Lec 21: Basic understanding of froth flotation

Hello everybody. Welcome to this massive open online course on solid fluid operations. So, we are actually discussing about that fluidization process where that multiphase systems are involving and in this lecture we will try to understand the basic concepts of flotation which is also comes under that fluidization operation. In this case, you will see that particulate materials will be separated from the slurry in presence of surfactant and also by aeration. So, here in this case 3 phases will be taking part which will be like gas, liquid and solid phase. This solid phase will be added in the liquid like as an application you can say that ore particles or ore that will be ground and making a slurry with a specific size of that particles and then it will be fluidized in a liquid medium just by action of driving force of that gas which will be continuously supplied from the bottom of a vessel in which that slurry processed to separate that particulate materials.

Now, this separation of this particulate materials will be based on that hydrophobic or hydrophilic nature of that particles. Suppose there is a mixture of particles like that some will be hydrophobic and some will be hydrophilic. that what is hydrophobic? Hydrophobic means water repellent whereas hydrophilic is water attractive. So, whenever these two types of materials will be floated or you can say that it will be fluidized or being suspended by the action of gas flow, gas flow where that gas will be supplied as a dispersed phase of bubbles.

But these bubbles can be stabilized just by adding some surfactants there or surface active agents there. And whenever you are adding this surface active agents there you will see that surface tension will be reduced. And because of that the size of that bubble which is actually formed just by supplying that gas through the distributor. And those bubbles will be stabilized or it will give you a certain size of that bubbles. And at the surface of the bubbles you will see that the hydrophobic particles will be attaching on that bubble surfaces and those particles along with that bubbles will be going upward by that rising of that bubbles because of their buoyancy effect.

So in that case that particulate material which will be hydrophobic in nature will be attaching to the bubble surface and then it will be going up. And in that case at the surface those particles will be separated. Now you will see that whenever you are adding that surfactants there will be a formation of froth. There will be a certain amount of surfactant to be added. So you will see that whenever fluid will be flowing inside that bed or mixing will happen that you will see that the formation of froth will be there.

That formation of froth that means there will be a particular size of that bubbles will be formed and along with that froth you will see that that froth will carry that solid particles attaching on that surface of that bubbles. So this is the process basically that froth flotation. So it is a process that selectively separates that materials based upon whether they are water repelling that means hydrophobic or have an affinity for water. It is called hydrophilic. The process of froth flotation is dependent upon the density of the material and its hydrophobic nature.

Now you will see that this froth flotation is frequently employed for separation of solids encountered particularly in the primary mineral and chemical industries. And materials mined from any deposit with the earth's crust usually represent a highly heterogeneous mixture of solidified phases. These are mostly crystalline and represent the various minerals. And you will see that occasionally they are non-crystalline some will be amorphous and such as for example coal, glasses, resins and hopel. And in that case this based on this froth flotation you will see that separation of that solid particles which will be hydrophobic nature and it will be separated to get this valuable value added product from those particles there.

So here in this figure you will see that in representation of a froth flotation there you will see that in this case air is supplied through a distributor here and also that distributor will be itself agitating this in this vessel. that whenever it will be agitating or rotating and you will see that at the same time simultaneously gas will be distributed through this distributor come agitator. And there bubbles or gas will be distributed as a dispersant of bubbles there. And you will see that from that the formation of the bubbles you will see that at the bubble surface you will see that the particles will be attaching on the surface of the bubbles from the slurry. And whenever that bubbles would be going upward you will see that the bubbles will carry that solid particles and it will be separated the froth at this surface like this.

And then froth will be collected and from that froth you will see that the solid particles will be separated. Whereas the hydrophilic particles those who are not going up with that bubble attached on the surface those will be coming out at the bottom as a trading. So, this is the basic structure here. So, here in the feed systems will allow to feed that slurry here and you will see that to form that bubbles it will be supplied to the distributor. Now in this case sometimes the arrangement will be different to supply that gas to form that bubbles it may be from the bottom itself from the compressor it will be supplied.

Whereas here in this case it will be that maybe the from the upper part of this vessel you will see that through a the pipe and then it will be supplied at this bottom. Here also it can be possible. So, here either from the top or bottom it can be possible to distribute that gas as a disbursement of bubbles. So, here is an basic structure of that froth rotation devices. And in this case you will see that mechanism is that there will be mixture of hydrophilic and hydrophobic particles and water there.

