Metallurgical and Materials Engineering Department
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Semester: 3rd **Subject: Introduction to Metallurgy & Materials**

Department: Metallurgical & Materials Engineering

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LECTURE IST

INTRODUCTION TO METALLURGY & MATERIALS

1.0 INTRODUCTION

The study of "Metallurgy and Material Science" forms a very fundamental subject for a majority of engineering students. In particular, it is an essential subject not only to the students of Metallurgical & Materials Engineering but is also of great priority to those from practically every discipline of engineering such as Mechanical Engineering, Chemical Engineering, Electrical Engineering, & Electronics Engineering. More often, the subject is taught with greater emphasis on the descriptive aspect rather than from the practical viewpoint. As a result, a fresh engineering graduate, when starts working, finds it very difficult to correlate what he or she has learned and what is required in practice. With this in mind, an attempt needs to be made during the course of class room teaching to have a detailed understanding of the subject and bring in and discuss as much as possible the practical aspect of each & every topic so as to make "Metallurgy and Materials Science" more useful & relevant subject for the engineering students.

Metallurgy

It is the science and technology of metals and involves the scientific study & technology of extracting metals from their respective ores, refining them for subsequent use, creating different alloys, & making useful objects from them for uses of mankind. It also involves the study of structure and properties of metals & alloys, thermal and mechanical treatment of metals and alloys, besides many other things. In simple terms, **metallurgy** is the branch of engineering which deals with the production of metals and alloys in the form and with the properties which are suitable for the practical use. It is the branch of a materials science and engineering which deals with all materials that the mankind uses in its activities.

In the present/modern industrial age metallurgy has attained a greater importance in view of the growing demand to produce materials that not only are cheap but have greater strength coupled with light weight, improved mechanical, electrical, magnetic, high temperature, and corrosion resistance, and are environmental friendly. It is very well recognised that the metallurgical engineering has a definite role to play in keeping pace with the growing industrial activities and with the demand to produce quality materials that ensure prolonged trouble free service of the products.

Material Science

It is a subject that is essentially based on physics and chemistry. It studies the fundamental physical and chemical basis for the controlled combination of atoms to form new compounds, phases and microstructures besides the characterisation of the resulting/developing structures and properties. In fact, there exist scientific and practical interrelationships between the processing, structure, properties and performance of all classes of materials that are useful to the society.

The subject under the title **"Introduction to Metallurgy and Materials"** has been introduced at 3rd Semester level in the course curriculum of the department of "Metallurgical and Materials Engineering" with an aim to provide a solid introduction to the majority of the subjects that the students of the department will be studying during the subsequent semesters of their engineering degree programme.

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1.2 Classification of Metallurgy

The field of metallurgy may be classified as under:

A) Extractive Metallurgy (Chemical Metallurgy)

It deals with the liberation of metals (ferrous or nonferrous) from their respective ores by employing different chemical processes and the subsequent refining of the extracted metal to a greater purity. Different activities involved in extractive metallurgy besides mining include concentration, extraction and refining of metals.

B) Physical Metallurgy

It basically involves the study of nature of ferrous or nonferrous metals and alloys, their structure, physical properties, behaviour and possible applications. It essentially involves the study of chemical composition-structure-property relations in metals and alloys.

C) Industrial Metallurgy

Industrial metallurgy deals with the following areas:

a) Mechanical Treatments/operations

It involves the study of behaviour of metals and alloys under externally applied loads. Various mechanical operations that are carried out on the material to change it into a desired product are as listed under:

- Machining
- Rolling

- Drawing
- Forging
- Forming, etc.

b) Foundry Metallurgy (Melting and Casting)

It is the field of metallurgy where in metals and alloys are shaped into useful products by first melting and then pouring into moulds where they cool, solidify and take the shape of the mould cavity.

