Part A: Locate states 1, 2, and 3 on a sketch of a T-s diagram (including the phase boundary for water)

State 1: Subcooled liquid

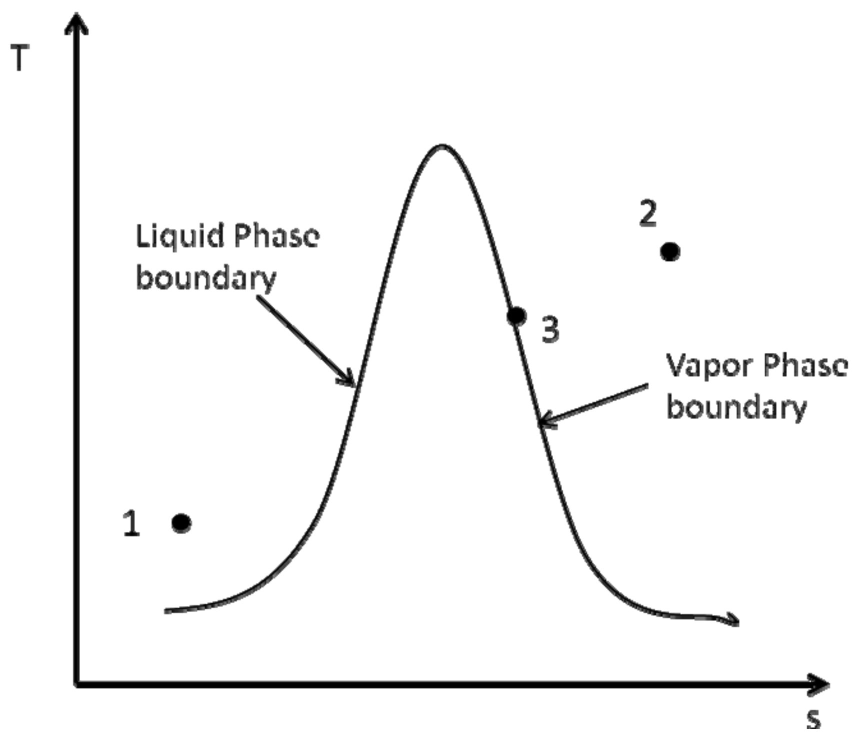
At P = 2.7 MPa, the low temperature of 40 ℃ is a good indication that the liquid is at a subcooled state.

State 2: Superheated vapor

State 3: Saturated vapor

At the same pressure, a saturated vapor has a lower temperature than superheated vapor. Furthermore, temperature decreases when pressure decreases. Thus at P = 2.5 MPa, the saturated vapor should have a lower temperature than State 2.

Inside the desuperheater, heat is transferred from the superheated vapor to the subcooled liquid. Thus the exiting stream should be at a temperature between T1 and T2.



- 1 point for correct identification of State 1
- 1 point for correct identification of State 2
- 2 point for correct identification of State 3
- 1 point for phase boundary of water

Part B: Determine the rate of entropy production within the desuperheater, in kW/K.

(2 points for identification of system boundary)

Assume:

- No significant change in kinetic and potential energy
- There is no loss of heat to the surroundings
- There is no significant work

(1 point for any assumption; 2 points max)

Apply Mass Balance to the open system at steady state

$$\frac{d\dot{m}}{dt} = \dot{m}_1 + \dot{m}_2 - \dot{m}_3 = 0$$

$$\dot{m}_3 = \dot{m}_1 + \dot{m}_2 \qquad \text{(2 points)}$$

Apply First Law of Thermodynamics to the open system at steady state,

$$0 = \sum_{in} \dot{m}_{in}(h + e_K + e_P)_{in} - \sum_{out} \dot{m}_{out}(h + e_K + e_P)_{out} + \dot{Q} + \dot{W}_S$$

Simplify the above equation ,

$$0 = \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3 \qquad \text{(2 points)}$$

$$0 = \dot{m}_1 h_1 + \dot{m}_2 h_2 - (\dot{m}_1 + \dot{m}_2) h_3$$

$$\dot{m}_1 = \frac{\dot{m}_2(\hat{h}_2 - \hat{h}_3)}{(\hat{h}_3 - \hat{h}_1)}$$

$$\dot{m}_1 = \frac{(0.28\frac{kg}{s})(3002.8 - 2803.1)\frac{kJ}{kg}}{(2803.1 - 169.9)\frac{kJ}{kg}}$$

$$\boxed{\dot{m}_1 = 0.0212\frac{kg}{s}} \qquad \text{(2 points)}$$

Apply Entropy Balance for the entire universe,

$$\left(\frac{dS}{dt}\right)_{univ} = \left(\frac{dS}{dt}\right)_{sys} + \left(\frac{dS}{dt}\right)_{surr} \geq 0 \qquad \text{(1 point)}$$

As the system is operating at steady-state,

$$\left(\frac{dS}{dt}\right)_{sys} = 0 \qquad \text{(1 point)}$$

Thus the entropy production becomes

$$\left(\frac{dS}{dt}\right)_{univ} = \left(\frac{dS}{dt}\right)_{surr} = \sum_{out} \dot{m}\hat{s} - \sum_{in} \dot{m}\hat{s} + \frac{\dot{Q}}{T_{surr}}$$

As there is no heat loss to the surroundings,

$$\left(\frac{dS}{dt}\right)_{univ} = \sum_{out} \dot{m}\hat{s} - \sum_{in} \dot{m}\hat{s} \qquad \text{(1 point)}$$

$$\left(\frac{dS}{dt}\right)_{univ} = (\dot{m}_1 + \dot{m}_2)s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2$$

Substitute in the corresponding values,

$$\left(\frac{dS}{dt}\right)_{univ} = (0.0212\frac{kg}{s})(0.5714\frac{kJ}{kgK}) + (0.28\frac{kg}{s})(6.6001\frac{kJ}{kgK}) - (0.0212 + 0.28)\frac{kg}{s}(6.2575\frac{kJ}{kgK})$$

$$\boxed{\left(\frac{dS}{dt}\right)_{univ} = 0.0248\frac{kJ}{K-s}}$$ (2 points)

Comments:

- For part (a), if the diagram does not have the phase boundary, no points will be given at all even if the states are labeled on the diagram.

- Steady-state operation is not considered an assumption in this case as it is explicitly stated in the problem statement

- For future exams and quizzes, start from full energy equation and show simplifications. Credits will not be given next time for equations given without origin.

  E.g. $0 = \dot{m}_1 h_1 + \dot{m}_2 h_2 - \dot{m}_3 h_3$

- A lot of students made the mistake of identifying m_1= 0.28 kg/s
- The students are given the benefit of the doubt if they did not state what type of $\left(\frac{dS}{dt}\right)$(universe or surroundings). However, if they calculate $\left(\frac{dS}{dt}\right)_{sys}$, no credit will be given. The students should realize that $\left(\frac{dS}{dt}\right)_{sys}$ =0.

- Common mistake: $\left(\frac{dS}{dt}\right)_{sys} = \sum_{out}\dot{m}\hat{s} - \sum_{in}\dot{m}\hat{s} + \frac{\dot{Q}}{T_{surr}}$ only when the whole process is reversible. i.e. $\left(\frac{dS}{dt}\right)_{univ} = 0$ But this process is not reversible.
- Common mistake: For entropy balance on the surroundings (or universe), it should be $\left(\frac{dS}{dt}\right)_{univ} = \sum_{out}\dot{m}\hat{s} - \sum_{in}\dot{m}\hat{s}$. Streams coming out of the system are entering the surroundings, thus they are contributing entropy to the surroundings.