Materials and Energy Balance in Metallurgical Processes

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Module No.# 01

Lecture No. #11

Materials Balance in Mineral Processing and FAQ

We will deal today with material balance in mineral processing. In the earlier lectures, I told about the concept that is required to develop material balance. Now material balance is required for several purposes; one of the purposes could be to take a stock of inputs and outputs and to identify the losses. Another important use of the material balancing is to develop the flow sheet. Flow sheet will exactly tell us the flow of material, the amount of material that is flowing from which way to which way, so for all these purposes material balance is important.

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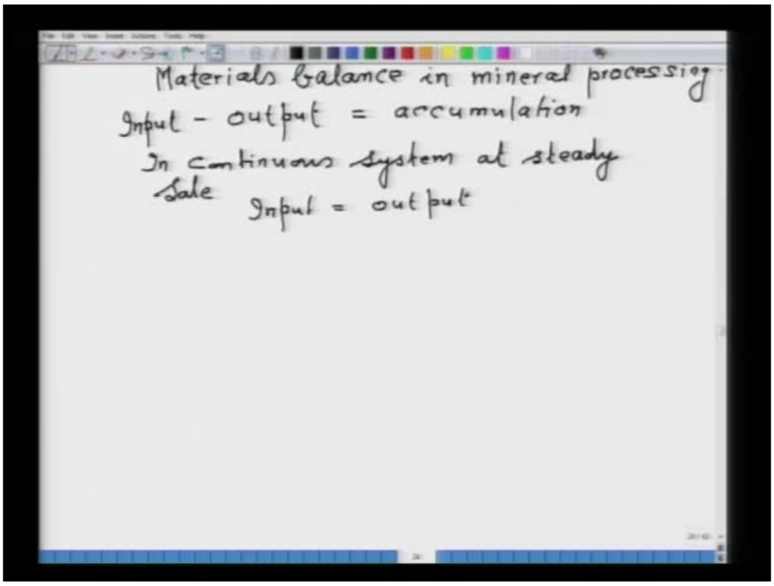

This material balance under unsteady state as you have seen in the basics, say input, it could be either kg or kg per hour or it does not matter, minus output that is equal to accumulation.

However, for steady state operation or in continuous system for example, if you have in continuous system at steady state obviously, there will be no accumulation as such; we have input that is equal to output, that is the basis of material balance.

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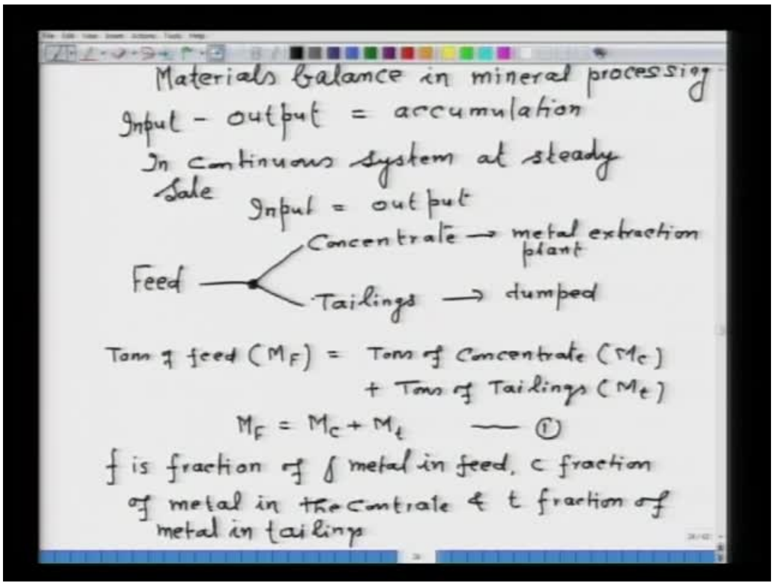

Now, we have seen the concept that in several mineral processing operations from a single feed we have got two products; that is, you will be developing a sort of two products that is feed. This here is the plant; then plant output in fact consists of concentrate and tailings.

As I have said, the middlings do not form the output of the plant; inside the plant YES, inside the middlings are further circulated. So, that they can join either concentrate or tailing but, the plant output is concentrate and tailing. Concentrate is sent for metal extraction plant, where tailing is dumped.

Now, let us say for input and output, we can say tons of feed, we denote M F. We can say tons of feed per hour or kg per hour or whichever way, that should be equal to tons of concentrate, let us denote by M c plus tons of tailings, let us denote it by M t.

So, as such we have M F that is equal to M c plus M t and let us say this is our equation number 1. Now, let us consider that f - small f - is fraction of metal in the feed. What this amount show? You can also call f is the metal grade in the feed, whichever way you want to say.

Let us say small c, is the fraction of metal in the concentrate and t - small t - is the fraction of metal in tailing. You can also understand the way that f is the metal grade in the feed; small c metal grade in the concentrate and small t is the metal grade in the tailing.

