# Answer Key

## Pure Substance, Rankine Cycle and Geothermal Power Plant

# 1

$m = 25\ kg$ @ $55°C$ saturated

$\bar{v} = \frac{V}{m}$

$V = \bar{v} m$

$\rightarrow v_g @ 55°C = 9568 \times 10^{-3}\ m^3/kg$

$V = (9568 \times 10^{-3}\ m^3/kg)(25\ kg)$

$\boxed{V = 239.2\ m^3}$

2

STEAM TABLES:

$S = S_f + x\,S_{fg}$

$S_{fg}$ @ 190°C = 4.2720 KJ/kg-K

$S_f$ @ 190°C = 2.2359 KJ/kg-K

S = 5.5 KJ/kg-K

$\boxed{x = 76.40\%}$

STEAM TABLES

$V_T = 25L$

$m_f = 10 kg$

$$m_f = \frac{V_f}{v_f @ 250°C}$$

$$10 kg = \frac{V_f}{(1.2512 \times 10^{-3}\ m^3/kg)}$$

$V_f = 0.01251\ m^3$ (volume of liquid)

and;

$$m_g = \frac{V_g}{v_g @ 250°C} = \frac{(0.025 - 0.01251)\ m^3}{(50.13 \times 10^{-3}\ m^3/kg)}$$

$m_g = 0.2491\ kg$ (mass of vapor)

Therefore;

$$x = \frac{m_g}{m_f + m_g} = \frac{0.2491\ kg}{(10 + 0.2491)\ kg}$$

$x = 2.4305\ \%$ (vapor content)

Hence; the moisture content

$y = (100 - 2.4305)\ \%$

$\boxed{y = 97.57\ \%}$

# 4

$$h = mC_p t = \left(4.187\ \mathrm{KJ/kg\text{-}K}\right)\left(45^\circ C\right)$$

$$\boxed{h = 188.415\ \mathrm{KJ/kg}}$$

# 5

$$h = m C_p t$$

$$C_p = \left(4.187\ KJ/kg\text{-}K\right)\left(\frac{0.24\ Btu/lbm\text{-}°R}{1.0062\ KJ/kg\text{-}K}\right)$$

$$C_p = 0.9987\ Btu/lbm\text{-}°R$$

$$h = \left(0.9987\ Btu/lbm\text{-}°R\right)\left(200°F\right)$$

$$\boxed{h = 199.74\ Btu/lbm}$$

# 6

$$m_f = \frac{V_f}{\bar{v}_f @ 120\,kPa} = \frac{6\,m^3}{1.0473 \times 10^{-3}\,m^3/kg} = 5729.0175\ kg$$

$$m_g = \frac{V_g}{\bar{v}_g @ 120\,kPa} = \frac{6\,m^3}{1428.4 \times 10^{-3}\,m^3/kg} = 4.20\ kg$$

$$x = \frac{m_g}{m_f + m_g} = \frac{4.20\,kg}{(5729.0175 + 4.20)\,kg} = 7.3257 \times 10^{-4}$$

Hence;

$$u = u_f + x\,u_{fg}$$

$$u = u_f + x(u_g - u_f)$$

$$u_f @ 120\,kPa = 439.20\ kJ/kg$$

$$u_g @ 120\,kPa = 2512.1\ kJ/kg$$

$$U = (440.7185\ kJ/kg)(5729.0175 + 4.20)\,kg$$

$$\boxed{U = 2.5267 \times 10^{6}\ kJ}$$

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$$h_2 - h_1 = m\,C_p\,(T_2 - T_1)$$

$$(2599.1 - 2592.1)\ \mathrm{kJ/kg} = C_p\,(53.97 - 50)^\circ C$$

$$\boxed{C_p = 1.7632\ \mathrm{kJ/kg\text{-}K}}$$

$m_f = 1.2\ kg$

$V_f = m_f\, v_f$

$\quad \hookrightarrow v_f @ 620\ kPa = 1.1021 \times 10^{-3}\ m^3/kg$

$V_f = (1.2\ kg)(1.1021 \times 10^{-3}\ m^3/kg) = 1.3225 \times 10^{-3}\ m^3$

and;

