

**Mass Transfer II**  
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**Lecture No. # 27**

So, in today's lecture, we continue our discussion on Continuous Counter-current Multi stage extractor. If you recall, in the previous class, we said that, if you fix the amount of solvents, then the number of stages will be fewer or if you fix the number of stages, then the amount of solvent required will be lesser in continuous countercurrent stages than you know cross current stages.

So, in the earlier class also, we had this equilibrium diagram, and we marked all this salient coordinates of different streams poor audio quality (no audio from 00:49 to 01:40) cross current extractors; there the approach was look for a mixing point. So, we have one stage where the fresh solvent comes in contact with the feed. So, we get a mixing point. Then we have this equilibrium between extract and the raffinate. Then the raffinate is taken to the second stage where the solvent is added, then we have again equilibrium between the raffinate and extract; two leaving stages. So, the mixing points keeps on changing and we track that mixing point, find the tie line which goes through the mixing point signifying the two leaving streams; extract and raffinate; they are in the equilibrium.

In case of counter-current multi stage reactors, we have the feed here, and we have the solvent; you know at the end and the two streams; they do not see each other, and similarly the two leaving streams; the raffinate and the extract, they also they do not see each other. So, they are not in equilibrium.

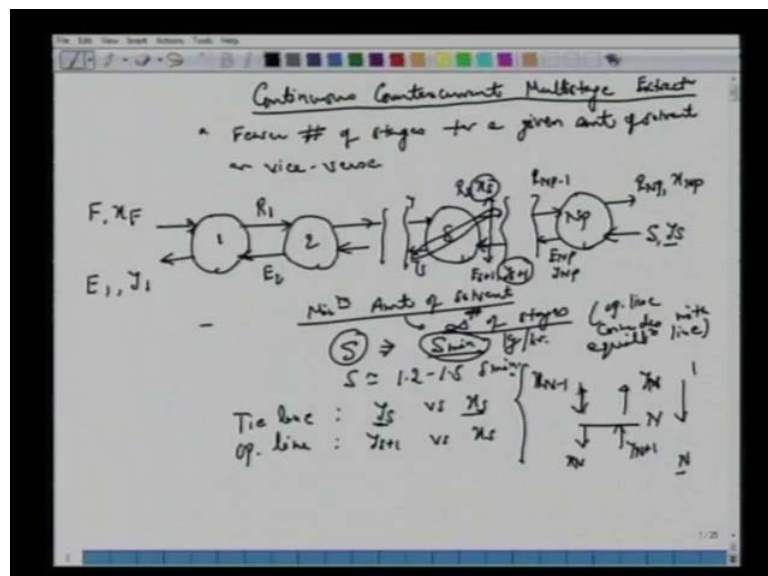
Otherwise in every stage, we do have two streams leaving; they are in the equilibrium. It is an ideal stage. So, the approach to solving the problems related to continuous countercurrent multi stage extractor is to locate difference points,  $\Delta$  points. This is also very similar to the approach we had it in case of distillations where we had, we located  $\Delta$  D for the rectifying sections, and  $\Delta$  b for stripping sections.

So, here we said that in case of continuous countercurrent multi stage contactors, the flow rates between the extract, and the raffinate at any stage is a constant, difference between the two is a constant.

So, we locate for that del D point and then we draw the different operating curves, all right. So, based on the same approach, here we will like to determine what the minimum amount of solvent is when the operating line becomes parallel to the tie line. That will give us infinite number of stages. So, then from the operation point of view, we have to choose the solvent or the amount of solvent in excess of this minimum amount of solvent.

So, let us start this new topic today which is how to determine the minimum amount of solvent in continuous counter-current extract. So, now we are continuing our discussion on continuous counter-current multi stage contactor for extract, all right. And we can make a note here that this gives fewer numbers of stages for a given amount of solvent or vice-versa, all right. We will come back and take this example on continuous counter-current multi stage extractor, and cross current extractor in the later in the class. So, what is the approach here?

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Suppose we have several stages, the cascades. So, feed enters from the left. So, we have  $F, x_F$  and let us say we have this general stage here  $s$ , and then we have at the end the last stage which is  $NP$ . So, the raffinate leaves with the molar flow rate  $r_{NP}$  with a

composition  $x_n$ . So, we have the feed enters here. So, in continuous counter current, we have solvent entering from the other end, say the mole fractions of the solute is very small. Let us say it is  $y_s$ .

So, we have this type of situation. And then the solvent or extract phase leaves at the stage 1. So, we have  $E_1$   $y_1$ . Here we have now  $R_1$  and this is  $E_2$ . So, same conventions; 1 goes with the 1 and 2; this is  $t$  originates from the stage 2. So, we have 2. So, this is  $s$  here, which means this would be  $r_s$   $x_s$ , and here we have  $e$   $S$  plus 1  $y$   $S$  plus 1. Similarly this should be  $E_n$   $y_n$  and here, we have  $R_{N-1}$ . So, this is what here and we want to find out what is the minimum amount of solvent. So, this is the amount of solvent which will give us infinite number of stages. So, that means, the amount of solvent required will be larger than  $s$  minimum.

So, first we have to determine how much amount kg per hour of  $s$  min is required which gives us infinite number of stages. And here we are saying that operating line coincides with equilibrium line for tie line, all right. So, the driving force of the mass transfer becomes 0. We have infinite number of stages, and then we calculate this minimum number of stages, and we choose in general say one 1.2 times or 1.5 times  $s$  minimum. And again here, following this conventions, we have this tie line or equilibrium line which connects  $y_s$  versus  $x_s$ .

So, if this is  $x_s$  here, this is  $y_s$ ; two streams are in equilibrium. We are considering ideal stages. So, tie lines connects for equation for the tie line connects  $y_s$  versus  $x_s$  and we have the same convention for the operating line. We have  $y_{s+1}$  versus  $x_s$ . So,  $y_{s+1}$  is here,  $y_s$  is here. So, we have  $y_{s+1}$  which would be next stage here. So, that would be select say  $y_{s+1}$  if a sorry excuse me.

