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Extraction materials

The ore, ore mining, Ore preparation, Breaking machines, Sifting, Separation by liquid, Magnetic separation Agglomeration, Environmental effect of extraction, Extraction methods, Thermal method, Extraction of oxidized ore, Production of iron and steel, Cast iron production, Steel production, Electrical method, Direct method, Production of non ferrous metals, Aluminum production, Copper production, Zinc production, Nickel production, Tin production, Magnesium production, Lead production, Chrome production, Glod production, Silver production, Uranium production.

References

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Extractive metallurgy

Introduction

The history of man can be broadly classified into three divisions, namely:

1. **The Stone Age**: where the old man used the non-metallic material like stone and quartz to manufacture his own tools like cutting tools, weapons and for making fire.

2. **The bronze age**: the transition from the stone age to metal age brought about the discover of the copper in around 8000 B.C.-can be consider one of the most significant phases of human history. The copper age was followed by the bronze age as it was discovered that by adding the Arsenic to copper and to tin will increase the mechanical properties of copper around 4000B.C.and this was the beginning of bronze age. The

bronze was used in huge quantity to manufacture special tools beside its use in manufacturing weapons.

3. The Iron Age: the iron metal was faster oxides by appearing free with air and humidity, so it is appear in nature as oxide which means that too much processing
should be made to get it; like melting in high temperature. That was the reason for its late discovery till 3000B.C. The Iron Age was very important as its extension to our age.

The precious metals (silver &gold) was known earlier in the 12000B.C.,but its use was limited to jewels and commercial aspects.

- from 1700-1800D.C. new metals were discovered (Co, Pt, Zn, Ni, Bi, Mn, Mo, Te, Wu, Zr, Ti, Be, Cr)-
- from 1800_1900D.C. another metals were discovered like (Ta, Os, Pa, Ph, K, Na, Ba, Ca, Mg, Sr, Ce, Li, Cd, Se, Si, Al, Th, V, La, Ra, Rb, In, Ac, Po, Ir).

Source of metals

Three main sources of metals and their compounds are the ***earth's crust***, the ***sea***, and ***scrap*** metal, the most important one being the earth's crust. The sea, which cover more than 70% of the earth surface, contain, on an average, 3.5%of dissolved solids. In the future, metal could be extracted by deliberately cultivating specific marine organisms which would concentrate one or more elements within their bodies by inherent biological activity. In addition, metal are also found in deposit of nodules which cover large areas of the sea floor.

Finally, scrap metal is becoming increasingly important, and a freely available source of metal in view of the rapid industrial growth all over the world. (The metal recovered from scrap metal are called *secondary metal*s), infect we may envisage situation where metal manufacturing processes would virtually refine and recycle increasingly huge quantities of metals which are periodically used and discarded. For instance, in current steel- making processes a significant portion of the "charge" consists of scrap metal.

1. Earth's crust

The Earth's crust contains many different rocks. Rocks are a mixture of minerals and from some we can make useful substances. The most common element in the nature that is representing in the earth's crust are formed from molten rock (magmas). Magmas are the source of the igneous rock, which is represent the organs of other type of rocks. From these rocks the earths crust are formed with a thickness about (33 km). The rock that formed the earth crust can be classified into three types:

1- **Igneous rock**: is formed through the cooling and solidification of magma.

2- **Sedimentary rock**: is a type of rock that is formed by sedimentation disintegration of material at the Earth's surface and within bodies of water. The disintegration occurs by withering or corrosion.

3- **Metamorphic minerals**: are those that form only at the high temperatures and pressures associated with the process of metamorphism. These minerals, known as **index minerals.**

2- Sea as source of metals

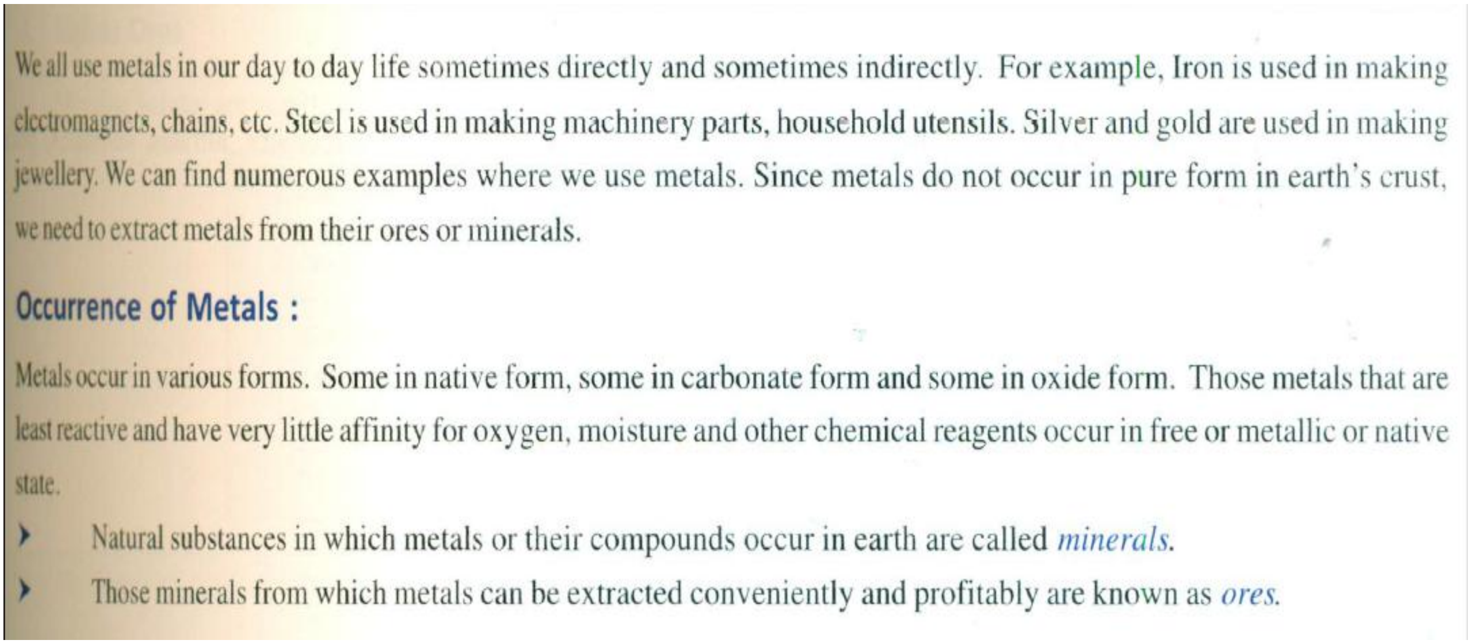
Sea water can be considered a dilute solution containing valuable minerals and chemicals compound. About (70) elements have so far been discovered in sea water. Since the seas form one continuous, nearly
homogenous body of water, these values are, remarkably, thesame all over the globe.

Although sea-water all over the earth is nearly homogeneous, there is a localized concentration of some elements in the organisms. For example, algae, a kind of seaweed, contain a very high concentration of iodine. Other sea organisms may contain element such as (Ba, Co, Cu, Pb, Ni, Ag and Zn) Trillions of tons of nodules are scattered across the ocean floor. These nodules whose principal constituents are (Mg, Ni, Fe, Cu, Co)

3- Scrap:

consists of recyclable materials left over from product manufacturing and consumption, such as parts of vehicles, building supplies, and surplus materials. Unlike waste, scrap has monetary value, especially recovered metals, and non-metallic materials are also recovered for recycling.

Definition of mineral and ore



We all use metals in our day to day life sometimes directly and sometimes indirectly. For example, Iron is used in making electromagnets, chains, etc. Steel is used in making machinery parts, household utensils. Silver and gold are used in making jewellery. We can find numerous examples where we use metals. Since metals do not occur in pure form in earth's crust, we need to extract metals from their ores or minerals.

Occurrence of Metals :

Metals occur in various forms. Some in native form, some in carbonate form and some in oxide form. Those metals that are least reactive and have very little affinity for oxygen, moisture and other chemical reagents occur in free or metallic or native state.

- Natural substances in which metals or their compounds occur in earth are called *minerals*.
- Those minerals from which metals can be extracted conveniently and profitably are known as *ores*.

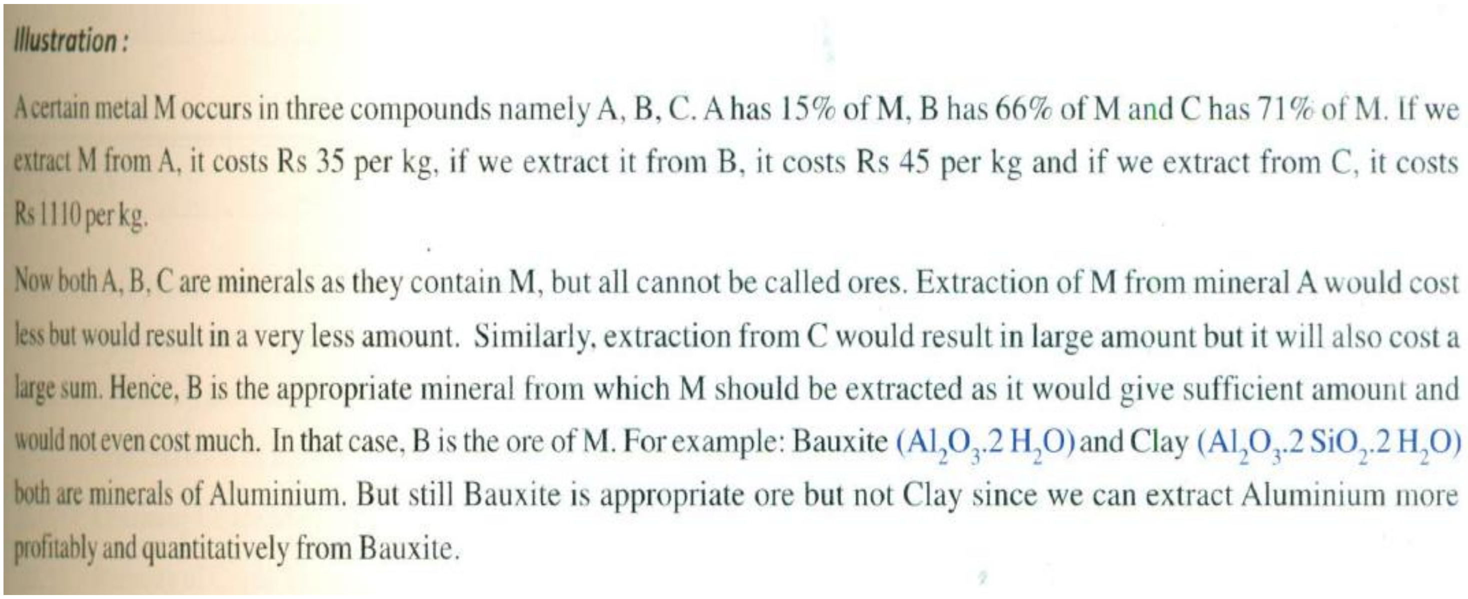


Illustration :

A certain metal M occurs in three compounds namely A, B, C. A has 15% of M, B has 66% of M and C has 71% of M. If we extract M from A, it costs Rs 35 per kg, if we extract it from B, it costs Rs 45 per kg and if we extract from C, it costs Rs 1110 per kg.

Now both A, B, C are minerals as they contain M, but all cannot be called ores. Extraction of M from mineral A would cost less but would result in a very less amount. Similarly, extraction from C would result in large amount but it will also cost a large sum. Hence, B is the appropriate mineral from which M should be extracted as it would give sufficient amount and would not even cost much. In that case, B is the ore of M. For example: Bauxite $(Al_2O_3.2\,H_2O)$ and Clay $(Al_2O_3.2\,SiO_2.2\,H_2O)$ both are minerals of Aluminium. But still Bauxite is appropriate ore but not Clay since we can extract Aluminium more profitably and quantitatively from Bauxite.

So A mineral is a natural inorganic compound of one or more metal in association with nonmetal such as oxygen, sulphur, and the halogens. A mineral has a fixed composition and well defined physical and chemical properties.

An ***ore*** may be defined as a natural occurring aggregate or a combination of minerals from which one or more metal or minerals may be economically extracted or the simplest definition of an ore is a mixture of a metal containing mineral and other materials ('minerals') from the surrounding rocks, which can be described as impurities with respect to what you want from the ore. Metal ores are obtained by mining and that this may involve digging up and processing large amounts of rock. Most ores are mined have to be concentrated before the metal is extracted and purified. This often results in lots of waste material that must be dealt with from an environment of view. The rock must contain enough of the metal compound, hence enough of the metal, to be worth exploiting the ore reserve and extract the metal by physical and chemical processes.

The economics of metal extraction are not only dependent on the quality of the ore and the cost of extraction (ie richer ores lead to cheaper production), but also depend on the market price and demand. If demand is high the metal price rises and may off–set the price of mining lower grade ores, but if demand is low, the metal price falls and inefficient mines and smelters will go out of business ie its not worth extracting the metal.

In ancient times, some minerals must have been spotted on the earth's surface itself because of their striking physical characteristics such as vivid colors and crystalline shapes, where those hidden under the soil would have remained unnoticed. Therefore, scientific methods are necessary for an accurate location and a quantitative estimation of mineral deposits. The principle methods employed in extraction are generally based on the magnetic, electric and electromagnetic properties of the ore bodies.

1- **Magnetic methods:** which is based on the fact that magnetic ore deposits disturb the earth's magnetic field in their vicinity. Instruments such as magnetometers are of detecting buried deposits of magnetite (an iron ore) and nickel and cobalt-bearing ores. Indirectly, they also help in locating alluvial deposits of gold and platinum which often contain abundant grain of magnetite.

2- **Electrical methods:** This is based on the differences between the electrical conductivity of certain ore deposits and those of the surrounding rocks. These methods are recommended particularly for certain sulphide minerals which have remarkably high conductivities-often several thousand time higher than the conductivity of the surrounding rock. Conductivity measurements, therefore, directly indicate both the presence and magnitude of the ore deposits.

3- **Electromagnetic methods:** it provide comprehensive on the position and shape of electrically conducting ore bodies hidden beneath the earth's surface. Such data are gathered by sending electromagnetic waves over area, and then recording the secondary field reradiated by the conducting ore bodies. Electromagnetic methods fined ready application even in mountainous regions, deserts, snow-laden, ice-covered lakes, and areas covered by nonconducting surface rock strata.

The physical and chemical characteristics of ore

4- Ore as in mined may be very large up to several meters but the maximum size of deep-mined ore must be much smaller to reduce handling problem. Ore should consist of valuable minerals and gangue with a minimum of (country rock). Often the rock can be eliminated by hand picking at the mine head.

The ore can be dividing into several types:

- The ore is almost a single pure crystalline mineral in very extensive deposits. This case is rare though important, for example, gold metal.
- In a general case a vein contains several minerals in banded array, the bands of the valuable minerals being sandwiched between layers of, for example, quartz, pyrites, fluorspar.

- The valuable mineral occupies fissures in anther mineral which may be the original country rock or an earlier filling of the vein.

The type of dispersion is important as it determined the size to which grinding must be carried out to expose the mineral particles to chemical action or as that they can readily be distinguished by physical characteristic as predominantly valuable mineral or gangue.

Chemically, an ore may contain three groups of mineral:

1- Valuable minerals of the metal which is being sough.

2- Compounds associated metals which may be of secondary value.

3- Gangue mineral of no value.

Commercially important Ores:

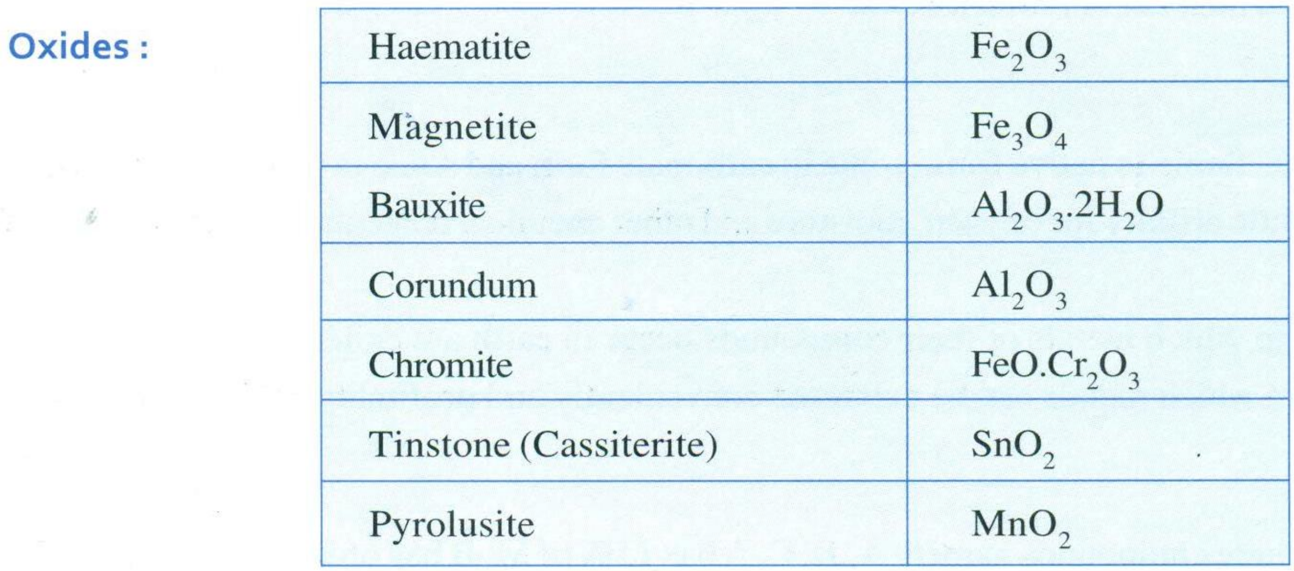
1- Native metal

These ores metals in the free state. They exist in free state because they are very unreactive. Some of important metals are: gold, silver, platinum metals, mercury and little copper. It is more likely to be found as filament or flakes than massive.

2- Oxides and Oxy-salts

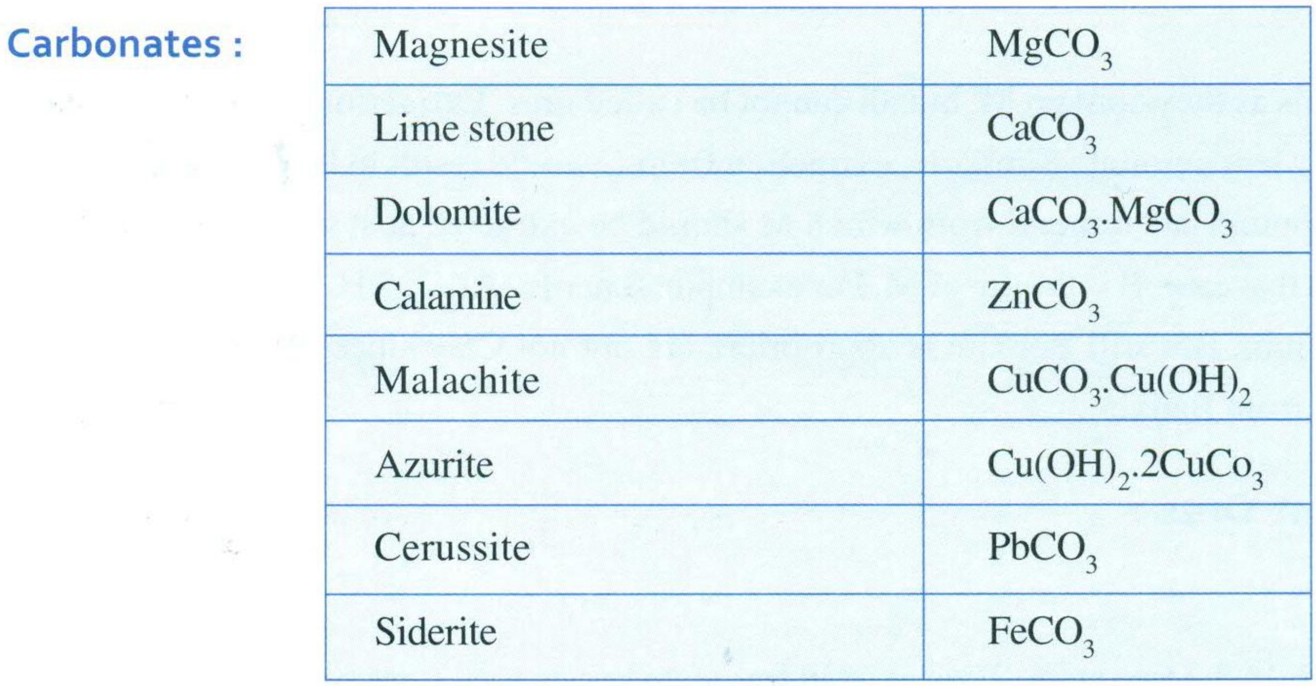
Oxides are often the result of oxidation of sulphides and if found in veins may gradually give way to sulphide as the veins are worked downwards. A few oxides do occur as primary deposits, notably (Fe_3O_4) in the magmatic stage and (SnO_2) and (TiO_2). Complex double and multiple oxides like niobite and tantalite are found in pegmatitic veins. These are all resistant to chemical attack and are frequently recovered beach sands and river gravels

Secondary sulphates, carbonates, nitrates, phosphates and silicates etc. are obviously members of oxy-salts group where some of which be described as mixed oxides. Some of these, like zircon (ZrSiO4) and the complex rare earth phosphates occur finely disseminated in granites and similar rocks but are naturally concentrated in placer deposits and in beach sands with other similarly chemically unreactive minerals.



