Lecture 17: Basics of heat balance in roasting

Contents:

Key words: Roasting, metal extraction, heat balance, thermochemistry

Introduction

Heat balanceis an important exercise in all high temperature processes.Heat balance can be used to determine the temperature,theoretically, which can be attained during roasting.Knowledge of temperature is useful to take a decision about the refractorymaterial.

Heat balance

At unsteady state

Heat input=Heat output +Heat accumulation +Heat losses

Inhightemperature processes,certain amount of thermal energy is retained within the reactor to maintainprocessing temperature.At steady state and at constant temperature.

Heat input=Heat output+ Heat losses. ..... 1)

Calculation Procedurefor temperature

In roastingore concentrate and coal are mixed to convert sulphide into oxide.Heat generated by roasting and combustion raises the temperature of the products of roasting and combustion.Thermodynamically it is possible to calculate the temperature under adiabatic condition,i.e. no heatis allowed to loss. This calculated temperature can then be adjusted by incorporating heat losses.We consider an adiabaticprocess of roasting:

Various heat input terms are:

- Heat of reaction
- Heat of combustion
- Sensible heat in reactants

This amount of heat input raises the temperature of products.
The products consists of solid products and gaseous

$$\sum_{i=1}^{n}(H_T - H_{298})_i = \sum_{i=1}^{n} m_i\, c_{pi} \int_{298}^{T} Cp\,(dT) \qquad \text{...... 2)}$$

Here T is the adiabatic temperature .Thus for adiabatic roasting and combustion.

$\sum(H_T - H_{298})$for reactants +Heat of reaction and combustion

$$= \sum_{i-i}^{n} m_i\, c_{pi} \int_{298}^{T} Cp\,(dT) \qquad \text{......3)}$$

Where i is number of reactants and combustion products.

In equation3 heat of reaction & combustion has to be added, since it is liberated.

If the material balance for roasting is known, as well as temperatures of fuel and air, heat content data and heat of reaction data can be used to setup an equation in which temperature of the products is unknown. Let me illustrate it with a problem.

Illustration

In afluid bed reactor Zinc concentrate of composition
$ZnS\ 75\%$, $FeS\ 18\%$, $PbS\ 3\%$, $SiO_2\ 3\%$ and $H_2O\ 1\%$ is roasted with stoichiometric amount of air. Roast product is discharged from the other end of the reactor.

During roasting 1% of total ZnS remains unoxidized,whereas 80% of total iron charged forms $ZnO.Fe_2O_3$.

Find the bed temperature when 10 % of heat input is lost to the surrounding.

*MaterialBalance***:**consider 1000 kg Zn concentrate

Roasting produces roast product and gases .Material balance is left for the exercise.

Roast product	Kg mols	Gases	Kgmols
ZnS	0.077	SO_2	9.7
ZnO	6.837	N_2	57.58
Fe_2O_3	0.204	-	-
ZnO. Fe_2O_3	0.818	-	-
$PbSO_4$	0.126	-	-
SiO_2	0.50	-	-
H_2O	0.555	-	-

Heat liberating reactions are:

$$ZnS + 1.5O_2 = ZnO + SO_2\,; -\Delta H° = 105950 \frac{\text{kcal}}{\text{kg mol ZnO}}$$

$$PbS + 2O_2 = PbSO_4 \quad ; -\Delta H° = 197000\ \text{kcal/kg mol PbS}\ O_4$$

$$ZnO + Fe_2\,O_3 = ZnO.Fe_2\,O_3 - \Delta H° = 4750\ \text{kcal/kg mol ZnO}\ Fe_2O_3$$

$$2\ Fe\ S + 3.5\ O_2 = Fe_2\,O_3 + S_{O\ 2} - \Delta H° = 292600\ \text{kcal/kg mol}\ Fe_2O_3$$

Heat liberated =1138938 kcal.

For calculations of heat output in roasted products and gases one requires specific heat values. All specific heat values are obtained from the references given in the reference section.

Using the thermochemical data following values are calculated;

Sensible heat in roast product $= 122.78\,T + 148 \times 10^{-3} T^2 - 36399$

Sensible heat in gases $= 500.35\ \text{T} + 35 \times 10^{-3}\text{T}^2 - 160619$

Total Sensible heat in product +gases is$623.13\ \text{T} + 49.83 \times 10^{-3}\text{T}^2 - 197018$

Heat input = Heat output + Losses

Substituting the values and solving for T we get

$\mathbf{T = 1723.6K}$ **Answer**

Similar calculation can be done for 20% excess air and 40% excess air

Temperature when 20% excess air $=$ 1545k

Temperature when 40% excess air $=$ 1407K

Excess air decreases the temperature

The following data are used for calculations

$$H_T - H_{298}|ZnO = 11.71\ T + (0.61 \times 10^{-3}\ T^2) + \left(\frac{2.18 \times 10^5}{T}\right) - 4277\ \text{kcal/kg mole.}$$

$$H_T - H_{298}|ZnS = = 12.16\,T + (0.62 \times 10^{-3}\,T^2) + \left(\frac{1.36 \times 10^5}{T}\right) - 4137\ kcal/kg\ mole.$$

$$H_T - H_{298}|Fe_2O_3 = 31.71\,T + (0.88 \times 10^{-3}\,T^2) - 8446\ kcal/kg\ mole.$$

$$H_T - H_{298}|ZnO.Fe_2O_3 = 27.71\,T + (8.86 \times 10^{-3}\,T^2) - 9044\ kcal/kg\ mole.$$

$$H_T - H_{298}|Pb_SO_4 = 10.96\,T + (15.5 \times 10^{-3}\,T^2) - \left(\frac{4.2\,0 \times 10^5}{T}\right) - 3327 \text{ kcal/kgmole.}$$

$$H_T - H_{298}|SiO_2 = 14.41\,T + (0.97 \times 10^{-3}\,T^2) - 4455 \text{ kcal/kgmole.}$$

$$H_T - H_{298}|SO_2 = 11.04\,T + (0.94 \times 10^{-3}\,T^2) - \left(\frac{1.84 \times 10^5}{T}\right) - 3992 \text{ kcal/kgmole.}$$

$$H_T - H_{298}|N_2 = 6.83\,T + (0.45 \times 10^{-3}\,T^2) - \left(\frac{0.12 \times 10^5}{T}\right) - 2117 \text{ kcal/kgmole.}$$

$$H_2O\text{ (liquid, 298K)} - H_2O\text{ (gas, 373K)} = 11170 \text{ kcal/kgmole.}$$

$$H_2\,O(g, 373K) \rightarrow H_2O\,(g, T) = 7.30\,T + (1.23 \times 10^{-3}\,T^2) - 2286 \text{ kcal/kgmole.}$$

$$H_T - H_{298}|O_2 = 7.16\,T + (0.50 \times 10^{-3}\,T^2) - \left(\frac{0.40 \times 10^5}{T}\right) - 2313 \text{ kcal/kgmole.}$$

Conclusion

In this lecture basics of heat balanceare illustrated witha problem. Readers are advised to solve the problem themselves.

References:

1) Rao, Y.K: Stoichiometry and thermodynamics of metallurgical process

2) Butts:Metallurgical problem