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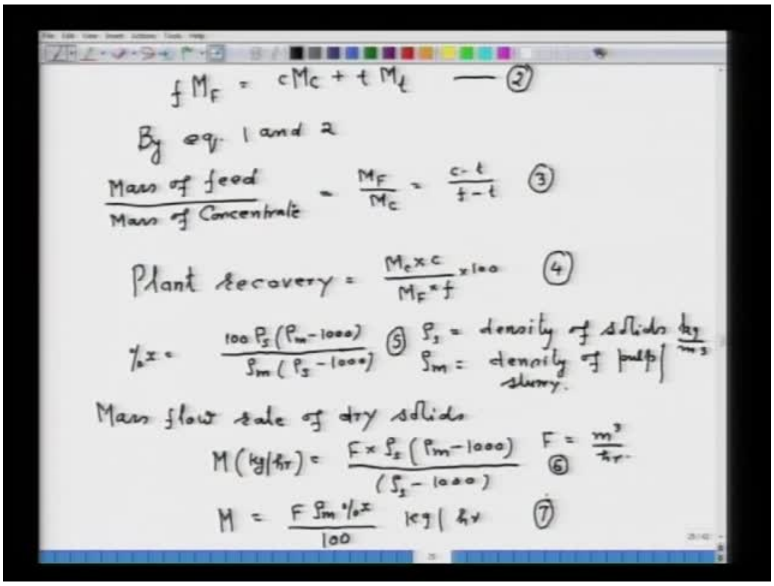

So, the following balance will also be applicable say f into M into F that will be equal to c into M c plus t into M t, this is also valid. Now here, we have made the balance in terms of the metal in the feed, concentrate and tailing.

Now for your information, let me tell you very clearly over here though I am using the term metal but, mineral processing does not separate metal; mineral processing separates particles containing mineral and that mineral has the metallic value. Remember we do not, in the mineral processing metal is not separated.

Now the question comes, why am I using the metal grade? I could have equally use the mineral grade. The fact that we are interested in the extraction of metal, so analyzing the feed concentrate and tailing in terms of metal it has a value because, other than metal everything is the gangue.

For example, in Fe 2 O 3; iron is the metal and oxygen is also the gangue because, it has to be removed but, when you talk of the mineral grade, then it is a different story. You can totally talk, say the mineral grade for example, of F e 2 O 3.

So that point should be understood clearly, I will say that we do not separate metal in any mineral processing operation. The objective of mineral processing operation is to increase the metal grade of the ore that is the objective. Metal grade we are telling because, we are interested in the production of metals, not mineral; that is where that point should be very well understood.

So, in this perspective the equation 2 is in fact the total metal balance - balance based on the metal. So by equation 1 and 2, we can obtain, say mass of feed upon mass on concentrate that is equal to M F upon M C that is equal to small c minus t upon small f minus t and let us call this is equation number 3.

We can define now, because we are interested in the recovery of the concentrate. So, plant will be assessed in terms of the recovery of the concentrate. So plant recovery that is equal to c into metal grade in the concentrate upon mass of feed into metal grade in the feed, metal grade or the analysis of metal or whichever way into. Of course, you have to multiply by 100 in order to get plant recovery in percentage.

Now say, in the lecture on measurement and units, you recall say we have derived a relationship between weight percent solid and slurry and pulp densities. So I am just reproducing here because I will need this expression for development of further quantification. So, we have developed for example, percent x - that is wet percent solid - we have got this particular expression say 100 into rho s rho m minus 1000, remember here water is a used as a medium to make a slurry or pulp, divide by rho m into rho s minus 1000.

We will write here rho s is a density of solids, here you must be care full in the units kilogram per meter cube because, I have substituted the density of water is 1000 kilogram per meter cube, rho m is the density of pulp or slurry. Let us call this equation is number 5.

Now, we also derived that mass flow rate, you recall say mass flow rate of dry solids in a slurry was M, which is in kilogram per hour that was equal to F into rho s rho m minus 1000 upon rho s minus 1000, where here F is a volumetric flow rate in meter cube per hour and that is why you get m also in kg per hour or we can also write down M; that also we have written, that is equal to F rho m percent x upon 100 again in kilogram per hour. Let us call this equation is number 6 and this equation is number 7.

Now, in all mineral processing operation as you recall in the concept, there I have said that water is in variably used as a medium to make the slurry.

