INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

NPTEL

NPTEL ONLINE CERTIFICATION COURSE

Unit Operations of Particulate Matter

Lec – 16
Flotation (Part-01)

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Welcome to the 4th week of the course unit operations of particulate matter now here we will start first lecture of week 4 and here we will discuss the topic flotation this topic flotation is divided in two lecture, lecture 1 and lecture 2 in lecture 1 we will defined the flotation we will discuss applications of flotation process and we will discuss mechanism it is operation and flotation agents involved in the process, so let us start the discussion of flotation.

Now what is flotation if in general mean we will discuss what is flotation is basically when something is floated over the fluid something is moving over the fluid that we call as the flotation so similarly in industry also this mechanism we apply to recover the valuable material from the gang you or from the minerals.

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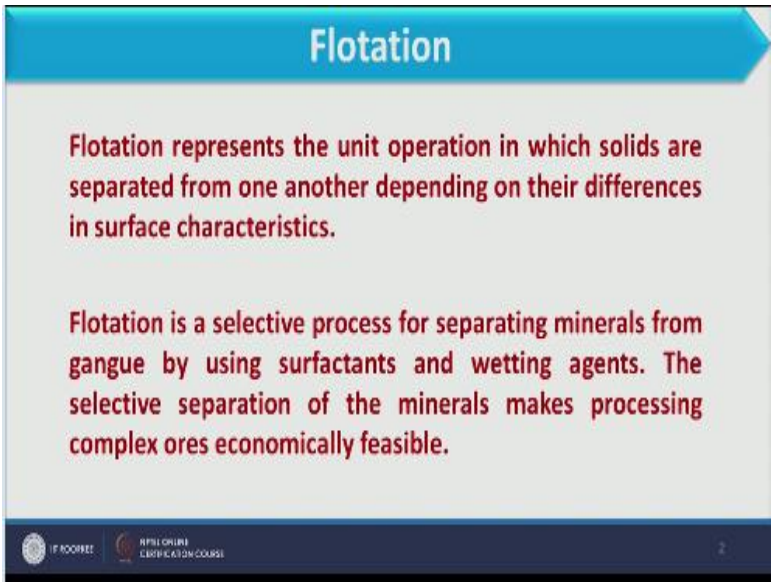

Therefore flotation represents the unit operation in which solids are separated from one another depending on their differences in surface characteristics so you see here because we want to separate the component from the bulk of component or from the bunch or from the bulk so some characteristics we need to separate on which bases it should separate so here the surface characteristics of a component of a material will be used to separate the material from the mixture.

So flotation is a unit operation which considered surface characteristics of a material to separate from the mixture of separate from the bulk separate from the bulk of different component so flotation is a selective process for separating minerals from gangue by using surfactants and wetting agents now here you see what we are what this statement says that flotation is a selective process what is the meaning of selective process we are discussing flotation over here and flotation separates the components separates the material from the mixture on the bases of surface characteristics.

So what is the meaning of selective process because if we consider the mixture it may have different materials and they may carries and they carry same surface characteristic so among this

we want one to separate so what should be how we should select that which should be separated first which should be separated second to select that sequence we because we have to select the sequence of component and therefore it is called as selective process.

So we can say that if we have only to material if we have only two material to be separated it means they would not be any selective process one will be separated from other easily but if I have a mixture I have to select I have to decide the sequence for the selection or for the separation so that sequence is basically so based on that sequence we can say that flotation is a selective process if we deal with more than 2 component more than two materials. And how decide this sequence that will be decided based on some flotation agents that will also called as surfactants etc so that we will discuss later on.

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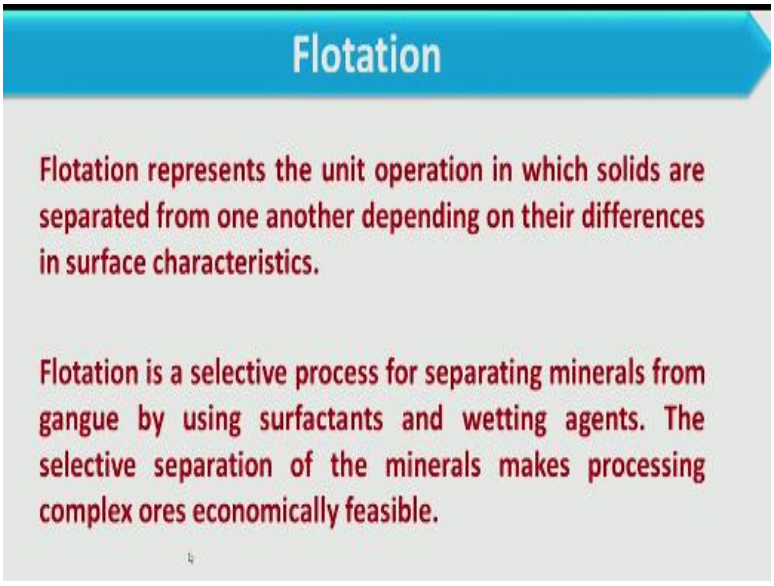

So the selective separation of the mineral makes processing complex or economically feasible, so whatever we are considering that is the complex ore or complex mixture and this selective process give economic solution to that because we can get the separation one by one after heading few surfactants or few agents and that will not be that much costly, so therefore it is economically viable also.

