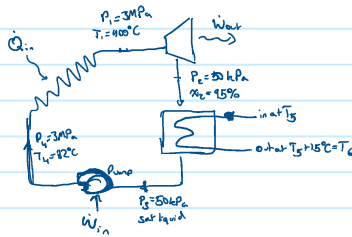


HW5

Monday, September 29, 2025

9:57 PM

1.



Energy loss, KE, PE negligible

a) Thermal efficiency

$$h_1 \text{ at } 3 \text{ MPa}, 400^\circ\text{C} = 3230.9 \frac{\text{kJ}}{\text{kg}}$$

h_4 at 3 MPa, 82°C

$$\text{At } 2.5 \text{ MPa}, 82^\circ\text{C}, h = 345.259$$

$$\frac{420.15 - 345.259}{100 - 80} = \frac{x - 345.259}{82 - 80}$$

$$\text{At } 50 \text{ kPa}, 82^\circ\text{C}, h = 347.237$$

$$\frac{420.15 - 347.237}{100 - 80} = \frac{x - 347.237}{82 - 80}$$

$$\frac{347.237 - 345.259}{5 - 2.5} = \frac{h_4 - 345.259}{3 - 2.5}$$

$$h_4 = 345.655 \frac{\text{kJ}}{\text{kg}}$$

$$W_{out} = \dot{m}(h_1 - h_2)$$

$$W_{in} = \dot{m}(h_4 - h_3)$$

$$\dot{m}(h_1 - h_2 - (h_4 - h_3)) = W_{net}$$

$$Q_{in} = \dot{m}(h_1 - h_4)$$

$$W_{net} = \eta_{th} = \frac{(h_1 - h_2 - (h_4 - h_3))}{h_1 - h_4} = 24.892\%$$

h_3 at 50 kPa, sat liquid =

$$0.5 \text{ bar} \rightarrow 340.44 \frac{\text{kJ}}{\text{kg}}$$

$$h_2 \text{ at } 50 \text{ kPa}, \eta_c = 95\% = 2530.63 \frac{\text{kJ}}{\text{kg}}$$

$$0.15(2645.9 - 340.44) + 340.44$$

b) mass flow rate of the cooling water

$$Q_{out} \dot{m}_c(h_2 - h_3) = \dot{m}_c(146.68 - 83.96)$$

$$\frac{\dot{m}_s}{\dot{m}_c} = 0.020639 \rightarrow 34.919 \dot{m}_s = \dot{m}_c$$

2. F-K-2

Saturated or superheated steam at 293°C, Condensing temp. is 33°C

a) Ideal machine

$$Q_{in} = \dot{m}(h_1 - h_4)$$

$$h_1 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_4 = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$W_{out} = \dot{m}(h_1 - h_4)$$

$$W_{in} = \dot{m}(h_3 - h_4)$$

$$h_3 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_4 = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_2 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_3 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_4 = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_5 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_6 = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_7 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_8 = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_9 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{10} = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_{11} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{12} = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_{13} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{14} = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_{15} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{16} = h_f = 128.91 \frac{\text{kJ}}{\text{kg}}$$

$$h_1 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_2 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_3 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_4 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

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$$h_6 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_7 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_8 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

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$$h_{15} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{16} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{17} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{18} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{19} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{20} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{21} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{22} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_1 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_2 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_3 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_4 = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

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$$h_{20} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{21} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$h_{22} = h_g = 2761.07 \frac{\text{kJ}}{\text{kg}}$$

$$s_{20} = \frac{0.2850 - 0.2945}{25} \cdot 2945 + 0.2945 = 0.2944$$

$$h_{20} = \frac{174.33 - 174.12}{25} \cdot 2.745 + 174.12 = 174.426$$

$$s_{40} = \frac{0.5694 - 0.5694}{25} \cdot 2.745 + 0.5694 = 0.5694$$

$$\frac{0.4471 - 0.2944}{0.5694 - 0.2944} = \frac{h_{21} - 91.26}{174.426 - 91.25} \Rightarrow h_{21} = 146.441$$

$$\text{network} = \dot{W}_{\text{out}} - \dot{W}_{\text{in}} = 994.089 \text{ kW}$$

$$\frac{3600}{\text{network}} = 3.621 \frac{\text{kg steam}}{\text{kWh hr}}$$

$$\dot{W}_{12} = (h_2 - h_3) \dot{m} = 8.41105 \text{ kW}$$

$$\dot{W}_{\text{out}} = (h_1 - h_2) \dot{m} = 1002.5 \text{ kW}$$

$$\dot{Q}_{12} = (h_2 - h_3) \dot{m} = 2614.3 \text{ kW}$$

#cycle 3

$$h_3 = h_f \text{ at } 30^\circ\text{C} = 138.33 \frac{\text{kJ}}{\text{kg}}, s_2 = 0.4789$$

$$\text{at } p = 5 \text{ MPa}$$

$$\frac{h_3 - 88.65}{174.42 - 88.65} = \frac{0.4781 - 29.86}{0.5705 - 0.2956}$$

$$h_2 = 143.964 \frac{\text{kJ}}{\text{kg}}$$

$$h_4 = h_{g \text{ at } 5 \text{ MPa}} = 640.23 \frac{\text{kJ}}{\text{kg}}$$

$$h_5 = h_{g \text{ at } 5 \text{ MPa}} = 2749.7 \frac{\text{kJ}}{\text{kg}}$$

$$h_{20} \text{ at } 5 \text{ MPa} = \frac{2892.2 - 2901.8}{2} + 2901.8 = 2853 \frac{\text{kJ}}{\text{kg}}, s_{20} \text{ at } 5 \text{ MPa} = \frac{59452 - 6.2568}{2} + 6.2568 = 6.091$$

