Metallurgy for Non-Metallurgists

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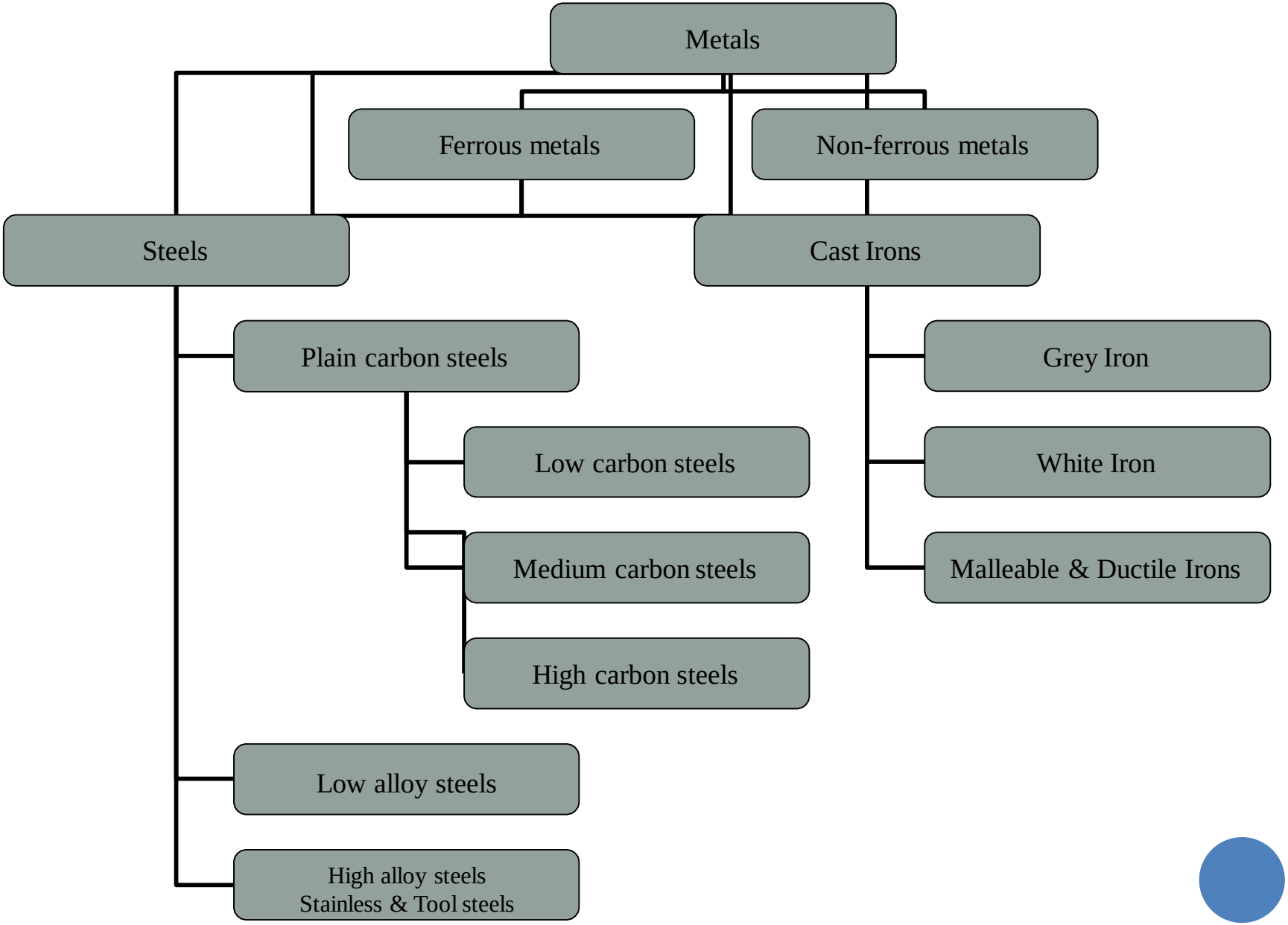
Syllabus

- Introduction to Metallurgy
- Metal Extraction from Ores

WHAT IS METALLURGY?

- **Metallurgy** is a domain of materials science and engineering that studies the physical and chemical behaviour of metallic elements, their inter-metallic compounds, and their mixtures, which are called alloys.
- Metallurgy comprises of 3 steps:
  i. Concentration of Ore
  ii. Isolation of metal from the concentrated Ore
  iii. Purification of the metal


Metals
Ferrous metals
Non-ferrous metals
Steels
Cast Irons
Plain carbon steels
Low carbon steels
Medium carbon steels
High carbon steels
Low alloy steels
High alloy steels
Stainless & Tool steels
Grey Iron
White Iron
Malleable & Ductile Irons

ENGINEERING REQUIREMENTS OF MATERIALS

- *Engineers of any branch, has to deal with materials for their* **proper utilization** .
- *Whether his product is a bridge, an automobile, knowledge of properties and behavior* **under service condition** *of the materials used for this purpose is necessary.*
- *Service condition include the effect of* **mechanical loading, temp., magnetic field, and chemical surroundings.**
- *It is* **impossible** *for the engineer to have detailed knowledge of thousands of materials.*

PROPERTIES OF METALS

- *1. Physical properties*
- *2. Chemical properties*
- *3. Thermal properties*
- *4. Electrical properties*
- *5. Magnetic properties*
- *6. Optical properties, and*
- *7. Mechanical properties*

PHYSICAL PROPERTIES

- **Density -Mass per unit volume** *is called as density. In metric system its unit is kg/mm3. Because of very low density, aluminum and magnesium are preferred in* **aeronautic and transportation** *applications.*
- *For a specific material density* **remains constant** *but it* **varies** *with materials.*

- **Size and shape - Dimensions** *of any metal reflect the size and shape of the material. Length, width, height, depth, curvature diameter etc. determines the size. Shape specifies the rectangular, square, circular or any other section.*

- **Specific Gravity-** *Specific gravity of any metal is the* **ratio of the mass of a given volume of the metal to the mass of the same volume of water** *at a* **specified temperature**.

