Materials and Energy Balance

Charge Calculations in Pyrometallurgical Processes
Smelting
It is a unit process similar to roasting, to heat a mixture of ore concentrate above the melting point
The objective is to separate the gangue mineral from liquid metal or matte
The state of the gangue mineral in case of smelting is liquid which is the main difference between roasting and smelting

Inputs – Ore, flux, fuel, air
Output – Metal or Matte, slag, off-gas

When metal is separated as sulphide from smelting of ore, it is called Matte smelting e.g. Cu$_2$S and FeS
When metal is separated as liquid, it is called reduction smelting e.g. Ironmaking

Density of liquid metal or matte is around 5-5.5 g/cm$^3$
Density of slag is around 2.8-3 g/cm$^3$

The additives and fluxes serve to convert the waste or gangue materials in the charge into a low melting point slag which also dissolves the coke ash and removes sulphur
Matte Smelting
Advantages of matte smelting
• Low melting point of matte so that less amount of thermal energy is required by converting the metal of the ore in the form of sulphide and then extracting the metal e.g. melting point of Cu$_2$S and FeS is around 1000 degrees Celsius

• Cu$_2$S which is contained in the matte, does not require any reducing agent
  It is converted to oxide by blowing oxygen

• Matte smelting is beneficial for extraction of metal from sulphide ore, particularly when sulphide ore is associated with iron sulphide which forms eutectic point with Cu and Ni

The grade of the matte is defined as the copper grade of matte
A matte of 40 percent means, it has 40% copper, so matte is always given in terms of copper, because it is used to produce copper not iron

Slag in matte smelting is mixture of oxides
e.g. in smelting of copper ore concentrate the slag may contain SiO$_2$, Al$_2$O$_3$, calcium oxide, FeO, Fe$_2$O$_3$, Fe$_3$O$_4$
The desirable properties of slag are low viscosity, solubility, low melting point
Typical reactions in Cu matte smelting:

\[ 6\text{CuO} + 4\text{FeS} = 3\text{Cu}_2\text{S} + 4\text{FeO} + \text{SO}_2 \]

or if the O\(_2\) pressure is high

\[ 6\text{CuO} + 4\text{FeS} = 2\text{CuSO}_4 + 2\text{FeS} \]
\[ 2\text{CuSO}_4 + 2\text{FeS} = \text{Cu}_2\text{S} + 2\text{FeO} + 3\text{SO}_2 \]
\[ \text{Cu}_2\text{O} + \text{FeS} = \text{Cu}_2\text{S} + \text{FeO} \]

Oxygen has greater affinity for iron than copper:

\[ 10\text{Fe}_2\text{O}_3 + \text{FeS} = 7\text{Fe}_3\text{O}_4 + \text{SO}_2 \]
\[ 3\text{Fe}_3\text{O}_4 + \text{FeS} = 10\text{FeO} + \text{SO}_2 \]

In the ideal condition matte contains only \(\text{Cu}_2\text{S}\) and \(\text{FeS}\), plus little amount of \(\text{Fe}_3\text{O}_4\) if oxygen is dissolved

Higher oxides of iron are difficult to remove by the slag

Roasting has to be controlled in order to minimize the formation of \(\text{Fe}_2\text{O}_3\) or \(\text{Fe}_3\text{O}_4\), which may enter the matte during smelting

Off-gas consists of \(\text{SO}_2\), nitrogen, oxygen if excess amount of air is used and sometimes \(\text{SO}_3\) depending on the reaction

If fuel is used, CO and \(\text{CO}_2\) may also be present depending upon the state of combustion
Flash Smelting

Conventionally smelting is carried out in reverberatory furnaces, fired with coal or oil. Nowadays reverberatory furnaces are being replaced by flash smelting furnaces that have been developed in recent years.

The advantages of flash smelting is that it combines both roasting and smelting, whereas in the reverberatory furnace the ore has to be roasted first and then it is transferred to reverberatory furnace for smelting purposes. The reason for this combination is the economical processing of large amount of sulphur dioxide that is created especially in roasting. Collecting the concentrated off-gas from flash smelting and converting to $\text{H}_2\text{SO}_4$ is much more feasible.