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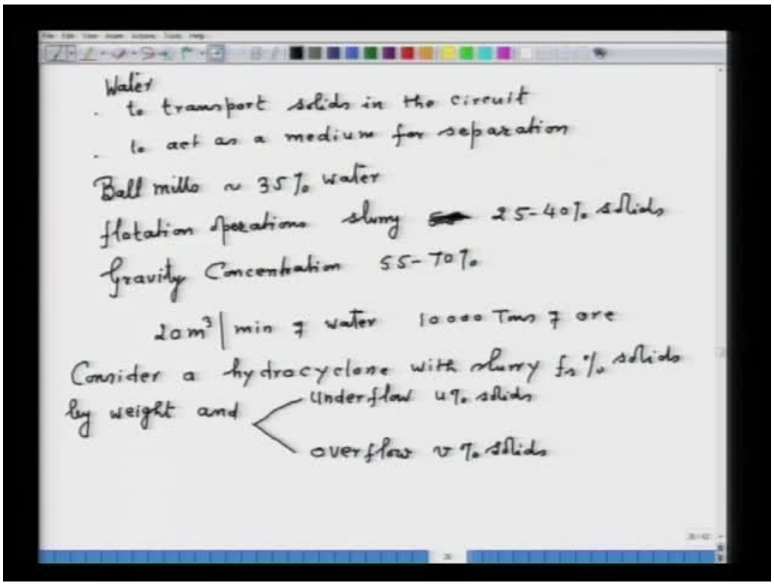

Not only to make the slurry, water is also used for several purposes, say the purpose of water, say number one purpose to transport solids in the circuit. This is one of the important purposes of addition of water because even in milling, we use large amount of water. After milling, when separation or concentration technologies are applied to separate the particle containing mineral from the feed, then a large amount of water is used.

Second objective is that it also acts as a medium for separation. Now, here the density difference between the water and the mineral is used to achieve separation. For example, ball mills they use as high as 35 percent of water for milling operation and the discharge of the ball mills is further diluted in order to separate under flow and over flow with the help of water.

Now, the most flotation operation require slurry which contains around 55 which contains around say 25 to 40 percent solid by weight; that means, again here very large amount of water is used. Some gravity concentration operations or methods they use as high as 55 to 70 percent of solids.

I mean, what I wanted to emphasis the fact that a large amount of water is required for mineral processing and approximately, you can think of that 20 meter cube per minute of water is required for a plant, which is treating 10,000 tons of ore. So, you can imagine there is a large requirement of water for the purpose of separation operation.

So, accordingly it is also important to find out the water balance. Let us consider now, say a hydrocyclone which is fed with slurry which contains f s percent solid by weight and it produces, you know one is the underflow and another is the overflow. Let us take underflow has u percent solids and overflow has v percent solids.

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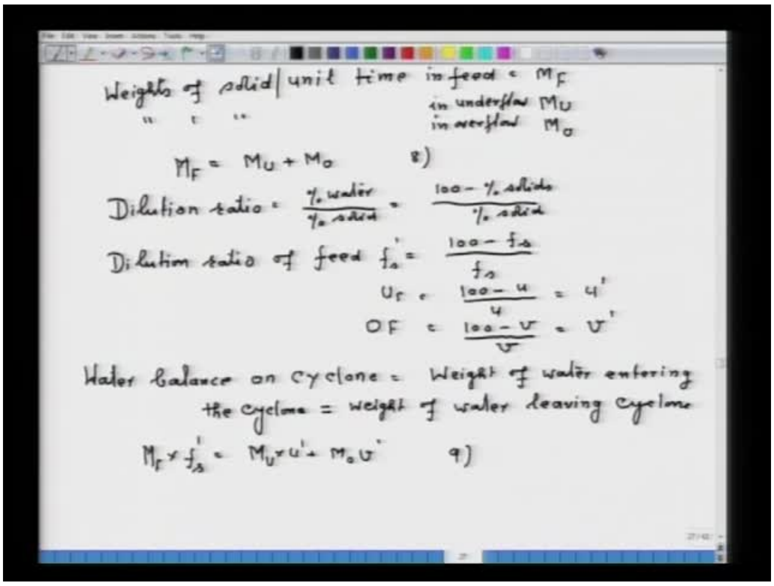

Let us consider say weights of solid per unit time in feed that is equal to M F, in underflow let us say equal to M U and in overflow it is M O. So, this is a weight of solid per unit of time in underflow and this is in overflow.

What we are doing? So at equilibrium condition of separation, again this balance must hold good M F that is equal to M U plus M O that is equation number, let us say it is equal to 8. Now, let us define a dilution ratio. Dilution ratio is percent water upon percent solid, so this will be equal to in general 100 minus percent solid upon percent solid.

Now we can say, dilution ratio of feed, let us take it f s dash that will be equal to 100 minus f s upon f s similarly, dilution ratio of underflow that will be equal to 100 minus u upon u, let us say this will be, let us call this is equal to u dash. Then dilution ratio of overflow that will be equal to 100 minus v upon v, let us put a that is equal to v dash.

We can make it now; say water balance on the cyclone that will be equal to weight of water entering the cyclone that should be equal to weight of water leaving the cyclone; very simple input that should be equal to output. So, we can we can make the following equation M F into f dash s that should be equal to M U into u dash plus M o into v dash and let us call this equation number 9.

