

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_2S and FeS

When metal is separated as liquid, it is called reduction smelting

e.g. Ironmaking

Density of liquid metal or matte is around $5\text{-}5.5 \text{ g/cm}^3$

Density of slag is around $2.8\text{-}3 \text{ g/cm}^3$

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_2S and FeS is around 1000 degrees Celsius
- Cu_2S 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

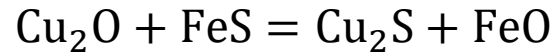
e.g. in smelting of copper ore concentrate the slag may contain SiO_2 , Al_2O_3 , calcium oxide, FeO , Fe_2O_3 , Fe_3O_4

The desirable properties of slag are low viscosity, solubility, low melting point

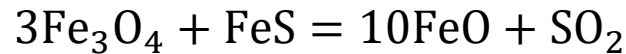
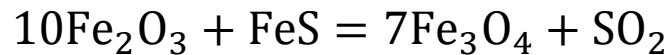
Typical reactions in Cu matte smelting:



or if the O_2 pressure is high $6\text{CuO} + 4\text{FeS} = 2\text{CuSO}_4 + 2\text{FeS}$



Oxygen has greater affinity for iron than copper:



In the ideal condition matte contains only Cu_2S and FeS , plus little amount of Fe_3O_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 Fe_2O_3 or Fe_3O_4 , which may enter the matte during smelting

Off-gas consists of SO_2 , nitrogen, oxygen if excess amount of air is used and sometimes SO_3 depending on the reaction

If fuel is used, CO and 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 converting and smelting, whereas in the reverberatory furnace the ore has to be smelted first and then it is transferred to reverberatory furnace for converting 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 H_2SO_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_2S
- c) If only excess S is eliminated in the ore concentrate, what is the composition of the resulting matte?

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

a- ore = Cu_2S + gangue

$$\% \text{ Cu} = 34 * (64/184) = 11.83 \%$$

$$\text{Gangue} = 100 - 11.83 * (160/128) = 85.21 \%, \% \text{ Cu}_2\text{S} = 14.78 \%$$

$$\text{b} - \frac{40}{100} = \frac{11.83\%}{14.78\% + \% \text{ FeS}}$$

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

$$\text{Initial \% Fe} = 34 * (56/184) + 30 * (56/120) = 24.35 \%$$

$$\% \text{ Fe to be removed} = 24.35 - 9.415 = 14.935 \%$$

c – CuFeS_2 decomposes according to the reaction $2\text{CuFeS}_2 = \text{Cu}_2\text{S} + 2\text{FeS} + \text{S}$

FeS_2 decomposes according to the reaction $\text{FeS}_2 = \text{FeS} + \text{S}$

$$\% \text{ FeS} = 24.35 * (88/56) = 38.26 \%$$

$$\text{Matte grade} = \frac{\% \text{ Cu}}{\% \text{ Cu}_2\text{S} + \% \text{ FeS}} * 100 = 22.2 \%$$

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 %

$$0.38 = \frac{\text{Amount of Cu}}{\text{Amount of Cu}_2\text{S} + \text{Amount of FeS}}$$
$$= \frac{160m * 128/160}{160m + 88n}$$

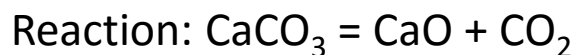
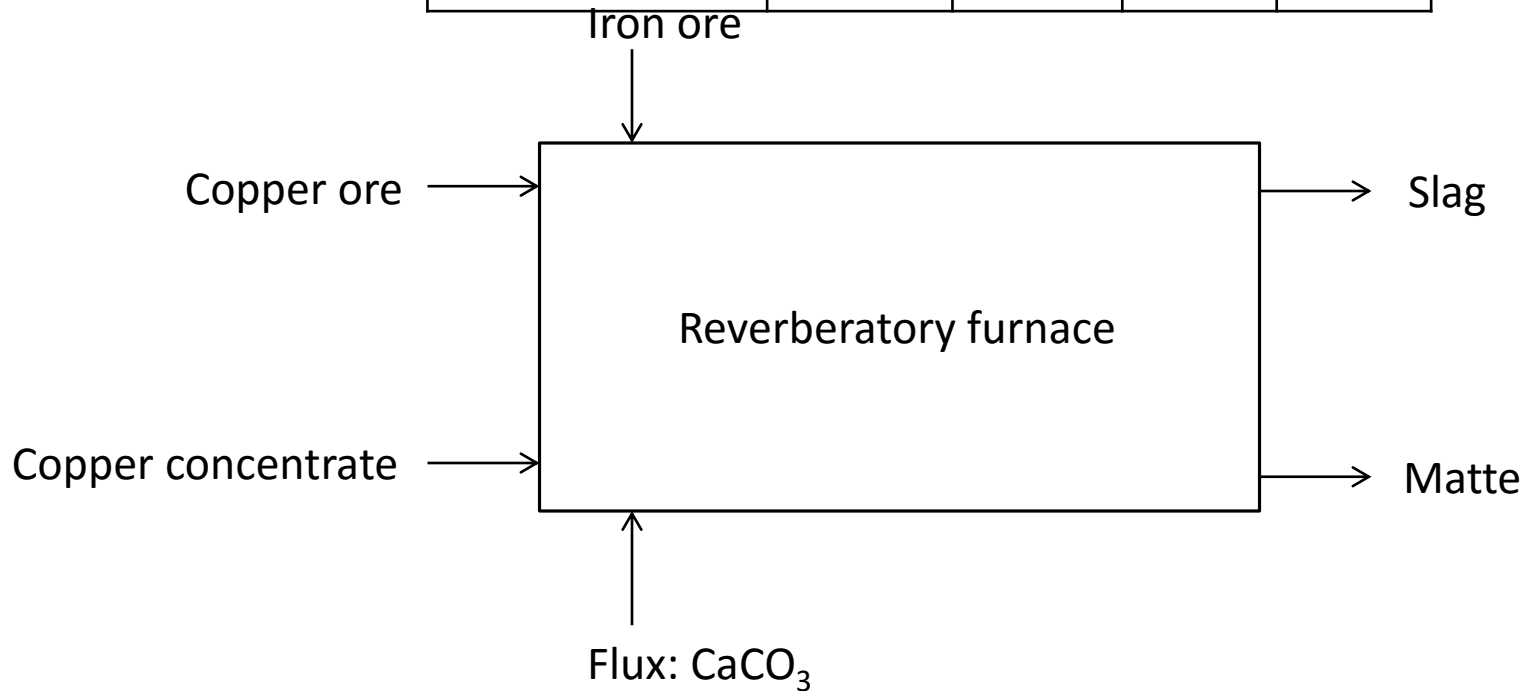
$$60.8m + 33.44n = 128m$$

