General principles and processes of extraction of Metals from the Minerals:—

The compounds of metals which occurs in the earth crust and are obtained by mining are called minerals.

A mineral is either a single compound of one element or a complex mixtures of several compounds of the same or different metals.

Ores:—

The minerals from which a metal can be extracted conveniently and profitably are called ores.

Extraction of Metals (Metallurgy):

The process of extraction of metal in the free state from its ores is referred to as metallurgy. The metallurgy of a particular metal involves several physical and chemical processes known as metallurgy operation.

However, following three steps are common to the metallurgy of the metals.

1. Concentration of the ore
2. Extraction of crude metal from the concentrated ore
3. Purification of crude metal.

1. Concentration of the ore:—

The ore of a metal is generally associated with unwanted material (sand, clay, compounds of other metals etc.) which are called "gangue".

Therefore, the first step in the extraction of a metal is removal of gangue. The process of removal of gangue from the ore called concentration or dressing of the ore. The concentration of ore is carried out in the following steps.

(A) Crushing and Grinding:—

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(A) Crushing and Grinding! —

Most of the ores are obtaining by mining and consist

of huge lumps. This huge lumps are first broken into small pices in the jaw crushers and then powdered with the help of a ball mill or stamp mill. This powder is called of pulverisation.

(5) Concentration of the ore :—

The following processes are used for the concentration of the ore.

(i) Hydraulic washing or Gravity separation :—

This process is used when the ore particles are heavier than the gangue particles.

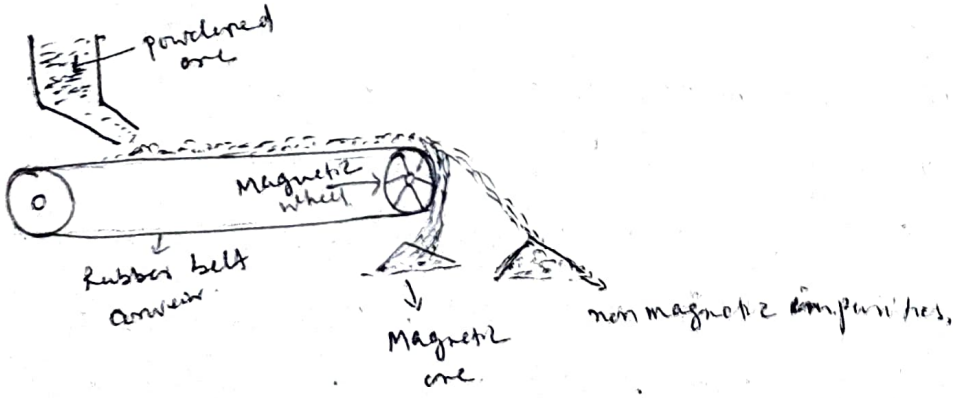
The principle involved in the separation of gangue particles from the ore by this technique is based on the difference in the specific gravities of the ore and the gangue particles.

The crushed ore is washed with a current of water when lighter impurity particles get washed away leaving the heavier ore particles. This method is called levigation and is generally used for the concentration of oxide ore.

(ii) Magnetic Separation :—

This method is used when the ore particles and not the gangue are attracted by a magnet.

In this method, powdered ore is made to fall on a rubber belt moving horizontally over two rollers, one of which is magnetic.



The magnetic ore particles get attracted by the magnetic roller and fall nearer to it while the non-magnetic gangue particles fly off and form a heap away from the magnetic roller.

The separation of non-magnetic ore particles from

magnetic impurities can also be effected by this technique. In this case, the magnetic gangue particles get collected near the magnetic roller while non-magnetic ore particles fall farther off. For example, concentration of wolframite, a non-magnetic ore of tungsten containing magnetic impurities of iron, can be carried out by this method.

(iii) Froth floatation.

Froth floatation is a physical method of separating mineral from the gangue that depends on differences in their wettabilities by liquid solution.

This method is used for the concentration of sulphide ores. The method is based on the preferential wetting properties with the frothing agent and water. Sulphide particles in ores, are preferentially wetted by the froth and rise to the surface while gangue is preferentially wetted by water and sink to the bottom.