- **Porosity-***A material is called as* **porous or permeable** *if it has pores within it.*

CHEMICAL PROPERTIES

- *The study of chemical properties of materials is necessary because* **most of the engineering materials, when they come in contact with other substances with which they can react,** *suffer from chemical deterioration of the surface of the metal.*
- *Some of the chemical properties of the metals are* **corrosion resistance, chemical composition and acidity or alkalinity.** *Corrosion is the gradual deterioration of material by chemical reaction with its environment.*

- **Composition –** *can be determined by* **analytical chemistry.**
- **Corrosion resistance -** *is the deterioration of a material by chemical reaction with its environment.*
- *It affects both metallic as well as nonmetallic materials like bricks, concrete etc…*

THERMAL PROPERTIES

- **Melting Point -** *Melting point is the temperature at which a* **pure metal or compound changes its shape from solid to liquid.**

- *It is called as the temperature at which the liquid and solid are in* **equilibrium.**

ELECTRICAL PROPERTIES

- **Conductivity-** *Conductivity is defined as the* **ability of the material to pass electric current** *through it easily i.e. the material which is conductive will provide an easy path for the flow of electricity through it.*

- **Dielectric Strength-** *It means insulating capacity of material at high voltage. A material having high dielectric strength can* **withstand for longer time for high voltage across it before it conducts the current through it.**

- **Resistivity-** *It is the property of a material by which it* **resists the flow of electricity through it.**

- **Thermoelectricity-** *If* **two dissimilar metals** *are joined and then this junction is heated, a small voltage (in the milli-volt range) is produced, and this is known as thermoelectric effect. It is the base of the thermocouple. Thermo -couples are prepared using the properties of metals.*

MECHANICAL PROPERTIES

- **Elasticity-** *It is defined as the property of a* **material to regain its original shape after deformation when the external forces are removed.**
- *It can also be referred as the power of material to come back to its original position after deformation when the stress or load is removed. It is also called as the tensile property of the material.*

- **Yield point-** *At a specific stress, ductile metals particularly ceases, offering resistance to tensile forces.*

- **Strength-** *Strength is defined as the* **ability of material to resist the externally applied forces or stresses without fracture.**
- *This property of material therefore determines the* **ability to withstand stress without failure.**
- *The maximum stress that any material can withstand before destruction is called its* **ultimate strength.** *The tenacity of the material is its ultimate strength in tension.*

- **Stiffness-** *It is defined as the* **ability of a material to resist deformation under stress.** *The resistance of a material to elastic deformation or deflection is called stiffness or rigidity.*

- **Plasticity-** *Plasticity is defined the mechanical property of a material which retains the deformation produced under load* **permanently.**
- *This property of the material is required in forging, in stamping images on coins. It is the ability or tendency of material to undergo some degree of permanent deformation without its rupture or its failure.*

- **Ductility-***Ductility is termed as the property of a* **material enabling it to be drawn into wire with the application of tensile load.**
- *The ductility is usually measured by the terms,* **percentage elongation and percent reduction in area** *which is often used as empirical measures of ductility.*
- *The materials those possess* **more than 5% elongation are called as ductile materials.**

- **Malleability** - *Malleability is the ability of the material to be* **flattened into thin sheets under applications of heavy compressive forces without cracking by hot or cold working means.**

- *It is a special case of ductility which permits* **materials to be rolled or hammered into thin sheets.**

- **Hardness -** *Hardness is defined as the* **ability of a metal to cut another metal.** *A harder metal can always cut or put impression to the softer metals by virtue of its hardness.*

- *It embraces many different properties such as* **resistance to wear, scratching, deformation and machinability etc.**

- **Brittleness-** *Brittleness is the property of a material opposite to ductility. It is the property of breaking of a material* **with little permanent distortion**.

- *The materials having* **less than 5% elongation** *under loading behavior are said to be brittle materials.*

- **Creep-** *When a metal part when is subjected to a high constant stress at* **high temperature for a longer period of time, it will undergo a slow and permanent deformation** *(in form of a crack which may further propagate further towards creep failure) called creep.*

- **Workability or Formability-** *It is the property of metals which denotes the ease in its forming in to various shapes and sizes.*
- *The different factors that affect the formability are crystal structure of metal, grain size of metal hot and cold working, alloying element present in the parent metal.*
- *Hot working increases formability. Low carbon steel possesses good formability.*

- **Castability-***Castability is defined as the property of metal, which indicates the ease with it can be casted into different shapes and sizes. Cast iron, aluminium and brass are possessing good castability.*

- **Weldability**-*Weldability is defined as the property of a metal which indicates* **the two similar or dissimilar metals are joined by fusion with or without the application of pressure and with or without the use of filler metal (welding) efficiently.**

- **Toughness-** *toughness is the amount of* **energy that a material can absorb before it fractures.**
- *It is desirable property for structural and machine parts which have to withstand shock and vibration.*

- **Resilience –** *resilience is the capacity of a material to absorb or store energy, and to resist shock and impact.*

- **Fatigue –** *The failure of a material caused under repeated loads or stresses is known as fatigue or fatigue failure.*

CRITERIA FOR SELECTION OF MATERIALS FOR ENGINEERING APPLICATIONS

- *PROPERTIES OF MATERIAL(***as per appl. Under loading condition***)*
- *PERFORMANCE REQUIREMENTS(***aerospace component***)*
- *MATERIALS* **REALIBILITY(capable in working condition***)*
- *SAFETY(***brittle to ductile***)*
- *DISPOSABILITY AND RECYCING AND REUSE OF MATERIALS*
- *PROCESSING OF MATERIALS*
- *ECONOMIC FACTORS*

ENGINEERING REQUIREMENTS OF MATERIALS

- *Engineers of any branch, has to deal with materials for their* **proper utilization** .
- *Whether his product is a bridge, an automobile, knowledge of properties and behavior* **under service condition** *of the materials used for this purpose is necessary.*

i. **Fabrication Requirements**

ii. **Service Requirements**

iii. **Economic Requirements.**

Fabrication Requirement

- Material should be able to get Shaped and joint easily
- Fabrication requirements relate themselves with material's machinability, Ductility, castability, Heat treatability, weld ability, etc

Service Requirement

- Material selected for purpose must stand up to service demands i.e
- Strength
- Wear resistance
- Corrosion resistance, etc

Economic Requirement

- Engg parts should be made with minimum overall cost
- Minimum overall cost - - - > by proper selection of Technical and Marketing Variables

EXTRACTION TECHNIQUES AND METALLURGY

BASIC TERMINOLOGIES

- **Mineral**: A solid, naturally occurring inorganic substance formed by geological processes
- **Ore**: A naturally occurring solid material from which a metal or valuable mineral can be extracted
- **Flux**: Its is a chemical cleaning agent used for purification of the ores.