There are different casting processes available to make products of different shapes and sizes.
Most commonly used metal casting processes are given below:

- Sand casting
- Die casting
- Investment casting
- Centrifugal casting
- Plaster mould casting, etc.

c) Metal Joining

It is the area of metallurgy wherein the joining of two (same or different materials) is done by heating them to an appropriate temperature, with or without the application of pressure or by the application of a suitable pressure alone and with or without the use of filler material.
Following are the different processes that are available to join the materials:

i) Soldering
ii) Brazing
iii) Welding

Soldering

It is the low temperature process of joining two dissimilar metals such as steel, copper and other materials with the use of filler metal (an alloy) having a melting point below 427^{o}C and not higher than the melting point (liquidus temperature) of the metals or alloys which are being joined. There are various soldering alloys that are used as the filler material during the joining process of different metals. These soldiering alloys are usually called as solders and are listed below:

- Tin-lead alloys
- Tin-antimony-lead alloys
- Tin-zinc alloys
- Lead-silver alloys
- Cadmium-silver alloys
- Cadmium-zinc alloys
- Zinc-aluminium alloys
- Indium-tin alloys, and
- Lead-bismuth-tin-cadmium alloys (Fusible alloys)

Brazing

It is the process of joining different metals and alloys such as steels, cast iron, copper, bronze, brass, aluminium and some of its alloys by heating them to a suitable temperature and by using a filler material that is an alloy (called as brazing filler alloy) having a melting temperature above 427^{o}C but definitely lower than the melting point (liquidus temperature) of metals or alloys being joined. The brazing filler alloys that are used during brazing process are as given below:

- Aluminium-silicon alloys
- Copper- zinc alloys
- Copper- phosphorus alloys
- Silver brazing alloys
- Magnesium filler metals
- Gold filler metals, and
- Nickel filler metals, etc.

Welding

It is the process of fusion or joining of two or more pieces of metal and alloy (same or different) by the application of heat and with or without the application of pressure, and with or without the use of filler material. Various welding processes that are being used to produce coalescence or joining of materials can be classified as under:

- Gas welding
- Arc welding
- Resistance welding
- Induction welding
- Thermit welding
- Cold welding
- Diffusion welding
- Friction welding
- Electron beam welding
- Laser beam welding
- Explosive welding
- Ultrasonic welding, and
- Electroslag welding

d) Powder Metallurgy

This area of metallurgy deals with the manufacturing of products from finely divided metal or alloy powers. The process consists of compacting the properly blended powder to the desired shape of the part under suitable pressure in a die and subsequently sintering the compact that has been ejected from the die in a furnace at an appropriate temperature (below the melting point of the metal) and under controlled atmosphere for a specific period of time in order to bond the particles together and develop the required properties in the product.

e) Corrosion and its control

Corrosion is defined as the destruction of material by chemical, electrochemical or metallurgical interaction between the environment and material. In simple terms, corrosion is the slow process of destruction of material in different types of atmospheres and liquids at any temperature. The process leads to the destruction of the material and its ultimate failure.

f) Heat treatments

It is an important operation to impart superior properties to many engineering products/components after their fabrication. Heat treatment involves controlled heating and cooling designed to induce desired combination of properties in the material due to the phase transformation and structural changes that occur during the process.

Different types of heat treatment processes that are used are:

- Annealing
- Normalising
- Hardening
- Tempering
- Case-hardening

TO be Continued……….

LECTURE 2nd

In continuation to Lecture 1st...........

g) Testing of materials

It is an important aspect of metallurgy engineering and deals with various testing methods that are performed to evaluate different properties of materials under different conditions/environments. In general, the material properties may be broadly categorised into the following types:

- Physical properties such as size and shape, density, and porosity, etc.
- Optical properties such as refractive index, and reflectivity, etc.
- Thermal properties such as melting point, specific heat, thermal conductivity, etc.
- Chemical properties such as chemical composition, and corrosion resistance, etc.
- Electrical and electronic properties such as conductivity, resistivity, and dielectric strength, etc.
- Magnetic properties, and
- Mechanical properties such as strength, and hardness, etc.

Mostly, testing methods are classified as **Destructive Testing Methods** and include the methods like Tensile test, Hardness test, Impact test, Fatigue test, and Creep test, etc., and **Non-destructive Testing Methods** that include Visual test, Leakage test, Liquid penetrant test, Radiography, Ultrasonic test, and Acoustic emission test, etc.

h) Failure analysis and prevention

Analysis of **Metallurgical Failures** has lately become an essential part of metallurgical engineering to understand **"Why And How"** failures take place in engineering materials, components, structural parts, machine elements and or an engineering device etc. in spite of taking all the necessary measures while designing, procuring the material and or fabrication.

In general **'Metallurgical Failure'** is an undesirable event as it puts human lives to danger, induces economic losses and creates disruption in service. As such, proper and systematic analysis of metallurgical failures is necessary to avoid premature failures in the future.

