Introduction to Mineral Processing
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Lecture – 55
Flotation (Contd.)

Hello. Welcome to this 11th week of this lecture series. We are almost towards the end of this course. We are having only two weeks left. So, we are discussing about the flotation process that is the froth flotation process, we will continue this in this week also.

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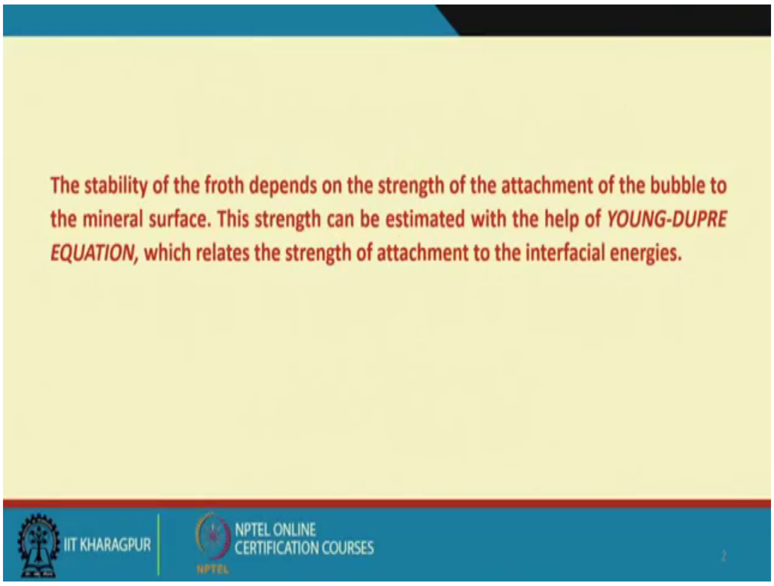

The stability of the froth depends on the strength of the attachment of the bubble to the mineral surface. This strength can be estimated with the help of *YOUNG-DUPRE EQUATION*, which relates the strength of attachment to the interfacial energies.

So, we are discussing about the flotation mechanism in much more detail. So, we are continuously saying that the stability of the froth is very important that is I have already trying to explain that you need certain stability that is certain retention time of the froth in to the froth phase.

So, that is I have written the stability of the froth. Now it depends on the strength of the attachment of the bubble to the mineral surface because if the mineral starts getting dis-lost from the bubble surfaces in the froth phase, then the entire effort is meaningless. So, it depends on at what intensity at the bubbles and particles; they are getting adhere to. Now how do we know what is this strength and can we not estimate it or can we not measure it? Of course, we can. So, this strength can be estimated with the help of a equation called Young Dupre equation which relates the strength of attachment to the interfacial energies. Now what is that; let me explain you.

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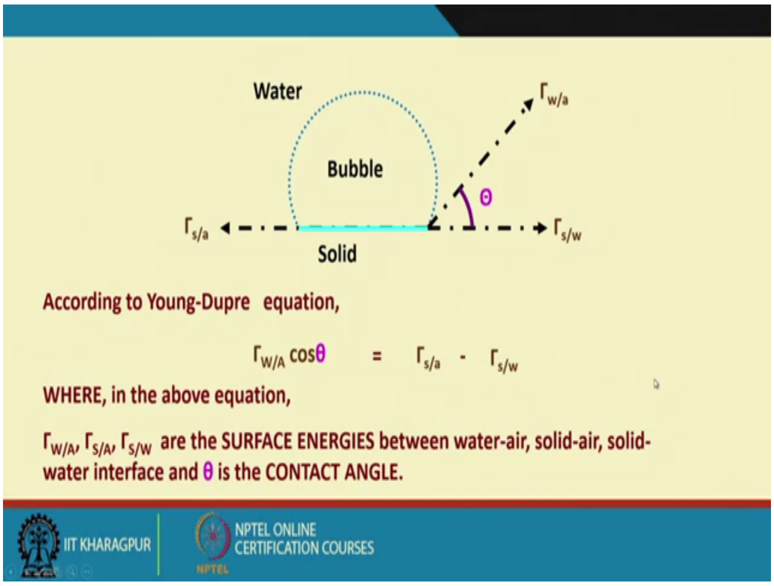

According to Young-Dupre equation,

$$\Gamma_{W/A}\cos\theta = \Gamma_{s/a} - \Gamma_{s/w}$$

WHERE, in the above equation,

$\Gamma_{W/A}$, $\Gamma_{S/A}$, $\Gamma_{S/W}$ are the SURFACE ENERGIES between water-air, solid-air, solid-water interface and θ is the CONTACT ANGLE.