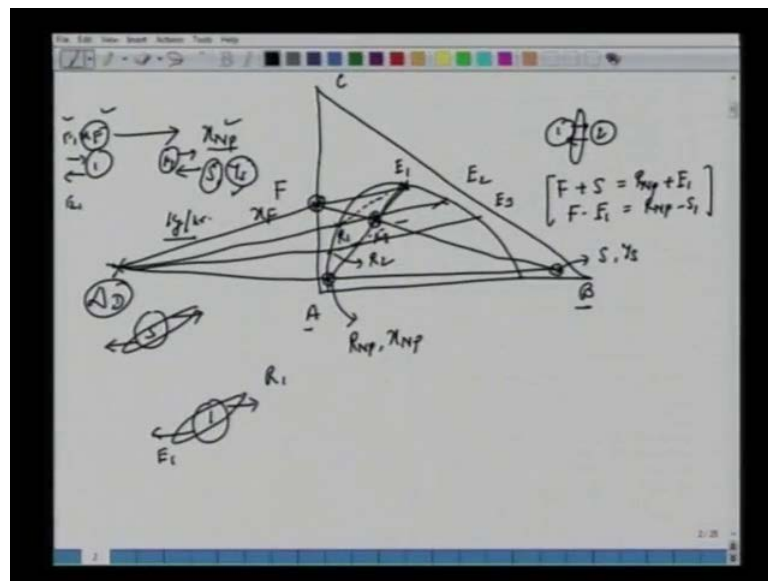
So, you going counting from this side 1 2 3, we have this stream here is  $y_{s+1}$  and we have this  $x_s$  operating line connects between  $y_{s+1}$  and  $x_s$ . So, we have the similar convention which we followed in case of distillation stages also. If you have the stage number  $n$  here, the leaving streams as  $y_n$ ,  $x_n$ , and here we have  $y_{n+1}$  capital  $n$  here  $y_{n+1}$ , if you are counting from the top to the bottom.

So, similarly, this is the liquid which comes here is  $x_{n-1}$ . So, now let us come down to this equilibrium curve here, and let us see how we address the minimum amount of solvent requirement. So, this is a feed,  $b$  is the solvent, and  $c$  is the solute and let us

see if they have the equilibrium curve like this. Now in general the feed composition is fixed here. So, we have  $f$  of course, and we have  $x_f$  denoted by this coordinate here, and let us say that solvent is nearly pure. So, we have  $s$  and we have this  $y_s$ .

So, generally it happens that the first feed is given here; we have been asked to treat this feed. So, feed composition is  $x_f$ , and we have been asked to reduce the concentration from  $x_f$  to the last stage  $x_{np}$  which is  $x_{np}$ . To do that, we have been given this solvent with the composition  $y_s$ .

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So, in general,  $F$ ,  $x_f$ ,  $x_{NP}$  and  $Y_s$  are given and we have been asked to find out what how much is amount Kg per hour of solvent required to bring down the level from  $x_f$  to  $x_{NP}$ . So, here corresponding to  $x_{NP}$ , very small amount of solute in the treated raffinate, we have let us say mark this location as  $RNP$  with the mole fraction  $x_{NP}$ . So, in general, you will see that most of the times  $f$ ; these three coordinates, they are fixed here.

So, now if you have  $F$  and  $s$ , if you connect, then we can have some where here mixing  $m$  coordinate as  $m$ . So, let us say that we have some coordinate  $m$ . So, this represents the combination of mixing of  $f$  and  $s$ . And now since we know the raffinate coordinate here, we can connect this to obtain this  $E_1$ . So, this would be  $E_1$ . So, now notice this that the two streams;  $E_1$  here and raffinate  $RNP$ ; they are mile apart. They are not in equilibriums. At every stage, the two leaving streams; it is raffinate and extract; they are in equilibrium, but here, this is a first stage and the last stage. All we have done we have

connected this, we have made over all material balance, and we have located this m point and then we have, knowing this RNP, we extend this connect this to make an intersection at this equilibrium curve at point E 1.

Then E 1; the stream here the first stage, one this is R 1, and here we have this E 1. So, these two streams are in equilibrium. What we did here that we can find this tie line to obtain this R1, but then to proceed further, what we did in the last class? There we realize that the difference between two stages. So, here we have stage 1, stage 2; the difference between the flow rate of these two streams is a constant.

So, essentially we are saying that  $f + s = R_1$  or  $RNP + E_1$ . And at the same time you can write like  $f - E_1 = RNP - S_1$ , so that if we extend this two line  $f$  and  $E_1$ , and we extend this line here, then they will intersect at a point; we call it  $\Delta D$ ; difference point. So, between any two stages in continuous counter current stages, we have this difference points here.

Once we know this difference point, we can proceed further. You have E 1, this stage E 1 in equilibrium with R 1, we extend, connect this R 1, extend here we have E 2. E 2 again in equilibrium with some stream here R 2 connect this, and we extend here. So, we have R 1, then we have this R 2.

So, the idea here is very similar to what we had in case of distillation column. We located  $\Delta D$  points and  $\Delta w$  points, because the molar flow rates between the two streams arriving and leaving is a constant and given to be equal to the top product molar flow rates or the bottom molar product molar flow rate. So, we have the similar approach here; realizing that the difference between the raffinate and extract stage 1 or a stage 2 or a stage  $s$  anywhere is a constant; difference between the two, we locate this difference points. And once we know the difference points, we can have this operating line and we can have this tie lines we can proceed.

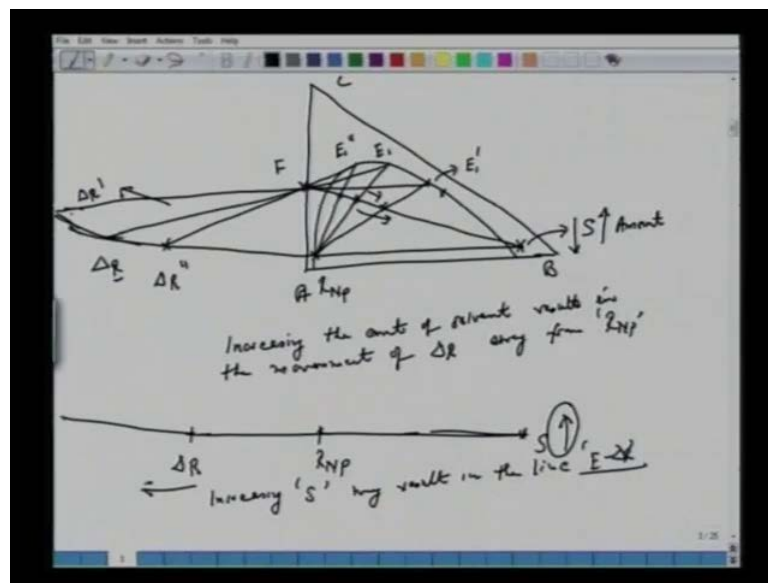
Now, to determine the minimum amount of solvent, we have to see that what is the condition when the operating line which originates from  $\Delta D$  and intersects the equilibrium curve becomes parallel to this tie lines or it coincides with the tie line. So, when it coincides with the tie line, that time the driving force or that stage driving force from mass transfer is 0, and we require minimum amount of may be require infinite

number of stages for the separations. So, we locate that del D min, then we take the operating point which is 1.2 times or 1.5 times.