Oxides :

Haematite	Fe_2O_3
Magnetite	Fe_3O_4
Bauxite	$Al_2O_3.2H_2O$
Corundum	Al_2O_3
Chromite	$FeO.Cr_2O_3$
Tinstone (Cassiterite)	SnO_2
Pyrolusite	MnO_2



Carbonates :

Magnesite	$MgCO_3$
Lime stone	$CaCO_3$
Dolomite	$CaCO_3.MgCO_3$
Calamine	$ZnCO_3$
Malachite	$CuCO_3.Cu(OH)_2$
Azurite	$Cu(OH)_2.2CuCo_3$
Cerussite	$PbCO_3$
Siderite	$FeCO_3$

Nitrates :

Chile saltpetre	$NaNO_3$
Salt petre	KNO_3

Sulphates :

Epsom salt	$MgSO_4.7H_2O$
Gypsum	$CaSO_4.2H_2O$
Glauber’salt	$Na_2SO_4.10H_2O$

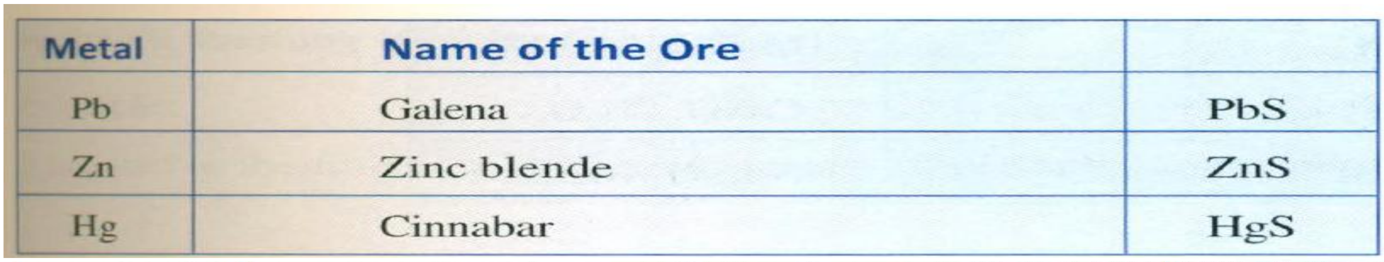
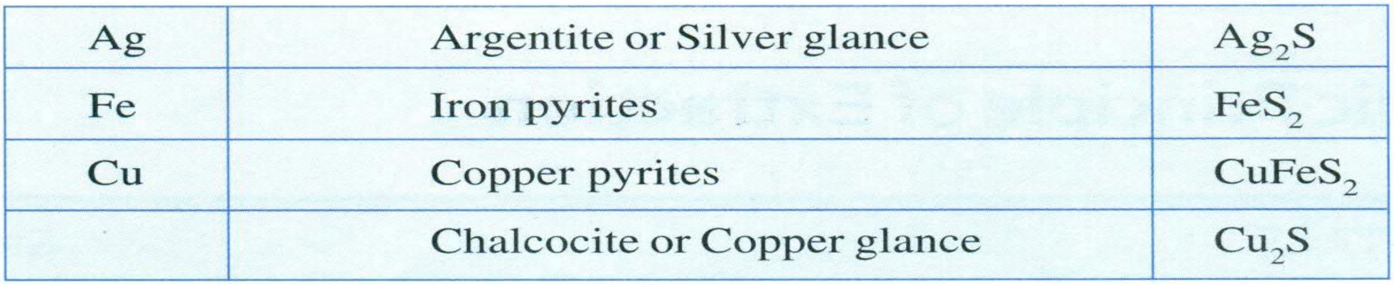
Phosphates and Silicates :

Fluor-apatite	$3Ca_3(PO_4)_2.CaF_2$
Felspar	$KAlSi_3O_8$

3- Sulphides and Arsenides

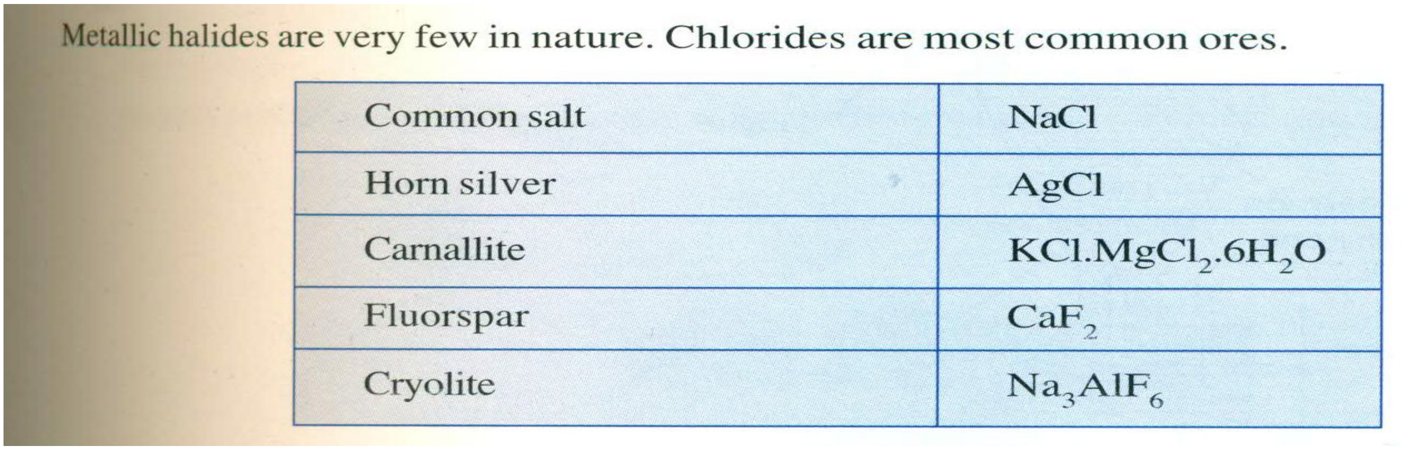
The last major class of ore mineral is probably the most common and is usually found on the sites at which it was deposits. Minerals in this group associate in families with iron almost always present thus lead and zinc are often found together, and lead is seldom found without some sliver. Cadmium is found associated with zinc, iron with copper, copper and iron with nickel and nickel with cobalt. Platinum occurs commonly with copper and nickel.

Arsenides or more often sulpharsenides occur in association with the corresponding sulphides in some cobalt, nickel, copper and lead ores and arsenates may occur among their oxidized deposits. The presence of these obviously affects the value of the deposits. The most important arsenide is sperrylite (PtAs2), the form in which platinum occurs when magmatically deposited with nickel sulphide.

Metal	Name of the Ore	
Pb	Galena	PbS
Zn	Zinc blende	ZnS
Hg	Cinnabar	HgS
Ag	Argentite or Silver glance	Ag_2S
Fe	Iron pyrites	FeS_2
Cu	Copper pyrites	$CuFeS_2$
	Chalcocite or Copper glance	Cu_2S

4. Halide Ores



Metallic halides are very few in nature. Chlorides are most common ores.

Common salt	$NaCl$
Horn silver	$AgCl$
Carnallite	$KCl.MgCl_2.6H_2O$
Fluorspar	CaF_2
Cryolite	Na_3AlF_6

The evaluation of ore deposits

Unless a mineral deposit can be worked with profit it would not be designated an ore by miners, but a deposit which can be worked with profit at one period in history need not be profitable at another period. The credits associated with the minerals deposit are the sum of the "**values**" of metals and non-metals (e.g. sulphur) which can be extracted from it and sold.

The "**costs**" involved are those of exploration, mining, concentration, transportation, waste disposal, extraction, refining, and marketing, research and administration.

If the "**values**" exceed the "**costs**" by a reasonable amount the deposit is workable ore. Several considerations should be taken to evaluate the ore deposit and can be divided into two groups:

1. Geological considerations: can be summarized to:

a- The size, the shape and the deposit ore

b- The concentration of the metal or the metals into the ore

c- The amount of the material which could be found in the ore deposit and the ability to extract them as byproduct like gold and silver, or gangue mineral in ore.

2. Non geological consideration: can be summarized to:

a- The cost of mining operations, which consist of mineral extractive

b- The cost of concentration processes, the chooses of concentration process depend on ore nature and gangue mineral.

c- The cost of transport waste away from working position.

d-The cost of assisting materials which is association in extraction process

e- The amount of energy needed in the sum of the free energy of the reduction of the compound of the metal as found in the ore to the metallic state. And the energy required for all mechanical and heating processes which it may be necessary to carry out.

f- Workers: the cost of the workers are different from location to another (from country to another) and almost unskilled workers were used in mining operations, but in some cases it was necessary to used a skilled workers In extraction operation.

The mining operation

By whatever methods a deposit is discovered, and after a full geological survey made to determine the workable ore. Then mining operation is commenced.

An ore body is mined by a method appropriate to its size, shape, and depth below the surface.

1- Open pits:

The simplest methods apply to deposits which outcrop over a large area. The ore being broken with explosive and shoveled into trucks. If the ore lies deeper below the surface but is extensive horizontally, open cast mining proceeds by first clearing the over-burden to form a wide trench at one edge of the deposit.

2- Under-mine

Most mining operations involved going underground. Again there are a number of methods available depending on the size and shape of the deposit.

a- Closed under-mine: massive deposits extended horizontally would be mined by the "room and pillar" method.

b- If the deposit extend vertical, a vertical shift is cut alongside it and horizontal galleries are driven across at various levels to the vein. The mineral content of the vein above each access point and up to the one above it is blasted down and taken out to the shaft.

Method of Beneficiation

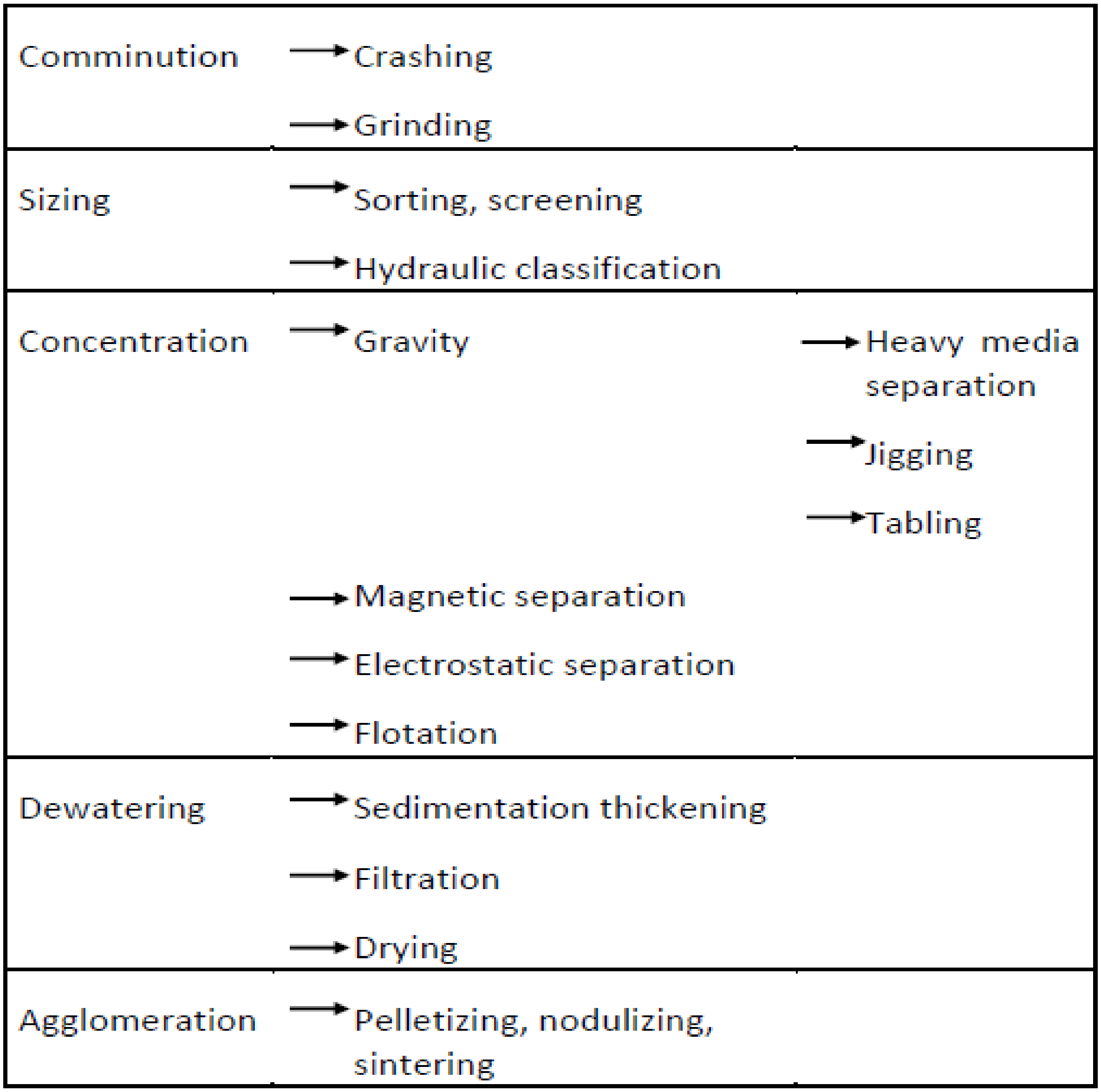
All metal extraction techniques are developed to produce a particular type of raw materials or a particular combination or raw materials. Whether or not a particular raw material is suitable for a giver extraction technique depends on both the physical nature of the ore and its chemical composition. Therefore, it is apparent that most of ores and minerals require some treatment before they can be processed either in increase their chemical purity or to better utilize their physical properties so as to facilitate the extraction of the metal.

The first process most ores undergo after they leave the mine is mineral dressing (processing), 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. These process a physical and chemical treatment or a combination of the two which aimed to altering the physical and chemical nature of the mineral so that the final combination of the minerals can be economically treated for metal extraction.

Mineral dressing is the processing of row materials to yield marketable products and west be means that not destroy the physical and chemical identity.

In general these processes can be summarized as below



Comminution	→ Crashing → Grinding	
Sizing	→ Sorting, screening → Hydraulic classification	
Concentration	→ Gravity	→ Heavy media separation → Jigging → Tabling
	→ Magnetic separation → Electrostatic separation → Flotation	
Dewatering	→ Sedimentation thickening → Filtration → Drying	
Agglomeration	→ Pelletizing, nodulizing, sintering	

1- Comminution

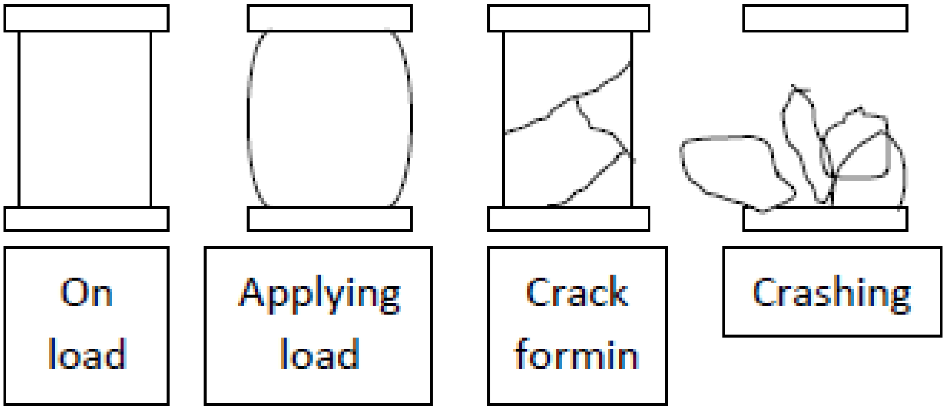
Since most ore minerals are usually finely disseminated and intimately associated with gangue minerals, the various minerals must be broken apart (freed) or “liberated” before they can be collected in separate products. Therefore, the first part in any ore dressing process will involve the crushing and grinding (which is also known by a common name called “comminution”) of the ore to a point where each mineral grain is practically free.

Basically comminution serves two purposes:

1- It detaches dissimilar minerals particles from each other.

2- Liberate the valuable components and it produced smallsized mineral particles which are more suitable than large-size ore for subsequent beneficiation operations.

Crushing and grinding are usually carried out in a sequence of operations by which the lump size is reduced step by step. These processes occur by applying energy or force on the ore to be crashing until reached a critical point and then it will be crashed.



There are 3 stages of crushing and 2 stages of grinding

The crashing stages are:

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 grinding stages are:

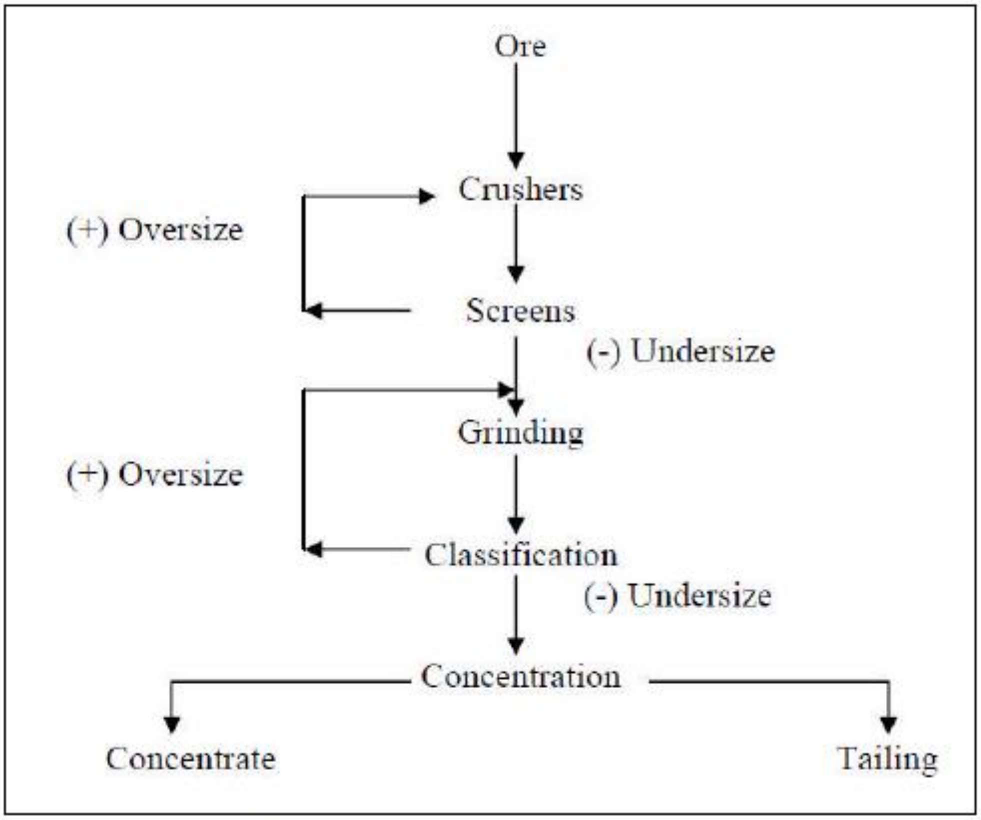
1-**Coarse Grinding**: Rod mills are generally used as coarse grinding machines. They are capable of taking feed as large as 50 mm and making a product as fine as 300 microns.

2-**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:

1- To obtain the correct degree of liberation in mineral processing.

2- 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 flow sheet shows diagrammatically the sequence of unit operations in the plant.



A simple flow sheet of a mineral processing plant

Crusher and Grinder

Machines such as jaw crusher, gyratory crusher, and rolls carry out the crushing of an ore as it mined. In most of these machines the ore is crushed in a wedge-shape space between two hard crushing surfaces one fixed and the other moving. The
smaller fragments of the crushed ore particles are collected as they fall through an opening provided in the machine.

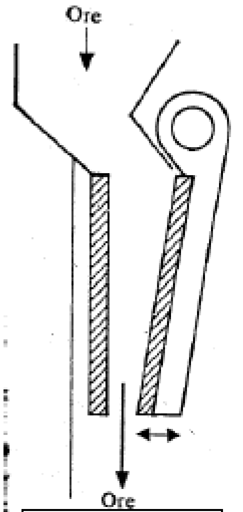
In jaw crusher ore is squeezed until it breaks and the fragments fall down to a narrower part of the wedge to be squeezed again, repeatedly, until they can escape through the minimum gap at the bottom. Its capability of processing up to 500 tons of ore per hour and reduction ratios range 4 to 10 in the biggest machines.

The gyratory crusher is similar in effect, but the relative motion of the crushing face is due to the gyration of the eccentrically and some tangential force is applied in the case as well as simple squeeze. Its capability of processing up to 5000 tons of ore per hour. Gyratories operate best on hard, brittle materials and do not work well on soft pr plastic minerals like clay while jaw crusher can deal these material mach better.

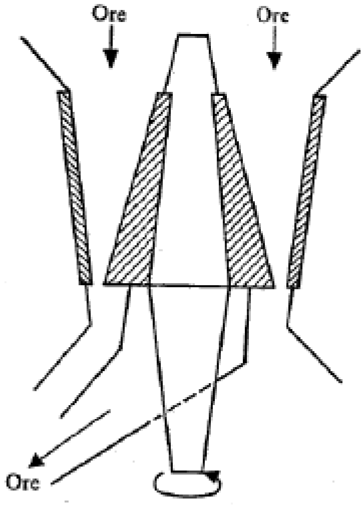
Rolls draw the ore lumps down into the gap between them and, after one nip, discharge the product. With a given roll diameter and set there is maximum size of lump that will be drawn in. With smooth rolls this limit the reduction ratio to about 3:1, but using slugger rolls which have ridges or knobs on the roll faces, the reduction ratio can be raised above 4:1. These are used on iron ore which are usually cohesive but not very hard. Fracture of ore between rolls is again mainly by squeezing and must occur by stages as the material is drawn into the narrowing space. Interaction between ore particles is much less than in jaw and gyratory crushers and the proportion of fines produced is smaller.

Secondary reduction would be carried in a cone crusher, by cone, or in a hammer mill. Of these the cone crusher is the most commonly used on ores. It is similar to the gyratory, but it self –cleaning because the gap widens to let the product fall through after the nip has been made. The inner cone sometimes rotates on an eccentric axis instead of gyrating.

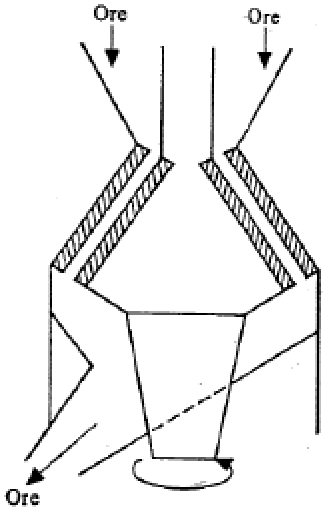
Hammer mills are used mainly for breaking weak, brittle materials like coal. The materials are fed through a hopper into the bath of the flying hammers which are freely swinging in smaller machines but fixed rigid with the rotor in the largest size. The ore lumps are broken by the impact fracture mechanism either when hit by the hammer, or on subsequent collisions with the impact plates enclosing the working space, with other lumps or with another hammer. Its capacities range up to 2000 tons per hour and reduction ratio can be as high as 40:1.



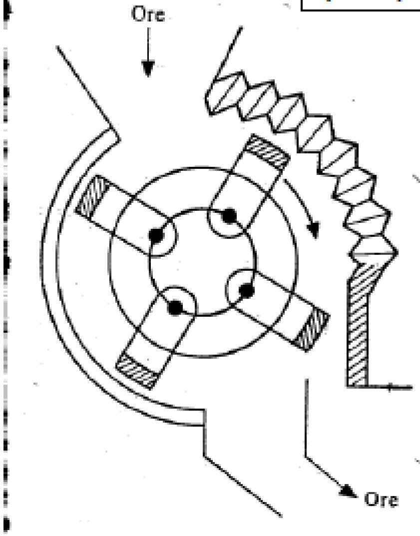
Jaw crusher



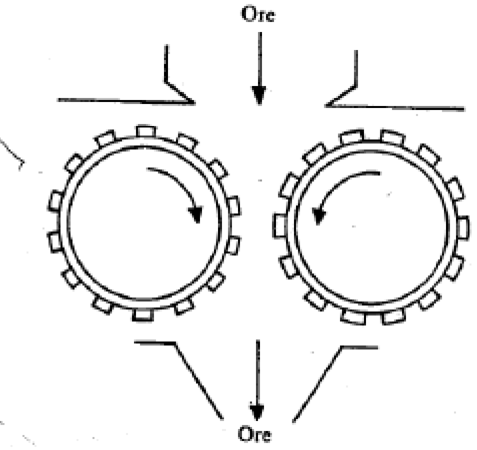
Gyratory crusher



Cone crusher



Hammer mill



Roll crusher

Grinding, a process that is slower than crusher, is usually carried out in a ball mill or in equipment similar to it, namely, a tube mill, a pebble mill, or a rod mill. These mills are closed chambers containing hard balls, rode or pebbles, which are

used in grinding. Since the operating mechanism of the each of these grinding mills is similar, we discuss only the ball mill. The ball mill is rotated in such a manner that the ball rise along the walls and then either roll down or throw themselves on the ore particles, which leads to fragmentation by grinding. In this

rotating mill, the ore particles are subjected to various forces which cause fracture such as:

(1) Catar acting (impact with balls, rods, or pebbles),

(2) Cascading (attrition among rolling ball),

(3) Interparticle collisions and rubbing,

(4) Frictional force at the lining of the mill.

It should be noted that if the speed or rotation of a mill is too high, then centrifuging takes place. As a result, the contents of the mill simply stick to the inner rotating surface, and there is hardly any grinding. Conversely, if the speed of rotation is too slow, then catar acting does not occur, and the particles and balls simply roll down the inner surface. In such a situation, only limited grinding takes place as a result of cascading. A successful grinding operation aims at a suitable speed among the various operation forces.

