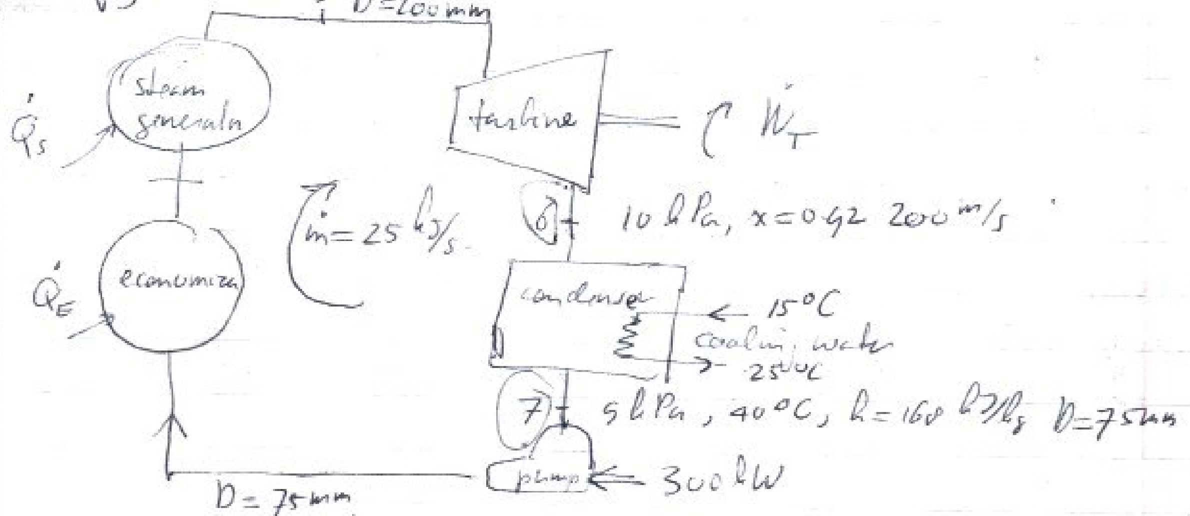
P6.100 Steam power plant
P3



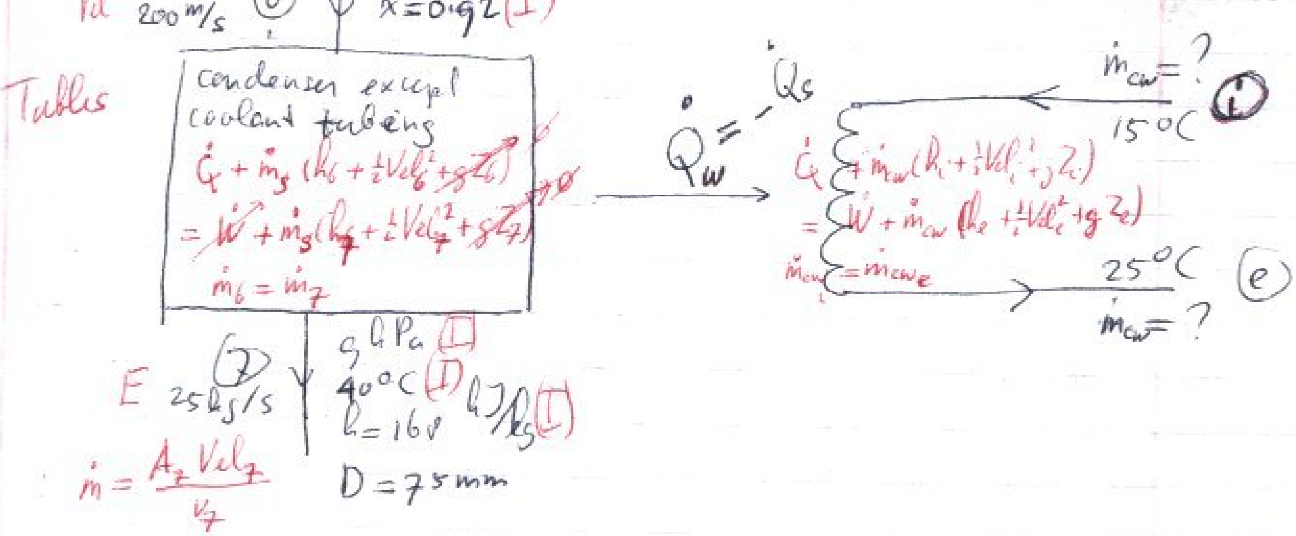
Asked: rate of heat transfer in the condenser, and the mass flow rate of cooling water.

Answer: The heat transfer is from steam in the condenser to cooling water. So we have two control volumes to deal with.

a) the flow of steam through the condenser; heat $\dot{Q}$ goes out of this C.V.

b) the flow of cooling water: heat $\dot{Q}$ goes into this C.V.

