**Problem 1** $CH_6N_2 - N_2O_4$ engine. $P_0 = 70\text{ bar} = 7e5\text{ Pa}$

$A_t = 0.0036 m^2$ $T_f = 298K$

**1a)** $r = 2$ $T_{adb} = T_2 = T_0 = 3363K$, composition in table.

Isentropic frozen flow, $T_e = 700K$, $P_e = P_a$. Find $J$

To find $\gamma_m$, $\bar{M}_m$:

$$\gamma_m = \frac{\bar{C}_{pm}}{\bar{C}_{vm}}, \quad \bar{C}_{pm} = \sum_i x_i \bar{C}_{p_i}$$

$$\bar{C}_{vm} = \sum_i x \bar{C}_{v_i} \quad \text{where } \bar{C}_{v_i} = \bar{C}_{p_i} - \bar{R}$$

$$\bar{M}_m = \sum_i x_i \bar{M}_i$$

-> solve in python

-> $\gamma_m \approx 1.222$, etc. -> in table

-> Real combustion w/ dissociation followed by frozen flow

$\gamma, \bar{M}$ frozen @ end of CC values

$$u_e = \sqrt{\frac{2\gamma_m \bar{R}}{(\gamma_m - 1)\bar{M}_m} T_{02}\left[1 - \left(\frac{P_e}{P_{02}}\right)^{\frac{\gamma_m - 1}{\gamma_m}}\right]}$$

$\rightarrow u_e = 3308.62\ m/s$

$J = \dot{m} u_e$ $(P_e = P_a)$

$$\rho_e = \frac{P_e}{RT_e}$$

$$\dot{m} = \rho_e \underbrace{M_e \sqrt{\gamma_m R_m T_e}}_{\text{should } = u_e} A_e$$

$\rightarrow J = (14.67 \, kg/s)(3308.6 \, m/s) = \boxed{48.5 \, kN = J}$

16) complete ideal stoich.

$$\alpha \, CH_6N_2 + \beta N_2O_4 \rightarrow \mu CO_2 + \nu H_2O + \xi N_2$$

i) Find $\beta, \mu, \nu, \xi$ in terms of $\alpha$ & min. value of $\alpha$

C: $\alpha = \mu$

H: $6\alpha = 2\nu$

N: $2\alpha + 2\beta = 2\xi$

O: $4\beta = 2\mu + \nu$

$\rightarrow \boxed{\mu = \alpha \quad \nu = 3\alpha}$

$4\beta = 2(\alpha) + (3\alpha)$

$\rightarrow \boxed{\beta = \frac{5}{4}\alpha}$

$2\alpha + 2(\frac{5}{4}\alpha) = 2\xi$

$\rightarrow \boxed{\xi = \frac{9}{4}\alpha}$

$\Rightarrow \boxed{\alpha = 4}$

$$4 \, CH_6N_2 + 5 N_2O_4 \rightarrow 4 CO_2 + 12 H_2O + 9 N_2$$

ii) OFR mole ratio $= \frac{n_{N_2O_4}}{n_{CH_6N_2}} = 1.25$

OFR mass ratio $= \frac{5(92.011)}{4(46.07)} = \boxed{2.5 = r}$

iii) same $P_0$, $P_a$, $A_e/A^*$, Find $T_{ad}$ & $J$

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

$Q_R = H_{RPf} = \sum_j (n_j Q f_j)_{prods} - \sum_i (n_i Q f_i)_{reacts}$

$Q_2 = \sum_j n_j(\bar{h} - \bar{h}_0) = \sum_j n_j \bar{c}_p (T_2 - T_F)$

$\rightarrow$ Solve in python $\rightarrow Q_R = 5.11e9$

why is $Q_R$ not normalized but in the equations $Q_R$ is per mass (same notation?)

Same $u_e$:
$$u_e = \sqrt{\frac{2\gamma_m \bar{R}}{(\gamma_m - 1)\bar{m}_m} T_{02}\left[1 - \left(\frac{P_e}{P_{02}}\right)^{\frac{\gamma_m - 1}{\gamma_m}}\right]}$$

$$T_{02} = T_{01} + \frac{Q_R}{c_p} = \frac{Q_R}{n \cdot \bar{c}_p} = \boxed{4344 \text{ K} = T_{02}}$$

$\rightarrow$ Solve for $u_e$ & $J$

$\rightarrow u_e = 3580.9$ m/s, $\boxed{J = 52.7 \text{ kN}}$

1c) $r = 2$, excess MMH

$$(4+x)\,CH_6N_2 + 5\,N_2O_4 \rightarrow 4CO_2 + 12\,H_2O + 9\,N_2 + x\,CH_6N_2$$

$$r = 2 = \frac{5(92.011)}{(4+x)(46.07)} \quad (4+x) = \frac{5(92.011)}{2 \cdot (46.07)}$$

$\rightarrow x \cong 1$

$\rightarrow$

$$5\,CH_6N_2 + 5\,N_2O_4 \rightarrow 4CO_2 + 12\,H_2O + 9\,N_2 + CH_6N_2$$

$\rightarrow$ Same code: $\boxed{T_{02} = 3832 \text{ K}}$

$\rightarrow u_e = 3360$ m/s, $\boxed{J = 49.58 \text{ kN}}$

1d) See table

1e) We see clearly that case b is the highest temperature since no energy is lost to either dissociation (case a) or heating non-stoichiometric products (case c).

case b has to heat the least amount of products and retains the most of the combustion heat.

Because of this, case b has high exhaust velocity and mass flow rate, and thus highest thrust.