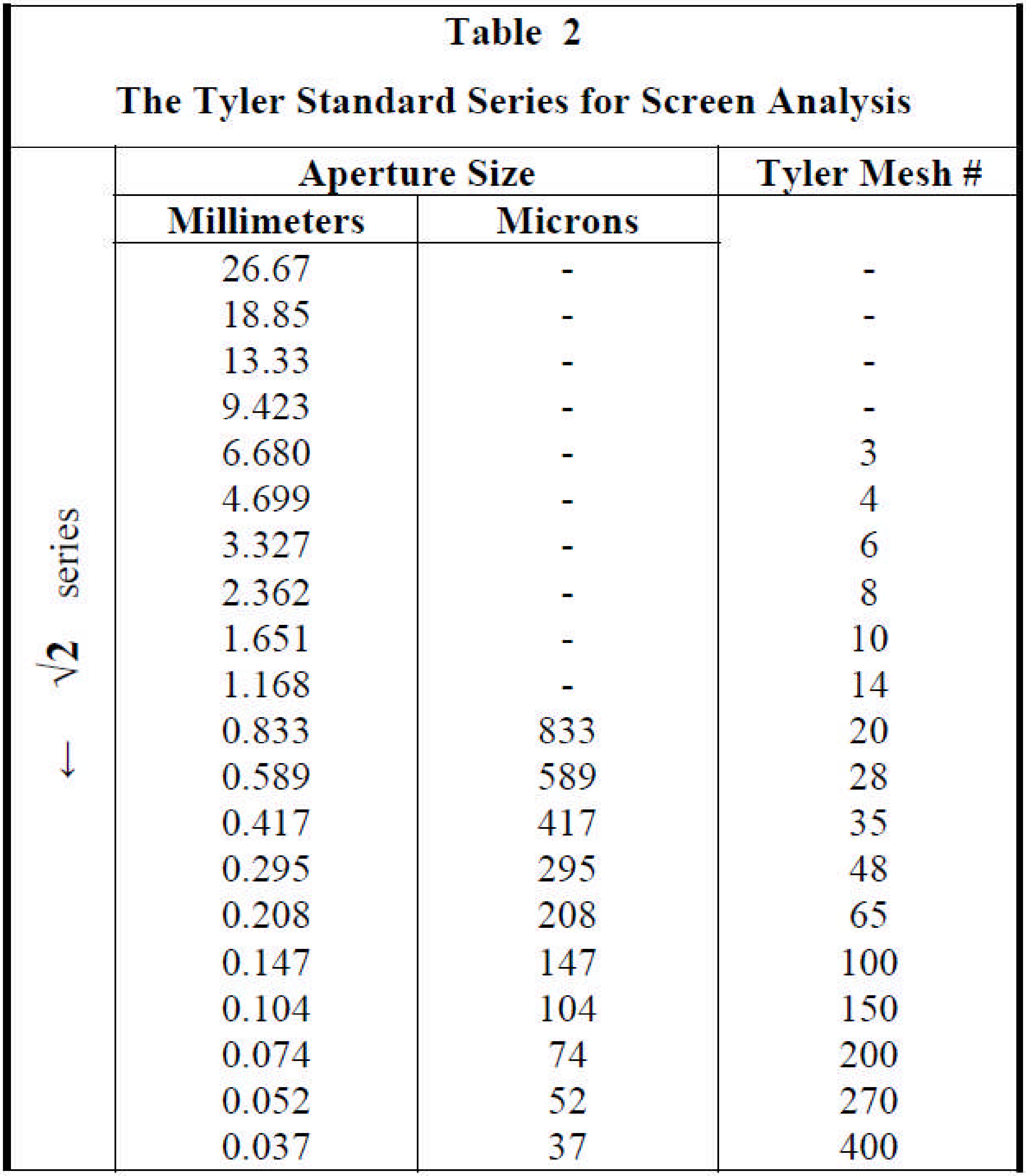


Table 2

The Tyler Standard Series for Screen Analysis

	Aperture Size		Tyler Mesh #
	Millimeters	Microns	
↓ √2 series	26.67	-	-
	18.85	-	-
	13.33	-	-
	9.423	-	-
	6.680	-	3
	4.699	-	4
	3.327	-	6
	2.362	-	8
	1.651	-	10
	1.168	-	14
	0.833	833	20
	0.589	589	28
	0.417	417	35
	0.295	295	48
	0.208	208	65
	0.147	147	100
	0.104	104	150
	0.074	74	200
	0.052	52	270
	0.037	37	400

The term 'mesh" is normally reserved from small aperture size. From bigger particles, screens may be made with any size of opening and down to about (50 mm).

Size of particles

In an ore benefication methods, when ore are subjected to force in order to reduce their size by crushing and grinding. It's necessary to identify the particle size of the products by sizing and classification methods.

Size is usually signifies the narrowest regular aperture through which a mineral particles can pass. Such a criterion may be suitable for a regularly shape polyhedron, especially a sphere, where the diameter is obviously the size, weal in the case of long-rod shape particles is meaningless.

When particles are sized into fraction using sieves, every fraction has bigger and smaller particles with upper and lower limits. The average size of particles in a fraction can calculated the mean of the upper and the lower level.

The determining the size of single particle in laboratory can occur by several methods. The common procedures are by microscopic and macroscopic observation to obtain the dimensions of a single particle. The volume "V" of the particle having dimensions "a,b,c" can be obtained from the equation

$$V_{(a,b,c)} = \frac{\pi d^2}{6}$$

Where "d" is the diameter of a single particle by assuming the particle is spherical.

The other sizing technique that using in the laboratory is sieving. A standard sieve is made of square mesh whose aperture size vary in geometry. The aperture sizes used in a sieve range from (37μ) upwards. In the longest series, standardized mesh size extend from 3 to 400. The mesh number specifies the number of square apertures per linear inch (25.4 cm) a standard size scale, called the "Tyler" series, and is given in table below. There are other systems of grading aperture size like ASTM and BS.

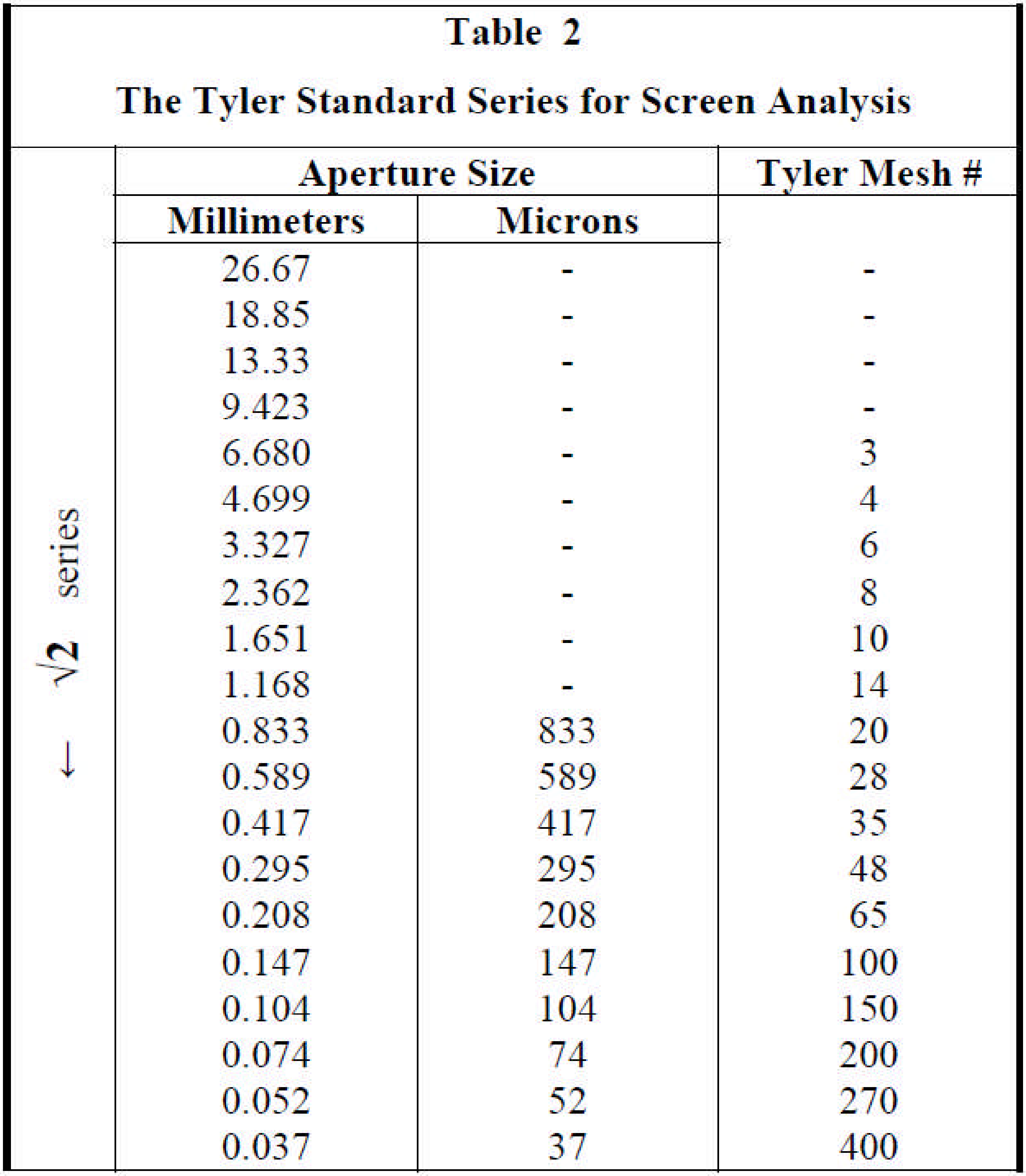


Table 2

The Tyler Standard Series for Screen Analysis

	Aperture Size		Tyler Mesh #
	Millimeters	Microns	
↓ √2 series	26.67	-	-
	18.85	-	-
	13.33	-	-
	9.423	-	-
	6.680	-	3
	4.699	-	4
	3.327	-	6
	2.362	-	8
	1.651	-	10
	1.168	-	14
	0.833	833	20
	0.589	589	28
	0.417	417	35
	0.295	295	48
	0.208	208	65
	0.147	147	100
	0.104	104	150
	0.074	74	200
	0.052	52	270
	0.037	37	400

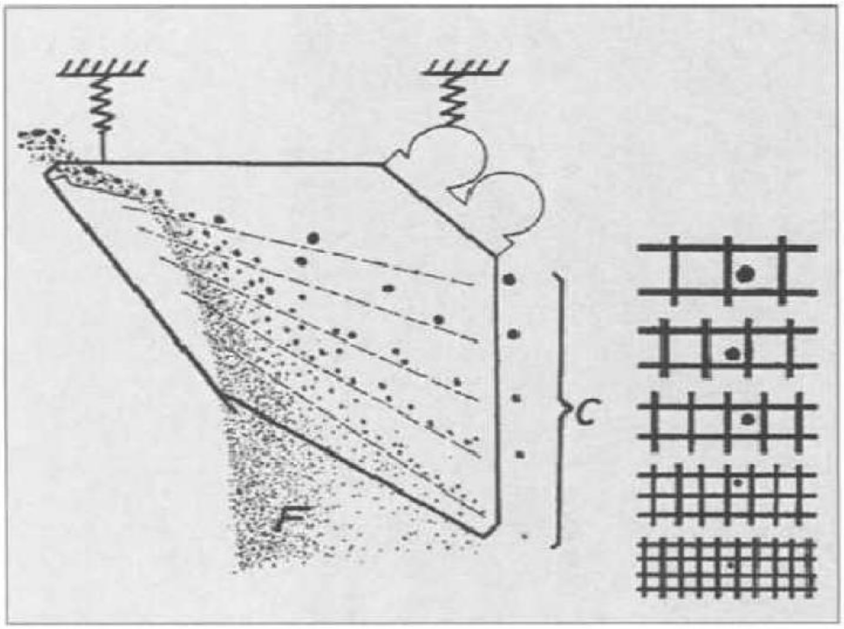
The term 'mesh" is normally reserved from small aperture size. From bigger particles, screens may be made with any size of opening and down to about (50 mm).

Sizing

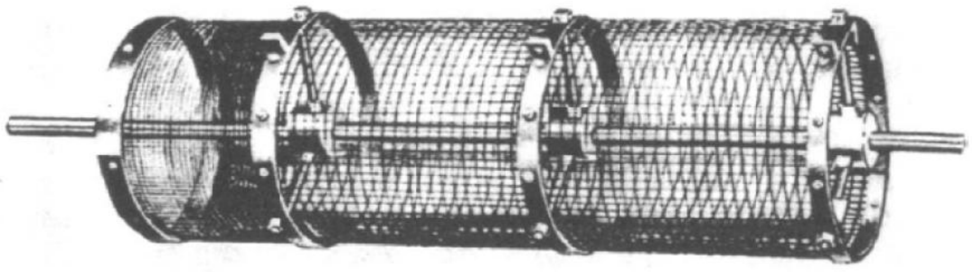
Most unit processes are designed to treat over certain size ranges. Thus the raw material must be chosen by proper selection process. It can be divided in two methods.

- Sorting or hand-picking: this method yields particles, approximate diameter range (40-500 mm) which are not only ideal for certain unit process but may also a high concentration of mineral.
- Screening: it more scientific than sorting, where the basis of separation is the particles size, as indicated by standardized apertures. In this way the particles can separated into two groups, namely, oversized and undersized.

The chief types of industrial screen



Grizzly screen



Trommel screen

Capacity of screen

The capacity of a screen primarily depends on the following factors:

1- The area of the screen surface;

2- The size of the opening on the screen surface;

3- Characteristics of the ore such as specific gravity, moisture content, temperature and the proportion of fines;

4- The type of the screening mechanism used.

Since the capacity of a screen depend directly on both the area of the screening surface and the screen aperture, it is expressed as (tons/ft2) or (tons/m2) screen aperture per (24 hr). The table below gives the approximate capacity range of certain type of screens:

Type of screen	capacity range per (24 hr) per (mm) aperture	
	tons/ft^2	tons/m^2
Grizzly	1-5	0.1-0.5
Trommel	0.3-2	0.03-0.2
Shaking screen	2-8	0.2-0.8
Vibrating screen	5-20	0.5-2

Classification

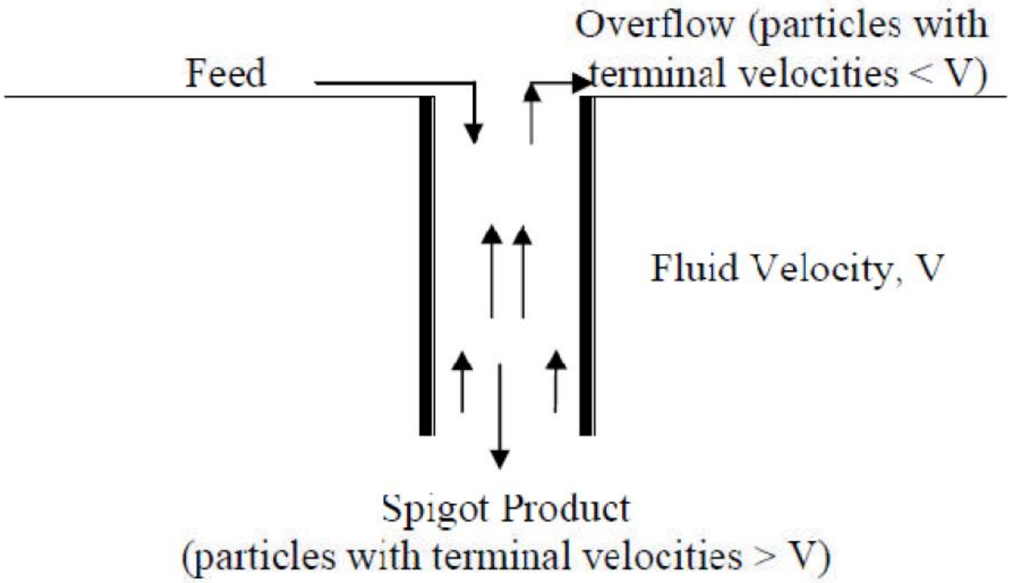
Classification is a process by which particles of different sizes and specific gravity are sorted out into uniform groups. Classification differs from sizing in two ways:

First: it is normally applicable to a very low range of particle size i.e. 65-200 mesh (208-74 μm).

Second: it separation the particles on the basis of their densities. Thus, if the particle sizes are comparable, then, the settling velocities of heavier and lighter particles would be difference, leading to a possibility of separation and concentration.

In general, classification depends on the settling rate of the individual particles in a fluid medium (usually water). Further, the difference in the settling rate between particles of different sizes and/or different specific gravities is the controlling factor in classification.

Classifiers consist essentially of a sorting column In which a fluid is rising at a uniform rate (Figure below). Particles introduced into the sorting column either sinks or rise according to whether their terminal velocities are greater or lesser than the upward velocity of the fluid. The sorting column therefore separates the feed into two products an over flow consisting of particles with terminal velocities lesser than the velocity of the fluid and an underflow or spigot product of particles with terminal velocities greater than the rising velocity.



There are two main kinds of settling, namely, ***free settling*** and ***hindered settling***.

Free settling: take place when the individual particles settle free, i.e., unhindered by other particles through a medium of still water or against a rising current of water.

Hindered settling: As the proportion of solids in the pulp increases, the effect of particle crowding becomes more apparent and the falling rate of the particles begins to decrease. The system begins to behave as a heavy liquid whose density is that of the pulp rather than that of the carrier liquid; hindered-settling conditions now prevail. Because of the high density and viscosity of the slurry through which a particle must fall in a separation by hindered settling.

Consider a spherical particle of diameter (d) and density (Ds) falling under gravity in a viscous fluid of density (Df) under free settling conditions, i.e. ideally in a fluid of infinite extent. The particle is acted upon by three forces: a gravitational force acting downwards, an upward buoyant force due to the displaced fluid, and a drag force (D) acting upwards. The equation of motion of the particle is

$$F = (m - m')g - D$$

Where (F) the summation of acting force, (m) is the mass of the particle, (m') is the mass of the displaced fluid. The main part of the equation is the drag force (D) which is directly depend on the settling rate of the particle, and can be

Calculated from:

$$D = C_D A(D_f V^2)/2$$

Where (V) the relative velocity between the particle and the fluid, (A) the cross section area of the particle, (CD) the drag force index.

The settling of a particle in water depends on several factors:

- **Specific gravity**: a particle that has higher specific gravity than anther particle settles faster when other parameters such a size are comparable.
- **Shape:** a rounded particle settles faster than a long narrow grain of a flat grain.
- **Size:** a large particle settles faster than a small one.
- Air bubbles: a particle that does not retain adhering air bubbles settles faster than one dose.
- **Density of liquid**: the settling rata of a particle is higher in a lighter than a heavier liquid.
- **Viscosity:** the settling rata of a particle is higher in a less viscous medium than in a more viscous one.

Types of classifier

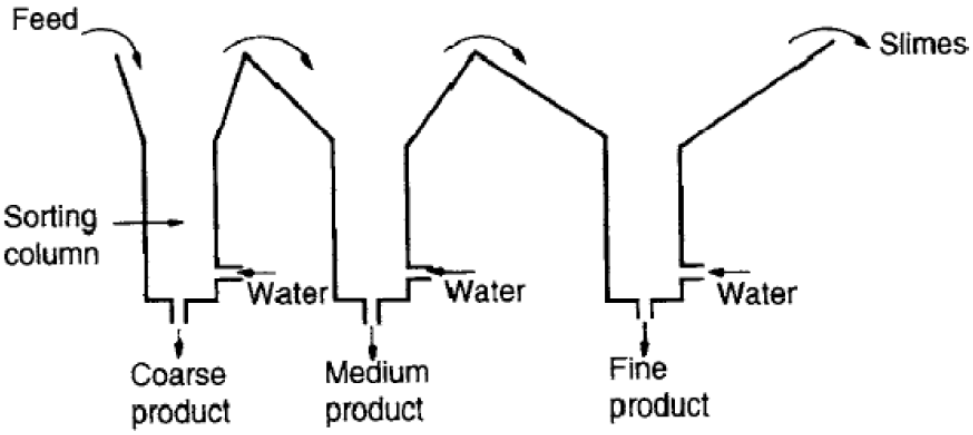
They may be grouped, however, into two broad classes depending on the direction of flow of the carrying current.

- **Horizontal current** classifiers such as mechanical classifiers are essentially of the free-settling type and especially the sizing function;
- **Vertical current** or hydraulic classifiers are usually hindered-settling types and so increase the effect of density on the separation.

Hydraulic classifiers

These are characterized by the use of water additional to that of the feed pulp, introduced so that its direction of flow opposes that of the settling particles. They normally consist of a series of sorting columns through each of which a vertical current of water is rising and particles are settling out (the fig. below)

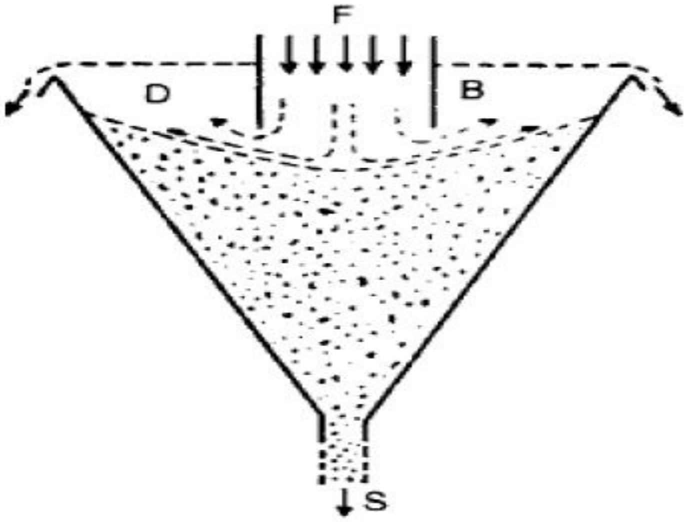
The rising currents are graded from a relatively high velocity in the first sorting column, to a relatively low velocity in the last, so that a series of spigot products can be obtained, with the coarser, denser particles in the first spigot and the fines in the latter spigots. Very fine slimes overflow the final sorting column of the classifier.



Principle of hydraulic classifier

Settling cones

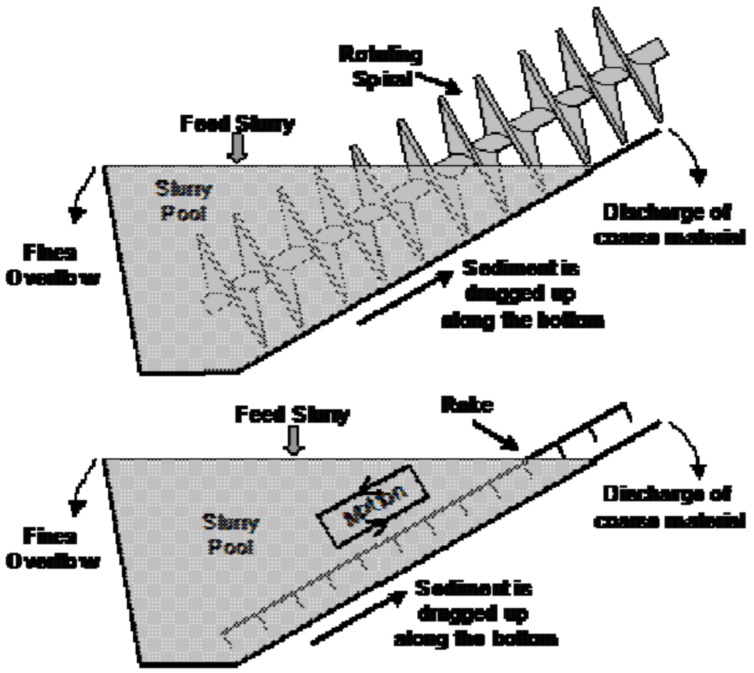
These are the simplest form of classifier, in which there is little attempt to do more than separate the solids from the liquid, i.e. they are sometimes used as dewatering units in small-scale operations. The principle of the settling cone is shown in Figure. The pulp is fed into the tank as a distributed stream at F, with the spigot discharge S initially closed. When the tank is full, overflow of water and slimes commences, and a bed of settled sand builds up until it reaches the level shown. If the spigot valve is now opened and sand discharge maintained at a rate equal to that of the input, classification by horizontal current action takes place radially across zone D from the feed cylinder B to the overflow lip. The main difficulty in operation of such a device is the balancing of the sand discharge and deposition; it is virtually impossible to maintain a regular discharge of sand through an open pipe under the influence of gravity.



Settling cone operation

Mechanical classifiers

Mechanical classifiers such as the spiral and rake classifiers work in a similar fashion in that both drag sediment and sand along the bottom of an inclined surface to a higher discharge point on one end of the settling chamber. The primary difference in the two systems is the mechanism by which the settled material is moved up the inclined surface (see figure). Spiral classifiers are generally preferred as material does not slide backwards which occurs in rake classifiers for separation of finer material when the rakes are lifted between strokes. This also allows spiral classifiers to operate at steeper inclines producing a drier product. The spiral classifier also produces less turbulence in the settling pool allowing for separation of finer material.

