Fundamentals of Food Process Engineering
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Lecture - 52
Leaching and Extraction (Contd.)

Hello everyone, welcome to the NPTEL online certification course on Fundamentals of Food Process Engineering. In the last class we have started the topic of Leaching and Extraction. We have discussed the basics of leaching and extraction process and few equipment that is used for leaching process right.

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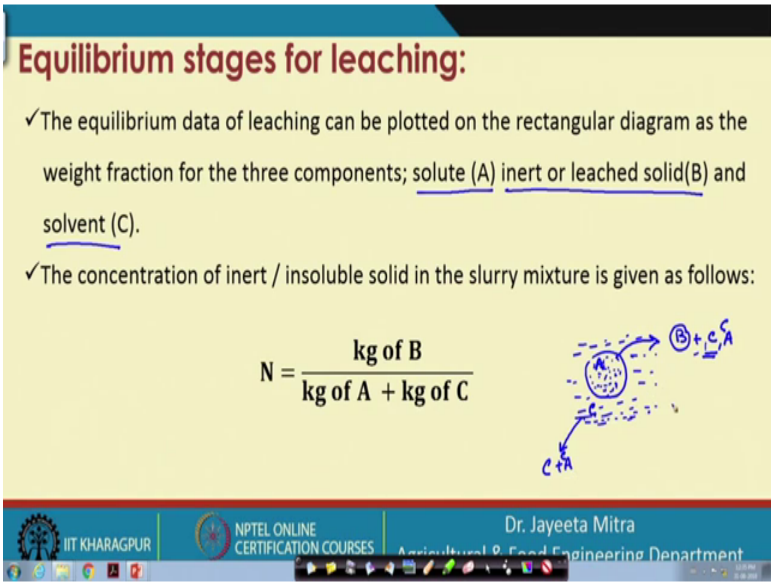

So, today we will discuss a very important thing that is the equilibrium stages for leaching. Since we are covering the basics of this leaching and extraction process here and to understand this in a better way, you need to know the equilibrium stages and that is you know generally, explained in distillation or mass transfer cases. But since that is not part of our course I will try to explain a bit of equilibrium stages to you so that, you can understand how the extraction process can happen. And what other limiting cases I mean, is the complete solute is removable from the mixture or how the how mathematically we can proceed if we want to estimate that or we want to design the extraction process.

So I will try to give you some over view related to the equilibrium stages for leaching process. First we will discuss leaching later on we will also give you the equilibrium stage concept or those diagrams and descriptions for the liquid extraction. So, considering equilibrium stages for leaching, the equilibrium data of leaching can be plotted on the rectangular diagram as the weight fraction for the three components. So, we have three comp1nts basically, one is the solute A, solute A that we want to separate from the mixture of inert or leach solid that is B and this process is done using the solvent C.

So A will getting mixed with the C and this A initially is in B which is inert, so at the end of the process also B will be inert, may be some part of C will be mixed with that, but I really want to separate A in the C. So, the concentration of inert or insoluble solid in the slurry mixture is given as follow; that is in, that is equal to kg of B by kg of B plus kg of C. So, as we have menti1d that in the slurry mixture, some amount of solvent will be there and some amount of you know some amount of solute will be there.

So ideally, what happened that suppose, this is a miscella, solid particle is there or solid miscella is there and this I want to separate; this I want to separate by contacting it with a particular solvent. So, what happens that, some when this separation has occurred and this solid become separated where we have mostly B, that is inert material and this liquid which was having C and here there was some amount of A which is solid so now, it has moved with C plus A. And here it is B, but B was not as a dried one, so B has some amount of C that is the solvent and in that some amount of A will also be there.

So in that suppose, the liquid when it becomes equilibrium when this solvent and the and the solid when the extraction or leaching process takes place then, we assume that the equilibrium stage has arrived; that means, the solute was there that has been leached to the solvent, the maximum extent possible has been leached to the solvent. So, suppose in the solvent initially the concentration of A was 0 and in the solid the concentration was 50 percent. So, if at the end of the process suppose you know 45 percent of that A has been extracted, so that 45 percent has come to the come to this solvent now, right.

So, when we take out the solvent we are getting now 45 percent of that A, now whatever small amount of solvent will be associated with the B that is the inert liquid that will also ideally have the same fraction or same concentration of C because, whatever liquid part is there some liquid part will be definitely there. So, this concentration of A if I say C A, C suffix concentration of A in the C stream or the solvent stream and concentration of A in the stream that is over flowed in the process, will have same concentration right. So this ideally we call as the equilibrium condition. So in that process, the when we call the concentration of slurry when we want to define the concentration of inert solid in the slurry then, N is equal to kg of B by kg of A plus kg of C.

