Guía 5

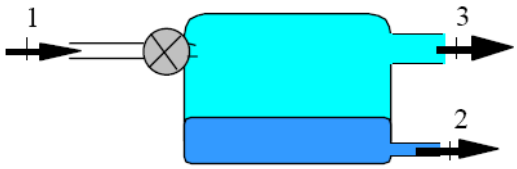
Andrés Yenes S.

1. (Pregunta 9.83, Borgnakke & Sontagge, 7th ed)

9.83

A geothermal supply of hot water at 500 kPa, 150°C is fed to an insulated flash evaporator at the rate of 1.5 kg/s. A stream of saturated liquid at 200 kPa is drained from the bottom of the chamber and a stream of saturated vapor at 200 kPa is drawn from the top and fed to a turbine. Find the rate of entropy generation in the flash evaporator.

Solution:



Two-phase out of the valve. The liquid drops to the bottom.

Continuity Eq.6.9: $\dot{m}_1 = \dot{m}_2 + \dot{m}_3$

Energy Eq.6.10: $\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_3 h_3$

Entropy Eq.9.7: $\dot{m}_1 s_1 + \dot{S}_{gen} + \int d\dot{Q}/T = \dot{m}_2 s_2 + \dot{m}_3 s_3$

Process: $\dot{Q} = 0$, irreversible (throttle)

B.1.1 $h_1 = 632.18$ kJ/kg, $s_1 = 1.8417$ kJ/kg K

B.1.2 $h_3 = 2706.63$ kJ/kg, $s_3 = 7.1271$ kJ/kg K,

$h_2 = 504.68$ kJ/kg, $s_2 = 1.53$ kJ/kg K

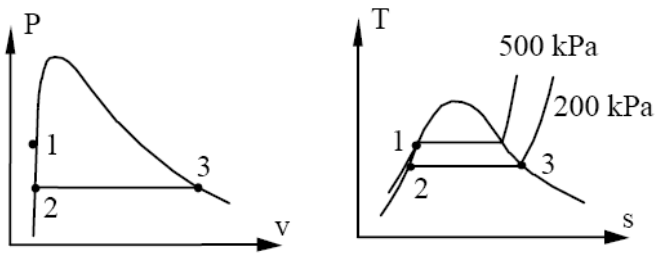
From the energy equation we solve for the flow rate

$$\dot{m}_3 = \dot{m}_1(h_1 - h_2)/(h_3 - h_2) = 1.5 \times 0.0579 = 0.08685 \text{ kg/s}$$

Continuity equation gives: $\dot{m}_2 = \dot{m}_1 - \dot{m}_2 = 1.41315$ kg/s

Entropy equation now leads to

$$\dot{S}_{gen} = \dot{m}_2 s_2 + \dot{m}_3 s_3 - \dot{m}_1 s_1$$
$$= 1.41315 \times 1.53 + 0.08685 \times 7.127 - 1.5 \times 1.8417$$
$$= \mathbf{0.01855\ kW/K}$$



2. (Pregunta 9.87, Borgnakke & Sontagge, 7th ed) → ojo las unidades…

A mixing chamber receives 5 kg/min ammonia as saturated liquid at −20°C from one line and ammonia at 40°C, 250 kPa from another line through a valve. The chamber also receives 325 kJ/min energy as heat transferred from a 40°C reservoir. This should produce saturated ammonia vapor at −20°C in the exit line. What is the mass flow rate in the second line and what is the total entropy generation in the process?

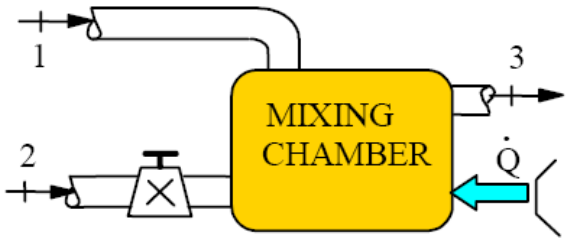
Solution:

