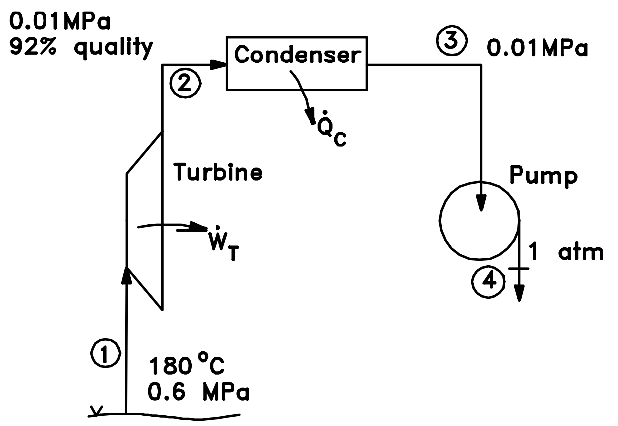
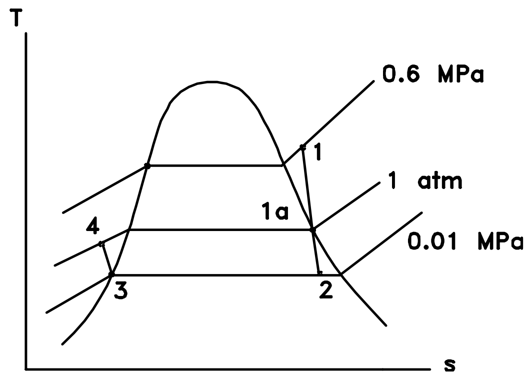
Problem: 5.46

Given: A geothermal power plant as shown below produces 12.5 MW of electric power. The electric generator efficiency is 0.95. Neglect the pump power

Find: a) Steam Flow Rate
b) Condenser heat transfer rate. Why does the system have a condenser and a pump?





Assumptions

1. Steady state, steady flow
2. $\Delta pe = \Delta ke = 0$
3. saturated liquid at state 3

a) Consider the turbine:

First law energy balance

$$\dot{m}(h_1 + \cancel{p}e_1 + \cancel{k}e_1) = \dot{m}(h_2 + \cancel{p}e_2 + \cancel{k}e_2) + \cancel{\dot{Q}}^{\,0} + \dot{W}_T + \cancel{\frac{dE}{dt}}^{\,0}$$

$$\dot{W}_T = \dot{m}(h_1 - h_2)$$

But we know the electrical output is 12.5 MW and the generator is 95% efficient. Therefore

$$\dot{W}_T = \frac{12.5 \times 10^3 \ kJ/s}{0.95} = 13,158 \ kJ/s$$

From Table B.2

$$\begin{aligned}
h_1 &= 2804.7 \ kJ/kg \\
h_2 &= h_f + X \cdot h_{fg} \quad @ \ 0.01 \ MPa \\
&= 191.8 + 0.92(2392.8) \\
&= 2393.2 \ kJ/kg
\end{aligned}$$

$$\begin{aligned}
\dot{m} &= \frac{\dot{W}_T}{(h_1 - h_2)} = \frac{13158 \ kJ/s}{(2804.7 - 2393.2) \ kJ/kg} \\
&= \boxed{32.0 \ kg/s}
\end{aligned}$$

b) Consider the condenser

<u>First law energy balance</u>

$$\begin{aligned}
\dot{m}(h_2 + \cancel{p}e_2 + \cancel{k}e_2) &= \dot{m}(h_3 + \cancel{p}e_3 + \cancel{k}e_3) + \dot{Q}_C + \cancel{\dot{W}_T}^{\,0} + \cancel{\frac{dE}{dt}}^{\,0} \\
\dot{Q}_C &= \dot{m}(h_2 - h_3)
\end{aligned}$$

From Table B.2

$$h_3(0.01 \ MPa, \text{sat. liq.}) = 191.8 \ kJ/kg$$

Therefore

$$\begin{aligned}
\dot{Q}_C &= (32.0 \ kg/s)(2393.2 - 191.8) \ kJ/kg \\
&= 70,455 \ kJ/s \\
&= \boxed{70.4 \ MW}
\end{aligned}$$

In order to extract as much energy as possible from the turbine, the steam is brought to a low pressure (0.01 MPa). Rather than losing the steam vapor to the atmosphere, a condenser is used to bring it to a liquid state so that the water can be returned to the ground. The pump is required to bring the water back to atmospheric pressure.