HARNESSING THE HEAT ANSWER SHEET

1) Overall thermal efficiency of Teapot Dome binary plant:

$$\text{Efficiency } (\xi) = \frac{P_{out}}{P_{in}} \Rightarrow \xi = \frac{P_e}{P_{th}}$$

$P_e = 250$ kW (given)

$P_{th} = \dot{m} c \Delta T$, $\dot{m} = 40$ kg/s $\quad c = 4.180 \frac{kJ}{kg \cdot K}$ $\quad \Delta T = 70°C = 70$ K $(90 - 20$ °C$)$

$$\Rightarrow P_{th} = (40 \text{ kg/s})(4.180 \text{ kJ/kg K})(70 \text{ K})$$

$$= 11704 \text{ kW}$$

$$\Rightarrow \xi = \frac{250 \text{ kW}}{11704 \text{ kW}} \simeq \underline{\underline{2\%}}$$

2) P, T @ 100m for a boiling spring:

Assume $\bar{\rho}$ for $z=0$ to $z=100$ m is 900 kg/m3

$$\Rightarrow P(z)\Big|_{z=100} = \bar{\rho} g z = (900 \tfrac{kg}{m^3})(9.8 \tfrac{m}{s^2})(100 \text{ m}) = 8.82 \times 10^5 \text{ Pa} = 8.82 \text{ bar from } H_2O$$

But, need to add ~1 bar for atmosphere $\Rightarrow$ $\underline{\underline{P = 9.82 \text{ bar}}}$

P = 9.82 bar, find T for boiling:

From steam table, $T\big|_{P=9.82} \simeq \underline{\underline{180 °C}}$

For P, T @ 100 m, specific volume $(\frac{1}{\rho})$ is 1.126 cc/g $\Rightarrow$ 1126 m³/kg

$$\Rightarrow \rho\Big|_{z=100} = 888 \text{ kg/m}^3$$

$\therefore$ $\bar{\rho} = 900$ kg/m3 is acceptable.

3) Some info about a producing geothermal well:

Liquid feed zone @ 240 °C ⇒ boiling @ 33.44 bar

Separator operates @ 7 bar gauge = 8 bar absolute

⇒ boiling @ 170 °C ⇒ liquid from separator @ 170 °C

Mass fraction of liquid & vapor from separator –

Conservation of energy requires:

$$H_i = f H_{os} + (1-f) H_{o\ell}$$

for H_i = enthalpy of input fluid
H_{os} = enthalpy of output steam
$H_{o\ell}$ = enthalpy of output liquid
f = steam fraction

$$\Rightarrow f = \frac{H_i - H_{o\ell}}{H_{os} - H_{o\ell}} = \frac{(1038 - 719)}{(2802 - 719)} \simeq 0.16$$

⇒ 16% steam (16 kg/s), 84% liquid (84 kg/s)

4) Efficiency of condensing turbine:

$$\xi = \frac{P_e}{P_{th}}$$

$P_{th} = \dot{m} H_{vap}$ for $H_{vap}\big|_{P = 8\,bar} = 2769\ \text{kJ/kg}$

$\dot{m} = 2\ \text{kg/s} \Rightarrow P_{th} = (2\ \text{kg/s})(2769\ \text{kJ/kg}) = 5538\ \text{kW} = 5.538\ \text{MW}$

$P_e = 1\ \text{MW}$ (given) $\Rightarrow \xi = \frac{1}{5.538} = 18\%$

5) For the well in Q3, how much power can turbine in Q4 produce?

$P_e = \dot{m}\gamma$ for $\gamma = \frac{1}{2}\ \frac{\text{MW}\cdot\text{s}}{\text{kg}}$ (2 kg/s per MW)

$$\Rightarrow P_e = (16\ \text{kg/s})\left(\frac{1}{2}\ \frac{\text{MW}\cdot\text{s}}{\text{kg}}\right) = 8\ \text{MW}$$

6) Overall effeciency of well (Q3) vs. turbine (Q5):

$$\xi = \frac{P_e}{P_{th}} , \quad P_e = 8000 \text{ kW (Q5)}$$

$$P_{th} = \dot{m} H_\ell \quad \text{for } H_\ell \Big|_{T=710} = 1038 \text{ kJ/kg} , \quad \dot{m} = 100 \text{ kg/s (Q3)}$$

$$\Rightarrow P_{th} = (100 \text{ kg/s})(1038 \text{ kJ/kg}) = 103800 \text{ kW}$$

$$\Rightarrow \xi = \frac{8000 \text{ kW}}{103800 \text{ kW}} \simeq \underline{\underline{8\%}}$$

7) Concentrations in separator output water:

Chloride & silica remain in solution, so output water has concentrations based on liquid fraction from separator (0.84 from Q3):

$$C_{Cl} = \frac{1000}{0.84} \text{ ppm} = 1190 \text{ ppm}$$

$$C_{Si} = \frac{400}{0.84} \text{ ppm} = \underline{\underline{476 \text{ ppm}}}$$

But, silica is saturated @ 400 ppm ⇒ output water is super-saturated & silica will precipitate in outflow pipes!