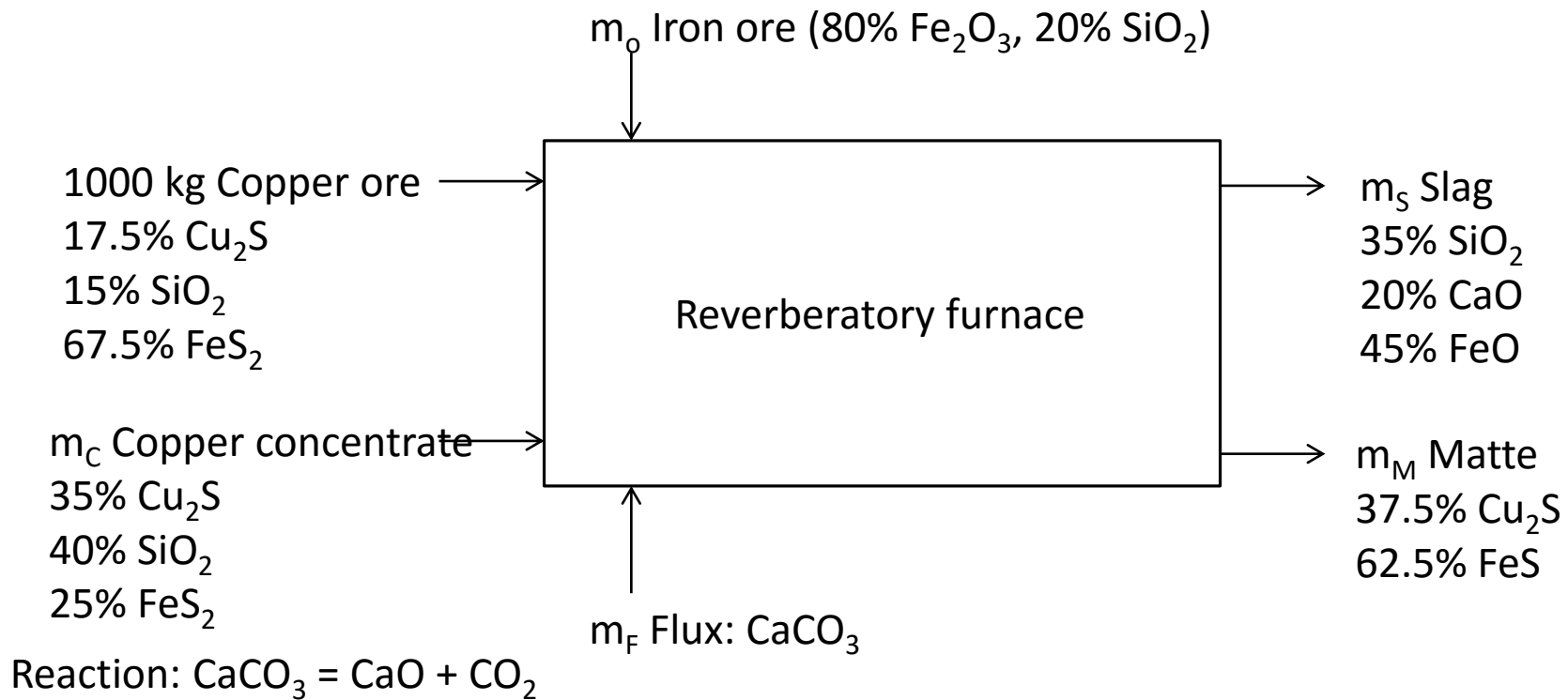
$$\frac{m}{n} = \frac{33.44}{67.2} \approx 0.5$$

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 CaCO_3 and iron ore

Rational Analysis wt%				
Material	Cu_2S	FeS_2	SiO_2	Fe_2O_3
Copper ore	17.5	67.5	15	
Copper concentrate	35	25	40	
Iron ore			20	80





DOF analysis

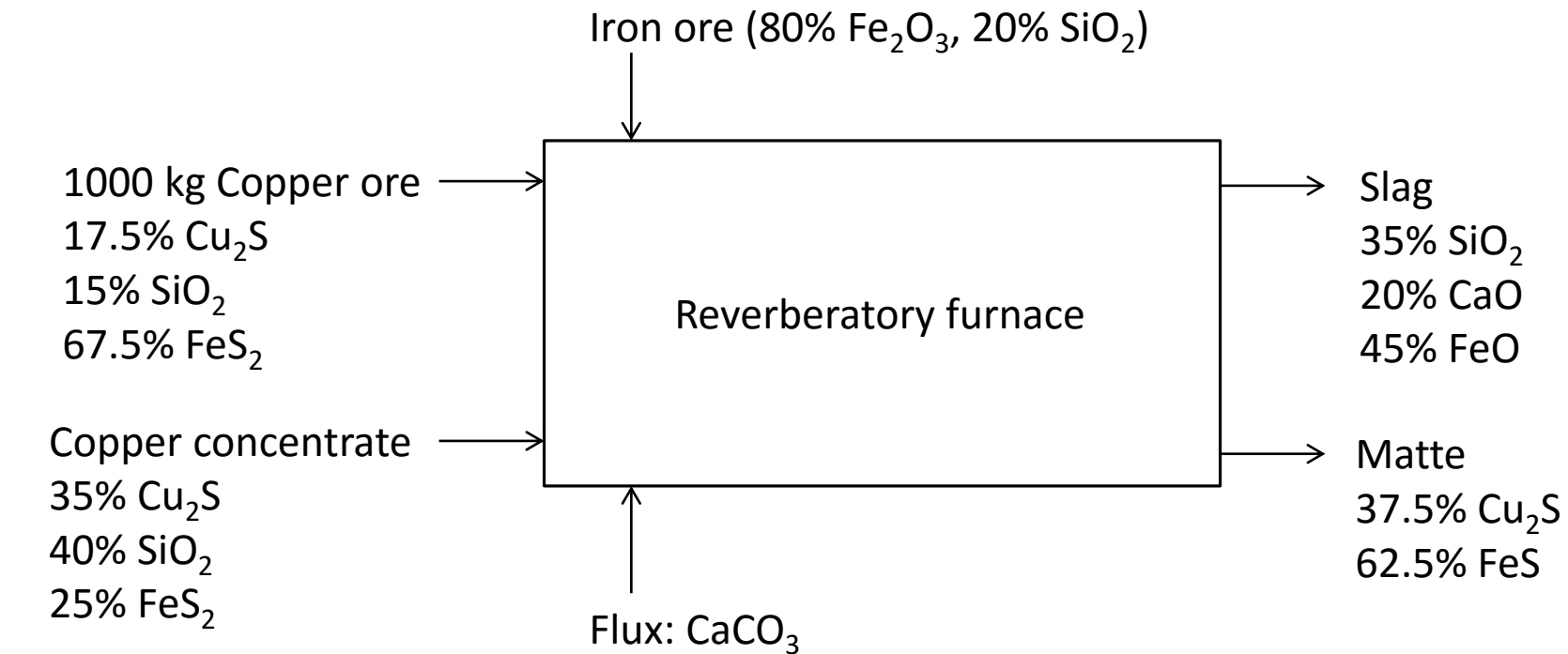
5 unknown labeled variables (m_c , m_o , m_F , m_s , m_M)

+ 2 independent chemical reactions

- 7 independent molecular species balances (Cu_2S , FeS_2 , SiO_2 , Fe_2O_3 , CaCO_3 , CaO , FeO)

- 0 other equation relating unknown variables

= 0 degrees of freedom



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% SiO_2 , 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

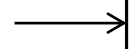
Let U be the quantity of slag

Four equations are needed to solve for the four variables X, Y, Z, U

Z kg Iron ore (80% Fe_2O_3 , 20% SiO_2)



