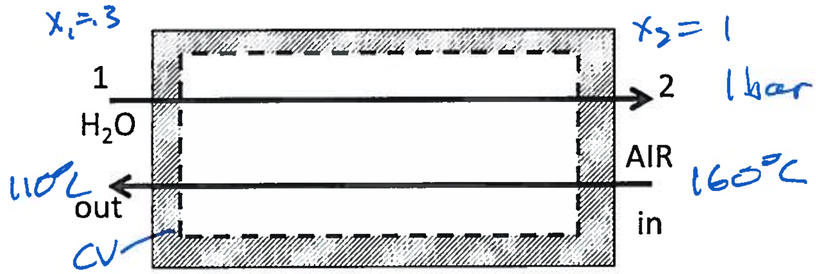
3. (15 marks) Part of your cooling system for the Venus lander is the evaporator, which boils water at 1 bar (quality x_1=0.3 to x_2=1) . The heat from the space probe electronics is not absorbed directly by the water. Instead, there is an air-to-steam heat exchanger as sketched below. The air temperature going in is $T_{in} = 160^o$ C and coming out it is $T_{out} = 110^o$ C. You can assume $P_{in} = P_{out}$.

   (a) (8 marks) Find the ratio of the mass flow of air needed per unit mass flow of water ie., $r = \frac{\dot{m}_A}{\dot{m}_w}$. Use the T-s diagram attached to get properties as appropriate.



First law for CV.

$$\underbrace{\frac{dE_{cv}}{dt}}_{0} = \underbrace{\dot{Q}}_{0} - \underbrace{\dot{W}_s}_{0} + \dot{m}_w(h_1 - h_2) + \dot{m}_A(h_{in} - h_{out})$$

$$\frac{\dot{m}_A}{\dot{m}_w}(h_{in} - h_{out}) = h_2 - h_1$$

$$r = \frac{\dot{m}_A}{\dot{m}_w} = \frac{h_2 - h_1}{h_{in} - h_{out}}$$

Property model.

Steam: use T S diagram $h_2 = 2680 \frac{kJ}{kg}$ $h_1 = 1090 \frac{kJ}{kg}$

used later $S_2 = 7.4 \frac{kJ}{kg\text{-}K}$ $S_1 = 3.2 \frac{kJ}{kg\text{-}K}$

Air : use $dh = C_p dT$ $C_p \approx 1.0\,kJ/kg\text{-}K$ from formula sheet.

$$r = \frac{1090 - 2680}{(1.0)(110 - 160)} = \frac{1590}{50} = \underline{32}$$

(b) (7 marks) Find the specific entropy generation in the heat exchanger, $\frac{\dot{S}_{gen}}{\dot{m}_w}$. Comment on whether or not the sign of your answer gives you confidence in your answer.

2nd Law $\cancel{\frac{dS_{cv}}{dt}}_{0} = \cancel{\sum \frac{\dot{Q}_i}{T_i}}_{0} + \dot{m}_w(s_1 - s_2) + \dot{m}_A(s_{in} - s_{out}) + \dot{S}_{gen}$

$$\frac{\dot{S}_{gen}}{\dot{m}_w} = (s_2 - s_1) + r(s_{out} - s_{in})$$

Models Steam, use T-s diagram $s_2 - s_1 = 7.4 - 3.2 = 4.2 \ \frac{kJ}{kg\text{-}K}$

Air use $s_{out} - s_{in} = C_p \ln \frac{T_{out}}{T_{in}} - \cancel{R \ln \frac{P_{out}}{P_{in}}}_{0}$

$$= 1.0 \ln \frac{110 + 273.15}{160 + 273.15} = -0.123 \ \frac{kJ}{kg\text{-}K}$$

$$\frac{\dot{S}_{gen}}{\dot{m}_w} = 4.2 - 32(0.123) = 0.3 \ \frac{kJ}{kg\text{-}K}$$

(tolerance $\pm 0.1 \ \frac{kJ}{kg\text{-}K}$ due to reading graph)

There is heat transfer with a large temperature difference (60°C at one end, 10°C at the other), so there is expected to be entropy generation.

