Materials and Energy Balance in Metallurgical Processes

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Module No. # 01

Lecture No. # 10

Introduction to Mineral Beneficiation

Today, I am going to talk on mineral beneficiation. As in the previous lecture on introduction to metal extraction, I have said that metal grade of the ore is very important. The technique of metal extraction that is pyrometallurgy or hydrometallurgy, they require a grade of ore or a metal grade of ore which should be sufficiently high, so that the waste production is as minimum as possible. Therefore, in all extraction processes whether it is pyrometallurgy or hydrometallurgy, it is necessary to increase grade of the ore or other metal grade of the ore, why? It is because of two benefits.

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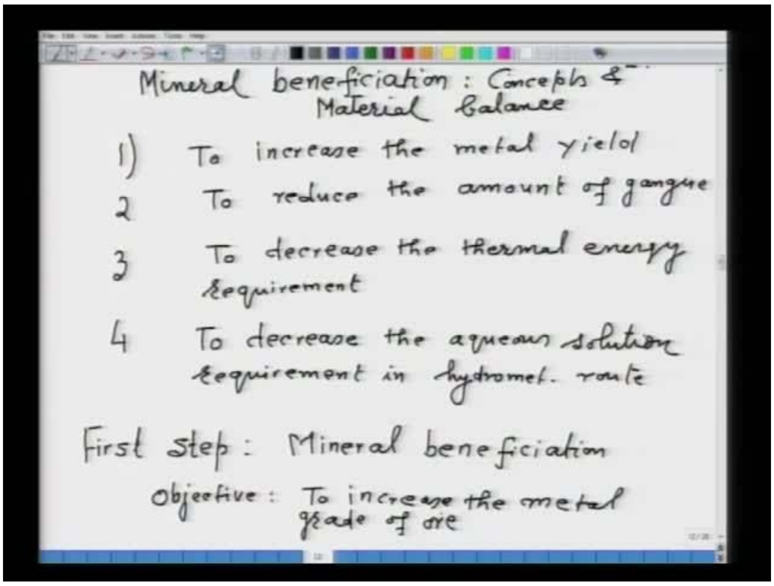

If you increase the metal grade of the ore, first to increase the metal yield and the associated second advantage is to reduce the amount of gangue. Third advantage by increasing the metal grade of the ore is to decrease the thermal energy requirement. In order to separate metal from gangue in pyrometallurgical technique, because as I have said a pyro means temperature, so the separation of metal from gangue occurs at high temperature. So, the third benefit is to decrease the thermal energy requirement.

The fourth benefit is that, you recall another route of metal extraction was hydrometallurgy their large amount of aqueous solution is need. So by increasing the grade of the metal, by increasing the metal grade of the ore, you will be able to decrease the aqueous solution requirement in hydromet route.

So these are some of the benefits in increasing the metal grade of the ore or the question comes, how to increase the metal grade of the ore? The first step, whether it is pyrometallurgical extraction or hydrometallurgical extraction, the first step is called mineral beneficiation. The objective of this step is to increase the metal grade of the ore, that we are very clear we have to increase the metal grade of the ore.

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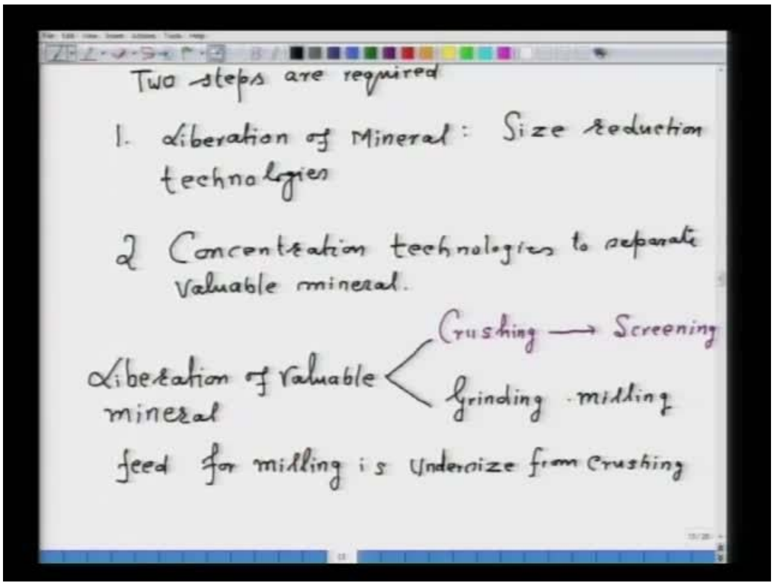

Now this mineral processing technique, it requires two things. One is the liberation of the mineral and second is the concentration of the mineral. So there are two steps required in mineral processing, one is called liberation of mineral. Now by liberation of mineral I mean, we take an ore from the natural reserve and try to observe under the macro scope then, you will find the valuable mineral is distributed within the grain, across the grain in very small amount.

So if you want to increase the metal grade of the ore then, you have to liberate the mineral from that metrics of the gangue. How can you do that? How can you liberate the mineral? In that you crush and ground it depending on the valuable mineral, which is present in the ore its size and shape, you plan your size reduction technology such that the liberation of valuable mineral is achieved.

