Lecture 13

Flame Temperature

Content

Exercise- 1Flame temperature with theoretical air

Exercise- 2 Effect of excess air on AFT

Exercise-3

Key words: Flame temperature, Combustion, furnaces

Exercise- 1Flame temperature with theoretical air

Calculate theoretical maximum adiabatic flame temperature of fuel gas of composition 96 % CH_4, 0.8 % CO_2 and 3.2 % N_2 when burnt with theoretical air. Assume fuel and air are mixed at 25^OC

Consider 1 mole of fuel gas

$CH_4 + 2(O_2 + 3.76\ N_2) = CO_2 + 2\ H_2O_{(g)} + 7.52\ N_2$

POC	Amount (kg mole)
CO_2	0.968
H_2O	1.920
N_2	7.52

Heat balance**:** Reference Temperature 25^OC Or 298 k.

Sensible heat in air & fuel +Heat of combustion = Heat in products of combustion 1)

Sensible heat of reactants = 0 since they are Supplied 25^OC .

$-\Delta H_{298}^{Comb.} = 0.968\ (94.05 \times 10^3) + 1.920\ (57.80) \times -10^3\ [\ 0.96\ \times 17.89] \times 10^3 = 184\ \times$ $103\ \text{kcal.}$ -------------- (2)

This heat of combustion raises the temperature of POC to the flame temperature.

The heat capacity of POC i. e. Cp'

$Cp' = n\ CO_2\ C_P\ CO_2 + n\ H_2\ OC_P\ H_2O\ +\ n\ N_2\ C_P\ N_2$

Where nCO_2, nN_2 and nH_2O are moles of CO_2 N_2 H_2O respectively.

$$C_p^1 = 0.968\,(10.55 + 2.16 \times 10^{-3}\,T - \frac{2.04\times10^5}{T2}) + 1.92(7.17 + 2.56 \times 10^{-3}T + \frac{0.08\times10^5}{T^2}) + 7.25\ (6.66 + 1.02 \times 10 - 3T) = 72.27 + 14.41 \times 10 - 3\,T - \frac{2.11\times10^5}{T^2}\frac{\text{kcal}}{\text{kg mole}^{ok}}. \quad - \qquad (3)$$

By 1 and 3

$$184 \times 10^3 = \int_{298}^{T_f} c^1\, P^{dT} \text{---} (4)$$

By 3 and 4

$$184 \times 10^3 = \int_{298}^{T_f} (72.27 + 14.41 \times 10^{-3}T - \frac{2.11\times10^5}{T^2})dT$$

Solution gives T_f =2300K.

Consider the use of expression C_P =a +b T and recalculating flame temperature Calculating C_p^1 and making heat balance gives

$$0.0072\,T_f^2 + 72.27\,Tf - 206\,157 = 0.$$

This is a quadratic equation whose solution gives

$$T_f = 2319\text{ K}.$$

Let us calculate flame temperature by using average C_P values of POC. Average C_P values of POC are given in lecture 12.

$$184000 = 0.96 \times 12.5\,(T_f - 25) + 1.92 \times 7.73(T_f - 25) + 7.12 \times 7.25(T_f - 25)$$

Solution gives T = 2643K.

We note that the accuracy of calculation depends on C_P values. For accurate calculations $C_P = a + b\,T + c/T^2$ must be used. However using $C_P = a + bT$, though simplifies calculation but flame temperature is slightly greater (a difference of 20 K in this example). Use of average C_P values though simplifies the flame temperature calculation but calculated flame temperature is greater than earlier ones

Exercise 2. Effect of excess air on AFT

Consider the fuel in 1. Now it is burnt with a) 20% excess air and b 50% excess air calculate AFT in each case.

In the following calculations we will be using

$C_P = a + b\,T$

However, readers may perform calculation using

$C_P = a + bT + C/T^2$

Take 20% excess air

Amount of POC: $CO_2 = 0.968$

$H_2O = 1.92$

$O_2 = 0.40$

$N_2 = 9.056$

We can calculate

$C_p^1 = 87.18 + 16.11\,T$ (kcal |kg mol)

Heat of combustion $= 184 \times 10^3$ kcal.

Heat balance

$184000 = \int_{298}^{T_f}(87.18 + 16.11T)\,dT$

Integration yields

$184000 = 87.18\,T_f - 25979.6 + 8.05\text{x}10^{-3}T_f^2 - 715.3$

Rearrangement.

$8.05 \times 10^{-3}\,T_f^2 + 87.18\,T_f - 210695 = 0$

$T_f = 2034$ K.

Similarly for 50% excess

POC: $CO_2 = 0.968$

$H_2O = 1.92$

$O_2 = 1.0$

$N_2 = 11.31$

Heat balance yields.

$$9.18 \times 10^{-13}\, T_f^2 + 102.88\, T_f - 215474 = 0$$

$$T_f = 1819 \text{ K}$$

We note that increase in excess air decreases flame temperature. This is due to increase in N_2 and O_2 in the POC.

Similar calculations can be done by enriching air with O_2.

Exercise-3:

Calculate AFT when producer gas of composition 22.4% CO 12.6% CO_2 and 65% N_2 is burned with theoretical air. The air and producer gas enter at 250^oC.

Hint Heat balance would be

Sensible heat in air + sensible heat in producer gas +heat of combustion= sensible heat in POC.

Steps:

1. Calculate composition of POC

2. Calculate sensible heats in air and POC

3. Calculate heat of combustion

4. Do heat balance and find AFT.

Ans $T_f = 1472.5^{O}C$ when $Cp = a + bT$ is used

Assignment

1) Calculate AFT when producer gas of composition 22.4% CO 12.6% CO_2 and 65% N_2 is burned with theoretical air. The air and producer gas enter at 250^oC.

2) Calculate the adiabatic flame temperature for combustion of blast furnace gas analyzing 24% CO 12% CO_2, 4% H_2 and 60% N_2 under the following conditions

- When theoretical air is used
- When air is 30% excess than theoretical
- When 30% excess air is preheated to 227^{O}C and 327^{O}c

3) Calculate theoretical maximum adiabatic flame temperature of fuel gas of composition 96 % CH_4, 0.8 % CO_2 and 3.2 % N_2 when burnt with theoretical air. Assume fuel and air are mixed at 25^{O}C