Principles and Practices of Process Equipment and Plant Design Prof. Gargi Das Department of Chemical Engineering Indian Institute of Technology, Kharagpur

Module - 02 Lecture - 39 Liquid-liquid extraction (L5)

Hello! Today, we are just continuing the last part which is left in the liquid-liquid extraction and if you remember, we were discussing the number of theoretical stages, how to estimate it. I had already told you that this particular estimation is based on a graphical procedure. You can do the graphical procedure either on a rectangular plot or on a ternary plot.

I was discussing it on a rectangular plot and I will be continuing the discussion today on the rectangular plot as well. And you must have realized by this time that the entire graphical construction, it is based on location of two points; the mixture point and the difference point. The mixture point gives you that total mixture location or rather where the mixture is located inside the immiscible dome.

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So, therefore, the next thing was the location of the delta point, the difference point which gives you the net result or rather which gives you the net outflow from any particular stage, starting from stage 1 to the last state stage n, it gives you the net outflow from any particular stage; maybe stage 1, stage 2, stage 3 etc.

So, therefore, all lines which locate the streams coming out from any particular state has to cross through this particular point. Similarly, E 1 F has to come here and in the same way, your S R N, it also has to come here. So, in the same way, your E 2 R 2 has to come here.

So, therefore, I had described the construction as initially, we draw F S, we draw R N and E 1, and then from F S if you know the total amount of solvent, you know M. Once you know M, you know R N. So, therefore, you can locate E 1. Then, you can join F E 1 and you can join S R N, you locate the delta point.

Once the delta point is located, then you know that all this E 1, R 2, E 3, sorry E 1, yeah I am sorry; R 1, E 2, R 3, E 4 all these things, they should go through this particular delta point. So, once you have located this delta, the next step was that from E 1 you drop a tie line, you get R 2. Then, from delta, you draw R 2 and extend it, you get E 2. From E 2, you draw a tie line, you get I am sorry, this was R 1; very sorry R 1.

Then, from E 1, you draw a tie line, you get R 1. From delta, you draw a draw the difference line, you get E 2. From E 2, you draw a tie line, you get R 2. From R 2, again from delta R 2 if you draw and to extend it, you are going to get E 3. Again, sorry; again from E 3, you can draw a tie line, you can continue this and till you reach this particular composition.

Now, there is just one thing here which needs to be remembered, how to construct tie lines. This is one other thing that you should be doing. Now, for constructing tie lines, what we can do? The is the different ways by which you can construct tie lines. The easiest thing from a graphical construction which I felt was that just beside this particular rectangular plot, you can draw a bind two-dimensional plot of the mole fraction of the raffinate sorry mole faction of the solute in the extract phase, mole fraction of the solute in the raffinate phase.

So, therefore, this is raffinate phase mole fraction of solute; this is extract phase mole fraction of solute, perfect and by this, you can generate this particular equilibrium curve. Now, in this equilibrium curve, this E 1 R 1 should lie here. So, what we do? From E 1, you draw a straight line here right. So, this gives you the point of x B and y B which are in equilibrium to one another. From here, you draw you drop a straight line.

And then, so therefore, this straight line also gives you the x B which is in equilibrium with the rather this also gives you the x B sorry which is in equilibrium with the with this y B star. From here you draw a straight line, then you can locate the point of tie line here. So, this is the process by which we locate the other tie lines. So, therefore, now to summarize the entire process, what we do? Again, I repeat you have located the M point, you have located the delta point. And then, from E 1, you will be drawing the tie line.

You have already drawn the equilibrium curve; from E 1, you come here, drop down, go straight, you have located R 1. Then, delta R 1 extent to go to E 2. From E 2, again draw a straight line, drop down to the x B the diagonal line, extend it straight, you get the point R 2. From delta R 2 and then extend it, you get E 3. Again, from E 3, come straight here and you locate this particular point, drop down straight, go back, you get R 3. Again, delta R 3, extend, you get E 4.

So, therefore, this is the entire process by which the number of theoretical stages can be constructed. It is important for you to remember that although it appears complex, it is not so. It is just based on location of the mixture point and location of the delta point and the location of the tie lines; these three things.

