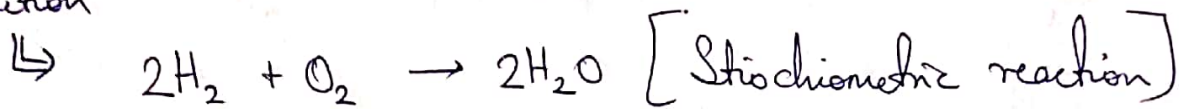


Ans 1) Given $\phi = 1 \Rightarrow$ Stoichiometric equation,
 $T_1 = 298$

$$\Delta H_{H_2O}^\circ = -241.997 \text{ kJ/mol},$$

$$C_p \text{ of } H_2O = \overset{53.9}{\cancel{33.9}} \text{ kJ/mol}$$

Reaction



Now, we can say that,

$$\Delta H_{\text{reactants}} = \Delta H_{\text{products}}.$$

$$\Delta H_{\text{reactants}} = 2\Delta H_{H_2}^\circ + \Delta H_{O_2}^\circ + 2C_{p_{H_2}}(T_1 - T_{\text{ref}}) + C_{p_{O_2}}(T_1 - T_{\text{ref}})$$

As H_2, O_2 are naturally occurring,

$$\Delta H_{H_2}^\circ, \Delta H_{O_2}^\circ = 0. \text{ \& } T_1 = T_{\text{ref}} = 298 \text{ K},$$

$$\Delta H_{\text{reactants}} = 0.$$

$$\Delta H_{\text{products}} = 2 \cdot \Delta H_{H_2O}^\circ + 2 \cdot C_{p_{H_2O}}(T_{\text{ad}} - 298)$$

$$\Delta H_{\text{products}} = 2 \cdot (-241.997) + 2 \cdot 0.0539 (T_{\text{ad}} - 298)$$

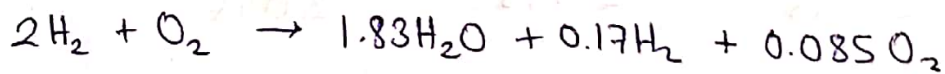
$$\text{As } \Delta H_{\text{reactants}} = \Delta H_{\text{products}}$$

$$\Rightarrow T_{\text{ad}} = 298 + \frac{\cancel{2} \times 241.997}{0.0539}$$

$$T_{\text{ad}} = 4787.74 \text{ K}$$

[Adiabatic Flame Temperature.]

Ans 2) This is a more realistic case of question 1.



As we found in question 1, $\Delta H_{\text{reactants}} = 0$ at $T_i = 298 \text{ K}$.

For $\Delta H_{\text{products}}$,

Species	n	$\Delta H_{\text{formation}}^\circ$	$C_{pi}(T_{ad} - T_{ref})$
H_2O	1.83	- 29 241.997	0.0539 ($T_{ad} - 298$)
H_2	0.17	0	0.0358 ($T_{ad} - 298$)
O_2	0.085	0	0.0389 ($T_{ad} - 298$)

As $\Delta H_{\text{reactants}} = \Delta H_{\text{products}}$

$$0 = (1.83)(-241.997) + (1.83)(0.0539)(T_{ad} - 298) + (0.17)(0.0358)(T_{ad} - 298) + (0.085)(0.0389)(T_{ad} - 298)$$

$$442.8545 = 0.10803(T_{ad} - 298)$$

$$T_{ad} = 4397.385 \text{ K}$$

As we can see, if we consider equilibrium effects the T_{ad} is less than the ideal case by around 385 K.

For average molecular mass,

$$MW_{\text{avg}} = \sum_{\text{products}} X_i(MW)_i$$

$X_i \rightarrow$ Mole fraction
 $MW_i \rightarrow$ Mol mass of the species.

$$(MW_{avg}) = \frac{1.83}{2.085} \times 18 + \frac{0.17}{2.085} \times 2 + \frac{0.085}{2.085} \times 32$$

$$MW_{avg} = 17.266 \text{ g}$$

$$R_p = \frac{R_u}{MW_{avg}} = \frac{8.314}{0.017266} = 481.524 \text{ J/Kg-K}$$

Now, $C_p - C_v = R_u$, But for that we need to find $C_{p(avg)}$ for the products

$$C_{p(avg)} = \sum X_i C_{p_i} \text{ (J/kg-K)}$$

$$= \frac{1.83}{2.085} \times 53.9 + \frac{0.17}{2.085} \times 35.811 + \frac{0.085}{2.085} \times 38.9$$

$$= 47.31 + 2.9198 + 1.6328$$

$$C_{p(avg)} = 51.862 \text{ kJ/kg-K}$$

$$\text{Now, } C_{v(avg)} = C_{p(avg)} - R_u$$

$$C_{v(avg)} = 43.548 \text{ kJ/kg-K}$$

Now we can find k_{avg} for products,

$$k = \frac{C_p}{C_v} \Rightarrow k_{avg} = 1.191, \text{ Hence,}$$

$$C^* = \frac{\sqrt{kRT_{ad}}}{k \sqrt{\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}}} \Rightarrow C^* = 2.25 \text{ km/sec}$$

Ans 3) Given, Fuel \Rightarrow Kerosene, ($C_{12}H_{24}$)

$\phi = 1 \Rightarrow$ Stoichiometric Equation.

$$T_1 = 298 \text{ K} = T_{ref}.$$

\Rightarrow Reaction can be written as,



For ΔH_r we can write,

$$\Delta H_r = 1 \times [\Delta H^\circ_{\text{kerosene}} + C_{p, \text{kerosene}} (T_1 - T_{ref})] \\ + 18 \times [\Delta H^\circ_{O_2} + C_{p, O_2} (T_1 - T_{ref})]$$

$$\Delta H_r = -159 \text{ kJ/mol}$$

For ΔH_p ,

$$\Delta H_p = 12 [\Delta H^\circ_{CO_2} + C_{p, CO_2} (T_{ad} - T_{ref})] \\ + 12 [\Delta H^\circ_{H_2O} + C_{p, H_2O} (T_{ad} - T_{ref})] = H_R$$

