

**Problem 1** Use Dalton's law to show mol. mass of mixture of  $n$  gases

$$\bar{M}_m = \sum_{i=1}^n x_i \bar{M}_i$$

Dalton's law: i)  $V_i = V_m = V$ ,  $T_i = T_m = T$

$$ii) P_m = \sum_{i=1}^n P_i$$

$$V_i = V \rightarrow n_1 V_1 = n_2 V_2 \dots \quad n_i = \frac{P_i}{\bar{P}}$$

$$\bar{M}_m = \frac{M_m}{n_m}, \quad \bar{M}_i = \frac{M_i}{n_i} \rightarrow M_i = n_i \bar{M}_i$$

$$M_m = \sum_{i=1}^n M_i = \sum_{i=1}^n n_i \bar{M}_i, \quad x_i = \frac{n_i}{n_m} \rightarrow n_i = x_i n_m$$

$$\rightarrow \bar{M}_m = \frac{M_m}{n_m} = \frac{\sum_{i=1}^n (x_i \cancel{n_m} \bar{M}_i)}{\cancel{n_m}} = \boxed{\sum_{i=1}^n x_i \bar{M}_i = \bar{M}_m}$$

**Problem 2** Mixture of gasses, 10 kg  $N_2$ , 10 kg  $H_2$ , 15 kg He.

$P_m = 6.7 \text{ MPa}$ ,  $T_m = 300 \text{ K}$  Find  $\bar{M}_m$  &  $\gamma_m$

	$\bar{M}$	$\gamma$
$N_2$	28	1.4
$H_2$	2	1.4
He	4	1.67

$$\bar{M}_m = \sum_{i=1}^n x_i \bar{M}_i$$

$$n_{N_2} = \frac{10 \text{ kg}}{28 \text{ kg/kmol}} = 0.357 \text{ kmol} \rightarrow x_{N_2} = 0.0392$$

$$n_{H_2} = \frac{10 \text{ kg}}{2 \text{ kg/kmol}} = 5 \text{ kmol} \rightarrow x_{H_2} = 0.549$$

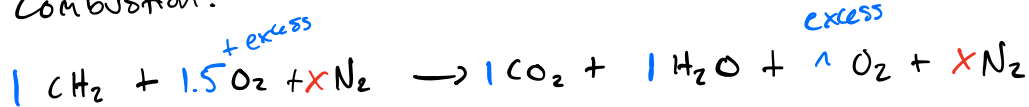
$$n_{He} = \frac{15 \text{ kg}}{4 \text{ kg/kmol}} = 3.75 \text{ kmol} \rightarrow x_{He} = 0.412$$

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$$n_m = 9.107 \text{ kmol}$$



Combustion:



Assume 1 mol CH<sub>4</sub> → Need 1.5 mol O<sub>2</sub> to react

30% extra : 1.5 mol · 0.3 → 0.45 mol excess O<sub>2</sub>

$$\text{N}_2 : \text{O}_2 = 79 : 21 \rightarrow \text{N}_2 = \frac{79}{21} \cdot 1.45 \text{ O}_2 = 7.336 \text{ mol N}_2$$

$$\text{N}_2 + \text{O}_2 \rightleftharpoons 2 \text{ NO} \quad K_p = \frac{P_{\text{NO}}^2}{P_{\text{N}_2} P_{\text{O}_2}} = e^{-6.866}$$

$$K_n = \frac{x_{\text{NO}}^2}{x_{\text{N}_2} x_{\text{O}_2}} = P_m^{1+1-2} K_p = K_p$$

$$x_{\text{NO}} = ?$$

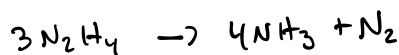
$$x_{\text{N}_2} = \frac{7.336}{1+1+0.45+7.336}$$

$$x_{\text{O}_2} = \frac{0.45}{1+1+0.45+7.336}$$

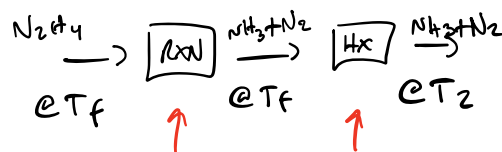
$$\rightarrow K_n = K_p = \frac{x_{\text{NO}}^2}{\frac{7.336 \cdot 0.45}{(1+1+0.45+7.336)^2}} = \frac{x_{\text{NO}}^2}{0.0345} = e^{-6.866} = 3.59 \text{ E-}5$$

$$\rightarrow x_{\text{NO}} = 0.005995 = 6000 \text{ ppm}$$

Problem 4 N<sub>2</sub>H<sub>4</sub> monopropellant



4a) Assuming T<sub>f</sub> = 298 K, Find T<sub>adiabatic flame</sub>



$$Q_R = H_{R,pf}$$

$$Q_2 = H_{P,2} - H_{P,f}$$

$$Q_R = H_{RPF} = \sum_j (n_j Q_{fj})_{\text{prods}} - \sum_i (n_i Q_{fi})_{\text{reacts}}$$