BASIC TERMINOLOGIES (CONTD…)

- **Slag**: Waste matter separated from metals during the extraction of ores.
- **Gangue**: In mining, gangue is the commercially worthless material that surrounds, or is closely mixed with, a wanted mineral in an ore deposit. It is thus distinct from overburden, which is the waste rock or materials overlying an ore or mineral body that are displaced during mining without being processed.
- The separation of mineral from gangue is known as mineral processing.

EXTRACTIVE TECHNIQUES

- It is the process of removing impurities or undesired materials from the ore leaving behind the required metal.
- Different process followed are
  i. Hydraulic washing
  ii. Magnetic separation
  iii. Froth floatation
  iv. Leaching

METALS AND THEIR ORES

- **Aluminium**

Bauxite	$AlO_x(OH)_{3-2x}$ [where $0 < x < 1$]
Kaolinite (a form of clay)	$[Al_2(OH)_4Si_2O_5]$

- **Iron**

Haematite	Fe_2O_3
Magnetite	Fe_3O_4
Siderite	$FeCO_3$
Iron pyrites	FeS_2

- **Copper**

Copper pyrites	$CuFeS_2$
Malachite	$CuCO_3.Cu(OH)_2$
Cuprite	Cu_2O
Copper glance	Cu_2S

- **Zinc**

Zinc blend/Sphalerite	ZnS
Calamine	$ZnCO_3$
Zincite	ZnO

METALS AND ITS EXTRACTING TECHNIQUES

Metals - in decreasing order of reactivity	**Reactivity**
Potassium Sodium Calcium Magnesium Aluminium	extract by **electrolysis**
Carbon	
Zinc Iron Tin Lead	extract by reaction with **carbon** or **carbon monoxide**
Hydrogen	
Copper Silver Gold Platinum	extracted by various chemical reactions

PYRO-METALLURGY

- **Pyro metallurgy** is a branch of extractive metallurgy.
- It consists of the thermal treatment of minerals and metallurgical ores and concentrates to bring about physical and chemical transformations in the materials to enable recovery of valuable metals.
- Pyrometallurgy is suitable for less reactive materials like iron, copper, zinc, chromium, tin, and manganese.

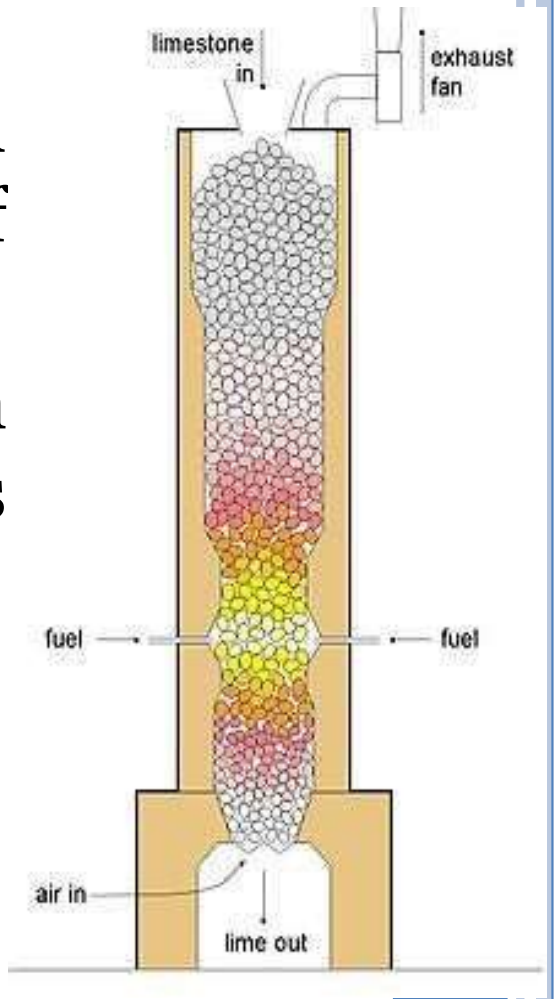
CLASSIFICATION

Pyro metallurgy is classified into following categories:

- Calcination
- Roasting
- Smelting
- Refining

CALCINATION

- Calcination is heating to high temperatures in the absence of air or oxygen.
- The main purpose of calcination of ores are to convert carbonates and hydroxides ores into oxides.
- $ZnCO_3 \rightarrow ZnO + CO_2$
- $CaCO_3 \rightarrow CaO + CO_2$
- $2Al(OH)_3 \rightarrow Al_2O_3 + 3H_2O$



- Purpose of calcination
  i. Remove the volatile impurities
  ii. To remove moisture
  iii. Make the mass porous

ROASTING

- The processing of strong heating of the ore in presence of excess amount of air below its melting point.
- Purpose of roasting:

i. To convert the sulphide into oxide and sulphate
ii. To remove impurities like S, As, Sb.
iii. To remove moisture
iv. To Oxidise easily oxidisable substances

- It is mainly used for sulphide ores
- it converts the sulphides into oxides

2ZnS+3O2 ----> 2ZnO+SO2

- **$4FeS_2 + 11O_2 \rightarrow 2Fe_2O_3 + 8SO_2$**

CALCINATION VS ROASTING

CALCINATION	ROASTING
It is the process of heating in absence of air	It is the process of heating in presence of air to oxidise the impurities
It is employed for carbonate ores	It is employed for sulphide ores
Calcination produces carbon dioxide along with metal oxide	Roasting produces sulphur dioxide along with metal oxide

SIMILARITIES

- Both are processes of heating the ore below its melting point.
- Both aim at removal of impurities in the ore.

SMELTING

- **Smelting** is a form of extractive metallurgy; its main use is to produce a base metal from its ore.
- Smelting makes use of heat and a chemical reducing agent to decompose the ore, driving off other elements as gases or slag and leaving only the metal base behind. The reducing agent is commonly a source of carbon such as coke, or in earlier times charcoal.