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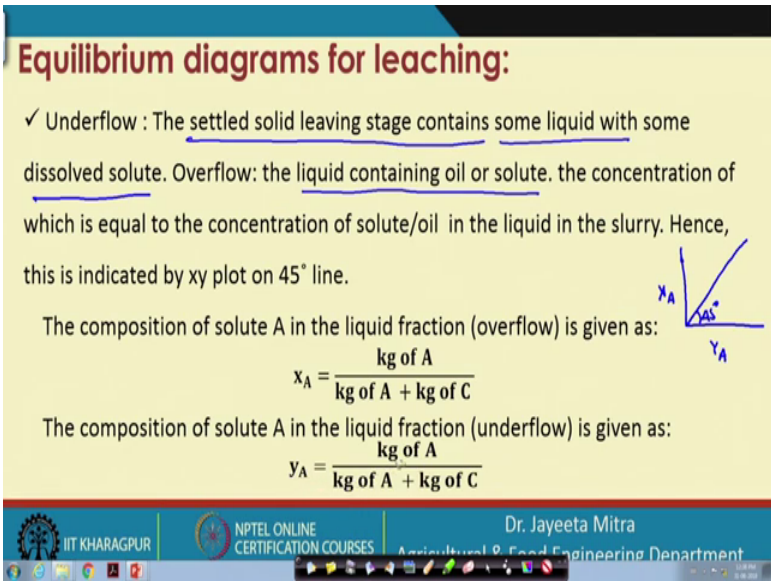

Now, in the equilibrium we will try to see that, what are the different you know equilibrium stages and the concentration in both the stream; that is the overflow stream and also in the under flow stream. So, under flow this is the settled solid leaving the stage. The settled solid leaving the stage contains some liquid as I said that, the inert solid B will not go alone or in a dried form some liquid will be associated. So, some liquid will be associated that is called the underflow and that liquid will have some dissolved solute as well. And over flow is the liquid containing the oil or containing the solute that is being extracted, so that has been taken away in the over flow right. So, the concentration of which is equal to the concentration of the solute in the liquid in the slurry.

So these two concentration that is concentration of the solute in the overflow and the concentration of the solute on the solvent, which is going with the underflow, these two will be same. Hence, this is indicated by X Y plot on a 45 degree line. So, if we plot this concentration, suppose I denote the concentration I denote the concentration of solute in the over flow by X A and this concentration of solute in the underflow solvent that is Y A, so this will follow a 45 degree line; this will follow a 45 degree line, we have that diagram in the may be in the next we will show you. So, what it says that, the composition if solute A in the liquid fraction, that is the over flow is given as X A equal to; that means, what kg of A that is solute divided by kg of A plus kg of C because, the stream that is going in the stream that is going in the over flow will have the solvent as well as the solute so kg of A plus kg of C. In that what is the fraction of kg of A that is the solute, so that is X A.

Then similarly, the composition of solute A in the liquid fraction, that is the under flow that is given by Y A equal to kg of A divided by kg of A plus kg of C. So, we are observed that these 2 are same; one stream that is going out and the same stream some fraction some part of that stream which is going in the under flow with the solid, so that has this concentration. So, X A and Y A ideally should be similar or should be same.

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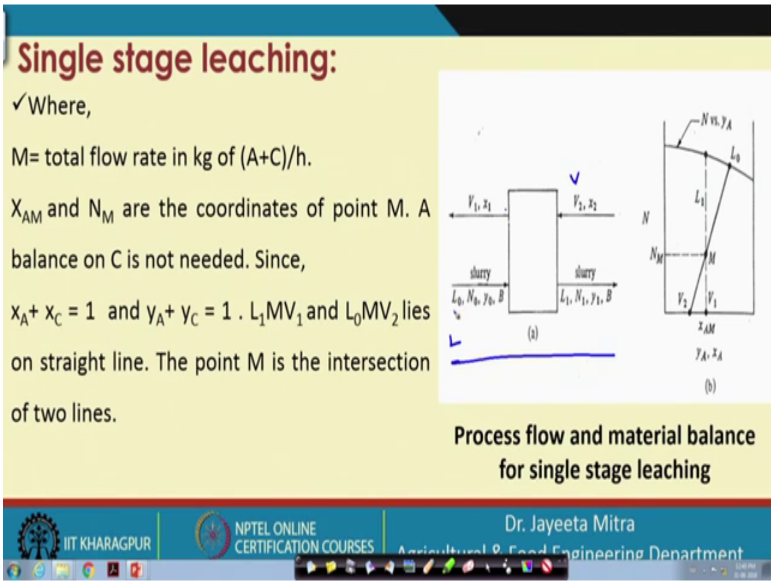

Now, a single stage leaching process, when we consider the single stage leaching; shown in a rectangular diagram. So, let me first show you that single stage leaching diagram. Yes, we will go back to that slide, first we will see what happen in a single stage. So, let see this is a single stage leaching is occurring, so we have the slurry solution which is entering the feed solution or slurry solution and we have solvent, which is entering. Then this solvent will take some fraction of the solute and then, it is moving out and this slurry which is again coming out as the slurry from the first stage right.

So, the V represent the kg of solvent that is entered, L represent the kg of slurry that is entered, 0 representing the concentration of inert solid, Y 0 representing the concentration of the solute in the feed slurry. Similarly Y 1 representing the solute concentration in the outgoing slurry and X 2 and X 1 or X this represent the solute concentration in the solvent. So, this is the single stage thing and now, we will see that, we will go little back.

