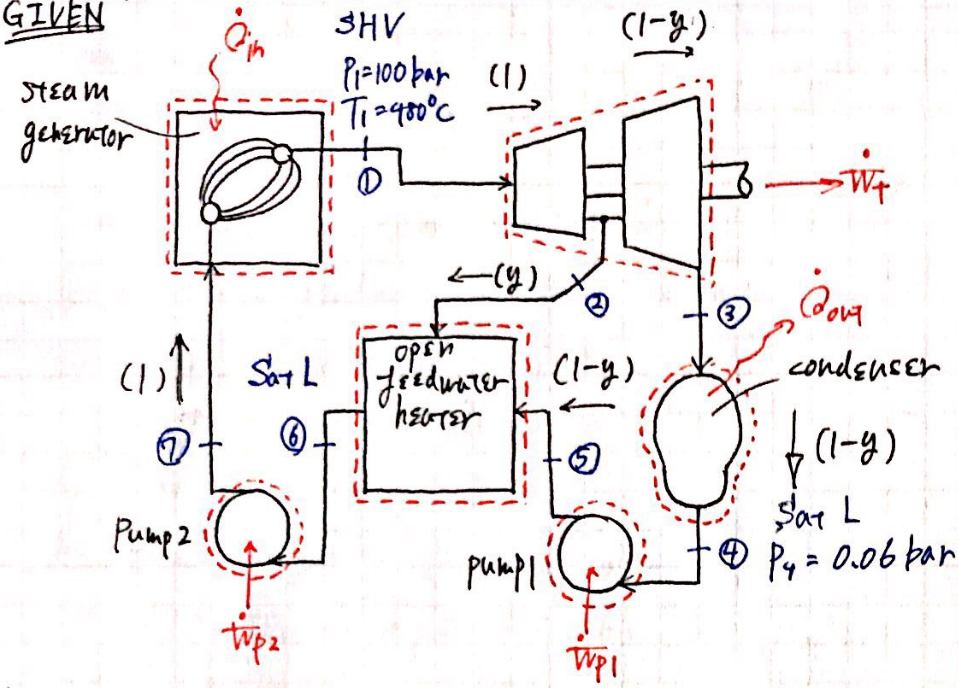
GIVEN



$P_2 = 7$ bar
$P_6 = 7$ bar
$\eta_T = 0.8$
$\eta_{P1} = \eta_{P2} = 0.8$

FIND
(a) $\dot{q}_{71}$ to water, kJ/kg in steam generator
(b) η_{TH}
(c) $\dot{q}_{34}$ (from heated fluid to cooling water) kJ/kg

ASSUMP
SSSF, 1-DUF, open sys, (steam generator, condenser, heater) $\dot{W} = 0$
(turbine, pump) $\dot{Q} = 0$, $\Delta KE = \Delta PE = 0$, open feedwater heater: p = const.

EQN
$$\cancel{\frac{dm}{dt}\Big|_{sys}}^{0} = \sum_i \dot{m} - \sum_e \dot{m}, \quad \cancel{\frac{dE}{dt}\Big|_{sys}}^{0} = \dot{Q} - \dot{W} + \sum_i \dot{m}(h + \cancel{pe}^{0} + \cancel{ke}^{0}) - \sum_e \dot{m}(h + \cancel{pe}^{0} + \cancel{ke}^{0})$$
$$\cancel{\frac{dS}{dt}\Big|_{sys}}^{0} = \sum \frac{\dot{Q}}{T} + \sum_i \dot{m} s_i - \sum_e \dot{m} s_e + \dot{\sigma}_{gen}$$

SOLN

	①	②	③	④	⑤	⑥	⑦
P (bar)	100	7	0.06	0.06	7	7	100
T (°C)	480		36.16	36.16		164.95	
h (kJ/kg)	3323.0	2813.7	2243.1	151.48	152.36	697.00	709.88
s (kJ/kg·K)	6.531	6.8198	7.2827	0.52082		1.9918	
v (m³/kg)	0.03163			0.0010065		0.0011080	

>> from <COM>

say $\begin{cases} \dot{m}_1 = \dot{m}_6 = \dot{m}_7 = \dot{m} \\ \dot{m}_2 = y\dot{m} \\ \dot{m}_3 = \dot{m}_4 = \dot{m}_5 = (1-y)\dot{m} \end{cases}$

>> for the steam generator, from <COE>

$\longrightarrow 0 = \dot{Q}_{71} + \dot{m}_1 h_1 - \dot{m}_7 h_7$

$0 = \dot{q}_{71} + h_1 - h_7$

$\dot{q}_{71} = h_7 - h_1 \cdots ①$

>> for the pump 2, from <COE>

$\longrightarrow 0 = -\dot{W}_{67} + \dot{m}_6 h_6 - \dot{m}_7 h_7$

$\dot{w}_{67} = h_6 - h_7 \cdots ②$

>> for the first-stage turbine

say $\Delta S = 0$, then $s_1 = s_{2s} = 6.531\ kJ/kg\text{-}K$

isentropic quality $\equiv x_{2s} = \left.\dfrac{s_{2s} - s_f}{s_g - s_f}\right|_{p=7bar} = \dfrac{6.531 - 1.9918}{6.7071 - 1.9918} \cong 0.96265 \approx 0.963$

thus, $h_{2s} = h_f + x_{2s}(h_g - h_f)\Big|_{p=7bar} = (697.00\ kJ/kg) + (0.963)(2762.8 - 697.00)\ kJ/kg$