$$h_{320} \text{ at } 5 \text{ MPa} = \frac{2952.6 - 2915.4}{2} + 2915.4 = 2984 \frac{\text{kJ}}{\text{kg}}, s_{320} \text{ at } 5 \text{ MPa} = \frac{6.1044 - 6.4553}{2} + 6.4553 = 6.320$$

$$\frac{(2892.2 - 2853) \cdot 13}{40} + 2853 = h_2 = 2895.58 \frac{\text{kJ}}{\text{kg}}, s_1 = \frac{6.320 - 6.091}{40} \cdot 13 + 6.091 = 6.165$$

$$s_2 = s_1$$

$$\dot{W}_{\text{out}} (h_1 - h_2) \dot{m} = 1012.61 \text{ kW}$$

$$(8.3728 - 0.4917) \times 10.4417 = 6.165$$

$$\dot{W}_{12} = (h_2 - h_3) \dot{m} = 5.634 \text{ kW}$$

$$\kappa_2 = 0.7199$$

$$\dot{Q}_{12} = (h_2 - h_3) \dot{m} = 2751.62$$

$$0.7199 \cdot 2823.4 + 138.33 = h_2 = 1882.97 \frac{\text{kJ}}{\text{kg}}$$

$$\frac{\dot{W}_{\text{out}} - \dot{W}_{12}}{\dot{Q}_{12}} = \eta_{\text{th}} = 36.60\% \text{ for cycle \#3}$$

$$\frac{3600}{100649 \text{ kW}} = 3.58 \frac{\text{kg steam}}{\text{kWh hr}}$$

$$\text{Carnot efficiency} = 1 - \frac{T_c}{T_h} = 1 - \left(\frac{35 + 273.15}{293 + 273.15} \right) = 0.4594$$

$$= 45.94\%$$

	cycle #1	cycle #2	cycle #3
η_{th}	38.03%	45.68%	36.60%
$\frac{\text{kg steam}}{\text{kWh hr}}$	3.621	5.41	3.58

$$\dot{Q}_{12} \text{ in } 3 \rightarrow 4 \left[\frac{\text{kJ}}{\text{kg}} \right] 1158.88 \quad 496.266$$

$$\dot{Q}_{12} \text{ in } 4 \rightarrow 1 \quad 1455.47 \quad 1455.47 \quad 2255.35$$

Advantages / Disadvantages

- Cycle #1 operates on a reheat Rankine cycle with actual reheat; this could be detrimental to the turbine required to get work out as any water could damage the blades. The pump also has to work less hard which could help prolong its use.
- Cycle #2 is a Carnot cycle which achieves maximum efficiency, but is unrealistic with actual machinery and presents a lot of heat transfer problems in terms of ensuring the fluid is at exactly the state necessary.
- Cycle #3 utilizes subcooled and superheated regions of the T-s graph. Though this has the lowest throughput & worst efficiency, it is the most realistic in terms of what physical machinery could withstand or aim to achieve. It would use #3 in the real world.

$$h_{5s} = 2008.6120 \frac{\text{kJ}}{\text{kg}}$$

$$h_c = 161.976 \frac{\text{kg}}{\text{kg}} \quad S_c = 0.5529$$

$$h_1 = 2773.442 \frac{\text{kJ}}{\text{kg}}; s_1 = 5.8216$$

$$\frac{h_6 - h_7}{h_6 - h_{7s}} = 0.85 \rightarrow h_7 = 162.856 \frac{\text{kJ}}{\text{kg}}$$

$$\begin{aligned} \dot{W}_{12} &= \dot{m}(h_1 - h_2) & \dot{W}_{12} &= \dot{m}(h_2 - h_6) \\ \dot{W}_{23} &= \dot{m}(h_3 - h_5) & \dot{W}_{23} &= \dot{m}(h_4 - h_8) \\ \dot{Q}_{12} &= \dot{m}(h_2 - h_1) & \dot{Q}_{12} &= \dot{m}(h_1 - h_4) \end{aligned}$$

$$\begin{aligned} \dot{w}_{out, in} &= 263.652 + 701.14 = 964.792 \frac{\text{kg}}{\text{s}} \\ \dot{w}_{in, tot} &= 0.68 + 7.801 = 8.481 \frac{\text{kg}}{\text{s}} \\ \dot{q}_{in, tot} &= 62.726 + 1440.99 = 2603.72 \end{aligned}$$

If ideal machine,

$$\dot{W}_{out} = \dot{m}(h_3 - h_{5s}) \quad \dot{W}_{in} = \dot{m}(h_5 - h_8)$$

$$\dot{Q}_m = \dot{m} (h_0 - h_{2s}) + (h_1 - h_2)$$

$$\frac{\omega_{\text{out}} - \omega_{\text{in}}}{\Delta t_{\text{inter}}} \cdot \tau_{\text{th}} = 4047^\circ/\text{s}$$