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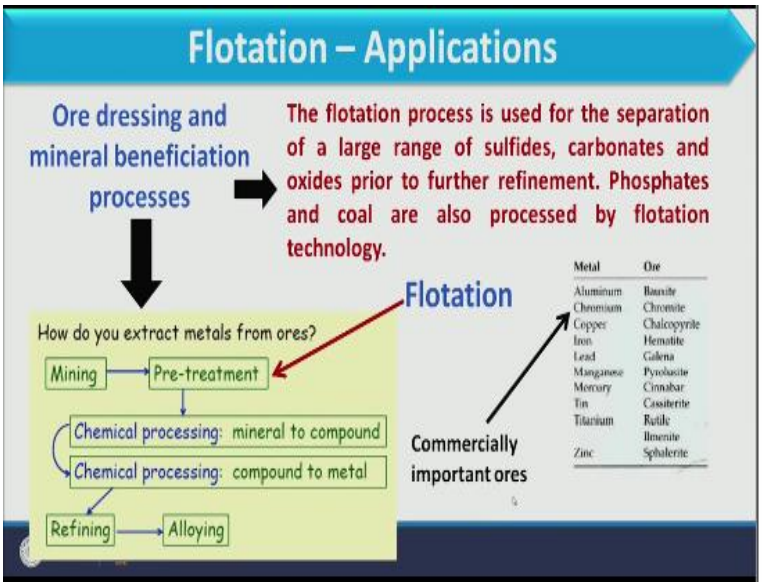

Now as far us flotation application is concerned the main application of this process is in ore dressing and mineral beneficiation process how we go for ore dressing, with this is the flow chart which speaks about recovery of metal from ores, so if we say the ore dressing what is the meaning of ore dressing is, we have to separate the material which are involved in the ore, so what should be the steps of this that is shown through this diagram.

So first of all we have to take the ore from the mining because that is the only source where ore is available so we will collect ore from mining and then we preterit ore over here, so what is the meaning of pre-treatment that when we collect the ore it will have different sizes some are of very large sizes so first of all we have to crush or grind these ores and then the pre-treatment will be carried out.

So if we consider flotation process it will help in pre-treatment, pre-treatment can be done through flotation so here what is the desired ore what we have to separate from the mixture of ores that we have to select over here so here basically through flotation we separate ore from the mixture of ore, once I am having the ore then through chemical processing you can go for extraction of compounds.

And then from compound to metal so if we see if here if we want to come extract the metal for example if I want to extract iron what I have to do the ore of iron is hematite so that I have to recover in flotation process and then from this we will recover iron through chemical processing and that can be done in sponge iron process because the metal iron when we are considering that is fe so that will be called as metallic iron or sponge iron.

Now once I am having this metal we will go for refining and then for alloying so this is the flow chart of extraction of metal from ore and then preparation for alloys. Further the flotation process is used for the separation of large range of sulphides, carbonates and oxides prior to further refinement as we have discussed in this flow chart, so phosphates and core are also processed by flotation.

So here you see the main application of floatation is in ore dressing and recovery of metal from ore. And here we have some commercially important ore and associated metal for example if we want to separate copper, copper will be carried in chalcopyrite and iron is in hematite lead if you want5 to recover for that we have to choose Galen and galvanizer ore and similarly we have many other like if we want to separate zinc we have to separate sphalerite from the mixture which I am getting from mining.