First, you are going to locate the mixture point, after that you are going to locate the delta point and then, the location of tie line if you are doing it in this particular way, it is not at all difficult; you can locate. And in this way the number of steps has to be continued till you reach the final concentration of the solute in the raffinate phase.

Well, so this gives you the entire construction. Now, there is one thing left. Normally, when you are given a problem you are specified the feed flow rate, you are specified the feed composition and you are also specified the final solute composition in the raffinate and as I have told you that this is usually specified in the after the solvent recovery.

So, therefore, to locate the point on the ternary plot, you need to join this R with S and then, the point where they meets the raffinate cure gives you the actual R N. So, normally these are the three things that you are given and you are ask to start with this feed composition, feed flow rate and arrive at this solute composition in the raffinate.

First, what you do? You select the solvent and after you select the solvent, you generate the equilibrium data. So, therefore, you are in a position to draw this curve, you are in a position to draw the ternary plot. Now, the important thing is how much solvent are you going to use. You know very well that the more amount of solvent you are going to use, M keeps on shifting towards the S.

Now, definitely you would like to do this particular separation by using the minimum permissible amount of solvent. How are you going to decide that? If you remember in absorption what we had discussed, we had discussed that the point where the operating line and the equilibrium curve, they touch each other that gives you the minimum solvent. Then, accordingly, you select 1.52 or 1.3 times the minimum solvent and to start working. Same concept applies here as well.

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This case also can you tell me what is going to define the minimum solvent? The minimum solvent if you think, it is going to it is going to be decided see from delta, if a you are you have located delta in this particular way sorry this R N E N plus 1. Wait, this becomes slightly clumsy, very sorry yeah. So, therefore, if suppose you are having a E 1 here. So, therefore, if from here and from E N, R, R prime if you are joining, you are going to get delta.

Now, one thing you remember suppose from delta to F, the line which you have which is their which are going to extend to find out E 1, if that coincides with a tie line. Then, what you get? You cannot go below that that is the minimum that you are going to get. So, therefore, in order to locate the minimum amount of solvent, what you need to do?

You need to locate the E 1 corresponding to the minimum solvent. How can you locate that? You have to locate F, then corresponding to F, you have to locate the tie line which passes through F or the tie line which corresponds or rather which is an extension of delta F.

Once this particular you can locate this location of tie line is the same, you will have a equilibrium curve here. From there, you are supposed to locate. Once you find out that the tie line from delta F that becomes the tie line, you extend the tie line. Then, the point where the tie line it intersects with the extract curve that gives you E 1 minimum. Once E 1 minimum is located, then in that case F and S are already joined. In order to locate M

minimum, you need to join R N and E 1 minimum. This gives you once you have done it, you can find out the M minimum point.

Once M minimum point is located, you can find out this length, you can find out this length. You know that this by this gives you S by F. So, from there, you are in a position to find out the minimum amount of solvent that you can use. Now, the other way around. Can you tell me, what is the maximum amount of solvent that can be utilized to bring about the same separation? If you keep on increasing the amount of solvent, M keeps on shifting; M can keep on shifting till M touches this particular point in the extract curve.

After that if you add more amount of solvent, naturally you entered the zone of miscibility and as a result, there is we cannot perform extraction. So, the maximum amount of solvent corresponds to M lying on the extract curve and the minimum number corresponds to the M, which can be located corresponding to the E 1 minimum.

Normally, what we do? We find out M minimum and then corresponding to the M minimum, we find out S by F minimum by the lengths as I have shown you. Once you have located R minimum, you have to find out R which lies between R minimum and R maximum; R maximum corresponding to M maximum which lies on the extract curve.

Usually, then the actual amount of solvent that we take that lies or that is around 1.1 to 2 times of the R minimum or dissolvent corresponding to the minimum point. So, therefore, before you start the problem, you have to decide the total amount of solvent. In order to decide the total amount of solvent before you have done anything, you know this point, you know this or this, any one of them depending upon the specification of the solvent.

First thing what you need to do is to locate this point. Once you have located this point, you in a position to find R minimum. Once you have found in R minimum, you can find out S minimum. Then, you take say about twice or 1.1 times, definitely we will like to start with 1.2, 1.3; if we get more or less optimum number of stages, we will proceed or else, we will slightly increase the amount of solvent.