PROCESS

- $2C + O_2 \quad 2CO$ (Burning of fuel to CO)
- $Fe_2O_3 + 3CO \quad 2Fe + 3CO_2$(CO reduces hematite to iron)
- $CaCo_3 \quad CaO + CO_2$ (Decomposition)
- $CaO + SiO_2 \quad CaSiO_3$(Impurities are removed)

HYDRO-METALLURGY

- **Hydrometallurgy** is a method for obtaining metals from their ores. It is a technique involving the use of aqueous chemistry for the recovery of metals from ores, concentrates, and recycled or residual materials. Hydrometallurgy is typically divided into three general areas:

  i. Leaching

  ii. Solution concentration and purification

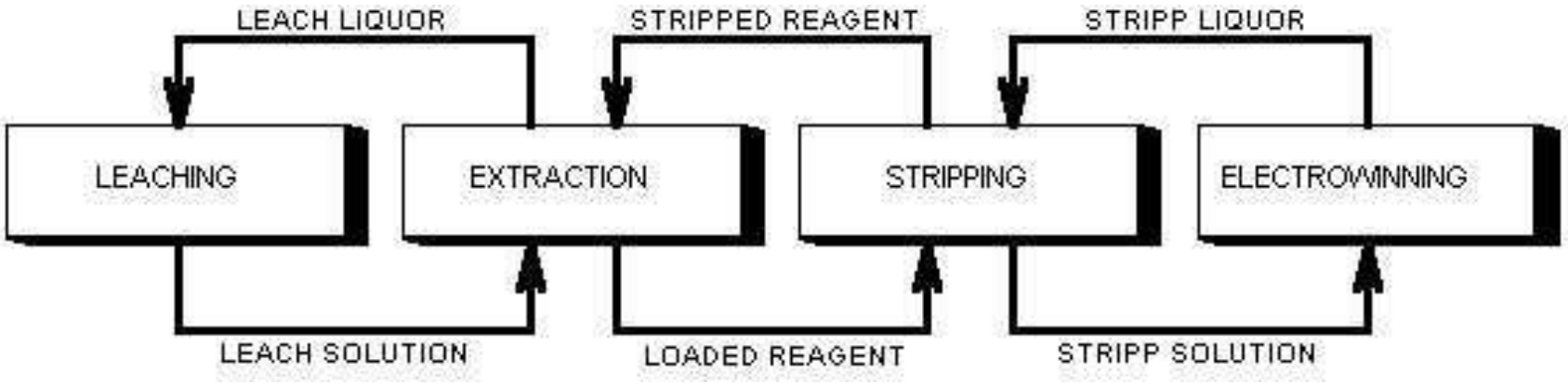
  iii. Metal or metal compound recovery

LEACHING

- It involves the use of aqueous solutions to extract metal from metal bearing materials which is brought into contact with a material containing a valuable metal. The aqueous solution conditions vary in terms of pH, oxidation-reduction potential, presence of chelating agents and temperature.

SOLUTION CONCENTRATION AND PURIFICATION

- After leaching, the leach liquor must normally undergo concentration of the metal ions that are to be recovered. Additionally, undesirable metal ions sometimes require removal.
- Two major types are: i) Solvent extraction ii) Ion Exchange



METAL RECOVERY

- Sometimes, however, further refining is required if ultra-high purity metals are to be produced.
- The primary types of metal recovery processes are i) electrolysis, ii) gaseous reduction, and iii) precipitation.
- For example, a major target of hydrometallurgy is copper, which is conveniently obtained by electrolysis. Cu^{2+} ions reduce at mild potentials, leaving behind other contaminating metals such as Fe^{2+} and Zn^{2+}.

ELECTRO-METALLURGY

- **Electrometallurgy** is the field concerned with the processes of metal electrode position There are four categories of these processes:
- Electrowinning
- Electrorefining
- Electroplating
- Electroforming
- Electropolishing

- Electrowinning, the extraction of metal from ores.
- Electrorefining, the purification of metals.
- Metal powder production by electrodeposition is included in this category, or sometimes electrowinning, or a separate category depending on application.

- Electroplating, the deposition of a layer of one metal on another.
- Electroforming, the manufacture of, usually thin, metal parts through electroplating.
- Electropolishing, the removal of material from a metallic workpiece.

Refining

- **Primary Refining:** Refining consists of purifying an impure metal. It is to be distinguished from other processes like smelting and calcining in that those two involve a chemical change to the raw material, whereas in refining, the final material isidentical chemically to the original one, only it is purer.
- **Electro Refining:** It is the process of using electrolysis to increase the purity of a metal extracted from its ore (compound or mixture of compounds from which a metal can be extracted commercially).

Refining (contd…)

- To use grey pig iron, a preliminary refining process was necessary to remove silicon. The pig iron was melted in a *running out furnace* and then run out into a trough. This process oxidised the silicon to form a slag, which floated on the iron and was removed by lowering a dam at the end of the trough. The product of this process was a white metal, known as *finers metal* or *refined iron*.

Secondary Refining

- The purposes of secondary refining are many: temperature homogenization or adjustment; chemical adjustments for carbon, sulphur, phosphorus, oxygen and precise alloying; inclusion control; degassing, and others. The equipment and processes are equally varied.

Electro-slag refining (ESR)

- The process of electro-slag refining (ESR) is well known for production of high cleanliness steels. It involves melting of an electrode by resistive heating through a slag pool, and solidification of the droplets at the bottom of the Pool.
- Steel of the desired overall chemical composition is prepared before-hand and shaped in the form of an electrode. This requires addition of the necessary ferro-alloys to the liquid steel in order to attain the aimed concentration of alloying elements.

Wrought Iron

- **Wrought iron:** The product of the blast furnace is pig iron, which contains 4–5% carbon and usually some silicon. To produce a forgeable product a further process was needed, usually described as *fining*, rather than *refining*. At the end of the 18th century, this began to be replaced by puddling (in a puddling furnace.