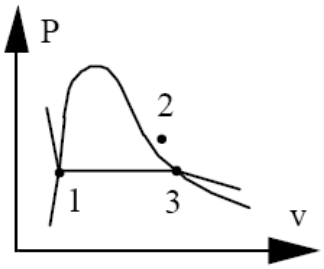
CV: Mixing chamber out to reservoir

Continuity Eq.6.9: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

Energy Eq.6.10: $\dot{m}_1 h_1 + \dot{m}_2 h_2 + \dot{Q} = \dot{m}_3 h_3$

Entropy Eq.9.7: $\dot{m}_1 s_1 + \dot{m}_2 s_2 + \dot{Q}/T_{res} + \dot{S}_{gen} = \dot{m}_3 s_3$





From the energy equation:

$$\dot{m}_2 = [(\dot{m}_1(h_1 - h_3) + \dot{Q}]/(h_3 - h_2)$$

$$= [5 \times (89.05 - 1418.05) + 325] / (1418.05 - 1551.7)$$

$$= \mathbf{47.288\ kg/min} \Rightarrow \dot{m}_3 = 52.288\ \text{kg/min}$$

$$\dot{S}_{gen} = \dot{m}_3 s_3 - \dot{m}_1 s_1 - \dot{m}_2 s_2 - \dot{Q}/T_{res}$$

$$= 52.288 \times 5.6158 - 5 \times 0.3657 - 47.288 \times 5.9599 - 325/313.15$$

$$= \mathbf{8.94\ kJ/K\ min}$$

3. (Pregunta 9.89, Borgnakke & Sontagge, 7th ed)

A condenser in a power plant receives 5 kg/s steam at 15 kPa, quality 90% and rejects the heat to cooling water with an average temperature of 17°C. Find the power given to the cooling water in this constant pressure process and the total rate of enropy generation when condenser exit is saturated liquid.

Solution:

C.V. Condenser. Steady state with no shaft work term.

Energy Eq.6.12: $\dot{m}\, h_i + \dot{Q} = \dot{m} h_e$

Entropy Eq.9.8: $\dot{m}\, s_i + \dot{Q}/T + \dot{S}_{gen} = \dot{m}\, s_e$

Properties are from Table B.1.2

$h_i = 225.91 + 0.9 \times 2373.14 = 2361.74$ kJ/kg , $h_e = 225.91$ kJ/kg

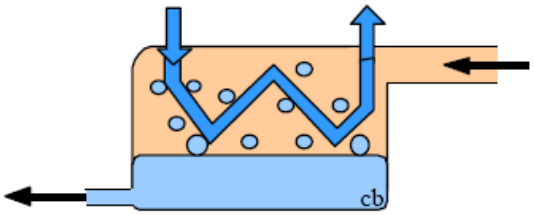
$s_i = 0.7548 + 0.9 \times 7.2536 = 7.283$ kJ/kg K, $s_e = 0.7548$ kJ/kg K

$\dot{Q}_{out} = -\dot{Q} = \dot{m}\,(h_i - h_e) = 5(2361.74 - 225.91) = \mathbf{10679\ kW}$

$\dot{S}_{gen} = \dot{m}\,(s_e - s_i) + \dot{Q}_{out}/T$

$= 5(0.7548 - 7.283) + 10679/(273 + 17)$

$= -32.641 + 36.824 = \mathbf{4.183\ kW/K}$



Often the cooling media flows inside a long pipe carrying the energy away.

4. (Pregunta 7.186, Cengel & Boles, 5th ed)

7-186 Two rigid tanks that contain water at different states are connected by a valve. The valve is opened and steam flows from tank A to tank B until the pressure in tank A drops to a specified value. Tank B loses heat to the surroundings. The final temperature in each tank and the entropy generated during this process are to be determined.

Assumptions **1** Tank A is insulated, and thus heat transfer is negligible. **2** The water that remains in tank A undergoes a reversible adiabatic process. **3** The thermal energy stored in the tanks themselves is negligible. **4** The system is stationary and thus kinetic and potential energy changes are negligible. **5** There are no work interactions.

