

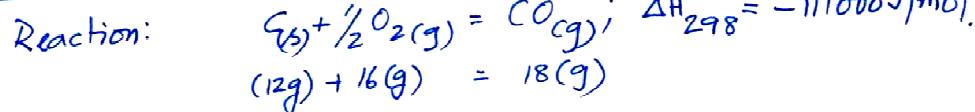
Note there will be no part marking below what has been shown.

1. A coal burning burner is fed with powdered coal (assume pure carbon) preheated to 1800K and dry air (N₂:O₂=79:21, by volume) preheated to 1200K. The coal to air ratio is such that the product is only a gas containing CO and N₂. Perform a material balance and a heat balance and calculate the adiabatic flame temperature (of the product gas).

Take only 1 mol (12g) carbon as the mass basis. You need to present data as mass and heat balance tables. (Only the entries in the table may be seen for valuation)

4 marks

Solution:



Input	mol	mass, g	mass output, g	mol	mass, g
C	1	12	CO	1	28
Air: O ₂	1/2	16	N ₂	1.8810	52.67
N ₂	$\frac{1}{2} \times \frac{0.79}{0.21} = 1.8810$	52.67			
		80.67			80.67

1 mark for correct & complete table

Input			Output		
<u>Sensible Heat</u>			<u>Sensible Heat</u>		
C _{1800K}	$1(23.5 \times 1800 - 11800)$	30500	CO	$1(36.6T - 16400)$	72439
Air, 1200K	$\frac{1}{2}(36.2T - 13500)$	14970	N ₂	$1.881(36.4T - 16500)$	135157
O ₂					
N ₂	$1.881(36.4T - 16500)$	51126			
<u>Reaction Heat</u> : $-1(-111000)$	111000	Loss	<u>adiabatic</u>	0	
<i>1 mark for correct completed table. 1/2 mark if P-H-S entries not made.</i>					
	207596				207596

$$T(36.6 + 68.47) - (16400 + 31037) = 207596.$$

$$T = \frac{207596 + 47437}{105.07} = \underline{\underline{2427.3 K}} \equiv \underline{\underline{2154.2^\circ C}}$$

(±5°) 2 marks

2. 1 mole of a super-cooled material is adiabatically contained at 400 K at constant pressure. If it spontaneously freezes, what is the final temperature? What fraction of the material freezes?

$$\Delta H_m^o = 2000 \frac{J}{mol} \text{ at } T_m = 600K$$

$$C_p: liq: 34.7 - 9.2 \times 10^{-3}T \text{ J/mol.K}$$

$$Sol: 18.5 + 2.6 \times 10^{-3} T \text{ J/mol.K}$$

[Note that starting from a temperature lower than the melting point, an adiabatically contained material cannot cross the melting point by releasing the latent heat and heating itself. This would violate the second law as we will see later. Hence the maximum temperature can be 600K. It can be lower]. 2marks

+2 marks bonus, if the numerical answer is rigorous conceptually ! There is a standard mistake that people commit.

Solution:

There are two options: (i) latent heat released is sufficient to heat products to m.pt.: 600K; some liquid remains.
(ii) Even after full solidification, temp. does not reach 600K.

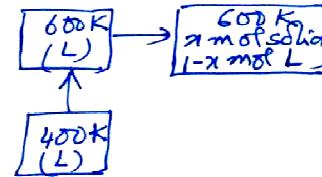
Explore option(i): final temp 600K. Fraction solidified: x .

Adiabatic & constant pr; $q_V = \Delta H = 0$.

Since enthalpy calculation, path does not matter.

$$\begin{aligned}\Delta H &= \int_{400}^{600} C_p dT + -(\Delta H_m^o, 600K) \cdot x \\ &= \left[34.7T - \frac{9.2 \times 10^{-3}T^2}{2} \right]_{400}^{600} - 2000x \\ &= 6940 - 920 - 2000x = 0. \Rightarrow x = 3.01. \text{ Not possible.}\end{aligned}$$

1 mark



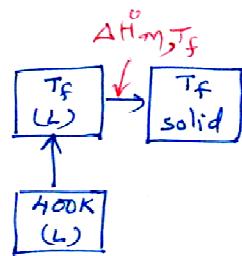
Premise wrong.