Refined iron

- **Refined iron:** To use grey pig iron, a preliminary refining process was necessary to remove silicon. The pig iron was melted in a *running out furnace* and then run out into a trough. This process oxidised the silicon to form a slag, which floated on the iron and was removed by lowering a dam at the end of the trough. The product of this process was a white metal, known as *finers metal* or *refined iron*.

Purpose of alloying

- Strengthening of the ferrite
- Improved corrosion resistance
- Better hardenability
- Grain size control
- Improved mechanical properties like ductility, strength, toughness, etc.
- Improved Cutting ability
- Better wear resistance

Major alloying elements

- Carbon:

Imparts hardness

Tensile strength

Machinability

Melting point

- Nickel:

Increases toughness and resistance to impact.

Lessens distortion in quenching

Strengthens steel

- Chromium:

Joins with carbon to form chromium carbide, thus adds to depth hardenability with improved resistance to abrasion and wear.

Improves corrosion resistance.

- Silicon:

Improves oxidation resistance
Strengthens low alloy steels
Acts as deoxidisers

SOME ALLOY STEELS

- Nickel steels
- Chrome steels
- Chrome -Nickel steels
- Chrome – Vanadium steels
- Manganese steel
- Silicon steels

CARBON STEEL

- LOW CARBON STEELS :

Carbon %------ 0.05 to 0.30%

APPLICATIONS: Connecting rods, valves, gears, crankshafts.

- MEDIUM CARBON STEELS:

Carbon %-------- 0.3 to 0.7%

APPLICATIONS: Die blocks, Clutch discs, Drop forging dies.

- HIGH CARBON STEELS:
- Carbon %---- 0.7 to 1.5%
- Applications: Pneumatic drill bits, Automatic clutch discs, Wheels for railway steels, Cutting tools.

Plain Carbon Steel

Low carbon

- Good formability and weldability
- Strengthening by coldwork
- Structure usually pearlite and ferrite

Medium carbon

- Can be quenched to form martensite or bainite
- Compromising structure between ductility and strength

High carbon

- Low toughness and formability
- Good hardness and wear resistance
- Can form martensite by quenching but risk of cracking

Compare to other engineering materials

- High strength and stiffness, reasonable toughness, easy to recycle and low cost
- Rust easily, require surface protection

CHROME STEELS

- Composition:
- Carbon- 0.15 to 0.5%
- Chromium- 0.7 to 11%

Mostly widely used in chemical industries because of its resistance to corrosion.

Very good strength.

High resistance to wear.

Cr increases tensile strength and corrosion resistance.

NICKEL STEELS

- Composition:
- Carbon --- 0.35%
- Nickel----- 3.5%
- Addition of nickel increases strength without a proportionality great decrease of ductility.
- Applications:
- Storage cylinder for liquefied gases and for low temperature applications.
- Turbine blades, highly stressed screws

CHROME- NICKEL ALLOYS

- Composition:
- Carbon- 0.35%
- Nickel – 1.25%
- Chromium – 0.6%
- Chrome-nickel steel will have ,after heat treatment, almost the same strength and ductility as 3.5% Nickel steel which has also been- treated.

- Nickel – increases the toughness and ductility
- Chromium- improves hardenability and wear resistance.

MANGANESE STEELS

- Composition :
- Carbon – 0.18 to 0.48%
- Manganese – 1.6 to 1.9%
- Silicon - 0.2 to 0.35%
- Manganese increases hardness and tensile strength.
- Increased resistance to abrasion and shock
- Applications: Grinding crushing machinery, railway tracks, etc.