So, to address this what is the... To determine what is the minimum amount of solvent required, let us see how to what is the locus of this del t, as we vary the amount of the solvent. So, let us re-draw this equilibrium curve and see how does this del point moves or changes as we increase the amount of solvents. So, we say that let us fix f, we know this RNP, it is given to us and we have been given quality of this solvent is fixed here which is given as s.

So, we connect this F s; over all material balance to begin with we know this m, we connect this to get this E 1. We extend f n E 1, we extend f and R N P and S.

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We have this del r, let us say r denote denotes for raffinate here. Now if we increase the amount of solvent, say let us notice so, this point is fixed here, this point is fixed here, and this coordinate is fixed here. All we are doing is we are increasing the amount of solvent. We increase the amount of solvent, and then you can make out that this point will move towards this. So, this fixing point will move here, then if we extend the second suppose the mixing point has moved from here to here, then we get new E 1, let us say u 1 prime, and now if we connect this E 1 and f 1, then you can make a notice that this del

r point is going to move further down. Let us say it makes connections here at different location del r 1, right.

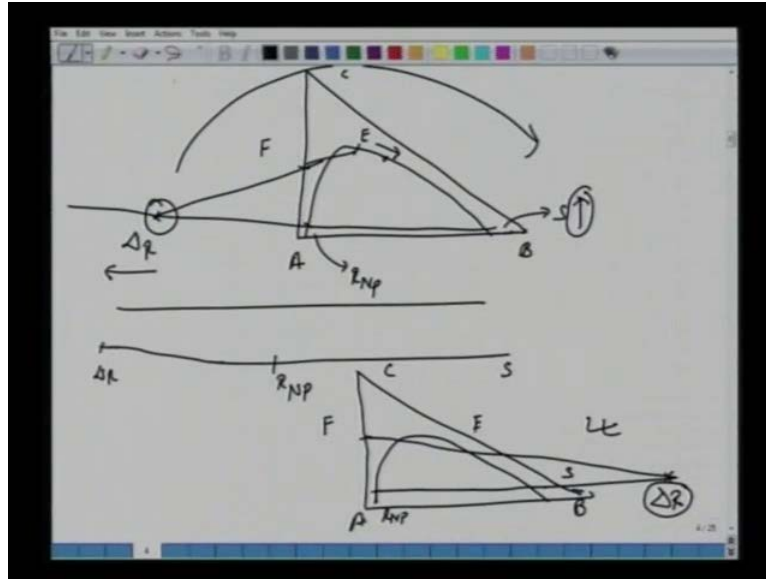
If you decrease the amount of solvent, then this m is going to move further here, then if you connect this raffinate to get another E 1 prime, and now if we connect this f 1, this point is going to move in this direction, l r double prime. So, we make a note that increasing the amount of solvent results in the movement of difference point del r away from RNP.

So, when we increase, this del R points moves in this directions. So, if we just let us say just locate s here, and let us say this RNP, and let us see this is your del R. So, this point is fixed, this point is fixed here, we can extend this line here, and if the amount of s increases, del R moves in this directions. What happens? If we keep on increasing the amount of s, ultimately this line which connects extract E, and f will become parallel to this line which connects s and r.

So, we also make a note that increasing amount of solvent may result in the line E dash del R. So, the line which connects extract and del R may result in the line parallel to line del R and s. So, we should make a note here that if you increase the amount of solvent, the increasing this amount of solvent del R moves in this directions. If s decreases all right, then del R moves in this directions. If you keep on further increasing, there is a stage where this extract, let us re-draw here.

So, we have a, we have b, we have c, this extract and this equilibrium curve here, we said point F is fixed, we have s fixed here, we have RNP fixed here. And this is the line which extends in this direction. If we keep on increasing the amount of solvent, then E 1 extract; this will move in this direction. So, s goes this direction, E will go in this directions, and the line connecting this E to f which gives us del R moves in this directions till keep on further increasing, this line E extract f and del R will become parallel to this line.

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So, there will be a stage where we have this S, RNP, and then very far from here it is possible that this line which we have connected is now parallel to this. If you further increase the amount of s, then we said that this  $\Delta R$  now will appear on the right hand side. In other words, if we have the equilibrium curve, let us re-draw A B C and we have the same equilibrium curve here. The point f is fixed, amount of raffinate R N P is fixed, and this solvent s is fixed. If you keep on increasing the solvent, then now the line which connects F and E will move in this direction. So, we have RNP, now we have a solvent here, now this point is going to move in this direction. So, we will have the  $\Delta R$  coming appearing on the right hand side. So, it is very important that we understand the locus of this  $\Delta R$  point.

At certain amount of solvent, if  $\Delta R$  is on the left hand side like in this case here, we increase the amount of solvent till this line becomes parallel to this **right**, keeps on moving in this direction till it becomes parallel to this, we further increase, now the line appears on this right hand side difference. So, we have now this F.

Now, let us see what is the stage, what are the conditions when the line operating line becomes parallel to the equilibrium curve, all right. So, before this, let us just try to summarize here that we have been able to locate the locus of this  $\Delta R$  points as the amount of solvent is increased.

So, to start with, if we have the feed composition is given us, raffinate composition is given to us and the solvent composition or the quality is fixed to us. We are only

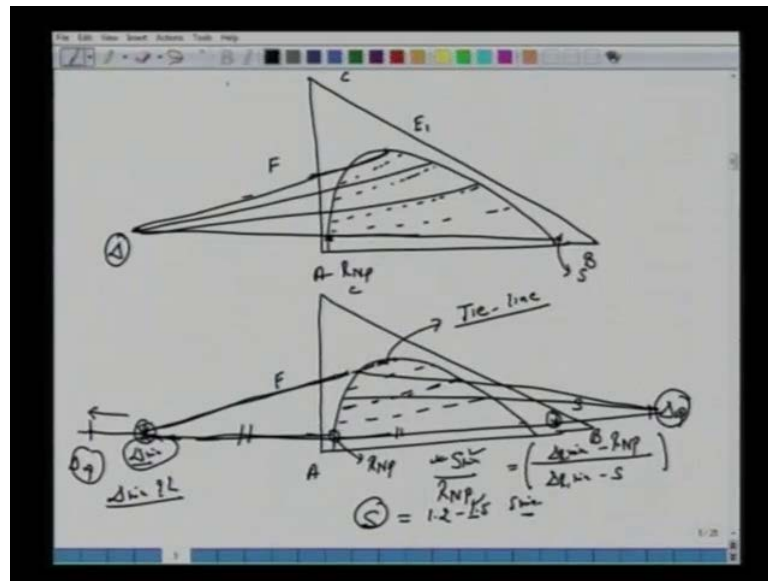


changing the amount of the solvent. So, if the difference point lies here; that means, F E extract, intersects that line connecting F and E intersects R and solvent and on the left hand side of the curve the curve. Then we further increase the amount of solvent, this point will move till this line becomes parallel to this further increase. Now the difference point appears on the right hand sides. In this case, now the slope of the operating curves has changed. Earlier it was on the left line in this directions, now it has changed in the other directions.