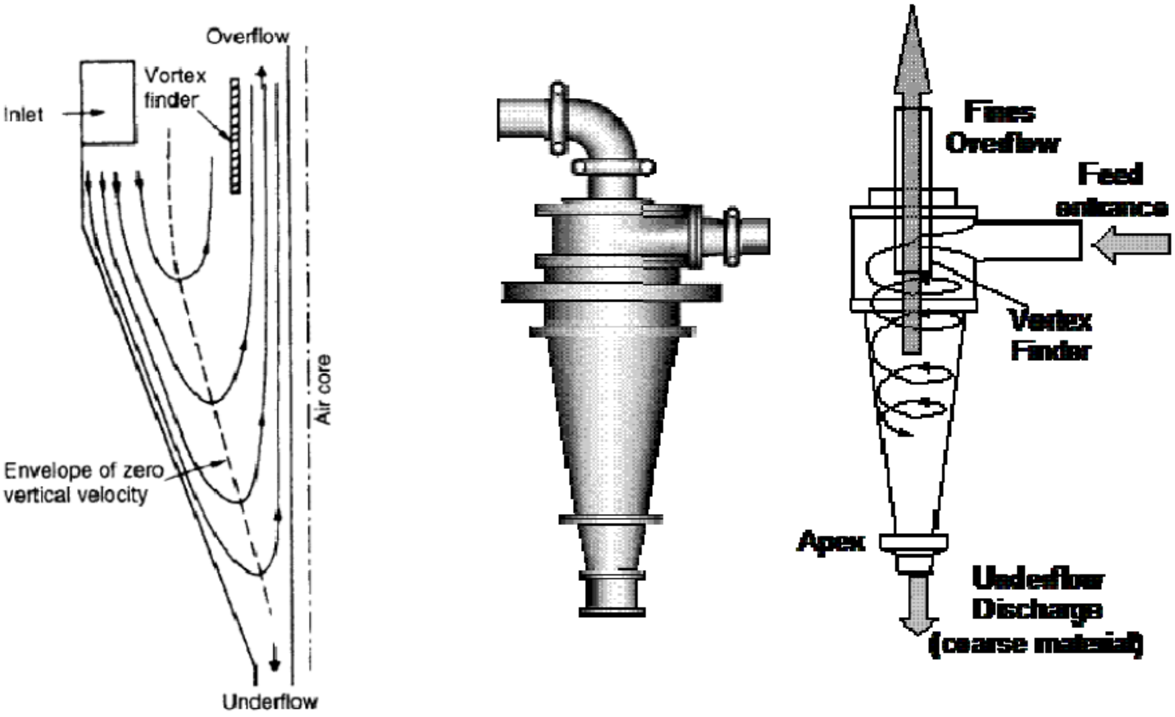


Principle of mechanical classifier (Spiral and rake)

Hydrocyclones (Cyclones)

This is a continuously operating classifying device that utilizes centrifugal force to accelerate the settling rate of particles. It is one of the most important devices in the minerals industry, which has proved extremely efficient at fine separation sizes. It is widely used in closed-circuit grinding operations. The main advantages of cyclones is that they have large capacities relative to their size and can separate at finer sizes than most other screening and classification equipment.

The separation mechanism in hydrocyclones relies on centrifugal force to accelerate the settling of particles. The slurry enters the cylindrical section tangentially above a conical section. The velocity of the slurry increases as it follows a downward helical path from the inlet area to the smaller diameter underflow end. As the slurry flows along this path, centrifugal forces cause the larger and denser particles to migrate to the fluid layer nearest the wall of the cone. Meanwhile, the finer or lower specific gravity particles remain in, migrate to, or are displaced toward the center axis of the cone. As the swirling slurry approaches the underflow tip, smaller and lighter material closer to the center reverses its axial direction and follows a smaller diameter rotating path back toward the top overflow discharge pipe.



Principle of Hydrocyclones

Heavy media separation

Is a special classification process which depends exclusively on the specific gravity of a particle. In this operation the particle size is not important. Generally, the comminuted ore (after the fine size have been removed from it) is put into a fluid whose specific gravity lies in between the specific gravities of the two mineral that are to be separated from each other. For example the densities of most metallic oxides lie in the range (3.5-4.5 g/cm^3) silica the main component of gangue having a density of (2.65 g/cm^3). Therefore, during heavy media separation in a liquid whose density is approximately (3g/cm^3) the metallic oxides sink but silica floats. Such a liquid can, however, be obtained by suspending fine, dense particles in water. Typical examples are galena (lead sulfide) (effective specific gravity of medium 4.3 g/cm3) and ferrosilicon (effective specific gravity of medium 2.5-3.5g/cm3).

Extraction of materials

Extraction Methods of Iron

Iron is mined almost exclusively in surface operations. The most predominant surface mining methods used to extract iron ore are open-pit and open-cut methods. However, there is currently one operating underground iron mine. Historically, underground mining methods, including caving and stopping, were commonly used to extract iron ores.

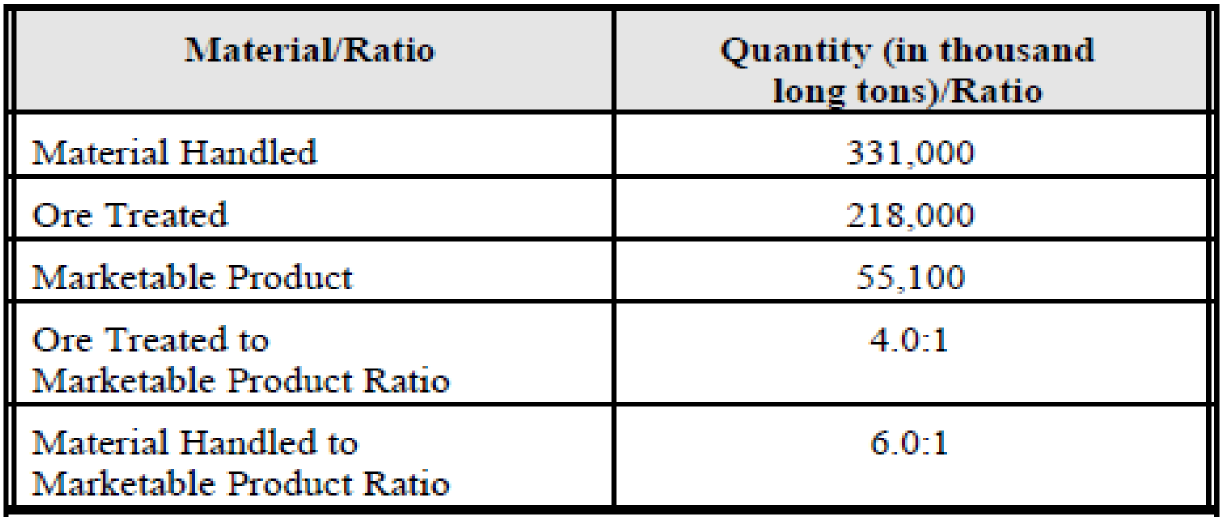
The mining of taconite (a low-grade iron ore), a tough and abrasive low-grade ore (ranging from 40 to 60 percent silica and 17 to 30 percent iron) common to Minnesota and Michigan, is especially difficult because of the extreme hardness of the ore. Because of this hardness, additional drilling, blasting, crushing, and grinding are often required to extract the ore.

Overburden and stripping ratios are important in determining whether a deposit will be mined. The stripping ratio describes the unit of overburden that must be removed for each unit of crude ore mined. Stripping ratios increase with the quality of the ore being mined and cost factors related to beneficiation and transportation. These ratios may be as high as 7:1 (for high-grade wash ores) or as low as 0.5:1 (for low-grade taconite ores). A summary of quantities of material handled, ore treated, and marketable product generated at iron mines in 1988 is presented in Table 1.

Other earthen materials associated with mining may include mine development rock. "Mine development rock" is the material removed while exploiting the ore body through underground mining. Typically, the term "mine development rock" excludes material removed at surface operations. Therefore, waste in the form of mine development rock is associated with historic underground iron mines.

Materials generated as a result of open-pit mining include overburden, waste rock, and mine water containing suspended solids and dissolved materials. Other wastes may include small quantities of oil and grease spilled during extraction. Mine water will contain dissolved or suspended constituents similar to those found in the ore body itself. These may include traces of aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, manganese, nickel, selenium, silver, sulfur, titanium, and zinc.

Table 1. Ore Treated to Product Ratios and Material Handled to Product Ratios for U.S. Surface Iron Ore Mines, in Thousand Long Tons, 1988



Material/Ratio	Quantity (in thousand long tons)/Ratio
Material Handled	331,000
Ore Treated	218,000
Marketable Product	55,100
Ore Treated to Marketable Product Ratio	4.0:1
Material Handled to Marketable Product Ratio	6.0:1

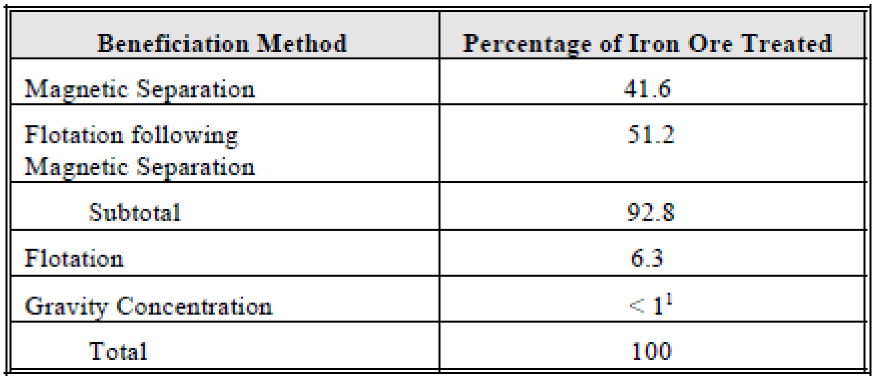
Beneficiation Methods of iron

The beneficiation methods applied to iron ore are : milling (crushing and grinding); washing; filtration; sorting; sizing; gravity concentration; magnetic separation; flotation; and agglomeration (pelletizing, sintering, briquetting, or nodulizing). Although the literature suggests that all these methods have been used to beneficiate iron ore, information provided by members of the American Iron Ore Association indicates that milling and magnetic separation are the most common methods used. Gravity concentration is seldom used at existing U.S. facilities. Flotation is primarily used to upgrade concentrates from magnetic separation by reducing the silica content of the concentrate.

Most beneficiation operations will result in the production of three materials: a concentrate; a middling or very low-grade concentrate, which is either reprocessed (in modern plants) or stockpiled; and a tailing (waste), which is discarded. Table 2 compares the percentage of total domestic ore treated by each iron ore beneficiation method in 1990.

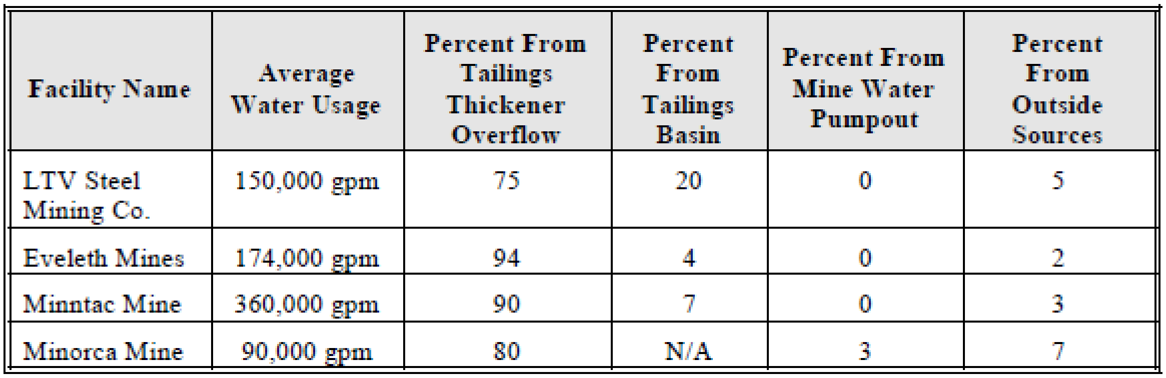
It should be noted that the iron ore industry uses large amounts of water. The beneficiation of iron ore typically occurs in a liquid medium. In addition, many pollution abatement devices use water to control dust emissions. At a given facility, these techniques may require between 600 and 7,000 gallons of water per ton of iron concentrate produced, depending on the specific beneficiation methods used. Table 3 presents a summary of the average water usage at four iron ore operations. The table also includes a breakdown of the sources of the water used; much of the water is recycled from plant operations. Industry has indicated that an average of 95 percent of the water appropriated by iron ore facilities is recirculated and reused according to the Iron Mining Association of Minnesota.

Table 2. Beneficiation Methods Commonly Associated With Iron Ores and the Percentage of Ore Treated by Each Method, 1990



Beneficiation Method	Percentage of Iron Ore Treated
Magnetic Separation	41.6
Flotation following Magnetic Separation	51.2
Subtotal	92.8
Flotation	6.3
Gravity Concentration	< 1[1]
Total	100

Table 3. Water Usage of Selected Iron Ore Operations and the Sources of the Water Used



Facility Name	Average Water Usage	Percent From Tailings Thickener Overflow	Percent From Tailings Basin	Percent From Mine Water Pumpout	Percent From Outside Sources
LTV Steel Mining Co.	150,000 gpm	75	20	0	5
Eveleth Mines	174,000 gpm	94	4	0	2
Minntac Mine	360,000 gpm	90	7	0	3
Minorca Mine	90,000 gpm	80	N/A	3	7

In 1984, the iron ore industry used a total of 652 billion gallons of water, down from a high of 849 billion gallons in 1973. Of the total water usage in 1984, approximately 584 billion gallons (90 percent) were recirculated water; 68 billion gallons were from new water sources. Sources of recycled water included tailings thickener overflow and tailings impoundments. New water was taken primarily from lakes and reservoirs (77 percent), rivers and streams (12 percent), mine water (10 percent), and ground water (<1 percent). New water replaces 11 billion gallons of water (2 percent) consumed in beneficiation processes and 57 billion gallons (8 percent) discharged offsite.

The amount of water used to produce one unit (one lt of crude ore) has increased considerably. In 1954, approximately 500 gallons of water were employed to produce 1 unit; in 1973, 3,480 gallons of water were needed per unit. By 1984, this number had risen to 3,700 gallons per unit. This increase was due to the industry's changeover from "natural" direct shipping ores to taconite mining. Additional water is needed in milling and magnetic separation of taconite ore according to the Iron Mining Association of Minnesota and the American Iron Ore Association.

Milling or Comminution of iron

Beneficiation begins with the milling of extracted ore in preparation for further activities to recover iron values. Milling operations are designed to produce uniform size particles by crushing, grinding, and wet or dry classification. The capital investment and operation costs of milling equipment are high. For this reason, economics plays a large part in determining the use of comminution equipment and the degree of crushing and grinding performed to prepare ore for further beneficiation. Other factors considered in determining the degree of milling include the value concentration of the ore, its mineralogy, hardness, and moisture content. Milling procedures vary widely both between mills and within individual mills depending on these variables.

Milling is a multi-staged process and may use dry or wet ore feed. Typically, primary milling which including crushing and screening take place at the mine site by using gyratory and cone crushers. Primary milling yields chunks of ore ranging in size from 6 to 10 inches. Secondary milling (comminution) further reduces particle size and prepares the ore for beneficiation processes that require finely ground ore feed. The product resulting from this additional crushing is usually less than 1 inch (1/2 to 3/4 inches). Secondary crushing, if necessary and economical, is accomplished by using standard cone crushers followed by short head cone crushers. Gyratory crushers may also be used. Subsequent fine grinding further reduces the ore particles to the consistency of fine powder (325 mesh, 0.0017 inches, 0.44 microns). The choice of grinding circuit is based on the density and hardness of the ore to be ground. Between each grinding unit, operation hydrocyclones are used to classify coarse and fine particles. Coarse particles are returned to the mill for further size reduction.

Gravity Concentration of iron

Although gravity concentration was once widely used in the beneficiation of iron ores, less than 1percent of total domestic iron ore was beneficiated using this method by the early 1990s (see Table 2). The decline of this method is chiefly due to the low cost of employing modern magnetic separation techniques and the exhaustion of high-grade hematite iron ores of the Mesabi Range.

Gravity concentration is used to suspend and transport lighter gangue (nonmetallic or nonvaluable rock) away from the heavier valuable mineral. This separation process is based primarily on differences in the specific gravities of the materials and the size of the particles being separated. Values may be removed along with the gangue material (tailings) despite differences in density if the particle sizes vary. Because of this potential problem, particle sizes must be kept uniform with the use of classifiers (such as screens and hydrocyclones). Three gravity separation methods have historically been used for iron ore: washers, jigs, and heavy-media separators.

Wastes from gravity concentration are tailings made up of gangue in the form of coarse and fine grained particles and process water. This material is pumped as a slurry to a tailings pond. The solid content of the slurry varies with each operation, ranging between 30 and 60 percent. Following separation of solids in a tailings pond, tailings water can be recycled to the mill or discharged.

Magnetic Separation

Magnetic separation is most commonly used to separate natural magnetic iron ore (magnetite) from a variety of less-magnetic or nonmagnetic material. Today, magnetic separation techniques are used to beneficiate over 90 percent of all domestic iron ore (See Table 2). Between 20 and 35 percent of all the iron units being beneficiated in the United States today are lost to tailings because hematite is only weakly magnetic. According to the Bureau of Mines, techniques used-to-date to try to recover the hematite have proven uneconomic.

Magnetic separation may be conducted in either a dry or wet environment, although wet systems are more common. Magnetic separation operations can also be categorized as either low or high intensity. Low intensity separators use magnetic fields between 1,000 and 3,000 gauss. Low intensity techniques are normally used on magnetite ore as an inexpensive and effective separation method. This method is used to capture only highly magnetic material, such as magnetite. High intensity separators employ fields as strong as 20,000 gauss. This method is used to separate weakly magnetic iron minerals, such as hematite, from nonmagnetic or less magnetic gangue material. Other factors important in determining which type of magnetic separator system is used include particle size and the solids content of the ore slurry feed.

Typically, magnetic separation involves three stages of separation: cobbing, cleaning/roughing, and finishing. Each stage may employ several drums in a series to increase separation efficiency. Each successive stage works on finer particles as a result of the removal of oversized particles in earlier separations. Cobbers work on larger particles (3/8 inch) and reject about 40 percent of the feed as tails. Cleaners or scavengers work on particles in the range of 48 mesh and remove only 10 to 15 percent of the feed as tails.

Finally, finishers work on ore particles less than 100 mesh and remove the remaining 5 percent of gangue (because of the highly concentrated nature of the feed at this point).

Low intensity wet processes typically involve conveyors and rotary drum separators using permanent magnets and are primarily used on ore particles 3/8 inch in diameter or less. In this process, ore is fed by conveyor into the separator where magnetite particles are attracted and held to sides of the drum until they are carried out of the magnetic field and transferred to an appropriate concentrate receiver. The nonmagnetic or less magnetic gangue material remains and is sent to a tailings pond. In some operations, several drums may be set up in series to obtain maximum recovery. Other mechanisms used include magnetic pulleys, induced roll separators, cross belt separators (see Figure 1), and ring-type separators. Low intensity dry separation is sometimes used in the cobbing stage of the separation process. A detailed description of these separator systems is provided in the Society of Mining Engineers' "Mineral Processing Handbook" (Weiss 1985).

High intensity wet separators produce high magnetic field gradients by using a matrix of shaped iron pieces that act as collection sites for paramagnetic particles. These shapes may include balls, rods, grooved plates, expanded metal, and fibers. A detailed description of several types of high intensity wet separators is provided by the Society of Mining Engineers' "Mineral Processing Handbook" (Weiss1985).

The primary wastes from this type of operation are tailings made up of gangue in the form of coarse and fine-grained particles, and waste water slurry in the case of wet separation. Particulate wastes from dry separation may also be slurried. Following separation of solids in a thickener or settling pond, solids are sent to a tailings impoundment and the liquid component can be recycled to the mill or discharged if water quality criteria are met.

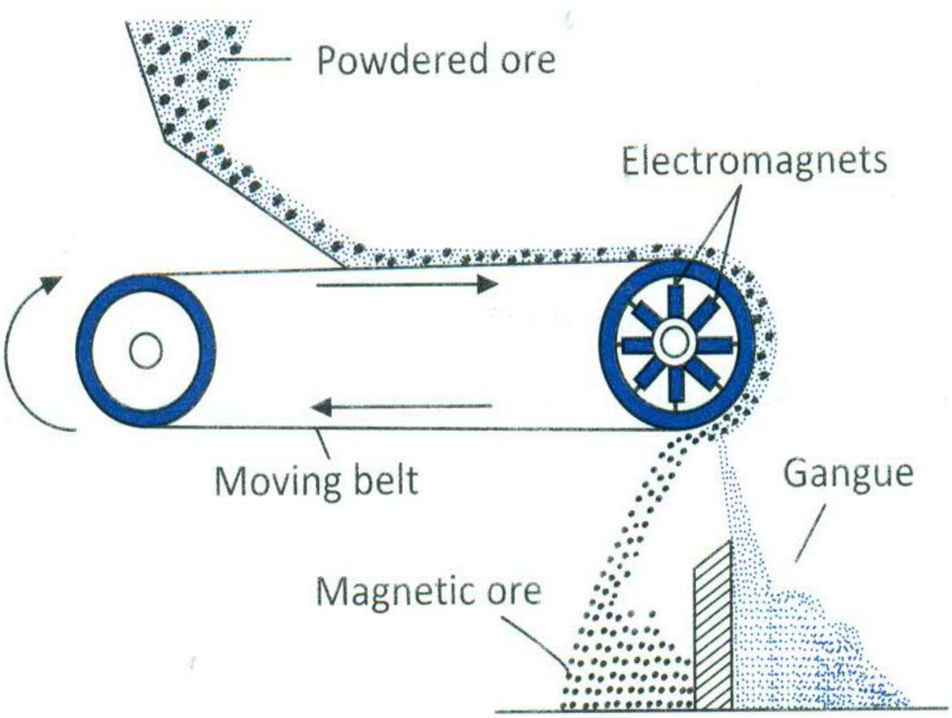


Figure 1 Cross Belt Separator

Flotation

Flotation is a technique where particles of one mineral or group of minerals are made to adhere preferentially to air bubbles in the presence of a chemical reagent. This is achieved by using chemical reagents that preferentially react with the desired mineral. Several factors are important to the success of flotation activities. These include uniformity of particle size, use of reagents compatible with the mineral, and water conditions that will not interfere with the attachment of the reagents to the mineral or air bubbles.

Today, flotation is primarily used to upgrade concentrates resulting from magnetic separation. Over 50 percent of all domestic iron ore is upgraded using this technique. Flotation, when used alone as a beneficiation method, accounts for approximately 6 percent of all ore treated (see Table 2).

Chemical reagents of three main groups may be used in flotation. A description of the function of each group follows:

- Collectors/Amines: Cause adherence between solid particles and air bubbles in a flotation cell.
- Frothers: Are used to stabilize air bubbles by reducing surface tension, thus allowing collection of valuable material by skimming from the top of the cell.
- Antifoams: React with particle surfaces in the flotation cell to keep materials from remaining in the froth. Instead, materials fall to the bottom as tailings.

Several factors are important when conditioning ore for flotation with chemical reagents. These include thorough mixing and dispersal of reagents through the pulp, repeated contact between the reagents and all of the relevant ore particles, and time for the development of contacts with the reagents and ore particles to produce the desired reactions.

Reagents may be added in a number of forms including solid, immiscible liquid, emulsion, and solution in water. The concentration of reagents must be closely controlled during conditioning; adding more reagent than is required may retard the reaction and reduce efficiency.

Figure 2 presents a cross section of a typical flotation cell. The current trend is toward the development of larger, more energy efficient flotation cells. A pulp containing milled ore, flotation reagents, and water is fed to flotation cells. Typically, 10 to 14 cells are arranged in a series from roughers to scavengers. Roughers are used to make a coarse separation of minerals (values) from the gangue. Scavengers recover smaller quantities of remaining values from the pulp. The pulp moves from the rougher cells to the scavengers as values are removed. Concentrates recovered from the froth in the roughing and scavenging cells are sent to cleaning cells to produce the final iron-bearing metallic mineral concentrate.