Draw them separately:



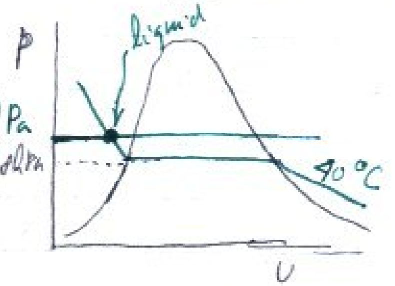
Answer :

a) I have full info about condensor inflow and outflow, and $\dot{W} = 0$ (no moving parts), so I should be able to figure out $\dot{Q}$:

State 6: Table $\overset{A-5}{B.1.2}$ @ 10 kPa : $h_f = 191.81 \frac{kJ}{kg}$ $h_{fg} = 2392.82 \frac{kJ}{kg}$

$$h_6 = h_f + x\, h_{fg} = 191.81 + 0.92\ 2392.82 \frac{kJ}{kg}$$
$$= 2393.20\ kJ/kg$$

State 7: Do <u>not</u> assume pressure is constant $p_7 = 9\,kPa \neq p_6$.



9kPa is not in $\overset{A-7}{B.1.4}$, so use saturated values at 40°C

$$v_7 = 0.001008\ m^3/kg$$
$$h_7 = 167.59 \text{ (was given as 168)}$$

$$\dot{m}_7 = \frac{Vel_7\, A_7}{v_7} \qquad 25\ kg/s = \frac{Vel_7\ \frac{\pi}{4} 0.075^2\, m^2}{0.001008\ m^3/kg}$$

$$\Longrightarrow Vel_7 = 5.7\ m/s$$

Use 1st law:

$$\dot{Q}_s + \dot{m}_s\left(h_6 + \tfrac{1}{2}Vel_6^2 + \cancel{g Z_6}\right) = \underset{\text{no moving parts}}{\cancel{\dot{W}}} + \dot{m}_s\left(h_7 + \tfrac{1}{2}Vel_7^2 + \cancel{g Z_7}\right)$$

ignore height differences

$$\dot{Q}_s + 25\frac{kg}{s}\left(2393.20\frac{kJ}{kg} + \tfrac{1}{2}\,200^2\frac{m^2}{s^2}\ \frac{1\,kJ}{1000\,\frac{m^2}{s^2}}\right)$$
$$= 25\frac{kg}{s}\left(168\,\frac{kJ}{kg} + \tfrac{1}{2}\,5.7^2\frac{m^2}{s^2}\ \frac{1\,kJ}{1000\,\frac{m^2}{s^2}}\right)$$

$$\Longrightarrow \underline{\dot{Q}_s = -56\,130\ kW}$$ (out of the steam, since negative)

Now know $\underline{\underline{\dot{Q}_{cw} = 56\,130\ kW}}$ added to the cooling water or $q = c_p(T_2 - T_1)$

$\dot{Q} = \dot{m}\, c_p(T_2 - T_1)$

(same)

b) Figure out the cooling water.

Note: I do not have pressures for the cooling water!

Idea: use $h_e - h_i = c_p\,(T_e - T_i)$. Requires only temperatures.

$$\dot{Q} + \dot{m}_{cw}\,(h_i + \cancel{\tfrac{1}{2}Vel_i^2}^{\text{ignore}} + \cancel{g Z_i}^{\text{ignore}}) = \overset{0}{\cancel{\dot{W}}} + \dot{m}_{cw}\,(h_e + \cancel{\tfrac{1}{2}Vel_e^2}^{\text{ignore}} + \cancel{g Z_e}^{\text{ignore}})$$

no moving parts

$$\dot{Q} \pm \dot{m}_{cw}\,(h_e - h_i) = \dot{m}_{cw}\, c_p\,(T_e - T_i)$$

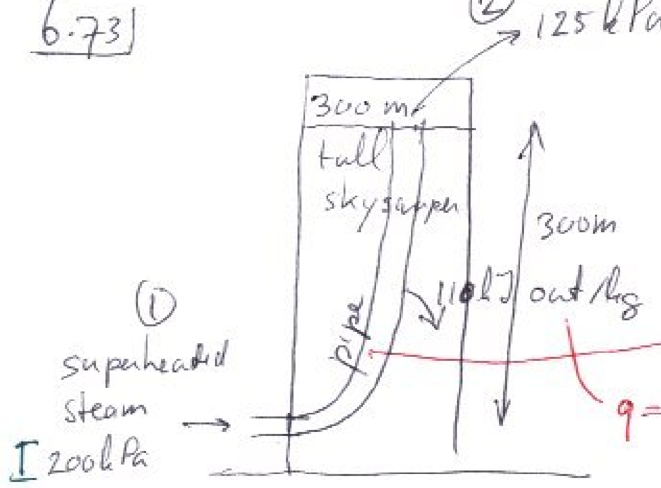
Table $\overset{\text{A-3a}}{\cancel{\text{A}}\,4}$: $c_p = 4.18\ \frac{kJ}{kg\,K}$ at 25°C, probably OK at 20° (interpolated: 4.19)