Now, with this we should be able to find out under what conditions these operating lines; either this way or this way becomes coincides with the tie line. That will give us the minimum amount of solvent. If we can locate  $\Delta R_{min}$ , then we can take 1.2 times or 1.5 times amount of solvent.

So, now here also there are two cases; we will consider case one when the equilibrium or the tie lines have the slopes very parallel or slopes nearly same as the operating lines. So, there are two cases here. So, we have A B C and this equilibrium curve here. Let us say this is a feed says RNP and here we have this s, and let us say  $\Delta r$  points passing through this is here. So, this is E 1. Now there is a possibly and there are several such tie lines. So, these are the equilibrium curves. So, let us say that equilibrium curves, the slope of the equilibrium curve is like this, all right. So, the way we did in case of distillations, let us find out what is that  $\Delta_{min}$  or right which corresponds to the operating line which we have drawn in the previous cases, several cases like this becomes or coincides with this tie lines.

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So, the first thing is that find out that tie line which extended, will pass through this for intersects this RNP s. In other words, find out the del R min in this case. All we have to do is, if we have curve like this, and this is F here, what we have located s, we have located RNP and we have extended this line, we are looking for del min. What is the minimum amount of solvent when the operating line becomes coincides with the tie. So, all we do we find that tie line in this case, which if we extend will intersect the point line here. So, you can say that now we have the amount of solvent corresponding to this del I del min, which will give us infinite number of stages, because now this is same operating line which is now coinciding with this tie line.

So, there are several such tie lines, first what we should do, find that tie line the first tie line which if you extent, intersects the line connecting between RNP n and s gives us del l. Once we locate this del l min, our definition for solvent we can apply lever rule along this line s, divide by RNP amount of solvent or amount of this raffinate l be equal to del R which is del R min here dash RNP. So, the segments s over RNP is the segment del R RNP. So, these segment divide by RNP. So, we have the total segment del R min S. So, the bigger segment from here to here.

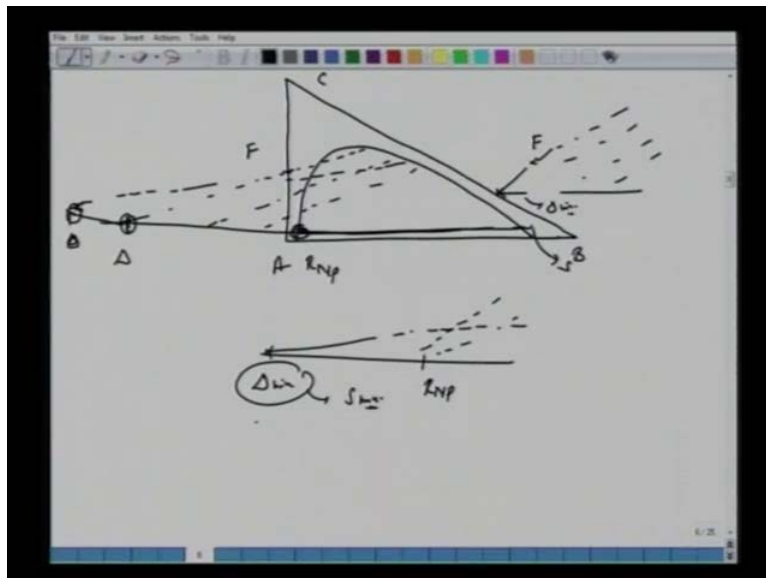
So, from here once we locate this point, you can calculate s minimum. Then we can choose s as 1.2 times or 1.5 times s min. Now, if you choose any amount of solvent greater than s min, recall just in a previous discussion, now the operating curve will

move further away, and if it goes to that extend that del operating point has come to the right hand side, then we will have we can also have operating line right here. This case all the operating line will originate from here, and in no way any of these operating lines will be coinciding with any of this tie line.

Now, there is one more important thing here that there is a possibility that some of the tie lines underneath this first tie line which crosses through f, can give del min larger than what we are getting right now.

So, let us try to take this special case. There is also a possibility that we have equilibrium curve, this is f here, you mark RNP, we have marked s, we have extended this line here; this is the tie line which extends with f and it meets difference point or it meets this line right here. Now we said that, in general it is possible that all the tie lines, they will be if we extend, then they will be intersecting this line closer to this r n, like this, but in some system, it is possible that certain tie lines are like this, which means if we extend, then this will be intersecting this line or this curve further away from this RNP.

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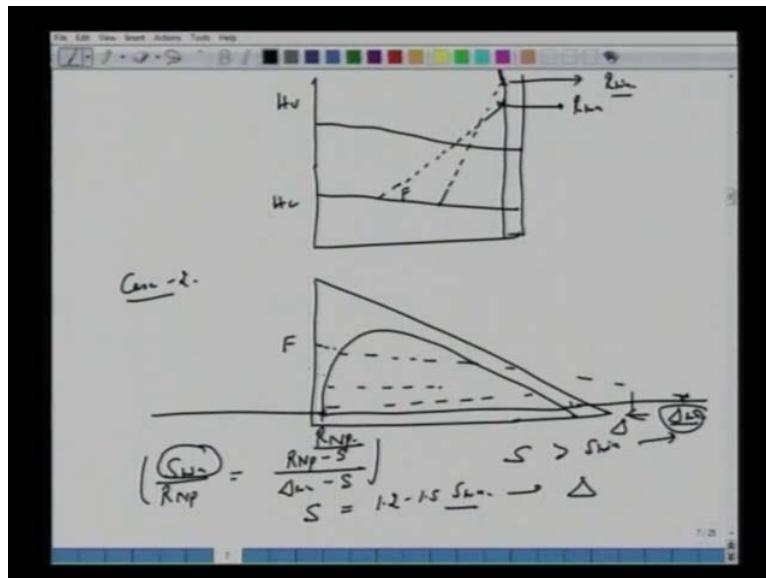


So, in this case, we must choose that intersections that del difference which is farthest away from r n. In other words, one is supposed to extend all the tie lines which intersects with this line connecting del, connecting this RNP and B further away, the farthest away from this RNP.

