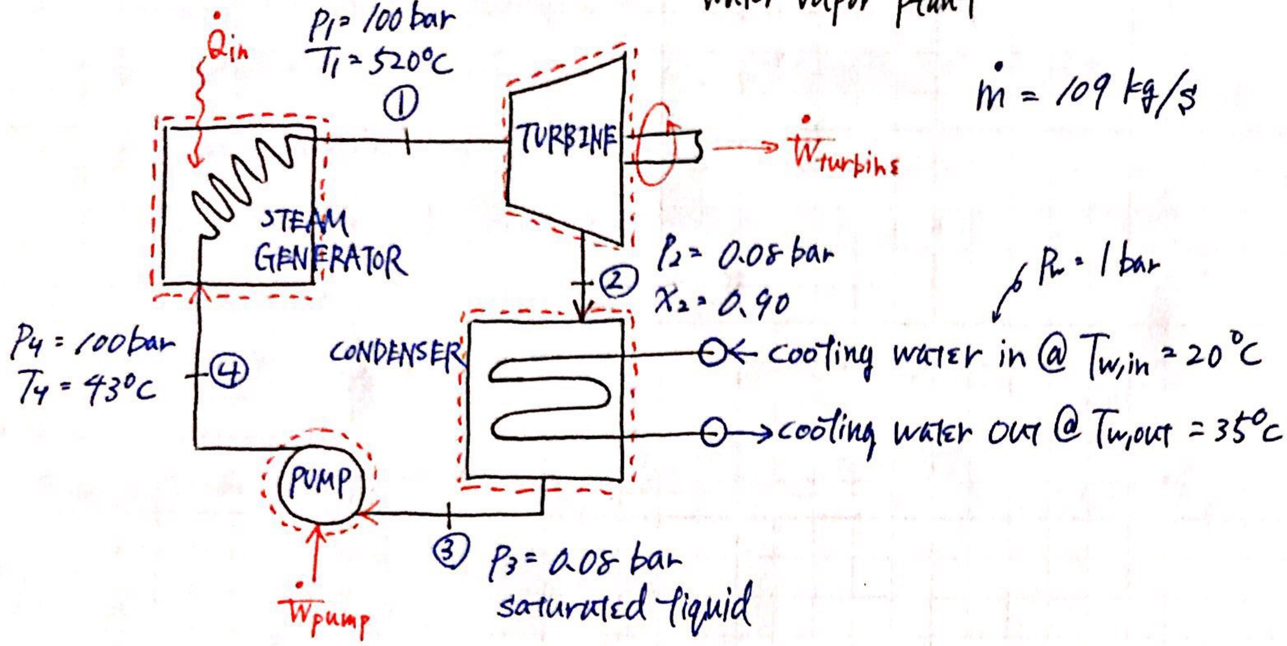
GIVEN & <EPD>

water vapor plant

$\dot{m} = 109\ kg/s$



FIND (a) net power, P_{net} kW
(b) thermal efficiency, $\eta_{thermal}$
(c) isentropic turbine efficiency $(\eta_{isentropic})_{turbine}$
(d) " pump " $(\eta_{isentropic})_{pump}$
(e) mass flow rate of water, $\dot{m}_w$ kg/s
(f) rate of entropy generation for each $(\dot{S}_{gen})_{turbine}$, $(\dot{S}_{gen})_{condenser}$, $(\dot{S}_{gen})_{pump}$

ASSUMP open sys, SSSF, 1-DUF, $\Delta KE = \Delta PE = 0$
Turbine: $\dot{Q} = 0$; condenser: $\dot{Q} = 0$, $\dot{W} = 0$; pump: $\dot{Q} = 0$
Steam generator: $\dot{W} = 0$

EQN $\cancel{\left.\frac{dm}{dt}\right|_{sys}}^{0} = \sum_i \dot{m} - \sum_e \dot{m}$, $\cancel{\left.\frac{dE}{dt}\right|_{sys}}^{0} = \dot{Q} - \dot{W} + \sum_i \dot{m}(h + \cancel{pe}^{0} + \cancel{ke}^{0}) - \sum_e \dot{m}(h + \cancel{pe}^{0} + \cancel{ke}^{0})$

$\cancel{\left.\frac{ds}{dt}\right|_{sys}}^{0} = \sum \frac{\dot{Q}}{T} + \sum_i \dot{m} s_i - \sum_e \dot{m} s_e + \dot{S}_{gen}$