Now, this Young Dupre equation; if you look at; so, that is the, this is called the this is through this your diagram, I am trying to explain you that is if I suppose, this is my bubble phase ok. So, you have got water here and this domain, it is the water and you have got the solid that is getting adhered to the bubble surface now what will happen now if we try to do the balancing of the your surface energies between water and air. So, you have three phases that you have got air bubble, you have got fluid that is a water and you have got the solid particles.

So, there will be three different types of surface energies. So, between water and air that is the bubble. So, there is a an one surface energy, there will be solid and air that is your bubble surface and the solid particles and solid and water solid and water interface that is your. So, that is the because solid is also having access to the water. So, that is the solid water interface according to Young Dupre equation that if we represent that tau W A and tau s a tau s w as the surface energies between the water air that is w stands for water a stands for air s stands for solid. So, the surface air is in between water air solid air and solid water interface and theta is the contact angle theta is the contact angle between the water and air phase air and your solid and water phase that is this angle there is that what angle it is there.

So, then according to Young Dupre equation, it is tau w a cos theta is equal to tau s a minus tau s w. So, what is this contact angle between this your water and air phase. So, that is that is between this and your tau s w that is solid and water. So, that is the call theta that is called the contact angle. So, if I do a force balance we can write that tau w a cos theta is equal to tau s a minus tau s w now what do I do with this. So, what will happen?

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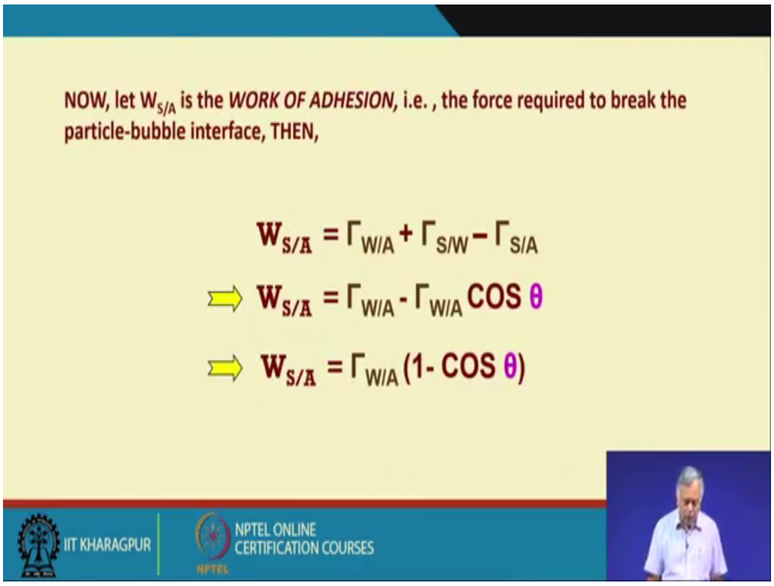

NOW, let $W_{S/A}$ is the ***WORK OF ADHESION***, i.e., the force required to break the particle-bubble interface, THEN,

$$W_{S/A} = \Gamma_{W/A} + \Gamma_{S/W} - \Gamma_{S/A}$$

$$\Rightarrow W_{S/A} = \Gamma_{W/A} - \Gamma_{W/A} \cos\theta$$

$$\Rightarrow W_{S/A} = \Gamma_{W/A}(1 - \cos\theta)$$

So, now let us say that work of adhesion is represented by the W S A that is the let W S A that is between the solid and the air because we need to know the particle and bubble attachment. So, let W S A is the work of adhesion that is the force required to break the particle bubble interface that is how intensely they are attached to. So, that interface if you want to break, then what are the conditions that W S A that your work of adhesion, how do I represent it? Adhesion is equal to tau W A that is your tau W A plus tau S W that is your solid and water minus tau S A that is minus tau S A that is solid air.