So, we also make a note of this in general of course, we said that all tie lines, if we extend, then there is possible that the first tie line which crosses this F will give us the minimum  $\Delta_{min}$ , but there are several different type of systems where we have this type of situation that tie lines need not be like this. Some of the tie lines may be cross may be like this which can be extended to give us  $\Delta_{min}$  farthest away from this RNP. So, based on this, then we should calculate  $s_{min}$ .

So, this is also very similar to what we had in case of distillation. If you recall, we had equilibrium curve  $h_v$  vs  $h_l$  and we said to find out this minimum amount of reflux ratios, if this is the location for feed, then find that tie line which extend here this gives us  $R_{min}$ , and then there is a possibility that in certain system non ideal system, certain other tie lines which you extend will give you  $R_{min}$ . So, we have also similar kind of situation in case of extraction. So, one has to do some inspections to find out the minimum amount of solvent.

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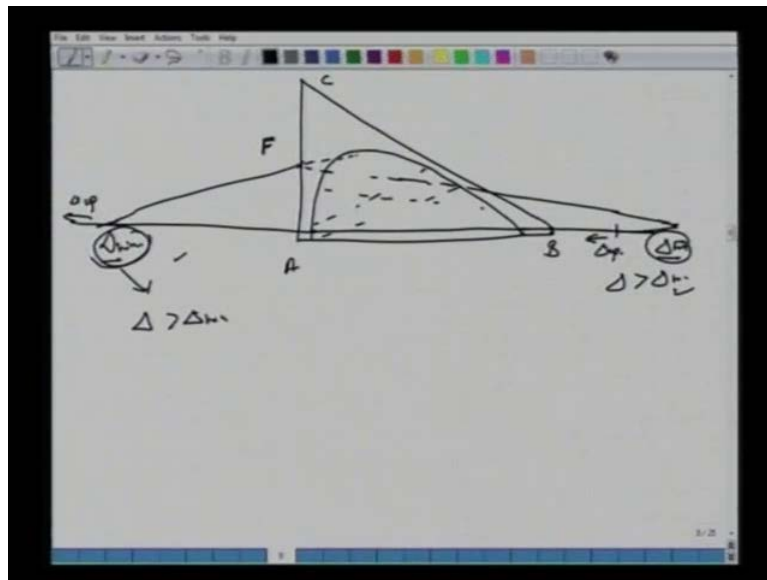
Similarly, if you have the tie lines; say case two, you know where the tie lines are downwards in the other directions, say if you have the tie lines like this, in this case also one has to extend. So, if you have this RNP and  $y_s$  extend like this and this. So, in this case, you can make out that the tie line which crosses which passes through  $F$ , if you extend, this will give us  $\Delta_{min}$ , and if you choose the amount of solvent greater than this  $S$

min, corresponding to this del min, then the del point will move further towards this RNP, all right.

So, in this case also, the amount of s min for given amount of RNP; the definition will remain the same. s min over RNP will be the tie line the segments connecting RNP and this ys or s over del min **ss**. So, the definition is same. From this, you calculate s min and then take s as 1.2 times or 1.5 times s min. And then that will give us new del, and then if you increase this any amount of solvent greater than this del; of course, never this operating line will be parallel or will coincide with any of the tie lines.

So, that is the discussions we had, we just want to summarize here one more time. This is equilibrium curve. It is all about the locus of this del points. And we have two types of situations; either the tie lines are like this or tie lines are like this. We have to find out the amount of solvent which coincides with any other tie lines which gives the maximum minimum amount of solvent, and then take 1.2 or 1.5 times to be in the safer sides. So, here if you fix this RNP and connect this s, this can go either way. To locate this f, find this tie line which you extend to give del min.

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With the tie lines are downward, then find that tie line which you extend in this directions, this will give you del min this way.

So, depending upon what type of systems we have, we will get  $\Delta$  min here,  $\Delta$  min here. One more important is that if you take larger any  $\Delta$  greater than this  $\Delta$  min, then  $\Delta$  operating will move in this directions. And if you choose  $\Delta$  greater than  $\Delta$  min, then your  $\Delta$  operator will move in this directions. So, it depending upon what type of systems we have, one has to be one has to inspect the type of equilibrium curve and then locate this  $\Delta$  min; either here in this case or in this case, all right.

So, that is the discussion we had for total amount of solvent. We will of course, take an example in this case to determine, to locate this  $\Delta$  min,  $\Delta$  min which corresponds to minimum amount of solvent required. And we said that you know it all depends on the slope of these tie lines. In some cases, extract equilibrium composition is greater than this raffinate. So, we have upward slope. In some cases, we have extract compositions smaller than the raffinate. So, we have the downwards slope like this and  $\Delta$  min can move from the left and the right hand side.

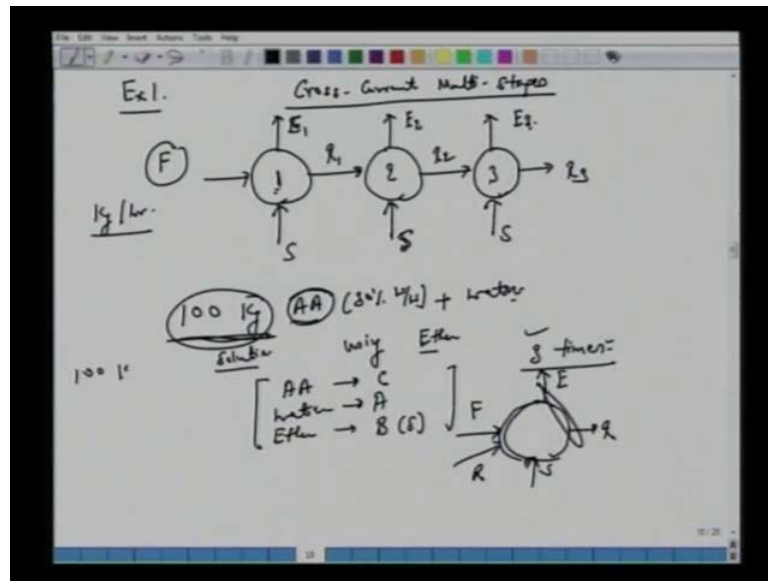
On the other hand, as far as the amount of solvent is concerned, if we keep on increasing and if we start if certain difference points - difference point is going to move further away from the raffinate till the line becomes parallel to this  $\Delta$  operating moves to the right hand sides, further increase it will move towards RNP.

So, the locations of this  $\Delta$  points is like clockwise, with the increasing amount of the solvent. Equilibrium line thermodynamic lines, that depends upon your type of the systems which you have. If you have tie line like this and your operating line is on the right hand side, then you are on the safe side. You do not have to worry about any of that operating line coinciding with these tie lines.