Analysis (*a*) The steam in tank A undergoes a reversible, adiabatic process, and thus $s_2 = s_1$. From the steam tables (Tables A-4 through A-6),

Tank A :

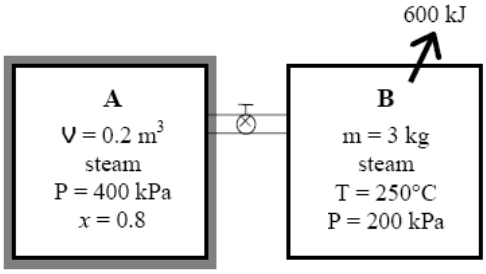
$$\left.\begin{array}{l} P_1 = 400 \text{ kPa} \\ x_1 = 0.8 \end{array}\right\} \begin{array}{l} v_{1,A} = v_f + x_1 v_{fg} = 0.001084 + (0.8)(0.46242 - 0.001084) = 0.37015 \text{ m}^3/\text{kg} \\ u_{1,A} = u_f + x_1 u_{fg} = 604.22 + (0.8)(1948.9) = 2163.3 \text{ kJ/kg} \\ s_{1,A} = s_f + x_1 s_{fg} = 1.7765 + (0.8)(5.1191) = 5.8717 \text{ kJ/kg} \cdot \text{K} \end{array}$$

$$T_{2,A} = T_{\text{sat@300 kPa}} = \mathbf{133.52°C}$$

$$\left.\begin{array}{l} P_1 = 300 \text{ kPa} \\ s_2 = s_1 \\ (\text{sat. mixture}) \end{array}\right\} \begin{array}{l} x_{2,A} = \dfrac{s_{2,A} - s_f}{s_{fg}} = \dfrac{5.8717 - 1.6717}{5.3200} = 0.7895 \\ v_{2,A} = v_f + x_{2,A} v_{fg} = 0.001073 + (0.7895)(0.60582 - 0.001073) = 0.47850 \text{ m}^3/\text{kg} \\ u_{2,A} = u_f + x_{2,A} u_{fg} = 561.11 + (0.7895)(1982.1 \text{ kJ/kg}) = 2125.9 \text{ kJ/kg} \end{array}$$

TankB :

$$\left.\begin{array}{l} P_1 = 200 \text{ kPa} \\ T_1 = 250°\text{C} \end{array}\right\} \begin{array}{l} v_{1,B} = 1.1989 \text{ m}^3/\text{kg} \\ u_{1,B} = 2731.4 \text{ kJ/kg} \\ s_{1,B} = 7.7100 \text{ kJ/kg} \cdot \text{K} \end{array}$$



The initial and the final masses in tank A are

$$m_{1,A} = \frac{V_A}{v_{1,A}} = \frac{0.2 \text{ m}^3}{0.37015 \text{ m}^3/\text{kg}} = 0.5403 \text{ kg}$$

and

$$m_{2,A} = \frac{V_A}{v_{2,A}} = \frac{0.2 \text{ m}^3}{0.47850 \text{ m}^3/\text{kg}} = 0.4180 \text{ kg}$$

Thus, 0.5403 - 0.4180 = 0.1223 kg of mass flows into tank B. Then,

$$m_{2,B} = m_{1,B} + 0.1223 = 3 + 0.1223 = 3.1223 \text{ kg}$$

The final specific volume of steam in tank B is determined from

$$v_{2,B} = \frac{V_B}{m_{2,B}} = \frac{(m_1 v_1)_B}{m_{2,B}} = \frac{(3 \text{ kg})(1.1989 \text{ m}^3/\text{kg})}{3.1223 \text{ kg}} = 1.1519 \text{ m}^3/\text{kg}$$

We take the entire contents of both tanks as the system, which is a closed system. The energy balance for this stationary closed system can be expressed as

$$\underbrace{E_{\text{in}} - E_{\text{out}}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{\text{system}}}_{\substack{\text{Change in internal, kinetic,} \\ \text{potential, etc. energies}}}$$

$$-Q_{\text{out}} = \Delta U = (\Delta U)_A + (\Delta U)_B \quad (\text{since } W = \text{KE} = \text{PE} = 0)$$

$$-Q_{\text{out}} = (m_2 u_2 - m_1 u_1)_A + (m_2 u_2 - m_1 u_1)_B$$

Substituting,

$$-600 = \{(0.418)(2125.9) - (0.5403)(2163.3)\} + \{(3.1223)u_{2,B} - (3)(2731.4)\}$$
$$u_{2,B} = 2522.0 \text{ kJ/kg}$$