Other advantages of flash smelting:
- Very fine particles of ore concentrates are injected, so the reaction is extremely rapid and very high temperatures are created.
- Heat generated is sufficient to carry out the smelting.
Examples – In a copper ore, chalcopyrite (CuFeS$_2$) is 34%, pyrite (FeS$_2$) is 30% and SiO$_2$ is 36%

a) Determine the % Cu and % gangue in the ore

b) What % Fe in the ore concentrate is to be removed to make 40% matte? Consider Cu$_2$S

c) If only excess S is eliminated in the ore concentrate, what is the composition of the resulting matte?

$AW_{Cu} = 64$, $AW_{Fe} = 56$, $AW_{S} = 32$

a) ore = Cu$_2$S + gangue

% Cu = 34 * (64/184) = 11.83%

Gangue = 100 – 11.83*(160/128) = 85.21 %, % Cu$_2$S = 14.78%

b) \[
\frac{40}{100} = \frac{11.83%}{14.78% + %FeS}
\]

0.4(14.78+%FeS) = 11.83, % FeS = 14.795 after removal of FeO, % Fe = 14.795*(56/88) = 9.415

Initial % Fe = 34*(56/184)+30*(56/120) = 24.35%

% Fe to be removed = 24.35 – 9.415 = 14.935%

c) CuFeS$_2$ decomposes according to the reaction 2CuFeS$_2$ = Cu$_2$S + 2FeS + S

FeS$_2$ decomposes according to the reaction FeS$_2$ = FeS + S

% FeS = 24.35*(88/56) = 38.26%

Matte grade = \[
\frac{%Cu}{%Cu_2S + %FeS} \times 100 = 22.2\%
\]
Examples – A copper matte may be represented as \( m\text{Cu}_2\text{S}.n\text{FeS} \) with no fixed values of \( m \) and \( n \). Calculate \( m \) and \( n \) for a matte grade of 38%.

\[
0.38 = \frac{\text{Amount of Cu}}{\text{Amount of Cu}_2\text{S} + \text{Amount of FeS}}
\]

\[
= \frac{160m \times 128/160}{160m + 88n}
\]

\[
60.8m + 33.44n = 128m
\]

\[
\frac{m}{n} = \frac{33.44}{67.2} \approx 0.5
\]

Matte may be represented as \( \text{Cu}_2\text{S}.2\text{FeS} \) or \( 2\text{Cu}_2\text{S}.4\text{FeS} \) or \( 3\text{Cu}_2\text{S}.6\text{FeS} \).
Example – Copper ore is smelted in a reverberatory furnace together with a copper concentrate. The fluxes are pure CaCO₃ and iron ore.

<table>
<thead>
<tr>
<th>Material</th>
<th>Cu₂S</th>
<th>FeS₂</th>
<th>SiO₂</th>
<th>Fe₂O₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper ore</td>
<td>17.5</td>
<td>67.5</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Copper concentrate</td>
<td>35</td>
<td>25</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>Iron ore</td>
<td>0</td>
<td>0</td>
<td>20</td>
<td>80</td>
</tr>
</tbody>
</table>

Flux: CaCO₃

Reverberatory furnace

Iron ore
Copper ore
Copper concentrate

Slag
Matte

Reaction: CaCO₃ = CaO + CO₂
Calculate the quantities of concentrate, iron ore and flux in order to smelt 1000 kg of copper ore and obtain a matte grade of 30% Cu and a slag with the composition 35% SiO₂, 20% CaO, 45% FeO

Let X be the quantity of Cu concentrate
Let Y be the quantity of matte
Let Z by the quantity of iron ore
Let U be the quantity of slag

Four equations are needed to solve for the four variables X, Y, Z, U
**Cu\_2S balance:**

\[ \text{Cu}_2\text{S (in ore)} + \text{Cu}_2\text{S (in Cu conc.)} = \text{Cu}_2\text{S (in matte)} \]

\[ \text{Cu}_2\text{S (in ore)} = 17.5\% \times 1000 = 175 \text{ kg} \]

\[ \text{Cu}_2\text{S (in Cu-conc.)} = 0.35 \times X \]

\[ \text{Cu}_2\text{S (in matte)} = 37.5\% \times Y = 0.375Y \]