But if you have  $\Delta$  points on the left hand side and you have the tie line also in the that direction, then there is a risk of operating line becoming or coinciding with this tie line. In that case, first find the  $\Delta$  min, take 1.2 or 1.5 times, and then increase your solvent amount.

So, now we take an example. Now we have if you recall we have taken three cases: one was single stage extractor, then we talked about cross current stages. So, we have 1 2 3 4 stages, but we had this cross current and then now we have taken third case, where we have this multi stage counter current extractors. So, we are going to take an example for each cases.

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So, we take this first example one on cross current multi stages. So, we are looking for stages like this, where we have this feed we bring in contact with the solvent, phase solvents, we have the raffinate sorry we have this extract, take this raffinate. So, stage one, this is R 1, E 1, bring to the second stage, bring fresh amount of solvent, we have extract here; heated raffinate R 2 bring in contact with this third, again the solvent in the third stage, and we have this R 3 and E 3, etcetera, all right

So, this example is about is like reads like this: you have 100 Kg of say acetic acid, 100 Kg of this solution in water which contains acetic acid as a solute which is thirty percent weight by weight. So, 100 Kg of solution containing acetic acid in water and we have been asked to extract this acetic acid using a solvent let us say ether, all right.

So, here acetic acid is now your C. Water is the solvent; its B, water is a feed here. So, we it is A and ether which is solvent is now B or we also use sometime S. So, the problem reads that we have to do it three times.

So, notice the difference here when we have this now we have when we draw this stages like this, it is a continuous process. So, this f is Kg per hour. So, we say that its feed is going to be treated in three stages. Here the problem says that feed amount of feed is given 100 Kg which is to be treated three times. So, it is like one is you choose a stage, you bring f, contact with s.

So, now we have extract and raffinate. We have a settling time, the two are in equilibrium. All it means that you take this E raffinate, remove this extract and take this raffinate bring it back to the same stage and bring in contact with s second time. So, first time, second time, third time; it is like a batch operations. Here it is a flow experiments or dynamic experiments, but the treatment mathematical treatment will be the same. 1 2 3; they denote a stages and you can also think that 1 2 3 they denote three times. So, in other words, first time whatever we have taken this raffinate. Again your treating it with the s in the same stage, all right. So, whether it is a three times or three stages or where whether we have the total amount given as 100 Kg or 100 Kg per hour, we have the same treatment, all right.

So, the equilibrium data is given as following. So, we have water and we have ether. So, you can make over, this is your its raffinate phase R, and this ether; this solvent is your extract phase. And here we have been given all weight percent of acid which is C, then we have water which is A, ether which is B. So, the problem statement or the data would be given in terms of acid, water, ether and we have to identify; this is a solute; you put C, water it is a feed; so, you put as it A, ether is a solvent; so, you put it as B.

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Raffinate (R)			Extract (E)		
Acid C	Water A	Ether B	AA C	A B	B
0.69	78.1	1.2	0.12	0.5	79.7
1.40	72.1	1.5	0.37	0.7	78.7
...	...	...	...	...	...
26.2	52.7	4.4	21.6	6.7	71.5
46.4	37.1	16.5	36.2	15.1	48.7

3 stages ~ 3 times  
 [ 40 kg ~ 40 kg/hr ]  
 [ 100 kg. ~ 100 kg/hr ]

Similarly, we have acetic acid again, we have A water, and we have B as a solvent in this extract phase. So, two phases; raffinate and extract and we have been given the data like this: A- acetic acid, C A B. And datas for example, we can write down few of them; 0.69,



98.1, 1.2. So, this is a raffinate phase, large amount of solvent, we have some solute here and some amount of solvent as well. We have 0.18, 0.5, and 99. And these two phases are in equilibrium. So, from here if this is  $x=0.69$ , this is our  $y$ .

So, we require a  $y-x$  diagram as well. So, you have to identify very carefully and similarly, you have a 1.40, this is 97.1, we have 1.5, this is 0.37, 0.7, 98.9. Any physical hand book or thermodynamics or if you do the Google search and type for this, you know ternary diagram for this water ether system with acetic acid, it should be able to locate such type of information.

Similarly, here we have 36.7, then we have 46.4, 58.9, 4.4, 37.1, you have 16.5 and similarly, some more data here which we skip 21.6, 6.9, 71.5, 36.2, 15.1, 48.7. Such type of thermodynamic data you are supposed to avail yourself. You can go through some of the thermodynamic hand book or Treybal McCabe Smith or the book by Dutta; these information is a very common combinations of three species; acetic acid water and ether.

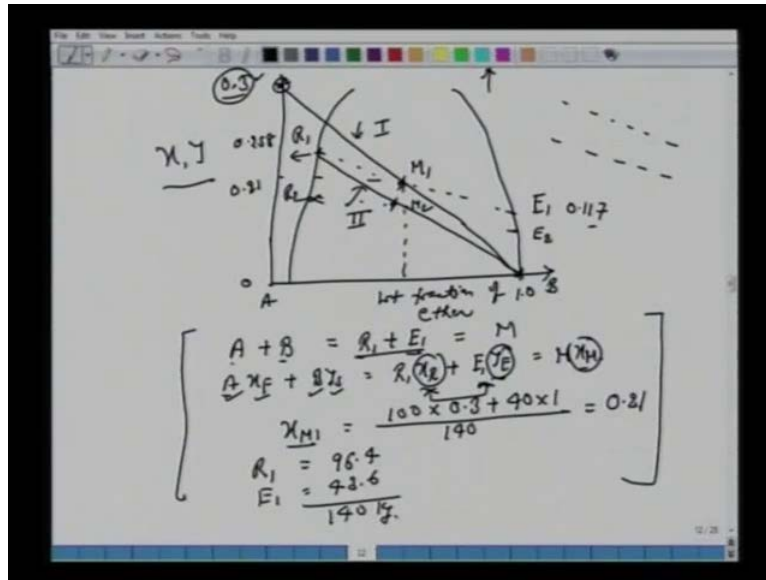
Now, in this problem it is given that, we have to use three stages or three times. We just now we discussed that they have the same meanings, our mechanical treatment for this type of problem is similar. And we have to use 40 Kg of solvent. So, this is 40Kg of solvent or we can say that this is solvent flow rate is 40 Kg per hour. So, which means if you are talking of this flow rate, then the feed is 100 Kg per hour or if it is a batch operation, then this is just 100 Kg. We have the same situations, all right.