Once we have increased the amount of solvent, then we locate the M point. Moment the M point has been located, we can locate the E 1 point. Once the E 1 point is located, then using F E 1 and this, we locate the difference point and then, we draw the x y the x y

equilibrium curve on the left hand side start locating tie lines and start doing the construction accordingly.

Aqueous phase (Raffinate) Chloroform phase (Extract) x4 x5 x8 y4 y5 y8 0.992 0.008 0 0.005 0.995 0 0.830 0.012 0.158 0.013 0.700 0.28 0.731 0.013 0.256 0.022 0.557 0.42 0.623 0.017 0.360 0.044 0.429 0.52 0.456 0.051 0.493 0.103 0.284 0.61 0.345 0.098 0.557 0.186 0.204 0.61	ffinate) contains no more than 5	6 acetone at • 0.05 Equilibri	fter solver um Data f	nt recover	ry.	chlorofor	m syster
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0.623 0.017 0.360 0.044 0.429 0.52 0.456 0.051 0.493 0.103 0.284 0.61 0.345 0.098 0.557 0.186 0.204 0.61 Plait point at (0.575, 0.575)	\geq	0.731	0.013	0.256	0.022	0.557	0.421
0.456 0.051 0.493 0.103 0.284 0.61 0.345 0.098 0.557 0.186 0.204 0.61 Plait point at (0.575, 0.575)		0.623	0.017	0.360	0.044	0.429	0.527
0.345 0.098 0.557 0.186 0.204 0.61 Plait point at (0.575, 0.575)		0.456	0.051	0.493	0.103	0.284	0.613
Plait point at (0.575, 0.575)		0.345	0.098	0.557	0.186	0.204	0.610
or water-accione-with system	$x_{\nu} y_{s} \rightarrow$ plot for water-acetone-MIB	(system		Plait	point at	(0.575, 0	.575)

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So, I have given a particular design problem here for you to try, where we need to recover acetone from 1000 kg per hour of an aqueous stream which contains 40 percent. So, therefore, x B F equals to 0.4 and we would like to go for x B R N equals to 0.05. Remember one thing this refers to the prime after solvent recovery; this is the amount of solvent that is there. So, therefore, this 5 percent acetone, it lies somewhere here at 0.05 curve, the this is what.

So, from here if you join S you will actually get the R N prime, R N point. This refers to the R N prime point. So, the problem is just as it is that acetone is there and we would like to recover acetone from a 1000 kg per hour aqueous stream which contains 40 percent weight per weight acetone and we would like to have something which has 5 percent acetone after solvent recovery. First thing if you remember the way we had done? We have to choose the solvent.

Now, the most common solvent which is there in this particular case is the MIBK ok. So, therefore, the first thing we would like to do is to is to start with MIBK. Now, we had obtained the equilibrium data for MIBK and this is the curve which this is that the rectangular plot corresponding to MIBK. Now, once we constructed this, what we

noticed is that the plate point if you observe here that is very close to 0.4 which corresponds to the feed composition.

So, therefore, the closer we go to the feed composition, we know that that we cannot perform extraction. So, therefore, although MIBK is the preferred solvent, we could not opt for MIBK. The next choice that we had we selected the chloroform phase. From the chloroform the data is there, we plotted it. We found the plate point to lie around 0.575, 0.575 which is quite far away from 0.4.

