MINERAL DRESSING

- The first process most ores undergo after they leave the mine is mineral dressing (processing), also called ore preparation, milling, and ore dressing or ore beneficiation.
- Ore dressing is a process of mechanically separating the grains of ore minerals from the gangue minerals, to produce a concentrate (enriched portion) containing most of the ore minerals and a tailing (discard) containing the bulk of the gangue minerals.
-
- Since most ore minerals are usually finely disseminated and intimately associated with gangue minerals, the various minerals must be broken apart (freed) or "liberated" before they can be collected in separate products. Therefore, the first part in any ore dressing process will involve the crushing and grinding (which is also known by a common name called "comminution") of the ore to a point where each mineral grain is practically free.

Comminution

Crushing and grinding are usually carried out in a sequence of operations by which the lump size is reduced step by step. There are *3 stages of crushing* and *2 stages of grinding*.

1. Primary Crushing (coarse crushing): In primary crushing, ore or run-of-mine ore (up to 1 m in size) is crushed down to about 10 cm and it is done in a jaw or gyratory crusher.
2. Secondary Crushing (intermediate crushing): In this case, ore is crushed from 10 cm to less than 1 – 2 cm size; for this purpose jaw, cone or roll crushers are used. These secondary crushers consume more power than primary crushers.
3. Tertiary Crushing (fine crushing): By tertiary crushers ore is crushed from 1 – 2 cm to less than 0.5 cm. Short head cone crushers, roll crushers, hammer mills can be used for this purpose.

The two stages of grinding are:

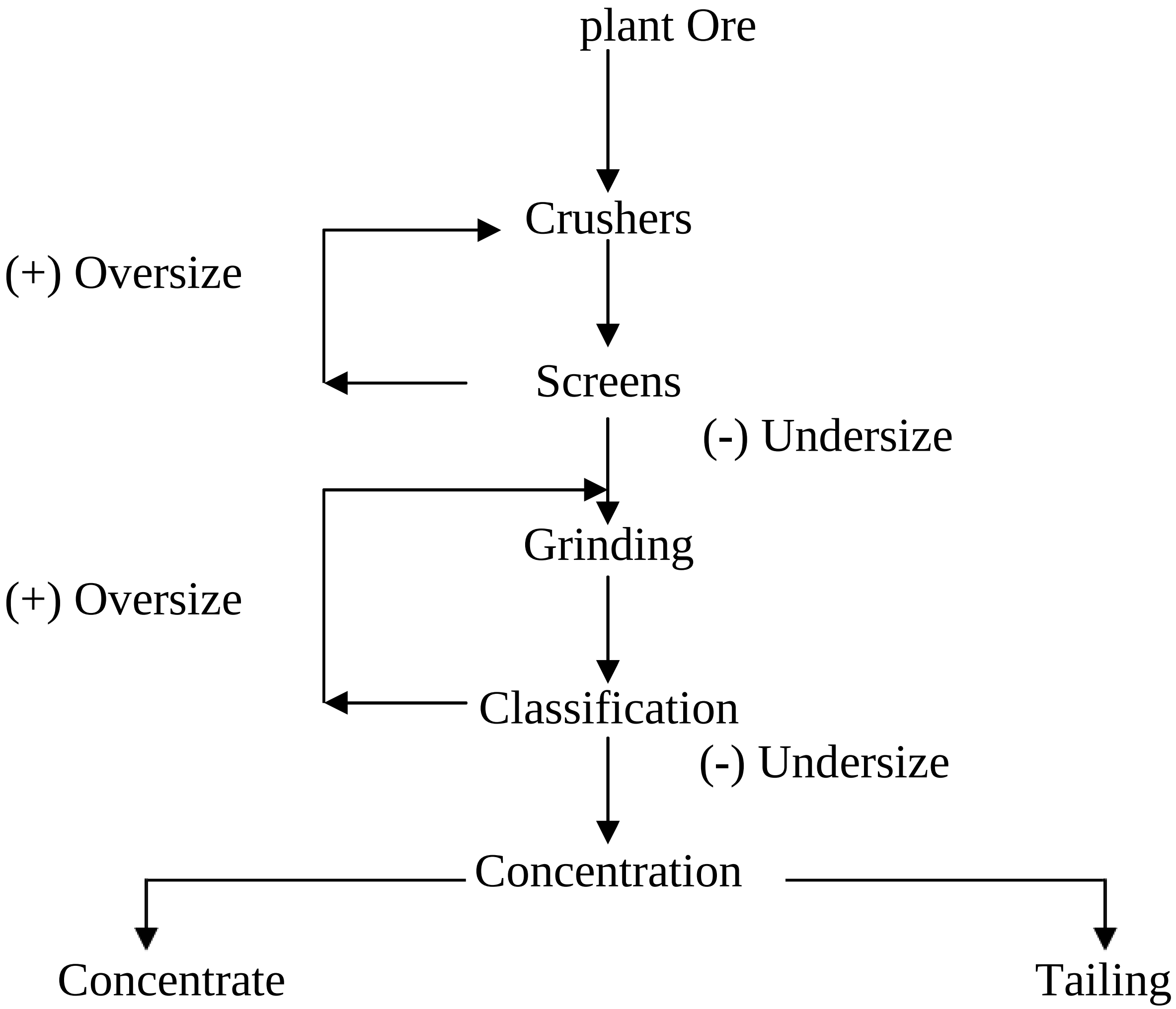
- Coarse Grinding: Rod mills are generally used as coarse grinding machines. They are capable of taking feed as large as 50 mm and making a product as fine as 300 microns.

- Fine Grinding: Fine grinding, which is the final stage of comminution, is performed in ball mills using steel balls as the grinding medium. The ball mill, after feeding 0.5 mm material may give a product that is less than 100 microns. Grinding is usually done wet.

The principle purposes of grinding are:

- To obtain the correct *degree of liberation* in mineral processing.
- To increase the *specific surface area* of the valuable minerals for hydrometallurgical treatment; i.e. leaching.
- Mineral processing combines a series of distinct unit operations. The flowsheet shows diagrammatically the sequence of unit operations in the plant.