So, now, all we do? We first draw this equilibrium diagram, but notice here that our feed was given as 30 percent, all right, weight by weight. And look at  $y$  versus  $x$  diagram, and the extract compositions of the solute is a smaller than this solute concentrations in the raffinate; that means, we can stop or we can plot only till here where the feed composition is 30 percent. You must understand that we do not require the data beyond this because weight composition is 30 percent. So, solid concentration increases 37.7 percent. So, maximum is 37.7 here, we can take this data here and we also realize that  $y$  is smaller than  $x$ .

So, if you choose only these data here, we should be able to solve the problem and we have been asked to find out what are the raffinate concentrations or find out the compositions of all streams. So, we plot right we said A B. So, this is the weight fraction of ether. And all we have to do is to only go till 0.3. So, we have this equilibrium

diagram like this, we do not need. So, this will be 1 here this is 0 here, we do not need any data beyond this because all the tie lines are sloped downward. So, this scale from 0 to 0.3 is good enough. So, this also very important that we realize that rest of the data we do not need so that we can expand our scale and we can work in this range.

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Now, the feed first stage, 0.3; it is a pure solvent. So, this is 1 here. We connect. So, we are mixing it first stage, and we mix and then we settle. So, knowing the amount of this 0.3 amount of the solvent, you can write A. So, let us say for the feed, added solvent added here, it gives us R 1 and E 1 raffinate and extract phase; they are in equilibrium. So, we can also write A x<sub>F</sub> plus B y<sub>S</sub> as R 1, x<sub>R</sub> plus E 1 y and it is ideal stage x<sub>R</sub> and y<sub>E</sub> they are in equilibrium. So, this gives us m; mixing, and this gives us x composition x<sub>m</sub> or in other words, knowing this two graphically, suppose we locate m 1 like this.

So, we know this compositions here, here we have plotted x and y, x and y versus weight fraction of ethyl here. So, we can solve mathematically or we can solve graphically. We have 1 2 3 4 is all known given to us, x<sub>R</sub> and y<sub>E</sub> not given to us, but we know they are in equilibrium, right, so two unknowns, two equations. We first we have to calculate this x<sub>m</sub>. Once we know x<sub>m</sub>, let us say let us calculate x<sub>m1</sub> which is put the number here, 100. For a feed is 0.3 solvent, amount is 40; either 40 kg per hour or 100 Kg per hour or just 100 Kg and 40 kg into 1; solvent is pure, 100 plus 40 140, get this 0.21. So, this

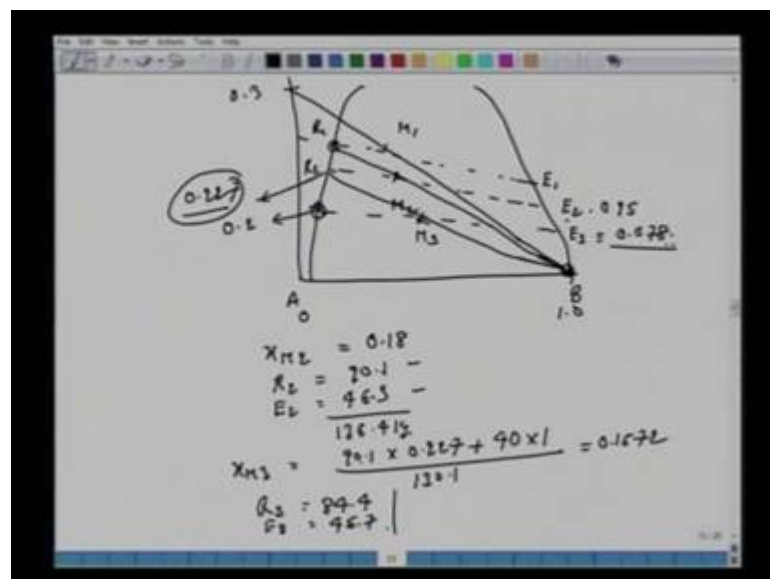
location here is say let us say, 0.21. All we have to find out a tie line which passes through this.

(No audio from 46:18 to 46:21)

So, we have this extract E 1, and here we have this raffinate R 1, all right. So, if you know this  $x_{m1}$ , then you can do the same exercise now for R 1 plus E 1 and  $x_r$  plus E 1, I leave this as a as an exercise. You should be able to obtain R 1 as 96.4, and E1 as 43.6 to make it total as 140 Kg. So, this raffinate R 1 and E 1; we have the amount from the equilibrium curve we can read this, should be 0.258 or you can also calculate and this E 1 is 0.117.

Now, take this raffinate and connect this to B. So, we have the stage two. So, this is stage one, and now we are taking of stage two. For the stage two also, we have the same similar equations. First you are supposed to find out what is M 2. So, what is the second mixture compositions, and then find a tie line which passes through this M t to give you R 2 and to give E 2. So, you can do this exercise yourself. Let us just plot here the three stages compositions. So, we have a let us say this is b 0, 1.0, this is 0.3, we have this equilibrium curve like this connected first stage. We find m mixing; m 1 here let us say, find a tie line. So, this one is R 1, this one is E 1. Connect this R 1 to this stage here again, find the new M 1, M 2 point, find another tie line; need not need not be parallel, E 2 and R 2.

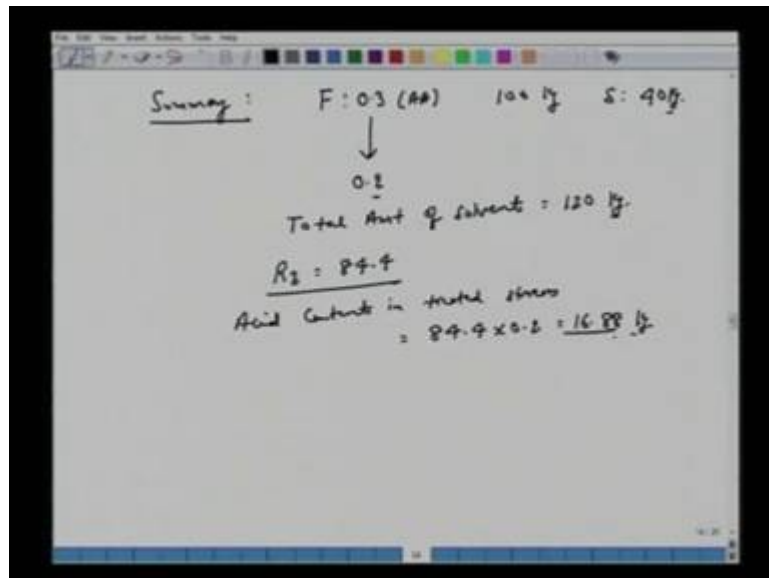
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Or mathematically you can solve you know this amount of R 1, you know this b, you know the compositions here, find the new M 2, and find the new tie line which passes through this M 2 here. In this case, you can show that your X m 2 will be equal to 0.18, and the amount of raffinate and extract will be 90.1, extract E 2 will be 46.3. If you add this two, this should be the amount of 136.4 K g; the amount of raffinate which we started with, right. So, this is the raffinate and E 1 E 2 here and this compositions here if you note down, this composition would be 0.095, and here this raffinate would be 0.227, all right.