SOLN from tables

	STATE	P (bar)	T (°C)	x	v (m³/kg)	h (kJ/kg)	s (kJ/kg·K)
SHV →	1	100	520	1	0.03397	3426.4	6.665
SLVM →	2	0.08	41.51	0.90	16.2892	2335.96	7.4638
sat liq →	3	0.08	41.51	0	0.0010085	173.84	0.59249
comp liq →	4	100	43	0	0.0010091	188.85	0.60605

(STATE 2)

$v_2 = v_f|_{p=0.08} + (v_g|_{p=0.08} - v_f|_{p=0.08})x_2$

$= (0.0010085\ m^3/kg) + (18.099\ m^3/kg - 0.0010085\ m^3/kg)(0.90) \approx 16.2892\ m^3/kg$

$h_2 = h_f|_{p=0.08} + (h_g|_{p=0.08} - h_f|_{p=0.08})x_2$

$= (173.84\ kJ/kg) + (2576.2\ kJ/kg - 173.84\ kJ/kg)(0.90) \simeq 2335.96\ kJ/kg$

$s_2 = s_f|_{p=0.08} + (s_g|_{p=0.08} - s_f|_{p=0.08})(x_2)$

$= (0.59249\ kJ/kg\text{-}K) + (8.2273\ kJ/kg\text{-}K - 0.59249\ kJ/kg\text{-}K)(0.90) \simeq 7.4638$

(STATE 4) interpolate

$h_{comp,liq}(100\ bar, 43°C) = (43°C - 40°C)\dfrac{342.94\ kJ/kg - 171.31\ kJ/kg}{80°C - 40°C} + 171.36\ kJ/kg$

$\simeq 188.85\ kJ/kg$

likewise interpolate

$s_4 = (43°C - 40°C)[(1.0691\ kJ/kg\text{-}K - 0.5685\ kJ/kg\text{-}K)/(80°C - 40°C)] + 0.5685\ kJ/kg\text{-}K$

$\simeq 0.60605\ kJ/kg$

(a) (turbine) $0 = -\dot{W}_{turbine} + \dot{m}(h_1 - h_2)$

$\dot{W}_{turbine} = (3426.4\ kJ/kg - 2335.96\ kJ/kg)(109\ kg/s) = 1.1886 \times 10^5\ kW$

(pump)

$0 = -\dot{W}_{pump} + \dot{m}(h_3 - h_4)$

$\dot{W}_{pump} = (173.84\ kJ/kg - 188.85\ kJ/kg)(109\ kg/s) \simeq -1.6361 \times 10^3\ kW$

$\dot{W}_{net} = \dot{W}_{turbine} + \dot{W}_{pump} \simeq 1.1769 \times 10^5\ kW$

$\boxed{\dot{W}_{net} = 1.18 \times 10^5\ kW}$

(b) (steam generator)

$0 = \dot{Q}_{in} + \dot{m}(h_4 - h_1)$

$\dot{Q}_{in} = \dot{m}(h_1 - h_4) = (109\ kg/s)(3426.4\ kJ/kg - 188.85\ kJ/kg)$

$\simeq 3.5289 \times 10^5\ kW$

$\therefore \eta_{thermal} = \dfrac{\dot{W}_{net}}{\dot{Q}_{in}} = \dfrac{1.1708 \times 10^5\ kW}{3.5289 \times 10^5\ kW} \simeq 0.33350$

$\boxed{\eta_{thermal} = 33.4\%}$

(c)

if isentropic

$$0 = \dot{m}(s_1 - s_{2s}) \iff s_{2s} = s_1 = 6.665 \text{ kJ/kg-K}$$

$$x_2' = \frac{s_{2s} - s_f|_{p=0.08}}{s_g|_{p=0.08} - s_f|_{p=0.08}} = \frac{6.665 \text{ kJ/kg-K} - 0.59249 \text{ kJ/kg-K}}{8.2273 \text{ kJ/kg-K} - 0.59249 \text{ kJ/kg-K}} \cong 0.79537$$

$$h_{2s} = h_f|_{p=0.08} + (h_g|_{p=0.08} - h_f|_{p=0.08})x_2'$$

$$= (173.84 \text{ kJ/kg}) + (2576.2 \text{ kJ/kg} - 173.84 \text{ kJ/kg})(0.79537) \cong 2.0846 \times 10^3 \text{ kJ/kg}$$