A simple flowsheet of a mineral processing



plant Ore

Crushers

(+) Oversize

Screens

(-) Undersize

Grinding

(+) Oversize

Classification

(-) Undersize

Concentration

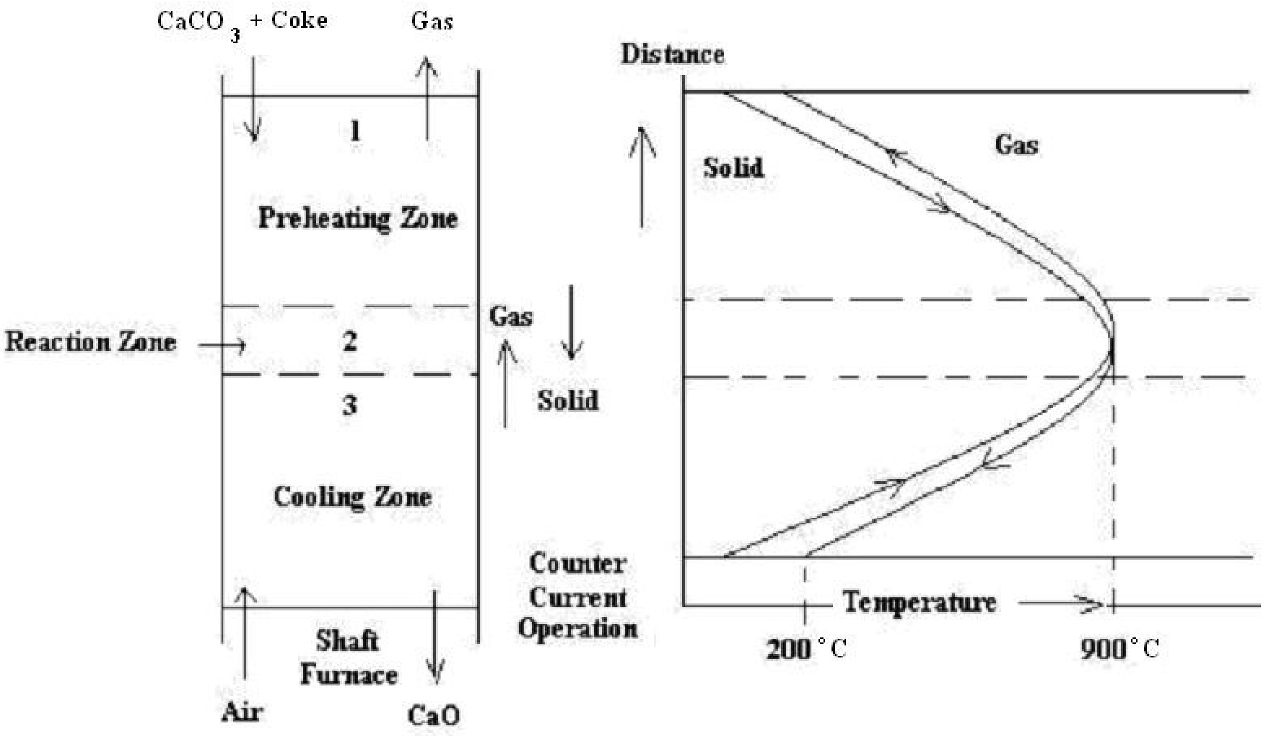
Concentrate

Tailing

Calcination Furnaces

- Shaft furnace – For the calcination of coarse limestone
- Rotary kiln – For the calcination of materials with mixed particle size or lumps which disintegrate during the process
- Fluidized bed – For materials of uniform, small particle size

Fuels used in calcination furnaces are gas, oil, coke, pulverized coal, etc



Roasting

General Definition: Roasting is the oxidation of metal sulfides to give metal oxides and sulfur dioxide.

Typical examples are:

$2ZnS + 3O_2 = 2ZnO + 2SO_2$, $\Delta H_{298^\circ K} = -220$ Kcal/gm-mole } Strongly
Exothermic $2FeS_2 + 11/2O_2 = Fe_2O_3 + 4SO_2$, $\Delta H_{298^\circ K} = -410$ Kcal/gm-
↓
mole Reactions

Product (calcine)

In addition other reactions may take place:

$SO_2 + ½ O_2 = SO_3$ Formation of SO_3
$2PbS + 4O_2 = 2PbSO_4$ Formation of metal sulfates
or
$2PbO + 2SO_2 + O_2 = 2PbSO_4$ Formation of metal sulfates
$ZnO + Fe_2O_3 = ZnFe_2O_4$ Formation of ferrites (complex oxides)

Typical ores or concentrates, which are roasted, are the sulfides of Cu, Zn and Pb. In these cases, the main purpose is to convert the metal sulfides, partly or completely, into oxides for subsequent treatment. SO_2 is then a by-product. But for pyrite roasting;

$2FeS_2 + 11/2O_2 = Fe_2O_3$ (pyrite cinder) $+ 4SO_2$

Fe_2O_3 is the by-product while SO_2 gas is the main product.

Types of Roasting

- Oxidizing roast
- Volatilizing roast
- Chloridizing roast
- Sulfating roast
- Magnetizing roast
- Carburizing roast
- Sinter or Blast roasting

Types of Furnaces for Roasting

- Development sequence:
- Stationary heaps-old days
- Hand rabbled furnaces-later development Multiple hearth furnaces -long time used for roasting Flash or Suspension roasting furnaces
- Fluidized bed roasting furnaces

Agglomeration

- When the particle size of an ore or concentrate is too small for use in a later stage of treatment, i.e. in the blast furnace, it must be reformed into lumps of appropriate size and strength that is agglomerated. Agglomeration is used particularly if the ore is to be smelted in a shaft furnace where fine-grained material would plug up the gas passage, i.e. decrease gas permeability.