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Aqueous phase (Raffinate) Chloroform phase (Extract) x_a x_g y_g y_g 992 0.008 0 0.005 0.995 0 830 0.012 0.158 0.001 0.757 0.217 .456 0.051 0.493 0.103 0.284 0.613 .345 0.098 0.557 0.810 0.204 0.610 Plait point at (0.575, 0.575) Only a small range of miscibility of chloroform (extraction solvent) and water (feed solvent), Acetone completely miscible with both solvents (water and chloroform).	sign l uilibriu	Illustrat um Data f	ion for water-	acetone-o	chlorofori	m system	Component	Density (kg/m³)	Viscosity µ (cP)	Surface tension σ (dyne/cm)	M
Aqueous phase (Raffinate) Chloroform phase (Extract) x_4 x_5 x_g y_4 y_5 y_g 0.992 0.008 0 0.005 0.995 0 0.830 0.012 0.158 0.013 0.700 0.287 0.731 0.013 0.256 0.022 0.557 0.421 0.623 0.017 0.360 0.044 0.429 0.527 0.456 0.051 0.493 0.103 0.284 0.613 0.345 0.098 0.557 0.186 0.204 0.610 Plait point at (0.575, 0.575) Only a small range of miscibility of chloroform (extraction solvent) and water (feed solvent), Acetone completely miscible with both solvents (water and chloroform).		<u> </u>					Acetone	790	0.316	24.1	58
(Raffinate) (Extract) x_4 x_8 x_8 y_4 y_5 y_8 0.992 0.008 0 0.005 0.995 0 0.830 0.012 0.158 0.013 0.700 0.287 0.623 0.017 0.360 0.044 0.429 0.527 0.456 0.051 0.493 0.103 0.284 0.613 0.345 0.098 0.557 0.186 0.204 0.610 Plait point at (0.575, 0.575) Only a small range of miscibility of chloroform (extraction solvent) and water (feed solvent), Acetone completely miscible with both solvents (water and chloroform).	Ac	queous ph	ase	Chlo	proform p	bhase	Water	996	0.89	72	18
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0.456 0.051 0.493 0.103 0.284 0.613 0.345 0.098 0.557 0.186 0.204 0.610 Plait point at (0.575, 0.575) Only a small range of miscibility of chloroform (extraction solvent) and water (feed solvent), Acetone completely miscible with both solvents (water and chloroform).	0.121										
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Plait point at (0.575, 0.575) Only a small range of miscibility of chloroform (extraction solvent) and water (feed solvent), Acetone completely miscible with both solvents (water and chloroform).	0.623	0.017 0.051	0.360 0.493	0.044	0.429	0.527 0.613					
We preceded with chiefedorem as extraction solvent	0.623 0.456 0.345	0.017 0.051 0.098	0.360 0.493 0.557	0.044 0.103 0.186	0.429 0.284 0.204	0.527 0.613 0.610					

And moreover, we found that chloroform has if you observe the data, you find chloroform has a very less miscibility with water. So, therefore, we can assume the solvent point to start from here and also, we found that acetone, it is completely miscible with both the phases.

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So, we had proceeded with chloroform as the extraction solvent and more or less, the just the way the process that I had told you in the same particular way, we had proceeded in this particular case and we had found out S minimum and then, from there initially, we had started with 1.3 You can try it out for yourself. We got a large number of stages.

So, therefore, just to bring it down, we increase the total amount of solvent the to about 1.75 times or in other words, K was R R sorry the K was taken as 1.75 and then, the calculation was repeated and we got a reasonable about 5 to 6 number of theoretical stages. You can try it out for yourself and you can see that at the end what you are getting right. Just the same way locate M minimum, then locate M, then locate the delta point, then drop the tie lines; the entire thing is shown in this particular figure.

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And just for your convenience, I have just jotted down the steps in sequences which you need to follow. Please do not follow anything blindly. Try to understand that we that the whole construction rests on locating the mixture point and the delta point and the construction of tie lines.

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In case of pure solvent and feed stream free of solvent, $y_{AS} = 0$, $y_{AS} = 1$ and $z_{SF} = 0$ 4. Line joining E_{N+1} and R' intersects the raffinate curve at R_N . 5. Tie line that passes through point F (extended beyond the envelope) is drawn and its extract end is E_{lmin} Coordinates of E_{lmin} denotes extract composition when minimum amount of solvent stream is used to produce raffinate of desired composition (R')6. The line joining E_{N+1} and F intersects the line $R_N E_{1min}$ at M_{min} which corresponds to the mixture composition using minimum amount of solvent stream.

