Mechanical Unit Operations
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Lecture 36 – Floatation

Welcome to the MOOCs course Mechanical Unit Operations, the title of this lecture is floatation. So, in the floatation what we do, we take the differences in the surface characteristics and then considering those differences in the surface characteristics we are going to do the separation of the solids from the mixture.

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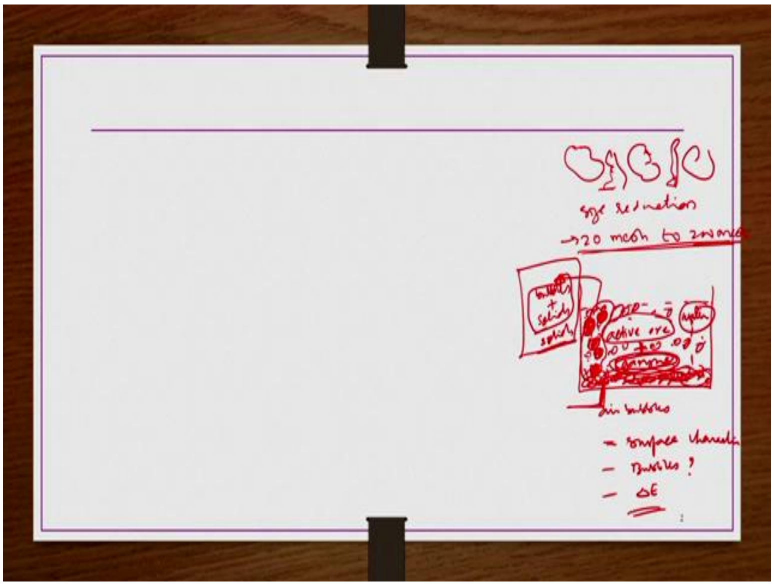

So, here we get natural ores in big, big lumps kind of things, whatever the ores that we get from the nature we have in a bigger size in general. What we do, we do the size reduction of these natural resources so that you know their size is in between 20 mesh to 200 mesh size only average, largest one is passing through the 20 mesh and then smallest one is passing through 200 mesh. So, whatever the material of this size that will be you know sufficiently smaller size so that the surface characteristics may have a kind of significant effect and then separation takes place.

So, now when you take these natural resources from earth whatever you get, when you crush them, you know into this smaller fraction there is a kind of mud and other kind of impurities are also there. Let us say you have active mineral ore and then gangue present in that mixture finally, ok. So, now you wanted to separate active mineral ore from that gangue. So, how to do based on the surface characteristics differences, that is what we are going to see in floatation.

So, here what we do, this mixture whatever is there so that is you know having the active ore plus gangue that you take in a container in which there is a kind of water in which you are already having water. So, you take a container in which water is there, in that container you pour the solid mixture which is having active ore plus gangue. So, you are interested in this active ore, whatever mineral is there. So, active mineral whatever is there, that you wanted to separate from this gangue, right, ok.

So, then what you do, when you mix it here so they will may be suspended or you know settled based on the density differences of this water and all that. So, then in this container you have some kind of provision to generate air bubbles. Ok, you have some provisions. So, we are going to see how to generate and all those things, that is a different thing. So, now these bubbles will form in this container along with this solid and then water phase now there is a kind of bubble phase also, right.

You have a provision, these bubbles are you know generated such a way that they are generated in a bigger size bigger than this you know 20 and then 200 mesh size, right. So, that is bubbles are much bigger size than the solid or active mineral that you wanted to separate. So, because of the difference in the surface characteristics of these 2 material only the minerals, only the minerals would be you know attached on the surface of these bubbles like this, ok because of the, you know, differences in the surface characteristics only active ore whatever is there that will be attached on the surface.

And then initially bubble was only one phase, now the solids are also adsorbed on the bubble surface. So, then average density of this bubble is going to be changing, right. Initially air bubble density, air density whatever is there, that is there. Now, onto this bubble surface solids, active ores are being attached so then their average density is going to be different, right. So, whatever is that density, average density of bubble adsorbed with solid is there, that average density is lower than the density of water, that is lower than the density of the water in general.

So, then what happens? Because of that one these bubbles will raise up to the interface, will raise up to the interface and then when they raise they carry the particles attached onto the surface. So, these bubbles are taken out as a kind of overflow. So, these bubbles plus solids are these bubbles which are onto on the surface you know, solids are attached that comes onto the surface because of the less average density compared to the water and then that you know, froth whatever is there that is having the bubbles and solids, that will be taken as a kind overflow from the top and then washed off for the solids, pure solids, or almost clear solids which are not having any kind of impurities, ok.

But now there is a gangue also in this one. So, mud et cetera that kind of other material is also there. Their surface characteristics are entirely different than the solid surface characteristics or active mineral surface characteristics. So, because of that one these gangue is going to be adsorbed by the water or adsorbed onto the water or these gangue surface whatever is there that will be covered by the water and then and the water density is you know higher than the bubbles and solids, that average density of bubbles and solids. So the water is going to, along with this gangue is going to sink.

So, whatever this gangue surface is there that is now attached with the kind of liquid layer, so that is going to sink; that is going to sink so that we can have a kind of you know gangue at the bottom as a kind of impurity, ok, like this and then whatever the solids or active ore that is there that we get as a kind of pure or almost pure solids from the top through the froth. So, this is the basic process. So, here you know surface characteristics we are saying so, what are the surface characteristics? And then we are saying that you know bubbles generation, how these bubbles are being generated.

And then we are talking about you know the froth formation, froth formation agents are there or something like that, those kind of thing, all those details related to this floatation aspect that we are going to see. So, when this froth is going to the surface, there is a some kind of energy losses, etc. What are those energy losses, all those things we are going to see now here, ok. We are going to see those all those basics.

So, this is the basic process that happens in a kind of a floatation. So, then how does it happen and how design can be modified to make this kind of floatation process effective, that is what we are going to say, how to enhance the froth generation, froth development, those kind of things we have to see. Sometimes you know, froth, you know onto the bubbles you know solids are strongly adsorbed. So, you do not want because you have to dissolve those solids from the bubble surface also.

So, what kind of depressions are required, so those kind of things also we are going to see. What are the kind of collectors, promoters, et cetera are required so that to enhance the process, all those details we are going to see in this particular lecture.

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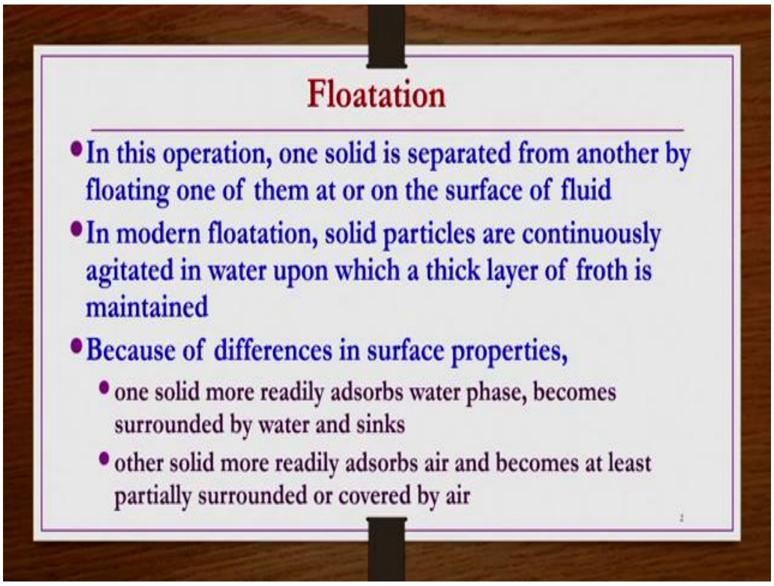

Floatation

- In this operation, one solid is separated from another by floating one of them at or on the surface of fluid
- In modern floatation, solid particles are continuously agitated in water upon which a thick layer of froth is maintained
- Because of differences in surface properties,
  - one solid more readily adsorbs water phase, becomes surrounded by water and sinks
  - other solid more readily adsorbs air and becomes at least partially surrounded or covered by air

So, floatation, in this process one solid is separated from another by floating one of them at or on the surface of fluid. In modern floatation solid particles are continuously agitated in water upon which a thick layer of froth is maintained and because of differences in surface characteristics, one solid more readily adsorbs water phase, becomes surrounded by water and sinks.

As in the case example that mineral ore, that example in that case you know gangue what happens? It is readily adsorbed by water phase and then surrounded by water and then sinks, ok. Whereas the other solid more readily adsorbs on air bubble surface and becomes at least partially surrounded or covered by the air.

