Given

Heating of liquid CO_2 at constant pressure

Find

Change in specific entropy ($\frac{kJ}{kg-K}$) using:
- Property table
- Saturated liquid approximation
- Specific heat at average temperature

System

N/A

Assumptions
- Liquid CO_2 is incompressible
- Specific heat constant with temperature change

Basic Equations

N/A

Solution

CO_2, $P_1 = 20$ bar $\longrightarrow$ $P_2 = 20$ bar

$T_1 = -40°C$ $\quad$ $T_2 = -20°C$

T_{sat} (20 bar) $= -19.503°C \Rightarrow T < T_{sat} \Rightarrow$ sub-cooled (compressed) liquid

(a) Compressed liquid table:

$s_1 = -0.00319 \frac{kJ}{kg-K}$, $s_2 = 0.16705 \frac{kJ}{kg-K}$

$\Delta s = s_2 - s_1 \Rightarrow \boxed{\Delta s = 0.17024 \frac{kJ}{kg-K}}$

(b) Saturated liquid approximation:

$s_1 \cong s_f(-40°C) = 0.00000 \frac{kJ}{kg-K}$, $s_2 \cong s_f(-20°C) = 0.16719 \frac{kJ}{kg-K}$

$\Delta s = s_2 - s_1 \Rightarrow \boxed{\Delta s = 0.16719 \frac{kJ}{kg-K}}$

Specific heat:

$c_{CO_2} = 2.082 \frac{kJ}{kg-K}$

$\Delta s = c_{CO_2} \ln \frac{T_2}{T_1} = 2.082 \frac{kJ}{kg-K} \ln \frac{(-20 + 273.15)\,K}{(-40 + 273.15)\,K}$

$\Rightarrow \boxed{\Delta s = 0.17135 \frac{kJ}{kg-K}}$

Given

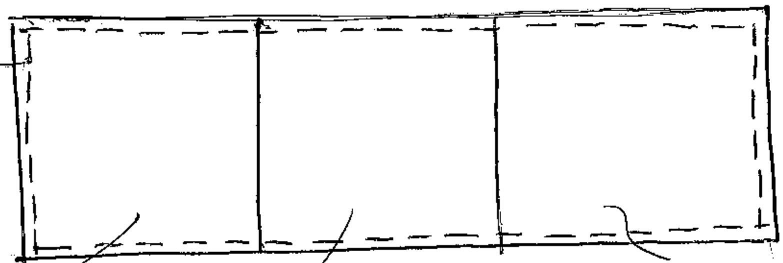
Heat transfer among three liquids inside a well-insulated, closed rigid tank

Find

Total entropy change $\left(\frac{kJ}{K}\right)$ of the system

System

Liquids inside the rigid tank is the system



$m_A = 5\ kg$
$c_A = 2\ \frac{kJ}{kg-K}$
$T_{A,i} = 100°C$

$m_B = 2\ kg$
$c_B = 4\ \frac{kJ}{kg-K}$
$T_{B,i} = 50°C$

$m_C = 1\ kg$
$c_C = 7\ \frac{kJ}{kg-K}$
$T_{C,i} = 40°C$

Assumptions

- Closed system (m = constant)
- Rigid tank: $W_{boundary} = 0$
- Insulated: $Q = 0$
- Ignore change in KE and PE
- Liquids are incompressible
- Specific heat constant with temperature change

Basic Equations

$$\cancelto{0}{Q} - \cancelto{0}{W} = \Delta E = \Delta U + \cancelto{no}{\Delta KE} + \cancelto{no}{\Delta PE}$$

$$W \rightarrow (\cancelto{0}{W_{boundary}} + \cancelto{0}{W_{other}})$$

Solution

See HW-11(ii)

$T_f = 67.2°C$

Total entropy change of the system:

$$\Delta S = \Delta S_A + \Delta S_B + \Delta S_C$$

$$= m_A c_A \ln \frac{T_f}{T_{A,i}} + m_B c_B \ln \frac{T_f}{T_{B,i}} + m_C c_C \ln \frac{T_f}{T_{C,i}}$$

$$\Delta S = 5\,kg * 2\,\frac{kJ}{kg-K}\ \ln\frac{340.35\,K}{373.15\,K}$$
$$+ 2\,kg * 4\,\frac{kJ}{kg-K}\ \ln\frac{340.35\,K}{323.15\,K}$$
$$+ 1\,kg * 7\,\frac{kJ}{kg-K}\ \ln\frac{340.35\,K}{313.15\,K}$$
$$= -0.92006\,\frac{kJ}{K} + 0.41486\,\frac{kJ}{K} + 0.58305\,\frac{kJ}{K}$$
$$\boxed{\Delta S = +0.07785\,\frac{kJ}{K}}$$

Note

Considering entropy balance: $\cancel{\frac{Q}{T_{boundary}}}^{\,0} + \sigma_{generation} = \Delta S$

