An insulated rigid tank is divided into two compartments by a partition. One compartment contains 3 kmol of N\textsubscript{2} and the other compartment contains 5 kmol of CO. Both gases are initially at 25°C and 200 kPa. Now the partition is removed, and the two gases are allowed to mix. Assume that the surroundings are at 25°C and both gases are ideal gases. Determine:

(a) the entropy change, in kJ/K.
(b) the exergy destruction associated with the mixing, in kJ.

**Given:**

In an insulated rigid tank,

State 1: One compartment of 3 kmol of N\textsubscript{2} at 25°C and 200 kPa +

the other compartments of 5 kmol of CO gas at 25°C and 200 kPa

State 2: a mixture of 3 kmol of N\textsubscript{2} and 5 kmol of CO

The surroundings are at 25°C

**Find:**

(a) the entropy change, in kJ/K.
(b) the exergy destruction associated with the mixing, in kJ.

**System sketch:**

<table>
<thead>
<tr>
<th>State 1</th>
<th>State 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 kmol N\textsubscript{2}</td>
<td>3 kmol N\textsubscript{2} + 5 kmol of CO</td>
</tr>
<tr>
<td>5 kmol of CO</td>
<td>5 kmol of CO</td>
</tr>
</tbody>
</table>
**Assumptions:**

1. After mixing, gases inside the tank are in equilibrium.
2. Both gases are ideal gases.
3. Neglect $\Delta KE$ and $\Delta PE$
4. No work
5. No heat transfer

**Basic equations:**

\[
\bar{s} = \bar{c}_p \frac{dT}{T} - R_u \frac{dP}{P} = \bar{c}_v \frac{dT}{T} + R_u \frac{dv}{v} = \bar{s}^e - R_u \ln \frac{P}{P_{ref}}
\]

\[
\Delta S = \frac{Q}{T_b} + \sigma
\]

\[
\bar{E}_d = T_0 \sigma
\]

**Solution:**

Because initial temperature and pressure of two gases are same,

$p_2 = 200 \text{ kPa}$ and $T_2 = 25^\circ\text{C}$

(a)

\[
\Delta S = S_2 - S_1
\]

\[
= \left( N_{N_2,2} \cdot \bar{s}_{N_2,2} + N_{CO,2} \cdot \bar{s}_{CO,2} \right) - \left( N_{N_2,1} \cdot \bar{s}_{N_2,1} + N_{CO,1} \cdot \bar{s}_{CO,1} \right)
\]

\[
= \left\{ 3 \text{ kmol} \cdot \left( 191.502 \text{ kJ/kmol} - 8.314 \text{ kJ/kmol} \cdot \ln \left( \frac{3/8 \cdot 200 \text{ kPa}}{100 \text{ kPa}} \right) \right) + 5 \text{ kmol} \cdot \left( 197.543 \text{ kJ/kmol} - 8.314 \text{ kJ/kmol} \cdot \ln \left( \frac{5/8 \cdot 200 \text{ kPa}}{100 \text{ kPa}} \right) \right) \right\} - \left\{ 3 \text{ kmol} \cdot \left( 191.502 \text{ kJ/kmol} - 8.314 \text{ kJ/kmol} \cdot \ln \left( \frac{200 \text{ kPa}}{100 \text{ kPa}} \right) \right) \right\}
\]

\[
= 44.00 \text{ kJ/K}
\]

(b)

Entropy balance:

\[
\Delta S = \frac{Q}{T_b} + \sigma
\]

\[
\sigma = \Delta S
\]
\[ \bar{E}_d = T_0 \sigma = (25 + 273)K \times 44\frac{kJ}{K} \]
\[ = 13,112 \text{ kJ} \]
SP-13

(1) Is it possible to obtain saturated air from unsaturated air without adding any moisture?

(Yes/No) It is possible by decreasing the temperature of unsaturated air, so that pressure of the water vapor, $P_v$, becomes the saturated vapor pressure, $P_g$, at the final temperature. For example, unsaturated air with relative humidity 32% at 40 °C can have saturated air (i.e. relative humidity 100%) at 20 °C just by decreasing the temperature.

(2) Is the relative humidity of saturated air necessarily 100 percent?

(Yes/No) Saturated air means 100 percent relative humidity.

(3) Can the water vapor in air be treated as an ideal gas?