So, you can write that W S A is equal to tau W A minus tau W A cos theta Y. Now we have already written that tau W A cos theta is equal to tau S A minus tau S W by rearranging this equation and putting the values here we can get W S A is equal to tau W A minus W A cos theta. So, we can write W S A is equal to tau W A one minus cos theta. So, what will happen that if the theta is equal to 0? So, cos theta is equal to 1 so, this will be 1 minus 1 so, that is 0. So, tau W S A will be 0. So, if theta is equal to 0 then; that means, the work of adhesion is that is the it is the particle will be will not be adhere to the surfaces of the bubble so, but if theta is 90 degree, then cos 90 is equal to 0. So, that is W S A is equal to tau W A.

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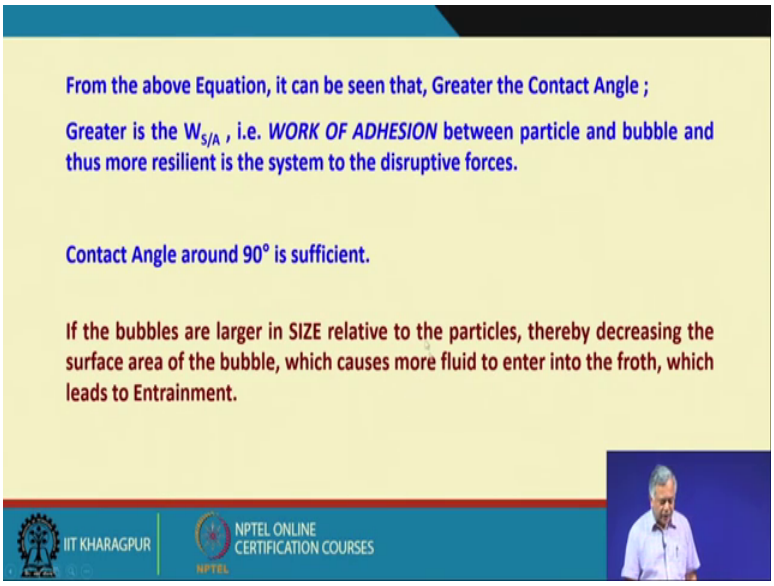

From the above Equation, it can be seen that, Greater the Contact Angle ;

Greater is the $W_{S/A}$, i.e. *WORK OF ADHESION* between particle and bubble and thus more resilient is the system to the disruptive forces.

Contact Angle around 90° is sufficient.

If the bubbles are larger in SIZE relative to the particles, thereby decreasing the surface area of the bubble, which causes more fluid to enter into the froth, which leads to Entrainment.

So, this is what I try to write here that from the above equation, it can be seen that greater the contact angle greater is that W S A that is the work of addition between particle and bubble and thus more resilient is the system to the disruptive forces.

So, what will happen if theta is more? So, W S A that is a is equal to tau W A is equal to tau W A so; that means, this is the force that will be much more dominant when the theta is the match higher level so; that means, that greater is the W S A; that means, that you need much more disruptive forces to dislodge them; that means, what is the intensity of the your or the what is the intensity of that adhesion forces in between the particle and the bubble which decides that how stable is this attachment. So, that depends on this contact angle more the contact angle the stable the more stable is that your attachment.

We have seen that contact angle around ninety degree is sufficient. So, if the bubbles are larger in size related to the particles. So, what will happen there by decreasing the surface area of the bubble; that means, if you are have much more bigger bubbles than the particles now what will happen the available surface area for the particles to get adhere to the bubble surfaces will be less and these causes also that your bigger bubbles they will have much more interstitial spaces and through which the fluid can enter that is your water can enter into the froth.

So, when the bubbles are carried, then you will have more vacant spaces between the bigger your bubbles. So, that fluid can get entered into that. So, that is your water can get entered into that which leads to entrainment because they know what will happen it will the particles which are carried towards the along with the water that will be also entrained into the your along with the bubble and then they will report to the froth phase.

So, if I want to reduce the entrainment effect I have to have larger bubble surface areas; that means, we need much more finer bubbles according to the particle sizes, therefore, the bubble diameter must be comparable to the particle diameter to ensure a good contact between them.

