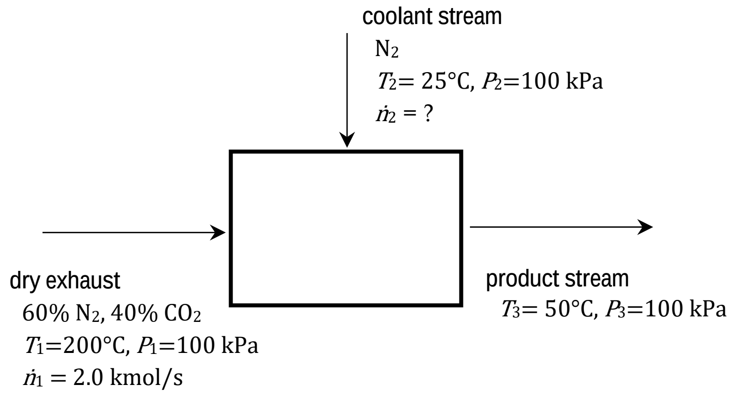
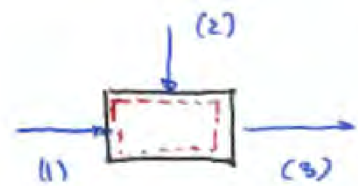
EXAMPLE: I'm exhausted, so I'm going to cool it

A flow of $\dot{n}_1$=2.0 kmol/s of a dry exhaust at T_1=200°C and P_1=100 kPa mixes with a stream of pure nitrogen at T_2=25°C and P_2=100 kPa in an adiabatic mixing chamber. The molar composition of the dry exhaust is 60% nitrogen and 40% carbon dioxide. If the product stream exits the chamber at T_3=50°C and P_3=100 kPa, determine



(a) the molar flow rate of the coolant N_2 stream, $\dot{n}_2$, in kmol/s and
(b) the rate of entropy generation inside the mixing chamber, in kW/K



Assume all gases behave as ideal gases with variable specific heats.

(a) CoM → A.o Species

N_2: $\frac{d}{dt}\cancel{(N_{N_2})}^{\,0} = \sum_{IN} \dot{n}_{N2} - \sum_{OUT} \dot{n}_{N2}$

$0 = y_{N2,1}\dot{n}_1 + \dot{n}_2 - \dot{n}_{N2,3}$

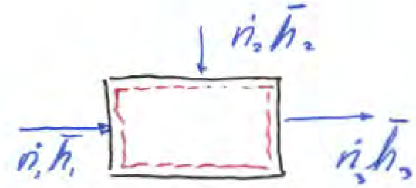
$\dot{n}_{N2,3} = y_{N2,1}\dot{n}_1 + \dot{n}_2$ [1]

CO_2: $\frac{d}{dt}\cancel{(N_{CO2})}^{\,0} = \sum_{IN} \dot{n}_{CO2} - \sum_{OUT} \dot{n}_{CO2}$

$= y_{CO2,1}\dot{n}_1 - \dot{n}_{CO2,3}$

$\dot{n}_{CO2,3} = y_{CO2}\dot{n}_1$ [2]

CoE, MOLAR BASIS



$\frac{d}{dt}\cancel{(E_{sys})}^{\,0} = \cancel{\dot{Q}_{NET,IN}}^{\,0} - \cancel{\dot{W}_{NET,OUT}}^{\,0} + \sum_{IN}\dot{n}\bar{h} - \sum_{OUT}\dot{n}\bar{h}$

$0 = \dot{n}_1\bar{h}_1 + \dot{n}_2\bar{h}_2 - \dot{n}_3\bar{h}_3$

$0 = \dot{n}_{N2,1}\bar{h}_{N2,1} + \dot{n}_{CO2,1}\bar{h}_{CO2,1} + \dot{n}_2\bar{h}_{N2,2} - \dot{n}_{N2,3}\bar{h}_{N2,3} - \dot{n}_{CO2,3}\bar{h}_{CO2,3}$ [3]

WITH ALL $\bar{h}$ VALUES KNOWN (KNOWN T_s) [1]–[3] ARE THREE EQNS WITH THREE UNKNOWN FLOWRATES.

Note that part (a) is conceptually solved at this point!