(Yes/No) The water vapor in air is treated as an ideal gas. In moist air, the overall mixture and each mixture component behave as ideal gases.
(4) In ME Room 2061, the dry-bulb temperature is 25°C, the wet-bulb temperature 20°C, and the air pressure is 1 atm. Determine (a) humidity ratio, (b) relative humidity, (c) dew point temperature, and (d) specific enthalpy of the moist air.

The humidity ratio, relative humidity, dew point temperature can be determined from psychrometric chart, Figure A-9.

(a) Humidity ratio, $\omega = 0.0126 \frac{kg\text{ water}}{kg\text{ air}}$

(b) Relative humidity, $\phi = 63\%$

(c) Dew point temperature, $T_{dew} = 17.5 \, ^{\circ}\text{C}$

(d) Specific enthalpy of the moist air, $h = 57.5 \frac{kJ}{kg \text{ air}}$
Air at 54°F, 1 atm, and 40% relative humidity enters a heat exchanger with a volumetric flow rate of 35 ft³/s. A separate stream of dry air enters at 536°F, 1 atm with a mass flow rate of 1.93 lb/s and exits at 450°F. Neglecting heat transfer between the heat exchanger and its surroundings, pressure drops of each stream, and kinetic and potential energy effects, determine:

(a) the temperature of the exiting moist air, in °F.
(b) the rate of exergy destruction, in kW, for $T_0 = 54°F$

**Given:**
Stream 1: A moist air flows at 1 atm with a volumetric flow rate of 35 ft³/s (constant pressure)
   State 1: 54°F and 40% relative humidity
Stream 2: A dry air flows at 1 atm with a mass flow rate of 1.93 lb/s (constant pressure)
   State 3: 536°F
   State 4: 428°F

Neglect heat transfer between the heat exchanger and its surroundings, pressure drops of each stream, and kinetic and potential energy effects.

**Find:**
(a) the temperature of the exiting moist air, in °F.
(b) the rate of exergy destruction, in kW, for $T_0 = 54°F$

**System sketch:**

![System sketch](image)
Assumptions:
1. Steady state steady flow
2. No work, No heat transfer between the heat exchanger and its surroundings
3. Neglect ∆KE and ∆PE
4. No pressure drops of each stream

Basic equations:
\[
\frac{dm_{cv}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e \\
\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_i \dot{m}_i \left( h_i + \frac{v_i^2}{2} + gz_i \right) - \sum_e \dot{m}_e \left( h_e + \frac{v_e^2}{2} + gz_e \right) \\
\frac{dS_{cv}}{dt} = \sum \frac{\dot{Q}_{cv}}{T_b} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}_{cv}
\]

Solution:
Mass balances for stream 1 give \( \dot{m}_{air,1} = \dot{m}_{air,2} \) and \( \dot{m}_{w,1} = \dot{m}_{w,2} \). Thus, \( w_1 = w_2 \).

\( h_1 \) and \( w_1 \) can found from the psychromatric chart in state 1 (54°F and \( \phi = 40\% \) at 1 atm),

\( h_1 = 17 \text{ Btu/lb-air} \)

\( W_1 = 0.0035 \text{ lb-water/lb-air} \)
The mass flow rate of dry air is evaluated using the volumetric flow rate at state 1 with the ideal gas equation of state

\[
\dot{m}_{\text{air},1} = \frac{(AV)_{1}}{v_{\text{air},1}} = (AV)_{1} \times \frac{p_{\text{air},1}}{(R/M_{\text{air}})T_{1}}
\]

where \(p_{\text{air},1} = p_{1} - p_{w,1}\) and \(p_{w,1} = \emptyset \times p_{g,1}\)

\[
= \left(35 \frac{\text{ft}^3}{\text{s}} \times 12^3 \frac{\text{in}^3}{\text{ft}^3}\right) \times \frac{14.7 \text{lbf/in}^2}{1 \text{atm} - 0.4 + 0.2064 \text{lbf/in}^2}
\]

\[
= \frac{(1545 \text{ ft-lbf/lbmol} \cdot \text{R})}{28.97 \text{ lbmol/R}} (54 + 459.67 \text{R})
\]

\[
= 32.292 \frac{\text{in-lb}}{\text{ft-s}} = 2.691 \frac{\text{lb}(\text{air})}{\text{s}}
\]

From ideal gas properties table of air,

\(h_{3} \approx 240 \text{ Btu/lb}\)

\(h_{4} \approx 218 \text{ Btu/lb}\)