1000 kg Copper ore



17.5% Cu_2S

15% SiO_2

67.5% FeS_2

X kg Copper concentrate



35% Cu_2S

40% SiO_2

25% FeS_2

Flux: CaCO_3



Reverberatory furnace

U kg Slag

35% SiO_2

20% CaO

45% FeO

Y kg Matte

37.5% Cu_2S

62.5% FeS

Cu_2S balance:

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

$\text{Cu}_2\text{S}(\text{in ore}) = 17.5\% * 1000 = 175 \text{ kg}$

$\text{Cu}_2\text{S}(\text{in Cu-conc.}) = 0.35 * X$

$\text{Cu}_2\text{S}(\text{in matte}) = 37.5\% * Y = 0.375 Y$

Equation 1: $175 + 0.35X = 0.375Y$

SiO_2 balance:

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

$0.15\% * 1000 + 0.40X + 0.20Z = 0.35U$

Equation 2: $0.40X + 0.20Z - 0.35U = -150$

Fe Balance:

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

$\text{Fe}(\text{Cu ore}) = 67.5\% * 1000 * (56/120) = 315 \text{ kg}$

$\text{Fe}(\text{iron ore}) = 80\% * Z * (112/160) = 0.56Z \text{ kg}$

$\text{Fe}(\text{slag}) = 45\% * U * (56/72) = 0.35U \text{ kg}$

$\text{Fe}(\text{Cu conc.}) = 25\% * X * (56/120) = 0.117X \text{ kg}$

$\text{Fe}(\text{matte}) = 62.5\% * Y * (65/88) = 0.398Y \text{ kg}$

Equation 3: $315 + 0.117X + 0.56Z = 0.398Y + 0.35U$

Z kg Iron ore (80% Fe_2O_3 , 20% SiO_2)

1000 kg Copper ore

17.5% Cu_2S

15% SiO_2

67.5% FeS_2

Reverberatory furnace

U kg Slag

35% SiO_2

20% CaO

45% FeO

X kg Copper concentrate

35% Cu_2S

40% SiO_2

25% FeS_2

Y kg Matte

37.5% Cu_2S

62.5% FeS

Flux: CaCO_3

Sulphur balance:

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

$S(\text{Cu ore}) = (0.175 * (32/160) * 1000) + (0.675 * (64/120) * 1000) = 395 \text{ kg}$

$S(\text{Cu conc.}) = (0.35 * X * (32/160)) + (0.25 * X * (64/120)) = 0.203X \text{ kg}$

$S(\text{matte}) = (0.375 * (32/160) * Y) + (0.625 * (32/88) * Y) = 0.3023Y \text{ kg}$

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: $315 + 0.117X + 0.56Z = 0.398Y + 0.35U$

Z=589.6 kg Iron ore

U=7463.4 kg Slag

X=3210.2 kg Cu conc.

Y=3462.7 kg Matte

$\text{CaO in slag: } 20\% * 7463.4 = 1492.7 \text{ kg CaO},$

$1492.7 * (100/56) = 2665.5 \text{ kg CaCO}_3$

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

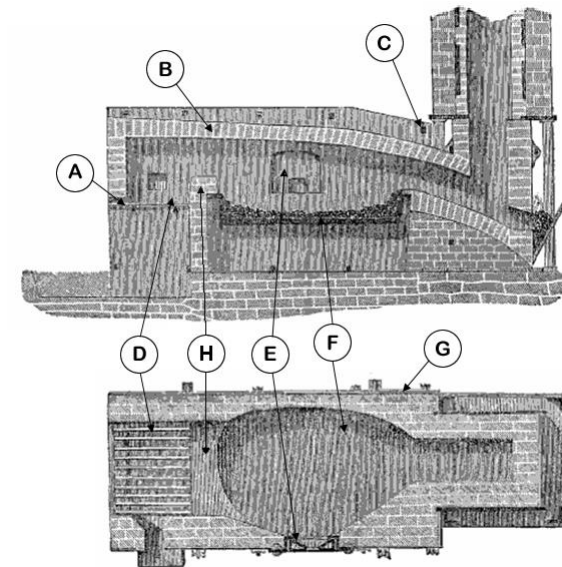
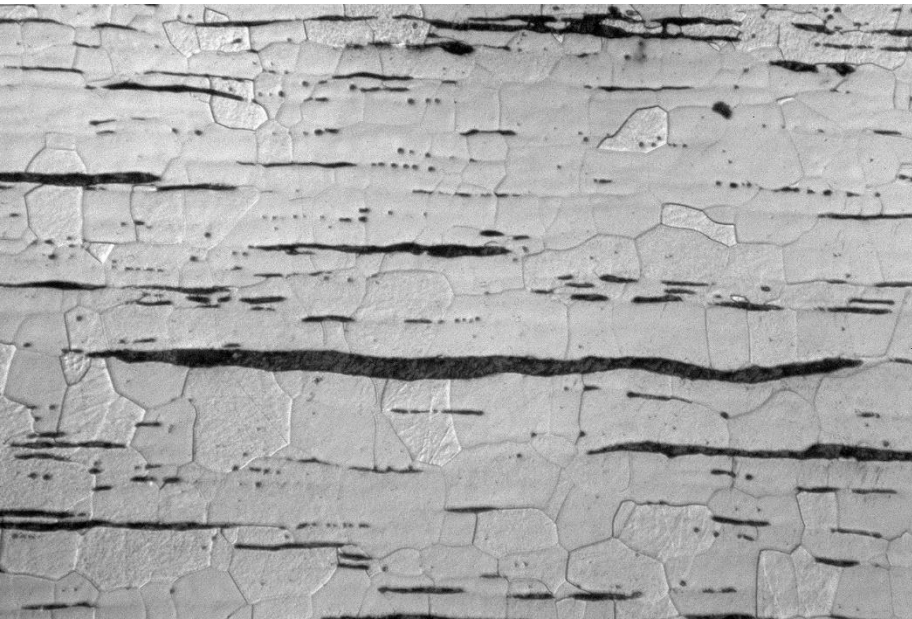
Slag up to 2% is mixed in its microstructure in the form of fibrous inclusions like wood

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;

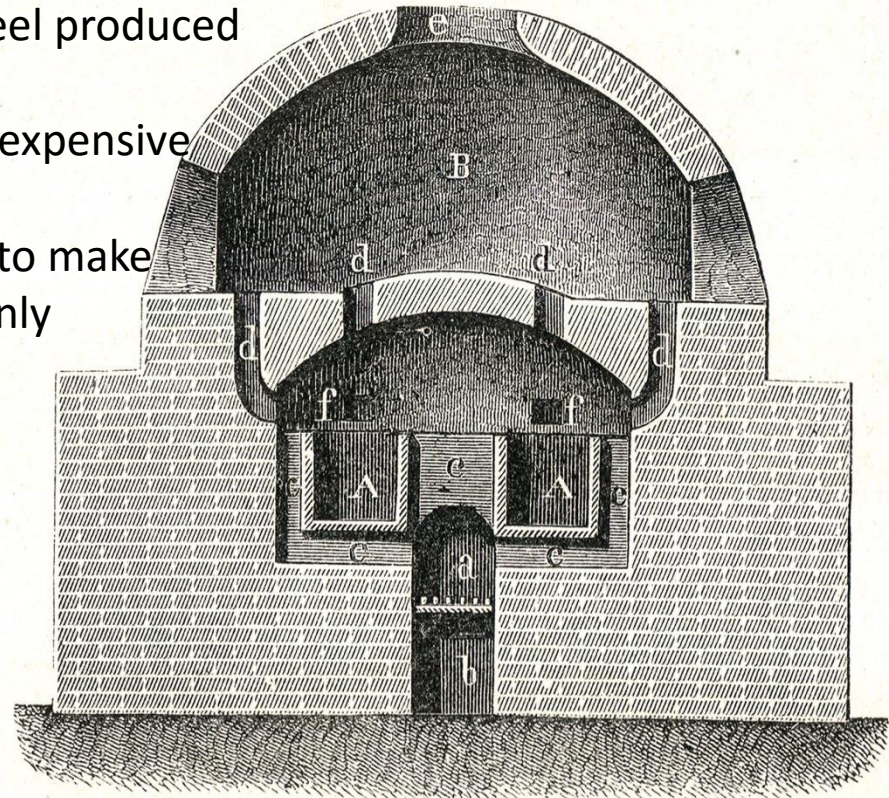
F. Hearth; G. Cast iron retaining plates; H. Bridge wall