Put in numbers

$$56130\ kW = \dot{m}_{cw}\ 4.18\ \frac{kJ}{kg\,K}\ (25 - 15)$$

$$\underline{\underline{\dot{m}_{cw} = 1343\ \frac{kg}{s}}}$$

6.73



minimum case : just ready to condense at top
$\rightarrow x = 1$ I

$\dot{m}_2 = \dot{m}_1$

nothing given about velocities

$$\dot{Q} + \dot{m}_1 (h_1 + \tfrac{1}{2}\cancel{Vel_1^2} + g Z_1)$$
$$= \cancel{\dot{W}} + \dot{m}_2 (h_2 + \cancel{\tfrac{1}{2}Vel_2^2} + g Z_2)$$

pipe : no moving parts

$q = -110$ kJ/kg

$$\Downarrow$$
$$q + h_1 + g Z_1$$
$$= h_2 + g Z_2$$
$$h_1 = h_2 - q + g(Z_2 - Z_1)$$

Asked : T_1 so that no water condenses in the pipe

Solution : ~~$h_1 = h_2 - q + g(Z_2 - Z_1)$~~

Table ~~B.1.2~~ A-5, sat wat P.E. @ 125 kPa : $h_{g2} = h_2 = 2685.35 \frac{kJ}{kg}$
$(T_2 = 105.97)$

$$h_1 = h_2 - q + g(Z_2 - Z_1)$$
$$= 2685.35 \frac{kJ}{kg} + 110 \frac{kJ}{kg} + 9.81 \frac{m}{s^2}\, 300m\, \frac{1 \frac{kJ}{kg}}{1000\, m^2/s^2}$$
$$= 2798. \frac{kJ}{kg}$$

Table ~~B.1.4~~ A-6, sup wat vap @ ~~200 kPa~~ 0.2 MPa, $h = 2798 \frac{kJ}{kg}$

$$g = 2798 \qquad g_1 = 2768.8 \qquad g_2 = 2870.46$$
$$d_1 = 150°C \qquad d_2 = 200°C$$

$$T_1 = d_1 + \frac{g - g_1}{g_2 - g_1}(d_2 - d_1) = 150 + \frac{2798 - 2768.8}{2870.46 - 2768.8}(200 - 150)$$
$$= \underline{\underline{164.5°C}}$$

Throttle flow

6.40

Helium is throttled from 1.2 MPa, 20°C, to a pressure of 100 kPa. The diameter of the exit pipe is so much larger than the inlet pipe that the inlet and exit velocities are equal. Find the exit temperature of the helium and the ratio of the pipe diameters.

Solution:

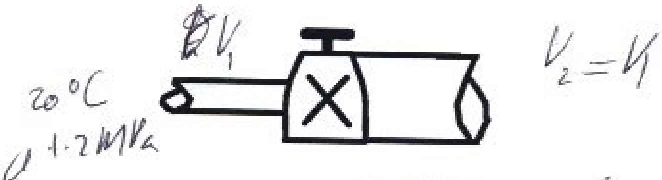
C.V. Throttle. Steady state,

Process with: $q = w = 0$; and $\mathbf{V}_i = \mathbf{V}_e$, $Z_i = Z_e$

Energy Eq.6.13: $h_i = h_e$, Ideal gas => $T_i = T_e =$ **20°C**

$\dot{m} = \frac{AV}{RT/P}$ But $\dot{m}$, $\mathbf{V}$, T are constant => $P_iA_i = P_eA_e$

$$\Rightarrow \frac{D_e}{D_i} = \left(\frac{P_i}{P_e}\right)^{1/2} = \left(\frac{1.2}{0.1}\right)^{1/2} = \mathbf{3.464}$$



$$\cancel{\dot{Q}} + \dot{m}\left(h_1 + \cancel{\tfrac{1}{2} Vel_1^2} + \cancel{g Z_1}\right) = \dot{m}\left(h_2 + \cancel{\tfrac{1}{2} Vel_2^2} + \cancel{g Z_2}\right) + \cancel{\dot{W}}$$

$h_1 = h_2$ $\Rightarrow T_2 = T_1 = 20°C$

asked T_2, D_2/D_1

$$\frac{A_2 \cancel{Vel_2}}{\cancel{R T_2}/P_2} = \frac{A_1 \cancel{Vel_1}}{\cancel{R T_1}/P_1}$$

$$\frac{A_2}{A_1} = \frac{P_1}{P_2} = \frac{\cancel{\pi} D_2^2 \cancel{\times 4}}{\cancel{\pi} D_1^2 \times 4} \qquad \frac{D_2}{D_1} = \sqrt{\frac{P_1}{P_2}} = \sqrt{12} = 3.464$$