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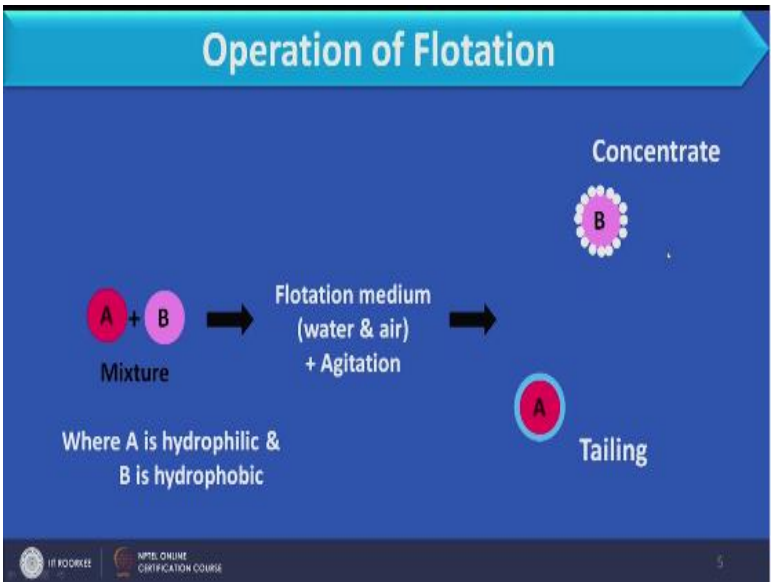

Now as far as operation of floatation is concerned here through this slide I will speak about the operation which is involved in flotation, so if you see this slide here I am having material A and material B so to demonstrate the flotation process I am considering binary mixture and here as far as material is concerned we have taken material A as well as B, These materials should be mixed before starting the operation.

So where A is hydrophilic and B is hydrophobic so if you remember the flotation process separate the compounds separate the component based on surface characteristics so surface characteristic should be such that it should accept water or it should repel the water so based on that only we separate in the flotation process, so in this case if A is hydrophilic, hydrophilic you understand which accepts the water and component B is hydrophobic.

Which repels the water and the complete mixture of A And B is carried in a flotation medium and the medium should be water and air because one is hydrophilic and another is hydrophobic so we have to take water along with air and that complete mixture will be agitated vigorously, so once I am having this mixture A and B in the flotation medium.

What will happen after sometime, if you see here if I am having the material A and material A is it surface characteristic is like that it accepts the water so after sometime what will happen it will have the water layer over its surface, so like this it has the skin of water, now what happens with component B, because component B is not accepting the water another component in the mixture I am having is air.

So it will be accepting the air bubbles, so after sometime what happens at the surface of material B air bubble will be forms so A around A, a film of water will be there and around B air bubbles are there, so what is this compound, this is basically solid + water and what is this compound, this is basically solid + air. So if we are considering the aggregated density so density of this A and water should be higher in comparison to density of B and Air.

Because density of air is very less in comparison to that of water, so obviously component A with water film over here become heavier in comparison to B + bubbles so component A will be settled down due to its heaviness and component B along with air bubble will be floated up, so because of this that component B is floating with the help of air bubble the complete process is known as flotation.

So once the component is floated and here we have collection of material B with air bubble and this combine we call as concentrate. And similarly material A and water film will be collected at the bottom and that we have taken as tailing. So you see concentrate is prepared with floating compound, whereas tailing is prepared with the compound which sinks.

So this is the basic operation of floatation. Now here we are discussing float floatation, now what is float floatation? If you remember the last slide we have discussed that component B floats because air bubbles are formed over its surface. Now when we have this air bubble and different particles of compound B carry air bubble over this and all this will be floated at the top, so at the top of the floatation cell of floatation equipment the float will be available. So therefore, this process is called as float floatation.

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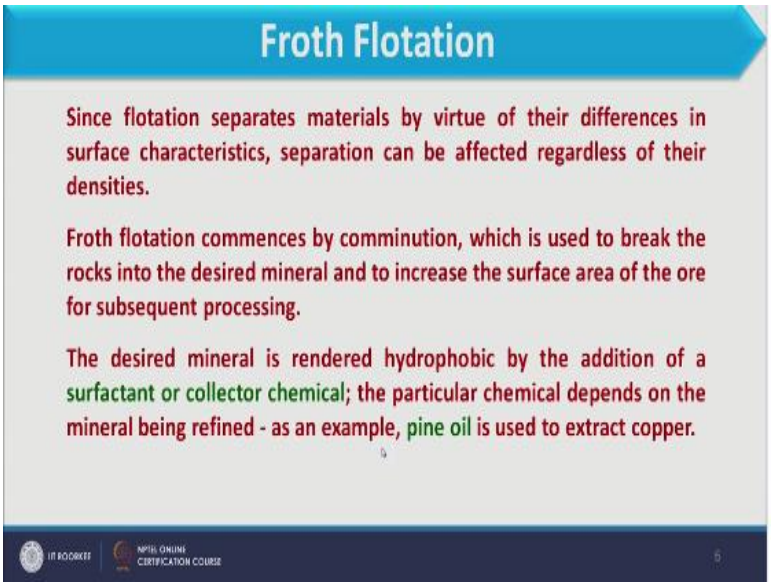

Since floatation separates material by virtue of their differences in surface characteristics, separation can be affected regardless of their densities. So the density of the compound will not affect the separation process only surface characteristics of the compound will matter. So froth floatation commences by comminution, which is used to break the rocks into desired minerals and to increase the surface area of the ore for subsequent processing.