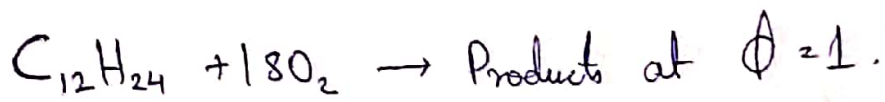
$$\frac{-159}{12} = -393.978 + 0.06043 (T_{ad} - 298) \\ - 241.997 + 0.0539 (T_{ad} - 298)$$

$$(0.11433) (T_{ad} - 298) = \cancel{619.225} 622.725$$

$$T_{ad} = 298 + \frac{622.725}{0.11433}$$

$$T_{ad} = 5744.73 \text{ K}$$

Stoichiometric mixture ratio can be found as,



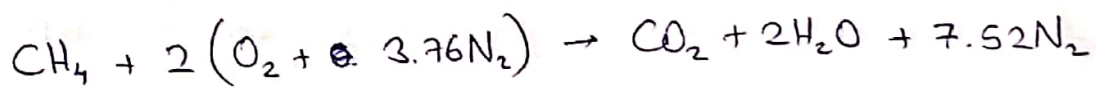
$$(MR)_{st} = \frac{(18) 32}{168}$$

$$\Rightarrow (MR)_{st} = 3.4286$$

Ans 4) Now instead of the stoichiometric combustion, we have, $\phi = 1.2$ (Fuel Rich) (Incomplete combustion)

But as in this case, we don't have information about carbon monoxides, we will assume that methane either gets converted to CO_2 , or doesn't get reacted at all.

The stoichiometric reaction of Methane combustion is,



from this we can find, $(MR)_{st}$ as,

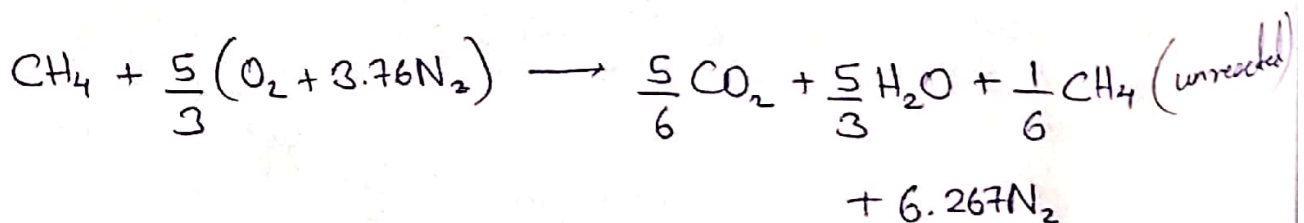
$$(MR)_{st} = \frac{2(32)}{16} = 4$$

$$\text{Given, } \phi = \frac{(MR)_{st}}{MR} \cdot 1.2 \Rightarrow \boxed{MR = 10/3}$$

Let the current reaction require 'n' moles of O_2 for 1 mole of CH_4 ,

$$MR = \frac{(n) 32}{16} = 10/3 \Rightarrow \underline{n = 5/3}$$

Hence we can now write the reaction as,



Now given the values of $\Delta h_{f,i}^\circ$ & $C_{p,i}$, we can write

$$\Delta H_R = 1 \times (\Delta h_{f, \text{CH}_4}^\circ + (T_1 - T_{\text{ref}}) C_{p, \text{CH}_4})$$

$$+ \frac{5}{3} \times (\Delta h_{f, \text{O}_2}^\circ + C_{p, \text{O}_2} (T_1 - T_{\text{ref}}))$$

$$+ \frac{5}{3} (3.76) (\Delta h_{f, \text{N}_2}^\circ + C_{p, \text{N}_2} (T_1 - T_{\text{ref}}))$$

Now assuming $T_1 = T_{\text{ref}} = 298\text{K}$ for simplicity,

$$\boxed{\Delta H_R = -74.83}$$

Now, for ΔH_p

$$\Delta H_p = \frac{5}{6} (\Delta h_{f, \text{CO}_2}^\circ + C_{p, \text{CO}_2} (T_{\text{ad}} - T_{\text{ref}}))$$

$$+ \frac{5}{3} (\Delta h_{f, \text{H}_2\text{O}}^\circ + C_{p, \text{H}_2\text{O}} (T_{\text{ad}} - T_{\text{ref}}))$$

$$+ \frac{1}{6} (\Delta h_{f, \text{CH}_4}^\circ + C_{p, \text{CH}_4} (T_{\text{ad}} - T_{\text{ref}}))$$

$$+ 6.267 (\Delta h_{f, \text{N}_2}^\circ + C_{p, \text{N}_2} (T_{\text{ad}} - T_{\text{ref}}))$$

$$\Delta H_p = \frac{5}{6} (-393.978) + \frac{5}{3} (-241.997) + \frac{1}{6} (-74.83) + 6.267 \times 0$$

$$+ \left[\frac{5}{6} (0.0562) + \frac{5}{3} (0.0439) + \frac{1}{6} (0.0358) + 6.267 (0.0337) \right] (T_{\text{ad}} - 298)$$

Equating ΔH_R & ΔH_p , we get

$$-74.83 = -744.115 + 0.3371 (T_{\text{ad}} - 298)$$

$$\Rightarrow \boxed{T_{\text{ad}} = 2283.42 \text{ K}}$$