2.0 Extractive Metallurgy

Introduction

The history of human civilization can be classified into three main divisions, namely, the **Stone Age**, the **Bronze Age**, and the **Iron Age**. The period, when both stone and metal were in use, is referred as the **chalcolithic period**. During the Bronze Age copper was replaced by Bronze (an alloy of Copper and Tin) which is harder and also has a lower melting point than Copper and can be shaped into various tools, and utensils with much ease. This period of the civilization did not last for long as new metal Iron replaced Bronze. Since then, there have been constant efforts to discover new metals and alloys not only by experimenting with the existing metals but also by developing new and efficient processes for metal extraction.

Extractive metallurgy deals with the liberation of metals by different chemical processes from the ores in which they are present. Besides mining, it includes concentration, extraction, refining of metals and alloys. Usually, extractive metallurgy is further divided into **‘Ferrous’** and **‘Non-Ferrous’** categories. Ferrous metallurgy is related to **Iron and Steel**, whereas Non-Ferrous metallurgy deals with all metals and alloys **except Iron and Steel**.

Metals have been in use since around 800 BC. However, till about 15th Century A.D., a very few metals such as Gold, Silver, Copper, Tin, Lead, Zinc, and Copper were known. However, with the passage of time the discovery of metals increased due to the further developments in knowledge and techniques of metal extraction processes. Since the start of the 19th Century, around 70% of the metals and alloys that are presently known have been discovered.

2.1 Mineral

It is a naturally occurring inorganic compound of one or more metals in association with non-metals such as Oxygen, Sulphur, and Halogens. It has a fixed composition and well-defined properties, both, physical and chemical. In simple terms, **mineral** is the **form** in which various metals and non-metals **exist** in **nature**.

Minerals may be **Metalliferous** such as Chalcopyrite ($Cu_2S.Fe_2S_3$), Sphalerite (ZnS), Cassiterite (SnC_2) etc., or **Non-metalliferous** such as Calcite ($CaCO_3$), Fluorspar (CaF_2), Quartz (SiO_2), and Salt (NaCl) etc.

2.2 Ore

It may be defined as a naturally occurring aggregate or a combination of minerals from which one or more metals (or minerals) may be **economically** extracted. There are some fundamental factors which determine the economical extraction of metals from their respective ores and these factors are listed below:

- ➢ The percentage of valuable metal in the ore
- ➢ The form in which the metal occurs, i.e. the nature of the mineral in the ore
- ➢ The amount and the type of the impurities present in the ore
- ➢ The physical condition of the ore
- ➢ The location and the magnitude of the ore deposits
- ➢ The proximity to transport facilities, and
- ➢ The market value of the metal to be extracted

For determining the exact location, and to make a quantitative estimation of the ore (mineral) deposits various scientific methods such as Magnetic, Electrical, and Electromagnetic are employed.

2.3 Sources of Metals

The three main sources of metals and their compounds are the:

- ✓ Earth's Crust
- ✓ Sea, and
- ✓ Scrap metal

Earth's Crust

It is the most important source of metal. A large amount of Oxygen and Silicon is present in the **Earth's Crust** as indicated in the Table 1. The first eight elements account for more than 98% of which around 75% is composed of only two elements, namely, Oxygen and Silicon. There are other elements like Titanium, Rubidium, and Vanadium present in sufficient quantity in the Earth's Crust but have only limited use. On the other hand, elements which are present in much less quantity in the Earth's Crust, namely, Copper, Zinc, and Lead find numerous applications in everyday life.

Sea

More than 70% of the Earth's surface is covered by the Seas and it is estimated that they contain about 3.5%of dissolved solids. There are possibilities that Metals could be extracted in the near future by deliberately cultivating specific marine organisms which would concentrate one or more elements within their bodies by inherent biological activity. Further, **NODULES** which cover appreciable areas of Sea floor also contain metals in their deposits.

Scrap metal

As a result of accelerated growth in industrial activities all over the globe huge quantities of scrap metal is generated and is readily available for further use. This scrap metal is being utilised as an important source for the recovery of metals and the metals that are recovered from it are called secondary **metals**. Considering the depleting state of our natural mineral resources, time is not far off when metal-manufacturing processes would focus on only refining and recycling increasingly huge quantities of scrap metal which is periodically used and discarded. At present, Steel-making processes are utilising a significant amount of the scrap metal as a part of the charge material.