So, again connect this R 2 to this feed, phase solvent, find the new m 3, and find this tie line. this time this point should read as 0.2, and this E 3 should read as 0.078. In this case also, you can note down the third stage; X m 3 will again be equal to say 90.1; that is what we had into 0.227. So, this is 0.227 here plus we have phase amount of solvent; 40 into 1 divide by 90.1 plus 40 130.1. This will give us 0.572. So, we locate this coordinate. Again we find the tie line which crosses through m 3 to obtain this 0.2 here, and we locate this 0.078 and then again one can find raffinate R 3 as 84.4 and extract amount as 45.7.

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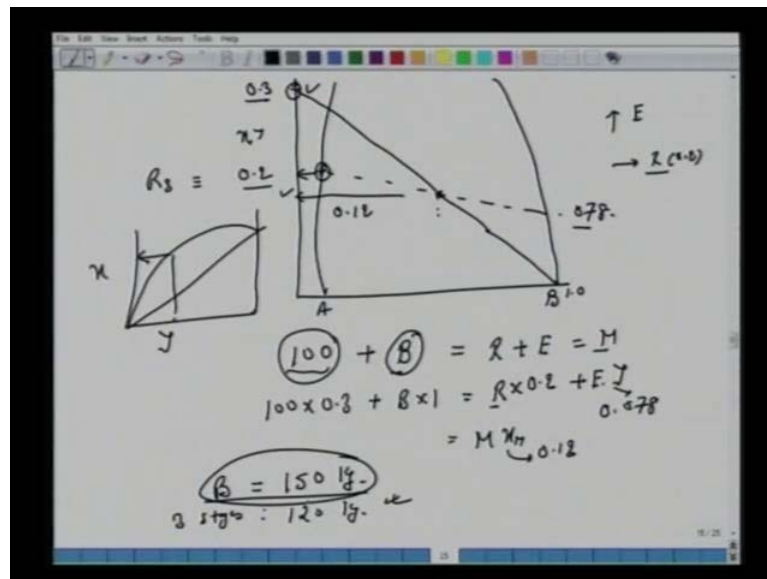
In other case, if you summarize here, we were given the feed which has a composition of 0.3, all right. So, this was the acetic acid present in this, we had the amount of feed, amount was 100Kg, three stages we had brought down this level to 0.2 by using three

times. So, we have the amount of solvent. Now we were using s or b, this was 40 Kg, all right. So, the total amount of solvent we had 120 Kg. (No audio from 51:44 to 51:49) We brought down the concentration from 0.3 to 0.2, and the last raffinate concentration molar flow rates R3 was 84.4; that means, the acid content in treated stream or the raffinate stream would be 84.4 multiplied by 0.2 16.88, so much acid in this, **right**.

So, here, on this example what we have done that, we have just three stages or we are doing it three times for the batch experiment. Every time we bring the amount of the solvent and we reduce the concentration of acetic acid from 0.3 to 0.2. Now one can also come do one more exercise here. Suppose we use only one stage, all right. So, instead of using three stages and equal amount of solvents 40 Kg 40 Kg, each the question is that if you use only one stage, how much amount of solvent is required to bring down the concentration levels from 0.3 to 0.2.

So, though we want to fix the composition of the feed and the raffinate treated raffinate which we have in the third stage at 0.2, and how much is the amount of solvent required. This will tell us whether single stage is beneficial or the three stages for the given amount of solvent or how much is the amount of solvent is required, if we do the treatment in one stage instead of three stages.

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So, this very quickly suppose we have used only one stage; that means, we can re-draw the equilibrium curve here or we can work on the same equilibrium curve. We have this A, and let us say this is B here, and this point was 0.3. So, what after third stage, we had this composition at 0.2. So, this was the composition of the raffinate R<sub>3</sub> at 0.2.

Now, we are supposed to use only one stage and the question is that we want to bring down the level from 0.3 to 0.2. So, how we do? We just add one stage here. The amount of solvent is not known to us. So, to find out how much amount of solvent we require, this is 1 here; phase solvent so that the treated stream, this raffinate contains 0.2.

Now, again, we have this R<sub>s</sub> stage. It is in equilibrium with the with the extract phase from that stage. So, again here we have to do this exercise, we find that tie line which connects this raffinate concentration at 0.2. So, if you do this, you have the equilibrium, y versus x diagram from the same information what we had in the beginning of this lecture, in the beginning from this exercise, you had look for 0.2 here, corresponding to this, find out what is composition in the y phase. So, this 0.2 here, you find this tie line, you will see that this corresponds to 0.078.

So, actually here this is... Now x this is your y. So, knowing this 0.3, what amount of solvent it requires so that we get only 0.2, find that tie line which goes through this, you will see that this reading here this would be around 0.1.

So, if you know this x m, again you have similar exercise; 100 Kg solvent, we have we add 100 Kg of feed, now we had this amount of solvent B, we have R plus E; raffinate and extract and we have 100 into 0.3 mixing rule plus B into 1, and we have this R raffinate into 0.2 here plus E into y. So, this is 0.078. This is you now x in m here and similarly we have this M into x m where x m is 0.12. So, if you do these small calculations, we can find that the amount of solvent here is 150 Kg.

So, this example tells which is if you have three stages, we required 120 Kg. And if you have just one stage for the same amount of concentration levels going from 0.3 to 0.2, we required only we required larger amount 150 Kg, all right.

So, this example we have done chosen for this lecture for cross current three stages, where we added the phase amount of solvent at every stage, and we were asked to identify on different compositions. We drew the equilibrium curve graphically. We said

that we can solve graphically as well as we can solve mathematically, but we have to plot both y versus x diagram, equilibrium and we have to draw this rectangular coordinates, amount of solvent, fraction of the solvent and y versus x; start with the first stage, add f nf, find the mixing rule x m, we can solve graphically, you can solve mathematically, find the new tie lines, second stage, third stage and the last question was put up; if you use just one stage, what is the amount of solvent. And we showed that if you just one solvent for the same level same reductions in the quality of the feed, we require more amount of solvent 150 Kg. Now, that is end of today's lecture. The second lecture when we take up, we will take an example **on cross on sorry** multi stage counter current stages.