$V_g = V_T - V_f = (1.5 - 1.3225 \times 10^{-3})\ m^3$

$V_g = 1.4987\ m^3$

Hence;

$$m_g = \frac{V_g}{v_g} = \frac{1.4987\ m^3}{306 \times 10^{-3}\ m^3/kg}$$

$$\boxed{m_g = 4.8976\ kg}$$

$$s = s_f + x\,s_{fg}$$

$$= 0.4417\ \text{Btu}/\text{lb-}^{\circ}\text{R} + (0.70)(1.6288 - 0.4417)\ \text{Btu}/\text{lb-}^{\circ}\text{R}$$

$$\boxed{s = 1.2727\ \text{Btu}/\text{lb-}^{\circ}\text{R}}$$

# 10

$$Q = m C_v \Delta T$$

$$(310\ \text{Btu})\left(\frac{1.055\ \text{kJ}}{1\ \text{Btu}}\right) = (1\ \text{kg})(4.2\ \text{kJ/kg-K})\,\Delta T$$

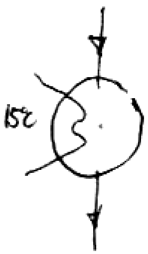
$$\boxed{\Delta T = 77.8690\ \text{K}}$$

$m_s = 1.0\ kg/s$

$P_1 = 160\ kPa$

$x_1 = 85\%$

$\Delta t = 15°C$



$Q_s = Q_w$

$m_s(h_1 - h_2) = m_w C_{pw} \Delta T$

$h_1 = h_f + x_1 h_{fg}$

$h_{fg} @ 160\ kPa = 2221.1\ kJ/kg$

$h_f @ 160\ kPa = 475.36\ kJ/kg$

$h_1 = 2363.295\ kJ/kg$

$h_2 = h_f @ 160\ kPa = 475.36\ kJ/kg$

then;

$(1.8\ kg/s)(2363.295 - 475.36)\ kJ/kg = m_w (4.187\ kJ/kg\text{-}K)(15°C)$

$\boxed{m_w = 54.1085\ kg/s}$

FACTOR OF EVAPORATION

$$F.E. = \frac{h_s - h_f}{2257}$$

$$1.3 = \frac{h_s - h_f}{2257}$$

$$h_s - h_f = 2934.1 \text{ KJ/kg}$$

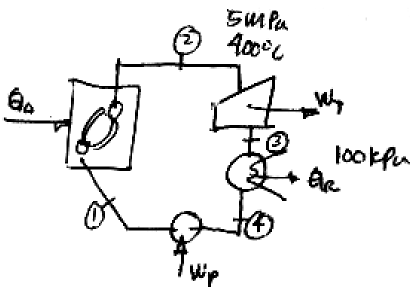
then;

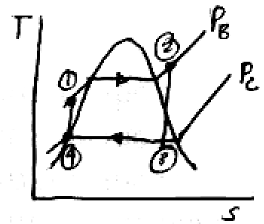
$$\eta_{th} = \frac{W_{net}}{Q_A} = \frac{W_{net}}{m_s (h_s - h_f)}$$

$$0.70 = \frac{6000 \text{ kW}}{m_s (2934.1 \text{ KJ/kg})}$$

$$m_s = \left(2.9213 \text{ kg/s}\right)\left(\frac{3600 \text{ s}}{1 \text{ hr}}\right)$$

$$\boxed{m_s = 10516.7318 \text{ kg/hr}}$$




$$\eta_{th} = \frac{Q_A - Q_R}{Q_A} = 1 - \frac{Q_R}{Q_A} = 1 - \frac{h_3 - h_4}{h_2 - h_1}$$