Table 1. The percentage of different elements present in the earth's crust.

Sl. NO.	Element	Percentage
1.	Oxygen	46.59
2.	Silicon	27.72
3.	Aluminium	8.1
4.	Iron	5.0

5.	Calcium	3.6
6.	Sodium	2.8
7.	Potassium	2.6
8.	Magnesium	2.0
9.		
10.		
11.		

impurity present in the metal are controlled by the conditions under which the smelting and refining operations are carried out. The aspects of prior processing have significant influence not only on further operations but on the ultimate properties of the product.

2.4 Occurrence of Metals

There are very few metals such as Gold, Copper, Silver, Platinum, etc., that occur in their free metallic state (**i.e., native**) in nature.

Generally, metals occur in the form of **chemical compounds** as:

- Oxides (e.g., Fe, Cu, Al, Sn, Cr, Mn, W)
- Sulphides (e.g., Cu, Pb, Zn, Ni, Ag, Co)
- Carbonates (e.g., Fe, Zn, Cu, Mg, Mn, Pb)
- Sulphides (e.g., Cu, Zn, Ni, Pb, Mo, Cd, Bi, Ag, Sb)
- Silicates (e.g., Ni, Cu, Zn),

- Sulphates, and
- Chlorides (e.g., Ag, Cu, Mg)

It is from these very forms that metals have to be reduced economically to the metallic state.

The metalliferrous minerals, as they occur in nature, are usually found in associated with appreciable quantities of unwanted foreign material like sand, clay, shale, etc. Therefore, the actual metal content of the mineral is determined by the amount of these valueless non-metalliferrous minerals called the **gangue**. In case of cheap metals like Iron, the amount of gangue may be in the range of 5-15%, whereas, in case of noble metal like Gold, the percentage of gangue may be almost 100%. It is only when the metal content of the mineral can be extracted economically, and at a profit, the particular mineral is considered as the Ore of that metal. As listed above, there are various factors which establish whether a particular mineral is an Ore of the metal or not. However, the economy of extraction and the market price of the metal may vary from time to time, and also from location to location. Therefore, a mineral, which may be an Ore of the metal at one particular location, may not be an Ore at a different location or time and vice versa. An Ore having only about 0.0014% of Gold may be an Ore of Gold in view of its high market price, and the total cost involved in its extraction is covered by the profit margin. Contrary to this, the Ores of cheaper metals like Lead and Zinc must contain a very high percentage of the respective metals to cover the cost of their extraction. The average percentage of the metal present in their respective Ores is given in Table 2.

Table 2. The average percentage of the metal present in their ores.

Sl. No.	Metal	Average Metal Content (%)
1.	Gold	0.001
2.	Silver	0.02

3.	Tin	1.5
4.	Aluminium	30
5.	Copper	2.0
6.	Lead	5.0
7.	Zinc	3.0
8.	Iron	50.0

It is evident from Table 2 that the metal content of the ores is very low. It is because of the fact that almost all ores as they occur in nature usually contain variable amounts of worthless and unwanted material called the **Gangue**. It is, therefore, necessary to remove the maximum of the gangue from the ore before it is subjected to expensive metallurgical operations for extracting the metal. The gangue is invariably highly infusible i.e. it has a very high fusion (melting) point. In order to make it fusible, **fluxes** are added to the furnace charge. These fluxes chemically combine with the gangue at the available furnace temperature and produce a new compound or compounds which fuse at temperatures which are much lower than the temperature at which the gangue alone or the flux alone would fuse. As the percentage of gangue in the ore increases, the quantity of flux to be added to the furnace charge also increases with the consequent increase in i) the quantity of fuel to be used, ii) the capacity of the furnace, and iii) the time needed for the smelting reactions to get completed. The overall effect of high percentage of the gangue in the ore is to make the extraction of metal from such ores costlier and time consuming. In order to make the process of metal extraction economical and less time consuming, it becomes necessary either to remove the gangue from the ore or to reduce its percentage in the ore. There are various methods; physical and mechanical, available to reduce the percentage of the gangue in the ore to a level that makes the process of extraction of metal cost effective. The process of gangue removal from the ore is called **ore-dressing** or **mineral dressing**.

