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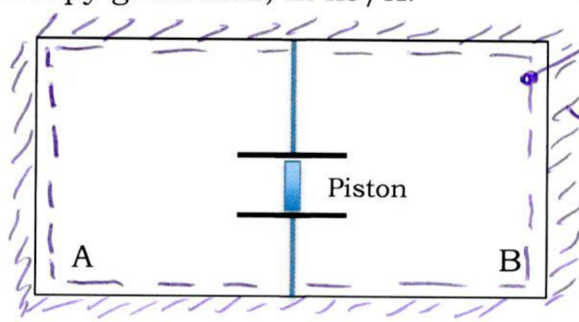
Solutions

Question 1 [10 marks]

An insulated, rigid tank is divided into two compartments by a frictionless, and thermally conductive piston that is initially locked. One compartment initially contains 1 m^3 of saturated water vapor at 400 kPa and the other compartment contains 1 m^3 of water vapor at 800 kPa and 400°C. The piston is released and equilibrium is attained.

a) (5 marks) Determine the final equilibrium specific volume in m^3/kg and the final equilibrium specific internal energy in kJ/kg;

b) (5 marks) If we assume that the final equilibrium pressure and temperature are 600 kPa and 275°C, respectively, determine the amount of entropy generated, in kJ/K.



Assumptions

* closed sysm
* Control mass includes Water Content in A and B
* ΔPE and ΔKE negligible
* frictionless Piston
* no external Work
* adiabatic Process.

initial states

A	B
$V_{A_1} = 1\,m^3$	$V_{B_1} = 1\,m^3$
$P_{A_1} = P_{sat} = 400\,kPa$	$P_{B_1} = 800\,kPa$
Sat. Vapor	$T_{B_1} = 400°C$

$$P_{sat} = 400\,kPa \longrightarrow \begin{cases} v_{A_1} = v_g = 0.46246\ m^3/kg \\ u_{A_1} = u_g = 2553.55\ kJ/kg. \\ s_{A_1} = s_g = 6.8958\ kJ/kg\text{-}K \end{cases}$$

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$$\left.\begin{matrix} P_{B_1} = 800\text{ kPa} \\ T_{B_1} = 400^\circ C \end{matrix}\right\} \xrightarrow[\text{Table}]{\text{Superheated}} \left\{\begin{matrix} v_{B_1} = 0.38426\ m^3/kg \\ u_{B_1} = 2959.66\ kJ/kg \\ s_{B_1} = 7.5715\ kJ/kg\text{-}K \end{matrix}\right.$$

$$m_{A_1} = \frac{V_{A_1}}{v_{A_1}} = \frac{1}{0.46246} = 2.162\ kg$$

$$m_{B_1} = \frac{V_{B_1}}{v_{B_1}} = \frac{1}{0.38426} = 2.6\ kg$$

$m_{final} = m_{A_1} + m_{B_1}$

$m_{final} = 2.162 + 2.6$

$m_{final} = \underline{4.762\ kg}$

$$** \rightarrow V_{final} = V_{A_1} + V_{B_1} = 2\ m^3 \rightarrow v_{final} = \frac{V_{final}}{m_{final}} = \frac{2}{4.762} = 0.419\ m^3/kg$$

Energy Balance

$$m_{final}\,u_{final} = m_{A_1} u_{A_1} + m_{B_1} u_{B_1}$$

$$** \rightarrow u_{final} = \frac{2.162 \times 2553.55 + 2.6 \times 2959.66}{4.762} = 2775.25\ \frac{kJ}{kg}$$

$$\text{b) assuming } \left.\begin{matrix} P_{final} = 600\text{ kPa} \\ T_{final} = 275^\circ C \end{matrix}\right\} \xrightarrow[\text{Table}]{\text{Superheated}} \left\{ s_{final} = 7.277\ kJ/kg\text{-}K \right.$$

interpolation.