Reagents employed in froth floatation are

(i) Frothers:- These create froth e.g. pine oil

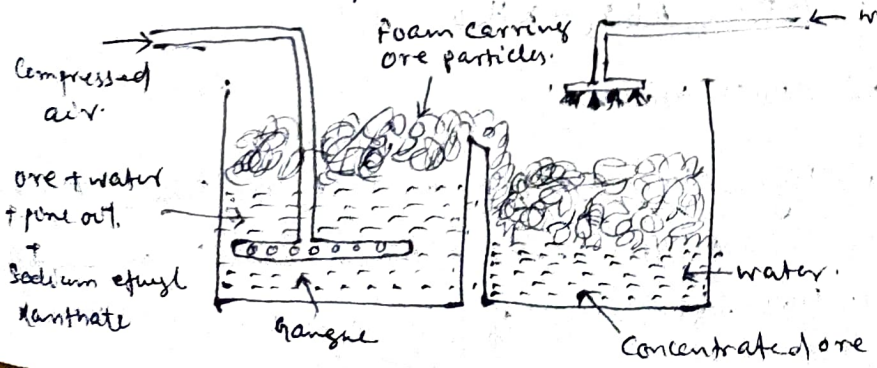
(ii) Collectors:- The help in attachment of the ore particles to air bubbles in froth, e.g. sodium xanthate.

(iii) Activators:- These increases the effect of collectors, e.g. Na_2S. These improve the floating characteristics of the ore.

(iv) Depressants:- These suppress the floatation of a particular species in a system.

A powdered ore is added to water containing pine oil (frothing agent) and sodium ethyl xanthate (Collecting agent). Cresols and aniline are also added. They act as froth stabilizers.

A vigorous stream of air is now passed through, which thoroughly agitates the mixture and disposes the oil into colloid sized particles.



As a result of this, the sulphide particles of the ore stick to the oil droplets and rise to the surface in the form of froth supported by air bubbles. Water wets the gangue particles which sink to the bottom. With this method, it is possible to concentrate the dense ores like PbS and ZnS etc.

(iv) Leaching:-

It is a chemical separation. It involves the treatment of the ore with a suitable reagent as to make it soluble while impurities remain insoluble.

The insoluble impurities are separated by filtration. The impurities include not only gangue but also chemical entities which are not solubilized during leaching operation.

Example:- Leaching of Alumina from Bauxite ore:-

Bauxite ore contains ferric oxide, titanium oxide and silica as impurities. When the powdered ore is digested with an aqueous solution 45% of NaOH at about 200°C under pressure. The alumina dissolves forming sodium aluminate while Fe_2O_3, TiO_2 and silica remain as insoluble.

$$Al_2O_3 \cdot 2H_2O + 2NaOH + H_2O \longrightarrow 2Na[Al(OH)_4]$$

Sodium aluminate.

The solution of sodium aluminate (soluble) is filtered. It may also contain some sodium silicate and free NaOH. The filtrate is neutralised by passing CO_2 gas, the hydrated Al_2O_3 gets precipitated.

$$2Na[Al(OH)_4] + 2CO_2 \longrightarrow Al_2O_3 \cdot xH_2O + 2NaHCO_3$$

The sodium silicate remains in the solution and hydrated alumina is filtered, dried and heated to about 1200°C to get pure alumina.

$$Al_2O_3 \cdot xH_2O \xrightarrow{1200°C} Al_2O_3 + xH_2O$$

EXTRACTION OF CRUDE METALS:-

Metals are usually extracted by reduction. Thus, the concentrated ore is converted into a form which is suitable for reduction. The extraction of metals involves the

the following two major steps:

(1) Conversion of the ore into metallic oxide.

(2) Reduction of metallic oxide to the free metal.

(1) Conversion of the ore into metallic oxide:-

The ores of the metals are usually in the form of hydrated oxide, carbonates, sulphides etc. Depending upon the nature of the ores, two following methods are used for conversion into oxides.

(A) Calcination:-

In this process, the concentrated ore is heated in a limited supply of air below its melting point.

During calcination following changes takes place.

(i) The moisture is removed and the ore becomes dry.

(ii) Volatile impurities get removed

(iii) The ore becomes porous.

(iv) If the ore contains carbonates, they get decomposed into oxides and lose CO_2. For example,

$$CaCO_3 \longrightarrow CaO + CO_2\uparrow$$

$$MgCO_3 \longrightarrow MgO + CO_2\uparrow$$

$$CuCO_3.Cu(OH)_2 \longrightarrow 2CuO + H_2O\uparrow + CO_2\uparrow$$

(v) Hydrated oxides lose their water of crystallisation and get dehydrated. For example.

$$Fe_2O_3.3H_2O \longrightarrow Fe_2O_3 + 3H_2O\uparrow$$

$$Al_2O_3.2H_2O \longrightarrow Al_2O_3 + 2H_2O\uparrow$$

(B) Roasting:-

Roasting is a process of heating the ore strongly in presence of excess of air below its melting point.

The process is usually carried out for sulphide ores.

During roasting, following changes takes place.