$$(\dot{W}_{isentropic})_{turbine} = \dot{m}(h_1 - h_{2s}) = (109 \text{ kg/s})(3426.4 \text{ kJ/kg} - 2.0846 \times 10^3 \text{ kJ/kg})$$

$$\cong 1.4626 \times 10^5 \text{ kW}$$

$$(\eta_{isentropic})_{turbine} = \frac{\dot{W}_{turbine}}{(\dot{W}_{isentropic})_{turbine}} = \frac{1.1886 \times 10^5 \text{ kW}}{1.4626 \times 10^5 \text{ kW}} \cong 0.8126$$

$$\boxed{(\eta_{isentropic})_{turbine} = 81.3\%}$$

(d)

if $\Delta s = 0$

pump $\Rightarrow s_3 = s_{4s} = 0.59249$ from compressed liquid table

interpolate @ $p = 100$ bar

$$h_{4s} = (s_3 - 0.5685 \text{ kJ/kg-K})\frac{(342.94 \text{ kJ/kg} - 176.36 \text{ kJ/kg})}{1.0691 \text{ kJ/kg-K} - 0.5685 \text{ kJ/kg-K}} + 176.36 \text{ kJ/kg}$$

$$\cong 184.34 \text{ kJ/kg} = 1.8434 \times 10^2 \text{ kJ/kg}$$

$$\therefore (\dot{W}_{isentropic})_{pump} = \dot{m}(h_3 - h_{4s}) = (109 \text{ kg/s})(173.84 \text{ kJ/kg} - 1.8434 \times 10^2 \text{ kJ/kg})$$

$$= -1.1445 \times 10^3 \text{ kW}$$

$$(\eta_{isentropic})_{pump} = \frac{(\dot{W}_{isentropic})_{pump}}{\dot{W}_{pump}} = \frac{-1.1445 \times 10^3 \text{ kW}}{-1.6361 \times 10^3 \text{ kW}} \cong 0.6995$$

$$\boxed{(\eta_{isentropic})_{pump} = 70.0\%}$$

(e)

@ $p_w = 1$ bar $T_{w,in} = 20°C$

$$h_{w,in} = h_f|_{T=20°C} + v_f|_{T=20°C}(100 \text{ kPa} - p_{sat}|_{T=20°C})$$

$$= 83.914 \text{ kJ/kg} + (0.0010018 \text{ m}^3\text{/kg})(100 \text{ kPa} - 2.3393 \text{ kPa})$$

$$\cong 84.012 \text{ kJ/kg}$$

$$h_{w,out} = h_f|_{T=35°C} + v_f|_{T=35°C}(100\,kPa - P_{sat}|_{T=35°C})$$
$$= 146.63\,kJ/kg + (0.0010060\,m^3/kg)(100\,kPa - 5.6290\,kPa)$$
$$\simeq 146.72\,kJ/kg$$

(condenser)

$$0 = \dot{m}(h_2 - h_3) + \dot{m}_w(h_{w,in} - h_{w,out})$$
$$\dot{m}_w = \frac{\dot{m}(h_2 - h_3)}{h_{w,out} - h_{w,in}} = \frac{(109\,kg/s)(2335.96\,kJ/kg - 173.84\,kJ/kg)}{(146.72\,kJ/kg - 84.012\,kJ/kg)}$$
$$\simeq 3.7582 \times 10^3\,kg/s$$

$$\boxed{\dot{m}_w = 3.76 \times 10^3\,kg/s}$$

(f)

$$(\dot{\sigma}_{gen})_{turbine} = \dot{m}(s_2 - s_1)$$
$$= (109\,kg/s)(7.4638\,kJ/kg\text{-}K - 6.665\,kJ/kg\text{-}K)$$
$$\simeq \boxed{87.069\,kW/K}$$

$$(\dot{\sigma}_{gen})_{condenser} = \dot{m}(s_3 - s_2) + \dot{m}_w(s_f|_{T=35°C} - s_f|_{T=20°C})$$
$$= (109\,kg/s)(0.59249 - 7.4638)(kJ/kg\text{-}K)$$
$$+ (3.76 \times 10^3\,kg/s)(0.505130 - 0.296480)(kJ/kg\text{-}K)$$
$$\simeq \boxed{35.551\,kW/K}$$

$$(\dot{\sigma}_{gen})_{pump} = (109\,kg/s)(0.60605 - 0.59249)\,kJ/kg\text{-}K$$
$$\simeq \boxed{1.4780\,kW/K}$$