Now in this case you will see that bubbles those are forming whenever it will be you know moving upward they will carry that hydrophobic particles here from that slurry of mixture of that hydrophilic and hydrophobic particles and it will be separated as a froth here. Whereas hydrophilic particles that will be coming downward as a trailing. So this is the mechanism here. Now for the solid particles to float you will see that the surfaces must be hydrophobic that is wetted only partially by water. And hydrophobic solids due to incomplete wetting and no spreading attached to the bubble surface.

So here this is the mechanism whose particles will be hydrophilic whose particles will be hydrophobic that can be identified or can be assessed based on its contact angle of that solid particles with the liquid. So that contact angle can be represent here some particles will be weakly hydrophobic in that case a small contact angle will be there if it is less than 90 degree that contact angle how that contact angle that means here solid particles will be that solid materials whenever liquid will be placed on that solid material as a drop you will see that how angles will be forming. So it will be called a contact angle that this as per picture shown here. So when this contact angle theta will be less than 90 degree to be called as weakly hydrophobic. And also a strong hydrophobic will be when this contact angle will be greater than 90 degree.

So those who are you will see that even air bubble you will see that clinging to submerged planar solids in that case you will see that weak bubble adhesion small contact angle it will exhibit. So in that case few particles will be attaching whereas a strong bubble adhesion that is large contact angle is greater than 90 degree that is many particle will be attached on this bubble surfaces. So based on this contact angle you can say whether these particles will be attaching on the bubble surface or drop surface there. Now here when the solid is highly hydrophobic the contact angles are high that means the theta almost could be equals to 90 degree or even greater than 90 degree. And hydrophobic particles immersed in aqueous solutions are more readily picked up by you know static bubbles contacted with the solids if their hydrophobicity is higher.

And for selective flotation to be carried out there must be a difference in the degree of wetting and non-wetting of the solid components in the mixture. So here in this case you will see that again that whenever that bubbles will be forming just by distributing it to the distributor in the slurry where that hydrophobic and hydrophilic particles will be there. So in that case this hydrophobic particles how that will be attached to that bubble surface here like this. So here that hydrophobic material these are hydrophobic material it will be attached to this in the bubble surface whereas other particles will not be attaching to the bubble surface that will be segregating or it will be coming out from the bottom. So in this case whenever bubbles will be arising you will see that those hydrophobic particles will be being carried out by this bubble and it will be separated at this froth and it will be taken out or collected in a separate vessel.

After that you will see that those particles would be washed or separated in a vessel as a hydrophobic material. Whereas from the bottom of this flotation cell you will see that it will be collected as a hydrophilic material. So in this way you can separate that hydrophilic and hydrophobic material by this froth flotation. Now what are the overall steps of that particle flotation? You will see that introduction of gas bubbles into the slurry first you have to do and then collision between the gas bubbles and suspended matter is to be floated. There will be certain collision between particle and bubbles and you will see that hydrophobic particles will be attaching on the surface of the bubble after collision.

Now attachment of that fine bubbles to that surface of the suspended matter will be there and after that you will see that collision between gas attached suspended particles with the formation of agglomerates there. So whenever you will see that more than one particles will be attaching on the surface of the bubbles there will be an agglomeration formation and then entrapment of more gas bubbles in the agglomerates. You will see that that during that agglomeration formation inside that agglomeration there will be a bubble. So that bubbles whenever it will be moving upward rise to that surface of that you will see that it will be then bursting in that upper surface of that flotation vessel and then that solid particles would be taken out from that from that top of that surface of the vessel. So this is the step here you can say that gas bubbles to be introduction and introduced and then collision will happen and then attachment will happen after that agglomeration will happen.

After agglomeration you will see that the bubble will try to go up and then those agglomerated particles will be separated at the surface. This is the overall step of particle flotation. And what are the key design variables for this flotation systems to get that better efficiency there. So key design variables in the system that controlling efficiency of the flotation are as like this first gas input rate what would be the gas input rate that means what is the gas velocity gas flow rate that will be maintained that you have to estimate or you have to taken care. And volume of gas entrained per unit volume of liquid that also you have to note down what the gas holdup it is called what the gas volume fraction out of that total gas liquid solid mixer.