So, let us see in this example, whatever the active mineral that is there in the present in the ore, you know that is you know being easily adsorbed onto the air surface, air bubble surface and then partially covered or totally covered by these bubbles and so that that can easily be separated. So, this is what the difference. Because of the surface characteristics differences, one solid phase sinks in the container and then another solid phase floats along with the bubbles and then taken as a kind of separate phase, pure phase like that.

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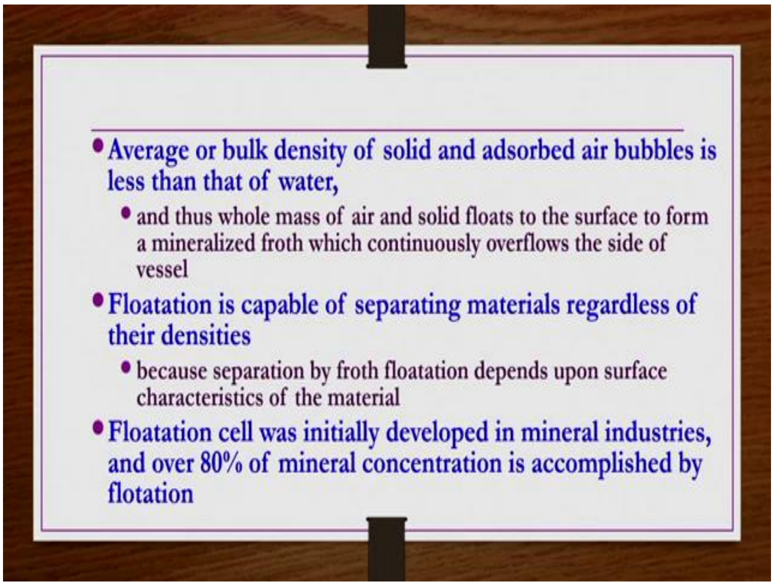
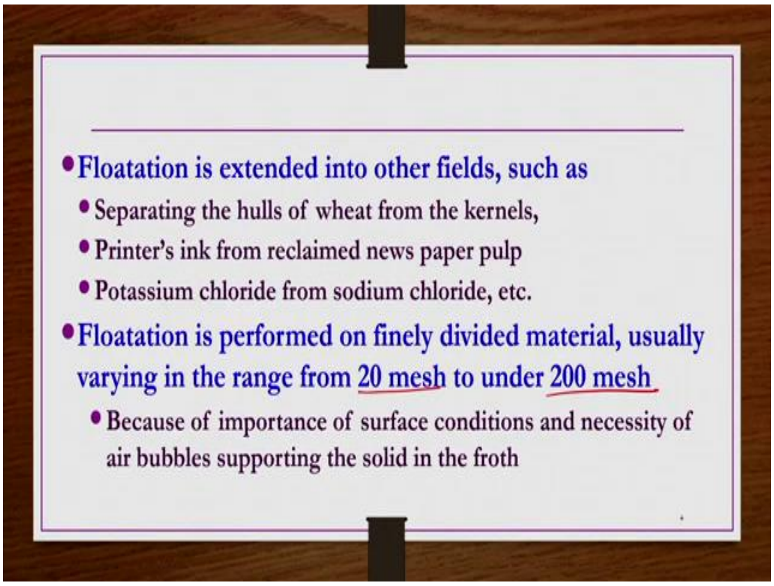


- Average or bulk density of solid and adsorbed air bubbles is less than that of water,
  - and thus whole mass of air and solid floats to the surface to form a mineralized froth which continuously overflows the side of vessel
- Floatation is capable of separating materials regardless of their densities
  - because separation by froth floatation depends upon surface characteristics of the material
- Floatation cell was initially developed in mineral industries, and over 80% of mineral concentration is accomplished by flotation



- Floatation is extended into other fields, such as
  - Separating the hulls of wheat from the kernels,
  - Printer's ink from reclaimed news paper pulp
  - Potassium chloride from sodium chloride, etc.
- Floatation is performed on finely divided material, usually varying in the range from 20 mesh to under 200 mesh
  - Because of importance of surface conditions and necessity of air bubbles supporting the solid in the froth

So, average or bulk density of solid and adsorbed air bubbles is less than that of water. And then because of that one whole mass of air and solid floats to the surface to form a mineralized froth which continuously overflows the side of the vessel in which we are doing this process. Floatation is capable of separating materials regardless of their density differences because separation by froth floatation depends upon the surface characteristics of the material, whatever the gangue and then solid individual if you take their individual densities may be higher than the water density in general, right.

So, then when you take them and mix them with the water, so then both gangue and then solid particles settling down, so then there is no separation because of the density, but because of introducing by this froth or air bubbles kind of thing, so these bubbles sizes are bigger and then onto which the solids active solids which we wanted to make their concentration higher so they will be attached. So, then the average density of this bubble and that adsorbed solid is going to be lower than the water density and then because of that one you know, then separation of this solids as overflow takes place.

So, that is the difference. So, that is the reason the separation here is not based on the density difference, it is because of this difference in the surface characteristics, because of that surface characteristics differences only the average density of the bubble phase or the froth plus solids is going to be less than the density of water, then only the separation is taking place. So, though the density is coming into the picture basically it is the surface characteristics because of that the average density of froth and solid is going to become less than the density of water and being separated as a kind of overflow from the top.

Floatation cell was initially developed in mineral industries and over 80% of mineral concentration is accomplished by flotations in most of the mineral industries. Floatation is extended into other fields also. Some application if you see, separating the hulls of wheat from the kernels, printer's ink from reclaimed the newspaper pulp. Whatever the old newspaper is still there, that you shred and then reduce their sizes to the smaller ones, smaller sizes and then if you do the same floatation process, whatever the ink is there that you can recover and then further you can use whereas the pulp cellulose et cetera kind of thing that can be taken as a kind of wastage.

So, that way the floatation is also found applications in these printing industries. Potassium chloride from sodium chloride et cetera are some of the examples where floatation is also extended to the other fields. Floatation is performed on finely divided material, usually varying in the range from 20 mesh to under 200 mesh because if the particle size, solid particle which you wanted to separate, you know, if their size is smaller much smaller then surface characteristics are the stronger influence and then the separation along with the froth of those solids can take place easily; that is the reason you need to have a kind of finer particles, ok.

So, in the floatation what happens? The particles are smaller whereas the bubbles are the bigger sized. Because of importance of surface conditions and necessity of air bubbles supporting the solid in the froth, this operation is taking place.

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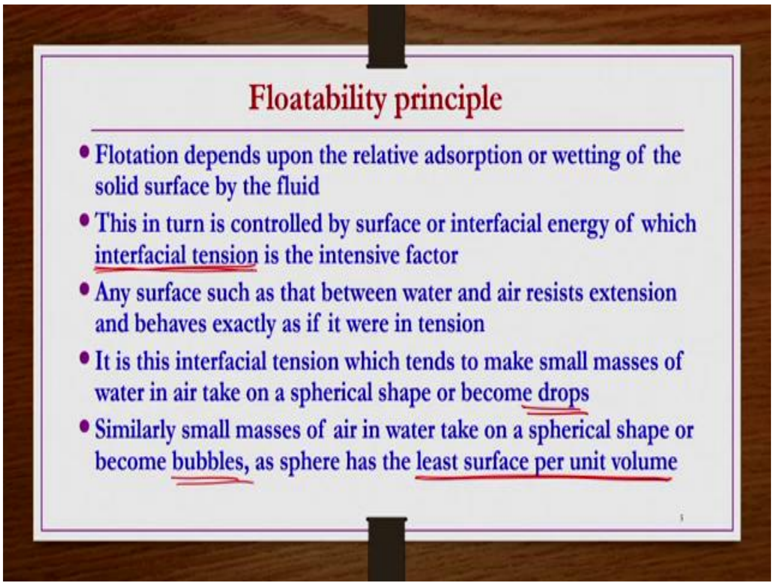

Floatability principle

- Flotation depends upon the relative adsorption or wetting of the solid surface by the fluid
- This in turn is controlled by surface or interfacial energy of which interfacial tension is the intensive factor
- Any surface such as that between water and air resists extension and behaves exactly as if it were in tension
- It is this interfacial tension which tends to make small masses of water in air take on a spherical shape or become drops
- Similarly small masses of air in water take on a spherical shape or become bubbles, as sphere has the least surface per unit volume

So, what is the principle of floatability? We have seen that you know experimentally how the separation takes place, that we have seen, right. But how, what is the floatability principle in general, that we are going to see.