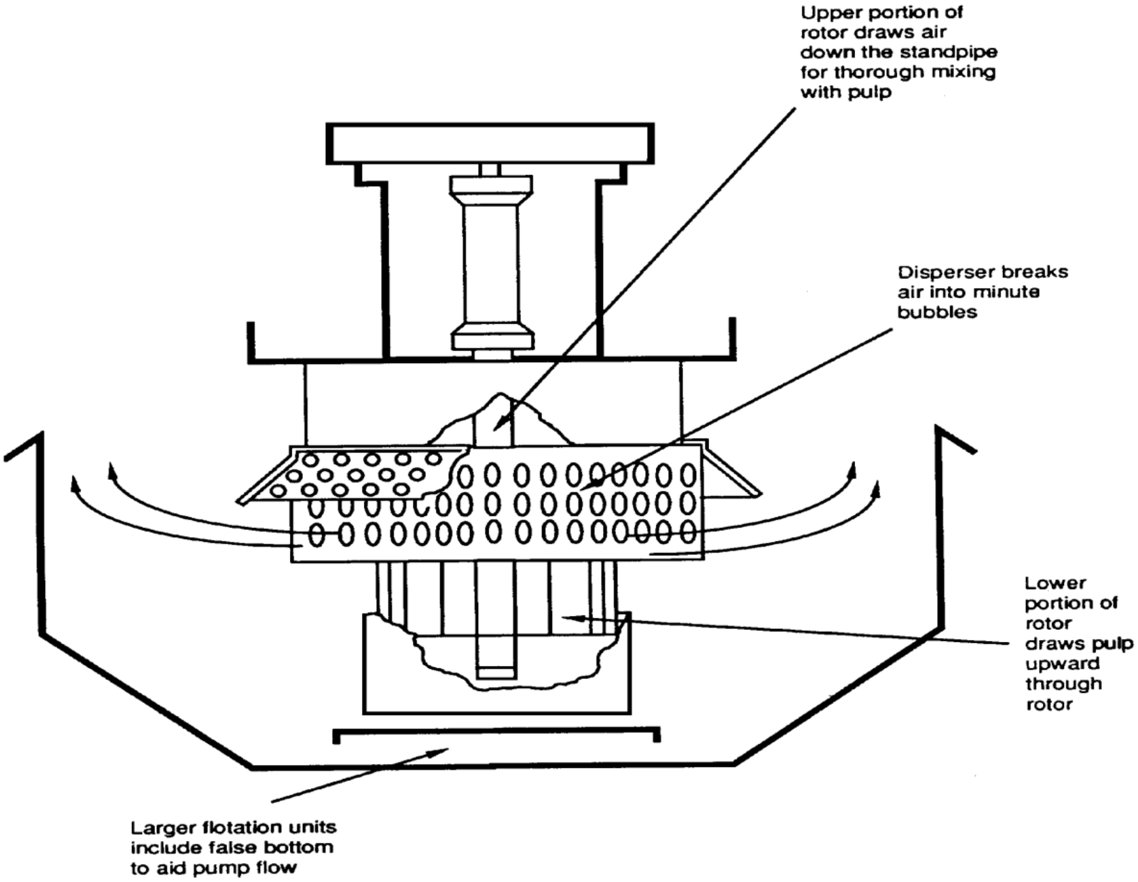


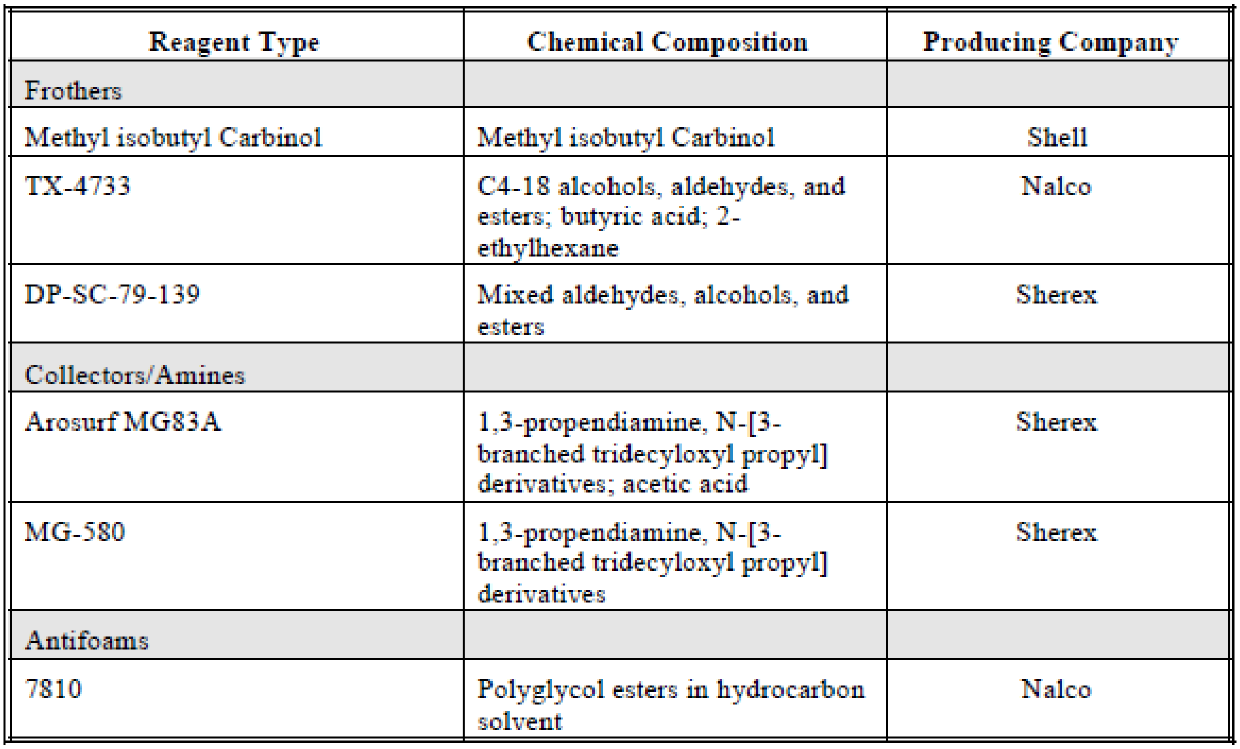
Figure 2. Cross-Section of a Typical Flotation Cell

Iron-bearing metallic mineral flotation operations are of two main types: anionic and cationic. The difference between the two methods is related to which material (values or gangue) is floated and which sinks. This is determined by preliminary test results, weight relationships of the values and gangue, and the type of reagents used. In anionic flotation, fine-sized crystalline iron oxides, such as hematite or siderite, are floated away from siliceous gangue material such as quartz or chert. In cationic flotation, the silica material is floated and the value-bearing minerals are removed as underflow.

Today, anionic flotation is not commonly used in North American operations. Three plants in Michigan (the Humboldt Mine, the Groveland Mine, and the Republic Mine) used anionic flotation techniques before shutting down because of the depletion of reserves or the reduction of demand for iron products.

The Tilden Mine operation owned by the Cleveland-Cliffs Company is one of any facilities currently using cationic flotation as part of its iron ore beneficiation process. Some of the reagents commonly used in the cationic flotation process are listed in Table 4. The resulting upgraded concentrate may be reground and magnetically reconcentrated before agglomeration activities commence.

Table 4. Reagents Commonly Used In Iron Ore Flotation Activities



Reagent Type	Chemical Composition	Producing Company
Frothers		
Methyl isobutyl Carbinol	Methyl isobutyl Carbinol	Shell
TX-4733	C4-18 alcohols, aldehydes, and esters; butyric acid; 2-ethylhexane	Nalco
DP-SC-79-139	Mixed aldehydes, alcohols, and esters	Sherex
Collectors/Amines		
Arosurf MG83A	1,3-propendiamine, N-[3-branched tridecyloxyl propyl] derivatives; acetic acid	Sherex
MG-580	1,3-propendiamine, N-[3-branched tridecyloxyl propyl] derivatives	Sherex
Antifoams		
7810	Polyglycol esters in hydrocarbon solvent	Nalco

The use of flotation techniques by operations such as the Minntac Mine has enabled the facility to produce pellets containing less than 4 percent silica. Lower silica content and higher iron concentrations in the pellets being produced result in an improved productivity and energy efficiency at blast furnaces. This may be particularly true at newly developed direct reduction electric furnaces should the economics become favorable in the future. Such furnaces produce a direct-reduced iron product that can then be used as a feed to a steel producing electric furnace according to the American Iron Ore Association and the Iron Mining Association of Minnesota.

Wastes from the flotation cell are collected from the tailings overflow weir. Depending on the grade of the froth, it is recycled for further recovery of iron units or discharged as tails. Tailings contain remaining gangue, unrecovered iron minerals, chemical reagents, and process waste water. Generally, tailings proceed to a thickener prior to going to a tailings impoundment. The solids content of the

slurry varies with each operation, ranging between 30 and 60 percent. After thickening, tailings may be pumped to an impoundment, solids may be recycled for further beneficiation to collect remaining values, and clarified water may be returned to the milling process. In the tailings pond, solids are settled out of the suspension and the liquid component may be recycled to the mill. It should be noted that the chemical reagents used in flotation generally adhere to the tailings particles and remain in the tailings impoundment.

Thickening/Filtering

Thickeners (see Figure 3) are used to remove most of the liquid from slurried concentrates and waste slurries (tailings). Thickening techniques may be employed in two phases of iron ore production: concentrates are thickened to reduce moisture content and reclaim water before agglomeration, and slurried tailings are thickened to reclaim water. Facilities usually employ a number of thickeners concurrently.

Typically, iron ore operations use continuous thickeners equipped with a raking mechanism to remove solids. Several variations of rakes are commonly used in thickeners. When concentrates are being thickened, underflow from the thickener (concentrate) is collected and may be further treated in a vacuum filter. The filter removes most of the remaining water from the concentrate.

The liquid component removed during the thickening process may contain flotation reagents, and/or dissolved and suspended mineral products. The liquid is usually recycled to a holding pond to be reused at the mill. When concentrates are thickened, the solid material resulting from these operations is collected as a final concentrate for agglomeration and processing. Thickened tailings are discharged to a tailings impoundment.

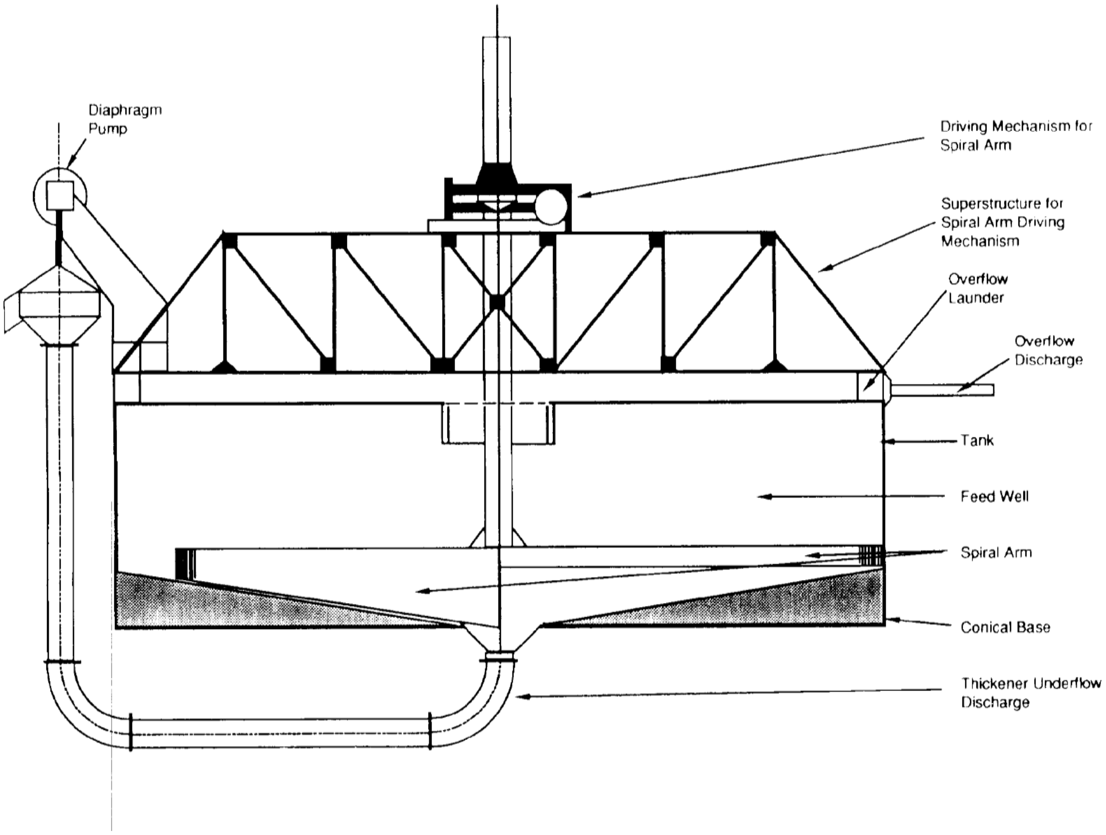


Figure 3Thickener

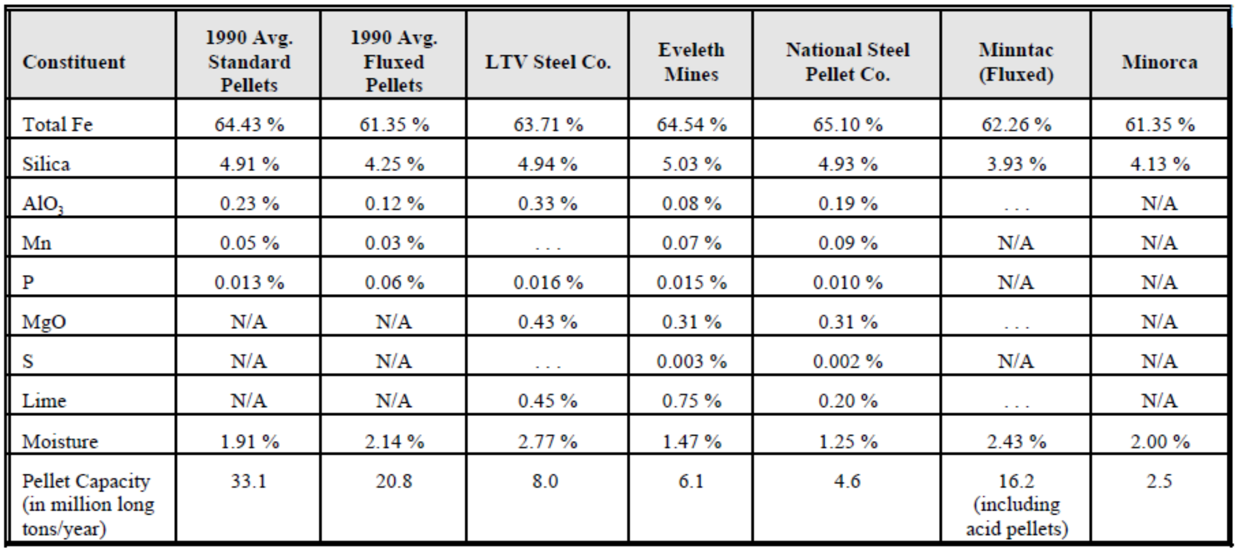
Agglomeration

After concentration activities, agglomeration is used to combine the resulting fine particles into durable clusters. The iron concentrate is balled in drums and heated to create a hardened agglomerate. Agglomerates may be in the form of pellets, sinter, briquettes, or nodules. The purpose of agglomerating iron ore is to improve the permeability of blast furnace feed leading to faster gas-solid contact in the furnace. Agglomerating the ore prior to being sent to blast furnaces reduces the amount of coke consumed in the furnace by increasing the reduction rate. It also reduces the amount of material blown out of the furnace into the gas-recovery system.

Historically, the four types of agglomerate products mentioned have been produced in varying amounts. Today, however, pellets account for more than 97 percent of all agglomeration products. Because of this, only the pelletizing technique will be discussed in this report. It should be noted, however, that the other agglomerates mentioned above are produced by similar high-temperature operations.

Pelletizing operations produce a "green" (moist and unfired) pellet or ball, which is then hardened through heat treatment. These pellets are normally relatively large (3/8 to 1/2 inch) and usually contain at least 60 percent iron. Pellets must be strong enough to withstand abrasion during handling, transport, and high temperature treatment within the furnace. It is also important for the material to be amenable to relatively rapid reduction (removal of oxygen) in the blast furnace. Bentonite is often added as a binder to form green pellets prior to agglomeration. In addition to iron, pellet constituents can include silica, alumina, magnesia, manganese, phosphorus, and sulfur. Additives such as limestone or dolomite may also be added to the concentrate in a process known as "fluxing," prior to balling to improve blast furnace recovery. In the past, these constituents were added in the blast furnace. However, the development of fluxed pellets, which incorporate the flux in the pellet material, has been shown to increase furnace efficiency. The composition of pellets produced by five taconite facilities is compared in Table 4.

Table 4. Chemical Composition of Average 1990 Standard and Fluxed Pellets and Pellets From Five Iron Ore Operations, 1990



Constituent	1990 Avg. Standard Pellets	1990 Avg. Fluxed Pellets	LTV Steel Co.	Eveleth Mines	National Steel Pellet Co.	Minntac (Fluxed)	Minorca
Total Fe	64.43 %	61.35 %	63.71 %	64.54 %	65.10 %	62.26 %	61.35 %
Silica	4.91 %	4.25 %	4.94 %	5.03 %	4.93 %	3.93 %	4.13 %
AlO_3	0.23 %	0.12 %	0.33 %	0.08 %	0.19 %	. . .	N/A
Mn	0.05 %	0.03 %	. . .	0.07 %	0.09 %	N/A	N/A
P	0.013 %	0.06 %	0.016 %	0.015 %	0.010 %	N/A	N/A
MgO	N/A	N/A	0.43 %	0.31 %	0.31 %	. . .	N/A
S	N/A	N/A	. . .	0.003 %	0.002 %	N/A	N/A
Lime	N/A	N/A	0.45 %	0.75 %	0.20 %	. . .	N/A
Moisture	1.91 %	2.14 %	2.77 %	1.47 %	1.25 %	2.43 %	2.00 %
Pellet Capacity (in million long tons/year)	33.1	20.8	8.0	6.1	4.6	16.2 (including acid pellets)	2.5

(American Iron Ore Association 1991; U.S. DOI, Bureau of Mines 1991b). Since their development in the late 1980's, fluxed pellets have gained in popularity. In 1989, standard pellets accounted for 73 percent of total pellet production, while fluxed pellets accounted for 24 percent. By 1990, about 40 percent of Minnesota pellet output was fluxed. According to the Bureau of Mines, North American iron industry pellet production was about 38 percent fluxed in 1990. The first step in pelletizing iron concentrates is forming the pellets. This is usually accomplished in a series of balling drums or discs. The pellets are formed by the rotating of the drums, which act to roll the iron concentrate into balls. One of three different systems may then be used to produce hardened pellets:

- Travelling-Grate—Is used to produce pellets from magnetite concentrates obtained from taconite ores. Green pellets are fed to a travelling grate, dried, and preheated. The pellets then proceed to the ignition section of the grate where nearly all the magnetite is oxidized to hematite. An updraft of air is then used to cool the pellets.
- Shaft-Furnace—Green pellets are distributed across the top of a furnace by a moving conveyor belt, then pass vertically down the length of the furnace. In the furnace, the pellets are dried and heated to 2400 F. The bottom 2/3 of the furnace is used to cool the pellets using an upward-rising air stream. The pellets are discharged from the bottom of the system through a chunk breaker.
- Grate-Kiln—Combines the grate technique with a rotary kiln. No fuel material is incorporated into or applied to the pellets in this process. The pellets are dried and preheated on a travelling grate before being hardened by high-temperature heating in the kiln. The heated gas discharge from the kiln is recycled for drying and preheating (United States Steel 1973).

Agglomeration generates byproducts in the form of particulates and gases, including compounds such as carbon dioxide, sulfur compounds, chlorides, and fluorides that are driven off during the production process. These are usually treated using cyclones, electrostatic precipitators (wet and dry), and scrubbing equipment. These treatment technologies generate either a wet or a dry effluent, which contains valuable iron units and is commonly recycled back into the operation according to the American Iron Ore Association and the Iron Mining Association of Minnesota.

Extraction of materials

EXTRACTION OF IRON IN A BLAST FURNACE

Iron is also below carbon in the reactivity series, so therefore carbon can be used to reduce it (note: reduction can also mean to remove the oxygen from a compound). This is done in a blast furnace.
The most common ore of iron is called haematite (iron(iii) oxide). Its formula is Fe_2O_3, pyrite FeS_2, magnetite Fe_3O_4, and siderite $FeCO_3$.

Process:

- high temperature
- continuous
- reduction of iron ores by carbon / carbon monoxide in the blast furnace
- possible because iron is below carbon in the reactivity series

Raw materials : Haematite is added to the top of the furnace along with coke (i.e. carbon) and limestone

Iron ore**:** Fe_2O_3 – haematite
Coke (90-93% C)**:** fuel / reducing agent - cheap and plentiful (the coke is produced from a mixture of coals. The coal is crushed and ground into a powder and then charged into an oven. As the oven is heated the coal is cooked so must of the volatile matter such as oil and tar are removed.

Air**:** for combustion of fuel
***Limestone* :** for conversion of silica into slag (calcium silicate) which is used in the construction industry

Reactions:

Firstly, the carbon in the blast furnace burns with the hot air to form carbon dioxide. This reaction produces a lot of heat, and is the main source of heat in the furnace.

$$C_{(s)} + O_{2(g)} \longrightarrow CO_{2(g)}$$

The heat produced by the reaction brings about the next reaction. At the bottom of the furnace, the temperature is very high. Here, the carbon dioxide reacts with more carbon to form carbon monoxide.

$$C_{(s)} + CO_{2(g)} \longrightarrow 2CO_{(g)}$$

At this point, the reaction takes a slightly different turn. Some of the iron(iii) oxide reacts with carbon to form pure iron (along with carbon monoxide). However, most of it reacts with carbon monoxide, which is the main reducing agent of iron(iii) oxide. This produces pure iron and carbon dioxide.

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

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

Limestone decomposes on heating:

Limestone (calcium carbonate) is added to the furnace at the beginning for a particular reason. Iron ores such as haematite are not in their pure form; they are mixed with other rocky bits which would not melt in the furnace, and would eventually clog it up. The limestone is broken down by the heat in the furnace to form calcium oxide and carbon dioxide:

$$CaCO_3 \longrightarrow CaO + CO_2$$

Slag production

- Silica is found with the iron ore
- It is removed by reacting it with limestone
- Calcium silicate (SLAG) is produced
- Molten slag is run off and cooled
- It is used for building materials

Calcium oxide combines with silica

The main impurity found in iron ore (i.e. the "rocky bit" that iron ore is often found mixed with) is sand, or silicon dioxide. The calcium oxide reacts with silicon dioxide to form calcium silicate:

$$CaO + SiO_2 \longrightarrow CaSiO_3$$

Overall $$CaCO_3 + SiO_2 \longrightarrow CaSiO_3 + CO_2$$

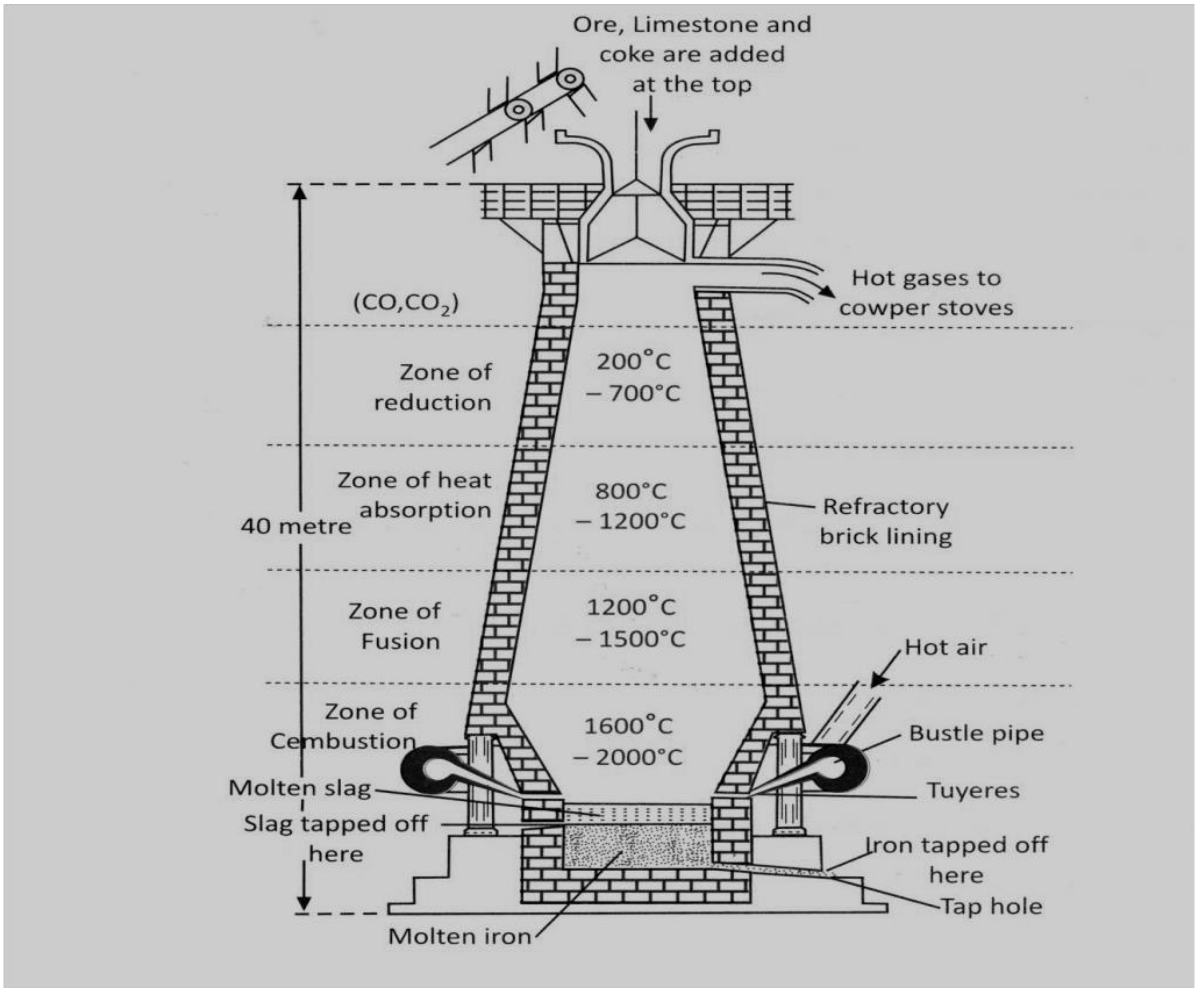
Pollution

- **SO_2** from sulphur in the fuel and sulphides in the ore gives rise to acid rain

$S + O_2 \longrightarrow SO_2$

$SO_2 + H_2O \longrightarrow H_2SO_3$ *sulphurous acid*

- **CO_2** burning fossil fuels increases the amount of this greenhouse gas



Blast Furnace

Limitations Theoretically, several other important metals can be extracted this way but are not because they **combine with the carbon to form a carbide**

e.g. Molybdenum, Titanium, Vanadium, Tungsten

Usefulness Iron produced from the Blast Furnace contains a lot of carbon which makes it brittle.