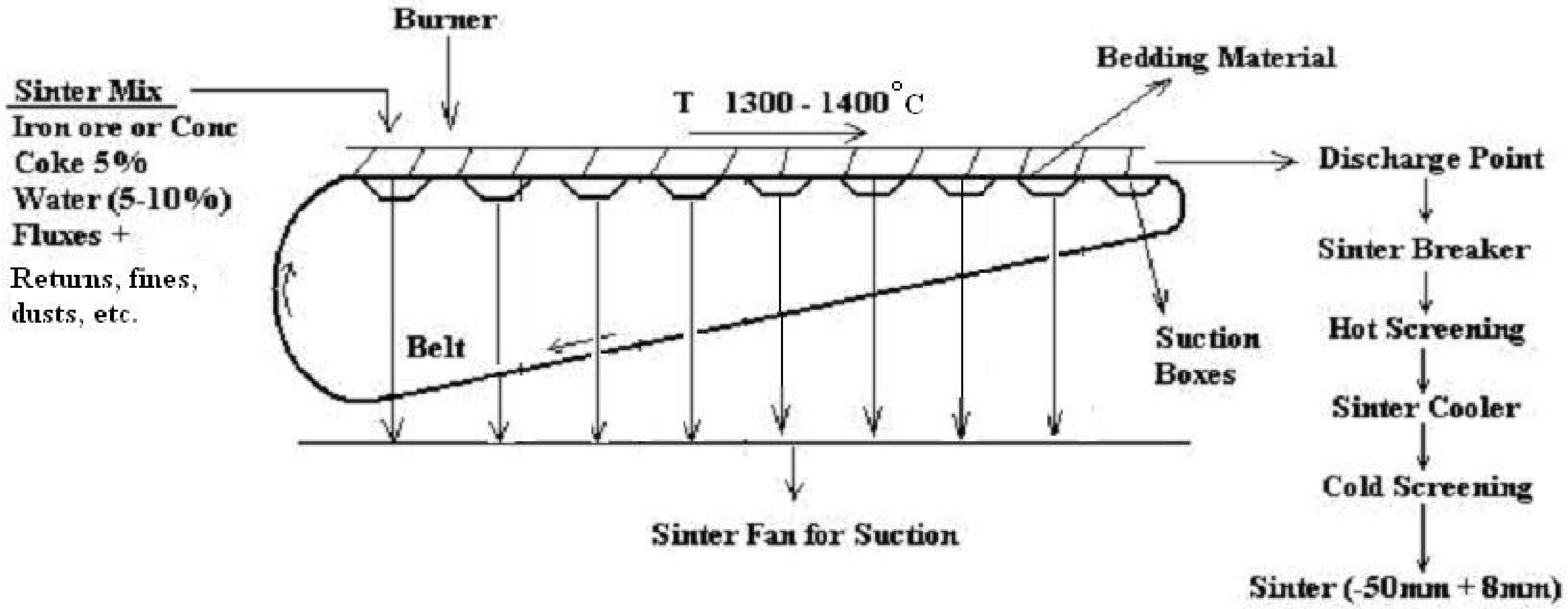
Types of agglomeration

- Sintering
- Pelletizing
- Briquetting
- Nodulizing

Below sintering and pelletizing of iron ores or concentrates are explained

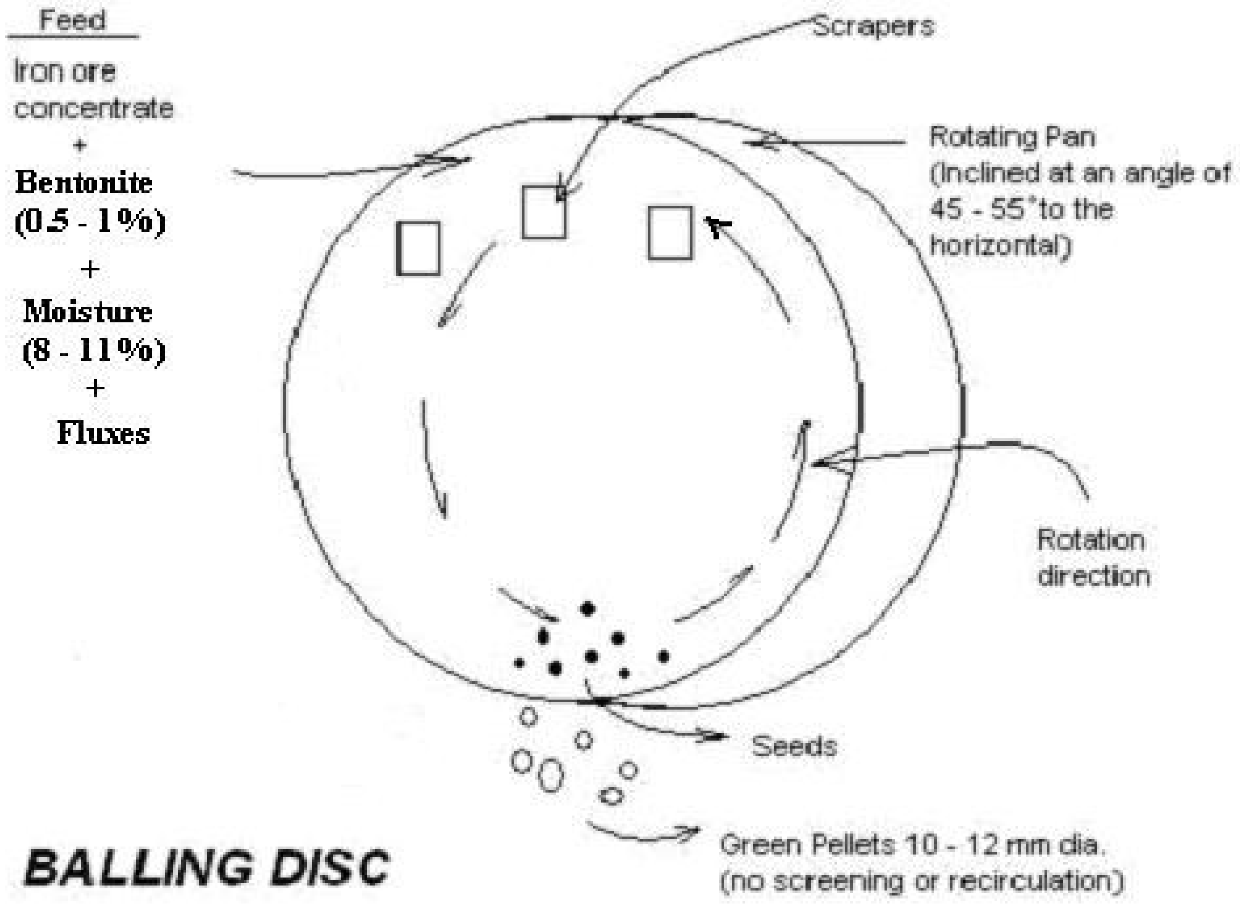
Sintering

- Sintering may be defined as a process in which relatively coarse materials, e.g. for iron ore concentrate –8mm + 0.15mm (100 mesh), are converted into coarse agglomerates by partial melting and fusion. The sinter product has a porous structure.
- Sintering is generally done by the use of a Dwight – Lloyd sintering machine. Sectional-view of a Dwight – Lloyd sintering machine is given below.



Pelletizing

Pellets are made by rolling critically moist finely divided material around in a drum or in a rotating inclined disc. Below pelletizing of iron ore concentrate is explained



Extractive Metallurgy

Dr. Wafaa K. mahmood

INTRODUCTION: -

It deals with extraction of metals from ore refining & alloying. There are mainly three routes by which metals are extracted from ore.

1. **Pyrometallurgy:** - It involves application of heat to reduce metal from ore. Most commonly used methods of pyrometallurgy are Roasting, Calcinations,

2. **Hydrometallurgy**: - It involves application of methods such as selective leaching, froth floatation to extract metal.

3. **Electrometallurgy**: - It involves application of electrolysis process to obtain metal from ore.