In fact liberation of mineral requires the so called size reduction technologies. What we are talking of to create a state from the lumpy ore which is in hand, two way state where we can obtain the separation of the liberal mineral. We are talking purely physical separation and that can only be achieved once that particular lump of the ore, you reduce its size so that the valuable mineral is set free. Later on, by the so called concentration technologies can be used to separate valuable mineral from the ore matrix.

What will I do now? I will take both these steps in brief because the objective of the course is not to go into detail of these processes. Towards the end, I will give the reference where you can read if you are interest in the detail. Here, I am going to give you those details which are required to develop the material balance in case of mineral processing because that is the objective the course.

So I will give in short what is required; so that while applying the concept of this liberation or concentration technologies to solve the problems on material balance that is the objective. So in that perspective, I am going to give you the brief details of both these technology.

Let me take, first of all the liberation. We are talking of liberation of valuable mineral; that is what our objective. Now this is achieved, crushing is the first stage what you do? You take the lump ore from the natural reserves because of its huge size it is being crushed to some of the intermediate size. The first step is crushing and crushing is followed by screening, so that you can remove the over size from the under size; under size means the product which is acceptable for further size reduction technologies.

So crushing which is followed by screening and in the screening you have over size and you have under size. One which is passing through a screen, you call it to under size and one which retains on the screen, you call it oversize. The oversize can be stand further back into the crusher whereas, the undersize is stand back to further size reduction operation.

Now you may argue – Sir, while in the crushing, we may have attained the mineral in its fully liberated state. No, it is not possible because of the size, then it is ground further; so the next stage in case of liberation that is called the grinding or sometimes this is also called milling operation. In the milling operation, the feed for milling operation is under size from crushing operation - that is the feed for the so called milling.

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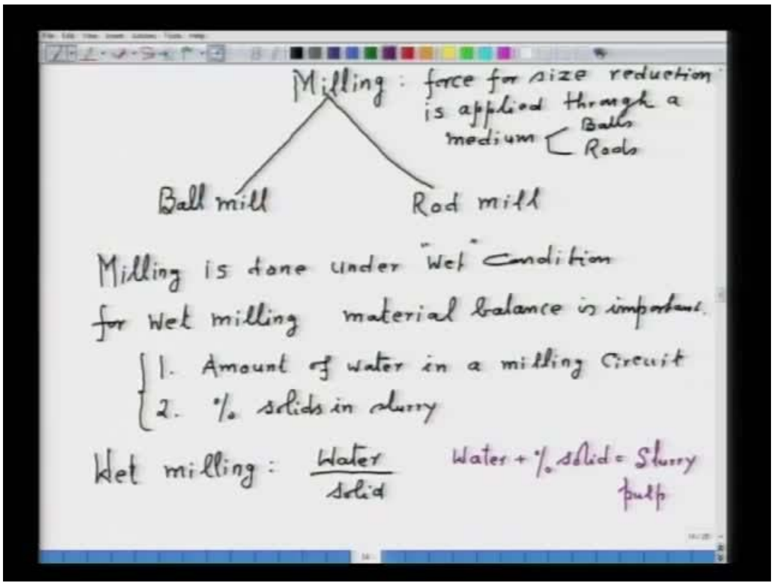

Now let us see, how the milling is attained? Milling in set is a size reduction technology where the feed is ground to a state of fully liberation of particles. So, this milling is in fact what is being done. The feed is taken into a cylindrical type of vessel which rotates at a particular speed and the size reduction of the feed occurs by the medium.

In fact, in the milling in short force for size reduction is applied through a medium. Now medium that could be balls of different sizes, they are spherical balls of different sizes then, there could be rods. So these are the medium they are used to ground the feed from the crusher so as to get the valuable mineral for further concentrating operation.

So, according to the vessel which is being used for milling purpose, the milling is named according to this. So, one is called ball mill. In the ball mill, the feed is rotated in a cylindrical vessel at a particular speed and the medium of grinding they are spherical balls that is why this is called the ball mill. Here speed of the mill is important; you cannot run the vessel too highest speed or too lowest speed, the details you see in any book.

One is the ball mill because their spherical balls are used as medium for grinding, another is called rod mill. In the rod mill any feed of a spherical balls, a straight rods being use to mill the feed. Since the objective of milling is to get the valuable mineral in its liberated state, so one has to go to a very fine size. I mean that fine size where you are sure that now the mineral is completely liberated from the matrix of the ore, because in the ore valuable mineral and gangue they are intimately mixed. So you have to separate it by reducing its size, so that is what the objective of this ball milling or rod milling.

Because of too much amount of fines is produced and because of lot of pollution and so on, milling particularly ball milling is done under wet condition. However, it depends upon the size up to which you want to ground the product but, mostly milling is done under wet condition; the objective is to reduce the amount of pollution.

So here, this you also called as a wet milling; one is the dry milling another is the wet milling. In the dry milling no water is used, in the wet milling water is used. So here, for wet milling material balance is important. Why it is important? First of all to know, what is the amount of water in a milling circuit. I will tell you what a milling circuit is and second is that percent solid in slurry. A slurry is a mixture of solid and water as I have discussed this when I was lecturing on stoichiometry.

Now both these information, why do you want it? You want to transport this material from one location to another location, say in the circuit also you have a crusher, followed by screening, followed by ball mill, followed by again a sort of a separation device, then you undersize, you oversize, then you want to transport from one operation to another operation; you require a huge amount of pump because you are not dealing with few kg of the material you are dealing with few 100 tons of material per day. So you require, what should be the capacity of the pump to transport the water or more over what should be the capacity of the pump to transport slurry, because slurry is a mixture of solid in water.