It <u>must</u> be ≥ 0, and in this case, we expect $\dot{S}_{gen} > 0$.

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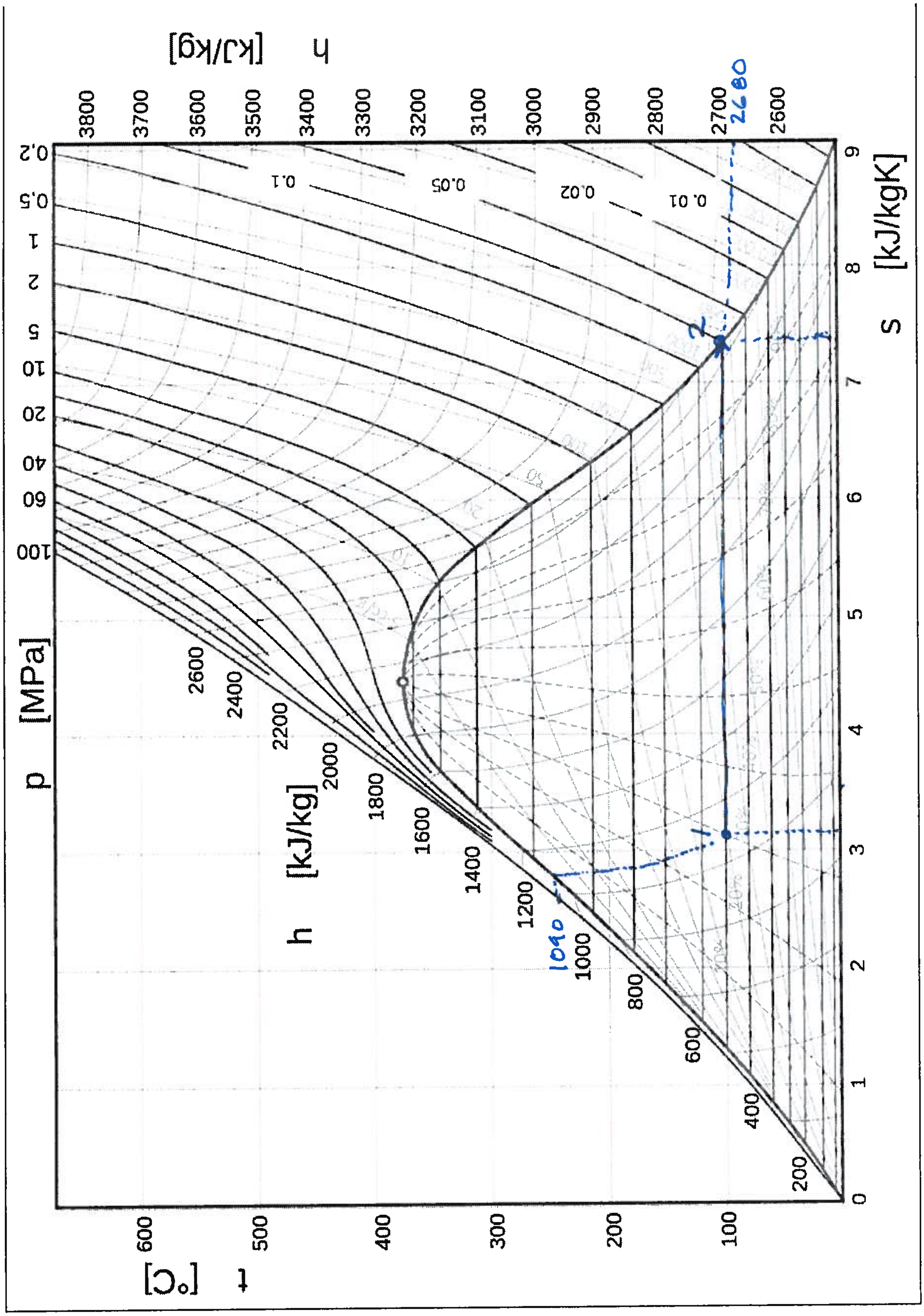
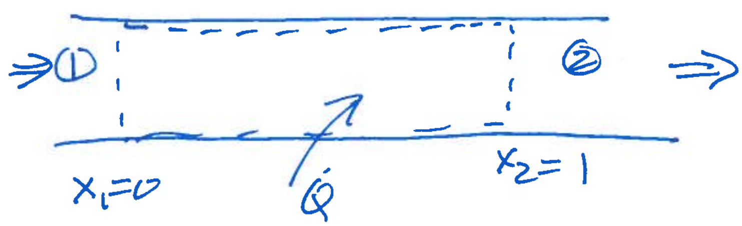