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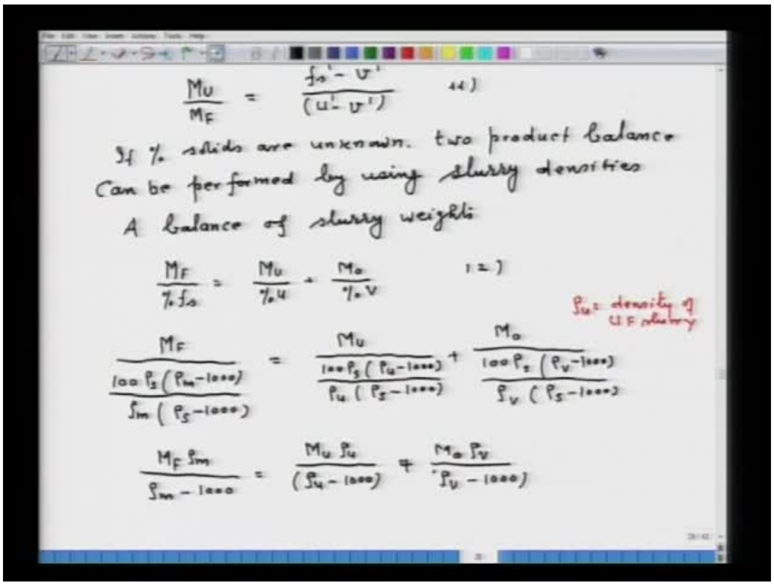

Now by 8 and 9, we can get M U upon M F that is section of underflow that will be equal to f s dash minus v dash upon u dash minus v dash, let us say this equation number 11. So, we can calculate mass of underflow by this expression, if we know the dilution ratios from that we can calculate.

Now say, if say this is the case, when percent solid is known; when suppose percent solids are unknown. So, if percent solids are unknown then this two product balance - what we have done we have developed two product balance - feed concentrate and tailing.

So, two product balance it can be performed by using slurry densities that is suppose by some way you do not know the percent solids but, you can find out the slurry density then that balance can ((assume in it)).

So, a balance of slurry weight that gives the following expression M F upon percent f s that is equal to M U upon percent u plus M o upon percent v, let us take this equation number 12. Now, we already know the percent solid expression. In the earlier, I have written the percent solid equation which was equation number 5.

So, we can substitute that particular value for percent solid and the following equation result; that means, M F upon 100 rho s into rho m minus 1000 upon rho m rho s minus 1000 that will be equal to M U, similarly I have to do here say 100 rho s rho u minus 1000 upon rho u rho s minus 1000.

Remember rho m in equation 5 is the density of slurry say accordingly, rho u is the density of slurry of underflows, I will write down here, rho u is the density of underflow slurry that point, it should be remembered.

So similarly, plus I have M o that will be equal to 100 rho s rho v minus 1000 upon rho v into rho s minus 1000. So all that one needs to simplify this expression and once you simplify, you will be getting M F, where everything cancels out into rho m upon rho m minus 1000 that will be equal to M u rho u upon rho u minus 1000 that is plus M o rho v upon rho v minus 1000 (Refer Slide Time: 25:55). So that is what the expression, we are getting.

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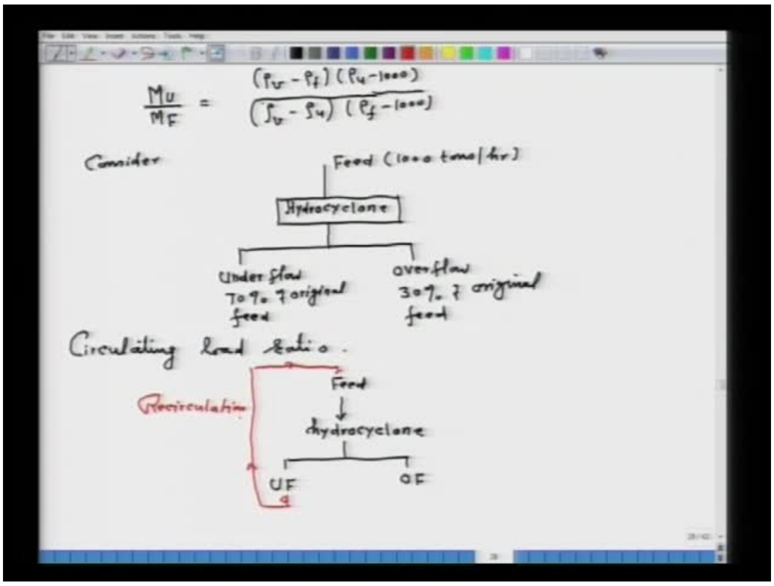

So on simplifying further, what will get we will be getting M U upon M F that will be equal to rho v minus rho f into rho u minus 1000 on rho v minus rho u into rho f minus 1000. So that is what the M U upon M F; that can also be determined from the slurry density. This is all that, if you know the density of the slurries one can find out the mass of underflow and so on.