You should know, what is the percentage of solid in the water is, so that you can decide on the pump what type of pump you require to transfer the slurry, which is a mixture of solid and water. All these things are important and another thing, say for wet milling also water upon solid ratio is important. As you all know, that I have said water plus percent solid, this mixture is called a slurry, as you may also called it as a pulp; both names they convey the same thing slurry or pulp.

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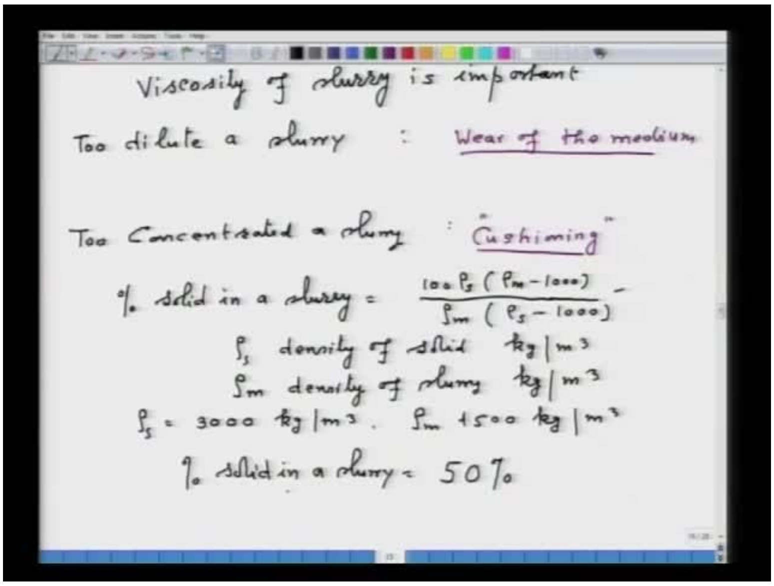

So here, what is important? The viscosity of slurry is important. Why it is important, can think you of? For that you have to think, what determines viscosity? Viscosity determines the flow ability of the mixture that you have formed. In the grinding operation since the mill is rotating at a particular speed, so this slurry should also be easily move into the vessel; for that the viscosity is important and for that percent solid in the slurry is an important issue.

Now, two things can occur: too dilute slurry or you have too concentrated slurry. As you have to dilute a slurry, that means what? The percent solid is very less, the amount of solid is less, and you have put the medium according to your calculation because solid is less, now the medium will interact with each other.

So, too dilute slurry will cause wear of the medium that is a very important. If you have too concentrated slurry, which means your percentage of solid is very high. You have thought of well, let me mix more amount of percent solid and you do not know what is the percent solid in your slurry and you have made too concentrated slurry, what will you do?

Slurry has to move, it viscosity has become very high, so it will be very difficult to move; so in that case too concentrated slurry will cause a so called cushioning effect. It will cause a sort of cushioning effect, whereas too dilute slurry will lead to wear of the medium which is spherical balls, in case of ball mill.

So these are the hazards of not having an optimum percent solid and percentage solid in the slurry. For that, it is important to calculate the percentage of solid in the slurry in order to come to an optimum composition of the slurry or you can call the optimum density of the slurry.

As you recall in my stoichiometry lecture, I had given you the formula; I will just write over here straightway, say percent solid in a slurry that will be equal to - if you recall this formula I am writing once again - 100 into rho s upon rho m minus 1000 divide by rho m into rho s minus 1000 this is all density where, rho s is the density of solid, rho m density of slurry, 1000 is coming because you have mixed solid in water and water is the density of 1000 kilo gram per meter cube.

So, just an illustration if I take, for example, a solid which has a density rho s equal to 3000 kilo gram per meter cube. I have to substitute the value all in kilo gram per meter cube because I used the density of water in kilo gram per meter cube. Let us take, we want to make, the density of slurry as 1500 kilo gram per meter cube then, I can find out by putting both these values into the formula on percent solid I can know now, the percent solids in slurry that will be equal to, you can just calculate it is 50 percent. You can substitute those values, it is very simple just substitute the values, and you will get the answer.

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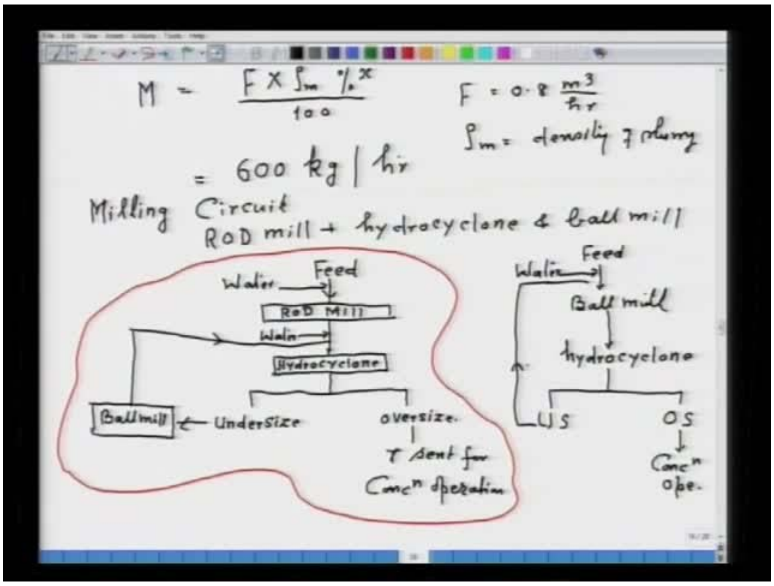

Now, what will I do with the percent solid? I can use the percent solid to find out the mass flow rate of the slurry. So, ultimately mass flow rate of the slurry, that will be volumetric flow rate of the slurry into density of the slurry into percent solid divided by 100. Now, if I take F which is the volumetric flow rate of the slurry as 0.8 meter cube per hour, rho m is the density of slurry.