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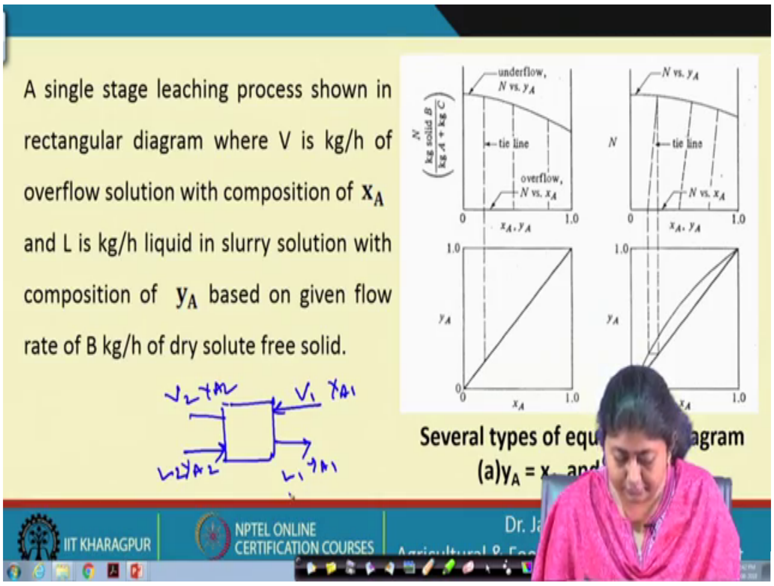

So we were here. So, in a single stage that we are seen, in a single stage where L is the slurry entering, V kg per hour that is the over flow solution with composition of XA, L kg of the liquid that is in the slurry solution with composition of YA.

And so, like that any A any notation you can give to them it is X A 1, X A 2 like that, so whatever. So, over flow solution with composition of X A and L kg per hour is the liquid slurry solution with composition of YA based on the given flow rate of B in kg per hour of the dry solute free solid. So, B here is the dry solute free solid So, B here is the dry solute free solid, in that term we are taking B as an inert. Now, the equilibrium diagram when we try to make what will do is, we represent we will draw a square plot, in that this bottom axis X axis represents N versus X A.

So, initially N means the inert solid concentration of the inert solid in the in in the total slurry that is kg of A by kg of C So, in that, the concentration of solute the concentration of the solute if we consider that is, Y A and X A, that is the concentration of the solute in the solvent stream, so X A will be 0 initially, compared to this N and as it moves other direction it is increasing because, from 0 to all the all the solute fraction from the inert solid was slurry, it is going to mix with the solvent. So, eventually X A will increase from 0 to 1, the maximum fraction will come out.

Whereas, the upper curves that that show the under flow; that means, this is N versus Y A So, what happen that initially, Y A was 100 percent Y A, so the fraction Y A will be 1.0 so, initially this was higher and as you know the slurry is getting mixed with the solvent and the solvent is taking the solute away.

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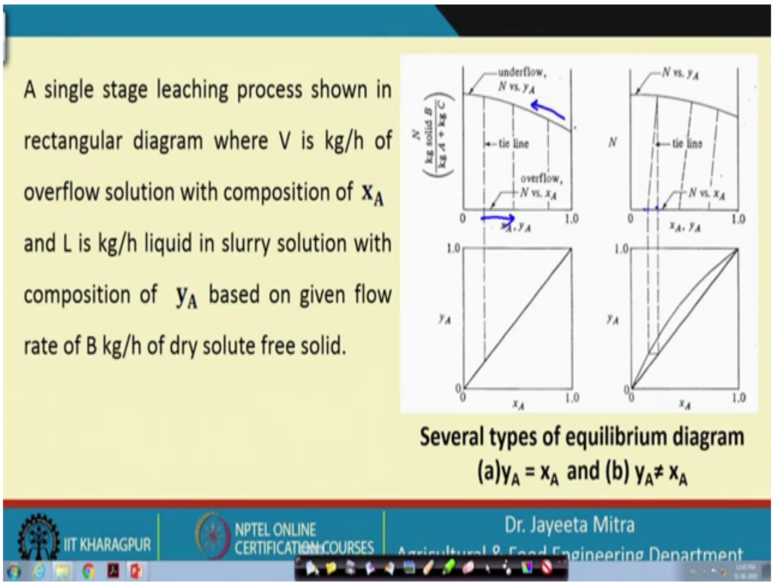

So, it is decreasing, Y is decreasing and X A is increasing right. So, ideally, if it happens then the concentration X A equal to YA because, that is the ideal case on in the equilibrium situation this should happen for ideal extraction. So, those 2 concentrations X A and YA are same and this we have discussed already. So, in that case that tie lines are vertical straight lines.

So when we plot YA versus X A, we will get a straight vertical line. So, this is you know 45 degree line. Now what will happen that if, suppose there is a deviation in the concentration of X A and Y A so; that means, whatever concentration was there in the slurry or in the feed solution as not fully gained by the solvent. So, there is always some gap. So, in that case we will not get the straight line as the operating or operating line. So, in that case we will get a little curve as an operating line. So, that represent this will be your the concentration of Y A and they will be the concentration of X A. So we can get this kind of a plot when the tie lines are not vertical; that means there is a deviation between the X A and Y A.