So that is called gas holdup that is also very important parameter based on which that efficiency of the flotation will be depending on. And also bubble size distribution and degree of dispersion is also important there whenever that you are going to separate that particles they are what will be the size of the bubbles the smaller size bubbles will give you the more surface area on which that more particles can be attached on it. Also you will see that whether this bubble size distribution will be wider or uniform that is also more important case. When you are getting more uniform bubble size that means narrow bubble size distribution there you will have that more efficient operation of that flotation. Also surface properties of the suspended matter is also more important whether it is hydrophilic or hydrophobic that you have to know on what a degree of hydrophilicity or hydrophobicity that you have to consider to design that flotation system.

And also your hydraulic design of the flotation chamber you will see that what are the different hydrodynamic whether this bubbles or particles will be well mixed or not or is there any stagnation region or not. Also you will see that is there any pressure difference frictional pressure or is there any drag force high drag force acting between particles and solid particle. What are the size of the particle that you have to consider here. Also concentration and type of dissolved materials what type of materials that you are using whether it will be dissolving or what concentration of that particles to be maintained so that it can be forming that agglomeration beyond that there may not be a formation of agglomeration or that attachment of the particles on the surface of the bubble. And also you will see that what type of agents that you have to use whether it is surfactant surface modifying agents or other surfactant active agents or not.

So, in that case some surfactant or surface active agents that you have to use so that that solid particles can be easily attached on the surface of the bubble. So, those type of materials to be considered and their concentration. And also you have to maintain at a certain pH value whenever you are going to operate that for protection at high pH it will be operated or give you better efficiency or not or lower pH value it will be sometimes you will see some material characteristic that also be affected by that pH regulation there inside the bed. So, accordingly that you have to use what type of chemicals to be used whether it will be active on lower pH or higher pH there. Also at a certain temperature that you have to at higher temperature that flotation cannot be possible sometimes because at higher flotation you will see that froth may not be stabilized there.

And also residence time of that materials or gas bubbles also important there. More residence time of the bubbles would give you that mixing but whereas bubbles would be rising in this flotation systems along with that particles there residence time should be as good as possible there. Otherwise you will see there will be more collision happens there and due to which that maybe separation of those particles will be hindering. So these are the things that you have to remember for this flotation. And also to float particles why a chemical reagent is required sometimes to get that better separation you have to add some floating agents or chemical reagents there.

In that case if the surface of the solid which is to be floated that does not possess the required hydrophobic characteristics that means material. It must be made to acquire hydrophobicity by treatment with specific chemical reagents so that you have to use some chemical reagents which will modify the surface of the material to get it that required degree of hydrophobicity there. So that that separation will be easier. The action of these reagents is at the mineral surface or in some cases in the solution in which the ore will be part or making a you will see that slurry there. There is a interaction of that reagents on the surface called surface chemical reactions whenever that surface active agents to be used there you will see that that surface active agents will be reacting on the surface of that solid and because of that reactions you will see that you will see that the surfactants that act at the surface as a adsorption.

So there will be an adsorption reaction will happen at the surface and because of which you will see that that hydrophobicity degree of hydrophobicity will increase. So here the whenever chemical reagents will be added that will be acting or will be reacting with the a surface of the solid and it will give you that better adsorption capability. So this adsorption capability will give you that better attachment of that solid material with the surface of the bubbles. So in that way you can have that better efficiency of that protection for the separation of the particles. So that is why chemical reagents is required.

Now chemical reagents sometimes it will be work as a collectors it will be a better term which is used as a collectors the reagents which are used to make that mineral surface hydrophobic are called collectors. So called as so called as they collect minerals or particles from the ore and are as a class of surfactants which is called collectors. So they act by interacting at the mineral surface by adsorption or by chemical reaction. The specific compound used depends upon the nature of the mineral chemistry of the flotation pulp and several other chemical factors. And then another term it is called frothers.

This is also one important chemical agents and here in this case in froth flotation you see that an addition of this another surfactant acting as frother is usually needed. In this case the basic function of the frother is to produce a swarm of air bubbles which remains sufficiently stable for the hydrophobic mineral particles which is to be captured by them. So when the pulp or slurry within the cell becomes adequately aerated this that means an bubbles will be formed. The hydrophobic solid particles will attach to this air bubble surface and are bound by them to the surface of the pulp. So the frother collector interactions that will strongly affect the degree of froth stabilization which is of course desired for this froth flotation system.