If I substitute, I get M equal to 600 kg per hour that is the mass flow rate of solid in the slurry. So I mean these are the important calculations that can perform while performing a material balance to know what the percentage solid is and so on.

As I have said, these flow in a circuit. What is a circuit? Suppose if I want to make a milling circuit, let me make a milling circuit. Now very often in the milling circuit, the feed is fade into the rod mill, then it goes for the separation, then you undersize, oversize and connected with the ball mill.

So a milling circuit if it comprises of rod mill, hydro cyclone and ball mill. This will look like for example, if I take a feed and feed it enters into rod mill here, I ate little amount of water in order to make a slurry and (in occurs), then the feed it flows into hydro cyclone. Here I made also water if it is required, so this hydro cyclone divides the feed into two products: one is the undersize and another is the oversize.

Normally in the hydro cyclone, the oversize is a useful product and this oversize it sent for concentration operation. That means in the oversize we have attend the mineral in the liberated state and that can go for further concentrating operation whereas, the undersize size bigger than the required, so what is done? This undersize is fed into a ball mill and the product of the ball mill it can go further to the hydro cyclone that is what the direct.

So this entire port, this entire thing is called a circuit of milling (Refer Slide Time: 27:00). You are required to analyze this circuit; that means you are required to know, what is the amount of water that is flowing? What is the amount of solid that is flowing? So on or another circuit which consists of only ball mill, you have the feed; one can directly go into the ball mill, here water is added (Refer Slide Time: 27:27), then it goes to hydro cyclone and as such, the hydro cyclone you have undersize and you have oversize. So, oversize is for concentration operation and undersize can further go for the further milling operation, this is called a circuit or the milling circuit.

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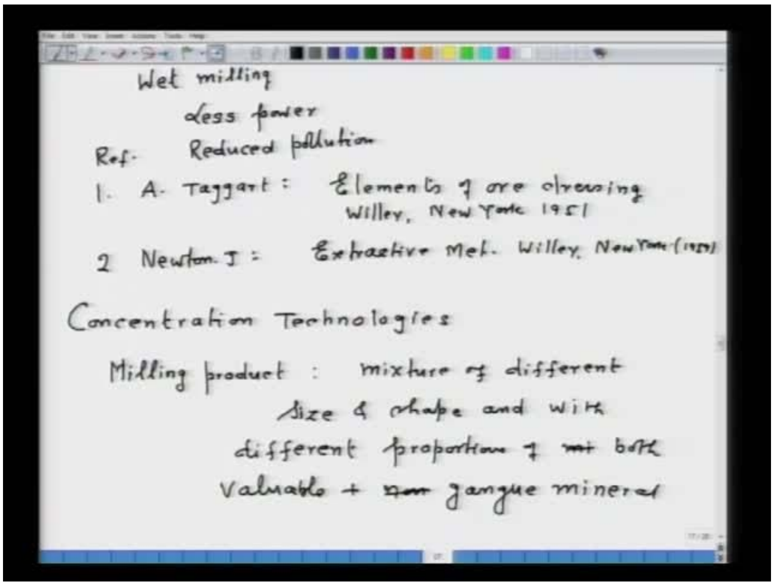

Now in this connection, I have to say something more. For example, in case of wet milling, you may be why wet milling is done? There are advantages of wet milling - one advantage is less power requirement then, reduces pollution because now fines will not be flying out of the vessel and because of water. So now, this analysis of the circuit is important and that we will do in the material balance.

Now for further reading, if you want to go further I give you few references. First you can go through in the book of A. Taggart - they are the reference where you should update - Elements of ore dressing, Willey, New York 1951 or you can also refer to another which is the Newton extractive metallurgy, John Willey, New York 1959. There are several books on ore dressing; you consult any book for updating these particular things or knowing more about the technological details of the milling operation.

Once the output of the liberation technology which is oversize, we have gotten the surety that now the mineral is liberated. Now you want to concentrate it, next are the concentration technologies. As the objective is very clear here, what we want? We want to separate the valuable mineral from the gain mineral that is what our objective.

So what we have? We have now a milling product; we have the oversize of milling product and milling product. What is this milling product? It is a mixture of different size, shape and with different proportions of minerals, let me say of both valuable plus non valuable mineral or let me call gangue mineral.

Now, we have gotten this mixture, it is a mixture or different size or different shape that means they are particles with different size, different shape and they are different proportion of both valuable and a gangue mineral.