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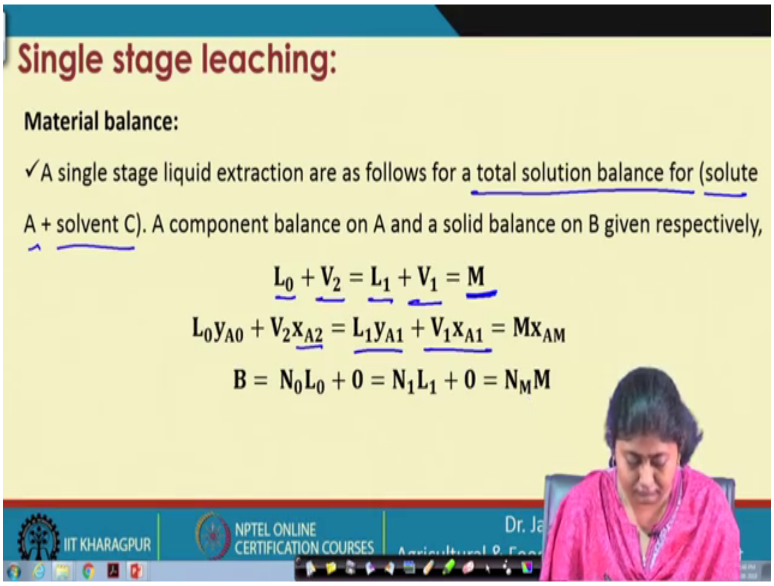

So, next is so single stage leaching, now will do the material balance so, this is our figure, if you remember that we have L 0 N 0 Y 0 and B that is entering and here V 2 X 2 that is entering. Here V 1 X 1 that is leaving stream or this is the over flow and this is the under flow that is L1 N 1 Y 1 B. So, considering that if single stage mass balance we want to see over all, so a single stage liquid extraction areas follows for total solution balance for solute A and solvent C because, if we know those 2 the other can be easily calculated.

So, a component balance on A and a solid balance on B that can be given respectively. So, the total balance will be L 0, that is the feed stream plus V 2 solvent that is equal to L1 that is the feed slurry that is out going or this is the under flow plus V 1 which is the over flow. So, this will be M and this will be constant. Now the solute concentration in the feed slurry is Y 0 So, Y A 0 into l 0 plus the entered solvent stream if the solid concentration is having X A 2 there. So, Y2 into X A 2 that will be equal to L 1 into Y A

1, so this is the this is the under flow that is going, so L 1 into Y A 1 plus over flow that is V1 into X A 1.

Now, this will be together coming as M into X A M; M into X A M. So, this is because, when these two stream is getting mix. So, let us say the separation will have an up to a certain point which is signified by the point M, when the equilibrium will be reached. So, that M the position of that M point we need to find, so that we can predict that, what will be the extraction efficiency or what will be the separation, what fraction of the separation of solute has been d1. So, M into X A M is required for that. Now you if you want to do balance on the inert material that is B, so B will be how much initially the stream L 0 has a concentration of N 0 for the B and the solvent did not have any trace of B, so, the total B will be equal to N1 L1 plus 0 that is N M into M.

So, then for a single stage case as I mention that, M will be the total flow rate in kg of A plus C per hour X A M and N M are the concentration of the point, X A M and [noise] M at the concentration of the point.

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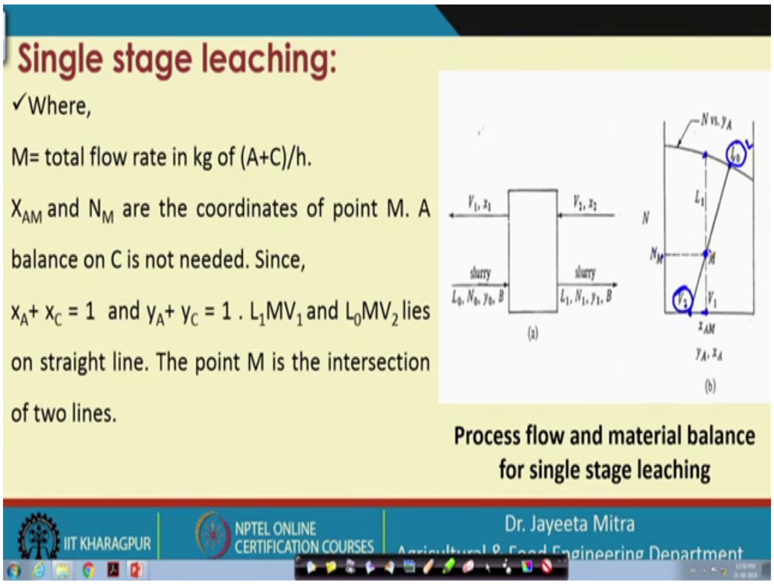

So, if suppose, we had initially we had L 0 that is the feed slurry and we had V 2 that is the solvent, we had some X A 2 for this V 2 and we have some Y A 0 for this L 0, now when these 2 streams are getting mixed they will come to an equilibrium at certain point M let us say, so that M from the M again if, we consider that they will be V 1 1 point V 1 that indicating our that indicating our over flow and that will have a concentration and here again L 1 that is our; L 1 is our slurry is going out. So, these will be the equilibrium point.