2.5 Ore-dressing (mineral-dressing)

It is the processing of ore (or mineral) to yield valuable products and waste by all those means that do not destroy its physical and chemical identity. The main aim of processing the ore (or mineral) by using various physical and chemical methods is to produces a **concentrate** that contains most of the ore minerals so that the **subsequent chemical treatment** becomes an **economical** proposition. The different processes utilised in ore (mineral) dressing are classified as under:

- **Comminution (or size reduction) by**
  - (a) Crushing
  - (b) Grinding
- **Sizing (or separation as per the size) by**
  - (a) Screening
  - (b) Classification
- **Concentration by**
  - (a) Hand picking
  - (b) Magnetic separation
  - (c) Gravity concentration by
    - (i) Panning
    - (ii) Jigging
    - (iii) Tabling
    - (iv) Spiralling
    - (v) Sinking floating (or heavy medium process)
  - (d) Flotation
  - (e) Filtration

Lecture 3rd

In continuation to the Lecture 2 ....

The main aim of mineral or ore dressing is to reduce the amount of the gangue in the ore and produce a **concentrate** that is rich in the **ore minerals,** thereby, make the subsequent **chemical treatment economically** feasible.

2.1.1 Comminution (sizing)

It is the **process** of reduction of the bulk ore to smaller sizes so that the ore minerals and the gangue minerals, which otherwise are in intimate association with each other in the ore, are separated from each other and collected separately. This liberation of the minerals from each other is achieved by crushing and grinding of the ore.

A. Crushing

Crushing of the ore is done by using different types of the crushers Such as:

- Jaw crushers
- Gyratory crushers
- Roll crushers

B. Grinding

Grinding is carried out by using grinders of the following types:

- Ball mills
- Rod mills

The size reduction of the bulk ore by crushing and grinding produces ore particles of non- uniform size.

2.1.2 Screening

Screening is the process of obtaining a **uniform sized** product by using screens which have apertures of different sizes.
For the efficient operation of the subsequent process of concentration, it is always desirable to have the ore particles of uniform size. Therefore, the discharge from the crushers, and or grinders which mostly comprises a non-uniformed sized ore particles is to be subjected to screening so as to a product of uniform sized ore particles.

There are different standard series of screens available and out of which the **Tyler Standard Series** is most commonly used. The size of these screens is represented by the **mesh number** which is the number of the meshes per linear inch.

2.1.3 Classification

It is the method of separating mixtures of minerals into two or more products on the basis of the velocity at which the mineral grains fall through the fluid medium, i.e., water or air. The different types of classifiers that are being used for the sorting purpose in the mineral industry are named below:

- Hydraulic classifier
- Cone classifier
- Mechanical classifier
- Thickeners, and
- Wet cyclones

The main purpose of the above described methods of ore dressing is to prepare the basic ore for the subsequent operations of **concentration** that are carried out to produce a **concentrate** that is rich in the **ore minerals**.

2.1.4 Concentration

It is the process of separating a mixture of minerals in to two or more products on the basis of the differences in the **various properties** of the minerals comprising the mixture. These properties, besides colour and lustre, **i**nclude density, magnetic, and surface properties. The different concentration operations that are based on the differences in these very properties of the minerals are listed in Table 1.

Table 1. Different concentration operations based on different mineral properties.

Sl. No.	Operation	Difference in Property
1.	Hand Picking	Colour and Lustre
2.	Magnetic Separation	Magnetic Properties
3.	Gravity Concentration	Density
4.	Froth Floatation	Surface Properties

Hand Picking

This concentration method is not being used very frequently except when the conditions are favourable as in the case of Gold ore. In this operation the ore from the coarse crusher is allowed to move very slowly over a conveyor belt on both sides of which the pickers are seated. These pickers pick off either high grade ore pieces or gangue pieces; each individual picker selects only one type of the material. In order to wash off dust and make the mineral recognition easier, the ore is sprayed with water.

1. Magnetic Separation

In this process of ore concentration, the magnetic mineral particles are separated from non-magnetic ones, for example, magnetite from other minerals, roasted pyrite from sphalerete, etc. This method too is not used very frequently except some times in the beneficiation of Iron ores.

2. Gravity Concentration

This method of ore separation is based on the differences in **density** of various ore minerals. Furthermore, the laws of free and hindered settling a have strong bear on this method.

A. Panning

This is the mineral separation process which is based on the principle of **stratification**. In panning, a pan of some definite (specific) dimensions is filled with the crushed ore and is then shaken which causes the particles of the minerals to stratify on the bases of the difference in their densities; the heavy (high density) mineral particles settle at the bottom of the pan and lighter (low density) ones remain at the top.