What happens in general? Like, you know that finely crushed very small fine solid particles are taken along with the bigger bubble size kind of thing and then floating on the surface, what happens, what is the principle that is occurring in this floatability, that we are going to see. Floatation depends upon the relative absorption or wetting of the solid surface by the fluid. This in turn is controlled by surface or internal energy of which interfacial tension is the intensive factor.

So, the surface characteristics whatever being discussing, this is the one. This interfacial tension is the very important intensive factor that is deciding the performance of floatation cell. Any surface such as that between water and air resist extension and behaves exactly as if it were in tension. It is this interfacial tension which tends to make small masses of water in air take on a spherical shape or become drops.

Sometimes what we see in the air, the water droplets are forming and then settling down because the water density is higher than the air density but this water why it is not falling as a kind of sheet? Why it is forming a kind of a drop? Because of this interfacial tension, ok, interfacial tension. In other word, it is a kind of resistance to extension of the surface, extension of the surface whatever the resistance force is there that is interfacial force.

So, then this interfacial tension what it is doing, it does not allow the material to stretch rather it will. So, since it is not allowing to stress the material, what it will try? It will try to take a different from where energy is going to be the lower which is having lower surface area can be developed. So, when the water droplet that is forming that spherical droplet whatever the surface is there, that is having the lower surface for the same amount of material, same volume of the material that is considered. So, because of that one rather being stretching out, it is forming a kind of droplet ok, so, it is this interfacial tension which tends to make small masses of water in air take on a spherical shape or becomes drops. Other way also if you see similarly small masses of air in water take on a spherical shape or become bubbles as sphere has the least surface per unit volume.

This is the reason, because whether it is drop formation, whether the droplet formation or whether it is the bubble formation, droplet formation in air or bubble formation in water whatever this spherical shape that take because their interfacial tension is such that it is not allowing the stretching of this material in the other phase. So, this material what it tries, it tries to take a kind of shape which is having the least possible surface per unit volume and then spherical shape is the one which is having the least possible surface area per unit volume. That is the reason this material, water in air takes a kind of droplet shape and then air in water takes kind of bubble shape in a kind of spherical form, ok.

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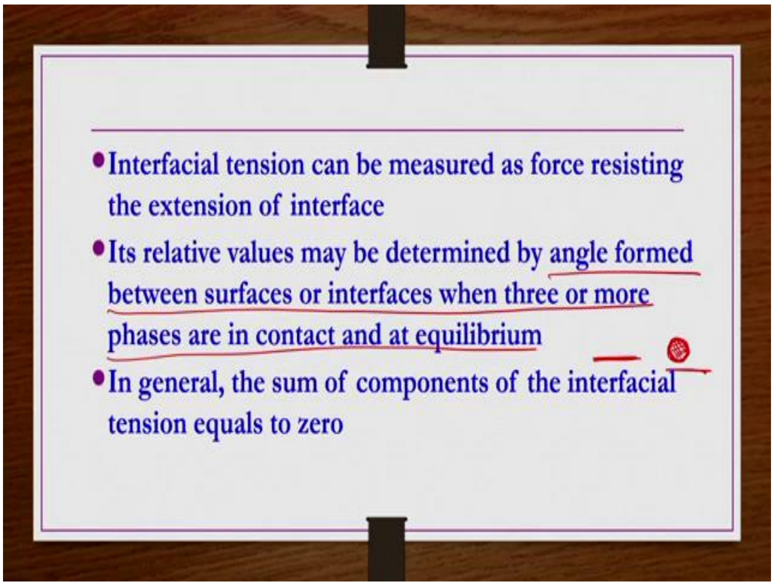

- Interfacial tension can be measured as force resisting the extension of interface
- Its relative values may be determined by angle formed between surfaces or interfaces when three or more phases are in contact and at equilibrium
- In general, the sum of components of the interfacial tension equals to zero

So, interfacial tension can be measured as force resisting the extension of the interface. So, this interfacial tension it does not allow the material to extend the interface. So, because of that one that material what it will try, it will try to take the form whichever is having the least surface area per unit volume. So, interfacial can be measured as force resisting the extension of surface or extension of interface.

Its relative values may be determined by angle formed between the surfaces our interface when three or more phases are in contact and at equilibrium. So, how much is this interfacial tension that we wanted to know, right. Now, this material, right, let us say whatever is there rather forming a kind of sheet like this, it is taking a kind of droplet form because of the this interfacial tension because that interfacial tension is resisting or offering the resisting force for this water not to extend its surface.

So, then this water, what it is trying, it is trying to take a shape which is having the lower surface area, right. So, what is that magnitude of that interfacial tension that causing here that if you wanted to know, you need to know the contact angle, you need to know the angle formed between the surfaces or interface when three or more phases are in contact and at equilibrium, that angle is known as the kind of contact angle, ok.

So, that is very important one. So, in general the sum of components of the interfacial tensions equal to 0. If you have a more than like, you know, 3 phases, 3 or more forces are there, so more than 3 or 4 components of this interfacial tensions may be there. So, when you take the sum of the components of the interfacial tensions that becomes equals to 0 because that is at equilibrium.

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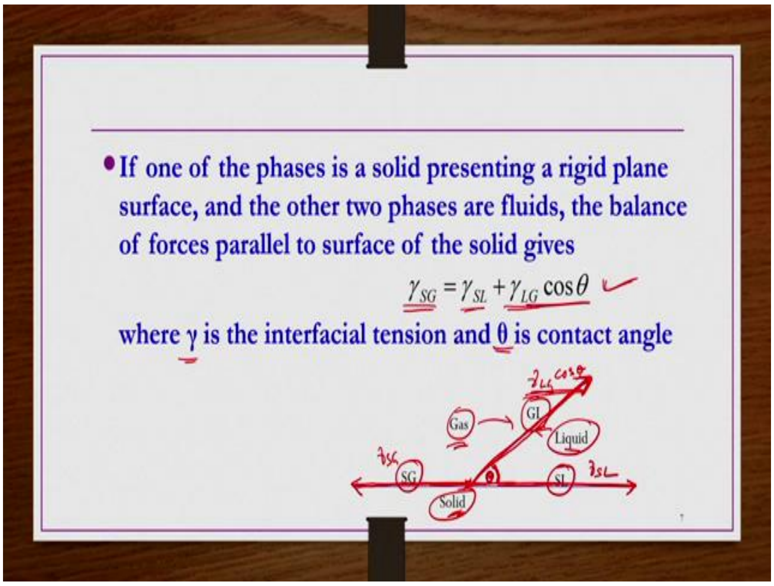

- If one of the phases is a solid presenting a rigid plane surface, and the other two phases are fluids, the balance of forces parallel to surface of the solid gives

$$\underline{\underline{\gamma_{SG}}} = \underline{\gamma_{SL}} + \underline{\underline{\gamma_{LG}\cos\theta}} \checkmark$$

where $\underline{\gamma}$ is the interfacial tension and $\underline{\theta}$ is contact angle

If one of the phases is a solid representing a rigid plane surface and the other 2 phases are fluids, the balance of forces parallel to surface of the solid gives this expression. Like let us say you have a kind of solid surface like this and there is a liquid and then gas, all 3 are in contact. So, let us at this point if you wanted to know the contact angle, so then you know at this point you know what is happening, how the interfacial forces are acting, that you wanted to know at this point. So, at this point let us say contact angle is theta, we are going to see how to measure this one, contact angle is theta.

So, whatever the surface tension in this direction SG direction is there, that should be balanced by the surface tension or interfacial tension in the other 2 direction. GL and then SL like this. So SG is the interface, rather saying the direction in general it is a kind of interface between solid and then gas phase. So, that interface between these 2 phases there is interface, that interface having some amount of interfacial tension.

So, that interfacial tension is nothing but γ_{SG}. Now here the liquid and then gas both 2 phases are there and then there is a kind of interface between these 2 and there is a kind of interface between these two, ok. So, because of this presence of interface the, what is there? That interfacial tension whatever is there that is γ_{LG}, or GL, ok. And then here we have a interface between liquid and then solid phase.

So, there is an interface between this liquid and solid phase. So, whatever the interfacial tensions is there that is nothing but γ_{SL} and then this interface GL is at angle θ with interface SL, right. Because of that one this γ_{GL} should be multiplied by this $cos\theta$. So, now by the directions if you see, you can easily understand by the direction this is in this direction and these 2 are in the other direction.