Thus,

$$\left.\begin{aligned} v_{2,B} &= 1.1519 \text{ m}^3/\text{kg} \\ u_{2,B} &= 2522.0 \text{ kJ/kg} \end{aligned}\right\} \begin{aligned} T_{2,B} &= \mathbf{113.2°C} \\ s_{2,B} &= 7.2274 \text{ kJ/kg} \cdot \text{K} \end{aligned}$$

(*b*) The total entropy generation during this process is determined by applying the entropy balance on an *extended system* that includes both tanks and their immediate surroundings so that the boundary temperature of the extended system is the temperature of the surroundings at all times. It gives

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer} \\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy} \\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change} \\ \text{in entropy}}}$$

$$-\frac{Q_{\text{out}}}{T_{\text{b,surr}}} + S_{\text{gen}} = \Delta S_{\text{A}} + \Delta S_{\text{B}}$$

Rearranging and substituting, the total entropy generated during this process is determined to be

$$S_{\text{gen}} = \Delta S_A + \Delta S_B + \frac{Q_{\text{out}}}{T_{\text{b,surr}}} = (m_2 s_2 - m_1 s_1)_A + (m_2 s_2 - m_1 s_1)_B + \frac{Q_{\text{out}}}{T_{\text{b,surr}}}$$
$$= \{(0.418)(5.8717) - (0.5403)(5.8717)\} + \{(3.1223)(7.2274) - (3)(7.7100)\} + \frac{600 \text{ kJ}}{273 \text{ K}}$$
$$= \mathbf{0.916 \text{ kJ/K}}$$

5. (Pregunta 9.117, Borgnakke & Sontagge, 7th ed)

Solution:

The pressure cooker goes through a transient process as it heats water up to the boiling temperature at 200 kPa then heats more as saturated vapor at 200 kPa escapes. The throttling process is steady state as it flows from saturated vapor at 200 kPa to 100 kPa which we assume is a constant h process.

C.V. Pressure cooker, no work.

Continuity Eq.6.15: $m_2 - m_1 = -m_e$

Energy Eq.6.16: $m_2 u_2 - m_1 u_1 = -m_e h_e + {}_1Q_2$

Entropy Eq.9.11: $m_2 s_2 - m_1 s_1 = -m_e s_e + \int dQ/T + {}_1S_{2\,gen}$

State 1: $v_1 = v_f = 0.001002\ m^3/kg$ $\quad V = m_1 v_1 = 0.003006\ m^3$

State 2: $m_2 = m_1/2 = 1.5$ kg, $v_2 = V/m_2 = 2v_1$, $P_2 = 200$ kPa

Exit: $h_e = h_g = 2706.63$ kJ/kg, $s_e = s_g = 7.1271$ kJ/kg K

So we can find the needed heat transfer and entropy generation if we know the C.V. surface temperature T. If we assume T for water then ${}_1S_{2\,gen} = 0$, which is an internally reversible externally irreversible process, there is a ΔT between the water and the source.

C.V. Valve, steady flow from state e (200 kPa) to state 3 (at 100 kPa).

Energy Eq.: $h_3 = h_e$

Entropy Eq.: $s_3 = s_e + {}_eS_{3\,gen}$ generation in valve (throttle)

State 3: 100 kPa, $h_3 = 2706.63$ kJ/kg Table B.1.3 $\Rightarrow$

$$T_3 = 99.62 + (150\text{-}99.62)\,\frac{2706.63 - 2675.46}{2776.38 - 2675.46} = 115.2°C$$

$$s_3 = 7.3593 + (7.6133 - 7.3593)\ 0.30886 = 7.4378\ kJ/kg\ K$$

$${}_eS_{3\,gen} = m_e(s_3 - s_e) = 1.5\ (7.4378 - 7.1271) = \mathbf{0.466\ kJ/K}$$