Commercial production of low carbon, low impurity steel was limited to inefficient and expensive process of adding carbon to carbon-free wrought iron between 17th and 19th 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^o C for about a week. 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

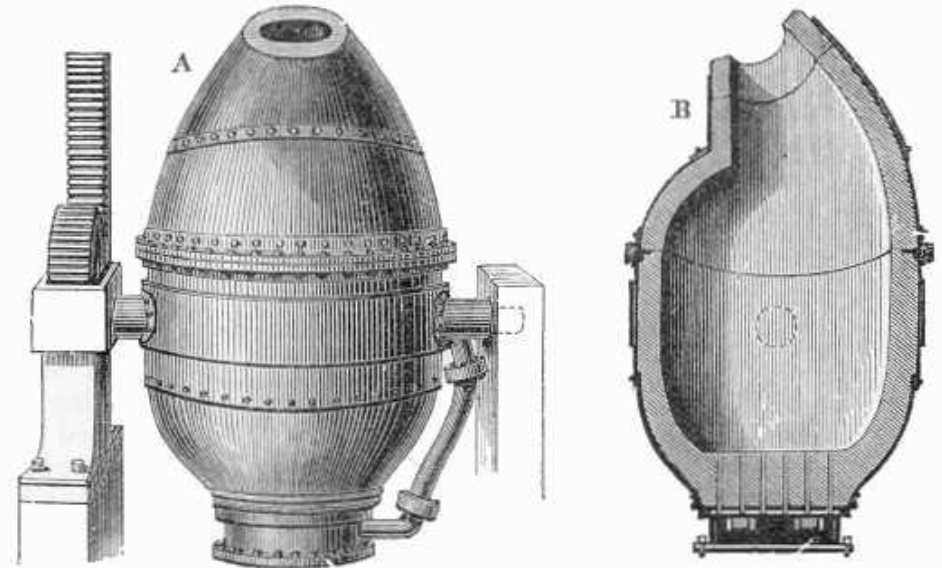
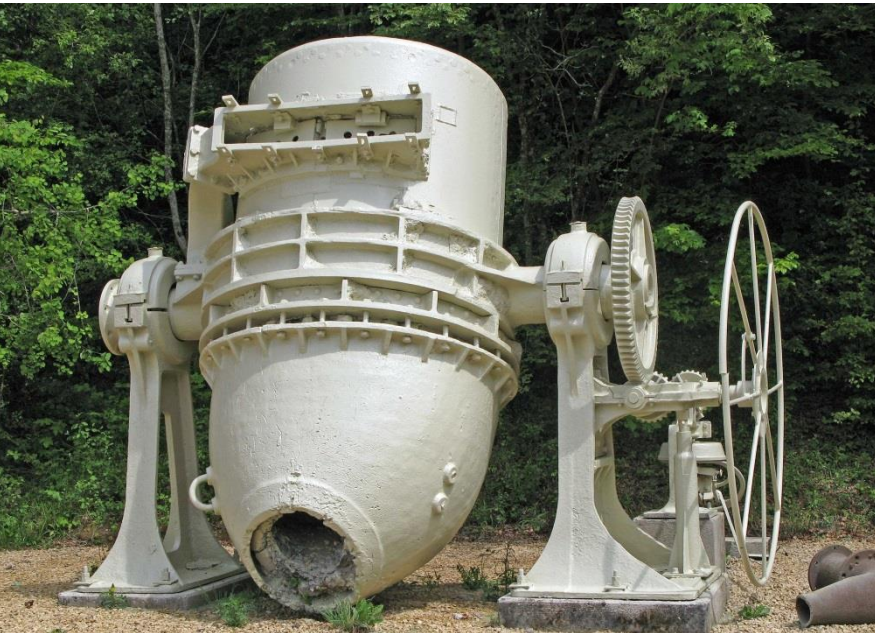
The oxidation process removes impurities such as silicon, manganese, and carbon as oxides

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

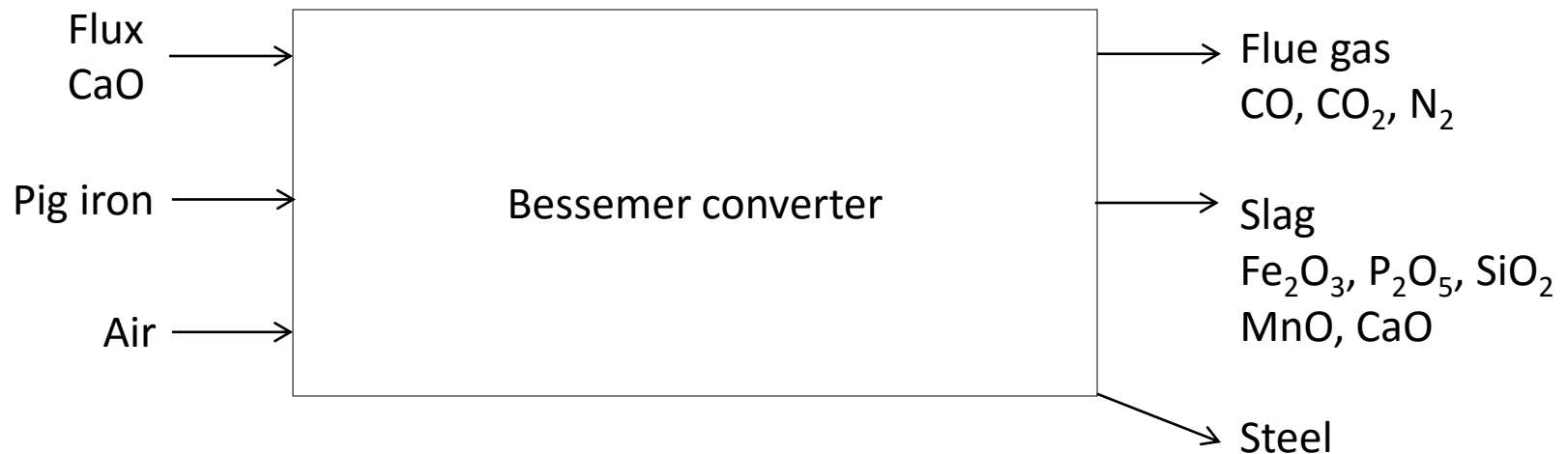
A basic pneumatic steel converter is charged with 25 tons of pig iron containing various impurities

