Chapter 3

ENTROPY GENERATION, OR EXERGY DESTRUCTION

Problem 3.1

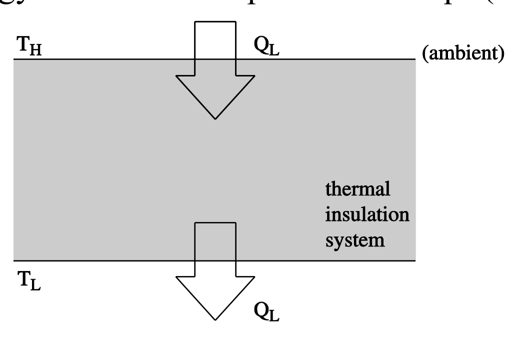
It was shown in Fig. 3.9 that the refrigerator deposits exergy in the (T_L) space at the rate

$$(-E_{Q_L}) = Q_L\left(\frac{T_H}{T_L} - 1\right) \qquad (1)$$

Looking now at the thermal insulation (the "system") sandwiched between (T_H) and (T_L), we see that Q_L enters from T_H and exits through T_L. The net exergy flow *into* this sytem is [see eq. (3.14)]

$$\begin{aligned} \text{net exergy inflow} &= Q_L\left(1-\frac{T_H}{T_H}\right) + (-Q_L)\left(1-\frac{T_H}{T_L}\right) \\ &= Q_L\left(\frac{T_H}{T_L}-1\right) > 0 \end{aligned} \qquad (2)$$

The fact that this quantity is positive means that the thermal insulation system acts as a "sink" for exergy. Note that the quantities of eqs. (1) and (2) are equal.



Problem 3.2

The nonflow exergy of a closed system is

$$\Xi = E - E_0 - T_0(S - S_0) + P_0(V - V_0) \quad (3.32)$$

If the system is isolated, then

(i) E is fixed, eq. (2.49)

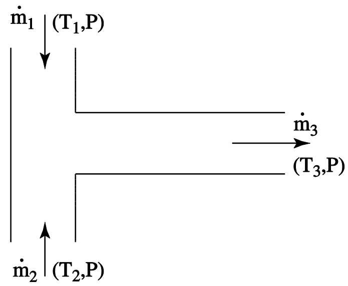
(ii) V is fixed [see then discussion above eq. (2.49)]

(iii) S increases or, in the limit, remains the same

In conclusion, if the isolated system undergoes a change, is nonflow exergy Ξ decreases or, in the limit remains the same.

Problem 3.3

The first law and the second law for the control volume (mixing chamber) are



$$x h_1 + (1-x) h_2 = h_3 \qquad (1)$$

$$\dot{S}_{gen} = \dot{m} s_3 - x \dot{m} s_1 - (1-x)\dot{m} s_2 > 0 \qquad (2)$$

where $\dot{m} = \dot{m}_1 + \dot{m}_2$. When the two streams $\dot{m}_1$ and $\dot{m}_2$ carry the same ideal gas, eqs. (1)– (2) become

$$x T_1 + (1-x) T_2 = T_3 \qquad (3)$$

$$\frac{\dot{S}_{gen}}{\dot{m} c_P} = x \ln \frac{T_3}{T_1} + (1-x) \ln \frac{T_3}{T_2} > 0 \qquad (4)$$

Eliminating T_3 between eqs. (3)–(4) yields

$$\frac{\dot{S}_{gen}}{\dot{m} c_P} = \ln \left[\frac{x + \tau(1-x)}{\tau^{1-x}} \right] > 0 \qquad (5)$$

in which τ is the inlet temperature ratio,

$$\tau = \frac{T_2}{T_1}$$

Solving $\partial \dot{S}_{gen} / \partial x = 0$, we obtain the critical mass flow rate fraction for maximum irreversibility:

$$x = \frac{\tau - 1 - \tau \ln \tau}{(1-\tau) \ln \tau}$$

Problem 3.4

The maximum useful work is the nonflow exergy "stored" in the purchased bottle,

$$\Xi = m\left[u - u_0 - T_0(s - s_0) + P_0(v - v_0)\right]$$

or, using u = h – Pv

$$\Xi = m\left[h - h_0 - T_0(s - s_0) + v(P_0 - P)\right]$$

In this problem, $P_0 - P = 0$ and

$$m = \frac{0.05\,m^3}{1.24\times10^{-3}\,m^3/kg} = 40.3\,kg$$

Hence

$$\begin{aligned}\Xi &= 40.3\,kg\,[-121.5 - 172.1 - 300(2.85 - 6.25)]\frac{kJ}{kg} \\ &= 2.93\times10^4\end{aligned}$$

Problem 3.5

Consider the aggregate system indicated by the dashed line in the figure below: This system is closed and contains all the components that operate at temperatures higher than T_0. We apply the first law to this system and obtain

$$\dot{W} = \dot{Q}_H - \dot{Q}_0 = T_0 \left(\frac{\dot{Q}_H}{T_0} - \frac{\dot{Q}_0}{T_0} \right)$$

where the quantity in the parentheses is the total rate of entropy generation of the system:

$$\dot{S}_{gen} = \frac{\dot{Q}_H}{T_0} - \frac{\dot{Q}_0}{T_0}$$

In conclusion, the power required by the heat pump is proportional to the rate of entropy generation in the heat pump and the rest of the space situated at temperatures above T_0:

$$\dot{W} = T_0 \dot{S}_{gen}$$