$\Rightarrow \sigma_{generation} = +0.07785\,\frac{kJ}{K}$

Since $\sigma_{generation} > 0$, the second law is not violated

Given

Air inside a closed piston-cylinder device undergoing four processes

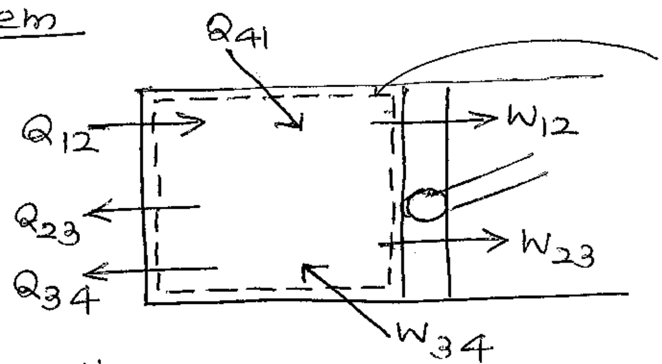
Find

(a) Entropy change ($\frac{kJ}{K}$) for each process

(b) Entropy change ($\frac{kJ}{K}$) for the cycle

(c) T-s diagram

System



$m_{air} = 2$ kg

Assumptions

- Closed system (m = constant)
- Quasi-equilibrium process
- Neglect friction between piston and cylinder wall
- Ignore KE and PE change
- Air behaves as an ideal gas

Basic Equations

N/A

Solution

See HW-13

State 1 $P_1 = 5$ bar, $T_1 = 600$ K

State 2 $P_2 = 4$ bar, $T_2 = 600$ K

State 3 $P_3 = 3$ bar, $T_3 = 554$ K

State 4 $P_4 = 3$ bar, $T_4 = 360$ K

$$R_{air} = \frac{\bar{R}}{M_{air}} = 0.287 \frac{kJ}{kg-K}$$

(a) Entropy change for each process:

$$\Delta S_{12} = S_2 - S_1 = m_{air}(s_2 - s_1) = m_{air}(\cancel{s_2^o - s_1^o} - R_{air} \ln \frac{P_2}{P_1})$$

$T_2 = T_1$

$$\Delta S_{12} = 2\,kg * -0.287 \frac{kJ}{kg-K} \ln \frac{4\,bar}{5\,bar}$$

$$\boxed{S_2 - S_1 = +0.128 \frac{kJ}{K}}$$

$$\Delta S_{23} = S_3 - S_2 = m_{air}(s_3 - s_2) = m_{air}(s_3^o - s_2^o - R_{air} \ln \frac{P_3}{P_2})$$

$T_2 = 600\,K \Rightarrow s_2^o = 2.410 \frac{kJ}{kg-K}$

$T_3 = 554\,K$ Interpolating: $s_3^o = 2.327 \frac{kJ}{kg-K}$

$$\Delta S_{23} = 2\,kg * (2.327 - 2.410 - 0.287 \ln \frac{3\,bar}{4\,bar}) \frac{kJ}{kg-K}$$

$$\boxed{S_3 - S_2 = -0.000871 \frac{kJ}{K}} \cong 0$$

$$\Delta S_{34} = S_4 - S_3 = m_{air}(s_4 - s_3) = m_{air}(s_4^o - s_3^o - R_{air} \ln \frac{P_4}{P_3})$$

$T_4 = 360\,K \Rightarrow s_4^o = 1.886 \frac{kJ}{kg-K}$

$$\Delta S_{34} = 2\,kg * (1.886 - 2.327 - \cancel{0.287 \ln \frac{3\,bar}{3\,bar}}) \frac{kJ}{kg-K}$$

$$\boxed{S_4 - S_3 = -0.882 \frac{kJ}{K}}$$

$$\Delta S_{41} = S_1 - S_4 = m_{air}(s_1 - s_4) = m_{air}(s_1^o - s_4^o - R_{air} \ln \frac{P_1}{P_4})$$

$T_3 = 600\,\cancel{kg} \Rightarrow s_1^o = 2.410 \frac{kJ}{kg-K}$

$$\Delta S_{41} = 2\,kg * (2.410 - 1.886 - 0.287 \ln \frac{5\,bar}{3\,bar}) \frac{kJ}{kg-K}$$

$$\boxed{S_1 - S_4 = +0.754 \frac{kJ}{K}}$$

(b) Entropy change for the cycle:

$$\boxed{\Delta S_{net} = 0}$$

$$\Delta S_{net} = \Delta S_{12} + \Delta S_{23} + \Delta S_{34} + \Delta S_{41}$$

$$= +0.128 \frac{kJ}{K} + 0 - 0.882 \frac{kJ}{K} + 0.754 \frac{kJ}{K}$$

$$= 0$$

(c)