So, whatever γ_{SG} is there that should be balanced by the $\gamma_{SL} + \gamma_{LG} cos\theta$. This cos theta is coming because of this contact angle θ between these 3 phases like you know gas, liquid and solid, right. This angle is this gas-liquid interface and then this is a solid phase. At these 3 phases, whatever the angle is there, contact angle that is theta. So, because of that one this component will be having, you know $\gamma_{LG} cos\theta$, ok.

So, or otherwise as the sum of the all interfacial tensions for this kind of situation should be 0, then you can write $\gamma_{SG} - \gamma_{SL} - \gamma_{LG} cos\theta = 0$ which is nothing but $\gamma_{SG} = \gamma_{SL} + \gamma_{LG} cos\theta$, ok. So, here γ is the interfacial tension and θ is the contact angle.

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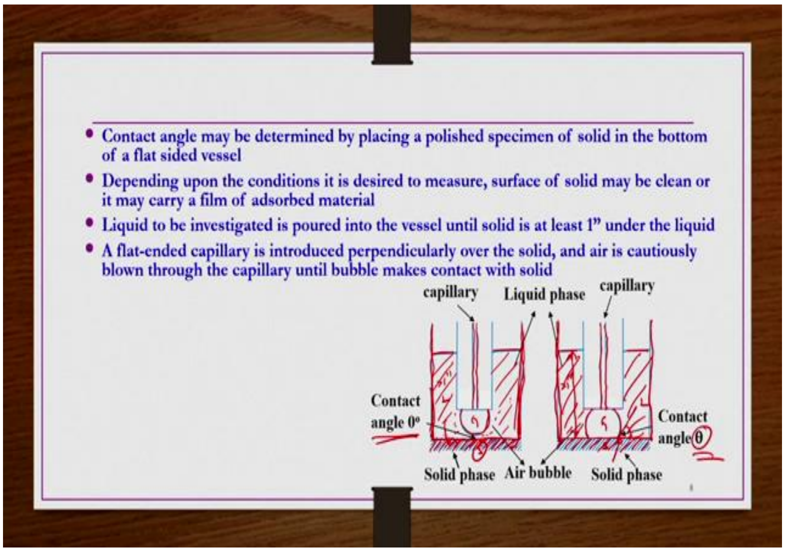

- Contact angle may be determined by placing a polished specimen of solid in the bottom of a flat sided vessel
- Depending upon the conditions it is desired to measure, surface of solid may be clean or it may carry a film of adsorbed material
- Liquid to be investigated is poured into the vessel until solid is at least 1" under the liquid
- A flat-ended capillary is introduced perpendicularly over the solid, and air is cautiously blown through the capillary until bubble makes contact with solid

So, now how to measure the contact angle? So, now what you do here, you take a solid surface, solid phase like this. So, contact angle may be determined by placing a polished specimen of solid in the bottom of a flat sided vessel, this flat sided vessel like this. You take a solid surface like this, ok. And then depending on the conditions it is desired to measure surface of solid maybe clean or it may be carrying a film of adsorbed material, ok. It may be clean or it may be having a kind of adsorbed material depending on what conditions, for what case you wanted to measure these conditions. If you wanted to measure the contact angle for the pure solid phase then then there should not be any kind of film on this one.

If you wanted to find out the contact angle of the film then the solid surface should be having a carrying a kind of adsorbed film material, ok. Then liquid to be investigated is poured into the vessel until solid is at least 1 inch under the liquid. So, what you do, you take this solid, or you know you place this solid in such a way that in the liquid phase for which you wanted to do this investigation of the contact angle, you know that you place it here so that solid is at least 1 inch under the liquid, solid is at least 1 inch under the liquid.

So, then this is the liquid interface. This is all liquid kind of thing, ok. Then a flat ended capillary is introduced perpendicularly over the solid and air is cautiously blown through the capillary until the bubble makes contact with the solid. So, this is a capillary you have, so you take a capillary here and then perpendicularly like this you put it and then cautiously blow air through it so that a kind of bubble forms and then blow this air until this bubble makes contact with the solid.

Let us say it is you know, if the bubble is forming like this and then you can see here between this solid phase and then this bubble phase, there is no contact and then liquid is coming and then occupying this one between these 2 phases, ok. Between this bubble phase and then solid phase there is no contact and then whatever the interfacial distance between these two there, that is occupied by the liquid.

What does it mean by here? There is no contact between the bubble and in solid phase or the all 3 phases are not in contact with each other. So then contact angle is 0, so that the contact angle is 0. So, for the solid surface when you take these 3 phases you know in a kind of combination as a system then contact angle is 0, ok. Because it is not attached, it is not attached to the solid surface. So, if the contact angle is 0 that means solid is not being attached to the bubble surface or bubble is not making any contact with the solid. That means, it is not going to float and then the flotation is not going to be effective for this case, ok.

So indirectly if you have the more contact angle or more contact between the solid and then bubble phase will take place and then more floatability of that material will be there and then that can easily be taken as overflow through the froth from the top, as a froth from the top it can be taken as a kind of overflow, ok. So, that is the case. Now, you take the other case where there is a kind of a contact angle, right.

So, let us say the same solid surface now, whether it is clean or you know attached with a kind of film depends on for which you are measuring the this contact angle. Let us say if you are measuring contact angle for pure solid surface, so that surface should be pure and there should not be any material attached to the surface. If you wanted to measure the contact angle for some foreign material, then that material has to be attached as a kind of thin layer on the surface solid surface and then similar process we have to do.

So, let us say this solid surface is there and then whatever the liquid you wanted to, for which you wanted to do this thing, so that you pour. So, that you pour on this one so that until you know the solid surface, solid surface whatever is there that should be at least you know 1 inch under the liquid. So, this distance between solid surface and then liquid surface should be more than 1 inch, this distance should be more than 1 inch, right, ok.

So, now, it is like this, this liquid is initially like this, initially liquid was occupied by this area also, ok. Now, in this one you take a capillary and then perpendicularly you place like this and then carefully you blow air so that the bubble forms and then you blow air continuously until this bubble reaches the solid surface and makes a contact. So, now if the bubble is making a contact with the solid surface, so now here this liquid gas and solid, liquid, this is the liquid phase, this is the gas phase and this is the solid phase, all 3 phases are making a contact at this point, all 3 phases are making a contact at this point.

So, if your draw a tangent here whatever this angle is there, that we call it as a contact angle that we call as a contact angle and then this contact angle is a kind of very important requirement in order to know the interfacial tension, ok. This is how you can measure the contact angle for a given system where 3 or more phases are in contact with each other and then they are at equilibrium, ok.

So, now we, you can see the difference here. When there is no contact or when there is a contact angle is 0, these all 3 phases are not coming into the contact at any point, that is what it meant by. So, this is a gas phase and then liquid phase. There is a contact between liquid phase and gas phase but there is no contact with the solid phase and then gas phase. Liquid and solid phase also there is a contact here, right.

The liquid phase and then solid phase also there is a contact; liquid phase and then gas phase also there is a contact between these 2, right. But there is no contact between gas and solid phase. That means, there is no point that all 3 phases are contacting each other. So, that means, the contact angle is 0 or otherwise between the solid and then gas the liquid is coming into the picture and then that is there is no point that all 3 phases are contracting with each other.

If the gas is making some contact and then being attached to the solid surface, so then so this is the point where liquid, solid, gas are contacting with each other and at this point if you draw a tangent, whatever the angle that makes, that is the contact angle.

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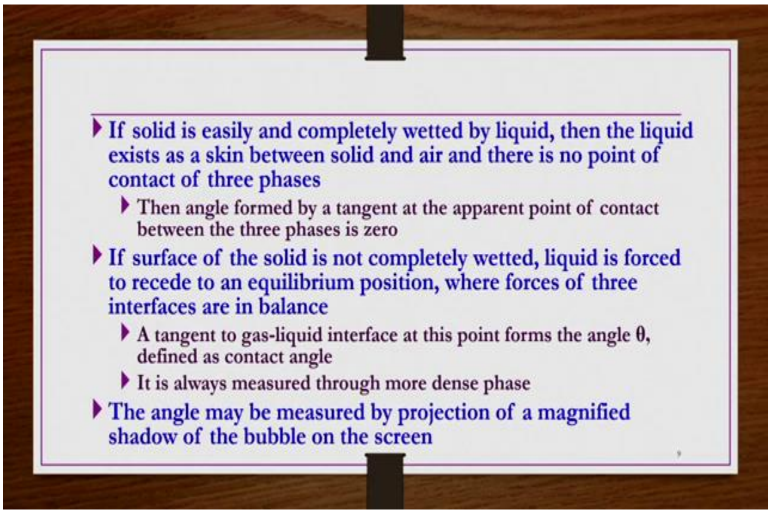

- If solid is easily and completely wetted by liquid, then the liquid exists as a skin between solid and air and there is no point of contact of three phases
  - Then angle formed by a tangent at the apparent point of contact between the three phases is zero
- If surface of the solid is not completely wetted, liquid is forced to recede to an equilibrium position, where forces of three interfaces are in balance
  - A tangent to gas-liquid interface at this point forms the angle θ, defined as contact angle
  - It is always measured through more dense phase
- The angle may be measured by projection of a magnified shadow of the bubble on the screen

A solid is easily and completely wetted by liquid. Then liquid exists as a skin between solid and air and there is no point of contact of 3 phases. Then angle formed by a tangent at the apparent point of the contact between the 3 phases is 0, that is contact angle is 0 in such case. If surface of the solid is not completely wetted, liquid is forced to recede to an equilibrium position where forces of 3 interfaces are in balance. Then, a tangent to gas liquid interface at this point forms the angle theta defined as contact angle, defined as contact angle. It is always measured through the more dense phase, so more dense phase through the more dense phase we measure it.