So frother is basically surfactant another type of surfactant which will give you the more froth to produce a swarm of bubbles there. Then another agent it is called modulating agents in addition to that collectors and frothers that is generally surfactants. The flotation process is controlled by certain inorganic or organic agents which is called modulating agents also known as modifying or regulating agents. There are three main class of modulating agents are there. It is called activators some are called depressants and other is called pH regulators.

So where activators you will see that the chemical compounds which will interact at the mineral surface will altering its chemical nature to promote its interaction with the collector. And for certain minerals pretreatment with an activator is necessary for the collector mineral introduction to occur. And depressants these are chemical compounds which alter the mineral surface to prevent or hinder the action of collectors. So in this case they are required to depress certain minerals to promote the selective flotation of desired minerals. Here in this case control of depressant concentration is an important parameter in selective flotation.

Whereas the pH regulator in case of flotation is often critical which is actually used to determine the selective separation of minerals. In this case the control of pH is achieved by a variety of bases and acids. The most common which are being used it is called soda ash that is called sodium carbonate or lime that is called calcium oxide. To raise the pH and also to lower the pH you will see that sulfuric acid you have to used for that. So it is also sometimes required to this type of modulating agents to regulate the selective separation of the particles from the mixer by this flotation.

You will see that in addition to this reagents there will be certain reagents another type of reagents that may directly control the flotation which are used in the treatment of flotation tailings. That means those who are hydrophilic those are coming from the bottom of this flotation vessel. These are flocculants or flocculating agents. They are also surfactants like collectors but their principal characteristics is a polymeric hydrocarbon chain which bridges together large number of fine particles producing an aggregate of solids which is called flocs. Whereas you will see some inorganic compounds which cause particles in a liquid to cuddle and clot together.

Those are called coagulants. The particles stay suspended in water rather than settling because they carry surface electrical surges that mutually repel each other. So in that case the coagulants you will see that carry the opposite charges to the particles and cause the charge to destabilize when added to the water and this will result in the particles cleansing together. So these are coagulants. So among the common coagulants some are lime, potassium, aluminum, sulphate and ferric sulphate.

So these are also important in froth rotations. And the components of a flotation system. Those are some components in the flotation system that you have to know. Those are the basic understanding. So one first is that flotation cell. There may be all the different types of flotation cells are available in the market and it is designed based on just considering all those surface active agents, characteristics of the material, even you will see that flow rate of the gas, even you can say the concentration of the surface active agents, even other geometrical shape that you have to consider.

So in that case these flotation cells, there are different types of flotation cells available. Specific designs also available to give to to get specific yield of that separation process. So here one component is called flotation cells. Sometimes you will see that instead of cell it may be as a column.

So it will be called flotation column. So there also from that column from the bottom side of that column, the gas will be distributed or air will be distributed as a dispersed phase of bubbles. Whereas in the column there will be a slurry of that specific site of the particles along with that surface active agents like collectors or prothers are also modulating agents. So whenever that gas or air will be supplied from the bottom of that column through the distributor, gas distributor, the air will be distributed inside the column as a dispersed phase of bubbles and those bubbles will carry that hydrophobic materials based on that operating conditions of those variables that is concentration, gas flow rate, that slurry concentration, even you will see that distributor type, all those based on which that solid particles will be separated by that rise of that bubbles through the column. And then it will be separated from the top of the column which will be collected as a concentrate.

So this is the component that is called flotation cell. So this is basically a container with an impeller or an aeration device which is capable of keeping the solids in suspension and providing aeration for frequent air bubble particle collisions. So it is required that getting that collision between bubbles and particles otherwise it will not be attaching. So for that there will be certain operating conditions to be required to get the attachment of that particles on the surface of the bubble. And then air which is to be supplied from the bottom or from the top of that bubbles or from the top of this vessel through the mechanical provision like a distributor. And then it will be sprayed or mixed inside that vessel either by impeller or distributor cum impeller that is conjugated system.

In that case this air will be injected under pressure into the pulp. Here in this case in amounts equivalent to 0.3 to 0.6 cell volume per minute like this. And feed as a mixture of solids to be separated which is to be separated and it will be suspended in water at usually about 1 is to 3 solids to water by weight and referred to as flotation pulp.

And also another component is called mineralized froth or float product. In this case hydrophobic solid particles attached to air bubbles and are beyond and are bound by this to the surface of the suspension and agglomerated air bubbles with those solids particles constitute a mineralized froth. And this builds up a top the pulp and overflows the lip of the flotation cell. And this material represents the separated particles and is called the float product. So this float product is one of the component for this flotation system.