To make it more useful, most iron is made into steel.

The term ***pig iron*** is generally applied to the metallic product of the blast furnace when it contains over 90% iron. The iron obtained by this process is known as 'pig' or cast iron and contains about 4% carbon (as well as some other impurities). The name pig iron arises from the fact that if it is not subsequently converted into steel it is poured into moulds called pigs. Because of its brittle and hard nature, the iron produced by this process has limited use. Gas cylinders are sometimes made of cast iron, since they are unlikely to get deformed during their use.

STEEL MAKING

The 'pig iron' obtained from the blast furnace contains between 3% and 5% of carbon and other impurities, such as sulphur, silicon and phosphorus. These impurities make the iron hard and brittle. In order to improve the quality of the metal, most of the impurities must be removed and in doing this, steel is produced.

The impurities are removed in the ***basic oxygen process***, which is the most important of the steel-making processes. In this process:

Process:

- Molten pig iron from the blast furnace is poured into the basic oxygen furnace.
- A water-cooled 'lance' is introduced into the furnace and oxygen at 5-15 atm pressure is blown onto the surface of the molten metal.
- Carbon is oxidised to carbon monoxide and carbon dioxide, while sulphur is oxidised to sulphur dioxide. These escape as gases.
- Silicon and phosphorus are oxidised to silicon (IV) oxide and phosphorus pentoxide, which are solid oxides.
- Some calcium oxide (lime) is added to remove these solid oxides as slag. The slag may be skimmed or poured off the surface.
- Samples are continuously taken and checked for carbon content. When the required amount of carbon has been reached, the blast of oxygen is turned off.
- The basic oxygen furnace can convert up to 300 tonnes of pig iron to steel per hour.

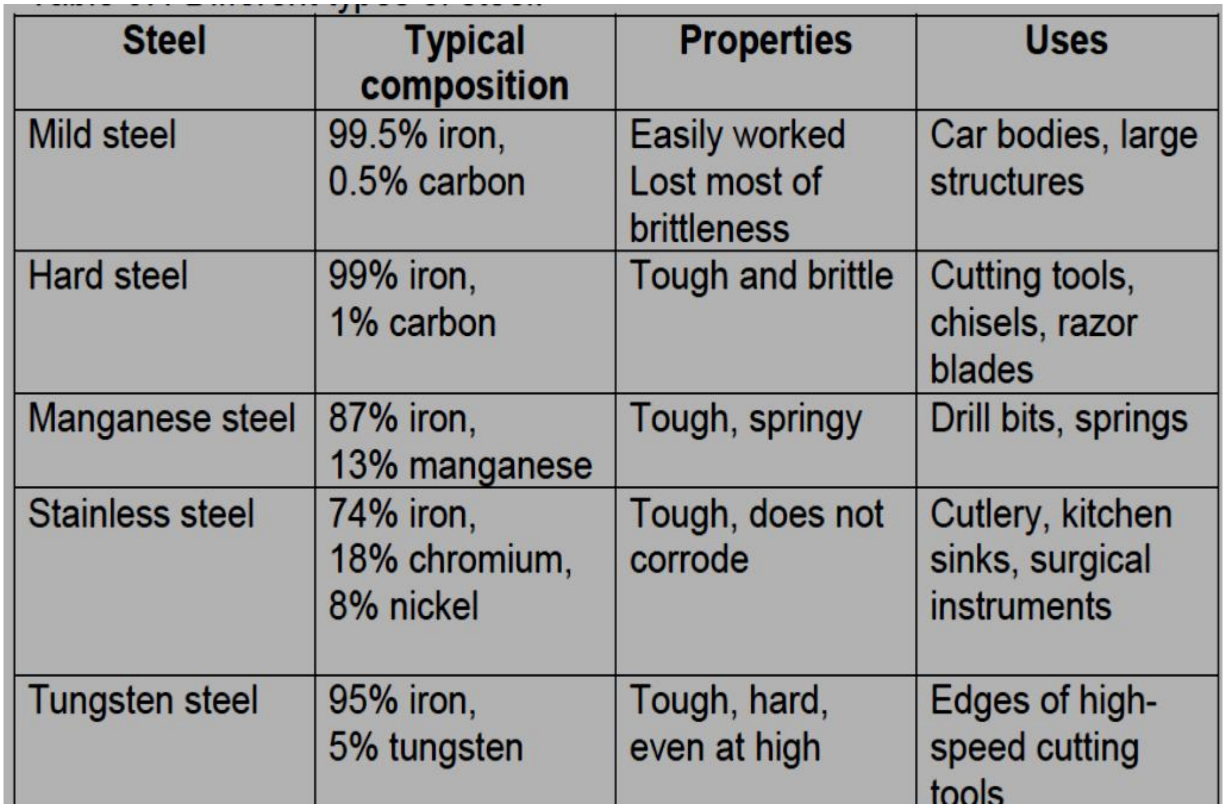
There are various types of steel that differ only in their carbon content. The differing amounts of carbon present confer different properties on the steel and they are used for different purposes (as shown in below Table). If other types of steel are required then up to 30% scrap steel is added, along with other metals (such as tungsten), and the carbon is burned off.

In the ***Basic Oxygen Process***, excess carbon is burnt off in a converter and the correct amount of carbon added to make steel. Other metals (e.g. chromium) can be added to make specialist steels.

Removal of impurities:

SILICA	add calcium oxide	$\mathbf{CaO + SiO_2 \longrightarrow CaSiO_3}$
CARBON	burnt off using oxygen	$\mathbf{C + O2 \longrightarrow CO_2}$
PHOSPHORUS	burnt off using oxygen	$\mathbf{2P + 5O_2 \longrightarrow P_4O_{10}}$
SULPHUR	magnesium is added	$\mathbf{Mg + S \longrightarrow MgS}$

Table: Different types of Steel



Steel	Typical composition	Properties	Uses
Mild steel	99.5% iron, 0.5% carbon	Easily worked Lost most of brittleness	Car bodies, large structures
Hard steel	99% iron, 1% carbon	Tough and brittle	Cutting tools, chisels, razor blades
Manganese steel	87% iron, 13% manganese	Tough, springy	Drill bits, springs
Stainless steel	74% iron, 18% chromium, 8% nickel	Tough, does not corrode	Cutlery, kitchen sinks, surgical instruments
Tungsten steel	95% iron, 5% tungsten	Tough, hard, even at high	Edges of high-speed cutting tools

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EXTRACTION OF ALUMINIUM

Introduction

Aluminum has many useful properties. It is the commonest metal in the rocks of the Earth's crust. About 8% of the crust is aluminium, not the metal itself but combined with other elements as natural minerals, such as bauxite.

MAIN PROPERTIES OF ALUMINIUM

1. An excellent conductor of heat and electricity.
2. Aluminium does not rust, it resists corrosion.
3. Low density compared with other common metals.
4. Good reflector of heat and light, it has a good metallic lustre (surface shine).
5. Nonmagnetic.
6. Can be alloyed to form stronger or harder alloys than pure aluminium.
7. Easily workable. It can be rolled into sheets, foil, and wire; cast or forged into useful shapes.

- **Aluminium ores are**

Bauxite $Al_2O_3.nH_2O$ (Main)

Gibbisite $Al_2O_3.3H_3O$

Diaspore $Al_2O_3.H_2O$.

It contains impurities as well as aluminium oxide. The bauxite must be purified to give alumina (Al_2O_3).

Bauxite is the most important aluminous ore for the production of alumina. Bauxite occurs close to the surface in seams varying from one meter to nine meters, formed as small reddish pebbles (pisolites). Bauxite contains 40 to 60 mass% alumina combined with smaller amounts of silica, titania and iron oxide. Alumina is mainly extracted from bauxite using **Bayer Process.**

- Aluminium is a very reactive metal, much more reactive than copper, iron or lead. Other metals have been extracted for thousands of years by heating them with carbon (smelting). Carbon is also needed to extract aluminium, but in a completely different way.
- **Ore dressing**– cleaning ore by means of separation of the metal containing mineral from the waste (gangue).

Bayer Process

- The bauxite ore is crushed and ground to produce slurry of coarse powder particles suspended in water.

- Sodium hydroxide (caustic soda) NaOH is added, and the slurry is heated with process steam to 160-180oC in a steel reactor or autoclave with pressure. The aluminum-containing hydroxides are dissolved during this digestion process, but other constituents of the bauxite remain solid.

$$2NaOH + Al_2O_3.nH_2O \longrightarrow 2NaAlO_2 + (n+1)\ H_2O$$

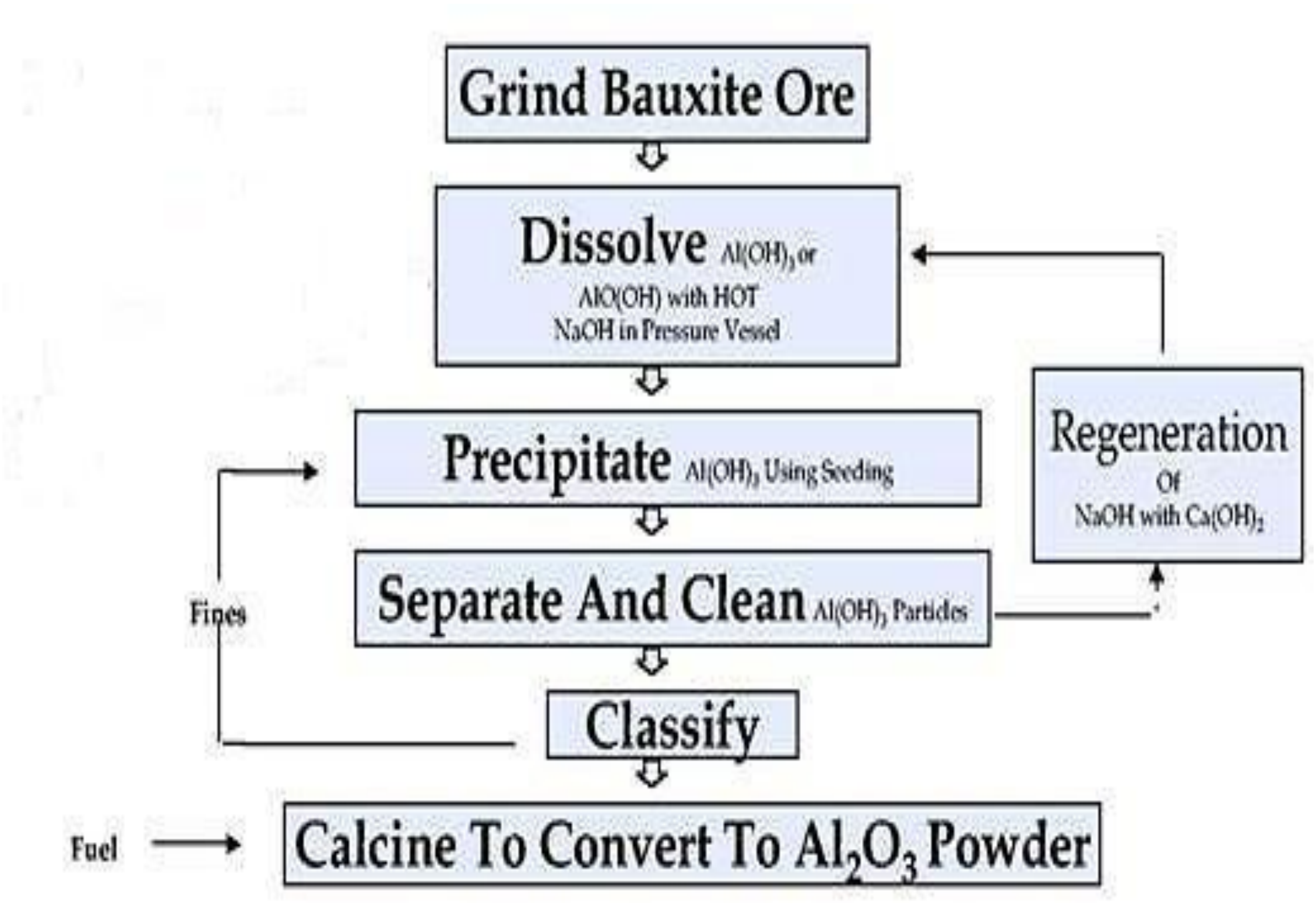
- The digested bauxite suspension, which contains solids plus dissolved Al compounds, is referred to as pregnant liquor. It leaves the digester at about boiling temperature and passes through several stages of filtration referred to as clarification.

- Precipitation is conducted in large flat-bottomed tanks about 30 m high and 10-12 m in diameter with typically 10 to 14 in a series. Cooled supersaturated liquor enters the first tank, and particles of aluminum hydroxide begin to precipitate. Seeds (small particles of aluminum hydroxide) are added to accelerate precipitation.

- Classification in which the aluminum hydroxide particles are separated from the liquor by a combination of cyclones and hydroclassifiers. The coarser particles proceed to the calciner. The finer particles are recycled as seeds.

- Calcination is the final step of the Bayer process. The particles are dried and heated to 1100C in either a rotary kiln (a tubular-shaped furnace that rotates as the powder passes through) or a fluidized bed (the kiln is stationary, but the powder is mixed by air bubbled through the powder bed).

- The aluminum hydroxide $Al(OH)_3$ (is decomposed to form aluminum oxide (Al_2O_3) particles suitable for the Hall-Heroult electrolytic smelting process. **Alumina (aluminium oxide Al_2O_3)** obtained is a fine white material similar in appearance to salt. Alumina is also used in abrasive, ceramics and refectory industries.



- Carbon can be used to extract metals lower in the series, ones which are less reactive than carbon. For example, iron from iron oxide (haematite) or tin from tin oxide (cassiterite).
- Carbon is less reactive than aluminium. This is why we need a different method, electrolysis, to extract aluminium from its oxide (bauxite). The rule is: Carbon can displace less reactive metals from their ores.
- The carbon forms the anode block and the lining of the pot (the electrolytic cell), the cathode. As electricity flows between them the alumina splits into liquid aluminium metal and oxygen gas.

Dissolved alumina → aluminium metal + oxygen gas

The key to this method of extracting aluminium (Hall-Heroult process) was to find a material which could dissolve the alumina. A natural ore called cryolite was used, although the cryolite is prepared artificially now. Each pot can produce about one ton of aluminium each day. The hot liquid metal is removed regularly from the pot and cast into blocks or ingots.

Cryolite - is the main constituent of the electrolyte used in alumina electrolysis. Chemically it is Na_3AlF_6, a double fluoride of sodium and aluminium. It is a white granular powder. Certain impurities may give it a grey or pink discoloration. The freezing point of cryolite is 1009°C.

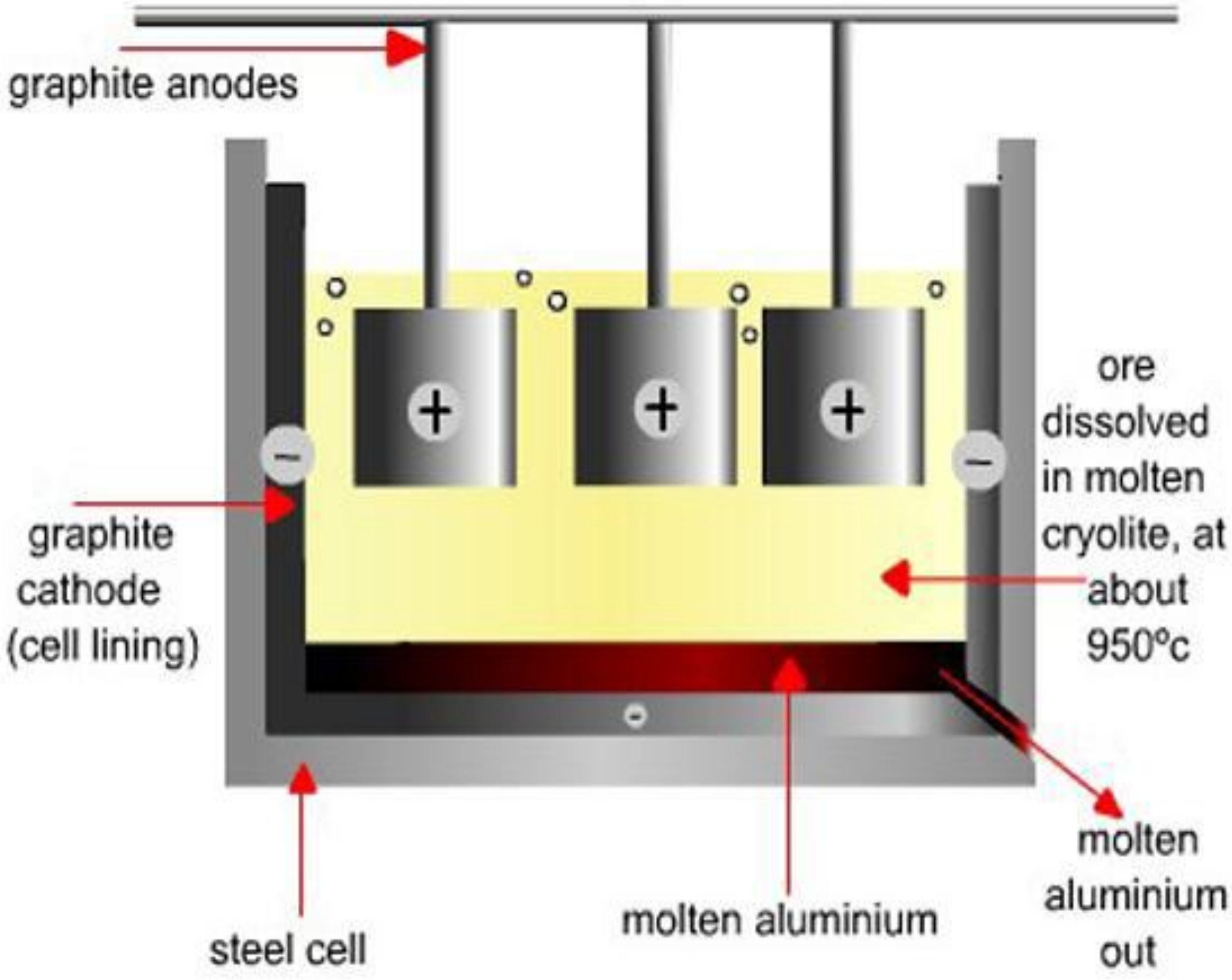
Synthetic Cryolite is made from fluorspar (CaF_2), which is found as a natural mineral. Fluorspar is treated with sulphuric acid to produce hydrofluoric acid HF.

$$\mathbf{CaF_2 + H_2SO_4 \xrightarrow{\qquad} 2HF\ (g) + CaSO_4\ (s)}$$

HF is then reacted with sodium oxide Na_2O and alumina to produce cryolite.

$$\text{Cryolite ratio} = \frac{\text{Molar Ratio of NaF}}{\text{Molar Ratio of } AlF_3}$$

CRYOLITE



In principle, aluminium could be produced by melting aluminium oxide (alumina) and passing an electric current through it. Unfortunately the oxide is a refractory material with an exceptionally high melting point of about 2000oC. Refractories are used to line furnaces.

The function of cryolite is to lower the melting point of aluminium oxide. By dissolving the alumina in a second aluminium compound (cryolite, Na_3AlF_6) the extraction process can operate at a more economical temperature of 950C. There is very little alumina in the melt, about 5% alumina and 95% cryolite. Fresh alumina is added regularly as the electrolysis proceeds.

When electric current passes between the anodes and the cathode through the cryolite, aluminum oxide decomposes to metallic aluminum deposited at the cathode and oxygen liberated at the anode. The molten aluminum is periodically tapped from the furnace into a crucible and cast into ingots.

Electrode Reactions

The carbon cathode (negative electrode) is the lining of the pot.

$4Al^{3+} + 12e^{-} \longrightarrow$ 4Al metal (Reduction) At the cathode

The aluminium ions gain electrons from the cathode and become aluminium atoms.

The carbon anodes (positive electrodes) are made by baking a mixture of **petroleum coke** and **pitch** (مزيج (القار او الزفت) و(فحم الكوك النفطي)). Carbon (graphite) is the only non-metal that is a good conductor of electricity.

$6O^{-2} - 12e^{-} \longrightarrow 3O_2$ (Oxidation) At the anode

The oxide ions lose electrons to the anode and become oxygen gas. There is a problem when hot carbon (the anode) comes into contact with oxygen. The anode burns away to form carbon monoxide and carbon dioxide gases. The anode is slowly lowered into the melt as the surface burns away.

$2C + O_2 \longrightarrow 2CO$ $\qquad$ $C + O_2 \longrightarrow CO_2$

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Extraction of Magnesium from ore oxide

Magnesium is the sixth most abundant element in the earth's crust.

The main sources of magnesium compounds are:

- Seawater (magnesium chloride, $MgCl_2$) and minerals:
- Dolomite ($CaCO_3 \bullet MgCO_3$), contain 13%.
- Magnesite ($MgCO_3$), contain 29%.
- Brucite $Mg(OH)_2$, contain 42%.

There are two principal magnesium extraction processes: silicothermic process and electrolytic process.

I. Silicothermic process (Pidgeon process)

The process involves reducing molten magnesium oxide slag by ferrosilicon under low gas pressure at a temperature of about 1400ºC.

The metallic magnesium, formed in the process, evaporates and then condensates away from the hot region.

The condensed magnesium, having purity of 99.95% is then remelt and cast.

The Three Steps of the Pidgeon Process are:

1. ***Calcination of Dolomite***, at 1300^{o}C, Highly Endothermic Reaction, CO_2 Released both from the reaction, and from Fuel Burned for Process Heat.