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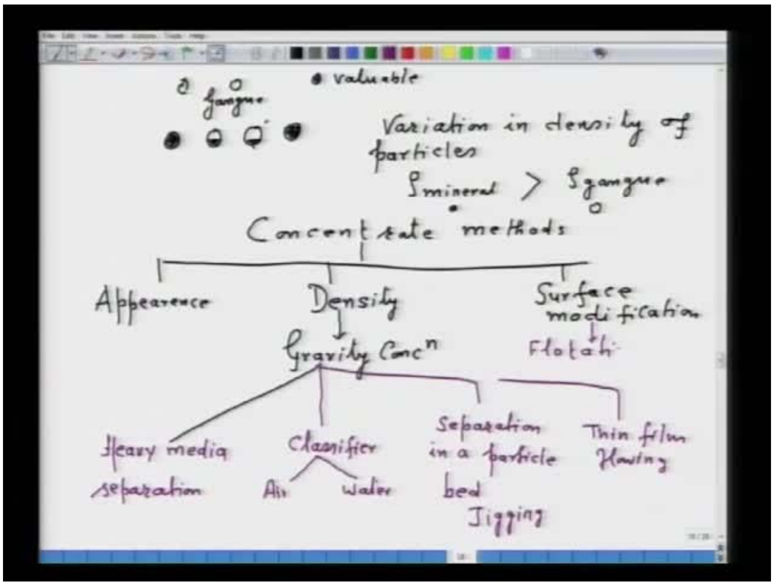

With this I mean, if suppose I have a feed for the concentrated operation say this I will denote for the so called gangue mineral and this I will denote the valuable mineral (Refer Slide Time: 32:32), so this is a valuable mineral and this is the gangue mineral.

So the feed will consist of in between these two minerals, that means you may have a feed which may consist of fully liberated mineral or you may have partially - you may still have this thing, you may still have this thing - so this portion is gangue, this portion mineral (Refer Slide Time: 33:00). So what I wanted to say from here that, in the feed which you have gotten from the milling operation it contains particles with different sizes, with different shape and different proportion of mineral.

Here it is very important to know that, in the liberation technologies you are producing particles containing mineral, that is an important; when you say you are producing particles containing mineral that means there are particles which are fully mineral, there are particles which are different proportion of mineral. So with this is what I mean to say, that you have to now develop the concentration technologies to develop the particles containing mineral.

We should also note from here that, in this mixture we have variation in density of particle, what does it mean? Say if we have, it is clear the density of mineral particle, pure mineral particle that means this type of particle is definitely greater than density of gangue mineral that means this (Refer Slide Time: 34:43).

Now in-between these two, with different particles, with different proportion of mineral will have different density. So, that is a key point for developing those concentration technologies. What we have to do now? We have to separate a valuable mineral from the gangue mineral.

So the concentration methods, essentially most of the concentration methods they are based on density. I will list down all the methods: say first method is based on appearance; well, if we can do this a physical, if you know the appearance of mineral they are being sorted out. Another based on the density, where most of the separation is done based on the density because the density of the mineral is larger as compare to density of the gangue and density of the particles in-between mineral and gangue. One can select the density of the medium, so that separation could be achieved. Another method very popularly done is surface modification.

Now I will just give you, little bit idea various method; the density method they are called gravity concentration methods. In gravity concentration method, we have one which is called heavy media separation that you select the medium of some density. So that the particle containing minerals can be floated or can be sink or can be float depending on the density of the medium. Another method is called classifier where air can be use as a medium or water can be used as medium and where the velocity off all of particle is used as a separation and that is different in air, different in water.

So accordingly, you have pneumatic classifier or you have hydro classifier. In hydro classifier you use water as a medium, in pneumatic classifier air is use as a medium and the difference in density is key concept of achieving separation of the mineral. Third technology is separation in a particle bed and the most important technology here is jigging and the last one is thin film flowing which is called tabling.

Now the surface modification, that means you modify the surface of the mineral; you know you are not chemically affecting the mineral, you are modifying the surface of the mineral so that it becomes hydrophobic or hydrophilic and this method is called flotation. Now the principle is the density difference between the particle containing minerals and the medium which is being used.

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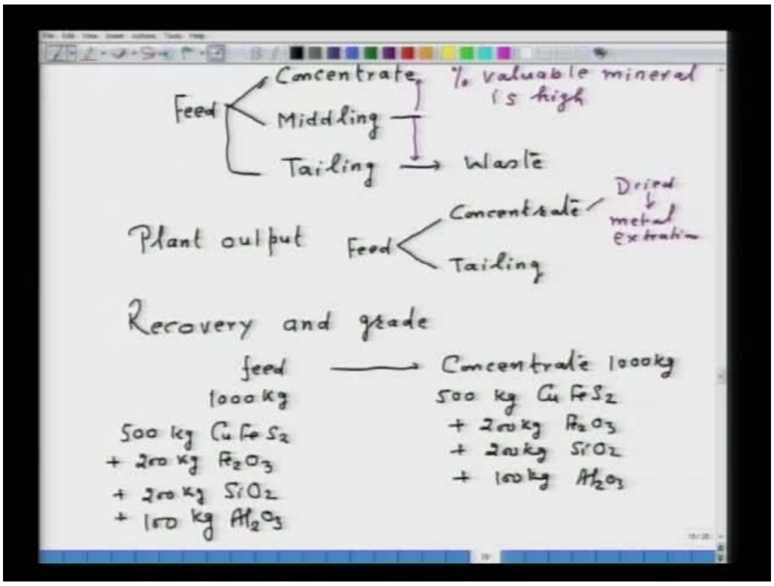

The objective of all these concentrating technologies is to separate the feed; that means you separate the feed into three products - one is the concentrate and in the concentrate the percent valuable mineral is suppose to be high. That is why you called concentrate and this concentrate goes for plant for extraction of the metal.