Now, let us take an example. Let us take say- Consider, say separation of feed from ball mill - I will draw a circuit. For example, this is the feed and I am considering 1000 tons per hour is the feed and it is passed into hydrocyclone for separation and as usual the hydrocyclone gives us underflow and let us say, underflow is 70 percent - contain 70 percent - of original feed and overflow it contains 30 percent of original feed.

So, the product of a ball mill is subjected for separation and we got the two product underflow. So, what we have to do? We have to first find out what is the circulating load ratio?

Now as you recall, the circulating load ratio means what? That means the underflow is circulated; that means, the amount of recycle upon the fresh feed that will give you the amount recirculated, so I draw now the flow sheet with recirculation. That is, the feed we have hydrocyclone, then we have underflow, we have overflow and the thing which is rather recirculating in the feed. So, this is called recirculation, because underflow is not a waste; it is further sent to the ball mill operation for further recovery of the particle containing mineral.

So, what we have to find out? Just load - the recirculation load - because, this is very important; this is particularly necessary, when you want to determine the capacity of the ball mill because the initial capacity of the ball mill, if no provision is given for the extra load which is coming from the recycling, then you may get the problem. For this purpose it is necessary to know, what is the recirculation load?

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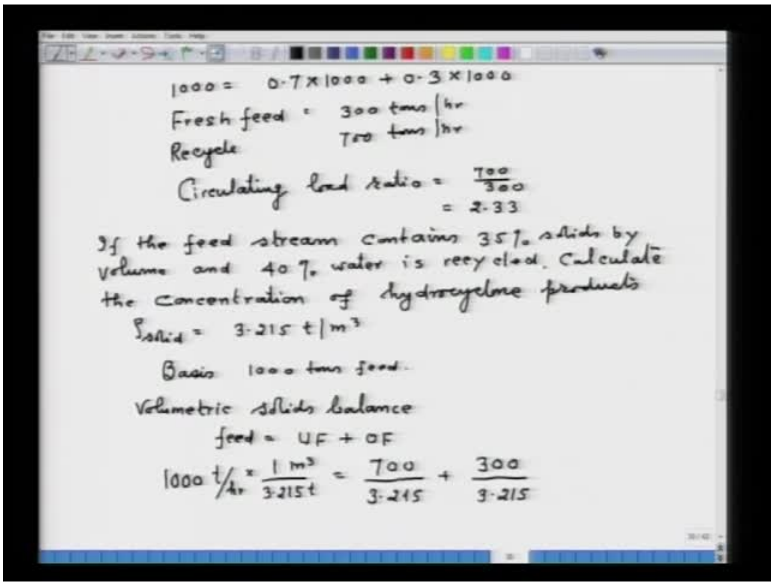

So easily we can determine say the simple balance 1000 that is equal to 0.7 into 1000 plus 0.3 into 1000. So, the fresh feed, how much will be the fresh feed? Can you think of, because the 700 tons is the underflow that will be recycled 300 tons is the overflow that will be taken for the further operations, so 300 tons is the fresh feed.

So 300 ton, fresh feed is 300 tons per hour, because every time 300 tons per hour, which is the overflow will be taken for further operation. So, every time you use the fresh feed will consist of 300 tons per hour and the recycle feed that is 700 tons per hour. So circulating load ratio is equal to 700 upon 300, so that is equal to 2.33.

I mean, this circulating load ratio is again a very important because to determine the capacity of the ball mill initially, because once the ball mill is installed, you cannot change its capacity.

So, if you have not taken care of the recycling load then, the ball mill may not be able to mill the product to a size which you have aspired or its capacity is over exhausted, so for that purpose circulating load is necessary.

Now, if suppose we take the same data earlier I mean, whatever we have taken over here. Now for example, if the feed is stream, let us take it now if the feed is stream it contains 35 percent solids by volume remember, not by weight; it is by volume and 40 percent water is recycled then, calculate the concentration of hydrocyclone products (Refer Slide Time: 33:15).

Now here, what I have done? We are now recirculating water because, we can also recirculate the water as we have recirculated solid. We can also circulate water why not because, water has to be conserved. So now, here it is given to you, say density of solid 3.215 tons per meter cube is given to us. So, solve the problem, calculate the concentration of hydrocyclone product? What will be the hydrocyclone product? That will be overflow and underflow. So basis of calculation is 1000 tons feeds.

Now we can also do volumetric solid balance, how will it look? Again, input is equal to output, so feed that is equal to underflow plus overflow. Now mind you, I am doing now volumetric balance, so I have to know a volume of the feed that will be equal to volume of underflow plus volume of overflow. So, volumetric solids balance feed is equal to underflow plus overflow. Now mind you, this is the volumetric balance that means we are balancing the volume.

