ME 24-221
THERMODYNAMICS I

Solutions to Assignment 11
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11.4 A steam power plant operating in an ideal Rankine cycle has a high pressure of 5 MPa and a low pressure of 15 kPa. The turbine exhaust state should have a quality of at least 95% and the turbine power generated should be 7.5 MW. Find the necessary boiler exit temperature and the total mass flow rate.

C.V. Turbine $w_T = h_3 - h_4$; $s_4 = s_3$

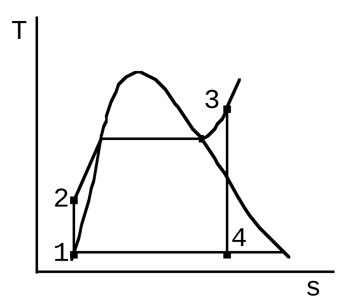
4: 15 kPa, $x_4 = 0.95$ => $s_4 = 7.6458$, $h_4 = 2480.4$

3: $s_3 = s_4$, $P_3 \Rightarrow h_3 = 4036.7$, $T_3 =$ **758°C**

$w_T = h_3 - h_4 = 4036.7 - 2480.4 = 1556.3$

$\dot{m} = \dot{W}_T/w_T = 7.5 \times 1000/1556.3 =$ **4.82 kg/s**

11.13 A steam power plant has a steam generator exit at 4 MPa, 500°C and a condenser exit temperature of 45°C. Assume all components are ideal and find the cycle efficiency and the specific work and heat transfer in the components.



From the Rankine cycle we have the states:

1: 45°C $x = \emptyset$, $v_1 = 0.00101$, $h_1 = 188.45$

2: 4 MPa

3: 4 MPa, 500°C, $h_3 = 3445.3$, $s_3 = 7.0901$

4: $P_{sat}(45°C) = 9.593$

C.V. Turbine: $s_4 = s_3 \Rightarrow x_4 = (7.0901 - 0.6386)/7.5261 = 0.8572$,

$h_4 = 188.42 + 0.8572 \times 2394.77 = 2241.3$

$w_T = h_3 - h_4 = 3445.3 - 2241.3 =$ **1204 kJ/kg**

C.V. Pump: $-w_P = v_1(P_2 - P_1) = 0.00101(4000 - 9.6) =$ **4.03 kJ/kg**

$-w_P = h_2 - h_1 \Rightarrow h_2 = 188.42 + 4.03 = 192.45$ kJ/kg

C.V. Boiler: $q_H = h_3 - h_2 = 3445.3 - 192.45 =$ **3252.8 kJ/kg**

C.V. Condenser: $q_{L,out} = h_4 - h_1 = 2241.3 - 188.42 =$ **2052.9 kJ/kg**

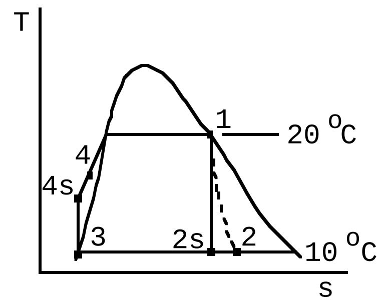
$\eta_{TH} = w_{net}/q_H = (w_T + w_P)/q_H = (1204 - 4.03)/3252.8 =$ **0.369**

11.8 Consider the ammonia Rankine-cycle power plant shown in Fig. P11.8, a plant that was designed to operate in a location where the ocean water temperature is 25°C near the surface and 5°C at some greater depth.

a. Determine the turbine power output and the pump power input for the cycle.

b. Determine the mass flow rate of water through each heat exchanger.

c. What is the thermal efficiency of this power plant?



