PROBLEM 4.102

KNOWN: Steady-state operating data are provided for a simple steam power plant.

FIND: Determine the thermal efficiency and the mass flow rate of the condenser cooling water.

SCHEMATIC & GIVEN DATA:

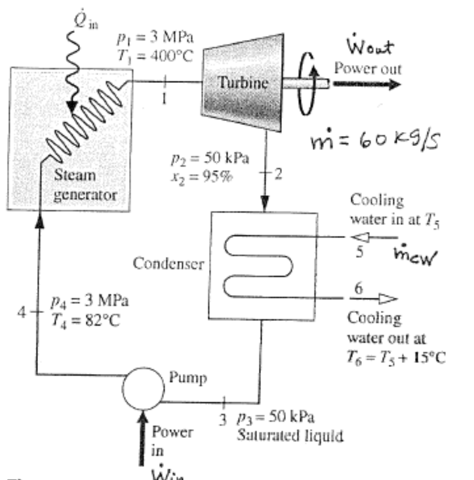

Fig. P4.102

ENGR. MODEL:

1. Control volumes at steady state enclose each of the four components.
2. For each control volume, stray heat transfer and kinetic and potential energy effects are negligible.
3. Energy transfers are in the direction of the arrows.
4. Model the cooling water as incompressible with $(p_6 - p_5) \approx 0$.

ANALYSIS: (a) For any power cycle, the thermal efficiency is

$$\eta = \frac{\dot{W}_{cycle}}{\dot{Q}_{in}}$$

where $\dot{W}_{cycle} = \dot{W}_{out} - \dot{W}_{in}$. In this case, mass and energy rate balances for control volumes enclosing the turbine and pump reduce to read

$$\dot{W}_{out} = \dot{m}\,[h_1 - h_2], \quad \dot{W}_{in} = \dot{m}\,(h_4 - h_3)$$

where $h_1 = 3230.9\ \frac{kJ}{kg}$ (from Table A-4), $h_2 = h_f + x_2(h_g - h_f) = 340.49 + 0.95(2305.4) = 2530.6$ kJ/kg and $h_3 = 340.9$ kJ/kg (Data from Table A-3), $h_4 = 345.66$ kJ/kg (Table A-5).

With these values,

$$\dot{W}_{out} = \dot{m}\,(h_1 - h_2) = 60\ kg/s\,(3230.9 - 2530.6)\frac{kJ}{kg} = 42{,}018\ kJ/s$$

$$\dot{W}_{in} = \dot{m}\,(h_4 - h_3) = 60\ kg/s\,(345.66 - 340.49)\frac{kJ}{kg} = 310\ kJ/s$$

Mass and energy rate balances for a control volume enclosing the steam generator reduce to give $\dot{Q}_{in} = \dot{m}\,(h_1 - h_4) = 60\ kg/s\,(3230.9 - 345.66)\frac{kJ}{kg} = 173{,}114$ kJ/s. The thermal efficiency is then

$$\eta = \frac{42{,}018 - 310}{173{,}114} = 0.241\ (24.1\%) \longleftarrow \eta$$

(b) Mass and energy rate balances for a control volume enclosing the condenser reduce to give

$$0 = \cancel{\dot{Q}_{cv}} - \cancel{\dot{W}_{cv}} + \dot{m}\,[h_2 - h_3] + \dot{m}_{cw}\,[h_5 - h_6]$$

$$\Rightarrow \quad \dot{m}_{cw} = \frac{\dot{m}\,[h_2 - h_3]}{[h_6 - h_5]}$$

where, with assumption 4 and Eq. 3.20b, $(h_6 - h_5) \approx c\,(\underbrace{T_6 - T_5}_{15K}) + \overbrace{v(p_6 - p_5)}^{\sim 0}$. Using $c = 4.2$ kJ/kg·K from Table A-19, we get

$$\dot{m}_{cw} = 60\frac{kg}{s}\left[\frac{2530.6 - 340.49}{(4.2)(15)}\right]$$

$$= 2086\ kg/s \longleftarrow \dot{m}_{cw}$$