And then other components like regulating or modulating agents like ions such as hydrogen ion hydroxyl ion to control that pH, desorbed oxidizing species like RS, hydrocarbon, cyanide and metal ions that is derived from partial dissolution of some solids are added purposely to act as this depressants and activators. Also you will see that specifically added organic compounds for depressing or activating action. So these are called regulating or modulating agents. And then another component that is surfactants the minimum of two are usually required here collector and frother.

These reagents are added in quantities of 0.05 to 100 gram per ton of solids or 0.02 to 035 ppm of the pulp or assuming molecular weight of 200 concentrations of 10 to the power minus 7 to 10 to the power minus 5 molar. So in this way this typical concentration that you can use for use as surfactants there for the collecting agents. And also another important whenever you are getting this float product or after cross flotation if you separate those particles maybe you will see that along with that hydro phobic particles some hydrophilic particles also will come because of that you know operating condition of maybe higher gas flow rate or bigger size bubbles will carry that fine bubbles also fine particles at high flow rate there at the top. So in that case maybe pure hydrophobic particles along with that some hydrophilic or other different types of particles would be coming with that bubbles to the surface of that rotation vessels.

So in that case you have to consider what is the grade. Grade means that in that mixer if you consider a certain type of materials to be separated then you have to consider that material out of total material what will be the concentration. So that will be considered as a grade. So the grade of a material whether it is an ore or a concentrate or a tailing with respect to a given metallic element. This is basically a percentage content of this metal in the material.

Thus a grade say 65.3 percent of lead means 65.3 percent of lead content in the product. And then recovery another important the recovery obtained in a particular separation process that denotes that proportion of the valuable components which is separated as a concentrate and it is expressed as percentage of that total metal content in the ore that is fed. Here in this recovery means what will be the amount of total materials fed in the flotation system flotation cell after froth flotation operation whatever particles for different types of mixture of particles that you are getting in the concentrate from the top that overall concentrate amount overall concentrate amount out of that total feed it will be regarded as a recovery. So thus for example you can say that if 100 percent metal like lead, copper, zinc etc mixture in the ore feed the concentrate may represent that only 87 percent recovered metal and the rest 13 percent is lost in the tailing or is distributed among the other products of the separation. So in this case 87 percent recovery will be there out of 100 percent of it.

Then another important whenever you are using this flotation system or flotation column or flotation cell that cell may be operated either batch wise or continuous wise. So in that case flotation system some say you will see that flotation column there may be continuous operation in a cell it will be batch wise. So in batch flotation when all floatable particles are removed with the overflowing froth the suspension of that hydrophilic solids remaining in the cell constitutes the final tailing of the separation process. And in a continuous flotation process you will see that there will be several individual cells will be joined together to form a multi component unit. This is sometimes referred as a bank of cells and from each cell you will see that in such a bank only a portion of floating solids is removed to launder and then intermediate tailing is discharged by an opening to the next cell.

So in this way you can operate whether this separation of these particles to be continued as a batch wise or continuous leaf. Now examples of industrial separations by flotation some examples are given here like sulfide mineral separation. Now separations of all sulfide minerals from the ores by flotation can be done in this case sulfide separation from ores containing dolomite guns minerals by ethyl or profile xanthate surfactant as a collector. Also separation of relatively coarsely liberated galena and spheroid using cyanide as a diffrescent and copper sulfate as an activator under alkaline pH 8 to 10 and one of the short-sane alcohols or low molecular weight polyoxypropylene or it is sometimes cause now froth 250 as a frother which is being used. So in this case you can separate that sulfide materials from the sulfide ores.

Ores like lead zinc ores there also you can separate lead minerals from this ores where in this lead zinc ores it is called galena lead sulfide as it will be there serocyte or lead carbonate where 83.5 percent lead will be there and also you see that on the only side they are lead sulfate where 73.6 percent lead will be there. Less common are the complex sulfides of lead and antimony, lead and arsenic and then lead and bismuth also you can say the crocite and also lead chromate.

