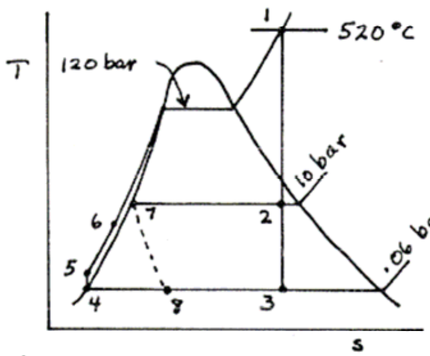
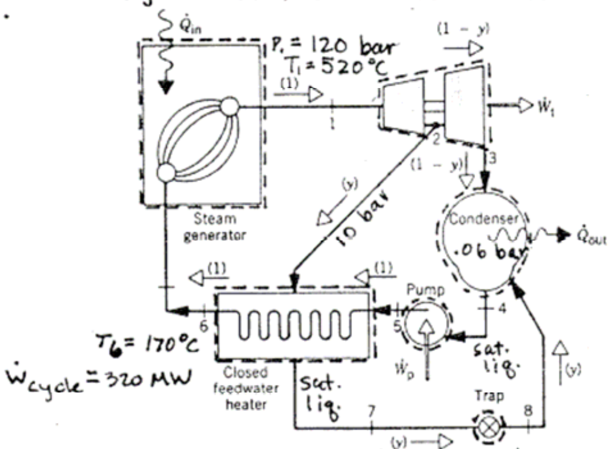
PROBLEM 8.52

KNOWN: Water is the working fluid in a regenerative vapor power cycle with one closed feedwater heater. Data at various locations are known and the net power output is given.

FIND: Determine (a) the thermal efficiency and (b) the mass flow rate into the first turbine stage.

SCHEMATIC & GIVEN DATA:





ENGINEERING MODEL: (1) Each component is analyzed as a control volume at steady state. (2) All processes of the working fluid are internally reversible, except for the expansion through the trap (a throttling process) and in the closed feedwater heater. (3) The turbines, pump, and feedwater heater operate adiabatically. (4) Kinetic and potential energy effects are negligible. (5) Condensate exits the closed heater and the condenser as saturated liquid at the respective pressures.

ANALYSIS: First, fix each of the principal states.

State 1: $p_1 = 120$ bar, $T_1 = 520°C \Rightarrow h_1 = 3401.8$ kJ/kg, $s_1 = 6.5555$ kJ/kg·K

State 2: $p_2 = 10$ bar, $s_2 = s_1 \Rightarrow x_2 = 0.9931$, $h_2 = 2764.2$ kJ/kg

State 3: $p_3 = 0.06$ bar, $s_3 = s_1 \Rightarrow x_3 = 0.7727$, $h_3 = 2018.3$ kJ/kg

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

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

$$= 151.53\ \frac{\text{kJ}}{\text{kg}} + (1.0064\times10^{-3})\frac{\text{m}^3}{\text{kg}}(120 - 0.06)\ \text{bar}\left|\frac{10^5\ \text{N/m}^2}{1\ \text{bar}}\right|\left|\frac{1\ \text{kJ}}{10^3\ \text{N}\cdot\text{m}}\right|$$

$$= 151.53 + 12.07 = 163.6\ \text{kJ/kg}$$

State 6: $p_6 = 120$ bar, $T_6 = 170°C \Rightarrow$ Interpolating in Table A-5, $h_6 = 725.86\ \frac{\text{kJ}}{\text{kg}}$

State 7: $p_7 = 10$ bar, sat. liquid $\Rightarrow h_7 = 762.81$ kJ/kg

State 8: Throttling process $\Rightarrow h_8 = h_7 = 762.81$ kJ/kg

(a) Applying mass and energy rate balances to the control volume surrounding the closed feedwater heater, the fraction of the flow y extracted at location 2 is

$$y = \frac{h_6 - h_5}{h_2 - h_7} = \frac{725.86 - 163.6}{2764.2 - 762.81} = 0.2809$$

For the control volume surrounding the turbine stages

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

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Problem 8-52 continued

$$= (3401.8 - 2764.2) + (1 - .2809)(2764.2 - 2018.3) = 1174.0 \text{ kJ/kg}$$

And, for the pump

$$\frac{\dot{W}_p}{\dot{m}_1} = h_5 - h_4 = 163.6 - 151.53 = 12.07 \text{ kJ/kg}$$

For the working fluid passing through the steam generator

$$\frac{\dot{Q}_{in}}{\dot{m}} = h_1 - h_6 = (3401.8 - 725.86) = 2675.9 \text{ kJ/kg}$$

Thus, the thermal efficiency is

$$\eta = \frac{\dot{W}_t/\dot{m}_1 - \dot{W}_p/\dot{m}_1}{\dot{Q}_{in}/\dot{m}_1} = \frac{1174.0 - 12.07}{2675.9} = 0.434 \ (43.4\%) \longleftarrow \eta$$

(b) The mass flow rate into the first turbine stage is found from

$$\dot{W}_{cycle} = \dot{m}_1 [\dot{W}_t/\dot{m}_1 - \dot{W}_p/\dot{m}_1]$$

or

$$\dot{m}_1 = \frac{\dot{W}_{cycle}}{[\dot{W}_t/\dot{m}_1 - \dot{W}_p/\dot{m}_1]}$$

$$= \frac{(320 \text{ MW})}{[1174.0 - 12.07] \text{ kJ/kg}} \left| \frac{10^3 \text{ kJ/s}}{1 \text{ MW}} \right| \left| \frac{3600 \text{ s}}{1 \text{ h}} \right|$$

$$= 9.91 \times 10^5 \text{ kg/h} \longleftarrow \dot{m}_1$$