**Equation 1:** \[ 175 + 0.35X = 0.375Y \]

**SiO\_2 balance:**

\[ \text{SiO}_2 (\text{Cu ore}) + \text{SiO}_2 (\text{Cu conc.}) + \text{SiO}_2 (\text{iron ore}) = \text{SiO}_2 (\text{slag}) \]

\[ 0.15\% \times 1000 + 0.40X + 0.20Z = 0.35U \]

**Equation 2:** \[ 0.40X + 0.20Z - 0.35U = -150 \]

**Fe Balance:**

\[ \text{Fe (Cu ore)} + \text{Fe (Cu conc.)} + \text{Fe (iron ore)} = \text{Fe (matte)} + \text{Fe (slag)} \]

\[ \text{Fe (Cu ore)} = 67.5\% \times 1000 \times (56/120) = 315 \text{ kg} \]

\[ \text{Fe (Cu conc.)} = 25\% \times X \times (56/120) = 0.117X \text{ kg} \]

\[ \text{Fe (iron ore)} = 80\% \times Z \times (112/160) = 0.56Z \text{ kg} \]

\[ \text{Fe (matte)} = 62.5\% \times Y \times (65/88) = 0.398Y \text{ kg} \]

\[ \text{Fe (slag)} = 45\% \times U \times (56/72) = 0.35U \text{ kg} \]

**Equation 3:** \[ 315 + 0.117X + 0.56Z = 0.398Y + 0.35U \]
Sulphur balance:

\[ S(\text{Cu ore}) + S(\text{Cu conc.}) = S(\text{matte}), \quad S(\text{flue gas}) \approx 0 \]

\[ S(\text{Cu ore}) = (0.175 \times \frac{32}{160} \times 1000) + (0.675 \times \frac{64}{120} \times 1000) = 395 \text{ kg} \]

\[ S(\text{Cu conc.}) = (0.35 \times X \times \frac{32}{160}) + (0.25 \times X \times \frac{64}{120}) = 0.203X \text{ kg} \]

\[ S(\text{matte}) = (0.375 \times \frac{32}{160} \times Y) + (0.625 \times \frac{32}{88} \times Y) = 0.3023Y \text{ kg} \]

Equation 4: \[ 395 + 0.203X = 0.3023Y \]

Equation 1: \[ 175 + 0.35X = 0.375Y \]

Equation 2: \[ 0.40X + 0.20Z - 0.35U = -150 \]

Equation 3: \[ 315 + 0.117X + 0.56Z = 0.398Y + 0.35U \]

CaO in slag: \[ 20\% \times 7463.4 = 1492.7 \text{ kg CaO}, \quad 1492.7 \times \frac{100}{56} = 2665.5 \text{ kg CaCO}_3 \]
Converting
Liquid metal or matte coming from the smelting furnace with impurities is converted to high purity metal in oxidizing environments
Either steady air, blown air or blown oxygen are utilized to oxidize the gangue species
Gangue oxide minerals are removed with the initially forming slag

Inputs – Pig iron, cast iron for steel converting, Cu-Fe matte for copper converting, flux, air
Outputs – Slag, steel or blister copper, off-gas

Furnaces used
Hearths
Puddling furnaces
Cementation furnaces
Bessemer furnaces
Open Hearth furnaces
Basic oxygen furnaces
Electric arc furnaces
Converting Pig Iron
Wrought or worked iron was the main malleable iron used in rails and structures until large scale, commercial production of steel. It contained low amount of carbon (0.04 to 0.08%) and was worked by hand into bars and various shapes due to its malleability. Slag up to 2% is mixed in its microstructure in the form of fibrous inclusions like wood.

Pig iron and cast iron were initially converted to wrought iron in hearths in ancient times then in puddling furnaces during 18th century. In these processes the charge was heated to melting temperature by burning charcoal and oxidized by air. Puddling process involves manually stirring the molten pig iron, which decarburizes the iron. As the iron is stirred, globs of wrought iron are collected into balls by the stirring rod and those are periodically removed by the puddler.