a) Turbine

$s_{2S} = s_1 = 5.0863 = 0.8779 + x_{2S} \times 4.3269$

$x_{2S} = 0.9726$

$h_{2S} = 227.08 + 0.9726 \times 1225.09 = 1418.6$

$w_{ST} = h_1 - h_{2S} = 1460.29 - 1418.6 = 41.69$

$w_T = \eta_S\, w_{ST} = 0.80 \times 41.69 = 33.35$ kJ/kg

$\dot{W}_T = \dot{m}w_T = 1000 \times 33.35 = \mathbf{33\ 350\ kW}$

Pump: $w_{SP} \approx -v_3(P_4 - P_3) = -0.0016(857 - 615) = -0.387$

$w_P = w_{SP}/\eta_S = -0.387/0.80 = -0.484$ kJ/kg

$\dot{W}_P = \dot{m}w_P = 1000(-0.484) = \mathbf{-484\ kW}$

b) $h_2 = h_1 - w_T = 1460.29 - 33.35 = 1426.94$

$\dot{Q}_{\text{to low T H2O}} = 1000(1426.94 - 227.08) = 1.1999\times10^6$ kW

$$\dot{m}_{\text{low T H2O}} = \frac{1.1999\times10^6}{29.38 - 20.98} = \mathbf{142\ 840\ kg/s}$$

$h_4 = h_3 - w_P = 227.08 + 0.48 = 227.56$

$\dot{Q}_{\text{from high T H2O}} = 1000(1460.29 - 227.56) = 1.2327\times10^6$ kW

$$\dot{m}_{\text{low T H2O}} = \frac{1.2327\times10^6}{104.87 - 96.50} = \mathbf{147\ 280\ kg/s}$$

c) $$\eta_{TH} = \dot{W}_{NET}/\dot{Q}_H = \frac{33\ 350 - 484}{1.2327\times10^6} = \mathbf{0.027}$$

11.15 Steam enters the turbine of a power plant at 5 MPa and 400°C, and exhausts to the condenser at 10 kPa. The turbine produces a power output of 20 000 kW with an isentropic efficiency of 85%. What is the mass flow rate of steam around the cycle and the rate of heat rejection in the condenser? Find the thermal efficiency of the power plant and how does this compare with a Carnot cycle.

Solution: $\dot{W}_T = 20\,000$ kW and $\eta_{Ts} = 85$ %

State 1 : $T_1 = 400^oC$, $P_1 = 5$ MPa , superheated

$h_1 = 3195.6$ kJ/kg , $s_1 = 6.6458$ kJ/kgK

State 3 : $P_3 = P_2 = 10$ kPa , sat liq , $x_3 = 0$

$T_3 = 45.8^oC$, $h_3 = h_f = 191.8$ kJ/kg , $v_3 = v_f = 0.00101$ m^3/kg

C.V Turbine : 1st Law: $q_T + h_1 = h_2 + w_T$; $q_T = 0$

$w_T = h_1 - h_2$, Assume Turbine is isentropic

$s_{2s} = s_1 = 6.6458$ kJ/kgK , $s_{2s} = s_f + x_{2s}\, s_{fg}$, solve for $x_{2s} = 0.7994$

$h_{2s} = h_f + x_{2s}h_{fg} = 1091.0$ kJ/kg

$w_{Ts} = h_1 - h_{2s} = 1091$ kJ/kg , $w_T = \eta_{Ts}w_{Ts} = 927.3$ kJ/kg

$\dot{m} = \dfrac{\dot{W}_T}{w_T} = 21.568$ kg/s , $h_2 = h_1 - w_T = 2268.3$ kJ/kg

C.V. Condenser: 1st Law : $q_c + h_2 = h_3 + w_c$; $w_c = 0$

$q_c = h_3 - h_2 = -2076.5$ kJ/kg , $\dot{Q}_c = \dot{m}\, q_c = -44786$ kW

C.V. Pump: Assume Isentropic

$w_{ps} = -\int v\, dP = -v_3(P_4 - P_3) = -5.04$ kJ/kg

1st Law : $q_p + h_3 = h_4 + w_p$; $q_p = 0$

$h_4 = h_3 - w_p = 196.8$ kJ/kg

C.V Boiler : 1st Law : $q_B + h_4 = h_1 + w_B$; $w_B = 0$

$q_B = h_1 - h_4 = 2998.8$ kJ/kg (or $q_B = w_T + w_B - q_c$)

$w_{net} = w_T + w_P = 922.3$ kJ/kg

$\eta_{th} = w_{net} / q_B =$ **0.307**

Carnot cycle : $T_H = T_1 = 400^oC$, $T_L = T_3 = 45.8^oC$

$$\eta_{th} = \frac{T_H - T_L}{T_H} = 0.526$$