Now, the correspondent to this equilibrium what will be the X M and what will be the NM that we find, so that we can get what will be the bulk liquid there and what is the concentration of the solutes. So, X A plus X C that is equal to 1 similarly, Y A plus Y C equal to 1 because, A and C both are the comp1nts of the solution plus solute mixture if 1 fraction we know the other can be the fraction can be calculated with considering both the fraction equal to 1. Now L 1 MV 1 so the line L 1 M V 1 and L 0 M V 2, these two are straight line and the point M is the intersection of these 2 line. So, they has to reach to this point for equilibrium.

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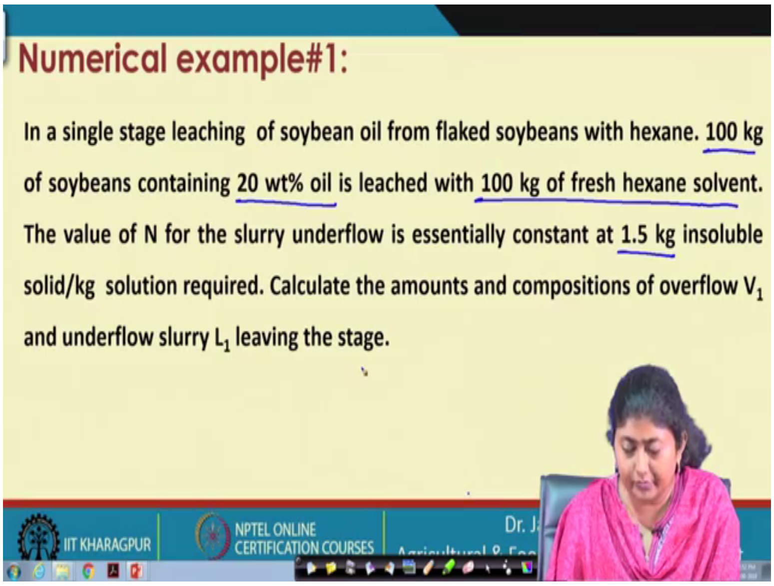

So, in a single stage leaching, we will solve a problem so that, we can we can see that how we can draw this, equilibrium diagram and how we can calculate that what fraction will be extracted by the solvent and what will be retained.

So, in a single stage leaching of soya bean oil from flaked soya bean with hexane, 100 kg of soya bean containing 20 weight percent oil is leached with hundred kg of fresh hexane solvent, 100 kg of soya bean was there, containing 20 weight percent oil with leached 100 kg of fresh hexane solvent. Now the value of N that is the inner material for the slurry under flow is essentially constant at 1.5 kg insoluble solvent per kg solution required. Calculate the amount and the composition of overflow V 1 and underflow slurry L 1 during the stage. So, this our question, calculate we have to calculate the amount and composition of overflow V 1 and underflow slurry L 1 leaving the stage.

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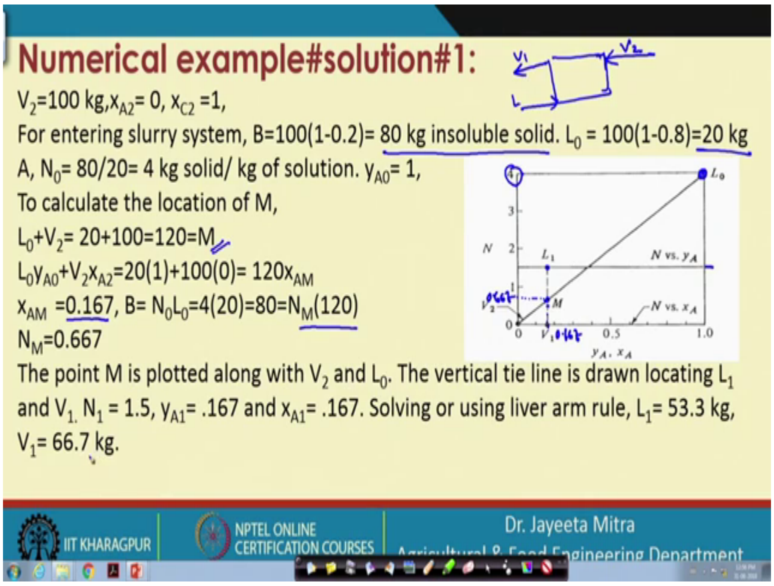

So, how we can proceed in that problem, first we have to see we have single stage case. So, we can we can have that diagram we can make this diagram were L is entering and there V is coming into. So, V first is V 2 stream that is coming that is 100 kg, but there is no trace of solute X A 2 0 and X C 2 that is it is purely solvent, so X C 2 is 1. Now for entering this slurry system, so this has 20 percent of the oil. So, solid will be 100 into 1 minus 0.2, So, 80 kg insoluble solid will be there So, what is L 0 then, so the mass of the solute that is entering that is there 20 kg. Now, N 0 that is 80 by 20 that is 4 kg of solid per kg of solution.