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10. The line $R_N M$ is drawn a the operating extract correction of the second	and extended to meet the extract curve at E_1 that corresponds to nposition from the process.
Construction continued on avoid clumsiness a separat continue with the construction	the same graph for estimating the number of stages (N) , but to the graph is often used to locate the difference point (Δ) and on.]
11. On the new graph, all o drawn.	except $R_N E_{1min}$ line and the tie line through E_{1min} is
12. Lines $E_I F$ and $E_{N+I} R_N$ point (Δ) as shown in Fi	are extended to meet at the operating difference gure 13.4b.
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So, the entire thing has been written down here just for your convenience.

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15. Tie line $(E_2 R_2)$ through point E_2 is drawn to obtain raffinate composition leaving stage 2 denoted by R_2 .
Tie lines are conveniently drawn with the help of a <i>x-y</i> plot (denoting equilibrium composition of solute B in the raffinate and extract phase) drawn beside the ternary rectangular plot. The procedure is illustrated in Figure P13.2 and Figure P13.3 and outlined
below.
A horizontal line is drawn from any point, say E on the extract curve to
intersect the diagonal of the x-y plot. This locates $y_E = x_E$. A vertical line
downward from $y_E = x_E$ point intersecting the equilibrium curve locates
x_{E}^{*} in equilibrium with y_{E} . A horizontal line from point x_{E}^{*} to the
raffinate curve locates x_E^* in the ternary rectangular plot. Line $y_E x_E^*$
drawn from the extract to the raffinate curve is then the required tie line
through point E.
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You can follow this and you can complete or you can find out the number of theoretical stages in this particular case right.

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Shortcut method similar to McCa	be-Thiele construction of stages (Straight op. & curved eqm. line)
Constant flow rate of feed solvent F' an Solute concentrations, as weight ratio (X If <u>F' and S' constant in all stages and lin</u> $X = \frac{1}{2}$	d extract solvent S' for perfectly immiscible solvents) of solute to feed solvent in raffinate & ratio (Y) of solute to extraction solvent in extract. lear operating curve of slope $(F'/S') = (E'/R')$ F' = F'
Material balance from feed end to stage $Y_{n+1} = \frac{F'}{S'}X_n + \frac{E'Y_E - F'X_F}{S'}$	From raffinate end to stage <i>n</i> $Y_{n} = \frac{F'}{S'} X_{n-1} + \frac{F'Y_{E} - R'X_{R}}{S'}$ From ov material balance, end points of operating line related as- $Y_{E} = \frac{F'X_{F} + S'Y_{S} - R'X_{R}}{E'}$
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The entire thing has been written here. Now, this is the conventional approach that you use. But under certain cases, where the feed and the solvent, they are completely immiscible with one another and under that case suppose you can express the solute concentration as weight ratio. What is weight ratio?

If you remember, this capital X is the weight the weight fraction by 1 minus x and the same way Y equals to y minus 1 by y. So, in this particular case, if F prime and S prime, they are constant in all stages. When it will happen? When both of them are perfectly

immiscible. Then under that case, we find that the situation becomes similar to stripping which you have learnt.

Under that conditions, we will be getting a linear operating curve whose equation will be given by F prime by S prime or by E prime by R prime right. Now, you can very well get it done or rather you can understand it, if you can perform a mass balance from the feed stage to any particular stage n. Same thing can be obtained if you start from the raffinate end and come to the stage n.

I have written down the mass balances for the two cases; you will find that it is completely identical to the thing that you are done for your absorption and stripping case. Only in those particular cases, the nomenclatures have been change to E prime and R prime in this particular case; accordingly, Y E and X are they denote the composition of the solute in the extract and the raffinate phase. Just the nomenclatures are changed otherwise everything is completely same.

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So, therefore, under this particular condition, we find that when you get when the two the feed as well as the solvent, they are completely immiscible with one another and under that condition, when you are expressing the operating line in terms of weight ratios or mole ratios whatever is convenient for you, under that condition we get a linear operating line and a curved equilibrium line. If you find here you can locate the end points, you can locate x B R N which is the point here and this refers to the refers to the inlet condition.

So, the two points are located, it can be joined by a straight line and just the wave, it was explained in absorption, you can find out the number of stages in this particular case. The procedure, the concepts are completely similar to what was told to you during absorption. To be honest, this is similar to the stripping operation; you have to keep in mind and that is why the operating line is below the equilibrium curve. You will remember that if for absorption the operating line is above the equilibrium curve.