These are actually common ores of that lead zinc ores. Here also you can separate this valuable ore materials by this proclotation. Some other copper ores may be that copper sulfides even you will see that copper sulfide ferrous sulfide you will see that hornite sulfide you will see that some other complex sulfide anerzite stannite and tetrahydrite some copper and antimony and sulfur complexes. Those are copper ores are shown in this slide. Those copper ores are being ground and then it will be processed in the proclotation column to separate that different valuable copper or lead minerals by flotation and also separation of the superficially oxidized and oxide type minerals by this proclotation. Also there are some other application like separation of the non-metallic industrial minerals like fluorspar silite even barites even phosphates for example apatite.

These are the materials you can separate it by this proclotation. Even you can separate that soluble salts from saturated brines also by this proclotation. Here some example it is given. Even separation of naturally hydrophobic minerals like coal is one of the naturally hydrophobic minerals that is now concentrated on a very large scale by flotation. Some non-mineral applications of flotation like to separate suspended solids in wastewater treatment to remove dissolved heavy metals from effluents.

Application of flotation for de-inking in the recycled paper industry. Then recovery of bitumen from oil sand that occurring in Alberta and Canada like this. Then one of the important aspects that you have to know how to analyze that flotation process or what will be the kinetics of that flotation process that means what fraction of recovery can be obtained by this flotation process and how to assess this. So, as we have already discussed in the earlier lecture that separation of minerals by flotation that involves selective concentration of hydrophobic minerals in the froth. The selectivity is based on the wettability differences of the treated minerals with only hydrophobic particles that is being able to attach to the bubbles. The process is accomplished in a flotation cell and the overall selectivity is determined by the difference in the flotation rates with which different mineral particles are carried over to get that final product.

So, this is the mechanism by which you can get that separation of that hydrophobic materials. Now this flotation kinetics what is that flotation kinetics you will see that generally froth flotation kinetics involve several mass transfer processes. You will see that selective transfer of material from the slurry to the froth by particle bubble attachment and non-selective transfer of materials from the slurry to the froth by mechanical and hydraulic entrainment. And you will see that mechanically or hydraulically induced material transport from the froth over the cell lip into the concentrated products.

This is the main transport of that solid particles. Now in this case the first process is the main part of the protection. In this case the step occurs in which zone referred to as collective zone. So the flotation kinetics basically the rate at which you can see that selective transfer of that material from the slurry to the froth by particle bubble attachment that occurs in the collection zone. So, in the next slide the kinetics is described like this here. If you consider that flotation kinetics which would be resembles the chemical kinetics that you have I think already aware of that how that chemical kinetics to be represent.

Suppose A and B two reactants are reacting with each other and giving the product C then the chemical kinetics can be assessed based on the interactions between the atoms molecules or ions in the chemical reaction.

Here the Equation

$$A + B = C$$

So in this case you will see that one of the reactants is in such a large excess that its concentration practically does not change with time. So when the solvent serves as one of the reactants a first order equation adequately describe that rate of the reaction. So this is the concept of that chemical reaction.

Now this chemical reaction concepts can be used in this flotation systems also. Whereas here there will be no reaction but there will be a separation based on that you know collision between bubble and particles and then attachment of that particles with the bubble surface and then it will be coming out from the top and you will give you it will give you the product. So here instead of reactions it will be that the interaction between particles and bubbles there and based on which there will be a collection of that particles at the top of that flotation cell. So this mechanism will be applied to assess that flotation kinetics. So let us consider here that in a flotation process mineral particles collide with bubbles.

Now flotation kinetics thus deals with the interaction between particles and bubbles. The particles are classified as floatable if they successfully attach to air bubbles and are removed with them from the pulp. So in this case we can write that solid particles plus bubble that will give you the product of particle bubble agglomerate at the surface.

Here the Equation

$$Solid\ particle + Bubble = Particle - bubble\ agglomerate$$

So this equation we can write here in the slide shown and the rate of removal of that solid particles from a cell it is basically second order interaction with respect to the

concentration of those particles and bubbles. But if it is assumed that the bubble surface is in excess of course bubble surface will be is in excess that means huge number of bubbles will be produced then the rate equation can be reduced to a first order reaction. So commonly the general rate equation for that expressing that reaction can be expressed by this equation number here 3 it is shown.
Here the Equation

$$-\frac{dC}{dt} = kC^n$$

So where n will be is equal to first order reaction and solid particle concentration is equal to C. And next for solid particles concentration where C is equal to C0 that means initially at time is equal to 0 and integration will give you this equation number 4.