So first of all we have to crush or grind the mineral, grind the rock and then the small particle of that will be used for floatation process. So the desired material is rendered hydrophobic by the addition of a surfactant or collector chemical. The particular chemical depends on the mineral being refined as an example pine oil is used to extract copper. So here you see some surfactants we are using for changing the characteristics, changing the surface characteristics of the compound and these surfactant will depend on different compound like same surfactant cannot be used for changing the surface characteristics for all, otherwise all will be floated.

So it would be selective, so surfactant would be based on what component we have to separate. So surfactant is chosen based on what component we want to float or we want to separate.

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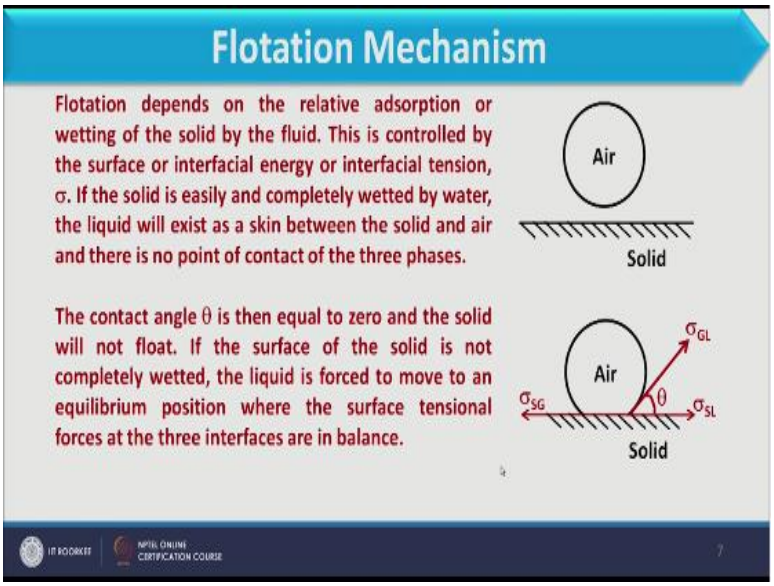

Now as far as floatation mechanism is concerned you see what happens when we are considering the mechanism when material will be float, when air bubble will be available at its surface. So when water more will be available at surface it will not float. So what happens there are basically three phases, first is water, then air, and then solid all three phases and mechanism of floatation can be illustrated, can be discussed while considering all these phases.

So floatation depends on relative absorption or wetting of the solid by fluid, this is controlled by surface or interfacial energy or interfacial tension. So you see solid basically attracts water or attracts air bubble. So in that case the surface tension will play an important role, so that the bubble will be attached to this or film will be attached to the solid. So if solid is easily and completely wetted by water.

As you see this figure here we have the solid and this is the air bubble and in between water layer is there. So if the solid is easily and completely wetted by water, the liquid will exists as a skin between solid and air, and there is no point of contact of three phases. So when we are considering this case where water is available between air and solid, so we can say that contact angle of air as well as solid is 0.

And once this contact angle is 0, solid will not float. So if the surface of solid is not completely wetted, if the surface of solid is not completely wetted it means some of the portion is covered by the air bubble, the liquid is forced to move an equilibrium position where the surface tension forces at the three interface are in balance. So you see here we have three surface tension, first is between solid and liquid and then we have between gas and liquid, after having contact angle that is θ and another surface tension we have between solid and gas.

So once we want to balance over here it should be like this, solid between solid and gas the surface tension is σ_{SG} and that should be equal to $\sigma_{SL}+\sigma_{GL}\cos\theta$. So this is basically the balance of forces and these forces is caused due to surface tension. So here you see θ is an important factor as far as bubble formation is concerned. So if bubble formation will be large θ will also be large. And if θ would be large it means portability should be enhanced.

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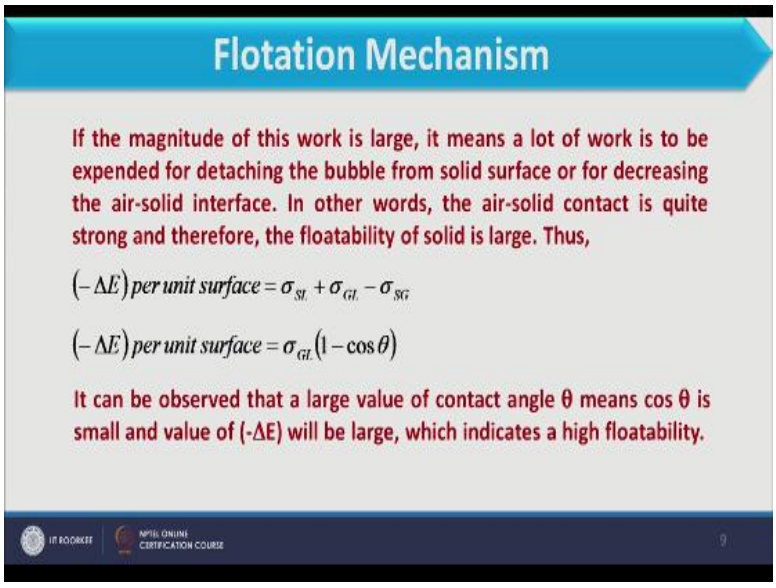