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Now, the other thing is when both the operating line and the equilibrium curve, they are linear and the equilibrium curve has a slope of m. This was also discussed during absorption and you are told that under that condition N can be obtained very easily from the Kremser equation.

In fact, if you remember, we have used Kremser equation for solving the mixer settler problem because there also we found that more or less the equilibrium and the operating line over the range of operation that we were performing, they were practically linear and the two phases they were completely immiscible with one another.

So, therefore, the same equation that was told to you during your absorption stripping class, the same equation you can use here in order to find out the number of theoretical stages, when the operating line and the equilibrium curve, they are linear to one another. The only thing is in absorption you had used the absorption factor which was equal to L

by m G and in this particular case, it is the extraction factor sorry it is equals to mL by G, there we had used.

In this particular case, it is the; it is the slope of the equilibrium line and the operating line, we call it the extraction factor and there it was called as the absorption factor. Otherwise, the expression is completely the same. If you are fortunate enough that you can get a linear operating an equilibrium curve, then once you calculate NTS in this way. In whatever way you calculate NTS, finally, the column height is given as a product of NTS and the HETP.

This HETP as you will see that more or less for extractors in pact column, sieve plates even from a for agitated contactors, more or less data on HETP is available from experience and you can use. There is a range of data available for HETP, you can use any particular point within that particular range and you can get an idea regarding the column height.

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Well, so therefore, once the column height has been decided the next thing is estimation of column diameter. Again, I will go back to your column internals that you have studied and under that condition when you are studying vapor liquid gas liquid contacting, how did we find out the column diameter? I had told you in the beginning of the last class itself that it was basically on the basis of flooding velocity and we considered the vapor flooding velocity because under flooding, what happens? The vapor velocity is high and as it flows up, it entrails a good amount of liquid and due to this particular liquid entrainment, flooding occurs.

So, therefore, the vapor velocity is considered and the vapor mass flux or the vapor volumetric flux is considered and accordingly, the diameter is found out. Now, here there is something that you need to keep in mind. The point is that in extractors flooding can occur in a slightly different way.

While in gas liquid vapor liquid contactors, flooding occurs just by increase of vapor velocity; in this particular case, definitely, if you increase the velocity of the continuous phase, you are going to get flooding. It goes without saying. Moment you increase the velocity of the continuous phase, quite naturally what happens? It starts entraining the dispersed phase and takes it out, similar to what had happened in vapor liquid contactors.

But there is one other thing. Instead of increasing the velocity of the continuous phase, if you increase the velocity of the dispersed phase, what do you get? That is a phenomenon known as phase inversion which is unique to liquid-liquid systems, it does not happen for gas liquid systems. During inversion, what happens?

You keep on increasing the velocity of the dispersed phase. At one particular time, you will find that the dispersed phase becomes the continuous phase. So, therefore, if you keep on increasing the velocity of the dispersed phase, you find that the dispersed phase becomes the continuous phase and then, it starts flooding because the continuous the initial continuous phase has now become the dispersed phase.

So, therefore, in this particular case, flooding can occur both by increase of the flow rate of the dispersed phase as well as the increase of the flow rate of the continuous phase and therefore, when you are going to calculate the total flooding velocity in order to calculate the tower cross section, you need to take the total mixture velocity into account.

Because flooding can occur by increase of not only U c, but also by increase of U d and you also need to remember that whenever there are some contaminants at the interface that can cause phase inversion by interface destabilization and that can also cause flooding. Now, how do you will understand that flooding has occurred?

The interesting part is as I had initially told you that when you have such a column, where the heavier phase is coming in here, going out here; may be the lighter phase is coming in going out. So, therefore, if the lighter phase is the dispersed phase, you have an interface at the top. Now, moment flooding is there, a second interface starts appearing and moment the second interface appears you know that flooding has occurred well.

So, to come back to the column diameter, so the column diameter is estimated by the flooding velocity which is the total mixture velocity and since from all this, you have understood that there are lot of uncertainties in predicting the flooding velocity. So, therefore, extraction columns, they are usually designed to operate at 50 percent flooding velocity, it can be lower flooding velocity as well.