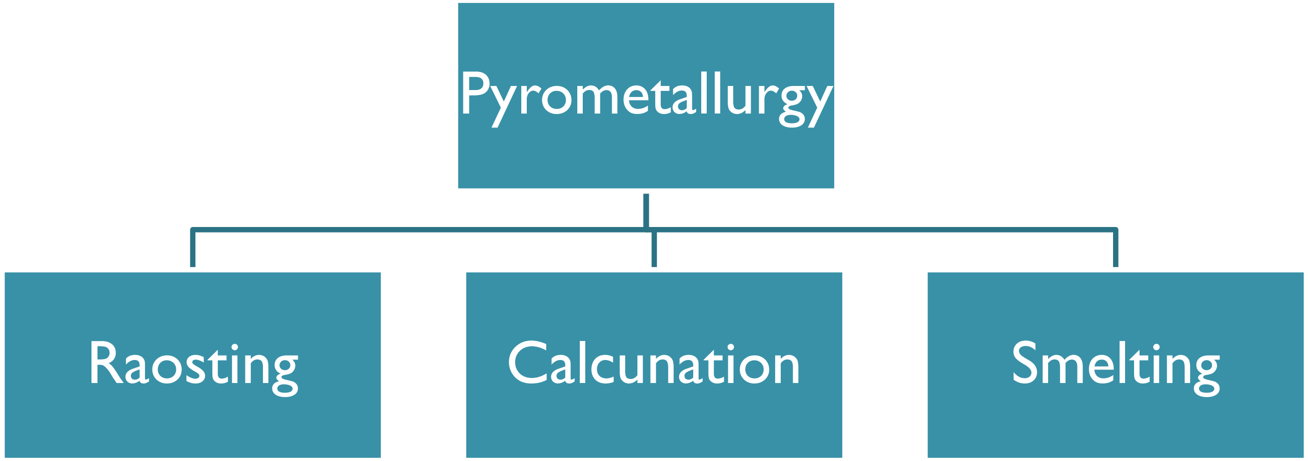
Pyro-metallurgy

is a branch of extractive metallurgy. It consists of the thermal treatment of minerals and metallurgical ores and concentrates to bring about physical and chemical transformations in the materials to enable recovery of valuable metals.

Pyro-metallurgical treatment may produce products able to be sold such as pure metals, or intermediate compounds or alloys, suitable as feed for further processing. Examples of elements extracted by pyro metallurgical processes include the oxides of less reactive elements like iron and copper.

Pyrometallurgy

- Pyrometallurgy deals with the extraction of minerals from ore by treating them with heat.