(a)

Energy balance:

\[
\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum_{i} \dot{m}_{i} (h_{i} + \frac{\nu_{i}^2}{2} + g z_{i}) - \sum_{e} \dot{m}_{e} (h_{e} + \frac{\nu_{e}^2}{2} + g z_{e})
\]

Rewrite the equation.

\[
0 = \sum_{i} \dot{m}_{i} (h_{i}) - \sum_{e} \dot{m}_{e} (h_{e})
\]

\[
0 = \dot{m}_{\text{air},1} h_{1} - \dot{m}_{\text{air},2} h_{2} + \dot{m}_{\text{air},3} h_{3} - \dot{m}_{\text{air},4} h_{4}
\]

\[
0 = 2.691 \frac{\text{lb-air}}{\text{s}} \times (17 - h_{2}) \frac{\text{Btu}}{\text{lb-air}} + 1.93 \frac{\text{lb-air}}{\text{s}} \times (240 - 218) \frac{\text{Btu}}{\text{lb-air}}
\]

\[
\Rightarrow h_{2} = 32.8 \frac{\text{Btu}}{\text{lb-air}}
\]

Note: Enthalpy from the psychromatric chart and enthalpy from the ideal gas table cannot be compared directly due to a different reference.

\[
h_{2} = 32.8 \frac{\text{Btu}}{\text{lb-air}} \quad \text{and} \quad w_{2} = 0.0035 \frac{\text{lb-water}}{\text{lb-air}} \quad \text{give} \quad T_{s} = 120^\circ\text{F} \quad \text{and} \quad \phi_{2} = 5\%
\]

(refer the attached psychromatric chart below)
(b)

Entropy balance:

\[ \frac{ds_{ev}}{dt} = \frac{Q_{cv}}{T_b} + \sum m_i s_i - \sum m_e s_e + \dot{\sigma}_{CV} \]

Rewrite the equation.

0 = \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}_{CV}

0 = \dot{m}_1 s_1 - \dot{m}_2 s_2 + \dot{m}_3 s_3 - \dot{m}_4 s_4 + \dot{\sigma}_{CV}

\[ \dot{\sigma}_{CV} = \dot{m}_1 (s_2 - s_1) + \dot{m}_3 (s_4 - s_3) \]

\[ \dot{\sigma}_{CV} = \dot{m}_1 (s_{air,2} - s_{air,1} + w(s_{v,2} - s_{v,1})) + \dot{m}_3 (s_4 - s_3) \]

\[ = \dot{m}_1 \left( s_{air,2} - s_{air,1} - R_{air} \frac{p_{air,2}}{p_{air,1}} + w(s_{g,2} - R_{vapor} \ln \phi_2 - (s_{g,1} - R_{vapor} \ln \phi_1)) \right) + \dot{m}_3 (s_4 - s_3) \]
\[
\frac{lb}{\text{s}} = 2.691 \left( (0.6179 - 0.5888 - R_{\text{air}} \ln \frac{p_{\text{air},2}}{p_{\text{air},1}}) \right) \frac{\text{Btu}}{\text{lb} \cdot \text{R}} + 0.0035 \frac{\text{lb}}{\text{lb} \cdot \text{R}} (1.9336 - \frac{1.986}{18} \ln 0.05 - (2.1131 - \frac{1.986}{18} \ln 0.4) ) \frac{\text{Btu}}{\text{lb} \cdot \text{R}} + 1.93 \frac{\text{lb}}{\text{s}} (0.72709 - 0.75042 - R \ln \frac{p_{\text{air},2}}{p_{\text{air},3}}) \frac{\text{Btu}}{\text{lb} \cdot \text{R}}
\]

\[
= 0.0338 \frac{\text{Btu}}{\text{s} \cdot \text{R} \cdot \text{s}}
\]

\[
\dot{\mathcal{E}}_d = T_0 \dot{\sigma}_{CV} = (54 + 459.7^\circ \text{R}) \star \left( 0.0338 \frac{\text{Btu}}{\text{s} \cdot \text{R} \cdot \text{s}} \right)
\]

\[
= 17.36 \frac{\text{Btu}}{\text{s}}
\]

(If a student has $\dot{\mathcal{E}}_d$ in kW, it is okay. $\dot{\mathcal{E}}_d = 17.36 \frac{\text{Btu}}{\text{s}} = 18.32 \text{ kW}$)