4. (7 marks) If you look at the saturated steam tables (or your T-s diagram), you will find that $h_{fg} = Ts_{fg}$. Is this a special relation true for water only, or would it hold for other fluids and other phase changes (S-L, S-V)? Explain with the aid of a brief analysis. *Hint: consider reversible isobaric boiling of a liquid.*



SSSF

$$\dot{Q} = \dot{m}(h_2 - h_1) \quad \text{from first law}$$
$$= \dot{m}\, h_{fg} \qquad *$$

also, reversible isothermal heating implies that the 2nd law is

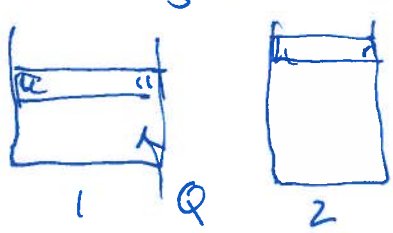
$$0 = \frac{\dot{Q}}{T} + \dot{m}(s_2 - s_1) + \cancel{\dot{S}_{gen}} \ \text{rev.}$$

$$\dot{Q} = \dot{m}\, T (s_{fg}) \qquad **$$

Equating * and ** gives

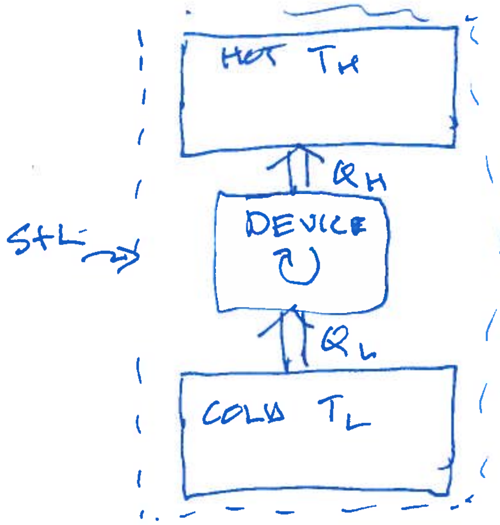
$$\cancel{\dot{m}}\, T s_{fg} = \cancel{\dot{m}}\, h_{fg} \qquad \text{QED}$$

You may also analyze a control mass to show this



$$H_2 - H_1 = Q \quad \text{from first law + isobaric}$$
$$m(h_{fg}) = Q$$
$$S_2 - S_1 = \frac{Q}{T} \quad \text{because T is constant}$$
$$s_{fg} = \frac{Q}{T} \Rightarrow h_{fg} = T s_{fg}.$$

5. (8 marks) Starting with the Second Law for a control mass, show that it is impossible, even with a "clever device", to transfer heat from a cold object to a hot object without putting work into the process (assuming your clever device is in the same state at the end of the process). Hint: First apply the 2nd Law to the hot and cold objects individually.



DEVICE OPERATES ON CYCLE, NO WORK $\therefore$ $Q_H = Q_L = Q$

$$\Delta S_H = \frac{Q_H}{T_H}$$

if object is large, temperature change is small.

$$\Delta S_L = \frac{-Q_L}{T_L}$$

$$\Delta S_{H+L} = \Delta S_H + \Delta S_L = Q\left(\frac{1}{T_H} - \frac{1}{T_L}\right)$$

But $T_L < T_H$ $\therefore$ $\frac{1}{T_H} - \frac{1}{T_L} < 0$ $\therefore$ $\Delta S_{H+L} < 0$

Entropy decreases!
Therefore, the device violates the 2nd Law.