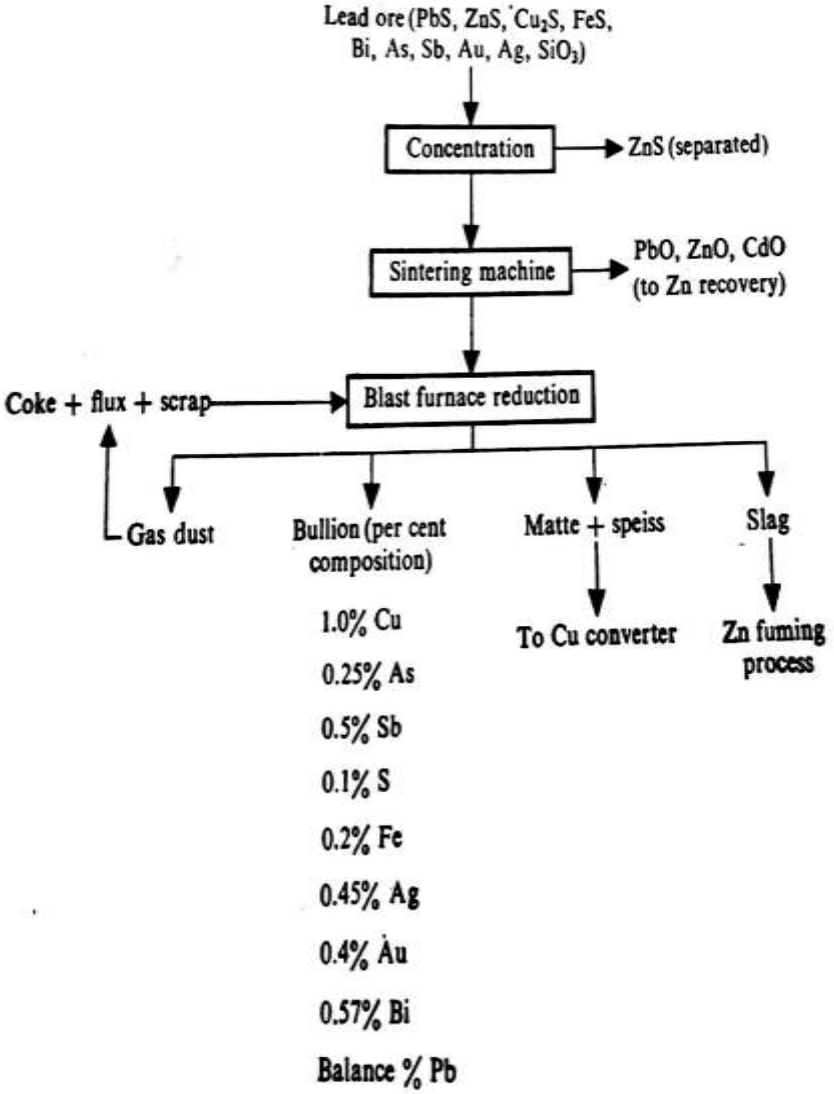
CHROME VANADIUM STEELS

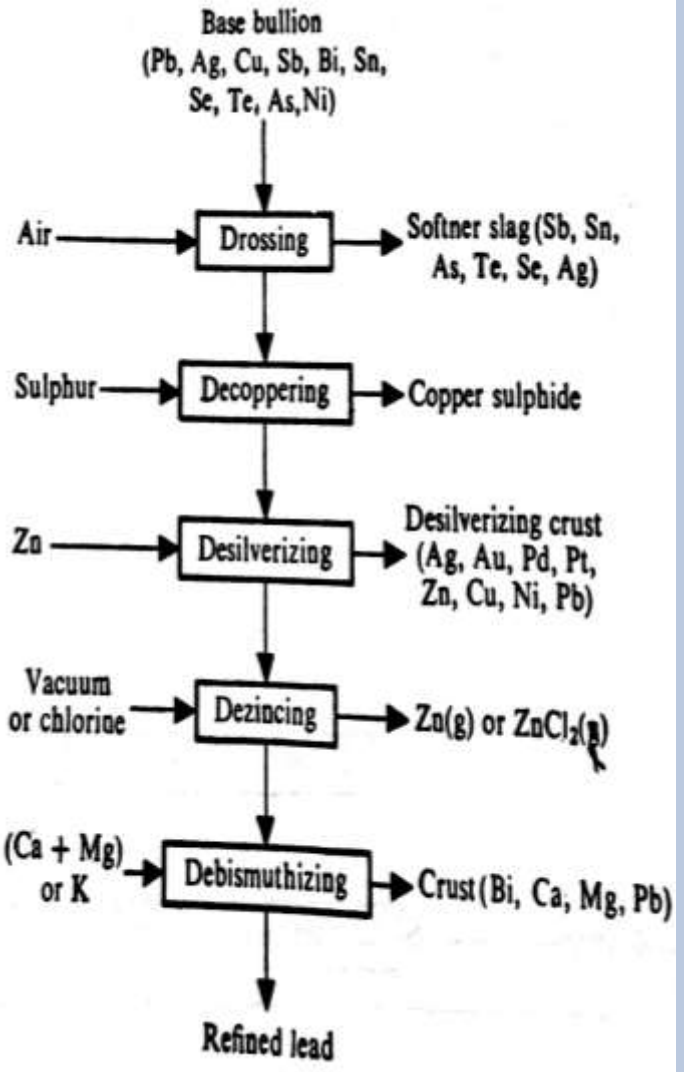
- Composition:
- C - 0.26%, Cr- 0.92%, V – 0.2%
- Chromium and vanadium increases hardenability and impart a finer grain structure.
- Applications:
- Shafts of automobiles, aeroplanes, locomotives.

SILICON STEELS

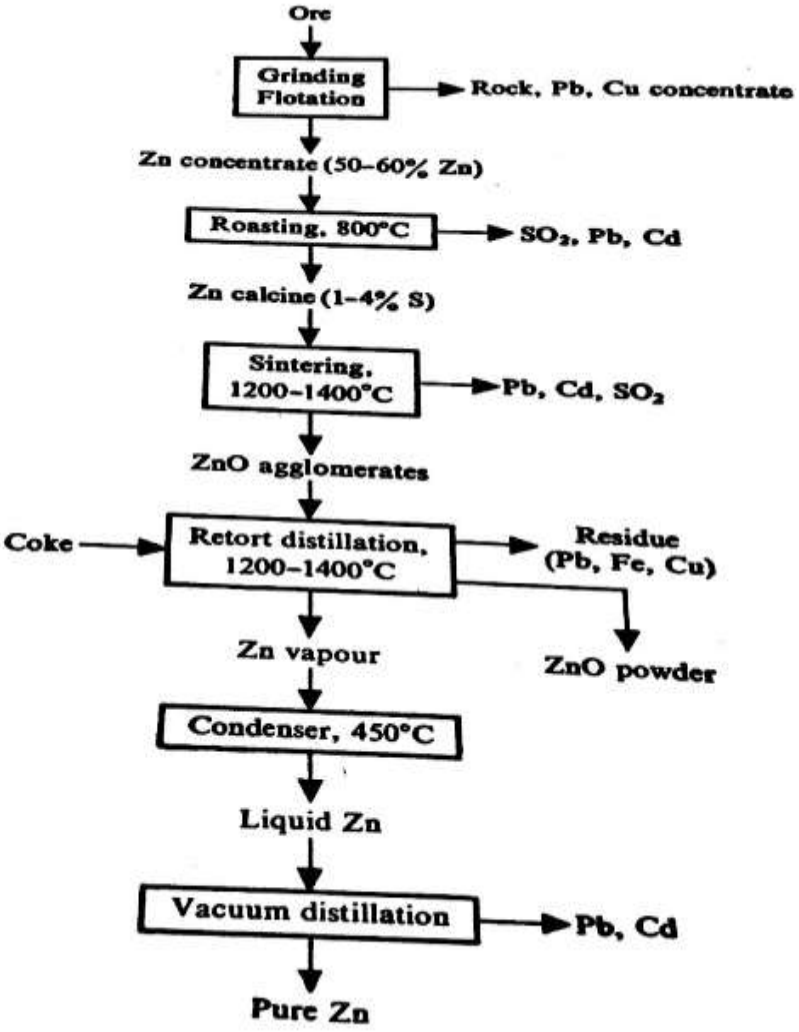
- Composition:
- C – 0.1%, Mn- 0.6%, Si -1%
- Silicon imparts Strength and fatigue resistance and improves electrical properties of steel.
- Many bridges are constructed with Silicon Structural steel which is stronger than carbon steel of equal ductility.
- Silicon steels with greater than 4%silicon called electrical steels.