So Y A 0 is equal to 1 because, initially all the concentration were was there in the in the C slurry itself, so Y A 0 equal to 1. Now to calculate the location of M, that is the mixture point, so if these two liquids are getting mixed, so what will be the equilibrium point. To calculate that, L 0 plus V 2 that is 20 plus 100, that is equal to 120, this will be our aim the total material of solvent plus solute. Then component balance when we do L 0 into Y A 0 plus V2 into X A 2 that is equal to 20 into 1 plus 100 into X 2 and this is equal to M into X A M. So, putting the value we are getting X A M as 0.167. So, this is very important, where the mixture condition the concentration of the solute is coming this, then B will be N 0 L 0 right because, there is no other component mixing with this. So, this is inert, so N 0 L 0 that is equal to 4 into 20, so 80.

And this 80 this V 0 N 0 equal to N M into 120, so N M also we are getting as 0.667. So, now the point M is plotted along with the V 2 and L 0. So, how we can plot, it was given that initially when V 2 was initially, when V 2 the concentration of X A 2 was 0 and the concentration of Y this was at 1. So L 0 we have taken from here and this was corresponding to the 4 kg of the solid per kg solution. So, there is 4 kg of per kg solution with respect to that the concentration YA 0 was 1, which was the initial point.

Now it says that that initial have to fix at 1.5, so this is this line showing and when this line is getting mix, so this has to because 2 stream are coming the L 1 stream and V 1 stream. So, this line has to pass through this point. So, this will be the M or mixing point for which N M will be 0.667 and the X AM that will be 0.167. So, solving or using the liver arm rule we can get the L 1 as 53.3 kg, L 1 will be 53.3 kg and V 1 that is the solvent that is 66.7 kg.

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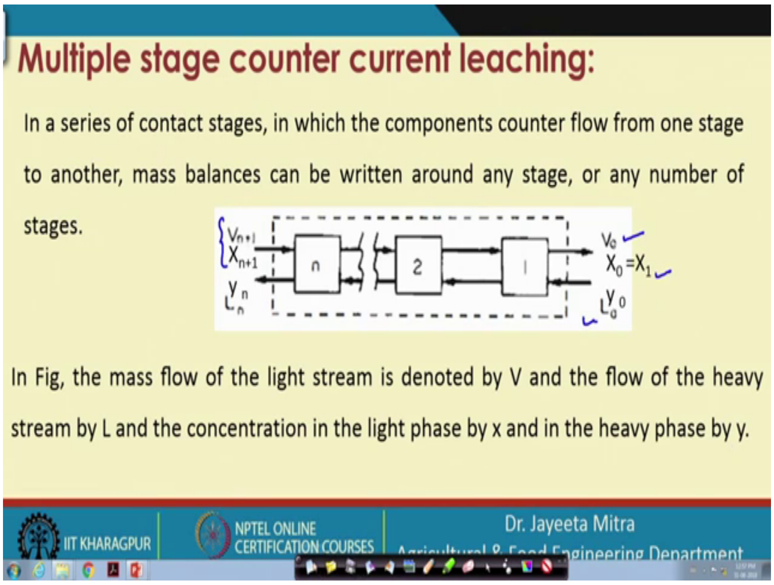

Siimilarly, we can have the multi stage counter current extraction. So, in the multi stage similarly like we had earlier 1 stage, we have now 1 2 and up to n stages, but the process will be same here. This is the counter current leaching, so we have to enter solvent we have to enter solvent from, we have to enter solvent from one side. So, here the solvent is entering V n plus 1 in the nth stage with X N plus 1 of the concentration. And then, it is moving on to stage 1 and there V 0 is coming out with X 0 equal to X 1 concentration, similarly L 0 Y A 0 that is the you know the solid or the slurry says entering that is L 0 and Y 0 and that is eventually coming to the end stage that is L n Y n.

So, in which we get the mass flow of the light stream is denoted by V and the flow of the heavy stream by L; that means, heavy stream in the sense that is the slurry solution and, the concentration in the light phase by X and the concentration in the heavy phase by Y as we did for earlier cases as well.

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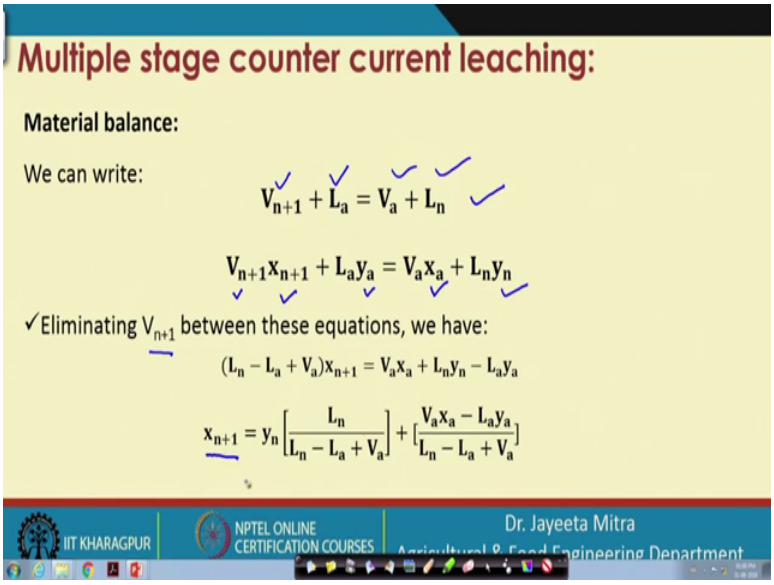