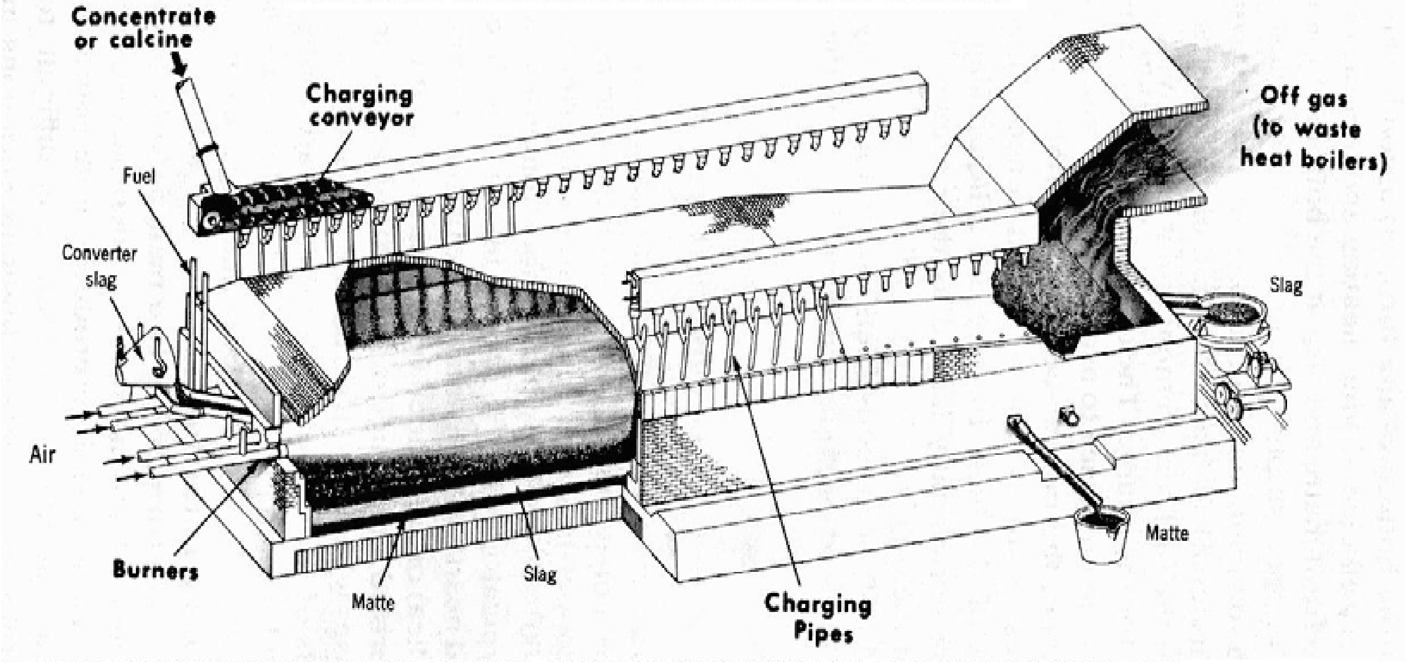
Pyrometallurgy

Raosting

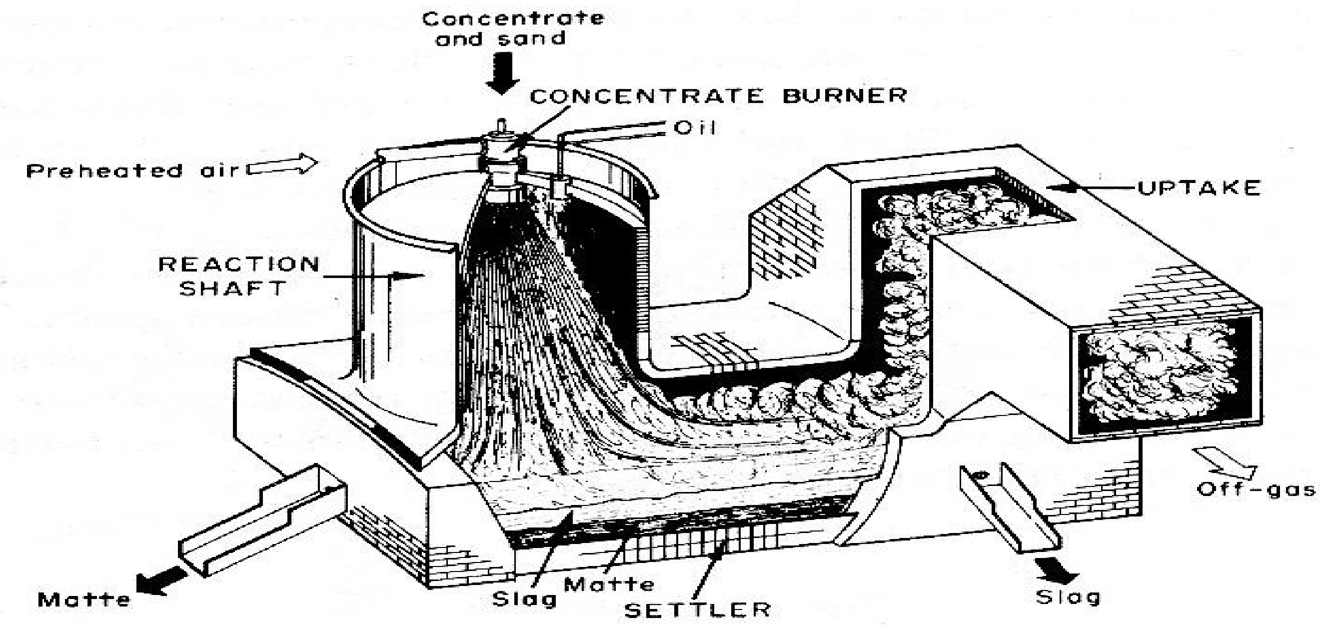
Calcunation

Smelting

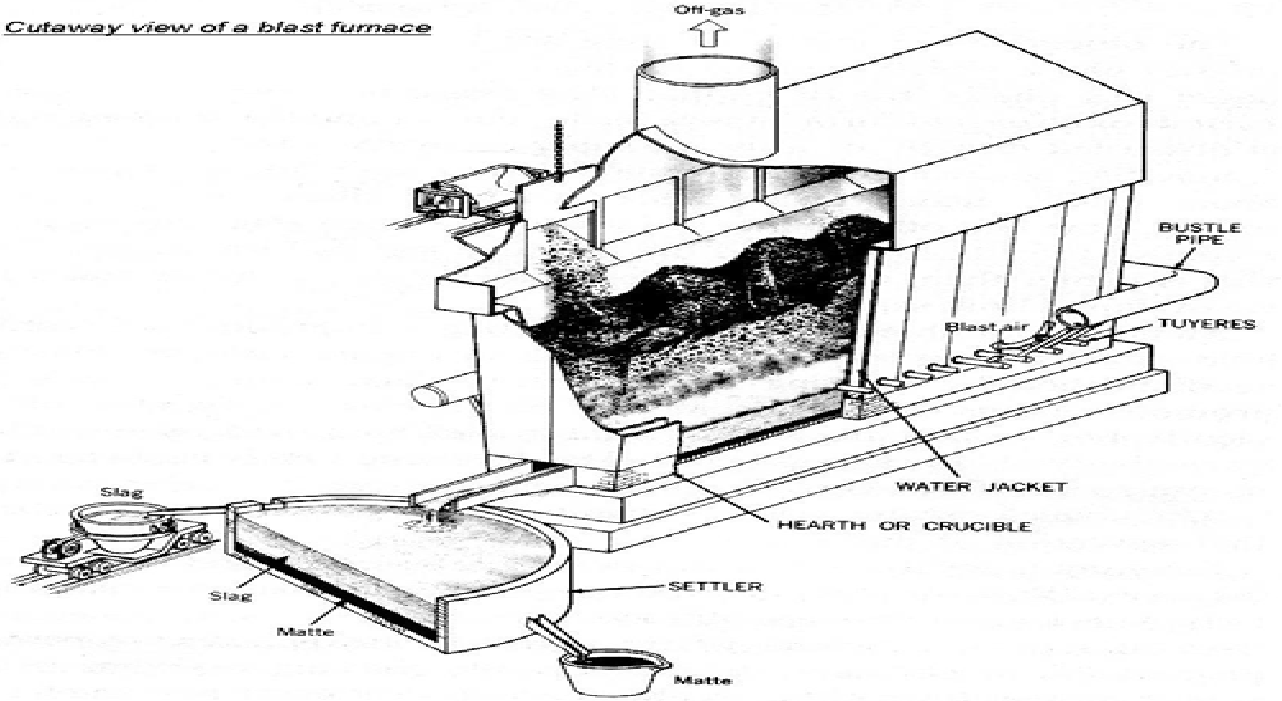
Cutaway view of a reverberatory furnace for the production of copper matte



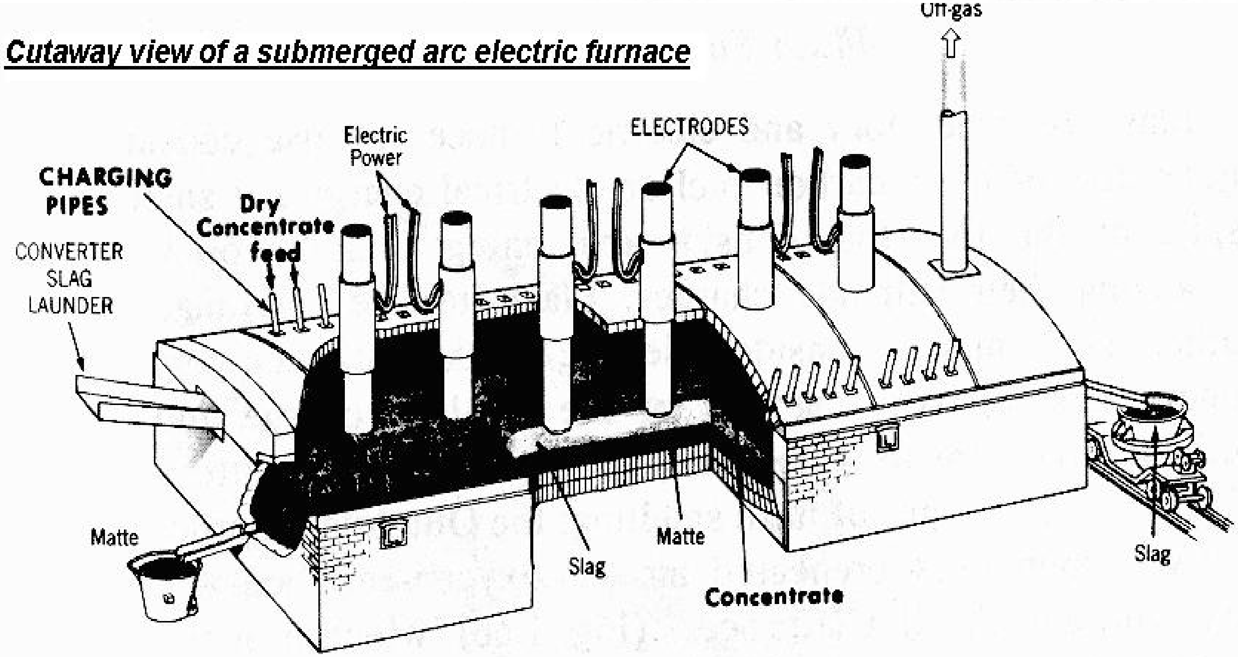
Cutaway view of Outokumpu preheated airflash-smelting furnace