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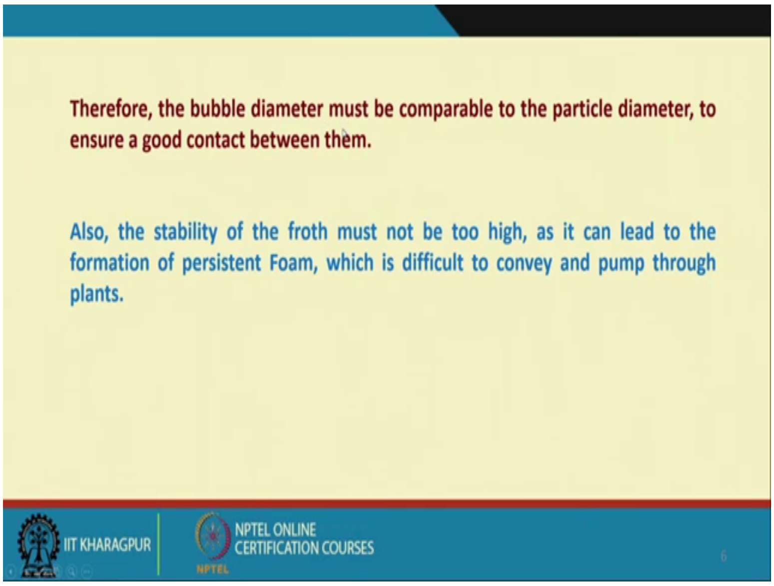

Therefore, the bubble diameter must be comparable to the particle diameter, to ensure a good contact between them.

Also, the stability of the froth must not be too high, as it can lead to the formation of persistent Foam, which is difficult to convey and pump through plants.

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So, one is the, if the bubble diameter is much bigger. So, the available surface area for the particles because the particles are also having larger surface area because they are too fine. So, they will have a lesser surface area of the bubbles to get adhere to that is number one and if you have only bigger bubbles then you will have void spaces in between the bubbles where the water can get entrained and along with the water your mineral part or the mineral and gangue without having any selectivity they can also get entrained and we have already discussed that the entrainment we have to minimize because it affects the separation efficiency.

So, this is one trick by adjusting the bubble diameter according to the particle diameter that is how you can minimize the entrainment also the stability of the froth must not be too high what will happen the we are saying the bubbles has to be stable, but too much of stability what will happen as it can lead to the formation or persistent foam which is difficult to convey and pump through plants; that means, if the bubbles do not; if they are difficult to break once they are collected into the concentrate launder then what will happen that transportation because you have to recover the concentrate particles which are reported endora concentrate launder.

Now, the first thing what do you have to do once they are collected there the bubbles should be the say destroyed, but if they are too adamant to be broken then what will happen you need additional energy to break them and then you have to transport it and for that you have some material handling system, you may have piping, you may have your transportation through the pipes because they are in the slurry form and then there will be viscous and then the pumps also will have problem in say pumping up this froth phase. So, you have to convert that froth phase into a slurry phase back again into the concentrate launder as soon as they are being collected into the concentrate launder.

So, the too much of froth stability is also not wanted, but you need a minimum amount minimum amount of stability for the froth, if they are too unstable, then what will happen when they are reported into the froth phase and if the bubble breaks immediately then again particle will come back to the your rotation cell without being collected through the scrapper to the concentrate launder. So, this is also what you need to control properly.

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Type of Ore	Metals (Common Ores)
Native Metals	Gold (Au), silver (Ag)
Oxide ores	Iron (Hematite, Fe_2O_3); Aluminium (Bauxite, $Al_2O_3 . 2H_2O$); Tin (Cassiterite, SnO_2); Copper (Cuprite, Cu_2O); Zinc (Zincite, ZnO); Titanium (Ilmenite, $FeTiO_3$, Rutile, TiO_2)
Sulphide ores	Zinc (Zinc blende, ZnS); Lead (Galena, PbS); Copper (Copper glance, Cu_2S); Silver (Silver glance or Argentite, Ag_2S); Iron (Iron pyrites, FeS_2)
Carbonate ores	Iron (Siderite, $FeCO_3$); Zinc (Calamine, $ZnCO_3$) , Lead (Cerrusite, $PbCO_3$)
Sulphate ores	Lead (Anglesite, $PbSO_4$)
Halide ores	Silver (Horn silver, AgCl); Sodium (Common salt or Rock salt, NaCl); Aluminium (Cryolite, Na_3AlF_6)
Silicate ores	Zinc (Hemimorphite, $2ZnO.SiO_2 .H_2O$)

Now, let us tell you that; what are the most common ores. Now I have already mentioned this, but let me elaborate this that which are being treated at present by the froth flotation techniques and some native metals like gold and silver then oxide ores like iron FeCO 3, aluminum ore like bauxite Al 2 O 3, 2H 2 O, tin the it is the metal, but the ore is cassiterite SnO 2, copper is could be cuprite Cu 2 O, it may be some sulfide form also, but these are the oxide or so, we are talking. So, that is the cuprite is another oxide ore of copper then zinc oxide like zinc site, then titanium oxide like FeTiO 3 ilmenite, it could be rutile TiO 2, then there are sulfide ores like zinc blende your galena your copper glance your silver glass or a argentite and then are imparted like your pyrites, we call it pyrites sometimes in some places they call it iron pyrites.

