Lecture 18: Material and heat balance in roasting of chalcoprite ore

Problem 1 Material balance

Problem 2 Material balance

Problem 3 Material and heat balance

Note: All thermochemical data for lecture 18 and 19 are given at the end of lecture 19.

Problem 1: Material balance

Roasting is a unit process in which sulphide is converted to oxide partially or fully. In production of copper from chalcoprite, partial roasting is carried out.

In one roasting unit, an ore concentrate of the composition 21% Cu$_2$S, 40% FeS$_2$, 31% SiO$_2$ and 8% H$_2$O is roasted using air. The roasting unit is heated by oil of composition 85% C and 15% H, the amount of oil is 5.2% of the weight of the ore. Air for combustion and roasting is 110% in excess of the theoretical requirement.

The gases from combustion and roasting mix together and are carried through a flue. S passes as SO$_2$. The roasted product consists of CuO, Fe$_2$O$_3$ and SiO$_2$.

Calculate:

a) Weight of roasted product
b) Cubic meter of air (i) 1 atm and 273 K and (ii) at 1 atm and 973K
c) Amount of H$_2$O / cubic meter of flue gas.

Solution: Basis 1000 kg ore concentrate

Roasting reactions are (considering roast product given in the problem)

Cu$_2$S + 2O$_2$ = 2CuO + SO$_2$  \hspace{1cm} (1)  
2FeS$_2$ + 5.52O$_2$ = Fe$_2$O$_3$ + 4 SO$_2$  \hspace{1cm} (2)

Weight of roasted product = CuO + Fe$_2$O$_3$ + SiO$_2$,

\hspace{2cm} = 210 + 266.7 + 310 \hspace{2cm} \hspace{2cm} = 786.7 \text{ kg } \hspace{0.5cm} \text{Ans (a)}

110% excess air is used in the process for roasting and combustion.

Combustion reactions are (assuming complete combustion)
\begin{align*}
    \text{C} + \text{O}_2 &= \text{CO}_2, \quad (3) \\
    \text{H}_2 + 0.5 \text{O}_2 &= \text{H}_2\text{O} \quad (4)
\end{align*}

From reactions 1, 2, 3 and 4 one can calculate mols of oxygen theoretically (or stoichiometrically) required for roasting and combustion. According to problem all sulphure passes to \( \text{SO}_2 \)

Total moles of \( \text{O}_2 \) required (theoretically) =17.42 moles.

Theoretic air: 1 mole of oxygen is equivalent to 4.76 moles of air and 1 kg mol of any gas occupies 22.4 m\(^3\) (1 atm., 273 k).

\textbf{Theoretical air} = 1858 m\(^3\) (1 atm., 273 k).

\textbf{Actual amount of air} = 3907 m\(^3\) (1 atm., 973 k) Ans b

The flue gas. Consists \( \text{CO}_2, \text{N}_2, \text{O}_2, \text{H}_2\text{O} \) and \( \text{SO}_2 \)

Amount of flue gas 3969 m\(^3\)

Amount of water 150.84 kg.

\textbf{Water/m}\(^3\) flue gas = 0.038 kg

\textbf{Note the following:}

- Roasting produces roast product which is approximately 78.6\% of the ore concentrate
- Roasting always employs excess amount of air since the roasting reactions are carried out in the solid state at high temperature. Excess air is necessary.
- Material balance shows that flue gas contains 77.9\% \( \text{N}_2 \), which amounts to 3091 m\(^3\) /1000 kg concentrate. Flue gas exist at temperature at least equal to roasting temperature. This means large amount of heat is carried out by \( \text{N}_2 \) of flue gas.
- Use of excess air brings \( \text{O}_2 \) in flue gas and so \( \text{O}_2 \) also carries heat.
- Excess air optimization would make roasting energy efficient

\textbf{Problem 2: Material balance}

The flue gas in one particular roaster analyses
(volume%) \( \text{CO}_2 \) 2\%, \( \text{SO}_2 \) 7.4\%, \( \text{H}_2\text{O} \) 0.6\%, \( \text{N}_2 \) 80\% and \( \text{O}_2 \) 10\%. The ore concentrate analyzes 10\% \( \text{Cu} \), 34\% \( \text{Fe} \), 15\% \( \text{SiO}_2 \) and 41\% \( \text{S} \). During roasting 80\% \( \text{S} \) is removed. The fuel is coal containing 75\% C. The ore and flue are separate, but the resulting gases mix

\textbf{Calculate:}

a) Amount of roasted product assuming it to contain \( \text{Cu}_2\text{S}, \text{FeS}, \text{Fe}_2\text{O}_3 \) and \( \text{SiO}_2 \).
b) The cubic meter of flue gases

c) Amount of fuel used.

d) %excess air used for combustion and roasting.

e) Theoretical ratio of air required for roasting to combustion

**Solution:**

This problem gives elemental analysis in terms of Cu, Fe and S of ore concentrate.