Pyrometallurgical Route for Lead

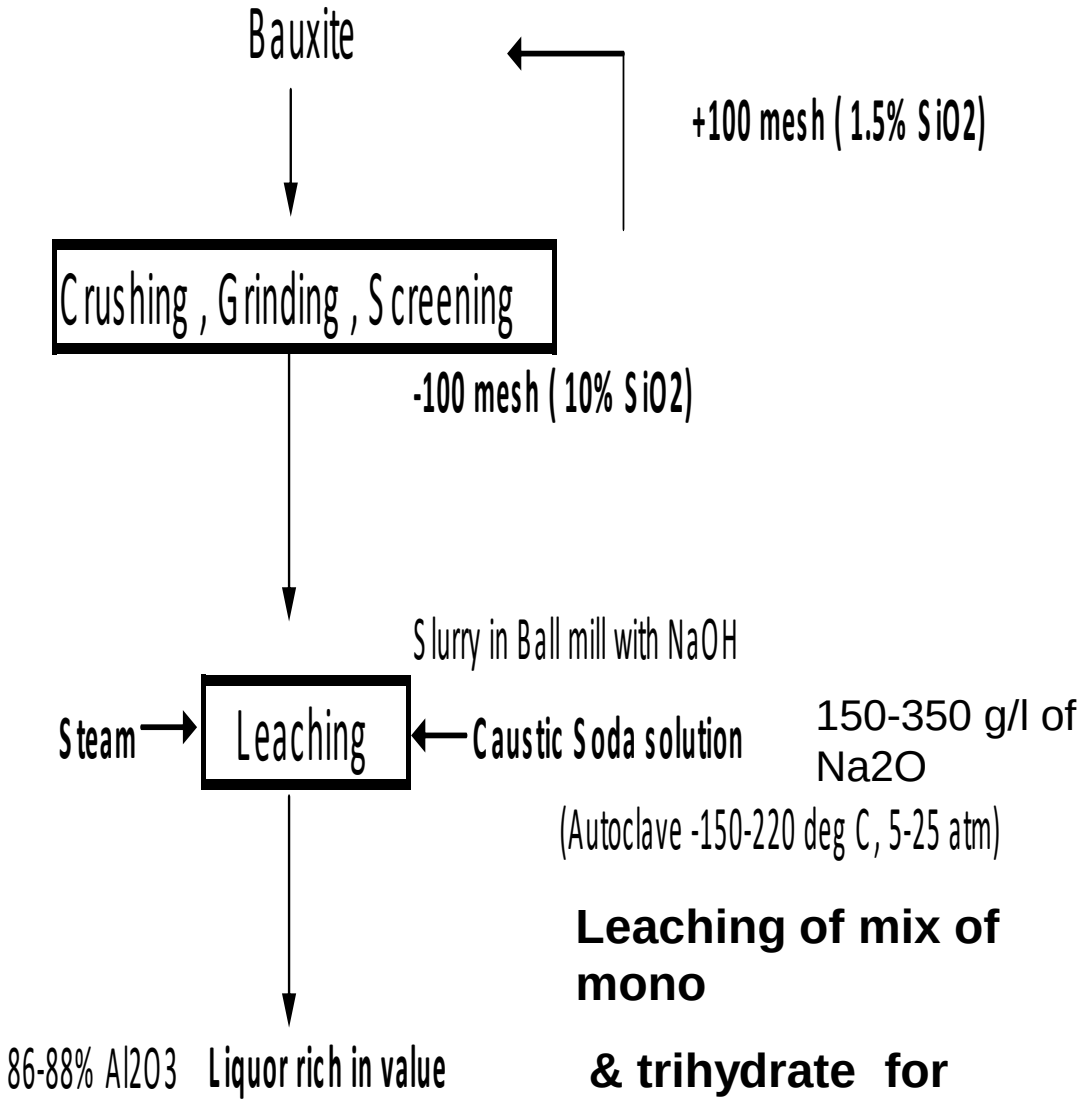




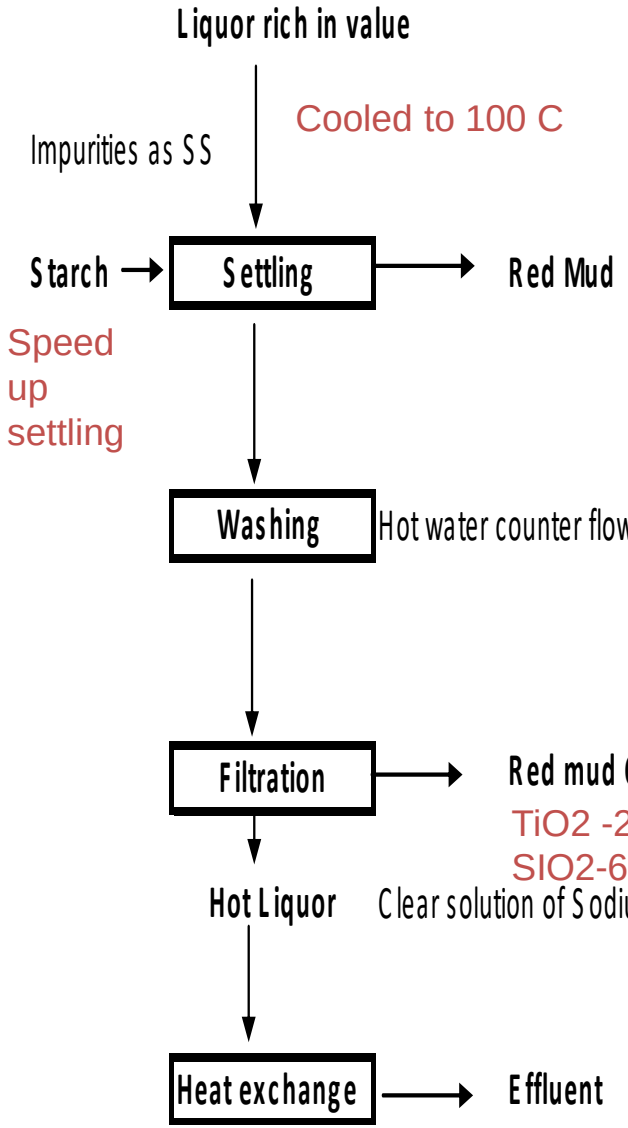
Pyrometallurgical Route for Zinc.