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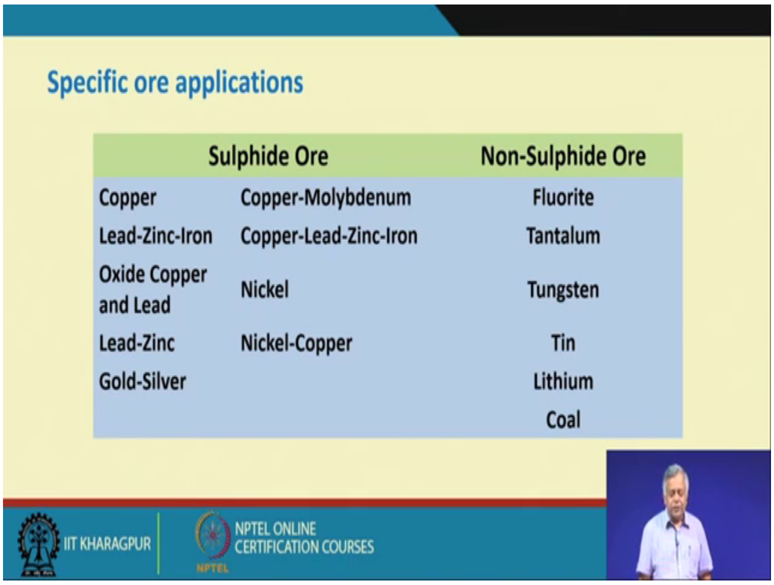

Specific ore applications

Sulphide Ore		Non-Sulphide Ore
Copper	Copper-Molybdenum	Fluorite
Lead-Zinc-Iron	Copper-Lead-Zinc-Iron	Tantalum
Oxide Copper and Lead	Nickel	Tungsten
Lead-Zinc	Nickel-Copper	Tin
Gold-Silver		Lithium
		Coal

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Carbonate ores like your siderite for iron and then calamine for zinc a cerrusite for lead like that your sulphate ores halide ores silicate ores and so on specific ore applications like your sulfide ores that is your copper molybdenum; they in your lead-zinc-iron, copper-lead-zinc-iron ore, then your oxide copper and then and lead, lead-zinc, gold-silver, the nickel, nickel-copper, fluorite that is your non sulphide ore tantalum, tungsten, tin, lithium, coal and it the list goes on.

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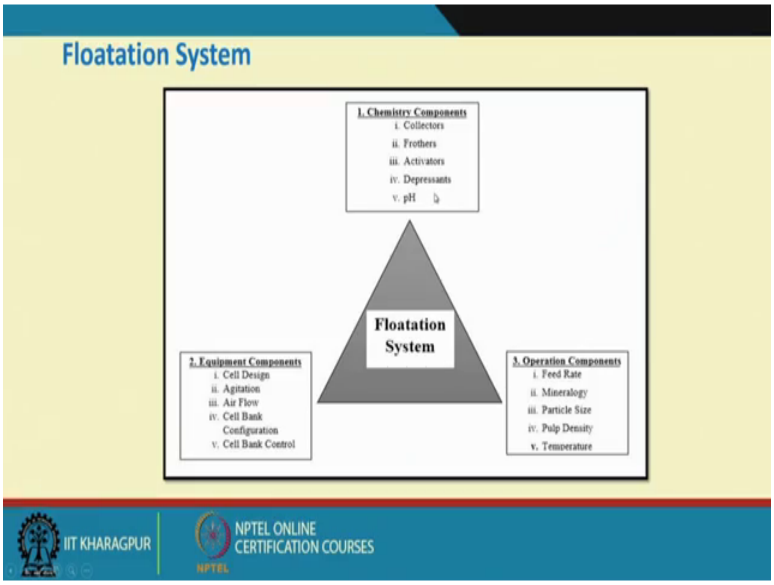