SUBSTITUTING [1] & [2] INTO [3]

$$0 = y_{N2,1}\dot{n}_1 \bar{h}_{N2,1} + y_{CO2,1}\bar{h}_{CO2,1} + \dot{n}_2 \bar{h}_{N2,2} - [y_{N2,1}\dot{n}_1 + \dot{n}_2]\bar{h}_{N2,3} - y_{CO_2,1}\dot{n}_1 \bar{h}_{CO2,3}$$

$$\dot{n}_2 = \frac{y_{N2,1}\bar{h}_{N2,1} + y_{CO2,1}\bar{h}_{CO2,1} - y_{N2,1}\dot{n}_1\bar{h}_{N2,3} - y_{CO2,1}\dot{n}_1\bar{h}_{CO2,3}}{\bar{h}_{N2,3} - \bar{h}_{N2,3}}$$

$= \ldots = 14.1$ kmol/s ← ANS

$\bar{h}_{N2,1} = \bar{h}_{N2}(T_1) = 13{,}782$ kJ/kg

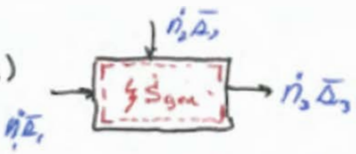
$\bar{h}_{N2,2} = 8669$ kJ/kg

$\bar{h}_{CO2,1} = 16483$ "

$\bar{h}_{CO2,3} = 10{,}301$ "

$\bar{h}_{N2,3} = 9393$ "

(b)



AoS $\quad \frac{d}{dt}(\cancel{S_{sys}}) = \sum \cancel{\frac{\dot{Q}_{in,i}}{T_{b,i}}} + \sum_{in}\dot{n}\bar{s} - \sum_{out}\dot{n}\bar{s} + \dot{S}_{gen}$

$$\dot{S}_{gen} = \dot{n}_3\bar{s}_3 - \dot{n}_1\bar{s}_1 - \dot{n}_2\bar{s}_2 = \dot{n}_{CO2,3}\bar{s}_{CO2,3} + \dot{n}_{N2,3}\bar{s}_{N2,3} - \dot{n}_{N2,1}\bar{s}_{N2,1} - \dot{n}_{CO2,1}\bar{s}_{CO2,1} - \dot{n}_2\bar{s}_{N2,2} \quad [4]$$

KNOWING ALL Ts & Ps SUFFICIENT TO FIND ALL $\bar{s}$ VALUES. Ps ARE PARTIAL PRESSURES:

$P_{N2,1} = y_{N2,1}P_1 \qquad P_{N2,2} = P_2 \qquad P_{N2,3} = y_{N2,3}P_3 \qquad y_{N2,3} = \dot{n}_{N2,3}/\dot{n}_3 = 0.95$

$P_{CO2,1} = y_{CO2,1}P_1 \qquad P_{CO2,3} = y_{CO2,3}P_3 \qquad y_{CO2,3} = \dot{n}_{CO2,3}/\dot{n}_3 = 0.05$

SUB. [1] & [2] INTO [4] $\qquad$ Part (b) is conceptually solved here!

$$\dot{S}_{gen} = y_{CO2,1}\dot{n}_1[\bar{s}_{CO2,3} - \bar{s}_{CO2,1}] + y_{N2,1}\dot{n}_1[\bar{s}_{N2,3} - \bar{s}_{N2,1}] + \dot{n}_2[\bar{s}_{N2,3} - \bar{s}_{N2,2}]$$

$$= y_{CO2,1}\dot{n}_1\left[\bar{s}^o_{T_3} - \bar{s}^o_{T_1} - \bar{R}\ln\left(\frac{y_{CO2,3}\cancel{P_3}}{y_{CO2,1}\cancel{P_1}}\right)\right]$$

$$+ y_{N2}\dot{n}_1\left[\bar{s}^o_{T_3} - \bar{s}^o_{T_1} - \bar{R}\ln\left(\frac{y_{N2,3}\cancel{P_3}}{y_{N2,1}\cancel{P_1}}\right)\right]$$

$$+ \dot{n}_2\left[\bar{s}^o_{T_2} - \bar{s}^o_{T_1} - \bar{R}\ln\left(\frac{y_{N2,3}\cancel{P_3}}{\cancel{P_2}}\right)\right]$$

$\bar{s}^o_{N2}(T_1) = 205$ kJ/kg·K

$\bar{s}^o_{N2}(T_2) = 191.5$ kJ/kg·K

$\bar{s}_{CO_2}(T_1) = 232.4$ "

$\bar{s}_{CO2}(T_3) = 216.7$ "

$\bar{s}_{N2}(T_3) = 193.8$ "

$\bar{R} = 8.314 \frac{kJ}{kmol \cdot K}$

$= \ldots = 534 \frac{kW}{K}$ ← ANS