The angle may be measured by projection of a magnified shadow of the bubble on the screen. This is how we do the contact angle measurements.

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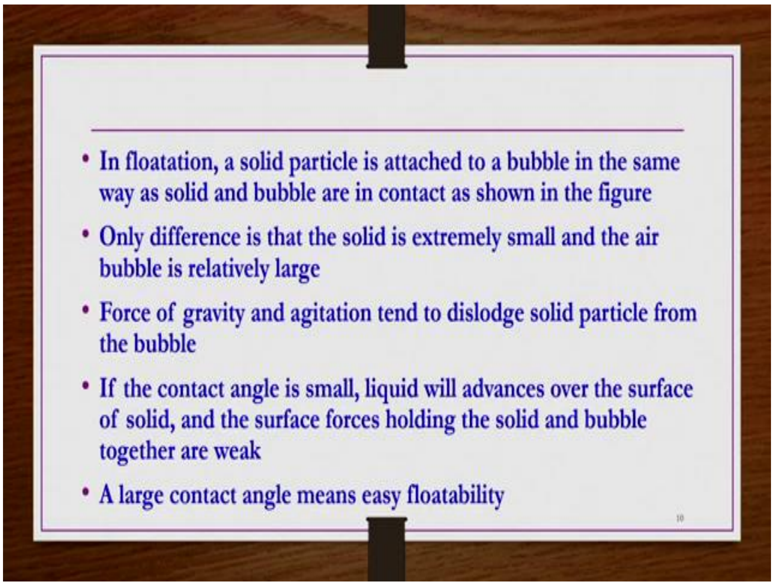

- In floatation, a solid particle is attached to a bubble in the same way as solid and bubble are in contact as shown in the figure
- Only difference is that the solid is extremely small and the air bubble is relatively large
- Force of gravity and agitation tend to dislodge solid particle from the bubble
- If the contact angle is small, liquid will advances over the surface of solid, and the surface forces holding the solid and bubble together are weak
- A large contact angle means easy floatability

In floatation a solid particle is attached to a bubble in the same way as solid and bubble or in contact as shown in the picture, then only difference is that the solid is extremely small and then air bubble is relatively large, that is what happens compared to the previous experiment what we have seen.

So, in floatation solid particle is attached to a bubble in the same way as solid and bubble are in contact in the previous figure that contact angle measurement that we have seen. But what is the difference here? In the previous figure, we have a bigger solid surface and then smaller bubble kind of thing, but in the floatation what we have? We have a kind of bigger bubbles and then small solid particles are attached to these bigger bubbles.

Force of gravity and agitation tend to dislodge solid particle from the bubble. If the contact angle is small, liquid will advance over the surface of the solid and then surface forces holding the solid and bubble together are weaker. As I said, if the contact between the gas bubble and then solid is not there, so then obviously the separation will not take place in the floatation. So, that means smaller the contact angle weaker is the interaction between the solid and then bubble, ok.

So, then weaker would be the performance of floatation. So, if you wanted to have a kind of better floatation performance you should make sure that contact angle for these 3 phases should be large enough. A large contact angle means easy floatability.

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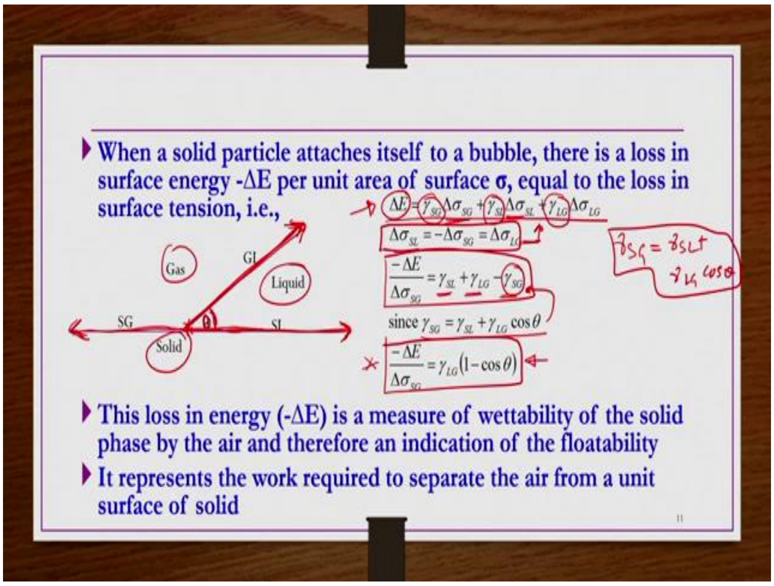

- When a solid particle attaches itself to a bubble, there is a loss in surface energy -ΔE per unit area of surface **σ**, equal to the loss in surface tension, i.e.,

$$\Delta E = \gamma_{SG}\Delta\sigma_{SG} + \gamma_{SL}\Delta\sigma_{SL} + \gamma_{LG}\Delta\sigma_{LG}$$

$$\boxed{\Delta\sigma_{SL} = -\Delta\sigma_{SG} = \Delta\sigma_{LG}}$$

$$\boxed{\frac{-\Delta E}{\Delta\sigma_{SG}} = \gamma_{SL} + \gamma_{LG} - \gamma_{SG}}$$

since $\gamma_{SG} = \gamma_{SL} + \gamma_{LG}\cos\theta$

$$\boxed{\frac{-\Delta E}{\Delta\sigma_{SG}} = \gamma_{LG}(1-\cos\theta)}$$

$$\boxed{\gamma_{SG} = \gamma_{SL} + \gamma_{LG}\cos\theta}$$

- This loss in energy (-ΔE) is a measure of wettability of the solid phase by the air and therefore an indication of the floatability
- It represents the work required to separate the air from a unit surface of solid

When a solid particle attaches itself to a bubble, there is a loss in surface energy, that loss let us say $-\Delta E$ per unit area of surface sigma equal to the loss in surface tension. So, that is you have these 3 phases, the same picture again. So, there is a kind of solid surface like this, there is a kind of liquid and then gas phases, all of them are in contact with each other at this point, right. At this point they are in contact with each other, all 3 are in contact.

So, at this point if you draw a tangent you know that whatever the angle is there, that is the contact angle θ, right. So, when this solid particle attaches itself to a bubble there is a loss in surface energy, whatever that loss in surface energy is there that should be balanced by the loss in surface tension.

So, that is what we do. Let us say, the loss in surface energy for this point if you see at the contact point, so that is let us say ΔE, right. That should be balanced by the loss in surface tension. So, surface tension in this direction between the solid and gas phase is nothing but γ_{SG} multiplied by the unit area of surface between the solid and liquid that is let us say in $\Delta\sigma_{SG}$, and then the interfacial tension between solid and liquid phases is nothing but γ_{SL} and then multiplied by the surface area between these 2 interfaces that is $\Delta\sigma_{SL}$ plus whatever this one that is interfacial tension between this gas and liquid phases is nothing but γ_{LG} multiplied by the surface area σ_{LG}.

Previously what we have seen, like you know this $\gamma_{SG} = \gamma_{SL} + \gamma_{LG} cos\theta$. Following these directions following this direction what we can understand here, we can understand $\Delta\sigma_{SL} = \sigma_{LG} - \Delta\sigma_{SG}$, that is what we can understand here. So, when you apply this relation here in this above equation, then you have $\frac{-\Delta E}{\Delta\sigma_{SG}} = \gamma_{SL} + \gamma_{LG} - \gamma_{SG}$, that is what you get.