So if the contact angle is small liquid will advance over the surface of the solid, since the surface force is holding the bubble and liquid together will be weak, so when contact angle will be lesser, so after some agitation, after some vigorous agitation bubble can be separated from the

solid and liquid will enter between solid and bubble, so it will reduce the wettability. So if we want compound to be floated, so if you want compound to be floated the contact angle should be large.

And this contact angle is between air bubble as well as solid. So large contact angle therefore, indicates easy floatability as we have just discussed. Now what happens when air bubble is formed on the solid surface what happens it takes some energy from the solid, so when air bubble is formed over solid surface some energy will be released from solid to air bubble. So and that loss of energy will be nothing but in terms of surface tension.

So the loss of energy that we represent as $-\Delta E$ is a major of wettability of the solid by air, and therefore, an indication of the floatability. Further, if the magnitude of this work is large it means a lot of work is to be expanded for detaching the bubble. Now how this work come into the picture, because we are considering the energy which is loss from solid to air. Now what happens when this energy will be large, we have to do large, we have to put more effort to detach this bubble from the solid.

So in terms of that work comes into the picture. So if the magnitude if work is large it means lots of work is to be expanded for detaching the bubble from the solid surface or from decreasing the air solid interface. In other word the air solid contact is quite strong and therefore, floatability of the solid is large. And if you want to make the expression of energy mathematically how we can represent because when air bubble is formed on the solid energy is released from solid to air.

So when we are considering total energy of the solid the balance should be in terms of σSL that is between solid and layer plus σGL because that is positive energy. However, energy will be released when air bubble is formed, and therefore this σSG will be considered through negative sign. Now considering previous equation and this equation we can further correlate loss of energy per unit surface as $\sigma GL1-\cos\theta$.

So you see here θ when we are considering as we are having more and more θ, more value of θ it means $\cos\theta$ would be reduced this factor will increase and then surface energy and then energy

loss from the surface will be increased. So once energy loss will be increased it means the solid can be floated easily. So large angle will speak about good floatability, so that is the mechanism of floatation process, it can be based on surface tension.

So here we are discussing the floatation agents, because this is the selective process when binary mixture we are considering there is no need for adding any agent, because one will float and another will sink, but if I am dealing with the mixture and that is generally seen in rock which is recovered through mineral, it has many different, it has many compound, so we should go for the selective floatation.

And when I am going to selective floatation I have to add some floatation agents to change the characteristics, to change the surface characteristics of some compound, so that it can be floated and other should not.

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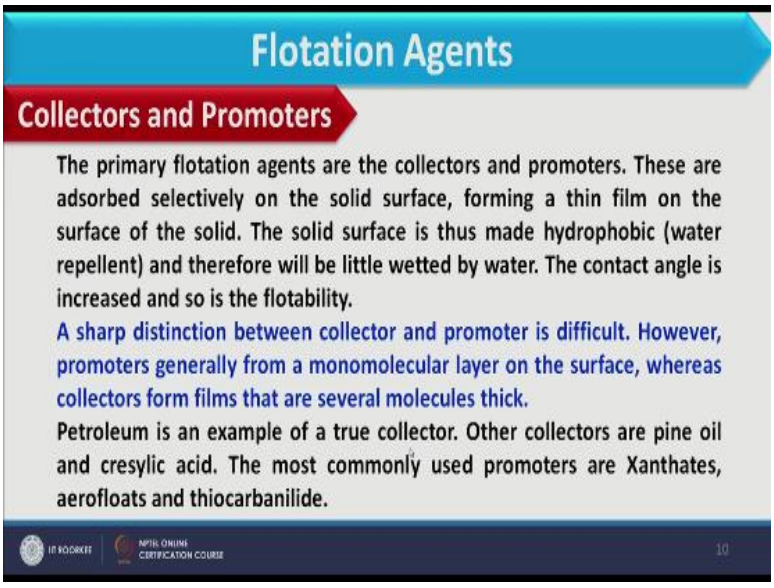

So there are different floatation agent first agent we call as collectors and promoters. So the primary floatation agents are collectors and promoters, these are absorbed selectively on the solid surface forming a thin film on the surface of the solid. Then solid surface is thus made

hydrophobic that is water repellent and therefore, will be little wetted by water. Contact angle is increased and so is the floatability.