Floatation System

1. Chemistry Components
- i. Collectors
- ii. Frothers
- iii. Activators
- iv. Depressants
- v. pH

Floatation System

2. Equipment Components
- i. Cell Design
- ii. Agitation
- iii. Air Flow
- iv. Cell Bank Configuration
- v. Cell Bank Control

3. Operation Components
- i. Feed Rate
- ii. Mineralogy
- iii. Particle Size
- iv. Pulp Density
- v. Temperature

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Now, if I look at the; what are the essentials essential variables in a floatations process. So, this is this can be shown like this your diagram that is a floatation system this has been named by someone that is called the floatation system. So, in a floatation system; what are the most important your components, we can group them into three different components with this form of a your triangle first one is the chemistry components and all three are equally important you cannot neglect one any one of them.

So, in the chemistry components there are basically we are adding different chemicals and all these chemicals they have got separate purposes like some that there are some names of these we call it collectors frothers activators depressions and pH modifiers, like it is not essential that in every cases you need all these chemicals, it depends on the those mineral surface characteristics and the your economics and then your accuracy that whether you need more say cleaner product or whether you need more recovery that is whether you want to have a more focus on a flotation process on the essay contained of your concentrate or on the recovery of the material.

So, but we have to understand what are the roles of this individually which we will discuss in due course of time that is what is the role of the collectors and what are the different types of collectors and where do you use them what are the different frothers. So, collectors are basically used for making the surfaces hydrophobic selectively frothers are being used to have some froth stability, but how much I will add these; what type of frothers because I mentioned that we do not want too much of stable froth and we do not want even as a weak froth.

So, what is the your optimum fraud stability; we want that has to be synchronized with your mechanical your design of your froth collection system, then activators like your many times you want to add some kind of chemicals to promote this process of your say actually to activate your collectors that is your to promote this your say bubble particle attachment processes are by applying, it is like just your synchronous to your catalyst, we use for catalyzing the chemical reactions in some cases. So, it activates, it is the activators depressants many a times, what happens your both the minerals that is a both your wanted and unwanted minerals they are having a similar surface chemical properties; that means, it is very difficult to selectively make your wanted material surface to be hydrophobic.

So, but in that case what we use the trick that is we use certain chemical which will try to depress that is your some unwanted material in case of reverse floatation, you can make the surface of your wanted material to be depressed; that is you do not want them to get adhere to the your bubble surfaces; that is by through some means they you want to do it and when you add some chemicals to those there and it will selectively sit on your targeted material surfaces which will depress it which will suppress it from being floated pH many.

All this your most of these your chemicals they work better in a particular pH condition that is and mainly the collectors they work better at a favorable pH conditions some collectors, they work nicely in alkaline atmosphere some some collectors they work in much better in a slightly acidic conditions like that frothers activated depressions also many times they require some pH adjustment of your slowly.

So, you have to add some pH modifiers. So, if you want to make it acidic you both some kind of your a dilute acid we want to make alkaline you add some alkali then they are there are basically equipment components what are those equipment components that what is the sale design that what is the l by d ratio what is the depth of that cell and how big is that cell because what will happen if you have your much longer cell, but the dimension diameter is too less. So, what will happen when you are a rating? So, there will be wall effects; that means, the wall will start playing a dominant role for them because you need to have control certain degree of suite mechanical behavior of the your movement of your fluids as well as the movement of solids in the fluid medium as well as the bubbles movement also in the your the system.

So, the cell design how it is designed what is the material of that and then what are the dimensions these are the main components then agitation how you are creating that agitation one example I have shown it with impellers, but you can do it in many ways. So, that how you are creating the agitation and how can, you can have a controlled agitation that is the most important factor. So, that you can create just the your say that kind of turbulent atmosphere which is required then airflow the weather the airflow is in the upward direction how do make the air flow consistently towards the upward direction. So, how the bubbles they will flow because if they are biased to as some direction. So, then all the froth will be only formed into a particular corner of your cell. So, how do you spread them?

So, you have to have your airflow to be monitored, then your cell bank configuration like whether you have got only one shell or like your; what we did that is you have got a big compared big your vessel and you have got separate compartments like that also floatation cells can be desired that is and then how the cell bag how will you be able to transfer your froth material to the next cell and from that to next cell and to that next cell how it will be automatically transferred what are the fluid mechanical behavior what are the mode of transport what are the mechanical means of transporting it then your cell bank control how do you control that is what I was telling that is how to do it automatically that this should travel and then your.