Here the Equation

$$C = C_0 e^{-kt}$$

Where C is equal to C0 into e to the power minus kT.

Here the Equation

$$\ln ln \frac{C}{C_0} =- kt$$

Where C is the floatable mineral concentration remaining in a cell at time t and k is the flotation rate constant which is the dimensions which are the dimensions of reciprocal of time. For graphical representation this equation 4 is commonly written as like this from this equation number 4 you can write by this equation number 5.

And since recovery R is defined as here recovery is defined as C0 minus C by C0.

Here the Equation

$$R = \frac{C_0 - C}{C_0}$$

C0 is the initial concentration and C is the concentration at a particular time. Then equation 4 will become R will be is equal to 1 minus e to the power minus kT.

Here the Equation

$$R = 1 - e^{-kt}$$

Letting R will be is equal to R infinity at t is equal to infinity. Then at infinite time that recovery will be considered that recovery will be represented by R infinity. So in that case it will be 1 that means here you will see that the fraction that is recovery fraction will be 1 there.

So in that case we can say that that R will be is equal to R infinity into 1 minus e to the power minus kT. So in the flotation kinetic equations k is a complex function involving among other things particle and bubble sizes, reagent concentration and flotation cell hydrodynamics. So here this rate equation is basically this kinetic equation R will be is equal to R infinity into 1 minus e to the power minus kT.

Here the Equation

$$R = R_{\infty}(1 - e^{-kt})$$

So in this case one of the important parameter is k, k is called flotation rate constant. And this flotation rate constant depends on you will see that particle size depends on flow rate, depends on that other material characteristics, even cell hydrodynamics also.

Even you can say that bubble sizes, bubble characteristics also you will say that distribution of the bubble. So although it is generally accepted that flotation recovery follows the first order kinetics, experimental evidence suggests that the order of the process may vary. So here in this case we are getting this equation number 7 as the kinetic equation where R represents the cumulative fractional recovery at time T and R infinity is the maximum fractional recovery and k is the flotation rate constant, which can be expressed graphically by this R recovery with respect to time will be represented by a cumulative fractional recovery. Whereas you will get that where there will be no change of concentration of that recovery material there it will be coming as constant value and it is the maximum that is represented by R infinity.

Now let us do an example for this flotation kinetics theory here. Let us consider there a fourth flotation experiment that is conducted to recover the graphite flux by flotation at air velocity of 1.05 meter per second with 6 molar sodium chloride solution at steady state condition. From the experimental results it was seen that with respect to time there are various recovery fractions are in the table. In this case you have to find what is the flotation rate constant. So here in this case what is that flotation rate constant, flotation kinetic equation is that R will be equal to R infinity into 1 minus e to the power minus kT.

The maximum fractional recovery is here given at time 30 minutes it will come as 0.93. So here in this case we can write ln 1 minus R by R infinity that will be equal to minus kT. So in this case we are having this equation with respect to time how that 1 minus R by R infinity of its logarithm will be changing with respect to time. Whereas k will be constant, flotation rate constant. So we can make a table like this what is the time and corresponding what is the recovery value and what is the R by R infinity value and then ln of 1 minus R by R infinity as per this equation here. So after that you can make a plot here like this with respect to T here in y axis ln of 1 minus R by R infinity here and then you will get a straight line since it is a straight line equation and then you will see that there will be a slope of negative and which will give you the rate constant here.

So this rate constant it is coming around that 0.23. So I think you understood this problem that how that recovery will be changing with respect to time in a plot rotation for this recovery of that graphite plate and you have to measure that graphite plate concentration and then you have to find it out what will be the recovery portion and out of that total feed and out of which you have to get that fraction and with respect to fraction what will be that and what will be the cumulative fraction and then you have to get what will be the as per that kinetic equation then you have to find out what the R infinity what will be the R value with respect to time and then plot it you will get this rate constant. So I think you understood that basic concept of that plot rotation where the application of the plot rotation and how that plot rotation can be assessed by this kinetic equation. So in the next lecture we will try to start with another module that is called separation of that solid materials from the mixture and how it can be done and in the next lecture in the module of that separation it will be a mechanism of separation like separation of particles by the size and what are the equipments generally sheaving and screening will be assessed based on its that governing equation from the mass balance and how that efficiency of that screening or effectiveness of the screening or sheaving can be assessed for this separation of the particles that will be discussed in the next lecture. So, thank you have a nice day.