But, we have already seen that $\gamma_{SG} = \gamma_{SL} + \gamma_{LG} cos\theta$. So, in place of γ_{SG} you substitute here and then simplify then you get $\frac{-\Delta E}{\Delta\sigma_{SG}} = \gamma_{LG}(1 - cos\theta)$, $1 - cos\theta$. So, this is the energy loss or loss in surface energy when the solid particles are being attached themselves to bubbles. So, when they when a single if you take a kind of single solid particle, when a single particle, when a single particle is being attached itself to a bubble, obviously there is a kind of loss of surface energy. That loss of surface energy you can calculate by this expression because that loss of surface energy must be balanced by the loss in the surface tension.

So, when you do this balance and then simplify, you can get this energy, loss in surface energy. So, this loss in energy $-\Delta E$ is a measure of wettability of the solid phase by air and therefore an indication of the floatability. It represents the work required to separate the air from a unit surface of solid. So, after you know froth whatever you have collected, this much of energy you have to provide so that the solids are being separated from the air bubbles.

So, that is about the basic floatation process and then digging out what is the floatability principle. Now, we see some of the floatation agents. So, collectors and promoters are the 2 kind of agents are there, these are kind of some kind of chemicals that we add to the mixture so that you know, they will form a kind of layer on the solid particle so that they can easily adsorbed onto the bubbles. Let us say the surface characteristics of the solid which you wanted to separate from the other solids, other impurities, that surface characteristics are not good enough that these solids are being, can easily adsorbed onto the bubbles. Then what you can do, you can add some kind of foreign material so that this material will form a kind of layer onto the solid surfaces and then make the surface so that they modify the surface characteristics of the solids such a way that they can easily be adsorbed onto the bubble surface and then easily can be separated from the remaining solid particles, right.

So, this foreign material whatever you add so that the surface characteristics of the solids gets improved and then easily attached to the bubble surface, these foreign materials are known as the floatation agents. And then if they are forming a one molecular thick kind of layer onto the solids, then we call them as a kind of promoters. If they are forming, if they are forming a kind of multiple layer of material as a contained material in a kind of multiple molecular thickness, then we call them as a kind of collectors. So, what are the in general promoters and collectors are available, that we see now.

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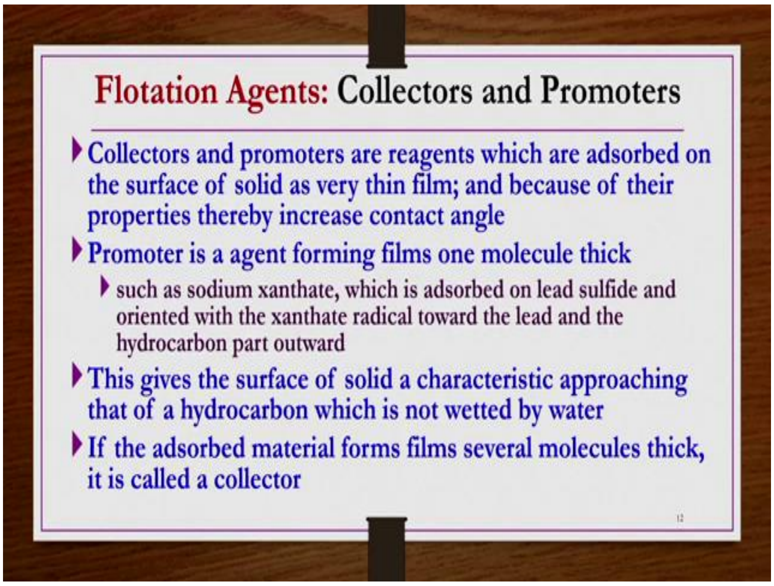

Flotation Agents: Collectors and Promoters

- Collectors and promoters are reagents which are adsorbed on the surface of solid as very thin film; and because of their properties thereby increase contact angle
- Promoter is a agent forming films one molecule thick
  - such as sodium xanthate, which is adsorbed on lead sulfide and oriented with the xanthate radical toward the lead and the hydrocarbon part outward
- This gives the surface of solid a characteristic approaching that of a hydrocarbon which is not wetted by water
- If the adsorbed material forms films several molecules thick, it is called a collector

Collectors and promoters are reagents which are adsorbed on the surface of solid as a very thin film and because of their properties thereby increase the contact angle. So, when you attach this reagent onto the solid surface whatever the contact angle of the pure solid is there, that will be increased because of deciding these collectors or promoters and then contact angle is increased, that means, they will be easily attached to the bubble surface and then floatability will increase; the separation would be better.

Promoter is a agent forming films one molecule thick in general such as sodium xanthate, which is adsorbed on lead sulfide and oriented with the xanthate radical toward the lead and the hydrocarbon part outward.

This gives the surface of a solid a characteristic approaching that of a hydrocarbon which is not wetted by the water. If that is not wetted by the water that will be easily wetted by the air bubble and then can be separated as a kind of you know overflow from the top of the floatation cell or floatation equipment. If the adsorbed material forms films several molecules thick, it is called a collector.

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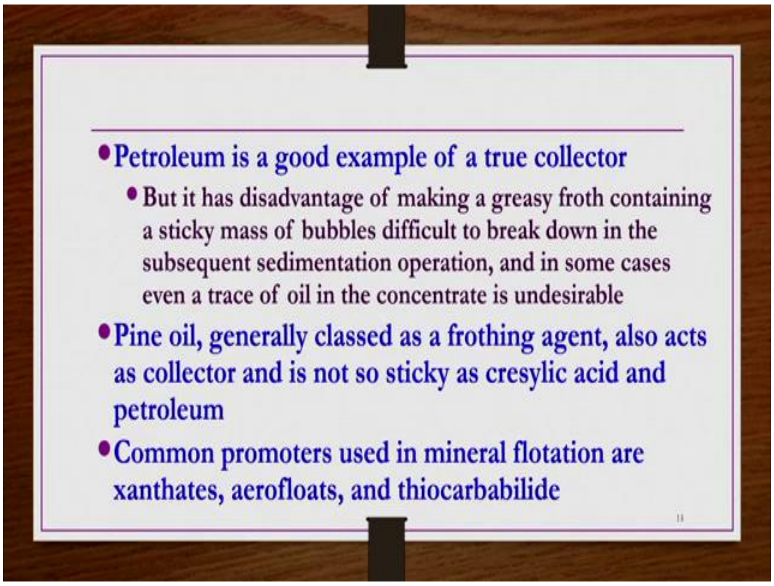

- Petroleum is a good example of a true collector
  - But it has disadvantage of making a greasy froth containing a sticky mass of bubbles difficult to break down in the subsequent sedimentation operation, and in some cases even a trace of oil in the concentrate is undesirable
- Pine oil, generally classed as a frothing agent, also acts as collector and is not so sticky as cresylic acid and petroleum
- Common promoters used in mineral flotation are xanthates, aerofloats, and thiocarbabilide

In general petroleum is a good example of true collector, but sometimes what happens you know this forms a very greasy kind of froth that forms and then removing that greasy kind of collectors after this operation of the solids is again kind of painful.

So, one should be careful about the amount of petroleum should be added as a kind of collector so that to improve the floatability, but this petroleum has the disadvantage of making a greasy froth containing a sticky mass of bubbles difficult to break down in the subsequent sedimentation operation after the solids are being separated from the other solids as a kind of froth. So, whatever the froth that is containing the solid particles, so that froth et cetera are becoming strong by adding this petroleum.

So, the interaction between the solids and then bubble is very strong because of this greasy froth by adding this petroleum. So, if these are the promoters and collectors it is enhancing the surface characteristic, but after that you need to separate them, you need to separate them because you do not want those foreign material in subsequent operations. In some kind of subsequent operations with the solids even minute traces of these promoters or collectors may be very disadvantageous, ok.

So, that is the reason one should be careful about adding the petroleum and then how much petroleum amount should be added one should be very careful about them. Pine oil generally classed as a frothing agent but also acts as a collector and is not so sticky as cresylic acid and petroleum. Common promoters used in mineral floatation are xanthates, aerofloats and thiocarbabilides.