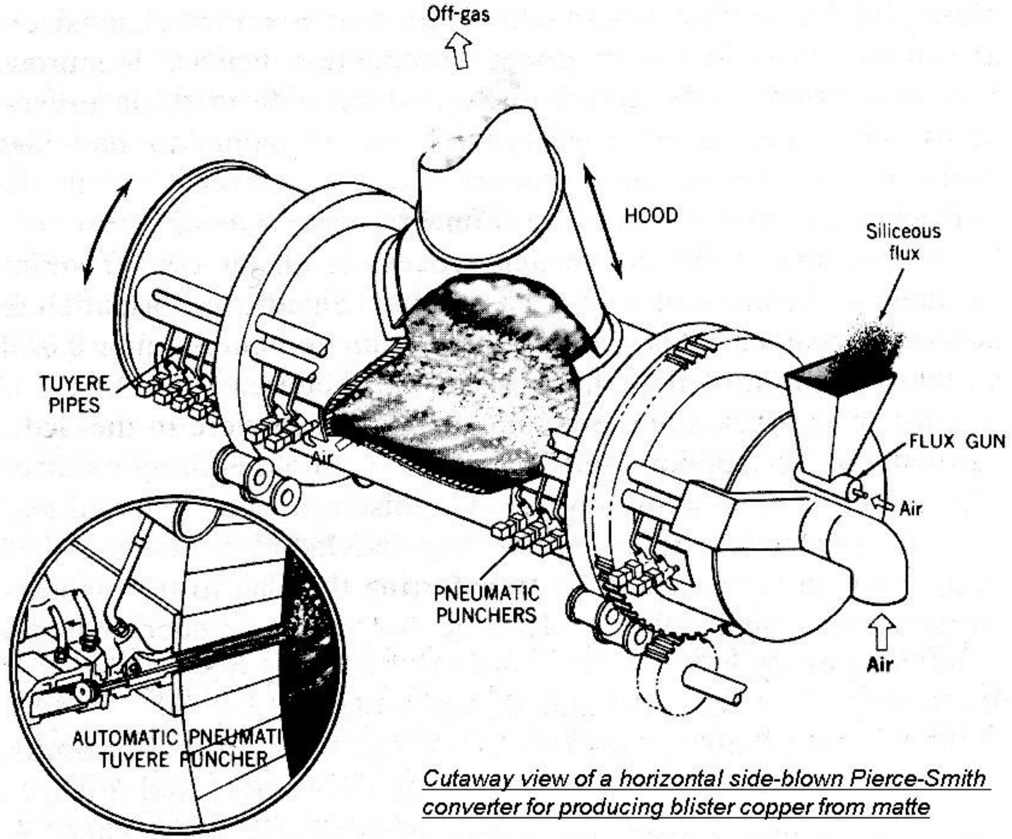


Cutaway view of a blast furnace



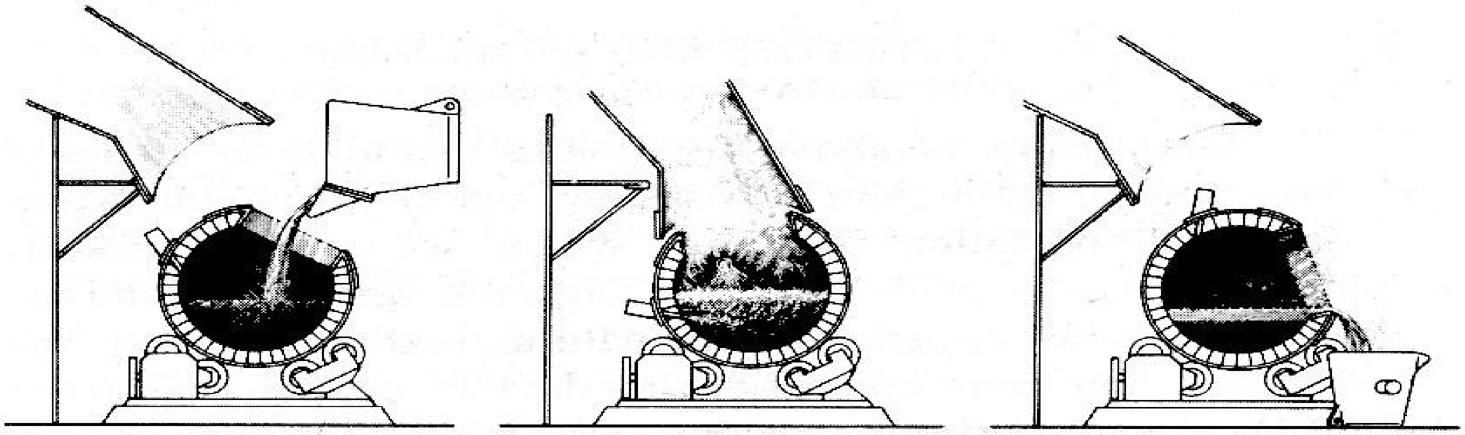
Cutaway view of a submerged arc electric furnace





Cutaway view of a horizontal side-blown Pierce-Smith converter for producing blister copper from matte

Positions of the Pierce-Smith converter for charging, blowing and skimming



Charging **Blowing** **Skimming**

Reduction of Metal Oxides

Metal oxides → Reduction → Metal

↓

Reduction is by C, CO, H_2 or other metals (metallothermic reduction)

e.g. $3MO + 2Al \rightarrow 3M + Al_2O_3$

$2MO + Si \rightarrow 2M + SiO_2$

ΔG° - T diagram can be used to assess the various reducing agents:

$2MO_{(s)} + C_{(s)} \rightarrow 2M_{(s)} + CO_{2(g)}$ below 650°C

$MO_{(s)} + C_{(s)} \rightarrow M_{(s)} + CO_{(g)}$ above 650°C

e.g. Fe, Mn, Cr, Sn, Pb and Zn are the main metal oxides reduced with carbon.

If $T_{reduction} > 1800°C$ cost of reduction increases substantially due to;

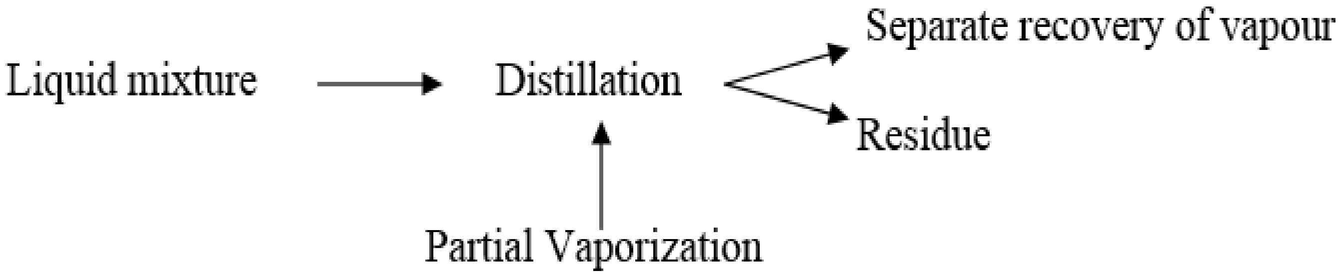
- Refractory problems
- Reactivity of the produced metal with its environment.

Distillation

Low boiling point (Bpt) metals can be separated and refined from higher boiling point metals by distillation, i.e. evaporation and subsequent condensation to the pure metal due to their difference in vapour pressures.

$$M_{(l)} \rightarrow M_{(g)}$$

The metals that may be refined by distillation are mainly limited to those with boiling point less than 1000°C. Use of vacuum distillation extends the range of metals that can be refined.