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

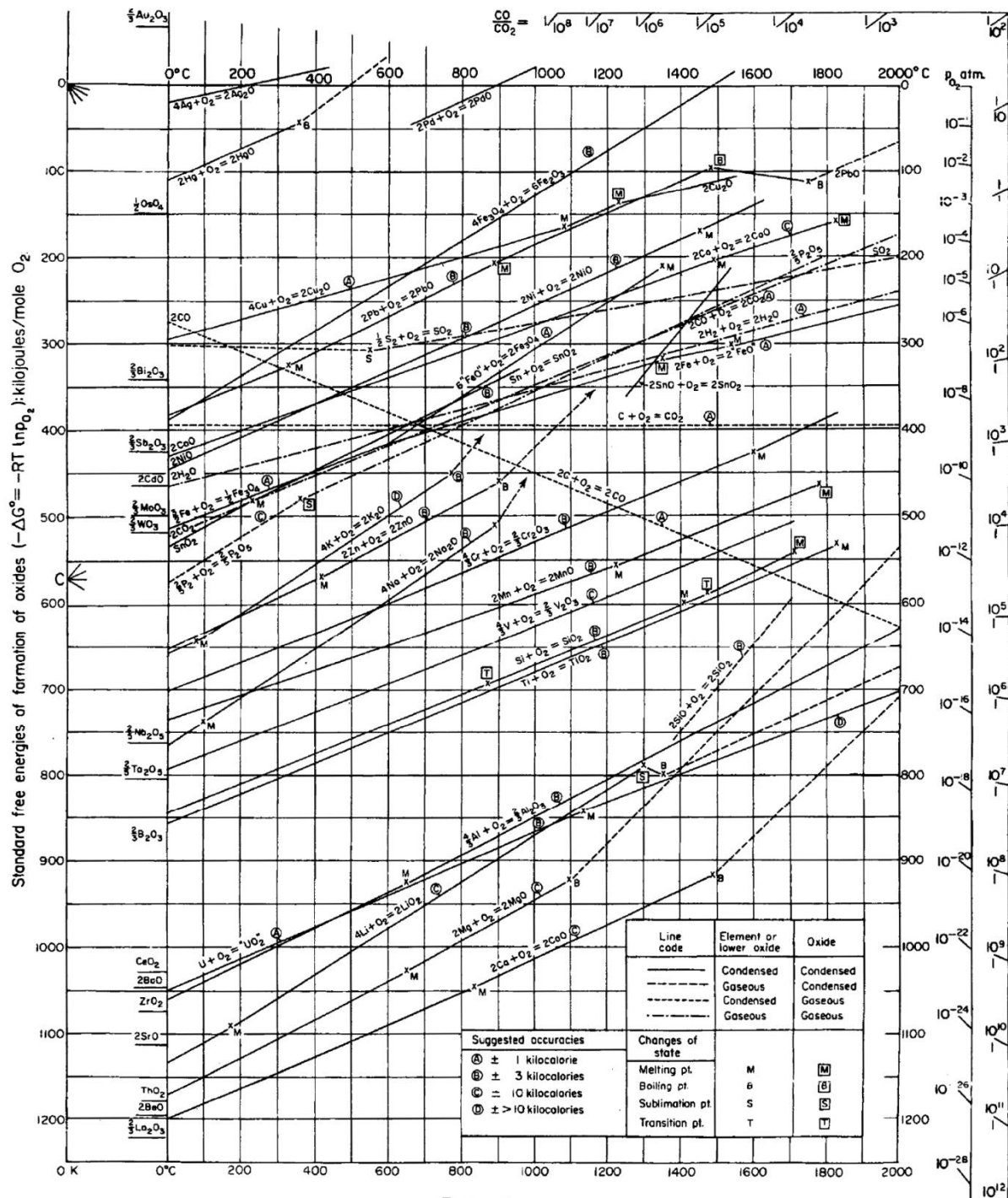
Enough lime is added to obtain a slag containing 35% CaO

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



Ultimate Analysis wt%					
Material	Fe	C	Si	Mn	P
Pig iron	91	3.5	2	1	2.5





DOF analysis

12 unknown labeled variables (\dot{V}_A , \dot{V}_F , m_F , m_s , m_{St} , $X_{Fe_2O_3}$, $X_{P_2O_5}$, X_{SiO_2} , X_{MnO} , X_{CO} , X_{CO_2} , X_{N_2})

+ 6 independent chemical reactions

- 14 independent molecular species balances (Fe, C, Si, Mn, P, SiO₂, Fe₂O₃, CaO, MnO, P₂O₅, CO, CO₂, N₂, O₂)

- 4 other equation relating unknown variables ($X_{Fe_2O_3} + X_{P_2O_5} + X_{SiO_2} + X_{MnO} = 0.65$, $X_{CO} + X_{CO_2} + X_{N_2} = 0.35$, 5% Fe oxidizes, 1/3 C oxidizes to CO₂)

= 0 degrees of freedom



Calculate the volume of air required for the operation
Basis 25 tons of pig iron

Oxidation step 1: $\text{Si} + \text{O}_2 = \text{SiO}_2$

Weight of Si in Pig iron = $0.02 * 25000 = 500 \text{ kg}$

$n_{\text{Si}} = 500/28 = 17.857 \text{ kg-atom}$

$n_{\text{O}_2} = 17.857 \text{ kg-mole}$

Oxidation step 2: $2\text{Mn} + \text{O}_2 = 2\text{MnO}$

Weight of Mn in Pig iron = $0.01 * 25000 = 250 \text{ kg}$

$n_{\text{Mn}} = 250/55 = 4.545 \text{ kg-atom}$

$n_{\text{O}_2} = 4.545/2 = 2.273 \text{ kg-mole}$

Oxidation step 3: $\text{C} + 1/2\text{O}_2 = \text{CO}$, $\text{C} + \text{O}_2 = \text{CO}_2$

Weight of C in iron = $0.035 * 25000 = 878 \text{ kg}$

$n_{\text{C}} = 878/12 = 72.917 \text{ kg-atom}$

$n_{\text{C}}(\text{for CO}) = (2/3) * 72.917 = 48.611 \text{ kg-atom}$

$n_{\text{O}_2} = (1/2) * 48.611 = 24.306 \text{ kg-mole}$

$n_{\text{C}}(\text{for CO}_2) = (1/3) * 72.917 = 24.306 \text{ kg-atom}$

$n_{\text{O}_2} = n_{\text{C}}(\text{for CO}_2) = 24.306 \text{ kg-atom}$

Oxidation step 4: $4\text{P} + 5\text{O}_2 = 2\text{P}_2\text{O}_5$

Weight of P in iron = $0.025 * 25000 = 625 \text{ kg}$

$n_{\text{P}} = 625/31 = 20.161 \text{ kg-atom}$

$n_{\text{O}_2} = (5/4) * n_{\text{P}} = 25.201 \text{ kg-mole}$



Calculate the volume of air required for the operation
Basis 25 tons of pig iron

Total O₂ used during Si, Mn, C, P oxidation = 93.94 kg-mole

Considering small amount of Fe oxidizing in all steps:

$$n_{\text{Fe}} = 1137.5/56 = 20.312 \text{ kg-atom}$$



$$n_{\text{O}_2} = (3/4) * n_{\text{Fe}} = (3/4) * 20.312 = 15.23 \text{ kg-mole}$$