So, then we have to do the material balance for the multiple stage counter current leaching. So, that will be from this 1 [vocalized-noise] n plus 1 plus La if you if you go back to the multi stage figure.

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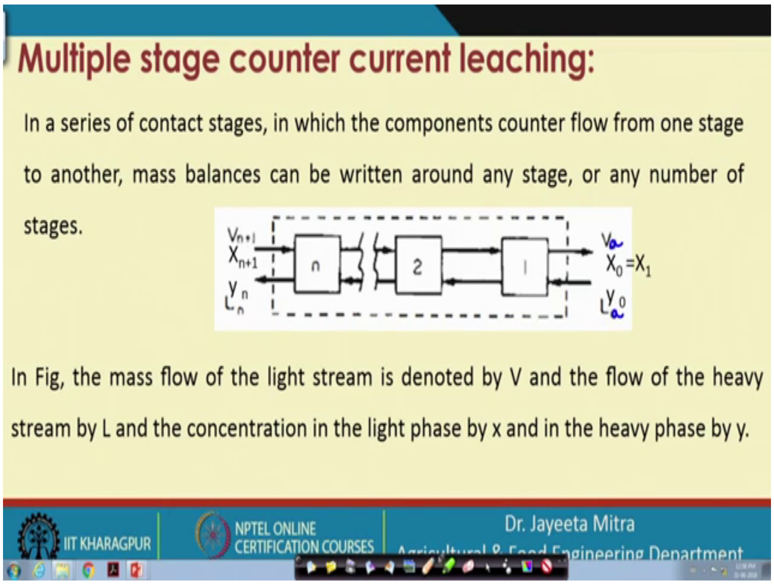

So, we have V a L a X 0 Y 0. So, if this is so this V and L n and n plus 1 and Y La, so this have to be balanced right.

So, V n plus 1 plus La that is equal to V a plus ln. So, whatever solvent enter into n plus 1 plus whatever slurry enter into the first that will be equal to the whatever slurry came out from the from the n plus 1th and what is the overflow came from the first 1. Then, we do the component balance as we did for the single stage and finally, from these 2 equation we eliminate Vn plus 1. So, from the balance of the multiple stage counter current leaching we have this equation which shows the mass balance of the solvent stream and slurry stream.

And then, we have comp1nt balance that is the solvent in what is the fraction of the solute component and what is the component in the slurry similarly, what is the component in the over flow and what is in the underflow. So, with that we eliminate the V n plus 1 and we put it in this equation in this equation. So, that we can get X n plus 1 that is; X n plus 1 that is the concentration of solute in the in the overflow stream or we can we can consider this as a solvent entry for the other one.

So, this is this can be defined by this equation were Y n into third bucket L n divided by Ln minus La plus V a plus V a X a minus La Y a. So, a stands for the first and X n plus 1 stands for the last 1, last stage or nth stage.

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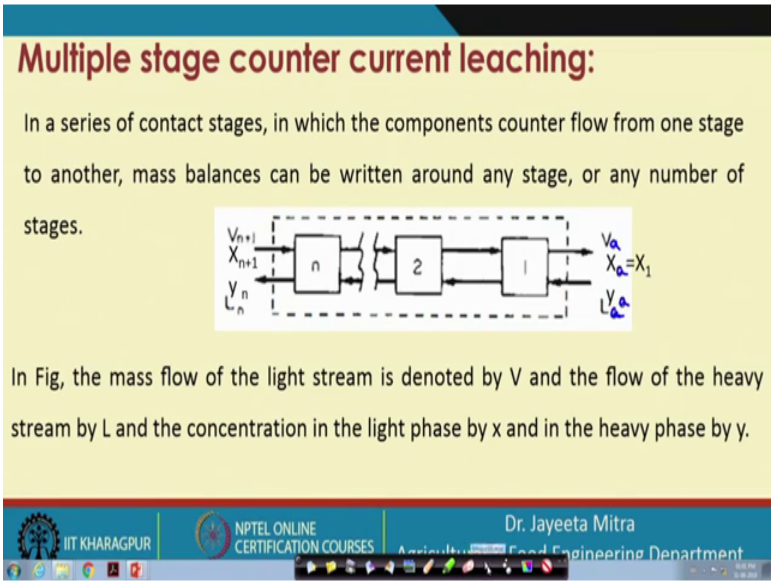

So, this is how we can we can observe here, there was nth stage and there was first stage and for the first stage the everything that is the entry of the slurry and exit of the overflow signified as l signified as a la Y a 0 and V a X A like that and here all are n plus 1. So, this is the equation that we have to use.