So, again here feed is equal to underflow plus outflow. So what I have to do? I have to make, now determine the volume, so 1000 tons per hour is the feed; if I divide by one upon its density which is 3.215, in side that is meter cube upon ton, so that has become now the volume (Refer Slide Time: 30:30). Similarly, I can do underflow 700 upon 3.215 plus overflow 300 upon 3.215. So that is how you will be doing this, so called volumetric balance. Remember to divide the weight by the density, you get the meter cube.

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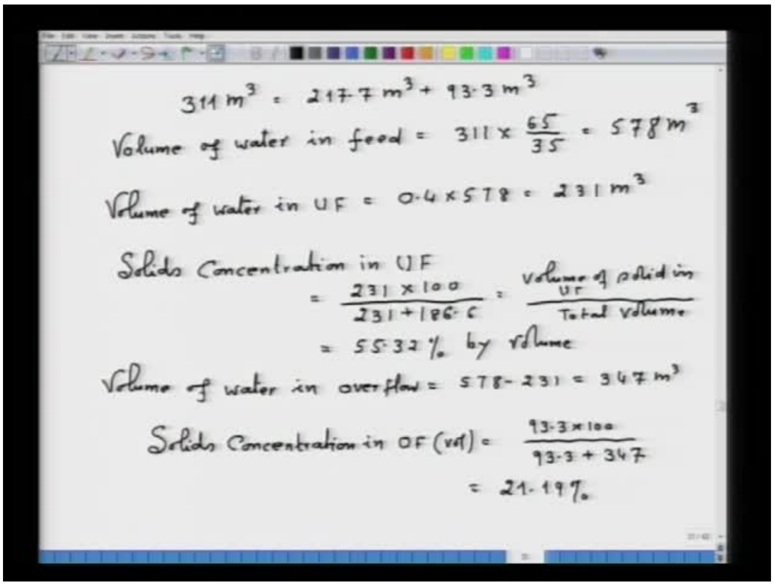

So if we do that then, we will be getting 311 meter cube that will be equal to 217.7 meter cube plus 93.3 meter cube. Now, we have to find out volume of water in the feed that is equal to 311 and you know it contains 35 percent solid, so this has become 65 upon 35 that is equal to 578 meter cube.

Similarly, I can find out now volume of water in underflow - you know 40 percent is recycled - so that will be equal to 0.4 into 578, so that makes 231 meter cube. Now, we have to find out the concentration of solid. So, I can find out now, say solids concentration in underflow that will be equal to 231 into 100 upon 231 plus 186.6 that is equal to what I have done? I have done here, volume of solid in underflow and divided by total volume.

So, this comes if we solved (Refer Slide Time: 38:35). This will be equal to 55.32 percent. Remember, it is by volume; it is not by weight. So I have to find out, volume of water in overflow that will be equal to 578 minus 231 that is equal to 347 meter cube. So, solids concentration in overflow in volume percent - that is what we have to find out - that will be equal to 93.3 into 100 divide by 93.3 plus 347, so this is equal 21.19 percent. So that is how you will be calculating the so called solid concentration. So, what I have illustrated today is through water balance or through solids balance. One can determine the various parameters that are required for the operation of the flow sheet. If you have some questions you can ask and i will try to clarify those questions.

Yes sir, sir I have some questions. Sir, how will be calculate plant recovery from metal grade only.

Well in the lecture, I have derived a formula where you can calculate the plant recovery when you know mass of the concentrate and mass of the feed. Now suppose, if you do not know the mass of concentrate and mass of the feed then, how to calculate plant recovery? That is your question.

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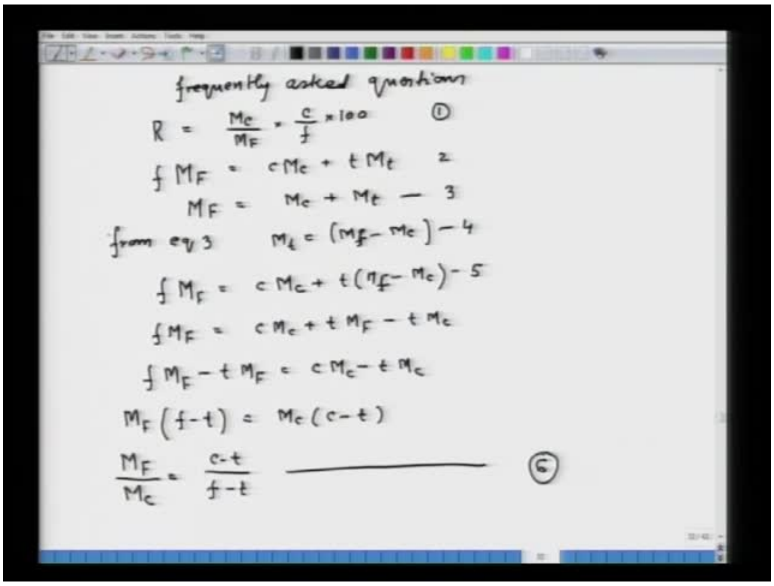

So in the lecture, what I have derived? I have derived plant recovery R that was equal to mass of concentrate upon mass of feed into grade of concentrate upon grade of feed into 100, that is what I have derived (Refer Slide Time: 41:18).