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

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

$$\text{Total blowing time} = 11644.8/500 = 23.29 \text{ minutes}$$



Calculate the durations of each blowing period

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

$$\text{Volume of air required for period 1} = (2.273/0.21) * 22.4 = 242.45 \text{ m}^3/500 \text{ kg Si}$$

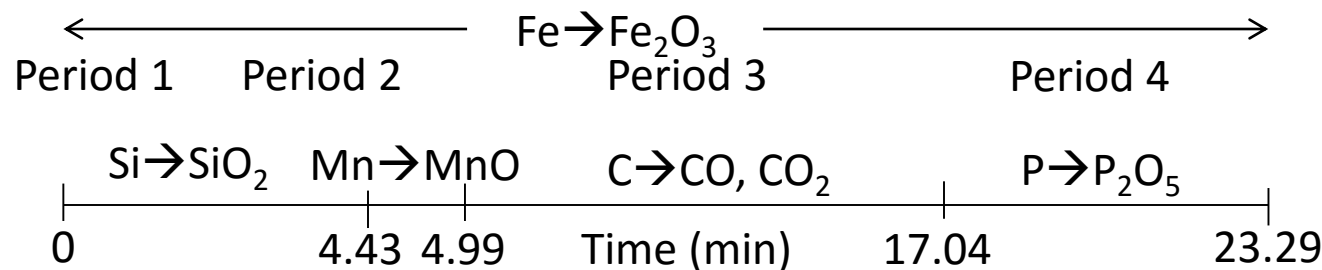
$$\text{Volume of air required for period 2} = (17.857/0.21) * 22.4 = 1904.75 \text{ m}^3/250 \text{ kg Mn}$$

$$\text{Volume of air required for period 3} = (48.162/0.21) * 22.4 = 5137.3 \text{ m}^3/878 \text{ kg C}$$

$$\text{Volume of air required for period 4} = (25.201/0.21) * 22.4 = 2688.1 \text{ m}^3/625 \text{ kg P}$$

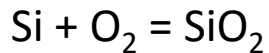
$$\text{Volume of air distributed in all periods} = (15.23/0.21) * 22.4 = 1624.5 \text{ m}^3/1138 \text{ kg Fe}$$

$$\text{Total blowing time} = 11644.8/500 = 23.29 \text{ minutes}$$





Calculate the weight of CaO added to the converter

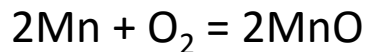


Weight of Si in Pig iron = $0.02 * 25000 = 500 \text{ kg}$

$n_{\text{Si}} = 500/28 = 17.857 \text{ kg-atom}$

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

Weight of SiO₂ in slag = $17.857 * 60 = 1071.4 \text{ kg}$

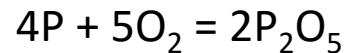


Weight of Mn in Pig iron = $0.01 * 25000 = 250 \text{ kg}$

$n_{\text{Mn}} = 250/55 = 4.545 \text{ kg-atom}$

$n_{\text{MnO}} = 4.545 \text{ kg-mole}$

Weight of MnO in slag = $4.545 * 71 = 322.7 \text{ kg}$

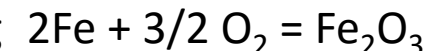


Weight of P in iron = $0.025 * 25000 = 625 \text{ kg}$

$n_{\text{P}} = 625/31 = 20.161 \text{ kg-atom}$

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

Weight of P₂O₅ in slag = $10.081 * 142 = 1431.5 \text{ kg}$

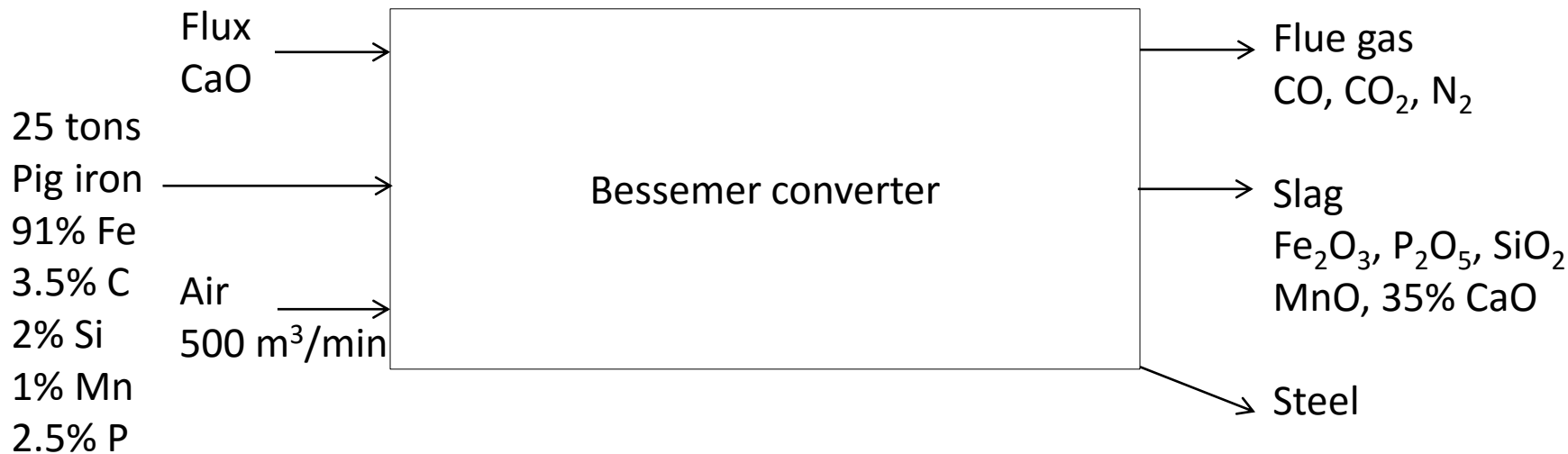


$n_{\text{Fe}} = 1137.5/56 = 20.312 \text{ kg-atom}$

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

Weight of Fe₂O₃ in slag = $10.156 * 160 = 1625 \text{ kg}$

$\text{MnO} + \text{SiO}_2 + \text{P}_2\text{O}_5 + \text{Fe}_2\text{O}_3 = 4450.6 \text{ kg}$, $35\% \text{ CaO} = (4450.6/0.65) * 0.35 = 2396.5 \text{ kg CaO in slag}$



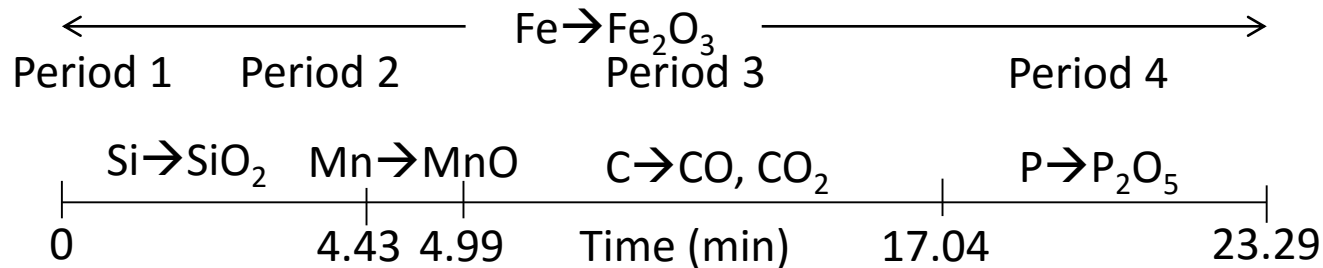
Calculate the weight and composition of the slag