So what is the purpose of collectors and promoters, they change the surface characteristic of compound in such a way so that it becomes water repellent. And once it becomes water repellent it can attract air bubble over there and then the floatation will be carried out. So a sharp distinction between collector and promoter is difficult. However, we can say that promoters generally prepare a monomolecular layer on the surface, whereas collectors form films that are several molecules thick.

So that is the only difference otherwise collector and promoter work in a same manner. Petroleum is an example of true collector, other collectors are pine oil and cresylic acid. The most commonly used promoters are xanthates, aerofloats and thiocarbanilide.

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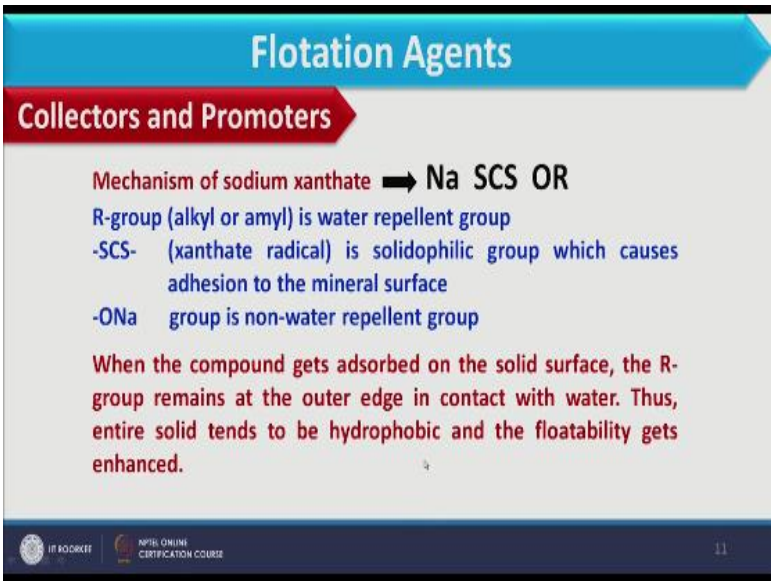

So here we will see the mechanism of sodium xanthate so that you can understand what happens. Here we have sodium xanthate that is Na SCS OR. So if you consider this compound here the R-group which is available over here that works as a water repellent group and this is alkyl or amyl

group, it works as water repellent. Xanthate radical that is SCS is solidophilic group which causes adhesion to the mineral surface. And ONa group is non water repellent.

So you see here we have three different group, among these three different group only R is the group which makes the compound water repellent and ONa will not be a water repellent group. So when this compound that is sodium xanthate come into contact with the solid, the ONa compound will be at the inner most, because that is water repellent and R compound should be at outermost label, because it makes the whole compound as water repellent.

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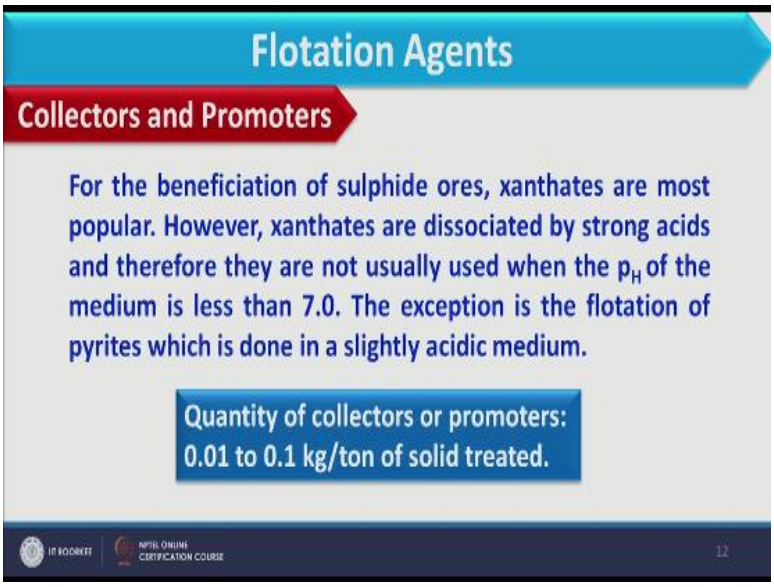

Further for the beneficiation of sulphide ores, xanthate are most popular. So when we have to recover a sulphide ore, we should use xanthates. However, xanthates are dissociated by strong acids and therefore, they are not usually used when the pH of the medium is less than 7. An exception we can have is, the floatation of pyrites which is done in slightly acidic medium. So for pyrite we can use xanthate and the pH of the medium, and pH of the medium should be towards acidic side, that is the exception as for a xanthate is concerned.