Now in many situations, suppose this M C by M F ratio is not known to us. Then, how to calculate plant recovery? For that we recall in the lecture, I have given this metal balance that is f into M F that was equal to small c into M C plus t into M t and also, we know that M F that is equal to M C plus M t this is also known to us.

Now from say from this let us say- Let us take this was equation 1; this is equation 2; this is equation 3. Now say from equation 3, we note that M t that is equal to M f minus M c, let us put this equation number 4. Now, I can replace M t in equation 2 by equation 4, so I get now, f into M F that is equal to c into M C plus t into M f minus M c.

Now here well you can see, this is the capital F - just the correction over here - this is a capital F, does not matter as long as we are clear. So, now it requires a solution, it has to be simplified; so if I simplify, I can write down, now f into M F that is equal to c into M C plus t into M F minus t into M C.

Now, f into M F minus t into M F that is equal to c into M C minus t into M C. Now, I take M F out then I get f minus t that is equal to M C c minus t therefore, M F upon M C that is equal to c minus t upon f minus t.

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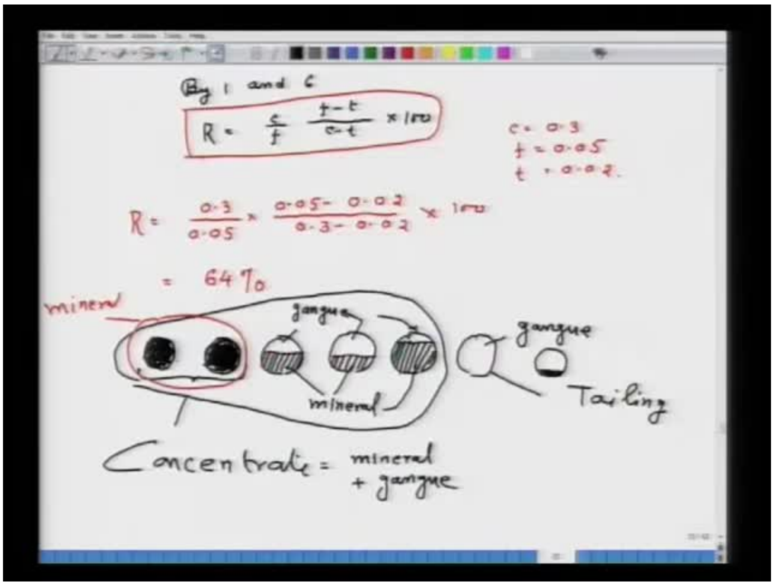

Now, this expression if I take 6. Now, if I use equation 1 and 6; I can replace M C by M F and if I do that, then R will be equal to small c upon f, f minus t upon c minus t into 100.

So, that is how you can calculate the plant recovery if you do not know the masses of the concentrate or feed. That is what you have to do. You have to replace the mass - ratio of masses - by grades which is possible by utilizing the mass balance and metal balance both if you combine, you will be getting this expression.

For example, if I want to give an example. So, let us take say c is 0.3 that is, metal grade of the concentrate; metal grade of the feed, let us take it 0.05 and metal grade of the tailing, let us take its equal to 0.02 then I can calculate R; R will be equal to 0.3 upon 0.05 into 0.05 minus 0.02 upon 0.3 minus 0.02 of course into 100. So if I solve this thing, I will be getting around 64percent. That is how you can also calculate the plant recovery, if you know only metal grades. I think that should be clear (Refer Slide Time: 45:51).

Sir, does concentrate contain gangue? Please explain.

In fact you recall, when I was telling you about the concentration technologies. I have said that you recover particle containing minerals. In fact, the key point to remember in case of all mineral processing operation, we do not concentrate mineral or we do not separate mineral, in fact we cannot separate mineral. We separate particle containing minerals, we can separate mineral only when the libration technologies are such that all the particles are with either fully minerals or fully gangue but, that is not the case. So, we have the varying proportion of mineral in the particle, so we recover the so called particle containing mineral.

So, that means let me explain once again. So, if I have say this particle; I have several particles over here that I am recovering now; all I have recovered in the concentrate. Let us take, say this is fully mineral. This particle also full mineral, now if this particle we would recover; this was the mineral and this is the gangue. Similarly, we had recovered also this particle; this is the metal or this is the mineral and this is the gangue (Refer Slide Time: 47:43).

This is the mineral of which we are interested in production of metal. Another situation is that for example, we have recovered this sort of situation. This is also mineral and this is the gangue and this is pure gangue.