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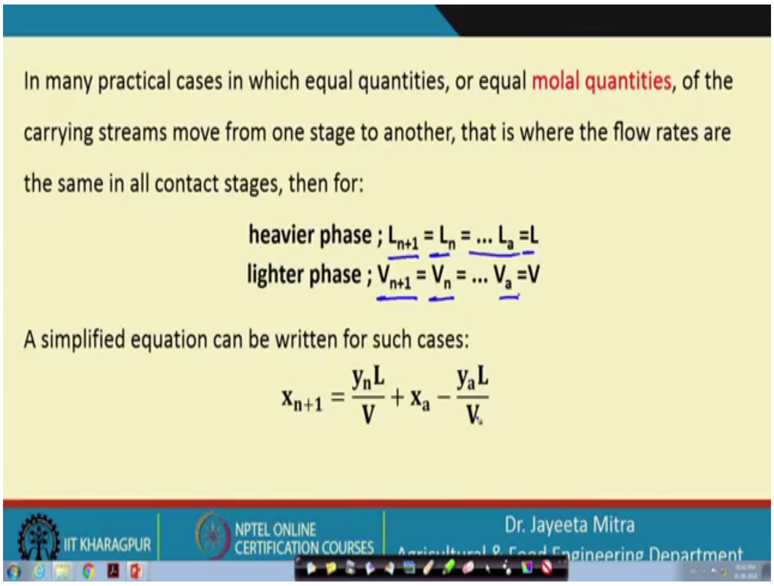

Now in many practical cases in which the equal quantities or equal molar quantities of the carrying streams, move from 1 stage to the other stage that is where the flow rates are the same in all the contact stages. Then for the heavier face or slurry face we can consider this L n plus 1, this is equal to L n, this is equal La up to L and for the lighter face again V n plus 1 that is the solvent entered into the nth 1 that is equal to V n that is the overflow of the nth 1 and eventually that is V a that is for the for the entry of the first 1 entry of the solvent in the first 1.

So, this is the mass of the solvent that is coming. Now a simplified equation can be written for such cases were we can take X n plus 1 that is equal to Y n L by V plus X a minus Y a L by V. So, this method can be applied were the were the flow rate from 1 stage to the other stage are similar.

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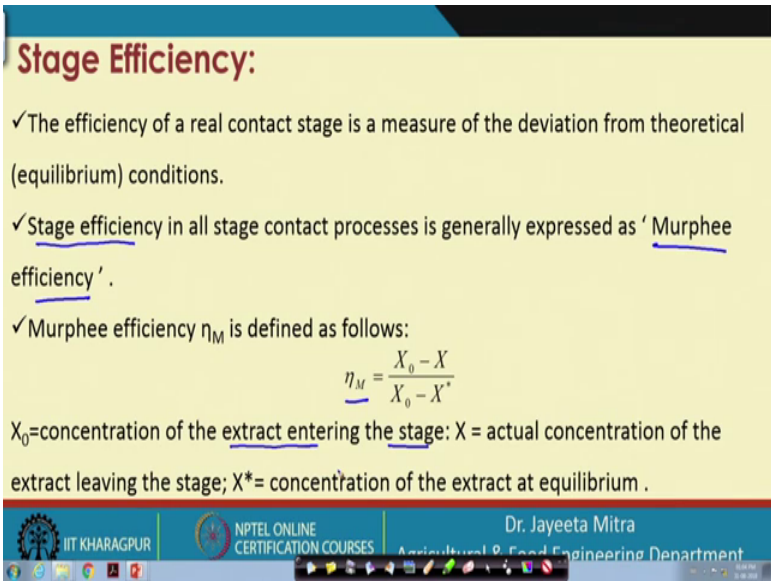

Now once you have to understand that, how the equilibrium point is determined in case of the leaching experiment, then the next stage is you have to calculate the efficiency of the leaching. So, for that the efficiency of real context stage is the measure of the deviation from the theoretical equilibrium condition. Because, theoretically we should have equal X a and Y a value, but there is some deviation from that. So, stage efficiency, stage efficiency in all stage conduct process is generally expressed as Murphee efficiency that is denoted by eta M that equal to X 0 minus X by X 0 minus X star, where X 0 is the concentration of the extract entering the stage, concentration of the extract entering the stage.

And X is the actual concentration of the extract leaving the stage. And X star is the concentration of the extract at equilibrium. So, X 0 is the concentration of the extract entering the stage, X is the actual concentration of the extract leaving the stage and X star is the concentration of the extract at equilibrium. So, this will give you the idea of how efficient your stage performance is, in case of a leaching; I mean this is true for a multi stage leaching or single stage leaching.

So, here will stop, in the next class will solve a few questions on the multi stage leaching and will also see the other you know specific cases were not only the solute, but the solid may be also required in some specific cases of food production. So, both ways we can use the leaching or extraction method either, to separate the particular solute component or in some cases, where the solid we want to get in pure form, where some impurity that is are mix with the with the solid material that has to be separated.

So, Thank you for now, we will meet in the next class.