Now as far as quality of collectors and promoters are concerned it is used in 0.01 to 0.1kg/ton of solid, so that amount is not very significant. And therefore, when we are using these agents even then the economy of the process will not be very high. Another agent we have is the frother, because while using the collector we prepare the surface of the metal, we prepare the surface of the solid as hydrophobic and now we will add the frother.

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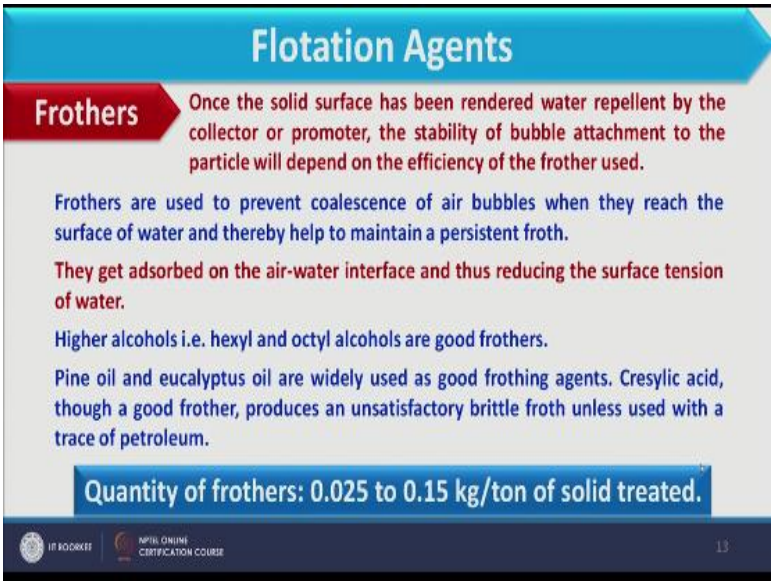

So what is the purpose of frother, frother is basically when we are using the frother it gives stability of the bubble, it means it would not allow bubble to separate from the solid or bubble to break. So frothers are used to attach the bubble to the solid surface. So once I am using the collector, it helps to prepare the surface hydrophobic and therefore, air bubble can be found over the surface and then these frother becomes a layer between air bubble and liquid, and so that liquid cannot be entered over here, and then the stability of the bubble will be ensured.

So frothers help to maintain a persistent froth, they get absorbed on the air water interface and thus reducing the surface tension of the water. Higher alcohols that is hexyl and octyl alcohols are good frothers. So these are some example of the frothers. Pine oil or eucalyptus oil are also

widely used as good frothing agents. Cresylic acid, though it is a good frother, it produces as unsatisfactory brittle froth unless used with the trace of petroleum.

So we can use cresylic acid with petroleum as a frother. Now as far as quantity is concerned it is used in 0.025 to 0.15 kg/ton of solid. So in this range it is used, next floatation agent we have is the modifiers.

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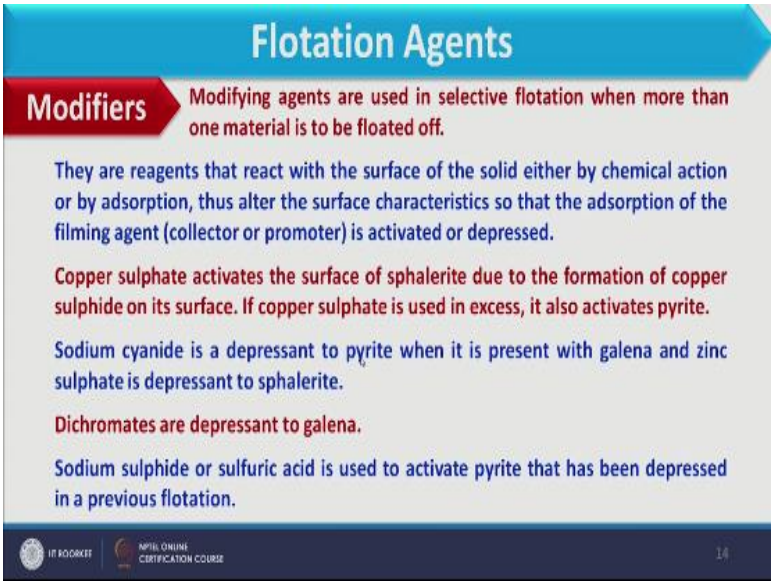

Now what is the purpose of modifier? These are used in selective floatation when more than one material is to be floated off. So here you see when we are having the mixture of compound and we have to separate these compound one by one, so we have to decide the sequence in which they should be floated off. So among the whole material only one we should float off, other we should not.