Horizontal (lower) and vertical (upper) cross-sections of a single puddling furnace. A. Fireplace grate; B. Firebricks; C. Cross binders; D. Fireplace; E. Work door; F. Hearth; G. Cast iron retaining plates; H. Bridge wall.
Commercial production of low carbon, low impurity steel was limited to inefficient and expensive process of adding carbon to carbon-free wrought iron between 17\textsuperscript{th} and 19\textsuperscript{th} centuries

The manufacturing process, called cementation process, consisted of heating bars of wrought iron in a furnace in between powdered charcoal layers at about 700\degree C for about a week to Carbon slowly diffuses into iron and dissolves in the iron, raising the carbon percentage Steel obtained from this process is called “blister steel” due to the blister-like marks formed on the surface due to the evolved gases during the manufacturing process

Up to 3 tons of coke was burnt for each ton of steel produced The fuel and labor costs resulted in a small scale production of steel that was about 8 times more expensive

The Bessemer process reduced the time needed to make steel of this quality to about half an hour while only requiring coke to melt the pig iron initially
The Bessemer process - Henry Bessemer patented the process in 1855
The process is carried on in a large ovoid steel container lined with clay or dolomite
The capacity of a converter is from 8 to 30 tons of molten iron

The key principle is removal of impurities from the iron by oxidation with air being blown through the molten iron
The oxidation process removes impurities such as silicon, manganese, and carbon as oxides
These oxides either escape as gas or form a solid slag
The oxidation also raises the temperature of the iron mass and keeps it molten
The refractory lining of the converter also plays a role in the conversion—the clay lining is used in the acid Bessemer, in which there is low phosphorus in the raw material
Dolomite, limestone or magnesite are used when the phosphorus content is high in the basic Bessemer
Once the converter is charged with molten pig iron, a strong thrust of air is blasted across the molten mass for about 20 minutes through tuyeres provided at the bottom of the vessel. The conversion process called the "blow" is typically completed in around twenty minutes. During this period, the progress of the oxidation of the impurities is judged by the appearance of the flame issuing from the mouth of the converter since there is not enough time to make material analyses. The blow may be interrupted at certain periods to avoid the oxidation of certain impurities. Required amount of flux is added at the beginning of each period to produce the slag of desired composition and amount. At the end of the process, all traces of the silicon, manganese, carbon, phosphorus, and sulphur are oxidized, leaving the converter with pure iron. In order to give the steel the desired properties, other impurities can be added to the molten steel when conversion is complete.
Steel converter analysis

A basic pneumatic steel converter is charged with 25 tons of pig iron containing various impurities. In addition to the removal of all of the C, Si, Mn and P, iron equivalent to 5% of the weight of charged iron oxidizes at a constant rate throughout the bessemerizing operation. Enough lime is added to obtain a slag containing 35% CaO. 2/3 of the carbon in steel oxidizes to CO and 1/3 goes to CO₂. Air compressor delivers air at a rate of 500 m³/min for specific periods of time.

- **Flux**: CaO
- **Pig iron**
- **Air**

![Diagram](attachment:diagram.png)

<table>
<thead>
<tr>
<th>Ultimate Analysis wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Pig iron</td>
</tr>
</tbody>
</table>
Calculate the volume of air required for the operation
Basis 25 tons of pig iron

Oxidation step 1: Si + O\(_2\) = SiO\(_2\)
Weight of Si in Pig iron = 0.02 * 25000 = 500 kg
\(n_{\text{Si}} = \frac{500}{28} = 17.857 \text{ kg-atom}\)
\(n_{\text{O}_2} = 17.857 \text{ kg-mole}\)

Oxidation step 2: 2Mn + O\(_2\) = 2MnO
Weight of Mn in Pig iron = 0.01 * 25000 = 250 kg
\(n_{\text{Mn}} = \frac{250}{55} = 4.545 \text{ kg-atom}\)
\(n_{\text{O}_2} = \frac{4.545}{2} = 2.273 \text{ kg-mole}\)