$\cong 2686.4\ kJ/kg$

then

$\longrightarrow h_2 = h_1 - \eta_T(h_1 - h_{2s}) = (3323.0\ kJ/kg) - (0.8)(3323.0 - 2686.4)\ kJ/kg$

$\cong 2813.7\ kJ/kg \longrightarrow$ implies <state 2> SHV

and from interpolation (SHV table @ p=7bar)

$\longrightarrow s_2 = (2813.7 - 2799.4)\ kJ/kg \cdot \dfrac{(6.888 - 6.789)\ kJ/kg\text{-}K}{(2845.3 - 2799.4)\ kJ/kg} + 6.789\ kJ/kg\text{-}K$

$\cong 6.8198\ kJ/kg\text{-}K$

>> now, for second stage turbine

if $\Delta S = 0$ $\quad s_{3s} = s_2 = 6.8198\ kJ/K$

isentropic

$\longrightarrow$ quality $\equiv x_{3s} = \left.\dfrac{s_{3s} - s_f}{s_g - s_f}\right|_{p=0.06bar} = \dfrac{6.8198 - 0.52082}{8.3290 - 0.52082} \cong 0.807$

thus

$\longrightarrow h_{3s} = h_f + x_{3s}(h_g - h_f)\Big|_{p=0.06bar} = (151.48)\ kJ/kg + (0.807)(2566.6 - 151.48)\ kJ/kg$

$\cong 2100.5\ kJ/kg$

therefore

$\longrightarrow h_3 = h_2 - \eta_T(h_2 - h_{3s}) = (2813.7\ kJ/kg) - (0.8)(2813.7 - 2100.5)\ kJ/kg \cong 2243.1\ kJ/kg$

then

$\longrightarrow$ actual quality $= x_3 = \left.\dfrac{h_3 - h_f}{h_g - h_f}\right|_{p=0.06\,bar} = \dfrac{2243.1 - 151.48}{2566.6 - 151.48} \cong 0.866$

so

$\longrightarrow s_3 = s_f + x_3(s_g - s_f)\big|_{p=0.06\,bar} = (0.52082\ kJ/kg\text{-}K) + (0.866)(8.3290 - 0.52082)\ kJ/kg\text{-}K$

$\cong 7.2827\ kJ/kg\text{-}K$

>> for pump 1

if $\Delta S = 0$

$h_{5s} = h_4 + v_4(p_5 - p_4) = 151.48\ kJ/kg + (0.0010065\ m^3/kg)(700\,kPa - 6\,kPa)$

$\cong 152.18\ kJ/kg$

$\longrightarrow h_5 = h_4 + \dfrac{1}{\eta_p}(h_{5s} - h_4) = (151.48\ kJ/kg) + \dfrac{1}{0.8}(152.18 - 151.48)\ kJ/kg$

$\cong 152.36\ kJ/kg$

>> for pump 2

if $\Delta S = 0$

$h_{7s} = h_6 + v_6(p_7 - p_6) = (697.00\ kJ/kg) + (0.001108\ m^3/kg)(100\times10^2\,kPa - 7\times10^2\,kPa)$

$\cong 707.30\ kJ/kg$

$\longrightarrow h_7 = h_6 + \dfrac{1}{\eta_p}(h_{7s} - h_6) = (697.00\ kJ/kg) + \dfrac{1}{0.8}(707.30 - 697.00)\ kJ/kg$

$\cong 709.88\ kJ/kg$

>> for steam generator

$\longrightarrow \dfrac{\dot{Q}_{71}}{\dot{m}} = \dot{q}_{71} = h_1 - h_7 = 3323.0\ kJ/kg - 709.88\ kJ/kg = 2613.12\ kJ/kg \cong \boxed{2610\ kJ/kg}$ —(a)

>> condenser

$\longrightarrow \dot{Q}_{34} = \dot{m}(1-y)(h_4 - h_3)$

$\dot{q}_{34} = (1-y)(h_4 - h_3)$ ....(1)

>> open feedwater heater

$\longrightarrow 0 = y\dot{m}h_2 + (1-y)\dot{m}h_5 - \dot{m}h_6$

$\Longleftrightarrow (h_2 - h_5)y = h_6 - h_5$

$\therefore y = \dfrac{h_6 - h_5}{h_2 - h_5} = \dfrac{697.00 - 152.36}{2813.7 - 152.36} \cong 0.205$

$\therefore (1) \longrightarrow \dot{q}_{34} = (1 - 0.205)(151.48 - 2243.1)\ kJ/kg \cong -1662.8\ kJ/kg$

$\eta_{TH} = \dfrac{\dot{q}_{71} - |\dot{q}_{34}|}{\dot{q}_{71}} = \dfrac{2613.1 - 1662.8}{2613.1} \cong \boxed{0.364}$ —(b)

FINALLY

since $\dot{q}_{34} = -1662.8\ kJ/kg$

the heat transfer going into cooling water is

$$\therefore \dot{q}_w = -\dot{q}_{34} = 1662.8\ kJ/kg$$

$$\simeq \boxed{1660\ kJ/kg}$$