So how we can do that by adding modifiers only compound which we want that should be floated off, other would be depressed. So modifier is basically providing the activity or, so modifiers are basically used to activate or depress a material. Now how it does, they are reagents that react with the surface of solid either by chemical action or by adsorption, thus alter the

surface characteristics so that the adsorption of the filming agent that is collector or promoter is activated or depressed.

So by chemical means, by chemical reaction or by adsorption it changes the surface characteristic of one compound and makes it assessable for collectors as well as promoters. So here we have few example, copper sulphate if I am using, copper sulphate activates the surface of sphalerite due to formation of copper sulphide on its surface. If copper sulphate is used in excess, it also activates pyrite.

So copper sulphate is used to activate sphalerite and when we are using invoke amount pyrite should also be activated through this. And sodium cyanide is a depressant to pyrite when it is present with galena and zinc sulphate is depressant to sphalerite. So you see here when we are having the mixture we can activate only one compound and other should be depressed by adding some modifiers.

Further dichromates are depressant to galena, sodium sulphide or sulphuric acid is used to activate pyrite that has been depressed in the previous floatation. If I am using pyrite with galena and sphalerite we can use sodium cyanide to depress pyrite. So galena should be floated of, and because we have already depressed it, it should be activated by adding sodium sulphide. So by this way modifiers work.

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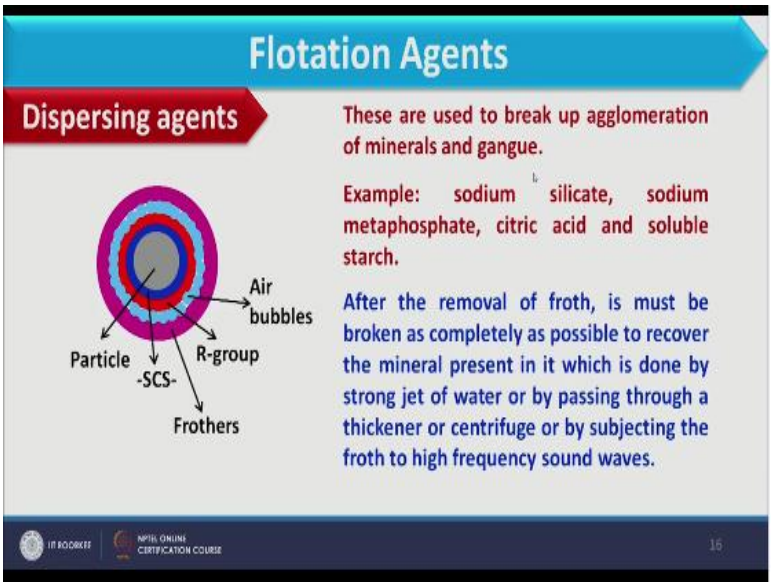

Another modifier I am having is the pH controllers, if you see this is the table where I am having different critical pH for the compound and for example, if I am considering a sphalerite and we are using collector as potassium di and if you are using this as a collector, the critical pH of medium for sphalerite to be floated off is 10.4. So if I am making the pH of the medium more than this so sphalerite should be floated off.

So there exists a critical pH of the medium corresponding to any given mineral below which only the mineral will float when a specific amount of a collector or promoter is used as we have just discussed through this table with the example of sphalerite. So pH controller is used as a modifier another floating agent is the dispersing agent, these are used to breakup agglomeration of minerals and gangue.

Example sodium silicate, sodium metaphosphate, citric acid and soluble starch, these are the dispersing agents. Now once we are using different floatation agent what happen with the material, you can see this figure here at the center we have the particle and then we are using collector, and before this, before collector we should use the modifier if I am having the mixture. So that modifier changes the surface characteristic as we have discussed.

So once I am having a particle we will add collectors over here and if you remember the xanthate radical of the collector is used to join particle as well as collector it will be placed over the particle, and over this xanthate radical we have R-group because R-group makes the whole particle as water repellant. Once it is making the particle water repellant air bubbles are formed over here and stability of these air bubbles can be ensured by adding frother.

So frother layer should be outer most, so in this way each agent will associate with the particle. Now once it will be floated off we have the froth, so after the removal of froth it must be broken as completely as possible to recover the mineral present in it, which is done by strong jet of water or by passing through a thickener or centrifuge or by subjecting the froth to high frequency sound wave.

So here you see we have discussed different floatation agent which take part in the process, floatation process, and this lecture we are stopping over here, we will continue discussion on floatation process in the next lecture. So that is all for now, thank you.

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