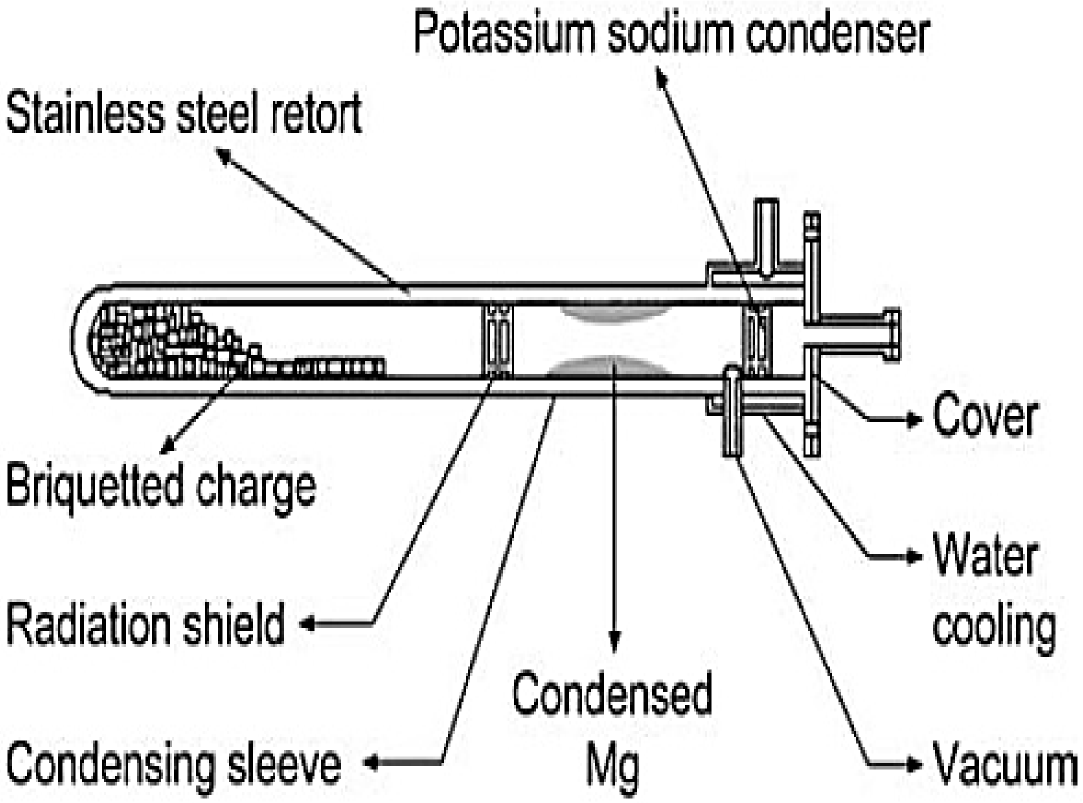
$$\mathbf{CaMg(CO_3)_2 \longrightarrow CaO + MgO + 2CO_2}$$

2. ***Ferrosilicon Alloy Production***, the Ferrosilicon Alloy Production by Electric Arc through Mixture of Hematite, Quartz Sand, and Coal. Extremely Endothermic Reaction; Emits Toxic CO.

$$\mathbf{Fe_2O_3 + 4SiO_2 + 11C \longrightarrow 2(Fe)Si_2 + 11CO}$$

3. ***Silicothermic Reduction of MgO by Ferrosilicon,*** at ~1400^{o}C under Vacuum for 8-10 hrs. Highly Endothermic Reaction, the ratio of feed are 6 calcine dolomite: 1 ferrosilicon as briquettes.

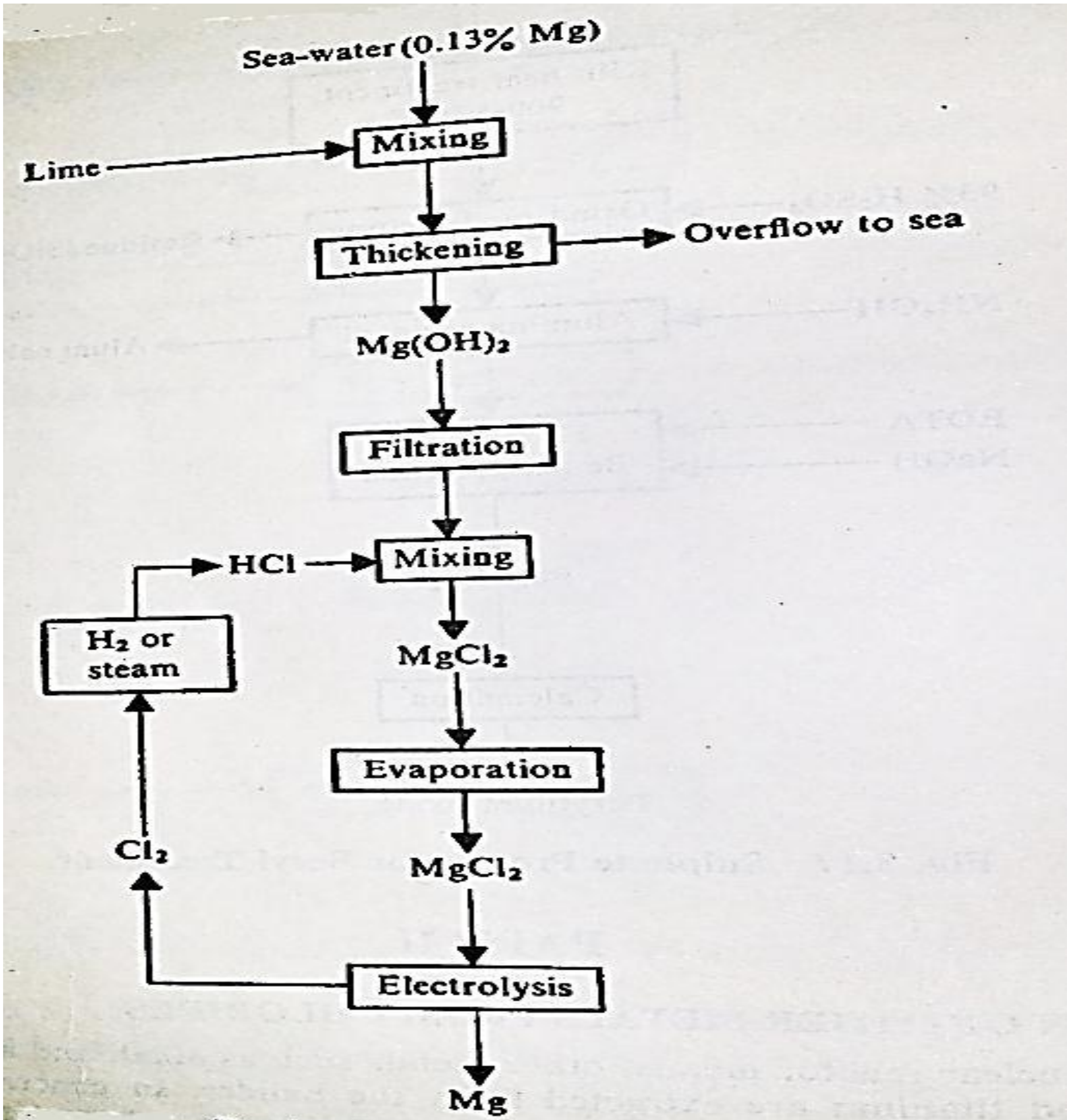
$$\mathbf{2MgO + 2CaO + (Fe)Si \longrightarrow 2Mg\ (g) + Ca_2SiO_4\ (s) + Fe}$$



II. Dow Process (Electrolysis)

The Dow Process is generally applied for extraction of Magnesium from Sea water. In this process first we add lime for thickening then mix with 10% HCl.

The electrolytic cell consists of a brick-lined vessel, divided into anode and cathode compartments by a semi-wall. Air- or water-cooled Graphite plate anode and steel cathode are submerged in electrolyte composed of alkaline chlorides with addition of magnesium chloride. The operating temperature is 680°C to 750°C. Magnesium chloride decomposes in the electrolytic cell according to the reaction:



Production of Magnesium from Sea-Water.

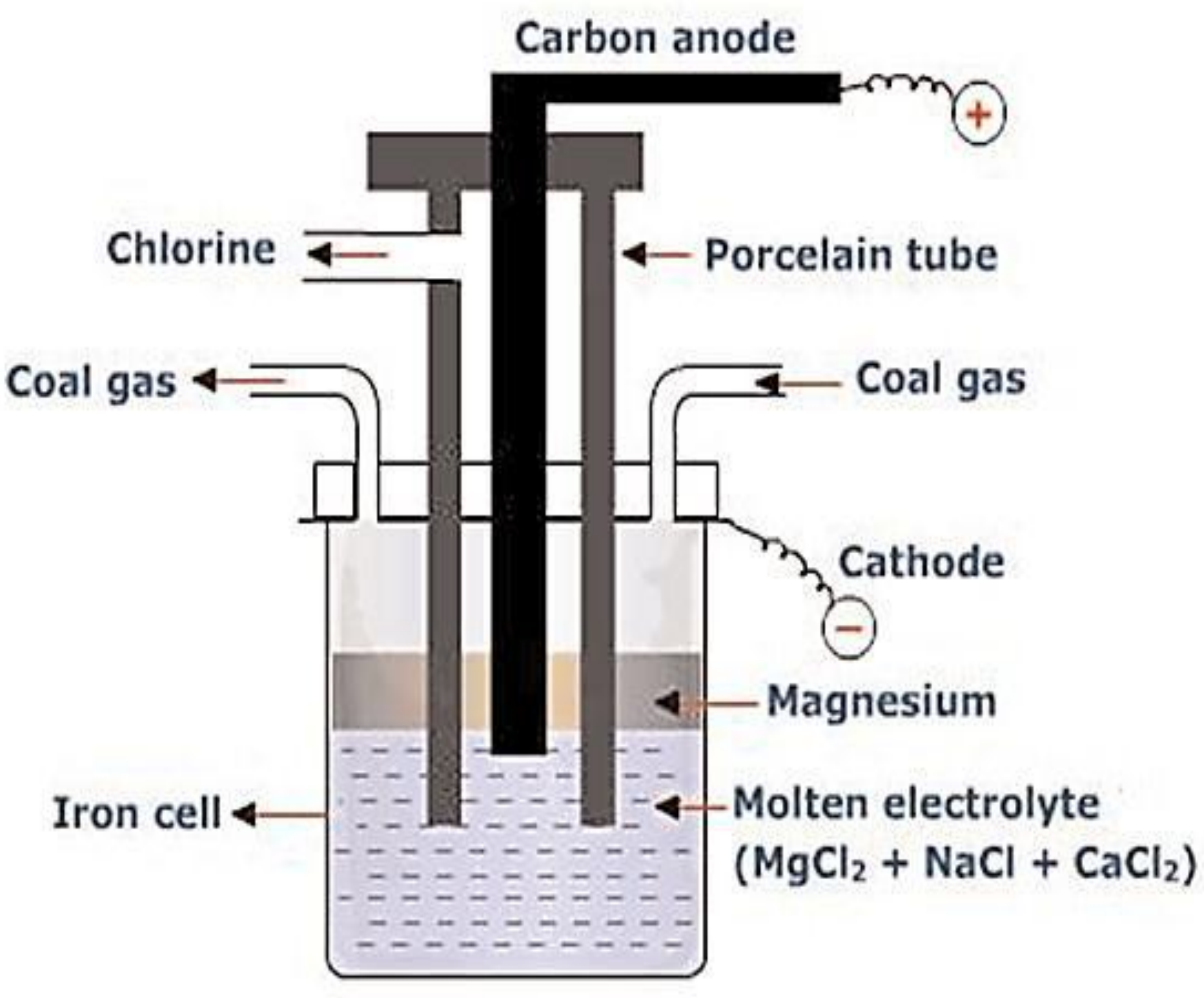
$MgCl_2 \longrightarrow Mg + Cl_2$ (g) (Ionization)

$Mg + 2e \longrightarrow Mg$ (at the Cathode)

$2Cl - 2e \longrightarrow Cl$ (at the Anode)

Metallic magnesium is formed at the cathode. It floats up (it is lighter than electrolyte) collecting in the cathode compartment. Chlorine, which is by-product of the process, is collected in the anode compartment.

In this method CaCl2 and NaCl are added to anhydrous $MgCl_2$ to decrease its melting point.



Dow Cell

Extraction of Zinc from Ore Sulphide

Overview:

- Zn is white silver color with melting point: 420°C.
- Density:7.13 g/cm^3
- Used to coat steel to protect it from corrosion at room temperature and for decorative finish.
- Fast rate of die casting. (ex. toys, car parts…etc.)

Electrochemical treatment *Ores:*

- Zinc blende or Sphalerite (ZnS)
- Marmatite (ZnFe)S.
- Typical zinc ores generally contain about 5-15 % metal. Zinc ores are mined on a large scale in many countries including Australia, USA, Canada and Peru. Current world production is about 9 million tons each year, including recycled metal.
- In a few cases, samples of native zinc have been found, for example in Australia. This is the pure metal.
- The low concentrations of the zinc sulphide mineral in most zinc ores mean that the ore must first be concentrated before extracting the metal.

There are two methods of zinc extraction;

1) Pyrometallurgy
⇒ **Electrochemical treatment**
2) Hydrometallurgy

1) Pyrometallurgical treatment

<u>Stage 1</u>

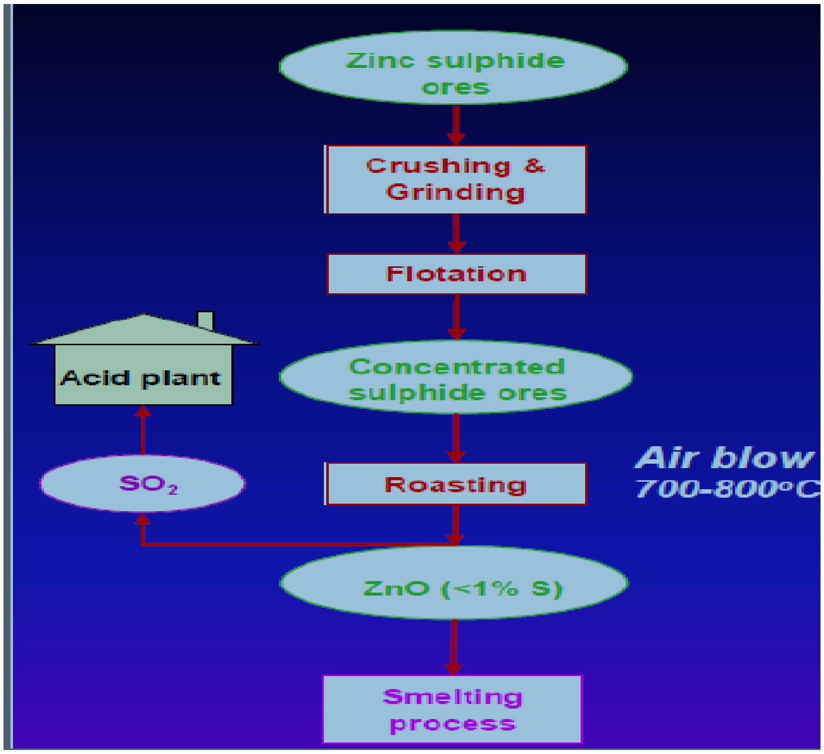
- The zinc blende (sphalerite: zinc sulphide) is first crushed to powder, wet grinding and then treated by froth flotation.
- Froth floatation has been used with aid of $CuSo_4$ to collect Zinc ore. The resulting material is known as 'concentrate'. It contains at least 50% zinc

Production of zinc using blast furnace

<u>Stage 2</u>

- **Roasting** was done to convert Zinc sulphide ores to its oxide, by O_2 flow and removal of SO_2 at T of $700\text{-}800^{o}C$. This reaction is exothermic, which increases the temperature up to $1000^{o}C$.
- $ZnS + 3/2\ O_2 \longrightarrow ZnO + SO_2$ (Pyrometallurgy)
- $ZnS + 2O_2 \longrightarrow ZnSO_4$ (Hydrometallurgy)

Soluble in water
& dilute acids



<u>Stage 3</u>

Smelting - Metal production

The zinc oxide is then reduced to the metal using either a thermal or an electrolytic process.

- ZnO is treated in blast furnace, reduction done with carbon and limestone (CaCo3) at 500°C as a preheating, then O_2 supplied from top furnace to produce carbon monoxide (CO) at 1300 °C to produce zinc vapor.

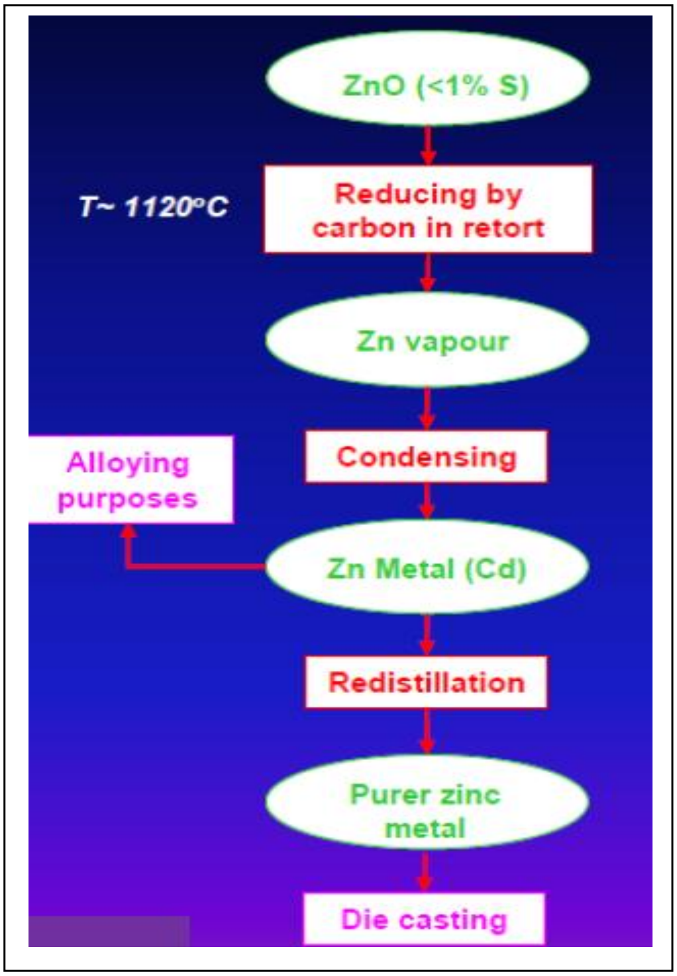
Reduction smelting reaction as follows:

$$C + 1/2\, O_2 \longrightarrow CO$$

$$C + O_2 \longrightarrow CO_2$$

$$C + CO_2 \longrightarrow 2CO$$

$$ZnO + CO \longrightarrow \underset{\text{Vapor}}{Zn} + CO_2$$



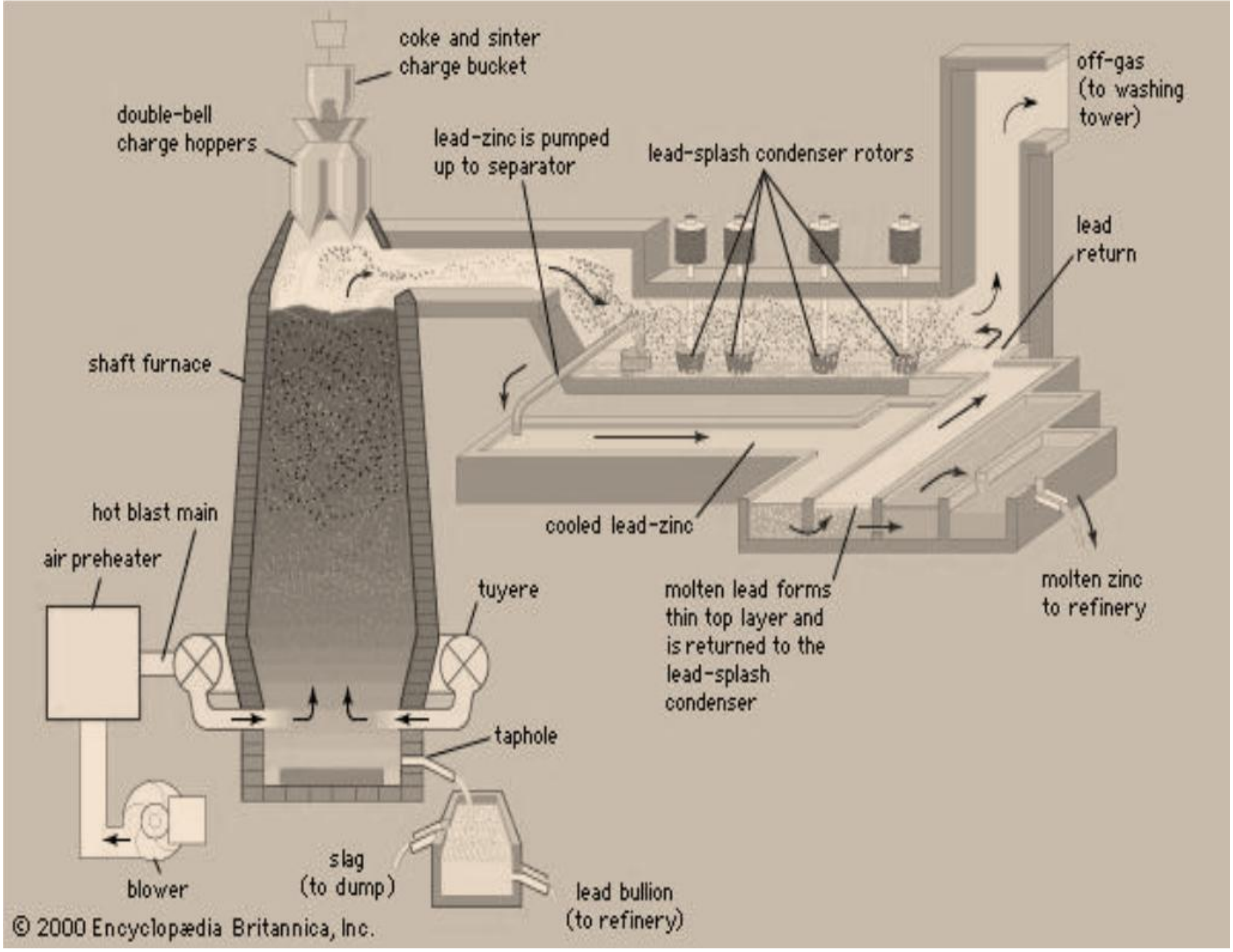
- Zn vapor is drawn at 1000°C then cooled rapidly to 550 °C in molten lead bath to produce condensate zinc (contain small amount of Cadmium Cd) which is denser than other component (Zn sink to the bottom), then tapped of, while slug (lighter) tapped from above.
- Two layers will form as follows:

1. Zinc contains 1wt%Pb → drawn to more refining by distillation to produce 99.9% Zn.
2. Pb contains 2.25wt% Zn → return to condenser.

- Then redistillation at T of 765°C to vaporize ***Cd*** off.

- Zinc produced by this process is about 98.5% pure and can be further refined if required.
- Around 15% of the world's zinc is produced by this way.

The blast furnace used in this process is illustrated in figure below.



2) Hydrometallurgy treatment (*Electrolytic refining)*

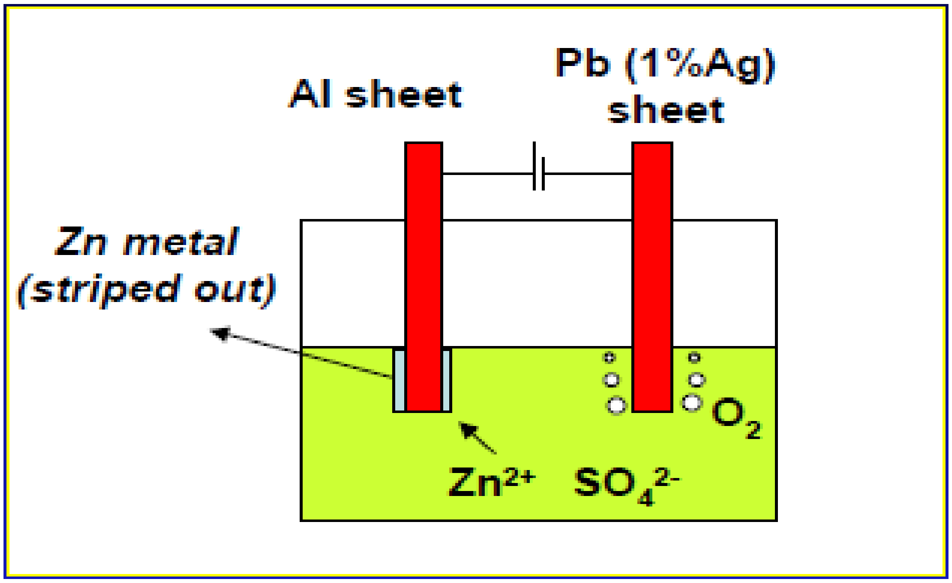
They consist of 4 steps: leaching, purification, electrolysis, and melting & casting.