Liquid mixture → Distillation → Separate recovery of vapour / Residue

Partial Vaporization → Distillation

e.g. Extractive metallurgy of zinc and mercury (Hg_{bpt} : 357°C)

Removal of as (arsenic) from (iron ores) liquid iron (fractional distillation)

Vacuum dezincing (Zn_{bpt} : 907°C) of desilverized lead bullion (Pb_{bpt} :1740°C)

Fluidized-bed roasting

- The ore particles are roasted while suspended in an upward stream of gas
- Finely ground sulfide concentrates in size over the range 0.005 to 0.05 cm in diameter is used
- As in the suspension roaster, the reaction rates for desulfurization are more rapid than in the older multiple-hearth processes.
- Fluidized-bed roasters operate under a pressure slightly lower than atmospheric and at temperatures averaging 1000°C (1800°F).
- In the fluidized-bed process, no additional fuel is required after ignition has been achieved.

Steps observed during roasting process

Stage-1

- When the gas flow rate is very low, and the ore bed is porous, the gas permeates the bed without disturbing the ore particles
- Pressure drop across the bed is proportional to flow rate

Stage-2

- Gas velocity increses, the bed expands upwards due to the effect of the drag forces exerted by gas stream
- The pressure drop across the bed depends on the gas velocity

Stage-3

- When gas velocity further increases a stage is reached
- Pressure drop = wt. of the particle per unit area of the bed
- Particles remain individually suspended and offer less resistance to gas flow

Stage-4

- Further increase in gas velocity lead to continued expansion of the bed
- Results in increase in interparticle distance
- Pressure drop across bed continues to decrease as the gas velocity increases

Stage-5

- Finally, the expansion of the bed is independent of gas velocity
- Outcoming gas stream appears in the form of bubbles bursting on the surface of the bed which looks like well stirred boiling liquid
- In this condition the bed is said to be fluidized.
- The fluidized bed has an apparent density distinctly different from the density of the solid and is capable of flowing like a liquid.

Advantages

- High energy efficiency because it can be autogenously operated
- Useful in recovery of sulphur because the gas that it produces has high SO_2 content
- Ideal for roasting of oxide ores because the oxidizing reactions that take place during roasting is highly exothermic.

  e.g. Pyrite FeS_2, Millerite NiS, etc.

HYDROMETALLURGY

PROCESSING STEPS IN HYDROMETALLURGY

Most hydrometallurgical processes can be divided into five main steps as shown in the following diagram, followed by residue treatment and possibly by–product recovery. The important steps will be discussed in more detail.

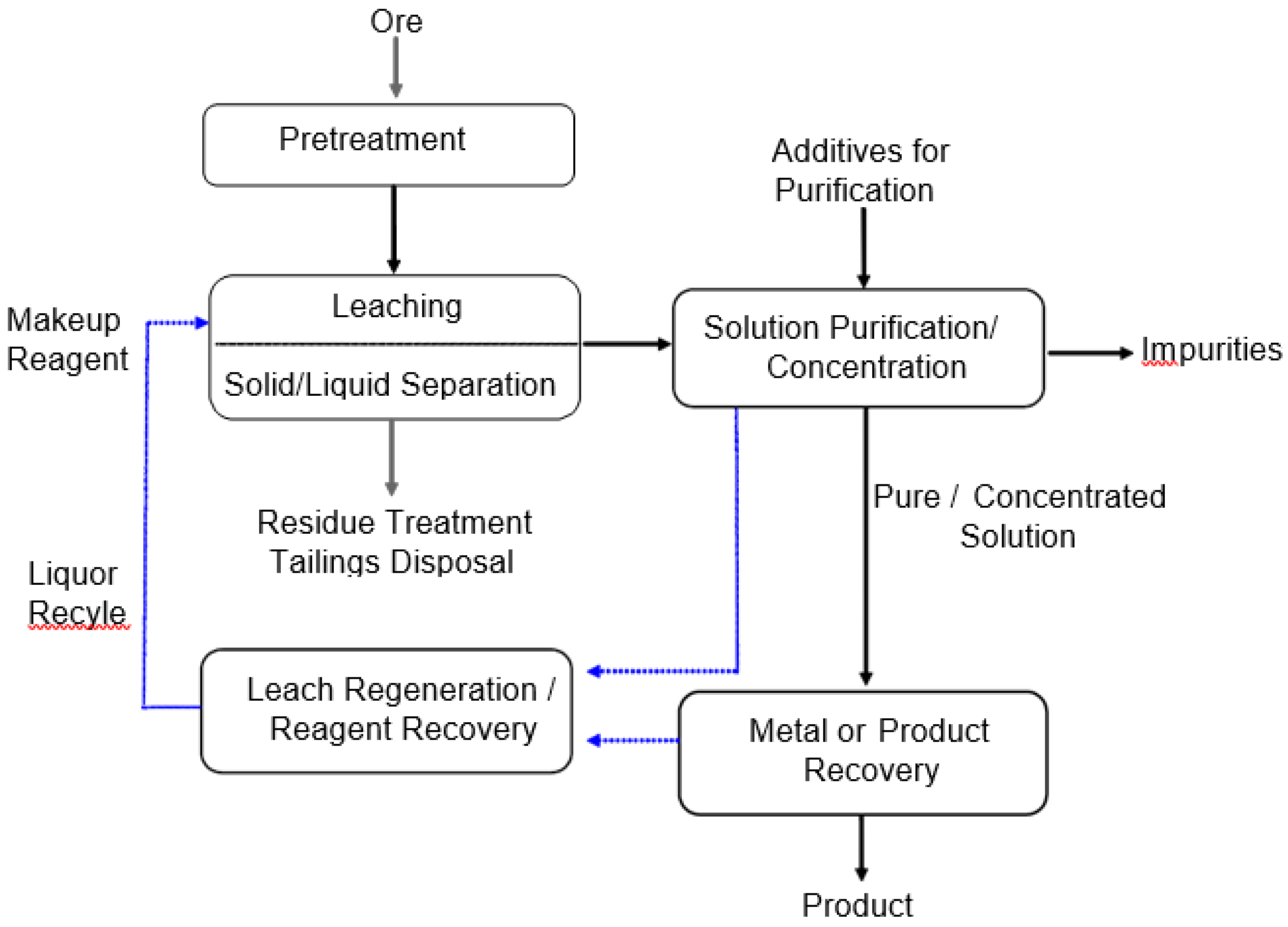


Figure 1. Typical Hydrometallurgical Processing Steps

Pretreatment

Pretreatment steps can be either (1) physical processes such as grinding, concentration (e.g. flotation) or agglomeration or (2) chemical processes such as roasting.