$$= [4 \cdot (-45.94 \text{ EJ}) + 1 \cdot (0)] - [3 \cdot (97.42 \text{ EJ})] \quad [5]$$

$$Q_R = -476.02 \text{ EJ}$$

$$Q_2 = H_{P2} - H_{PF} = \sum_j n_j (\bar{h} - \bar{h}_0) \xrightarrow{\text{assume } c_p = \text{const}} \sum_j n_j \bar{c}_p (T_2 - T_f)$$

$$Q_2 = (T_2 - T_f) [4 \cdot (63.5 \text{ EJ}) + 1 \cdot (32 \text{ EJ})]$$

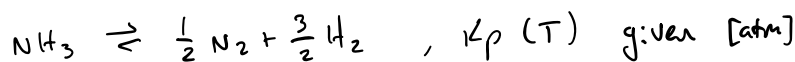
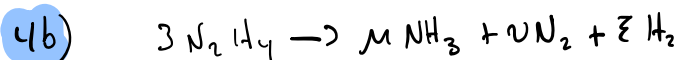
$$Q_2 = (T_2 - 298) (286 \text{ EJ})$$

$$Q = Q_R + Q_2 = 0 \rightarrow Q_2 = -Q_R$$

$$\rightarrow (T_2 - 298) (286 \text{ EJ}) = -(-476.02 \text{ EJ})$$

$$T_2 - 298 = \frac{476.02 \text{ EJ}}{286 \text{ EJ}}$$

$$\rightarrow T_2 = 1664.4 + 298 = 1962.4 \text{ K} = T_{\text{adi}}$$



Assume incomplete decomp. @  $P_m = 75 \text{ atm}$ .

Find  $\mu, \nu, \xi, x_{\text{NH}_3}, x_{\text{N}_2}, x_{\text{H}_2}, T_{\text{adi}}$

CONS. MASS:

$$\text{N: } 6 = \mu + 2\nu \rightarrow \nu = \frac{6 - \mu}{2}$$

$$\text{H: } 12 = 3\mu + 2\xi \rightarrow \xi = \frac{12 - 3\mu}{2}$$

chem. EQ:

$$X_{NH_3} = \frac{M}{M+V+Z} \quad X_{N_2} = \frac{V}{M+V+Z} \quad X_{H_2} = \frac{Z}{M+V+Z}$$

$$K_n = \frac{X_{N_2}^{1/2} X_{H_2}^{3/2}}{X_{NH_3}} = P_m^{1-1/2-3/2} \quad K_p = P_m^{-1} K_p$$

$$P_m^{-1} \cdot \left[ 10^{-(AT^4 + BT^3 + CT^2 + DT + E)} \right] = \frac{\left( \frac{V}{M+V+Z} \right)^{1/2} \left( \frac{Z}{M+V+Z} \right)^{3/2}}{\left( \frac{M}{M+V+Z} \right)}$$

→ Solve for T w/ root solver

Thermo:

$$Q = Q_R + Q_2 = 0$$

$$Q_R = H_{R,pf} = \sum (n_i Q_{f,i})_{prod} - \sum (n_i Q_{f,i})_{React}$$

$$= M(-45.9486) + V(0) + Z(0) - 3 \cdot (97.4286)$$

$$Q_2 = H_{p,2} - H_{p,f} = \sum [n_i \bar{c}_{p,i} (T_2 - T_f)]_{prod}$$

$$Q = 0 \rightarrow Q_R = -Q_2$$

$$\rightarrow -H_{R,pf} = [M(63.5 \text{ EJ}) + V(32 \text{ EJ}) + Z(30 \text{ EJ})](T_2 - T_f)$$

Solve for  $T_2$  in matlab w/ thermo

$$\rightarrow T_2 = 1360.08 \text{ K}, \quad M = 0.02018$$

$$\rightarrow V = 2.998$$

$$\rightarrow Z = 5.970$$

$$\rightarrow X_{NH_3} = 0.00225, \quad X_{N_2} = 0.333, \quad X_{H_2} = 0.665$$

4c)  $T_{adb}$  from a: 1962.4K;  $T_{adb}$  from b: 1360.08K

The adiabatic flame temperature is lower for part b because part b includes decomposition, which takes energy that would otherwise be used to raise the temperature of the products.

4d)  $P_m = [150, 300, 600]$  atm

$\& \mu_{start} = [0.03, 0.05, 0.05]$

4e) As pressure increases, adiabatic flame temperature increases. This is because less dissociation is occurring (visible in the increasing  $X_{NH_3}$  values) due to the increase in pressure.