Option(ii) $\alpha = 1$, T_f unknown.

$$34.7(T_f - 400) - \frac{9.2 \times 10^{-3}}{2} (T_f^2 - 400^2) = 2000$$

$$-4.6 \times 10^{-3} T_f^2 + 34.7 T_f - (13800 - 736 + 2000) = 0$$

$$\boxed{T_f = 465.1 \text{ and } \alpha = 1} \quad \textcircled{1} \text{ mark}$$



[Award 2 marks, if option(ii) directly tried]

BONUS Question: (no part marking)

The error in the above is that $\Delta H_{m,465.1K}^\circ = \Delta H_{m,600K}^\circ$.

calculate ΔH_m° at T_f : Kirchoff's Law.

$$S \rightarrow L; \Delta H_{m,T_f}^\circ - \Delta H_{m,600}^\circ = \int_{600}^{T_f} [C_p(L) - C_p(s)] dT$$

$$= \int_{600}^{T_f} (16.2 - 11.8 \times 10^{-3} T) dT$$

$$= 16.2(T_f - 600) - 11.8 \times 10^{-3} (T_f^2 - 600^2)$$

Heat Balance therefore is: 18.5°

2 marks

$\text{A this eqn. written correctly}$

$$34.7(T_f - 400) - 4.6 \times 10^{-3} (T_f^2 - 400^2) = 2000 + 16.2(T_f - 600)$$

$$-11.8 \times 10^{-3} (T_f^2 - 600^2) + 1736.2$$

$$T_f^2 (-4.6 \times 10^{-3} + 11.8 \times 10^{-3}) + T_f (34.7 - 16.2)$$

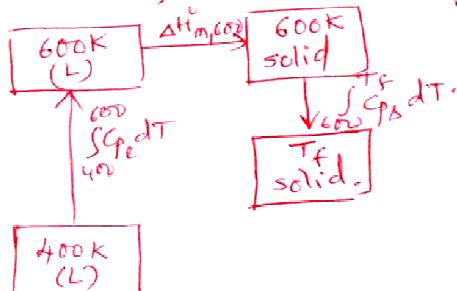
$$+ (-13800 + 736 - 2000 + 9720 - 4248) = 0$$

$$7.2 \times 10^{-3} T_f^2 + 18.5 T_f - 9592 = 0 \quad \frac{-18.5 \pm 24.870}{2 \times 7.2 \times 10^{-3}}$$

$$T_f = 442.34K$$

Significant difference? $\Delta H_{m,642K}^\circ \approx 1385 \text{ J/mol}$.

Alternatively, one can follow the following scheme.



3. A mixture of steam at 400K and oxygen at 300K, both at 1 atm., react with a bed of graphite granules at 1000K to yield a mixture of H₂ and CO at 1000K. Calculate the composition of the CO/H₂ mixture, if the above process should be adiabatic (i.e. no heat effect). Answer in tables 4 marks

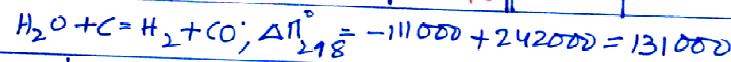
Further data

	$H_T^0 - H_{298}^0, \text{J/mol}$	$\Delta H_{298}^f, \text{J/mol}$
CO	36.6T - 16400	-111000
CO ₂	61.0T - 30500	-394000
H ₂ O(g)	47.4T - 22200	-242000
N ₂	36.4T - 16500	-
O ₂	36.2T - 13500	-
C	23.5T - 11800	-
H ₂	35.2T - 17200	-

Note : $H_T^0 - H_{298}^0 = \int_{298}^T C_p \cdot dT$; that is, it is an integrated expression.

Basis: Take 1 kmol H₂O; x kmol O₂

Input	kmol	kg			
H ₂ O	1	18	CO	$1+2x = 2.589$	72.49
O ₂	$x = 0.79433$	25.42	H ₂	1	2
C	$1+2x = 2.589$	31.06			
		74.48			74.49



		kJ			
H ₂ O (400K)	$1(47.4 \times 400 - 22200) (-3240)$	-5240	CO	$(1+2x)(36.6 \times 1000 - 16400) (20200)$	5229
O ₂	$x(36.2 \times 300 - 13500) (-240)$	-2077	H ₂	$1(35.2 \times 1000 - 11800) (18000)$	18000
C	$(1+2x)(23.5 \times 1000 - 11800) (11700)$	30287			
R _n H _{298K}	$1\left(\frac{131000}{111000} + 2.589x\right) 111000$	45341			
		70291			70291

$$x(-2640 + 23400 + 222000 - 40400) = 20200 + 18000 + 3240 - 11700 + 131000$$

NOTE : H₂O + C = H₂+CO ; $\Delta H_{298}^f = H_{CO}^f - H_{H_2O}^f$ (since at 298K, H_{element} = 0)