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Entropy Balance

$$m_{final} s_{final} - m_{A_1} s_{A_1} - m_{B_1} s_{B_1} = S_{gen_{1-2}}$$

$$4.762 \times 7.277 - 2.162 \times 6.8959 - 2.6 \times 7.5715 = S_{gen_{1-2}}$$

$$34.653 - 14.91 - 19.686 = 0.057 \text{ kJ/K}$$

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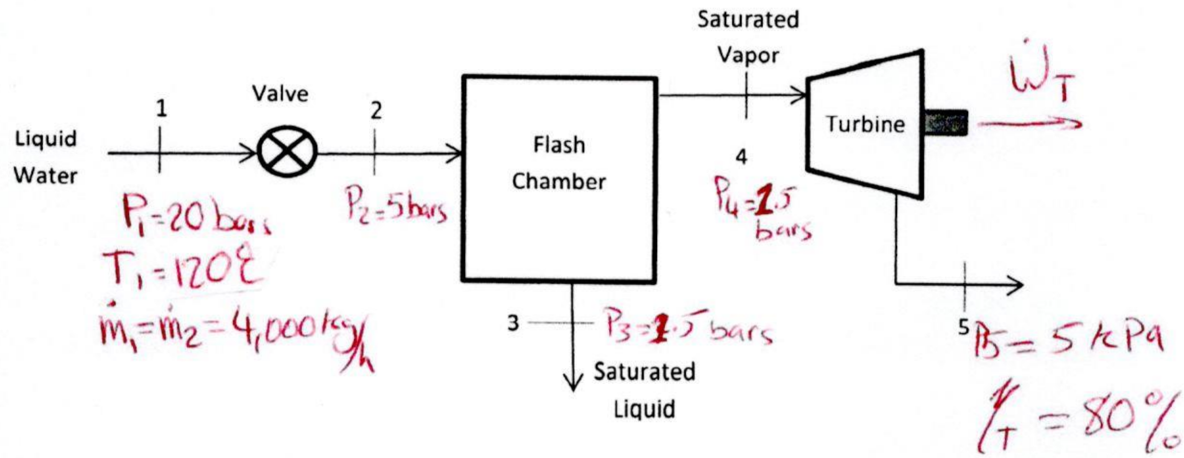
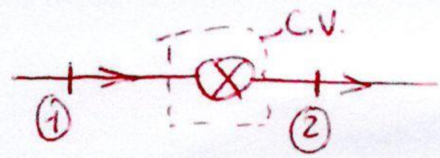
2. (25 marks) Figure below shows liquid water at 20 bars and 120°C entering a flash chamber through a valve at a rate of 4,000 kg/h. At the valve exit, the pressure is 5 bars. Saturated liquid at 1.5 bars exits from the bottom of the flash chamber and saturated vapor at 1.5 bars exits from near the top. The saturated vapor is fed to a steam turbine having an isentropic efficiency of 80% and an exit pressure of 5 kPa. Assume the operation is steady-state and there is negligible heat transfer with surroundings.



a. (7 marks) Determine the rate of entropy generation in kW/K for the valve



* Steady state
* Negligible Heat Transfer
* $\Delta PE \simeq 0$; $\Delta KE \simeq 0$

Mass * $\dot{m}_1 = \dot{m}_2 = 4{,}000\ \text{kg/h} = \frac{4{,}000}{3{,}600} = 1.11\ \text{kg/s}$

1st law * $\dot{m}_1 h_1 = \dot{m}_2 h_2 \longrightarrow h_1 = h_2$

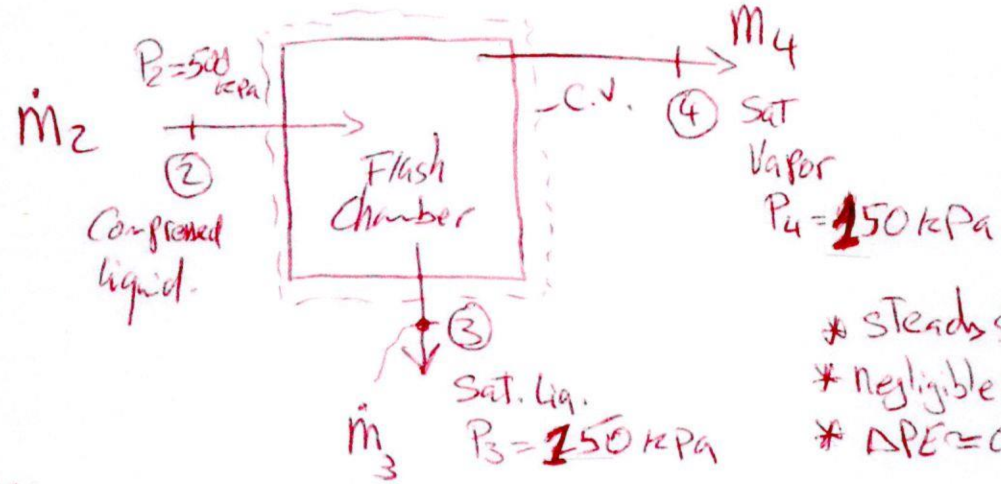
2nd law * $\dot{m}_1 (s_2 - s_1) = \dot{S}_{gen\,1-2}$

Compressed liq. data Table "B1.4" $\xrightarrow{P_1; T_1}$ $\begin{cases} h_1 = 504.96 \\ s_1 = 1.5259 \end{cases}$