So, these are the chemistry component this is the equipment components and then there are the operational components that is your operating variables like feed rate at what rate you are feeding because if you are feeding it too fast. So, what will happen although your capacity may be increased, but your selectivity may be compromised, what is the meaning of that that you are you may be having more recovery of the minerals that is your wanted middles, but you will be you will not be able to have your desired grade of your concentrate.

So, feed rate you have to have your optimum feed rate based on the cell design depending on the your efficiency of your collectors and your other chemicals. So, these are all interdependent these are chemistry equipment and your operating conditions, they are all your interdependent your variables. So, you cannot isolate that will focus only on the chemistry part though these 2 also you cannot neglect.

So, if you want to be a good floatation engineer you have to give half due consideration in all these three components. So, feed rate and then what is the mineralogy; that means, what are the mineral different minerals you have because your as I said that your unknown your wanted minerals could be many times; 3-4 different minerals, similarly your unwanted minerals could be of varieties of different minerals like you can have a mixture of carbonates and then you can have your mixture of silicates these are all basically unwanted minerals.

So, like a good example is a rock phosphate or where the ore is called your appetite and this appetite many times you may have your impurities like your iron could be impurities silicate minerals could be impurities then carbonates also in various form like CsCO 3 that is your dolomite and your calcite. So, all these could be your impurities in certain cases, you can have only your silicates are the major impurities in some cases carbonates could be only the major impurities in some cases may be your say iron could be the major impurities, but when you have a mixture of this impurities then the process becomes very difficult.

So, I should have proper knowledge about the mineralogical behavior of my ore not only focusing at your wanted material, but also the unwanted material because this is surface chemistry based phenomena suppose I want to float only apatite, but your carbonates also you are seeing that that is also being floated although you could discard the iron based particles and your silicate particles.

Now, how do you separate the carbonates and your appetite that becomes a difficult part. So, we need to know have the complete your knowledge about the mineralogical behavior then particle size and size distributions bulk density that is again it is related to your capacity that is what is that your maximum percentage of solids you can feed in your slurry. So, that also controls the pulp density basically if you have more of pulp density so; that means, your particle concentration is more; that means, your the relative surface area of your particles if it is much higher than the bubble surface area what we have generated then again you are some particles although they are you have made them hydrophobic, but they will be starving for bubbles to get leaked it up.

So, you should observe what will happen you will have a loss in recovery drastic loss in recovery. So, what is the; and then if it is too much of solids your pulp may be too viscous. So, if there is a viscous your pulp then you will have problems in pumping and then even your air flow and all this will be hindered then what is the temperature that is also very important in froth flotation because that temperature again controls not only the viscosity of the pulp and the your fluid phase, but also the temperature controls the effectiveness of your chemicals that is various chemicals, if it is too hot or it is too cold then their effectiveness also gets affected severely.

So, all these 3 aspects all these three, your in a floatation system we have to give due consideration and that is your chemistry component your equipment component and your operational components and on top of that there are many other variables like which I have not discussed because in a flotation we say there are more than hundred variables like your what is the material of construction of your flotation cell because how do you protect it from your because you are using your many chemical seven for pH modifiers you may be using your acid or maybe your alkalies.

So, how do prevent your predation cell from getting corroded then there are basically the water quality that what is that water quality does it have already the desorbed solids. So, what will happen if you have dissolved solids? So, these collectors and frothers and activators and depressants their effectiveness may be reduced drastically. So, that is the main reason that we have seen many times that same mineral if you are using the simulate cell and with the similar chemicals at one place using that what are available there and if you try to reproduce those experiments at a different place using a different water you will have you may have different responses most of the cases you will have different responses the main design is your water chemistry is different.

So, this is a not cell the variables, but I personally believe that if we have your thorough knowledge about each of these aspects you can optimize your protection system to some extent which is acceptable to your plant your plant our authority or it may be economically viable, but again and again I am repeating that these are connect these are all interrelated. So, we whenever we try to optimize any parameter we have to have due consideration about other 2 parameters.

So, this is in sort about the flotation system. So, we will continue this lecture and the because the flotation has got different aspects that is now quite evident now, but I will only try to give you some brief your exposure that is why they are important and why we have to know the much more details about this and I will try to make you interested to learn more on this subject for the aspiring flotation engineers.

Thank you very much.