B. Jigging

The different minerals in the crushed but comparatively coarser ore material are separated by the process of jigging wherein a bed of ore is supported on a screen under water and is subjected to pulsation i.e. brought into suspension at regularly recurrent intervals. After each pulsation, the ore particles are made to settle back on the screen and in the process heavy minerals (concentrate) settle at the bottom and the lighter ones (tailings) at the top.

C. Tabling

In this method of ore concentration, the separation of the ore minerals is carried out on the **'Walfley Table'** on the basis of differences in the densities of the mineral particles in the ore. The Walfley table consists of a slightly inclined deck with the arrangement for water to flow over it from top to bottom. The table, besides being covered with **Linoleum,** has on the surface a number of thin wooden strips (or riffles). The crushed and ground ore is introduced at the upper right hand corner of the table and thereafter, it is made to vibrate longitudinally as a result of which the particles of the mixture of minerals in the ore move diagonally across the inclined deck from the upper right hand corner to the lower left hand corner of the table. Concentration of the ore during tabling takes place due to the separation of the small heavy minerals from the larger light minerals as heavy mineral particles move to the bottom of the table whereas the larger light mineral particles stay at the top.

D. Froth Floatation

This process of mineral separation exploits the difference in the surface properties of the minerals present in the crushed and ground ore. The process has been developed very lately and is used to concentrate the sulphide ores. This process of mineral concentration is carried out in specially designed cell called the '**Floatation Cell'**.

In this process, the particles of heavy sulphide minerals such as PbS_2, Cu_2S, Fe_2S_3, and ZnS, etc., when agitated in water containing a very little quantity of oil such as the pine oil, attach themselves to the froth that is produced and thus float, while the lighter particles that constitute the gangue sink to the bottom as they are not buoyed up.
In this process of mineral separation, some chemicals are deliberately added to the pulp (ore and water mixture) for achieving different purposes. The different chemicals that are usually added for the effective separation of the sulphide minerals are as under:

- ✓ Frothers
- ✓ Collectors, and
- ✓ Conditioners

Frothers

It is observed that under normal conditions when the air is bubbled through water, the bubbles break up/disintegrate as soon as they reach the surface and as such do not form a stable froth. Therefore, a reagent called 'frother' is added to the pulp to stabilise the air bubbles and forms the froth which will hold the desired mineral particles. Frothers as such have no effect on the floatability of minerals. An appropriate quantity of pine oil, and cresylic are most commonly used as frothers.

Collectors

The collector is a chemical used to alter the surface characteristics of the mineral in order to enable it to float and adhere to the froth (air bubbles). The most commonly used collectors are Xanthates.

Conditioners

For making the heavy mineral particles buoyed up by air bubbles, it is necessary to maintain the proper pH of the pulp and to do so a little amount of different chemicals are added.

In **Froth floatation** process, the Floatation cell is filled with the ore water mixture (pulp) and air is blown from the bottom of the cell in order to disperse it throughout the pulp in the form of small air bubbles. The bubbles carry the floatable minerals from the pulp upward where they are collected in the froth which is subsequently scraped off.

In case, there are two or more floatable minerals present in the ore they are separated by the process called as the **'Differential Floatation Process'**. In this process of separation, different types of chemicals are used with an aim to:

i) Depress one of the minerals from the mixture of minerals present in the ore so that the other mineral only is allowed to float up, and to achieve these different inorganic chemicals, usually referred as **'DEPRESSORS'** are added to the ore-water mixture, and

ii) Allow buoying up one mineral in preference to the other minerals present in the ore by adding chemicals called as **'ACTIVATORS'** to the ore-water mixture.

Therefore, in **differential floatation process,** it is possible to concentrate the ore that contains a mixture of several floatable minerals by using appropriate depressors and activators.

In extractive metallurgy, these floatation methods have gained an appreciable importance in exploiting numerous ore deposits that could not be processed economically earlier.

E. Filtration

To be continued...............

NOTE

1. The contents given above in the lecture note is compiled from various sources and is only for the study purpose of the students. The students are advised to refer the relevant books as listed at the end of the syllabus in the course curriculum for further understanding of the topic/subtopics covered in this lecture note.

2. In case of any doubt/difficulty the students are free to contact me in person or through E-mail on my E-mail ID: ***rajinderambardar@gmail.com***