Point (2) $\xrightarrow[P_2 = 500\ \text{kPa}]{h_2 = 504.96}$ $\begin{cases} s_2 - 1.5273 = \dfrac{1.5273 - 1.7389}{503.90 - 589.20}(504.96 - 503.9) \\ s_2 = 1.53\ \text{kJ/kg-K} \end{cases}$

$\dot{S}_{gen} = \dot{m}_1 (s_2 - s_1) = 1.11 \times (1.53 - 1.5259) = 0.0045\ \text{kW/K}$

b. (9 marks) Determine the rate of entropy generation in kW/K for the flash chamber



* Steady state
* Negligible Heat Transfer
* $\Delta PE \approx 0$; $\Delta KE \approx 0$

* mass $\rightarrow$ $\dot{m}_4 = \dot{m}_2 - \dot{m}_3$ and $\dot{m}_2 = 1.11$ kg/s

1st law $\rightarrow$ $\dot{m}_2 h_2 = \dot{m}_3 h_3 + \dot{m}_4 h_4$

2nd law $\rightarrow$ $\dot{m}_4 s_4 + \dot{m}_3 s_3 - \dot{m}_2 s_2 = \dot{S}_{gen}$

$P_{sat} = 150$ kPa $\longrightarrow$
$$\begin{cases} h_3 = h_f = 467.08 \\ s_3 = s_f = 1.4335 \\ h_4 = h_g = 2693.54 \\ s_4 = s_g = 7.2232 \end{cases}$$
F.C.

$h_2 = 504.96$ kJ/kg
$s_2 = 1.53$ kJ/kg-K

$$\dot{m}_2 h_2 = (\dot{m}_2 - \dot{m}_4) h_3 + \dot{m}_4 h_4$$

$$\dot{m}_4 = \frac{\dot{m}_2 (h_2 - h_3)}{h_4 - h_3} = \frac{1.11 \times (504.96 - 467.08)}{(2693.54 - 467.08)} = 1.11 \times 0.017$$

$$\dot{m}_4 = 0.019 \text{ kg/s}$$

$$\dot{m}_4 s_4 + \dot{m}_3 s_3 - \dot{m}_2 s_2 = \dot{S}_{gen}$$

F.C.

$$0.019 \times 7.2232 + (1.11 - 0.019) \times 1.4335 - 1.11 \times 1.53 = \dot{S}_{gen}$$

$$\dot{S}_{gen} = 0.0029 \text{ kW/K}$$

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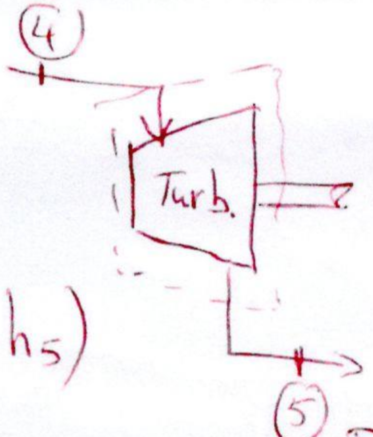
c. (9marks) Determine the power generated in kW for the turbine



$\dot{m}_4 = \dot{m}_5$ $\longrightarrow \dot{W}_T$

$\dot{W}_T = \dot{m}_4 (h_4 - h_5)$

* Steady state
* Adiabatic
* $\Delta PE \simeq 0$
$\Delta KE \simeq 0$

$P_5 = 5\,kPa$

$$\eta_T = \frac{\dot{W}_T}{\dot{W}_{T_{isen}}} = \frac{h_4 - h_5}{h_4 - h_{5s}} = 0.8$$

$S_{5s} = S_4 = 7.2232\ kJ/kg\text{-}K$
$P_5 = 5\ kPa$

$P_{sat} = 5\,kPa$:
$S_f = 0.4763$
$S_g = 8.3950$
$h_f = 137.79$
$h_g = 2561.45$

$S_{5s} < S_g \longrightarrow$ two-phase

$$x_{5s} = \frac{S_{5s} - S_f}{S_g - S_f} = \frac{7.2232 - 0.4763}{8.3950 - 0.4763} = 0.852$$

$$h_{5s} = h_f + x_{5s}(h_g - h_f) = 137.79 + 0.852(2561.45 - 137.79) = 2202.75\ kJ/kg$$

$$\frac{h_4 - h_5}{h_4 - h_{5s}} = 0.8 \rightarrow h_5 = h_4 - 0.8(h_4 - h_{5s}) = 2693.54 - 0.8(2693.54 - 2202.75)$$

$$\longrightarrow h_5 = 2300.9\ kJ/kg.$$

$$\dot{W}_T = \dot{m}_4 (h_4 - h_5) = 0.019\ kg/s \times (2693.54 - 2300.9)$$
$$= 7.46\ kW$$