Now, this concentrate is of high grade and it can be use for further processing took at the metal. Another say product which is form the feed which is called middling and third product is tailing - it is purely waste, it contains most of the gangue mineral. Middling it may contain concentrate as well as tailing, so what is being done? The middling is further treated, so that some portion may go to concentrate and another portion goes to tailing.

Normally the output of a plant, that means plant output it consist of feed is separated into concentrate and tailing. This is the output of a plant that means, feed is separated either as concentrate or as tailing and this concentrate is dried or in wet condition and sent for metal extraction; while tailing is a waste and it is rather dumped or for the waste treatment or whatever you want to do you can do it.

The one of the most important thing that you should know is the recovery and grade. Recovery of particles containing valuable minerals or let me put recovery of a valuable mineral can be 100 percent but, the metal grade will not be 100 percent it will belong to the metal grade of a pure mineral.

So, that means let me illustrate by an example. If I take an example where I take a feed as say 1000 kg and in 1000 kg I have 500 kg chalcopyrite, 200 kg Fe 2 O 3, plus 200 kg let us take Si O 2 and 100 kg Al 2 O 3. I have got now feed say concentrate; I produce a concentrate now, which has also 1000 kg in which 500 kg Cu Fe S 2, plus 200 kg Fe 2 O 3, plus 200 kg Si O 2, plus 100 kg Al 2 O3.

What I have done? I have done nothing, I have taken a feed and said that it is a concentrate and told that I have recover 100 percent, no doubt. The valuable mineral in the feed was chalcopyrite; let Fe S, you have recovered all valuable mineral in the concentrate but now, what is the grade of these concentrate? The grade of the concentrate is very low because the gangue minerals are as it is as, it were in the feed. If the feed has some x is the metal grade then, concentrate also as the x as a metal grade because you are not removed at all gangue mineral.

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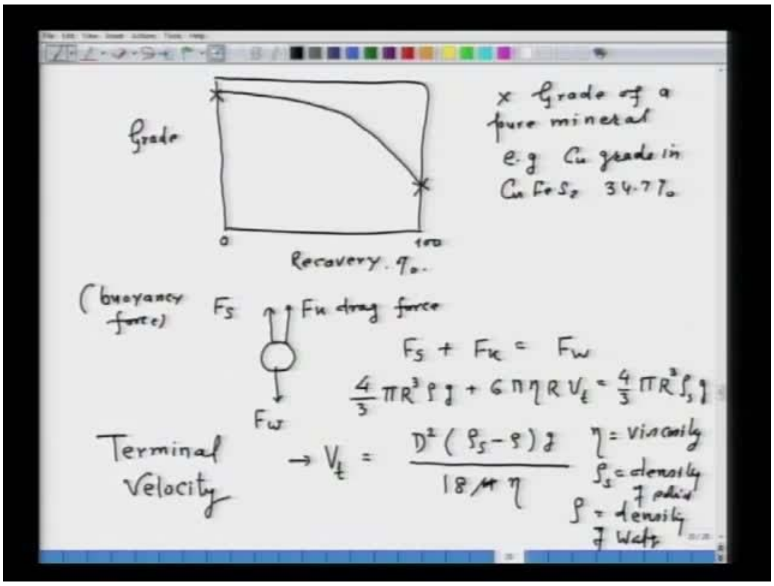

Therefore, the recovery and grade they are important, now if you want to see how they vary? The variation it goes something like this, say if I take here recovery which could be for example, 0 to 100 in percent and I take here grade for 0 percent recovery I have this is the value of the grade (Refer Slide Time: 44:44) and this value correspond to grade of a pure mineral. For example, copper grade in Cu Fe S 2 is 34.7 percent that point is this. Now, you cannot go mix beyond this; the metal grade cannot be more than 34.7 percent. So, you see the metal grade can never reach a 100 value; it will depend upon the composition of the compound and their stoichiometric value.

So, remember grade can never be 100. Here, if I increase the recovery what will happen? The grade will decrease and ultimately I will get at 100 percent recovery, this will be my grade (Refer Slide Time: 45:45). So that is how the relation between grade and recovery it has. So that means the recovery and grade, a recovery can be 100 percent in that I do nothing; that is entire feed I divert to the concentrate but, then the grade is very important because we want to produce metal from the concentrate this is the one.

Number two important thing is that for all gravity concentration operation it is the velocity of the particle that is very important. For example, if I consider a particle which is falling, so with experience says these are the three forces: this is due to weight F w and this is a sort of a buoyancy force (Refer Slide Time: 46:46), and this is a so called drag force. This you must have experience, if you take a particle in dip in water because of its weight sinks and if the upward forces equalize their downward forces then, it is stable otherwise, it will move.