Oxidation step 3: C + 1/2O\(_2\) = CO, C + O\(_2\) = CO
Weight of C in iron = 0.035 * 25000 = 878 kg
\(n_{\text{C}} = \frac{878}{12} = 72.917 \text{ kg-atom}\)
\(n_{\text{C}}(\text{for } \text{CO}) = \frac{2}{3} * 72.917 = 48.611 \text{ kg-atom}\)
\(n_{\text{O}_2} = \frac{1}{2} * 48.611 = 24.306 \text{ kg-mole}\)
\(n_{\text{C}}(\text{for } \text{CO}_2) = \frac{1}{3} * 72.917 = 24.306 \text{ kg-atom}\)

Oxidation step 4: 4P + 5O\(_2\) = 2P\(_2\)O\(_5\)
Weight of P in iron = 0.025 * 25000 = 625 kg
\(n_{\text{P}} = \frac{625}{31} = 20.161 \text{ kg-atom}\)
\(n_{\text{O}_2} = \frac{5}{4} * n_p = 25.201 \text{ kg-mole}\)
Calculate the volume of air required for the operation
Basis 25 tons of pig iron

Total O\textsubscript{2} used during Si, Mn, C, P oxidation = 93.94 kg-mole

Considering small amount of Fe oxidizing in all steps:

\[ n_{Fe} = \frac{1137.5}{56} = 20.312 \text{ kg-atom} \]

\[ 2Fe + \frac{3}{2} O_2 = Fe_2O_3 \]

\[ n_{O_2} = \left(\frac{3}{4}\right) n_{Fe} = \left(\frac{3}{4}\right) \times 20.312 = 15.23 \text{ kg-mole} \]

Total O\textsubscript{2} used = 2.273 + 17.857 + 24.306 + 24.306 + 25.201 + 15.23 = 109.17 kg-mole O\textsubscript{2}

Volume of air required = \( \frac{109.17}{0.21} \times 22.4 = 11644.8 \text{ m}^3/25 \text{ ton of Pig iron} \)

Total blowing time = \( \frac{11644.8}{500} = 23.29 \) minutes
Calculate the durations of each blowing period

Total $\text{O}_2$ used = $2.273 + 17.857 + 24.306 + 24.306 + 25.201 + 15.23 = 109.17$ kg-mole $\text{O}_2$

Volume of air required for period 1 = $(2.273/0.21) \times 22.4 = 242.45$ m$^3$/500 kg Si
Volume of air required for period 2 = $(17.857/0.21) \times 22.4 = 1904.75$ m$^3$/250 kg Mn
Volume of air required for period 3 = $(48.162/0.21) \times 22.4 = 5137.3$ m$^3$/878 kg C
Volume of air required for period 4 = $(25.201/0.21) \times 22.4 = 2688.1$ m$^3$/625 kg P
Volume of air distributed in all periods = $(15.23/0.21) \times 22.4 = 1624.5$ m$^3$/1138 kg Fe
Total blowing time = $11644.8/500 = 23.29$ minutes

- Period 1
  - $\text{Fe} \rightarrow \text{Fe}_2\text{O}_3$
  - $\text{Si} \rightarrow \text{SiO}_2$
  - Time (min): 0

- Period 2
  - $\text{Mn} \rightarrow \text{MnO}$
  - Time (min): 4.43

- Period 3
  - $\text{C} \rightarrow \text{CO, CO}_2$
  - Time (min): 4.99

- Period 4
  - $\text{P} \rightarrow \text{P}_2\text{O}_5$
  - Time (min): 17.04

Fe $\rightarrow$ Fe$_2$O$_3$
Si $\rightarrow$ SiO$_2$
Mn $\rightarrow$ MnO
C $\rightarrow$ CO, CO$_2$
P $\rightarrow$ P$_2$O$_5$
Calculate the weight of CaO added to the converter

\[
\text{Si} + \text{O}_2 = \text{SiO}_2
\]

Weight of Si in Pig iron = 0.02 \times 25000 = 500 kg

\[n_{\text{Si}} = \frac{500}{28} = 17.857 \text{ kg-atom}\]

\[n_{\text{SiO}_2} = 17.857 \text{ kg-mole}\]

Weight of SiO\(_2\) in slag = 17.857\times60 = 1071.4 kg

\[
2\text{Mn} + \text{O}_2 = 2\text{MnO}
\]