@ 5 MPa & 400°C

$h_2 = 3195.7$ kJ/kg

$S_2 = 6.6459$ kJ/kg-K

$S_2 = S_f + x_3 S_{fg}$

$S_{fg}$ @ 0.1 MPa $= 6.0568$ kJ/kg-K

$S_f$ @ 0.1 MPa $= 1.3026$ kJ/kg-K

$x_3 = 0.8821$

$h_3 = h_f + x_3 h_{fg}$

$h_{fg}$ @ 0.1 MPa $= 2258.0$ kJ/kg

$h_f$ @ 0.1 MPa $= 417.46$ kJ/kg

$h_3 = 2497.4518$ kJ/kg

$h_4 = h_f$ @ 0.1 MPa $= 417.46$ kJ/kg

$h_1 - h_4 = \bar{v}_4 (P_1 - P_4)$

$\bar{v}_4 = \bar{v}_f$ @ 0.1 MPa $= 1.0432 \times 10^{-3}$ m³/kg

$h_1 = 422.5717$ kJ/kg

Therefore;

$$\eta_{th} = 1 - \frac{(2497.4518 - 417.46)\ \text{kJ/kg}}{(3195.7 - 422.5717)\ \text{kJ/kg}} * 100\%$$

$\boxed{\eta_{th} = 25\%}$

Exponential LEAP ONLINE REVIEW

$W_T' = 650\ kJ/kg$, $\eta_T = 85\%$

$W_p' = 4\ kJ/kg$, $\eta_p = 70\%$

$\eta_{th} = 30\%$

required: $Q_A$

$$\eta_{th} = \frac{W_T' - W_p}{Q_A}$$

$$\eta_T = \frac{W_T'}{W_T}$$

$$0.85 = \frac{650\ kJ/kg}{W_T}$$

$$W_T = 764.7059\ kJ/kg$$

$$\eta_p = \frac{W_p}{W_p'}$$

$$0.70 = \frac{W_p}{4\ kJ/kg}$$

$$W_p = 2.8\ kJ/kg$$

subst;

$$0.30 = \frac{(764.7059 - 2.8)\ kJ/kg}{Q_A}$$

$$\boxed{Q_A = 2539.6863\ kJ/kg}$$

$$\Delta h = m_s (h_2 - h_1)$$

$h_1 = h_f @ 60°C = 334.91\ kJ/kg$

$h_2 = 1300\ kJ/kg$

$$\Delta h = (1300 - 334.91)\ kJ/kg$$

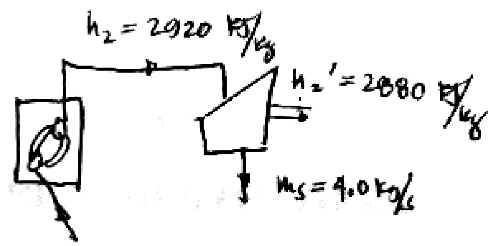
$$\boxed{\Delta h = 965.09\ kJ/kg}$$

# 16

$W_{NET} = W_T - W_P$

$= (3.5\ kg/s)(3500 - 30)\ kJ/kg$

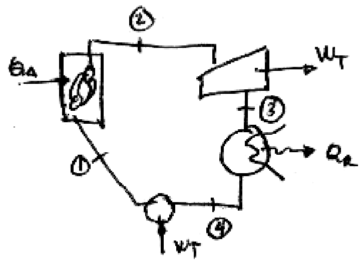
$\boxed{W_{NET} = 12145\ kJ/s}$




$$\text{Heat loss} = m_s (h_2 - h_2') = (4.0 \text{ kg/s})(2920 - 2880) \text{ kJ/kg}$$

$$\boxed{\text{Heat loss} = 160 \text{ kW}}$$

$$\eta_{th} = 1 - \frac{h_3 - h_4}{h_2 - h_1}$$




$h_2 = h_g @ 4MPa = 2801.4 \ kJ/kg$

$S_2 = S_3 = S_f + x_3 S_{fg}$

$6.0701 \ kJ/kg\text{-}K = 1.1143 \ kJ/kg\text{-}K + x_3 (6.4422 \ kJ/kg\text{-}K)$