All SiO₂ of ore concentrate will enter into roast product.

Sulphur balance gives amount of S reacting with Cu and Fe.

Similarly Fe balance gives Fe to FeS and Fe to Fe₂O₃.

**Amount of roast product = 775 kg (a) Answer**

To calculate cum of flue gas one has to do sulphur balance.

Let x kg moles is flue gas.

S in feed = S in flue gases + S in roast product.

X = 3102.7m³ (1atm, 273k) (b) Ans.

**Amount of fuel can be determined by CO₂ and is 44.32 kg (c) Ans.**

Excess air in % = \( \frac{\text{Actual amount of air–theoretical air}}{\text{Theoretical air}} \)

N₂ balance determines actual air = 140.28 kg moles.

Theoretical air (for combustion and roasting) = 79.27 kg mols.

Excess air = 77% (d) Ans.

\( \frac{\text{theoretical air for roasting}}{\text{theoretical air combustions}} = 4.23 \) (e) Ans.

**Problem 3: Material and heat balance**

In a multiple hearth roaster, copper, concentrate of composition Cu FeS₂ 33% Cu₂S 7%, Fe S₂ 34%, SiO₂ 19% and moisture 7% is roasted. All iron is oxidized to Fe₂O₃, and 50% of Cu oxidizes to CuO and rest to Cu₂S. The furnace gases analyze 12%O₂ and
leaving the furnace at 900 K. The roast product is also discharged at 900 K. Reactants enter at 298 K. No fuel is used. Assume heat loss to be 10% of the heat input. Calculate

- a) Weight of roasted product per ton of concentrate
- b) % S in the roast product and express it as % of original S,
- c) Volume of air and excess air.
- d) Composition of the gases, and
- e) Heat balance of the process

Solution: Basis 1000 kg copper concentrate.

Weight of roasted product can be determined easily, it is 773.6 kg (a) Ans.

Sulphur in roast product (%) = 6.7% (b) Ans.

Flue gas analysis is not known. Problem states that flue gas contains 12% O₂ which suggests that excess air is used.

From the problem S oxidized = 9.04 kg mols

One can calculate theoretical amount of oxygen by considering that S is oxidized to SO₂, Cu is oxidized to CuO and Fe to Fe₂O₃. Amount of CuO and Fe₂O₃ have already been determined.

\[
S + O_2 = SO_2
\]
\[
Cu + 0.5O_2 = CuO
\]
\[
2Fe + 1.5O_2 = Fe_2O_3
\]

Theoretical oxygen = 49.632 kg mole

Let Z kg mole is flue gas; Amount of O₂ in flue gas = 0.12 Z.

This excess oxygen coming from air will also contain 0.451ZexcessN₂.

Now the flue gas contains SO₂, H₂O, excess O₂ + theoretical N₂ + excess oxygen = Z

\[
Z = 145.83 \text{ kg mols} = 3266.59 \text{ m}^3
\]

Excess air = 132.57% (c) Ans.

Composition of flue gas SO₂ = 6.3%, H₂O = 2.7%, N₂ = 79% and O₂ = 12%.

Heat balance: heat input = Heat output

Basis of calculation: 298 K.
Heat input is due to oxidation reaction like Cu → CuO, Fe to Fe₂O₃, Cu to Cu₂S and S to SO₂.

Heat input = 1164446 kcal

Decomposition of Cu Fe S₂ absorbs 71675 kcal heat.

Heat output by flue gases = 706623 kcal.

Sensible heat in roast product = 92243 kcal.

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<th>Heat input</th>
<th>kcal</th>
<th>Heat output</th>
<th>kcal</th>
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<tbody>
<tr>
<td>Heat due to oxidation</td>
<td>1164446</td>
<td>Roasted product</td>
<td>706623</td>
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<tr>
<td>Cu Fe S₂ decomposition</td>
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<td>Fluegases.</td>
<td>92243</td>
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<td><strong>Total</strong></td>
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<tr>
<td><strong>Total</strong></td>
<td>908143</td>
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Surplus heat = 184628 kcal

Heat balance is an important exercise.