If you do the force balance and you say that F s plus F k that is equal to F w if I substitute the value as spherical particle then, 4 by 3 pi R cube rho into g plus, this is the drag force, this is the viscosity (Refer Slide Time: 47:42), V t - I will tell you what is V t - that will be equal to 4 by 3 pi R cube density of the solid into g. So if I solve this then I will get, V t that is equal to D square rho solid minus rho into g upon 18 mu, so V t is called terminal velocity and this terminal velocity is very important in case of gravity concentration operation.

However, these terminal velocity we have determine for the ((Reynolds number)) to be very less than one even less than point one; however, for larger ((Reynolds number)) the turbulent forces also come into the picture and accordingly the value of velocity is to be determined but, what I wanted to say for here that for the gravity concentration operation let me put it this nu, that is the viscosity.

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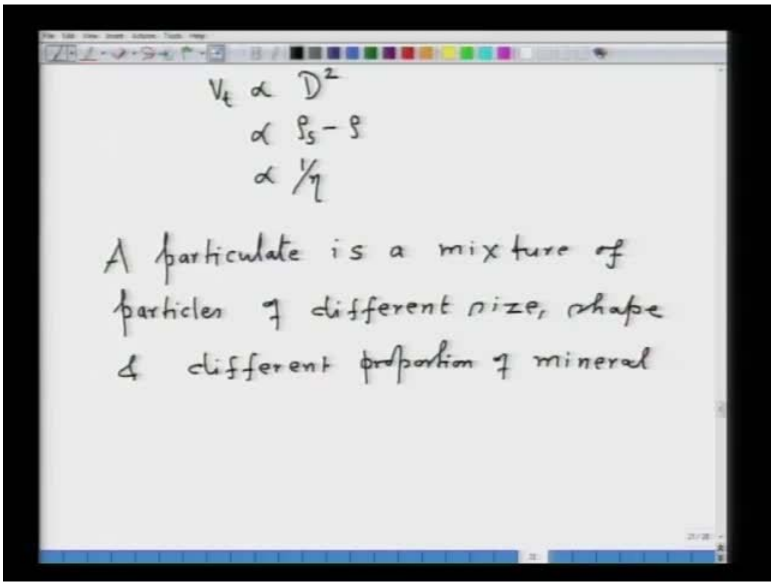

So let me say, this is the viscosity, rho s is the density of solid and rho density of water. What I wanted to derive from here is that, the V t is proportional to D square; see that larger is the size of the particle, better is the velocity or higher is the terminal velocity. So, it can float up easily, also it is proportional to difference in rho s minus rho. You see it is also inversely proportional to viscosity of the fluid, so all these three factors have to optimized in order to produce a concentrate from the milled product.

Now I think they are - frequently asked questions would be there, so let us see some of the questions.

Sir, can you please explain the difference between ore and mineral?

This difference is very commonly asked and many time some student they get confusion also. Let me tell you very clearly, an ore is an aggregate of minerals; that means it contains valuable mineral as well as gangue mineral whereas, a mineral is an inorganic compound in which the elements are combined in stoichiometric proportions.

For example, if I take iron oxide say Fe 2 O 3, so Fe 2 O 3 is not an ore. It may be confused, people may say it is an ore; no, it is not an ore it is a mineral. In that mineral two molecules of iron they are combined with 1.5 molecule of oxygen and you get a mineral, but when you call as an ore then, it becomes hematite never means it has only

Fe_2O_3 though people say it has only Fe_2O_3; no, it never means it has only Fe_2O_3 but, when you say hematite then it has Fe_2O_3, Al_2O_3, TiO_2, SiO_2 alkali so on.

In fact ore is an aggregate of mineral whereas mineral is an inorganic compound, that is a very important thing. Once you perceive this difference, then you immediately know that the metals - they do not occur in the nature. Yes metal but, they occur in the form of chemical compounds, one. Number two these mineral are the metal of a mineral; it does not occur as a pure mineral, but it occurs along with these several other minerals therefore, the technologies are important.

Sir what is a particulate?

Well I think, I have not explained this because say when you take a lumpy ore from the mines, you crush it. After crushing it undergoes to milling operation and the milling operation, that is the product which is there of the milled product is in fact called a particulate.

So essentially, I can write down the definition; say a particulate is a mixture of particles of different size, shape and different proportion of mineral. So when you say particulate in fact, the milled product which is subjected to concentration technologies for recovering the valuable mineral that feed you can call as a particulate.

That means you have in that particulate, they are particles of different sizes shapes and different proportion of mineral. Now also remember, we never say we never separate the mineral, we separate particles containing mineral that the two different things; we separate particle containing minerals.

That means a particle may have full mineral or it may have partially liberated mineral. That means a concentrate you should not think that it has only mineral but, it has valuable mineral as well as gangue also because you are concentrating particle containing minerals and a particulate has different sizes with different proportion of mineral. So in the concentrate, the gangue will also be present though its percentage is very small but, it will present; so that is what a difference and that is what is a particulate.

Sir, can you give some examples of metal that I extracted by a hydrometallurgical routes.

Now there are several metals which are extracted by hydrometallurgical route now typically the hydrometallurgical extraction route is implied for lean grade ores; for high grade ores one does pyrometallurgical route because pyrometallurgical technique can produce very large amount of metal compare to hydrometallurgy.