PROCESS


Bauxite
+100 mesh (1.5% SiO2)
Crushing , Grinding , Screening
-100 mesh (10% SiO2)
Slurry in Ball mill with NaOH
Steam
Leaching
Caustic Soda solution
150-350 g/l of Na2O
(Autoclave -150-220 deg C, 5-25 atm)
Leaching of mix of mono
& trihydrate for 2.5 hrs
86-88% Al2O3
Liquor rich in value

Process

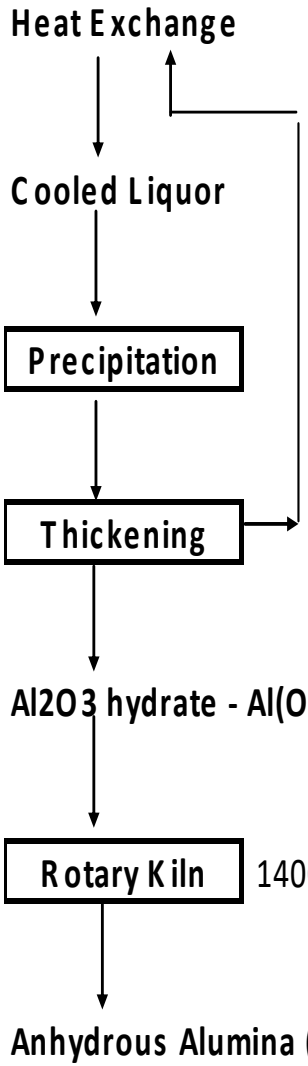


$$Al2O3.H2O + 2\,NaOH = 2\,NaAlO2 + 2\,H2O$$

$$Al2O3.3H2O + 2\,NaOH = 2\,NaAlO2 + 4\,H2O$$

To eliminate redmud in liquor

Process



below critical temp , addition of Al(OH)3 for nucleation

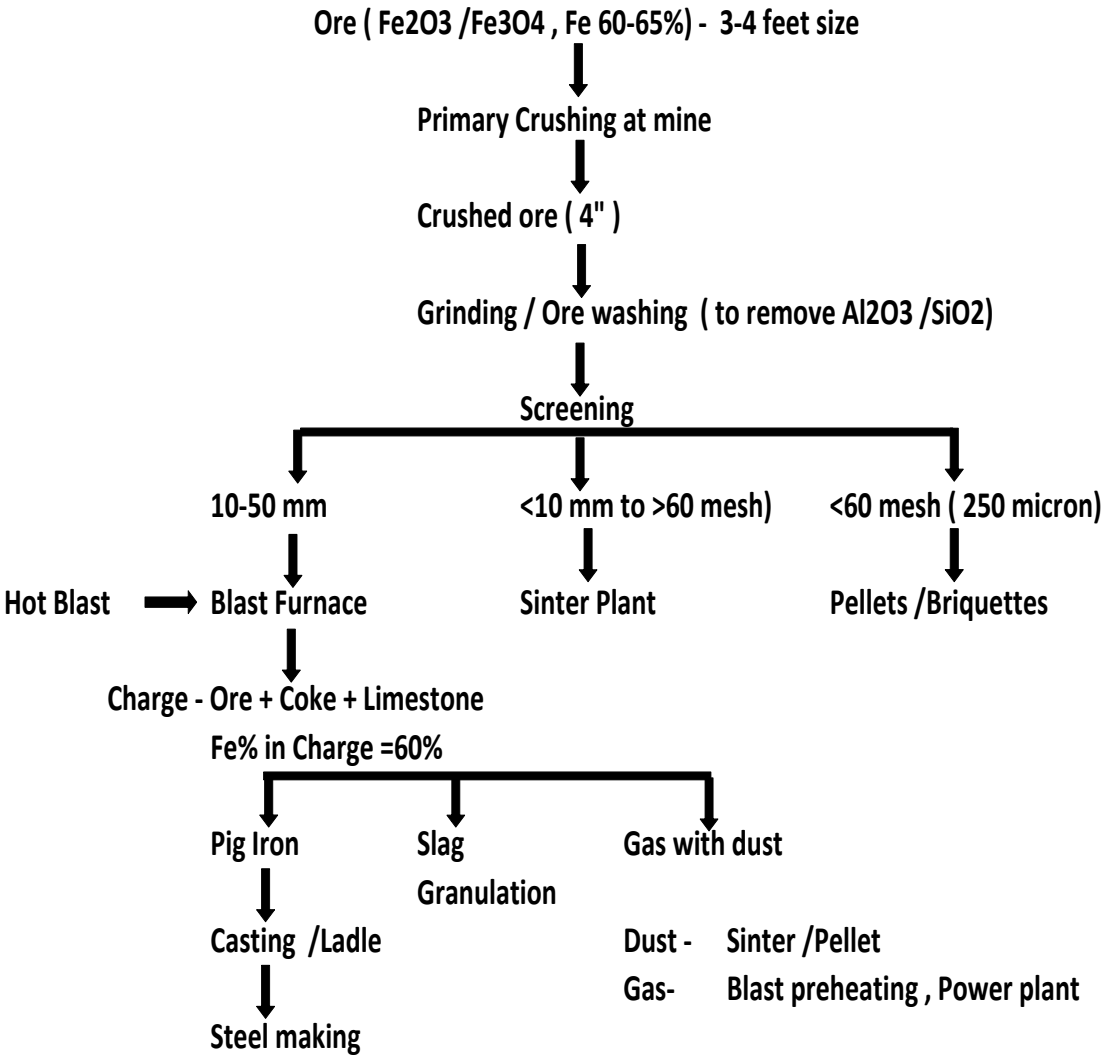
T < 80 deg C

Series of thickeners

Mono & Trihydrate

1400 deg C

IRON MAKING FLOWSHEET



STEEL MAKING FLOWSHEET

Pig Iron (C ~ 3.5-4% , Si ~1% , Mn ~1% , P~ 1% , S ~0.1%)

↓

Steel Making Furnace (Bessemer , LD , Open Hearth , Eletric F/c)

↓

Air blowing for oxidation of Si , C

Addition of fluxes - Limestone , MgO

↓

Desiliconisation

↓

Dephosphorisation

↓

Desulphurisation

↓

Steel (C<0.6% , Si , P , S < 0.035)

THANK YOU