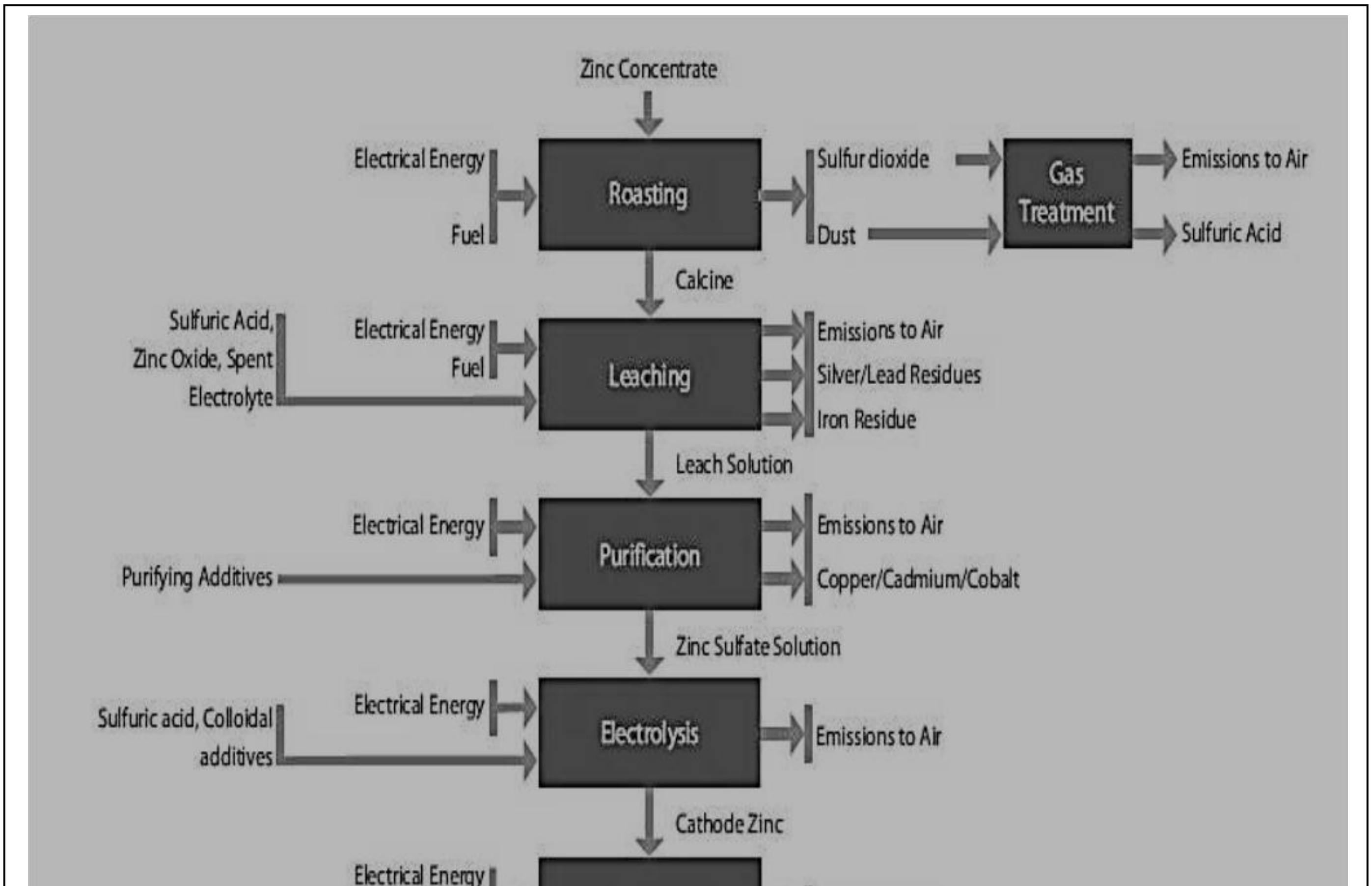
- The crude zinc oxide is dissolved in dilute sulphuric acid (H_2SO_4) to produce a solution of Zinc sulphate after filtration and purification the solution.

  $ZnO+H_2SO_4 \longrightarrow ZnSO_4 + H_2O$
- $ZnSO_4$ electrolysed using a lead–silver alloy (Pb-1%Ag) as anode and an Aluminium (Al) as cathode.

- O_2 is released at anode, while Zinc is deposited on the cathode. H_2SO_4 is regenerated at the anode and can be used again.

  You can't use solid zinc oxide directly because its insoluble and the ions must free to carry the current and migrate to the electrodes in some sort of solution.
- The zinc is stripped periodically from the cathode melted and cast into blocks (ingots) for many different purposes.
- Electrolytically refined zinc is generally 99.995% pure.
- About 80% of the world's zinc is produced using this process.





Hydrometallurgy of zinc extraction

Extraction of Nickel by Pyrometallurgical Process:

Details about of Ni:

Atomic Number: 28

Atomic Weight: 58.69 amu

Density: 8.98 gm/cm ^{3}

Melting Point: 1452 ^{0} C

Boiling Point: 2900 ^{0} C

Common Ores of Ni:

Pentalandite – [$(NiFe)_9S_8$]

Violarate – [Ni_2FeS_4]

Extraction of Ni from Sulphide Ore:

Explanation of Flow Sheet:

Initial Treatment: The ore is a mixed Cu-Ni ore with nearly equal amount of Cu and Ni. The ore undergoes into grinding and froth floatation to produce a bulk concentrate which sent to copper cliff mill for separation of Cu concentrate, Ni concentrate and Pyrrohotite concentrate with iron sulphide with about 0.8% Ni.

Then the Cu concentrate subjected to O_2flash smelting for Cu extraction. From Pyrrohotite after roasting iron oxide form and Ni separated by leaching. The Ni concentrate with about 10% Ni, 2% Cu, 40% Fe, and 30% S goes for extraction of Ni in next stage.

Roasting: In conventional process, the concentrate partially roasted to oxidize the iron sulphide either multiple hearth roaster or fluidized bed roaster. But fluidized bed roaster is more preferable because of

- High output and rich SO_2gas stream generates
- Process is Autogeneous
- Temperature range (550-600)^{0}C about 40% S oxidized

Smelting: The roasted calcine contains desired amount of siliceous flux is smelted in a reverberatory furnace to produce a matte containing Ni , Cu as 20%, 7% respectively where the slag discarded contains gangue and oxidized iron. There is also converter slag of both Ni and Cu converters are returned to the reverberatory furnace.

Converting: Furnace matte is converted to Ni enriched matte with 50% Ni, 25% Cu, 0.7% Fe, and 21.5% S at 1150^0 C in Pierce-Smith converter. The slag discarded contains 2% Ni, 1.5% Cu, 40% Fe, and 25% SiO_2return to reverberatory furnace for recovery of Ni and Cu.

Slow Cooling: Converter matte subjected to slow cooling process from melting point to 400 ^{0}C for 3 days to form three layers precipitate out as

- First layer, Cu_2S precipitate and grows
- Second layer, metallic Cu-Ni alloy at 700^{0}C
- Third layer, solid Ni_3S_2 phase precipitate at 575^0 C

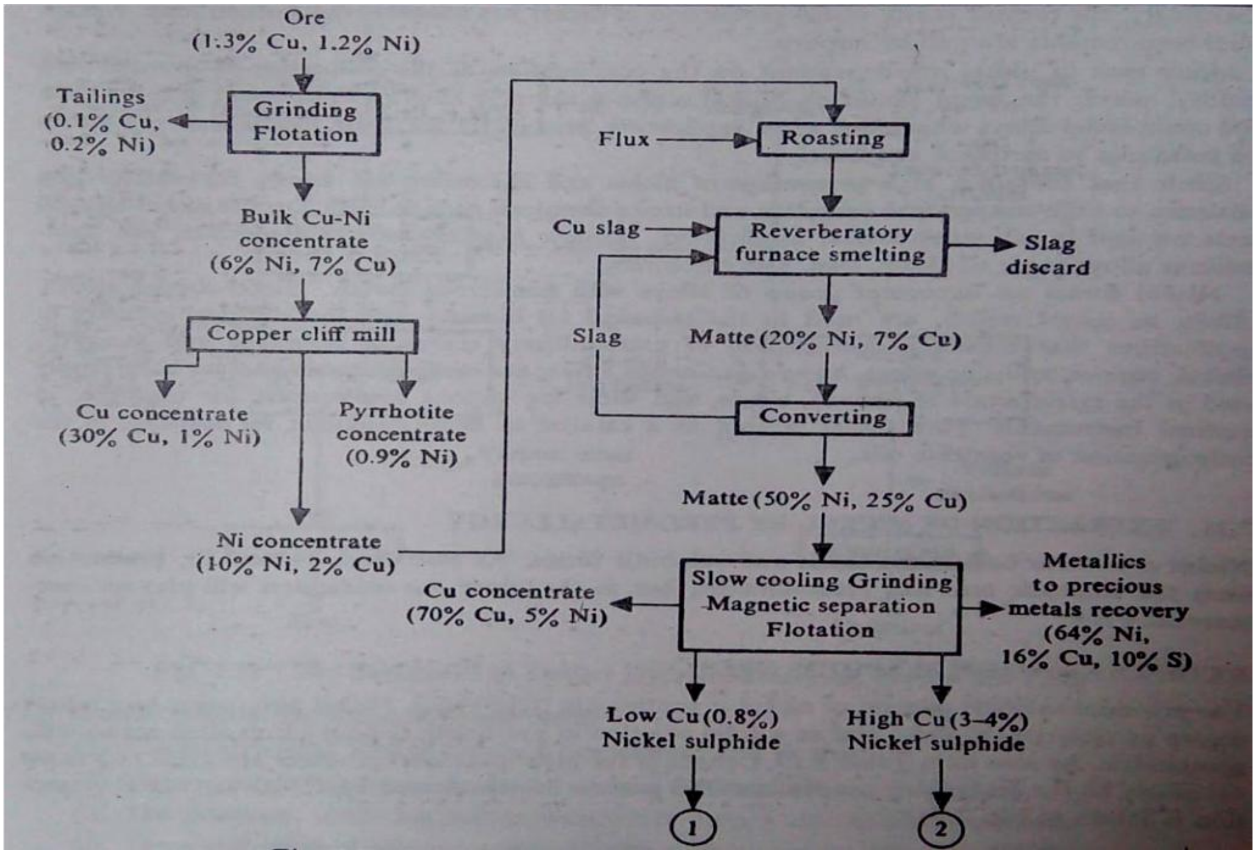
Question : Why slow cooling required after converting process?

Answer: Slow cooling required obtaining necessary grain growth, which then go for subsequent processing of sulphides to recover it in the froth floatation.

Magnetic Separation and Floating: In floatation, Ni-Cu alloy contains 95% precious metals is undergo for magnetic separation for recovery of it. Cu_2S produced by floatation contains 70% Cu, 5% Ni, 20% S. Ni sulphide recovered as a low Cu-Ni sulphide with 74% Ni, 0.8% Fe, 0.8% Cu, and 22% S. High Cu-Ni sulphide with 72% Ni, (3-4) % Cu, 0.8% Fe, and 21% S at a temperature (1100-1250)^{0}C roasting produce granular nickel oxide.

Final Treatment:

- Low Cu-Ni oxide is marketed directly as Nickel oxide or reduced to metal.
- High Cu-Ni oxide sends for refining by carbonyl process and other half by electrolytic refining.


Ore
(1.3% Cu, 1.2% Ni)
Tailings
(0.1% Cu,
0.2% Ni)
Grinding
Flotation
Bulk Cu-Ni
concentrate
(6% Ni, 7% Cu)
Copper cliff mill
Cu concentrate
(30% Cu, 1% Ni)
Pyrrhotite
concentrate
(0.9% Ni)
Ni concentrate
(10% Ni, 2% Cu)
Flux
Roasting
Cu slag
Reverberatory
furnace smelting
Slag
discard
Slag
Matte (20% Ni, 7% Cu)
Converting
Matte (50% Ni, 25% Cu)
Slow cooling Grinding
Magnetic separation
Flotation
Cu concentrate
(70% Cu, 5% Ni)
Metallics
to precious
metals recovery
(64% Ni,
16% Cu, 10% S)
Low Cu (0.8%)
Nickel sulphide
High Cu (3–4%)
Nickel sulphide
1
2

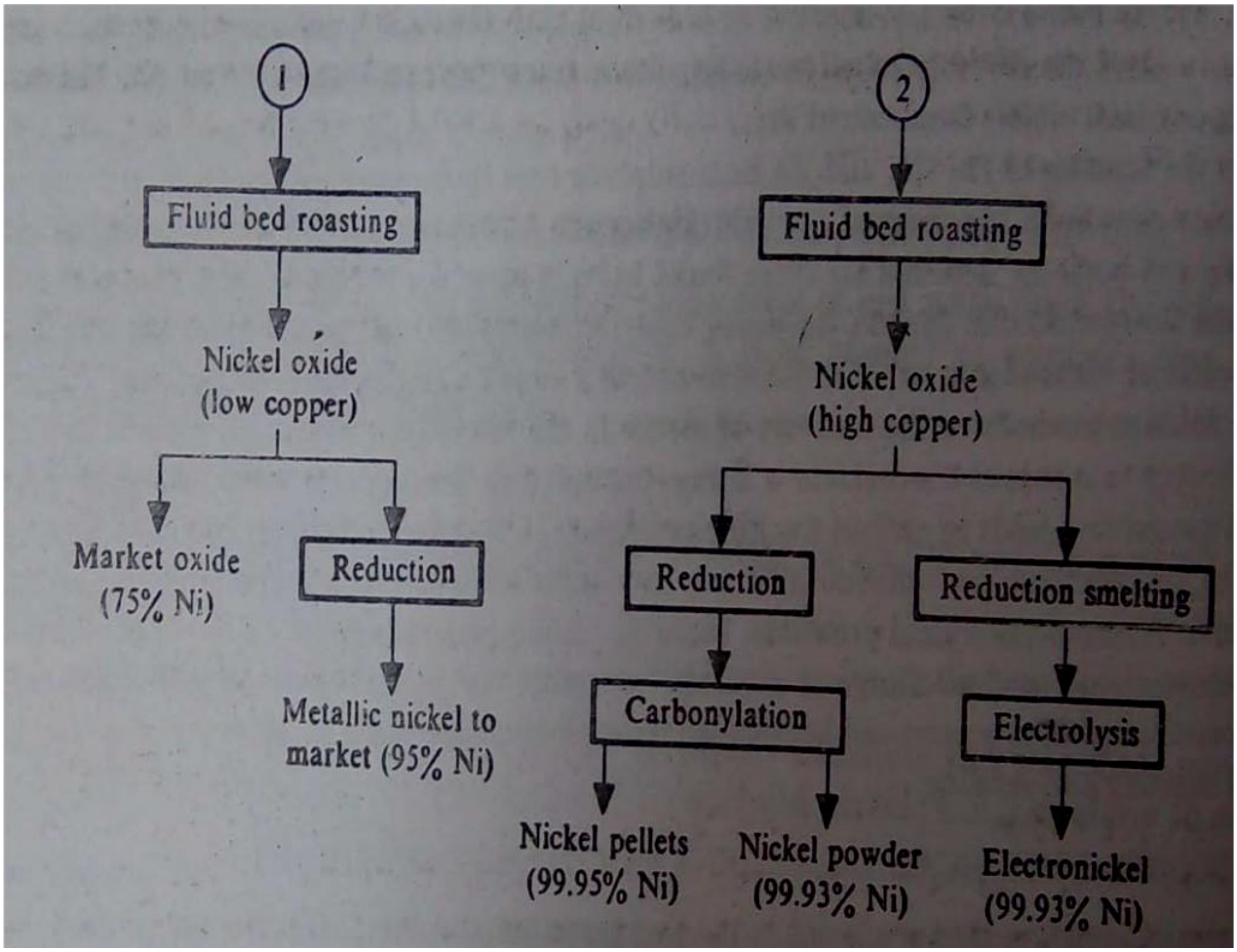

1
Fluid bed roasting
Nickel oxide
(low copper)
Market oxide
(75% Ni)
Reduction
Metallic nickel to
market (95% Ni)
2
Fluid bed roasting
Nickel oxide
(high copper)
Reduction
Reduction smelting
Carbonylation
Electrolysis
Nickel pellets
(99.95% Ni)
Nickel powder
(99.93% Ni)
Electronickel
(99.93% Ni)

Fig.1 : Nickel Extraction (INCO Process)

Refining Process:

1. Carbonyl Process for Refining Ni:

(i) Mond's Process:

In 1889, this refining process of Ni recovered by Carl Langer and Ludwig Mond. In this process, at temperature (40-90)^{0} C metallic Ni combine with CO to give gaseous nickel carbony [$Ni(CO)_4$]. At higher temperature (150-300)^{0} C $Ni(CO)_4$ decomposes to give Ni and CO gas. The reactions are

$$Ni+4\ [at\ 50^{0}C] \longrightarrow Ni(CO)4$$

$$Ni\ (CO)_4\quad [at\ 230^{0}C] \longrightarrow Ni+4CO$$

Other forms of Carbonyls are volatile carbonyl [$Fe(CO)_5$], CO carbonyl in tetracarbonyl [$CO_2(CO)_8$], tricarbonyl [$CO_4(CO)_{12}$] form. Cu and other major elements are not form carbonyls.

(ii) INCO Process:

INCO Atmospheric Carbonylation Process:

The oxide first reduces to active Ni in the presence of H_2 at about 400^{0} C. Then active Ni undergoes for carbonylation at 50^{0} C to form $Ni(CO)_4$ then at 230^{0}C goes for decomposed to Ni either in pellets about 1 cm dia or powder form about 3.5 µm size.

INCO Pressure Carbonylation Process:

The carbonylation reaction has 4 to 1 volume change permits at about 180^{0} C and 70 atm pressure carbonyls of Ni, Fe, and Co formed. From which $Ni(CO)_4$ recovered by fractiona distillation and converted to metallic Ni in pellet decomposer or a powder decomposer.

2. Electrolytic Refining of Ni:

Fig.2 Electrolytic Refining of Ni

The Ni oxide reduce by coke in fuel fired furnace or electric furnace, and then cast into Ni metal anode. These anodes are electrolytically refined in a bath contains 60 gm/lit Ni^{+2}, 95 gm/lit SO_4^{2-}, 35 gm/lit Na^+, 55 gm/lit Cl^-, 16 gm/lit H_3BO_3. This electrolysis carried out at 60^0 C. Cu remove by cementation with active Ni powder, Fe and other impurities remove by aeration of electrolyte, Co remove by Cobaltic Hydroxide for further Chlorine oxidation. Electrolyzed Ni analyzes about 99.93% Ni.

Uses of Ni:

- Important alloying elements used in chemical processing, space research and nuclear reactor.
- Ni-Cu alloys known as Mnel metals are used in chemical oil industry and electric industry.
- Ni, Cu, and Zn alloys are known as German silver. It is used for manufacture of ribbons, bands, and wires for various applications.

Area of Extraction: Canada, INCO-80% production

Extraction of Gold

Characteristics and uses of gold

Density: 19.3 g/cm3, melting point:1064 ^{o}C

Shinny: for Jewelry

Durable: does not tarnish or corrode easily, sometimes used in dentistry to make the crowns for teeth.

Malleable and ductile: can be bent and flattened. For this reason it is used to make fine wires and thin, flat sheets

Good conductor for heat & electricity: used in transistors, computer circuits and firefighting cloths.

Types of ores:

- Gold occurs principally as a **Native metal**, usually **alloyed with silver** (as **Electrum**), or **with mercury** (as an **Amalgam**). Native gold can occur as sizeable nuggets, flakes, grains or microscopic particles embedded in other rocks.
- Ores in which gold occurs in chemical composition with other elements are comparatively rare. They include **calaverite, sylvanite, nagyagite, petzite** and **krennerite**

Gold mining

- **Hard rock mining** – used to extract gold encased in rock. Either open pit mining or underground mining.
- **Panning** **الفصل**– sand and gravel (حصى) containing gold is shaken around with water in a pan. Gold is much denser than rock, so quickly settles to the bottom of the pan.

- **Sluicing** – water is channelled to flow through a sluice-box with riffles (تموجات) at the bottom which create dead-zones in the water current which allows gold to drop out of suspension.

  Sluicing and panning results in the **direct recovery** of small gold nuggets and flakes.

Gold ore processing - Gold Cyanidation:

- The most commonly used process for gold extraction.
- Used to extract gold from low-grade ore.
- Gold is oxidised to a water-soluble aurocyanide metallic complex $Au(CN)_2$.
- In this dissolution process, the milled ore is agitated with dilute alkaline cyanide solution, and air is introduced:

$$4Au + 8NaCN + O_2 + 2H_2O \longrightarrow 4NaAu(CN)_2 + 4NaOH$$

- At a slurry concentration of around 50% solids, the slurry passes through a series of agitated mixing tanks with a residence time of 24 hrs.
- The gold-bearing liquid is then separated from the leached solids in thickener tanks or vacuum filters & the tailings (مخلفات المعالجة) are washed to remove Au and CN- prior to disposal.

Gold ore processing   Gold cyanidation:

Merrill-Crowe process

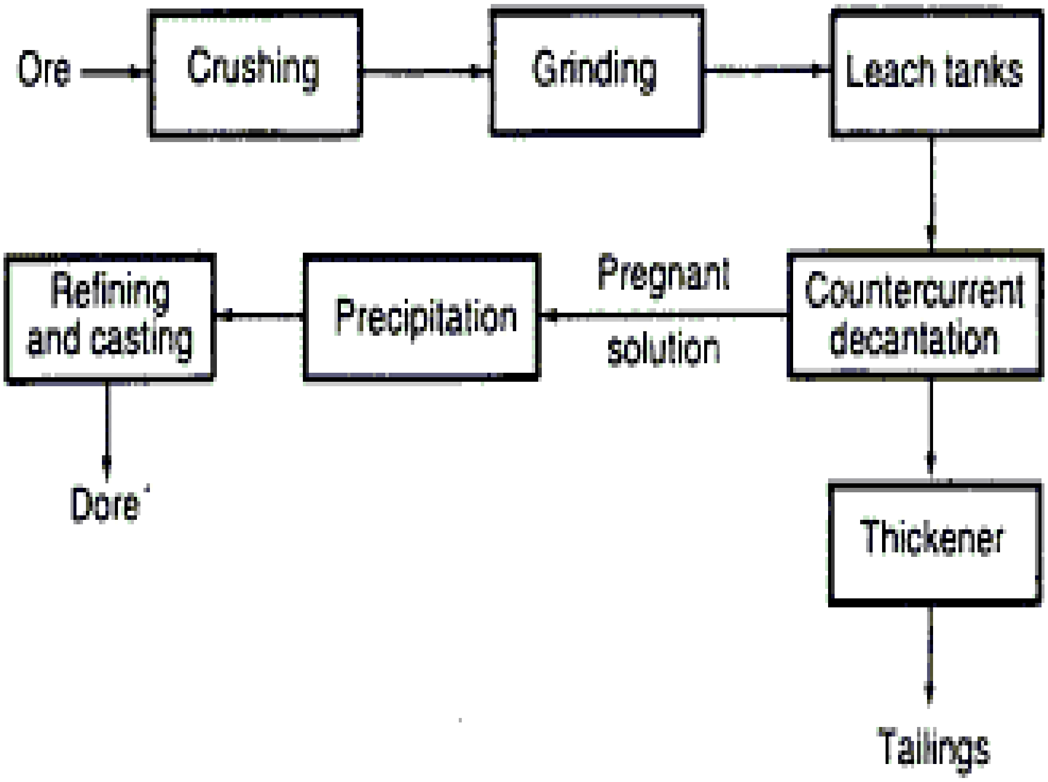
Traditional method for Au recovery from pregnant cyanide solutions.

- Once dissolution of Au is complete, the remaining rock pulp if filtered off through various filters to produce a sparkling (لامع) clear solution.
- O_2 is removed from the clarified solution by passing the solution through a vacuum deaeration column.
- Zinc dust is then added to the cyanide solution to chemically reduce the gold to the metal.

$2Au(CN)_2 + Zn \longrightarrow 2Au + Zn(CN)_4$

- The metallic gold is then **filtered** out and **refined**.
- **Smelting** of resultant powder (rich Au) into steel molds and the slug is removed from the top furnace.
- **Electrolysis** is done to get high gold grade 99.999% purity

Cyanide process of gold production



Gold ore processing - Heap Leaching

- Is an alternative to the agitated leaching process.
- Drastically reduced gold recovery costs of low grade ore.
- Ore grades as low as 0.3 g per ton can be economically processed by heap leaching.
- Generally requires 60 to 90 days for processing ore that could be leached in 24 hrs in a conventional agitated leach process.
- Au recovery is around 70% as compared with 90% in an agitated leach plant.

- But, has gained wide favour due to vastly reduced processing costs.
- Frequently, mines will use agitated leaching for high-grade ore & heap leaching for low grade ores that would otherwise be considered waste rock.