(i) The moisture is removed.

(ii) The volatile impurities are removed.

(iii) The impurities of sulphur, arsenic, phosphorous

$$2Cu_2S + 3O_2 \longrightarrow 2Cu_2O + 2SO_2\uparrow$$

$$2Cu_2O + Cu_2S \longrightarrow 6Cu + SO_2\uparrow$$

$$2PbS + 3O_2 \longrightarrow 2PbO + 2SO_2\uparrow$$

$$2Cu_2S + 3O_2 \longrightarrow 2Cu_2O + 2SO_2\uparrow$$

$$2PbS + 3O_2 \longrightarrow 2PbO + 2SO_2\uparrow$$

$$2ZnS + 3O_2 \longrightarrow 2ZnO + 2SO_2\uparrow$$

Reduction of the metal oxide into free metal:-

The crude metal is obtained when the roasted or calcined ore is put to reduction by using a suitable reducing agent. The selection of suitable reducing agent depends upon the reactivity of metal. Some of the commonly used methods are

a) **Smelting:-**

This involves reduction of ore to the molten metal at a high temperature. For extraction of less electropositive metals such as Pb, Zn, Fe, Sn etc, powerful reducing agent such as C, H_2, CO, water gas, Na, K, Mg, Al may be used.

Ex:

$$PbO + C \longrightarrow Pb + CO\uparrow$$

$$WO_3 + 3H_2 \longrightarrow W + 3H_2O\uparrow$$

$$CuO + CO \longrightarrow Cu + CO_2\uparrow$$

$$Cr_2O_3 + 2Al \longrightarrow 2Cr + Al_2O_3$$

b) **Carbon Reduction process:-**

It is generally called smelting. The oxides of less electropositive metals are reduced by strongly heating them with coal or coke. Carbon combines with the oxygen of the metal oxide to form carbon monoxide, which can also act as a reducing agent.

$PbO + C \longrightarrow Pb + CO$

$PbO + CO \longrightarrow Pb + CO_2$

$Fe_2O_3 + 3C \longrightarrow 2Fe + 3CO$

$Fe_2O_3 + 3CO \longrightarrow 2Fe + 3CO_2$

The ores, even after concentration, contain some infusible gangue. To remove these gangue, certain substances are mixed with concentrated ore which combine with the gangue to form a fusible material which is not soluble in molten metal.

The substances used are called fluxes and the fusible material formed during reduction process is called slag.

Concentrated ore + Reducing agent + flux

$\xrightarrow{\text{Heat}}$ Metal + Slag + gases.

Gangue + flux $\longrightarrow$ Slag

(infusible mass) (fusible mass)

Slag is usually lighter and floats on the surface of the molten metal.

Flux are classified as a) Acidic flux
b) Basic flux.

An acidic flux is the chemical substance which removes the basic impurities.

$SiO_2 + CaO \longrightarrow CaSiO_3$

Acidic flux. Basic impurities. Slag

The basic flux is the chemical substance which removes the acidic impurities.

$MgCO_3 + SiO_2 \longrightarrow MgSiO_3 + CO_2\uparrow$

Basic flux Acidic impurities Slag

(ii) Reduction by Aluminium:-

The process of reducing the roasted ore with the help of aluminium powder is known as aluminothermic process and is used to reduce those metal oxides which possess very high melting points and are not easily reduced by

carbon.

Metal oxides like Cr_2O_3, Mn_3O_4 etc. are such oxides are mixed with aluminium powder and taken in a fire clay crucible kept in a sand bath. The reaction is started with the help of an ignition mixture containing magnesium powder and BaO_2.

$$Cr_2O_3 + 2Al \longrightarrow Al_2O_3 + 2Cr$$

$$3Mn_3O_4 + 8Al \longrightarrow 4Al_2O_3 + 9Mn$$

(B) Self reduction process:-

This process is also called auto reduction process. In this process, the sulphide ores of less electropositive metal like Hg, Pb, Cu etc are heated in air as to convert part of the ore into oxide, which then react with the remaing sulphide ore to give metal and SO_2. In this process no external reducing agent is used.

Ex:-

$$2Cu_2S + 3O_2 \longrightarrow 2Cu_2O + 2SO_2$$

$$Cu_2S + 2Cu_2O \longrightarrow 6Cu + SO_2$$

(C) Electrolytic Reduction:-

The highly electropositive metals such as alkali metals (Li, Na, K, etc), alkaline earth metals (Mg, Ca, etc) and aluminium are obtained by electrolytic reduction.

During electrolytic reduction, the oxides, hydroxides or chlorides of these metals are taken in the fused state and are subjected to electrolysis using inert electrodes.