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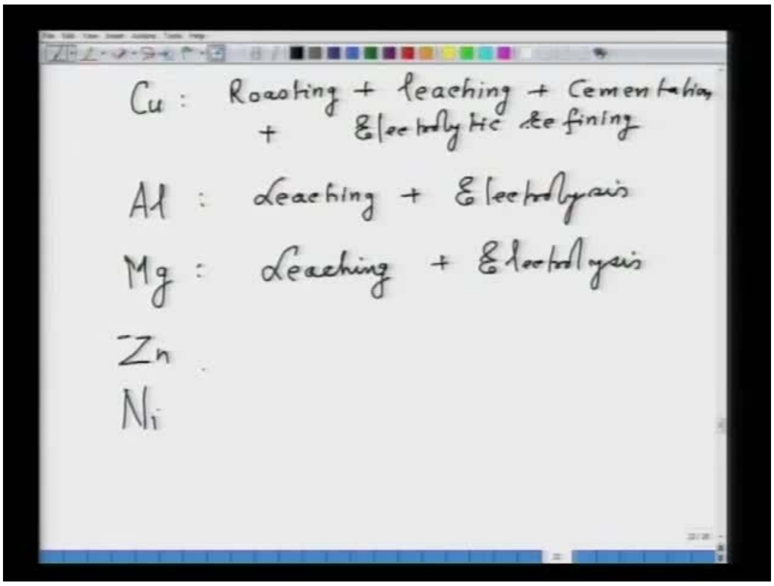

So for lean grade ores, you say the hydrometallurgical technique I can give example. For example, copper or copper the unit processes or roasting because in all hydrometallurgical operation sulphide is first of all converted to oxide or sulphate because in hydrometallurgical operation also you have to recover the metal and gangue you have to separate.

So for recovery of the metal you have to find a solvent which can recover the metal in the solution form. So, sulphides are normally not leachable; so first of all it is converted to oxide or sulphate depending upon the type of ore.

So for copper roasting and followed by leaching followed by cementation or hydrogen reduction whichever is that plus electrolytic refining; for aluminum - because aluminum we have bauxite with oxide ore - so you have leaching plus electrolysis. Similarly, for example, magnesium you again follow the route leaching plus electrolysis.

So in fact in hydrometallurgy also, some times the roasting is used in order to convert sulphide into oxide or into sulphate because sulphate and oxide can be leachable, so that the metal can be brought in the form of solution and then you can adopt the separating technology.

So, there could be several examples; for example, zinc - It can also be done by way of hydrometallurgy, nickel by way of hydrometallurgy again roasting, leaching and these are the separated technologies.

Sir is there any difference between slurry and pulp.

Well, in all mineral processing operations these terminologies are interchangeably used. In fact slurry and pulp they convey the same meaning. You take percent you take solid and resolve in water, you can call it as slurry or you can call it as a pulp also but, pulp I think it is coming from sugar industry; I do not know from where the pulp is coming but, well both are interchangeably use as a pulp and slurry when both are a mixture of in mineral processing solid and water.

Sir, please explain once again the separation of feed into products.

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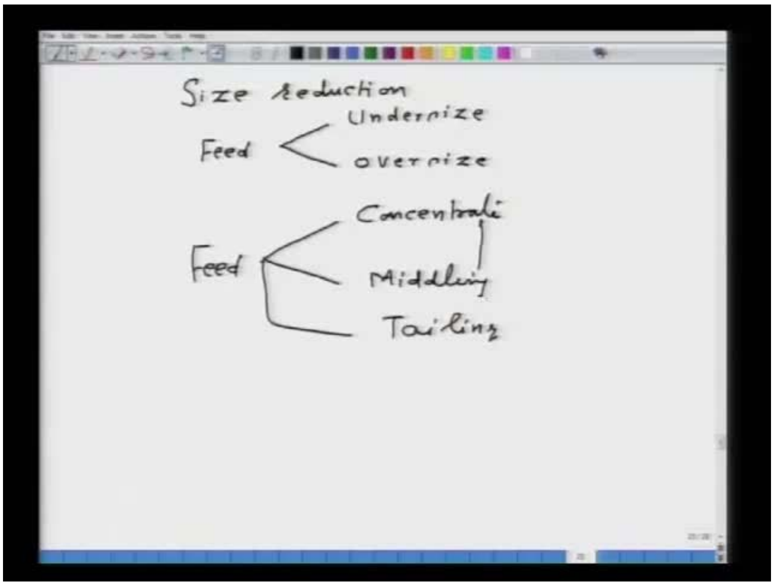

Well here, when you say imply size reduction technology and concentration technology. In case of size reduction technology, the feed is as undersize and oversize, the feed separates into undersize and oversize and when you perform screening utilizing Cu then undersize is one which is passing that it is send for further operation and oversize which is send for further size reduction operation.

But when hydro cyclone is use for separation, in hydro cyclone because of the way in which separation occurs the overflow is useful and underflow is send for granting operation, that is an important thing. Now recall in the ball milling circuit, the overflow was sent for the concentration operation and the underflow or the undersize were sent back for the milling operation but, if you perform separation by using Cu then it is other way round; so that point is important.

Now for concentration technology - the feed normally separates into three products: that I have said, is a concentrate, you have middling and you have tailing. Now middling, you can think of 'who beech ka cheez hai' between concentrate and tailing, that is the middling.

So middling is rather further processed, so either portion goes to concentrate or portion goes to middling. In fact, in the plant output it has only concentrate and tailing concentration goes for plant extraction and tailing goes for waste.

Thank you, sir.