Component	Weight (kg)	Weight %
SiO ₂	1071.4	15.64%
MnO	322.7	4.71 %
P ₂ O ₅	1431.5	20.90%
Fe ₂ O ₃	1625	23.75%
CaO	2396.5	35.00%
Total	6848	100.00%



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 = $102.9 \times 4.43 = 455.8$ kg

CaO consumed in period 2 = $102.9 \times 0.56 = 58.02$ kg

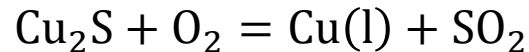
CaO consumed in period 3 = $102.9 \times 11.95 = 1229.4$ kg

CaO consumed in period 4 = $102.9 \times 6.25 = 643.3$ 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



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

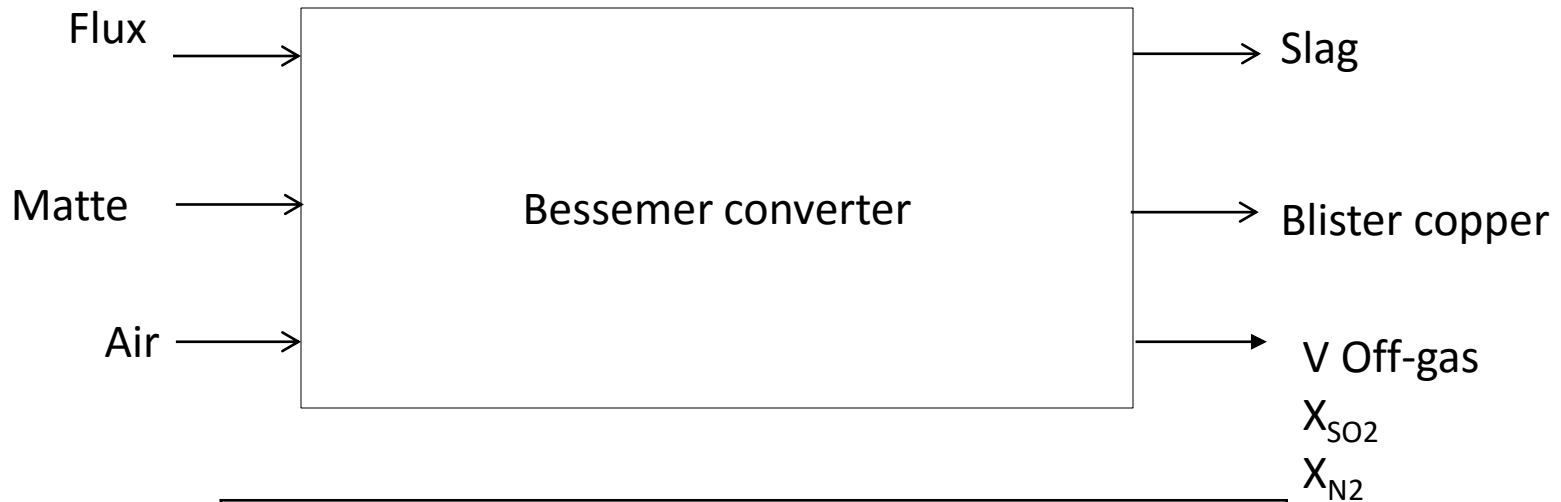
Copper converter analysis

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

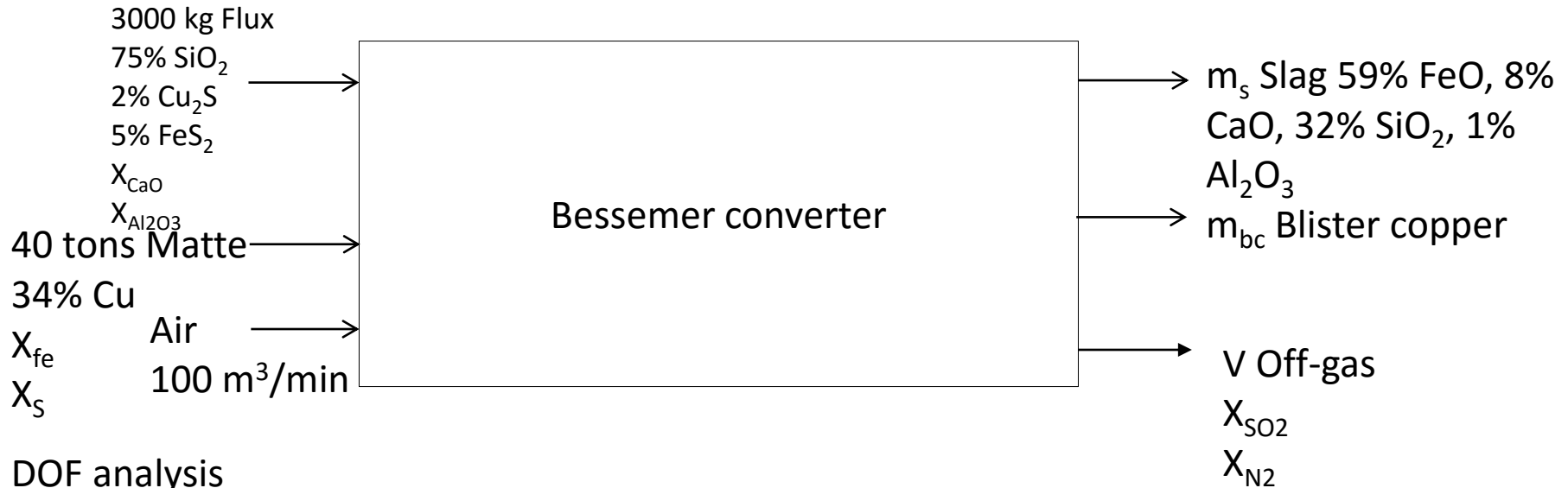
Blister copper is produced after the removal of slags formed using partially added fluxes

Air is blown at a rate of 100 m³/minute



Rational Analysis wt%						
Material	FeO	CaO	SiO ₂	Al ₂ O ₃	Cu ₂ S	FeS ₂
Slag	59	8	32	1		
Flux		?	75	?	2	5

Air is blown at a rate of $100 \text{ m}^3/\text{minute}$



DOF analysis

9 unknown labeled variables (m_s , m_{bc} , V , X_{Fe} , X_{S} , X_{CaO} , $X_{\text{Al}_2\text{O}_3}$, X_{SO_2} , X_{N_2})

- 4 independent atomic species balances that are involved in the reactions (Cu, Fe, S, O)
 - 4 molecular balances on independent nonreactive species (N_2 , CaO, SiO_2 , Al_2O_3)
 - 3 other equation relating unknown variables ($X_{\text{Fe}} + X_{\text{S}} = 0.66$, $X_{\text{CaO}} + X_{\text{Al}_2\text{O}_3} = 0.18$, $X_{\text{SO}_2} + X_{\text{N}_2} = 1$)
- = -2 degrees of freedom!

