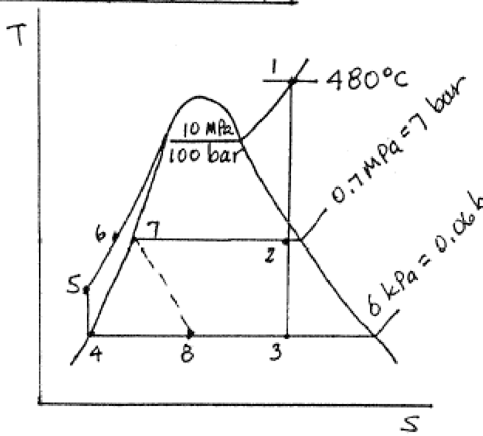
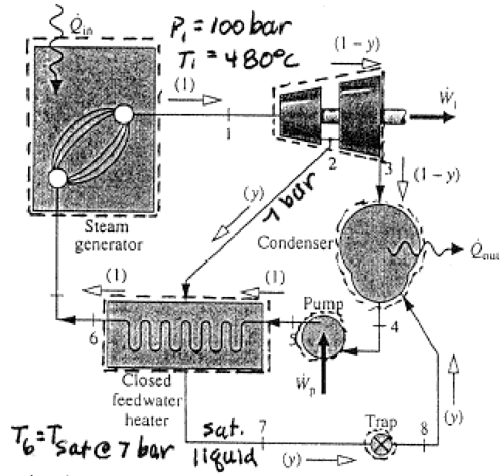
PROBLEM 8.49

KNOWN: Water is the working fluid in an ideal regenerative Rankine cycle with one closed feedwater heater. Data at various locations are known.

FIND: Determine (a) the rate of heat addition per kg of steam entering the first-stage turbine, (b) the thermal efficiency, and (c) the rate of heat transfer for the condenser per kg of steam entering the first-stage turbine.

SCHEMATIC & GIVEN DATA:





ENGINEERING MODEL: (1) Each component is modeled as a control volume at steady state. (2) There are no stray heat transfers. (3) The working fluid undergoes an internally reversible process in passing through each component except the trap. (4) For the trap, $h_7 = h_8$ (throttling process). (5) Kinetic and potential energy effects are negligible.

ANALYSIS: First, fix each principal state.

State 1: $p_1 = 100\text{ bar}, T_1 = 480°C \Rightarrow h_1 = 3321.4\text{ kJ/kg}, s_1 = 6.5282\text{ kJ/kg·K}$

State 2: $p_2 = 7\text{ bar}, s_2 = s_1 \Rightarrow x_2 = \dfrac{s_2 - s_{f2}}{s_{g2} - s_{f2}} = 0.9619, \; h_2 = 2684.8\text{ kJ/kg}$

State 3: $p_3 = 0.06\text{ bar}, s_3 = s_2 \Rightarrow x_3 = 0.7692, \; h_3 = 2009.8\text{ kJ/kg}$

State 4: $p_4 = 0.06\text{ bar}$, sat. liquid $\Rightarrow h_4 = 151.53\text{ kJ/kg}$

State 5: $h_5 \approx h_4 + v_4(p_5 - p_4)$

$$= 151.53 + (1.0064\times10^{-3})\frac{m^3}{kg}(100 - 0.06)\text{bar}\left|\frac{10^5\text{ N/m}^2}{1\text{ bar}}\right|\left|\frac{1\text{ kJ}}{10^3\text{ N·m}}\right|$$

$$= 151.53 + 10.06 = 161.59\text{ kJ/kg}$$

State 6: T_{sat} @ 7 bar $= 165.0°C \Rightarrow h_6 \approx h_f(T_7) = 697.22\text{ kJ/kg}$

State 7: $p_7 = 7\text{ bar}$, sat. liquid $\Rightarrow h_7 = 697.22\text{ kJ/kg}$

State 8: $h_8 = h_7 = 697.22\text{ kJ/kg}$

(a) For the steam generator

$$\dot{Q}_{in}/\dot{m}_1 = h_1 - h_6 = (3321.4 - 697.22) = 2624\text{ kJ/kg} \leftarrow \dot{Q}_{in}/\dot{m}_1$$

(b) Applying mass and energy balances to the control volume enclosing the closed feed water heater

$$y = \frac{h_6 - h_5}{h_2 - h_7} = \frac{697.22 - 161.59}{2684.8 - 697.22} = 0.2695$$

For a control volume enclosing the turbine stages

$$\dot{W}_t/\dot{m}_1 = (h_1 - h_2) + (1 - y)(h_2 - h_3)$$

$$= (3321.4 - 2684.8) + (1 - 0.2695)(2684.8 - 2009.8) = 1129.7\text{ kJ/kg}$$

For the pump

$$\dot{W}_p/\dot{m}_1 = h_5 - h_4 = 161.59 - 151.53 = 10.06\text{ kJ/kg}$$

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Problem 8-49 continued

The net power developed, per unit mass entering the first-stage turbine, is

$$\frac{\dot{W}_{cycle}}{\dot{m}_1} = \frac{\dot{W}_t}{\dot{m}_1} - \frac{\dot{W}_p}{\dot{m}_1} = 1129.7 - 10.06 = 1119.6 \text{ kJ/kg}$$

And the thermal efficiency is

$$\eta = \dot{W}_{cycle}/\dot{Q}_{in} = 1119.6/2624 = 0.427 \ (42.7\%) \leftarrow \eta$$

(c) For the condenser

$$\frac{\dot{Q}_{out}}{\dot{m}_1} = (1-y)h_3 + yh_8 - h_4$$

$$= (1 - 0.2695)(3321.4) + (0.2695)(697.22) - 151.53$$

$$= 1504.1 \text{ kJ/kg} \leftarrow \dot{Q}_{out}/\dot{m}_1$$