1. Physical Processes

a. *Concentration*

Hydro processes are normally most suitable for ores which cannot be concentrated. However two commercial examples where concentration is used are in the Roast/Leach/Electrowin process for zinc production, which involves the production of a ZnS concentrate by flotation as the first step, and also the CLEAR process for copper which uses flotation to produce a copper sulfide concentrate as the first step.

Agglomeration

- In the leaching of low grade ores, the reagent is often percolated through heaps (heap leaching). If fines, clays or slimes are present these can block channels and stop reagent flow. The process can be greatly improved by agglomeration of fines into porous pellets or balls by mixing with cheap binders such as lime or cement.

Grinding

- Grinding of ores liberates the valuable mineral and makes it more accessible to the leach solution. However, size reduction (especially fine grinding) is expensive and becomes prohibitively so as the grade of the ore decreases.

Chemical Alteration

This can either be by gas/solid reaction (roasting) or by liquid/solid reaction.

1. *Roasting*

Some roasting processes have been considered in the introduction to pyrometallurgy lecture. Some of the more important commercial applications are summarized here:

- *Roasting of ZnS:* Air is used at 600 oC to produce ZnO, which is easier to leach than ZnS, for subsequent leaching in sulfuric acid:

$$2ZnS + 3O2 = 2ZnO + 2SO_2(g)$$

- *Roasting of Auriferous Pyrite:* In many major deposits, gold is associated with iron sulfides such as pyrite (FeS2), from which it is often difficult to leach. Roasting in air at 600 oC results in an insoluble porous iron oxide calcine from which gold can be readily leached using cyanide solution.

$$Au/FeS2 + O2 = Au + Fe2O3 + SO2(g)$$

- *Roasting of Nickel Laterites:* Nickel laterites contain around 1.5% Ni (actually as complex oxides such as (Fe,Ni)O(OH) but unlike sulfide ores cannot be upgraded by mineral processing. The Caron process involves an initial reducing roast at around 900 oC using coal or oil, followed by leaching of the resultant nickel metal in ammoniacial liquor (e.g. Greenvale in Qld). The reduction reaction can be idealised as:

$$2NiO + H2 + CO = 2Ni + H2O + CO2$$

A number of other roasting processes are used on a smaller commercial scale. These include:

- *Segregation roast:* Low grade copper oxide ores are difficult to concentrate and are treated hydrometallurgically, usually by leaching with sulfuric acid. One different process involves so-called "segregation roasting" in which the ore and a small amount of salt (NaCl) and carbon are heated at around 600 oC. A complex reaction occurs and copper is concentrated by migrating onto carbon where it is reduced to its metallic form. The calcine is screened to separate carbon and the copper recovered from it by leaching. This complex reaction can be idealised by:

$$\mathrm{CuO} + \mathrm{C} \xrightarrow{\mathrm{NaCl}} \mathrm{Cu(on\ carbon)} + \mathrm{CO(g)}$$

- *Becher Process:* Ilmenite (FeTiO3) from mbe upgraded into synthetic rutile TiO2 by removal of iron. An important method is the Becher Process developed in W.A. Ilmenite is firstly roasted in air to oxidize all iron to Fe3+, and then with coal to reduce it to metallic Fe, which is finally ineral sands, can removed by accelerated "rusting" to Fe2O3 in aerated water. This complex process can be idealised as:

$$\mathrm{FeO.TiO_2} \xrightarrow{\text{air roast}} \mathrm{Fe_2O_3.TiO_2} + \mathrm{TiO_2} \xrightarrow{\text{C roast}} \mathrm{Fe} + \mathrm{TiO_2}$$

Sulfation Roast: Copper and cobalt sulfides can be converted into water soluble sulfates by roasting at 600 °C in air under closely controlled conditions, such that the iron impurities remain as insoluble ferric oxide. The valuable sulfates can then be preferentially leached in dilute sulfuric acid. Sulfation roasting of chalcopyrite can be idealised as:

$$CuFeS_2 \xrightarrow{Air/SO_2} CuSO_4 + Fe_2O_3 + SO_2(g)$$

Solid/Liquid Reaction

- A commercial example is "pug-roasting" in which oxides are heated with concentrated sulfuric acid to produce water soluble sulfates in a highly exothermic reaction. For example, in the sulfate process for the production of TiO2 from ilmenite, ilmenite is first pug-roasted at 100-200 ^{o}C with concentrated H2SO4 to yield a honeycombed mass of iron and titanium sulfates which are then dissolved in water:
    - $FeTiO_3 + 2H_2SO_4 = TiO.SO_4 + FeSO_4 + 2H_2O$
- Other examples which have not yet been used commercially include the roasting of $CuFeS_2$ with S to produce Cu2S which is more easily leached (than $CuFeS_2$) and the treatment of complex Cu/Pb sulfides with sulfuric acid to produce sulfates.

Types of Leaching Reactions

In general, commercial leaching reactions can be classified into the following main types: water salvation, acid attack, alkali attack, complexation and oxidation (often with complexation).

1. Water solvation

Water solvation refers to the dissolution of naturally soluble salts in water, such as $CuSO_4$ or $CoSO_4$ from sulfation roasting:

$$CuSO_{4(s)} \rightarrow Cu^{2+}{}_{(aq)} + SO_4{}^{2-}{}_{(aq)}$$

These ions are actually solvated (=complexed) with water molecules and the usual convention (not followed here for convenience) is to indicate this by Cu (aq) and SO4 (aq).

2. Acid attack

Most important examples are the dissolution of ZnO calcine (with subsequent electro winning) with sulfuric acid and the leaching of low grade copper oxide ores also with sulfuric acid (the latter accounts for the majority of copper extracted by hydrometallurgy). Reactions are simple:

$$ZnO + 2H^+ \rightarrow Zn^{2+} + 2H_2O$$

$$CuO + 2H^+ \rightarrow Cu^{2+} + 2H_2O$$

Oxidation

Solids can be brought into solution by oxidation (=*anodic reaction*) which involves the loss of electrons. This must be accompanied by reduction (= *cathodic reaction*) within the leach solution to absorb the electrons. Anodic reactions of industrial importance involve either the oxidation of metals (=*corrosion*) or the oxidation of sulfur contained in sulfides. The most important cathodic reactions are those using either dissolved oxygen or ferric ions as oxidants (= electron absorbers) in leach solutions.

Industrial Anodic Reactions (Oxidation)

Oxidation of Metals

$Au \rightarrow Au^{+} + 1e^{-}$ (Leaching gold in NaCN) (1)

$U^{4+} \rightarrow U^{6+} + 2e^{-}$ (Leaching of uranium oxide) (2)

$Ni \rightarrow Ni^{2+} + 2e^{-}$ (Caron Process for low grade Ni ores) (3)

Oxidation of Sulfur

$S^{2-} \rightarrow S^{0} + 2e^{-}$ ($CuFeS_2$ for Heap Leaching & CLEAR process) (4)
(Direct acid pressure leaching of ZnS)

$S^{2-} \rightarrow S^{6+} + 8e^{-}$ (Pressure oxidation NiS & ZnS) (5)