Weight of Mn in Pig iron = 0.01 \times 25000 = 250 kg

\[n_{\text{Mn}} = \frac{250}{55} = 4.545 \text{ kg-atom}\]

\[n_{\text{MnO}} = 4.545 \text{ kg-mole}\]

Weight of MnO in slag = 4.545\times71 = 322.7 kg

\[
4\text{P} + 5\text{O}_2 = 2\text{P}_2\text{O}_5
\]

Weight of P in iron = 0.025 \times 25000 = 625 kg

\[n_P = \frac{625}{31} = 20.161 \text{ kg-atom}\]

\[n_{\text{P}_2\text{O}_5} = 20.161/2 = 10.081 \text{ kg-mole}\]

Weight of P\(_2\)O\(_5\) in slag = 17.081\times142 = 1431.5 kg

\[
2\text{Fe} + 3/2 \text{O}_2 = \text{Fe}_2\text{O}_3
\]

Weight of Fe in iron = 0.91 \times 25000 = 22750 kg

\[n_{\text{Fe}} = \frac{1137.5}{56} = 20.312 \text{ kg-atom}\]

\[n_{\text{Fe}_2\text{O}_3} = 20.312/2 = 10.156 \text{ kg-mole}\]

Weight of Fe\(_2\)O\(_3\) in slag = 10.156\times160 = 1625 kg

\[
\text{MnO} + \text{SiO}_2 + \text{P}_2\text{O}_5 + \text{Fe}_2\text{O}_3 = 4450.6 \text{ kg}, \quad 35\% \text{CaO} = (4450.6/0.65)\times0.35 = 2396.5 \text{ kg CaO in slag}
\]
Calculate the weight and composition of the slag

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight (kg)</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>1071.4</td>
<td>15.64%</td>
</tr>
<tr>
<td>MnO</td>
<td>322.7</td>
<td>4.71 %</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>1431.5</td>
<td>20.90%</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>1625</td>
<td>23.75%</td>
</tr>
<tr>
<td>CaO</td>
<td>2396.5</td>
<td>35.00%</td>
</tr>
<tr>
<td>Total</td>
<td>6848</td>
<td>100.00%</td>
</tr>
</tbody>
</table>
Calculate the weight of CaO added to the converter in each blowing period

Total CaO added as flux = 2396.5 kg CaO

CaO consumed each minute = 2396.5 / 23.29 = 102.9 kg
CaO consumed in period 1 = 102.9 * 4.43 = 455.8 kg
CaO consumed in period 2 = 102.9 * 0.56 = 58.02 kg
CaO consumed in period 3 = 102.9 * 11.95 = 1229.4 kg
CaO consumed in period 4 = 102.9 * 6.25 = 643.3 kg
Copper converting
Liquid matte from the smelting process is oxidized in a bessemer or basic oxygen furnace by blowing air or oxygen.
The difference between steel converting and copper converting is that the value mineral $Cu_2S$ is oxidized as well in the latter process.

$$Cu_2S + O_2 = Cu(l) + SO_2$$

$FeS_2$ in the matte is oxidized initially due to its higher oxidation free energy.
Excess $S$ in the matte may also oxidize preferentially prior to reduction of copper.

Blowing, fluxing and slagging may be done periodically due to convenience.
Flux is commonly added in batches due to the high amount of charge material and the limited space of furnaces.
The amount of flux batches and blowing rate affects the time taken to produce slag in periods.

$SO_2$ on the surface of the copper evaporate and form blisters on the solidifying copper.
Blister copper purity is around 99% and electrolysis treatment is needed to obtain pure copper.
Converted blister copper is considered as 100% pure for convenience in material balance.
Copper converter analysis

40 tons of matte carrying 34% Cu is charged in a bessemer converter. The flux is added in batches of 3000 kg, the converter is blown after each addition to obtain slag of the given composition. Blister copper is produced after the removal of slags formed using partially added fluxes. Air is blown at a rate of 100 m³/minute.