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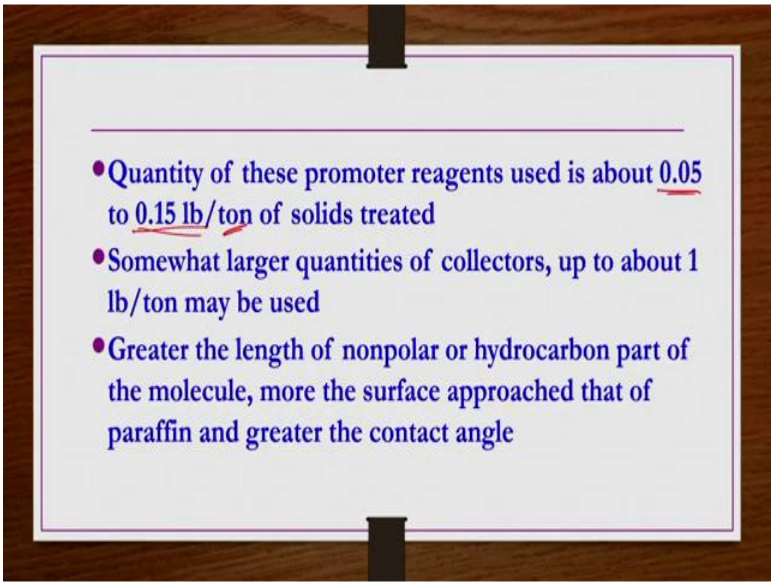

- Quantity of these promoter reagents used is about 0.05 to 0.15 lb/ton of solids treated
- Somewhat larger quantities of collectors, up to about 1 lb/ton may be used
- Greater the length of nonpolar or hydrocarbon part of the molecule, more the surface approached that of paraffin and greater the contact angle

Quantity of this promoter reagent used in general about 0.05 to 0.15 lb per ton of solids treated. You can see how small traces or small quantities are being added in general, 0.05 lb to 0.15 lb per ton of solids, such small amounts one has to add in order to get the promoters, that is forming one layer of 1 molecular thick layer. Somewhat larger quantities of collectors up to about 1 lb per ton may also be used. If you wanted to have a kind of many layers of this foreign material being formed a kind of mini, a mini molecular thing thicker, then you can add up to 1 lb per ton of this material.

So, then you can treat them as a kind of collectors. Greater the length of non-polar or hydrocarbon part of the molecule, more the surface approached that of paraffin and greater the contact angle.

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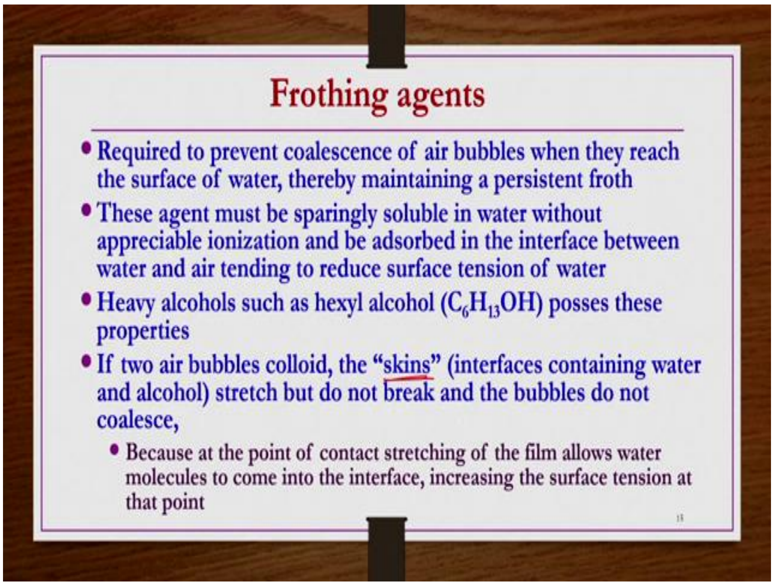

Frothing agents

- Required to prevent coalescence of air bubbles when they reach the surface of water, thereby maintaining a persistent froth
- These agent must be sparingly soluble in water without appreciable ionization and be adsorbed in the interface between water and air tending to reduce surface tension of water
- Heavy alcohols such as hexyl alcohol ($C_6H_{13}OH$) posses these properties
- If two air bubbles colloid, the "skins" (interfaces containing water and alcohol) stretch but do not break and the bubbles do not coalesce,
  - Because at the point of contact stretching of the film allows water molecules to come into the interface, increasing the surface tension at that point

Now, we see frothing agents. So, previously whatever the promoters or collectors are there, they are a kind of floatation agents, they are a kind of a floatation agent which enhance the surface properties of solids, which enhance the surface properties of solids so that they can easily be adsorbed on solids. Because of adding this floatation agent the contact angle increases and then they can easily float. So, that is the reason they are known as the floatation agents. But sometimes you need to have a kind of agents which improves the bubble formation, froth formation also. It is not necessary that always because of the solids surface characteristic that you know the separation is takes place, it is also important in some applications.

In some applications, it is also important to make sure that sufficient amount of froth is forming. If the solid materials are such a way that you know generally by aerating or something like that, you may not able to generate enough amount of bubbles. So, in under such conditions you can add some kind of reagent like promoters, collectors for floatation as you are using. Similarly, you can add them kind of reagents or chemicals which can enhance the froth formation, ok. So, they are known as the frothing agents.

These are required to prevent coalescence of air bubbles when they reach the surface of water, thereby maintaining a persistent froth. These agent must be sparingly soluble in water without appreciable ionization and be adsorbed in the interface between water and air tending to reduce surface tension of water. Heavy alcohols such as hexyl alcohol possess these properties. If two air bubbles collide, the skins interface containing the water and alcohol stretch but do not break and then bubbles do not coalesce.

That is the purpose of this thing, frothing agents. Because at the point of contact stretching of the film allows water molecules to come into the interface increasing the surface tension at that point.

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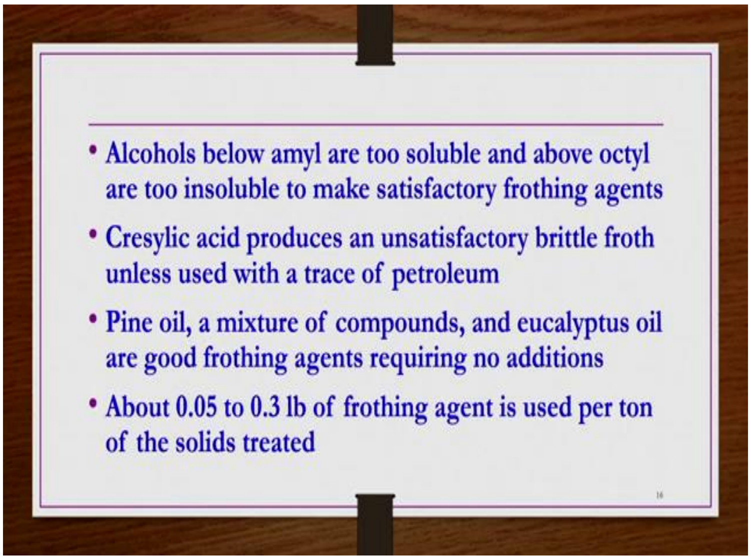

- Alcohols below amyl are too soluble and above octyl are too insoluble to make satisfactory frothing agents
- Cresylic acid produces an unsatisfactory brittle froth unless used with a trace of petroleum
- Pine oil, a mixture of compounds, and eucalyptus oil are good frothing agents requiring no additions
- About 0.05 to 0.3 lb of frothing agent is used per ton of the solids treated

Alcohols below amyl are too soluble and above octyl are too insoluble to make satisfactory frothing agents, so one should be careful about these alcohols. Cresylic acid produces an unsatisfactory brittle froth unless used with a trace of petroleum.

Pine oil, a mixture of compounds and eucalyptus oil are good frothing agents requiring no additions. About 0.05 to 0.3 lb of frothing agent used per ton of the solids treated in general. These are all kind of experimental observation that have been found by doing several experiments, experiments to improve this floatation process.(Refer Slide Time: 45:16)

Modifying agents

- May be used to “activate” or to “depress” adsorption of the filming agent (collector or promoter)
- They react with the surface of sold, either by chemical action or by adsorption, to change the character of the surface of one or more of the solids,
  - thereby preventing adsorption of the collector or promoter on the solid
- Addition of copper sulfate activates the surface of zinc sulfide so that latter is readily floated if a small quantity of copper sulfate is added in conditioning tank
  - This may be due to the formation of copper sulfide or perhaps metallic copper on the surface of the zinc sulfide

Then there are some kind of modifying agents which are required, may be used this, these modifying agents in general used to activate are depress adsorption of the filming agent. Collector or promoters whatever the filming agent that we have provided, so sometimes it is also required to remove them or sometimes you want to enhance their activity also. So, either to activate or to depress the absorption of the filming agent we may need some kind of modifying agents, what are they that we see. These modifying agents react with the surface of solid either by chemical action or by adsorption to change the character of the surface of one or more of the solids so that thereby preventing adsorption of the collector or promoter on the solid.