For example, in extraction of Aluminium, fused Alumina (Al_2O_3) mixed with cryolite (Na_3AlF_6) is subjected to electrolysis where graphite electrodes are used.

$$2Al_2O_3 \xrightarrow[\text{electrolysis}]{\text{Cryolite}} Al^{3+} + AlO_3^{3-}$$

Reaction at cathode:- $Al^{3+} + 3e \longrightarrow Al$.

Reaction at Anode:-

$$4AlO_3^{3-} \longrightarrow 2Al_2O_3 + 3O_2 + 12e$$

Refining or purification of Crude Metal:—

The metals obtained by the reduction methods are usually impure. These impure metals may be associated with small amount of unchanged ore, other metals, non-metals like silicon, carbon, phosphorous etc., residual flux, slag etc. Therefore these impure metal is thus subjected to purify processes known as refining.

The following refining processes may be applied depending upon the nature of the metal and the nature of the impurities.

a) Liquation process:—

This process is based on the difference in fusibility of the metal and impurities. When the impurities are less fusible than the metal it self, this process is employed.

The impure metal is placed on the sloping hearth of a furnace and gently heated. The metal melts and flows down leaving behind the impurities on the hearth.

This method is used to purify the metal like Bi, Sn, Pb, Hg etc.

b) Distillation:—

This process is used for those metals which are easily volatile. The impure metal is heated in a retort and its vapours are seperately condensed in a receiver. The non-volatile impurities are left-behind in the retort. This is used for purification of Zn, Cd, Hg etc.

c) Cupellation:—

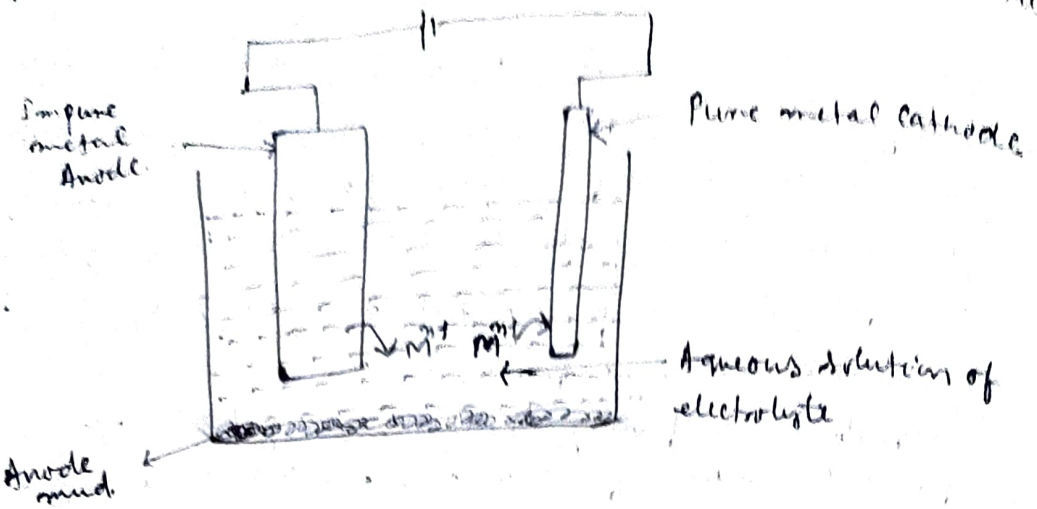
The impure metal is heated in a cupel or oval shaped crucible made of bone ash or cement and a blast of air is passed over the molten mass. The impurities get oxidised and removed with the blast of air. For example, the impurity of lead present in silver is removed by cupellation process.

d) Electrolytic Refining:—

This method is based upon the phenomenon of electrolysis and is widely used to refine a number of metals such as copper, silver, gold, aluminium etc.

In this method impure metal is made anode whereas a thin sheet of pure metal is used as cathode in an electrolytic tank. The electrolyte used in the tank is usual

the aqueous solution of a salt or complex salt of the metal



On passing the electric current, the metal ions present in the electrolyte solution get deposited on the cathode and an equivalent amount of the metal passes from anode to the electrolyte solution in the form of metal ions. Thus, indirectly the metal is transferred from anode to the cathode through electrolyte solution. In general the following processes occur in the tank.

Reaction at Anode

$$M \longrightarrow M^{n+} + ne^-$$

(passing into the solution)

Reaction at cathode:-

$$M^{n+} + ne^- \longrightarrow M$$

(from the solution) (deposited at cathode)

The impurities present in the crude metal settle down below the anode as anode mud or anode sludge.