Now, situation number one: if you recover only these two and forget about all other things. Say in a feed, you recover only particle containing 100 percent mineral, then your concentrate will consist of that of the mineral and in that case, the metal grade of the concentrate will be that of the metal grade of the pure mineral.

Now if you do that then, what you are doing? You are unnecessary loosing these one, two and three particles. They also contain a large proportion of minerals in that. Now, it will depend upon what is the mineral under consideration, if the mineral is valuable. Now for example, in case of chalcopyrite the grade of the feed is only 5 to10 percent in that you like to recover almost all particles containing mineral. Even particle which contain, let us say 10 percent of mineral your effort would be to recover that because it is the value of the metal that will be deciding, because you are losing - in the economic front - you are losing it. So what you do now? You recover all these and call this is my concentrate. Of course, this is the tailing (Refer Slide Time: 49:25).

Now, when you recover this particle which contain mineral and call it is a concentrate? Now your concentrate consists of what? Mineral plus gangue; if you recover only these two then, your concentrate consist of pure mineral - you are right - then in that case- but, then you will be losing so many mineral which has a very high metallic value that you do not want do it.

So, that is why a concentrate will always contain mineral plus gangue. So, it is always better to say that in all mineral processing operation; we recover particle containing minerals that will gave you the feel that there are particles which contain different proportion of mineral and that is why we talk of metal grade of the concentrate. So in that case, metal grade of the concentrate can never be equal to metal grade of the pure mineral.

Similar is the case, if the tailing also. In tailing also in some situation for example, you imagine this is the particle now (Refer Slide Time: 50:41). Now, that particle has only this much as the mineral, which is not possible to recover, so it has gone into tailing. So similarly, you have tailing will also consist of gangue plus particle which contain mineral. However, the effort would be that metal grade in the tailing should be very low. So, your effort should be as much metal to recover in concentrate as possible. Other way around, your effort should be to recover as much particle which contain mineral as possible.

So as such the concentrate will always contain mineral plus gangue and so tailing will also contain gangue plus mineral. However, the proportion of mineral will be very very less. So that is the important thing to remember here. The key to remember in almost all mineral processing operation, you always perceive that you are separating particle containing minerals you are not separating minerals, because the product from the ball mill it has particles containing different sizes, shapes and varying amount of minerals in the particle (Refer Slide Time: 51:57).

So if you remember this particular concept that you are separating particle containing minerals, then you will never have a doubt that concentrate will consists of only minerals.

It is a particle containing minerals and from economic purpose, you want like to recover as many particle contain mineral as possible where you cannot stop your concentration operation only on pure mineral, which is not economical to you. So that is what the important thing is. Again I repeat we concentrate particle containing minerals that is the key of mineral processing operations.

Sir, what is two product balance?

In a two product balance, now well you can also make three product balance or two product balance. Now, when we say a three product balance?

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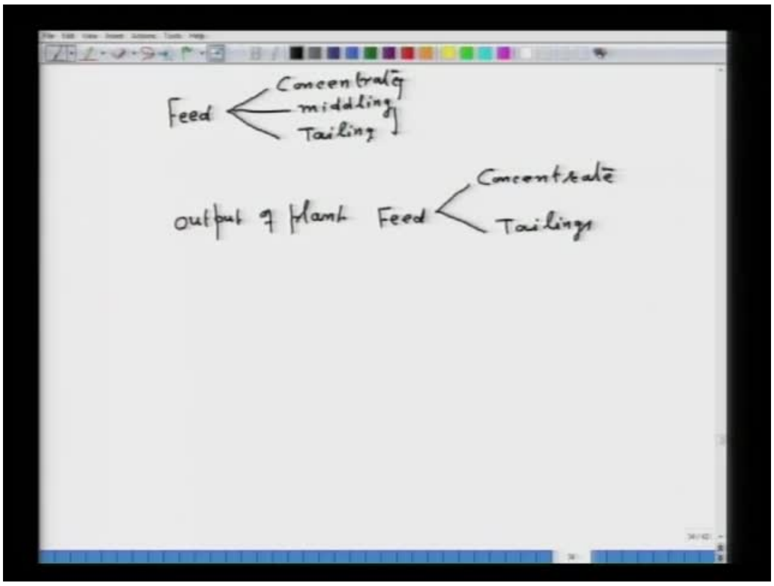

Let me tell first of all the product balance, now say feed within the plant it produces concentrate, it produces middling and it produces tailing. This I am talking feed separation within the plant but, since now so- this you can call as a three product formula. You can also develop material balance within the plant for this but, and then it is unnecessary wastage of effort because middlings are further recycled.

The middling will either join concentrate or either tailing; they are further subjected to concentration operation. So, either they will go there and there. So the plant output, I am not talking within the plant and I am not talking output of the plant it will always have two products that is concentrate and tailing. Middlings are not the product of the plant they are the product within the plant, they are circulated within the plant. So for all calculation proposes, the output of a plant is important which a concentrate (( )) so that is what the two product means. Thank you, sir.