Addition of copper sulfate activates the surface of zinc sulfide so that later is readily floated if a small quantity of copper sulfate is added in conditioning tank. This may be due to the formation of copper sulfate or perhaps metallic copper on the surface of the zinc sulfide.

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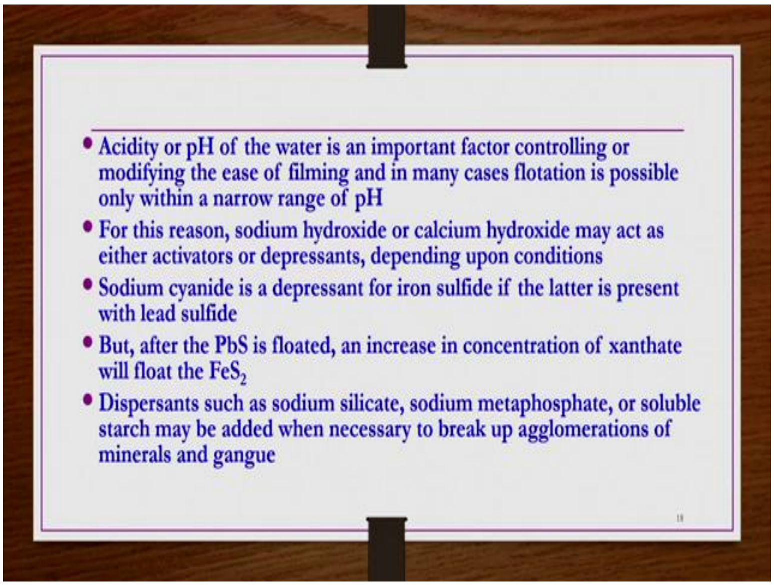

- Acidity or pH of the water is an important factor controlling or modifying the ease of filming and in many cases flotation is possible only within a narrow range of pH
- For this reason, sodium hydroxide or calcium hydroxide may act as either activators or depressants, depending upon conditions
- Sodium cyanide is a depressant for iron sulfide if the latter is present with lead sulfide
- But, after the PbS is floated, an increase in concentration of xanthate will float the FeS_2
- Dispersants such as sodium silicate, sodium metaphosphate, or soluble starch may be added when necessary to break up agglomerations of minerals and gangue

Another parameter is acidity or pH of the water is an important factor controlling or modifying the ease of filming and in many cases, floatation is possible only within a narrow range of pH. So, this another kind of modifying agent is that you know, that modifies the pH, that modifies the pH because few cases what happens, this floatation is good only under narrow range of pH. If you want to bring the pH of the system to that narrow range, so then you may need to add some more modifying agents. So for this reason sodium hydroxide or calcium hydroxide may act as either activators or depressants depending upon conditions.

Sodium cyanide is a depressant for iron sulfide if the later is present with the lead sulfide, ok. But after the PbS is floated, an increase in concentration of xanthate will float the iron sulfide as well. Dispersants such as sodium silicate, sodium metal phosphate or soluble starch may be added when necessary to break up agglomerations of minerals and gangue, ok. This is about the some basics about floatation process, floatation principles and then floatation agents, froth forming agents, modifying agents. Those are the required information to know if we are undergoing kind of floatation processes, so you need to have information about these agents and then these processes, principles etc; that we have seen.

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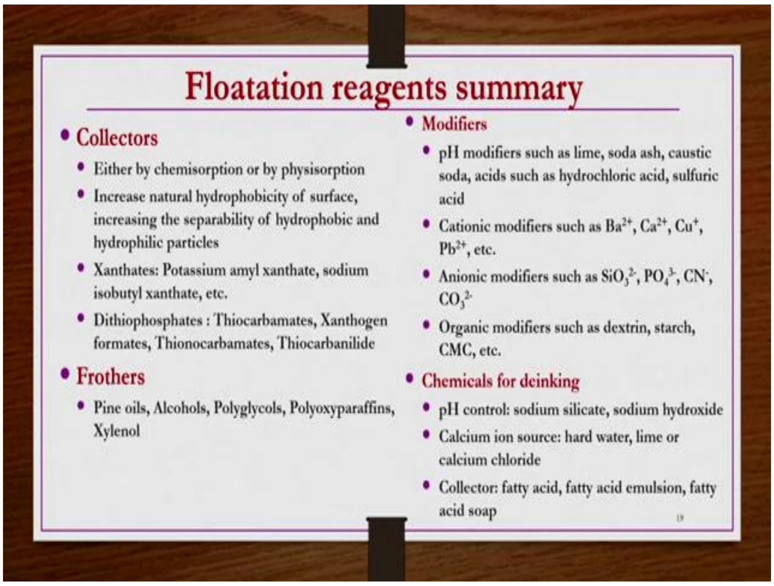

Floatation reagents summary

- Collectors
  - Either by chemisorption or by physisorption
  - Increase natural hydrophobicity of surface, increasing the separability of hydrophobic and hydrophilic particles
  - Xanthates: Potassium amyl xanthate, sodium isobutyl xanthate, etc.
  - Dithiophosphates : Thiocarbamates, Xanthogen formates, Thionocarbamates, Thiocarbanilide
- Frothers
  - Pine oils, Alcohols, Polyglycols, Polyoxyparaffins, Xylenol
- Modifiers
  - pH modifiers such as lime, soda ash, caustic soda, acids such as hydrochloric acid, sulfuric acid
  - Cationic modifiers such as Ba^{2+}, Ca^{2+}, Cu^{+}, Pb^{2+}, etc.
  - Anionic modifiers such as SiO_3^{2-}, PO_4^{3-}, CN^-, CO_3^{2-}
  - Organic modifiers such as dextrin, starch, CMC, etc.
- Chemicals for deinking
  - pH control: sodium silicate, sodium hydroxide
  - Calcium ion source: hard water, lime or calcium chloride
  - Collector: fatty acid, fatty acid emulsion, fatty acid soap

Now what we see, we see a kind of summary. Summary of floatation reagents. Collectors, either by chemisorption or by physisorption we can do this forming a layer of foreign material onto the solid surface of several molecule thick size. So, that can be done either by chemisorption or by physisorption. Increase natural hydrophobicity of surface and then increasing the seperability of hydrophobic and hydrophilic particles.

Then, some types of collectors are xanthates, potassium amyl xanthates, sodium isobutyl xanthate are good collectors. Dithiophosphates are also good collectors like something like Thionocarbamates, Xanthogen formates, Thionocarbamates, Thiocarbanilide etc. Then frothers are the frothing agents: pine oils, alcohols, polyglycols, polyoxyparaffins, xylenol, et cetera are good frothing agents. Then modifiers: like activators or depressants, et cetera, so are also pH modifiers.

So, some of the pH modifiers are lime, soda ash, caustic soda, acid such as hydrochloric acid, sulfuric acid, etc. Cationic modifies are such as barium 2 plus, calcium 2 plus, copper 2 plus, lead 2 plus, etc. Anionic modifier such as SiO3 2 minus, PO4 3 minus, CN minus, CO3 2 minus, et cetera are good modifies. Organic modifies are also available such as the dextrin, starch, carboxymethyl cellulose, et cetera are good modifiers.

Deinking can also be enhanced by floatation, that is what we have seen as a kind of one of the example where floatation is also used other than the mineral industries. So, there are some chemicals are required for this deinking either as a kind of collectors or modifiers or froth agents, they are we see. So, in order to control the pH of the system then, in deinking process you can use sodium silicate, sodium hydroxide, or calcium ion sources like hard water, lime or calcium chloride et cetera you can use. If you need collectors for such processes, fatty acids or fatty acid emulsions, fat is or fatty acid soap solutions can be used as a collectors for this deinking process using the floatation principles. This is the summary of floatation reagents.

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Now the references, we have several references. First one is Unit Operations of Chemical Engineering by McCabe, Smith and Harriot. The other one is Unit Operations of Particulate Solids: Theory and Practice by Ortega-Rivas. Then Coulson and Richardson's Chemical Engineering series, second volume by Richardson and Harker. Transport Processes and Unit Operations by C. J. Geankoplis.

Unit Operations by Brown et al., and Principles of Unit Operations by Foust et al. So, this is a very good book for this chapter that we are discussing now on floatation. Some material you can also find in this book, Richardson and Harker. Some information is also available in this Ortega and Rivas. Thank you.