$x_3 = 0.7693$

$h_3 = h_f + x_3 h_{fg} = 350.54 \ kJ/kg + (0.7693)(2299.3 \ kJ/kg)$

$h_3 = 2119.3257 \ kJ/kg$

$h_4 = 350.54 \ kJ/kg$

$h_1 - h_4 = v_4 (P_1 - P_4)$

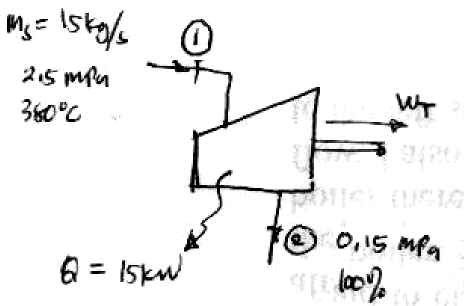
$h_1 - 350.54 \ kJ/kg = (1.0316 \times 10^{-3} \ m^3/kg)(4000 - 55) \ kPa$

$h_1 = 354.6097 \ kJ/kg$

therefore;

$$\eta_{th} = 1 - \frac{(2119.3257 - 350.54) \ kJ/kg}{(2801.4 - 354.6097) \ kJ/kg}$$

$$\boxed{\eta_{th} = 27.71\%}$$




$$[E_{in} = E_{out}]$$

$$h_1 = h_2 + Q + W_T$$

$$(15\ kg/s)(3194.4\ kJ/kg) = (15\ kg/s)(2693.6\ kJ/kg) + 15\ kW + W_T$$

$$\boxed{W_T = 7497\ kW}$$

$$\eta_T = \frac{W_T'}{W_T}$$

$$W_T' = (0.80)(1300\ \text{KJ/kg}) = 1040\ \text{KJ/kg}$$

then;

$$4500\ \text{KJ/s} = m_s(1040\ \text{KJ/kg})$$

$$m_s = 4.3269\ \text{kg/s}$$

in terms of kg/kW-hr

$$m_s = 4.3269\ \frac{\text{kg}}{\text{s}}\left(\frac{3600\ \text{s}}{1\ \text{hr}}\right)\left(\frac{1}{4500\ \text{kW}}\right)$$

$$\boxed{m_s = 3.4615\ \text{kg/kW-hr}}$$

$$Q_c = Q_w$$

$$m_s(h_2 - h_1) = m_w C_p \Delta T$$

$$(15\ kg/s)(2690 - 290)\ kJ/kg = m_w (4.187\ kJ/kg\text{-}K)(30 - 15)°C$$

$$\boxed{m_w = 573.2028\ kg/s}$$

$$Q_g = Q_w$$

$$m_g C_{p_g} \Delta T = m_w C_p \Delta T$$

$$R = \frac{\bar{R}}{M} = \frac{8.3143 \text{ kJ/kg-K}}{30 \text{ kg/kg}} = 0.2771 \text{ kJ/kg-K}$$

$$k = \frac{C_p}{C_v} \; ; \quad R = C_p - C_v$$

$$R = C_p - \frac{C_p}{k}$$

$$R = C_p\left(1 - \frac{1}{k}\right)$$

$$0.2771 \text{ kJ/kg-K} = C_p\left(1 - \frac{1}{1.33}\right)$$

$$C_p = 1.1169 \text{ kJ/kg-K}$$

subst;

$$(0.90 \text{ kg/s})(1.1169 \text{ kJ/kg-K})(160-75)°C = (0.60 \text{ kg/s})(4.187 \text{ kJ/kg-K})(T_2 - 288 \text{ K})$$

$$T_2 = 322.0111 \text{ K}$$

$$\boxed{t_2 = 49.0111°C}$$

$$\eta_T = \frac{W_T'}{W_T}$$

$$W_T = h_1 - h_2$$

$$s_1 = s_2 = s_f + x_2 s_{fg}$$

$$7.0573 \text{ KJ/kg-K} = 1.1453 \text{ KJ/kg-K} + x_2 (6.3867 \text{ KJ/kg-K})$$

$$x_2 = 0.9257$$

$$h_2 = h_f + x_2 h_{fg}$$

$$= 359.86 \text{ KJ/kg} + (0.9257)(2299.3 \text{ KJ/kg})$$

$$h_2 = 2488.2615 \text{ KJ/kg}$$

subst;

$$W_T = (3564.2 - 2488.2615) \text{ KJ/kg}$$

$$W_T = 1075.9385 \text{ KJ/kg}$$

Hence;