Air is blown at a rate of 100 m³/minute

3000 kg Flux

75% SiO₂

2% Cu₂S

5% FeS₂

40 tons Matte

34% Cu

Air

100 m³/min

Bessemer converter

Slag 59% FeO, 8 CaO
32% SiO₂, 1% Al₂O₃

Blister copper

V Off-gas
X_{SO2}
X_{N2}

Calculate the time of each partial blow

$$\text{Cu}_2\text{S in matte} = 40000 * 0.34 * (160/128) = 17000 \text{ kg,}$$

$$\text{FeS} = 23000 \text{ kg}$$

Let X be the weight of slag

SiO₂ balance:

$$75\% * 3000 = 0.32 X$$

$$X = 7031 \text{ kg}$$

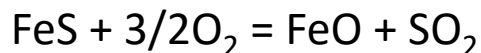
Let Y be the weight of FeS oxidized in one blow

Fe balance:

$$(56/88) * Y + 5\% * 3000 * (56/120) = 59\% * 7031 * (56/72)$$

$$Y = 4963 \text{ kg} = 56.4 \text{ kg-moles}$$

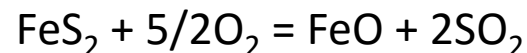
Oxygen required for 1 blow:



$$\text{O}_2 \text{ required} = 56.4 * (3/2) = 84.6 \text{ kg-moles}$$

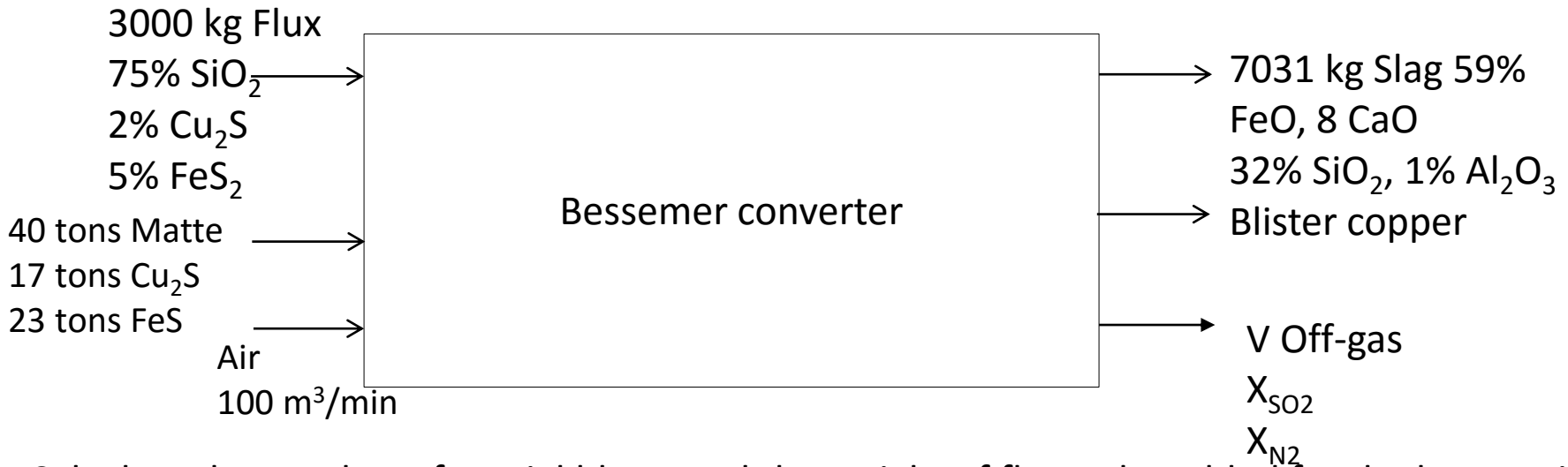
$$\text{Total O}_2 \text{ required} = 87.725 \text{ kg-moles}$$

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



$$\text{O}_2 \text{ required} = 1.25 * (5/2) = 3.125 \text{ kg-moles}$$

Air is blown at a rate of 100 m³/minute



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

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

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

$$\text{Number of partial blows} = 23000/4963 = 4.63 \approx 5$$

$$\text{FeS oxidized in the 5}^{\text{th}} \text{ blow} = 23000 - (4 * 4963) = 3148 \text{ kg}$$

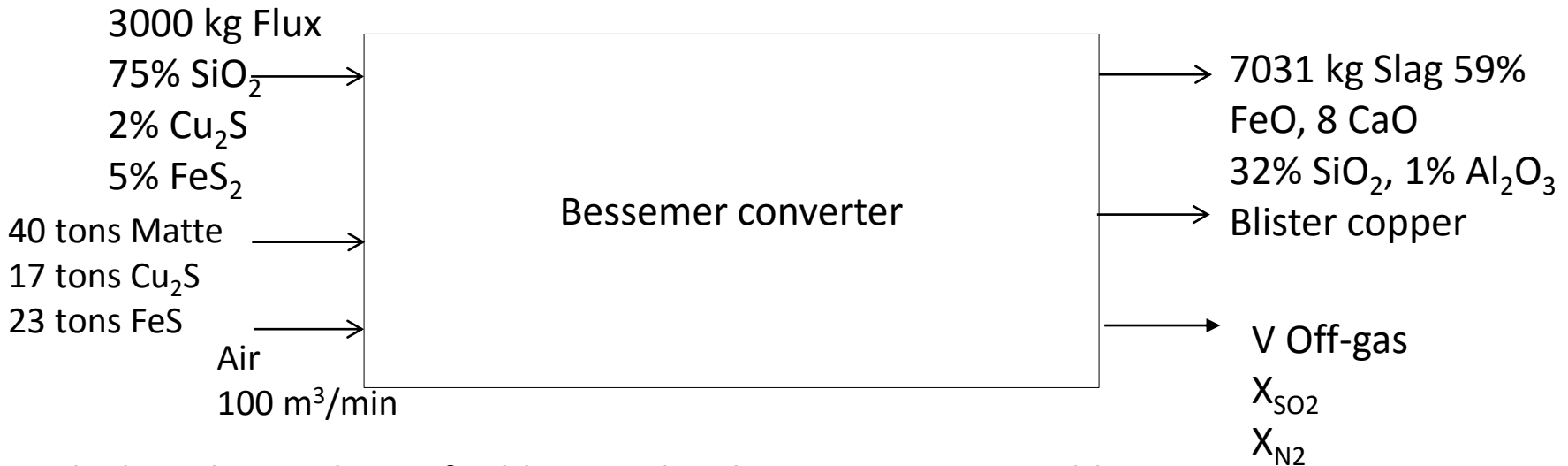
Let Z be the amount of flux batch added in the last period

O₂ balance:

$$(3148/88) * (3/2) + (0.05Z / 120) * (5/2) = 87.725 * 3148/4963$$

$$Z = 1903 \text{ kg}$$

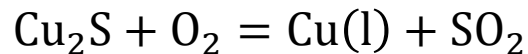
Air is blown at a rate of 100 m³/minute



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

Blow	Period (min)
1	93.57
2	93.57
3	93.57
4	93.57
5	$3148/4963 * 93.57 = 59.40$ minutes

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



Total Cu₂S = 17000/160 = 108 kg-moles, Total O₂ required = 108 kg-moles

Total air required = (108/0.21) * 22.4 = 11520 m³, Time required to convert Cu = 115.2 minutes

Total time of operation = 546.88 minutes