<table>
<thead>
<tr>
<th>Rational Analysis wt%</th>
<th>FeO</th>
<th>CaO</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Cu₂S</th>
<th>FeS₂</th>
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</thead>
<tbody>
<tr>
<td>Material</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Slag</td>
<td>59</td>
<td>8</td>
<td>32</td>
<td>1</td>
<td></td>
<td></td>
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<tr>
<td>Flux</td>
<td>?</td>
<td>75</td>
<td>?</td>
<td>?</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Diagram:

- Flux → Bessemer converter → Slag
- Matte → Bessemer converter → Blister copper
- Air → Bessemer converter → Blister copper
Air is blown at a rate of 100 m$^3$/minute

3000 kg Flux
75% SiO$_2$
2% Cu$_2$S
5% FeS$_2$

40 tons Matte
34% Cu

Air 100 m$^3$/min

Bessemer converter

→ Slag 59% FeO, 8 CaO
32% SiO$_2$, 1% Al$_2$O$_3$

→ Blister copper

Calculate the time of each partial blow

Cu$_2$S in matte = 40000 * 0.34 * (160/128) = 17000 kg, FeS = 23000 kg

Let X be the weight of slag
Let Y be the weight of FeS oxidized in one blow

SiO$_2$ balance:
75% * 3000 = 0.32 X
X = 7031 kg

Fe balance:
(56/88) * Y + 5% * 3000 * (56/120) = 59% * 7031 * (56/72)
Y = 4963 kg = 56.4 kg-moles

Oxygen required for 1 blow:
FeS + 3/2O$_2$ = FeO + SO$_2$
FeS$_2$ + 5/2O$_2$ = FeO + 2SO$_2$
O$_2$ required = 56.4 * (3/2) = 84.6 kg-moles
O$_2$ required = 1.25 * (5/2) = 3.125 kg-moles

Total O$_2$ required = 87.725 kg-moles

Time for 1 blow = $\left(\frac{87.725}{0.21}\right) * \left(\frac{22.4}{100}\right) = 93.57$ minutes
Air is blown at a rate of 100 m³/minute

3000 kg Flux
75% SiO₂
2% Cu₂S
5% FeS₂

40 tons Matte
17 tons Cu₂S
23 tons FeS

Air
100 m³/min

Bessemer converter

7031 kg Slag 59%
FeO, 8 CaO
32% SiO₂, 1% Al₂O₃
Blister copper

Calculate the number of partial blows and the weight of flux to be added for the last partial blow to completely remove FeO in the slag

Time for 1 blow = \( \left( \frac{87.725}{0.21} \right) \times \left( \frac{22.4}{100} \right) = 93.57 \) minutes

The weight of FeS oxidized in one blow = 4963 kg = 56.4 kg-moles

Number of partial blows = \( \frac{23000}{4963} = 4.63 \approx 5 \)

FeS oxidized in the 5th blow = 23000 – (4*4963) = 3148 kg

Let Z be the amount of flux batch added in the last period

O₂ balance:
\( (3148/88) \times (3/2) + (0.05Z /120) \times (5/2) = 87.725 \times 3148/4963 \)

Z = 1903 kg
Air is blown at a rate of 100 m$^3$/minute

3000 kg Flux
75% SiO$_2$
2% Cu$_2$S
5% FeS$_2$

40 tons Matte
17 tons Cu$_2$S
23 tons FeS

Air
100 m$^3$/min

Bessemer converter

7031 kg Slag 59%
FeO, 8 CaO
32% SiO$_2$, 1% Al$_2$O$_3$

Blister copper

Calculate the total time for blowing the charge to convert to blister copper

<table>
<thead>
<tr>
<th>Blow</th>
<th>Period (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>93.57</td>
</tr>
<tr>
<td>2</td>
<td>93.57</td>
</tr>
<tr>
<td>3</td>
<td>93.57</td>
</tr>
<tr>
<td>4</td>
<td>93.57</td>
</tr>
<tr>
<td>5</td>
<td>3148/4963 * 93.57 = 59.40 minutes</td>
</tr>
</tbody>
</table>

Total time to remove Fe in the matte and flux completely = 431.68 minutes

Cu$_2$S + O$_2$ = Cu(l) + SO$_2$
Total Cu$_2$S = 17000/160 = 108 kg-moles, Total O$_2$ required = 108 kg-moles
Total air required = (108/0.21) * 22.4 = 11520 m$^3$, Time required to convert Cu = 115.2 minutes
Total time of operation = 546.88 minutes