$$0.85 = \frac{W_T'}{1075.9385 \text{ KJ/kg}}$$

$$\boxed{W_T' = 914.5477 \text{ KJ/kg}}$$

Exponential LEAP ONLINE REVIEW

$$\eta_T = \frac{W_T'}{W_T} = \frac{h_1 - h_2'}{h_1 - h_2}$$

$$S_2 = S_1 = S_f + x_2 S_{fg}$$

$$6.9646 \ kJ/kg\text{-}K = 0.8931 \ kJ/kg\text{-}K + x_2(6.9383 \ kJ/kg\text{-}K)$$

$$x_2 = 0.8751$$

$$h_2 = h_f + x_2 h_{fg}$$

$$= 271.93 \ kJ/kg + (0.8751)(2346.3 \ kJ/kg)$$

$$h_2 = 2325.1074 \ kJ/kg$$

Hence;

$$0.90 = \frac{3593.8 \ kJ/kg - h_2'}{(3593.8 - 2325.1074) \ kJ/kg}$$

$$\boxed{h_2' = 2451.9767 \ kJ/kg}$$

exponential LEAP ONLINE REVIEW

$$\eta_t = \frac{W_T'}{W_T} = \frac{h_1 - h_2'}{h_1 - h_2}$$

$$S_2 = S_1 = S_f + X_2 S_{fg}$$

$$1.4361\ Btu/lb\text{-}R = 0.3359\ Btu/lb\text{-}°R + X_2(1.3969\ Btu/lb\text{-}°R)$$

$$X_2 = 0.7876$$

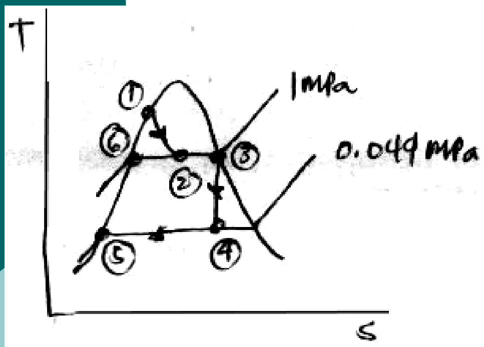
$$h_2 = h_f + X_2 h_{fg} = 196.2\ Btu/lb + (0.7876)(960.2\ Btu/lb)$$

$$h_2 = 952.4535\ Btu/lb$$

subst;

$$0.82 = \frac{(1202.4558\ Btu/lb - h_2')}{(1202.4558 - 952.4535)\ Btu/lb}$$

$$\boxed{h_2' = 997.4539\ Btu/lb}$$




$W_T = m_s(h_3 - h_4)$

$h_3 = h_g @ 1.0\ MPa = 2778.1\ kJ/kg$

$S_3 = S_4 = S_f + x_4 S_{fg}$

$S_f @ 0.044\ MPa = 1.0536\ kJ/kg\text{-}K$

$S_{fg} @ 0.044\ MPa = 6.5839\ kJ/kg\text{-}K$

$S_3 = S @ 1.0\ MPa = 6.5865\ kJ/kg\text{-}K$

$x_4 = 0.8404$

$h_4 = h_f + x_4 h_{fg}$

$h_f @ 0.044\ MPa = 327.26\ kJ/kg$

$h_{fg} @ 0.044\ MPa = 2313.4\ kJ/kg$

$h_4 = 2271.4414\ kJ/kg$

Solving for $m_s$,

$50000\ MW = m_s(2778.1 - 2271.4414)\ kJ/kg$

$m_s = 98.6858\ kg/s$

For the mass flow rate of the well water

$m_g = \frac{m_s}{x}$ ; $h_1 = h_2 = h_f + x_2 h_{fg}$

$h_1 = h_f @ 200°C = 858.45\ kJ/kg$

$h_f @ 1.0\ MPa = 762.81\ kJ/kg$

$h_{fg} @ 1.0\ MPa = 2015.3\ kJ/kg$

$x_2 = 0.04747$

Hence;

$m_g = \frac{98.6858\ kg/s}{0.04747}$

$\boxed{m_g = 2079.4803\ kg/s}$

$$\dot{m}_s = x\,\dot{m}_g = (0.14)(48\ kg/s)$$

$$\boxed{\dot{m}_s = 6.72\ kg/s}$$