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Well, so after this I do not have much to say, there are certain parameters which I have put down specifically for packed tower design. Here we see that we can use as I have told you both random and structured packing's. It is important for you to remember that with structured packing's, the throughput is higher, the turn down is higher.

Yet in industries, the random packing's are preferred because they are cheaper and they are easier to clean and when we select packing materials, it is important to consider the corrosion and its important, its desirable that the packing material is wetted by the continuous phase and it has got sufficient strength.

Considering that ceramic is no usually not adopted because if it is quite brittle and if it breaks down, there is a chance that it is going to clog the pipelines etcetera. But of course, at the same time, when aqueous phase is continuous, we often select ceramic for corrosive liquids.

Even for water continuous phase, this is cheaper, we can use stoneware and metal packing's. For when the organic phase is continuous, we use carbon rings or saddles. There is one very important thing that I would like to mention. When you were you discussing gas liquid vapor liquid contacting, if you remember the packing surface provided the interfacial area or the area for mass transfer. So, therefore, a was important.

In this particular case, you know that the mass transfer occurs around the droplet surface. So, therefore, the packing surface is does not influence the mass transfer or the mass transfer area is almost independent of the packing surface. It is a function of the dispersed phase holder because around the droplets mass transfer occurs, packing is kept just to increase the turbulence and to re-disperse the coalesced drops.

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 $C = \exp \left| 8.8082 - 0.0563 \times \left\{ ln(D) \right\}^2 - 0.4981 \times ln(D) \right\}$ Liquid-Liquid Flooding in packed bed $D = \left(\frac{\sigma}{\rho}\right)^{0}$ $\Delta \rho = \rho_c \sim \rho_d \quad \sigma$ - interfacial tension in dyne/cm $\left(\sqrt{U_{s,d}} + \sqrt{U_{s,c}}\right) \rho_c$ Valid for 1<C<1000 $U_{s,d} U_{s,c}$ - Superficial velocity (volumetric flow rate per unit tower cross section) of dispersed & continuous phase in ft/hr. ρ_c - density in lb/ft³ $\sigma = -7.34 \ln \left[x_{AS} + x_{SA} + \frac{(x_{BA} + x_{BS})}{2} \right]$ μ_c -viscosity of continuous phase in lbm/ft.hr. a - Specific surface area of packing is in ft2/ft3 While working with SI units, conversion factors to be used ε- packing void fraction. 1 m/sec = 11811 ft/hr 1 kg/m3=0.062428 lb/ft3 1 kg/(m.sec)=2419.08833 lb/(ft.hr) & 1 cP=2.419 lbm/(ft.hr) $1 \text{ m}^2/\text{m}^3 = 0.3048 \text{ ft}^2/\text{ft}^3$

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Liquid-Liquid Flooding in packed bed	(A)
In absence of experimental data, σ in dyne/cm can be estimated for a ternary system of solvent A, so	olvent S and solute B
$\sigma = -7.34 \ln \left[x_{AS} + x_{SA} + \frac{(x_{BA} + x_{BS})}{2} \right] - 4.90 \qquad \text{Valid for} 4 \le \sigma \le 52.$	5
x_{AS} - mole fraction of solvent A in saturated solvent rich S	
x_{Sd} is the mole fraction of solvent S in Saturated solvent field X x_{Bd} x_{BS} are the mole fractions of solute B in A and S respectively	
Redistributors after 1.5 to 3 m to ensure proper drop size distribution. Long bed Heights (>10-12m) with structured packing are not advisable.	
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So, these things, I will be; I will be skipping these are just the equation to predict liquidliquid flooding. I will not be covering these things. In case you need this later, all the details are provided in the slide that the way you are supposed to find out the flooding velocities based on these diameters. I will not be going into the details of all this.

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Acetone is to solution (raffin	be recovered nate) contair	l from a 100 ns no more th)0 kg/hr aqueou han 5% aceton	us stream t e after solv	nat contains 40 ent recovery.	%w/w aceton	ne at around 26°C	' such that the spe
Component	Density (kg/m³)	Viscosity µ (cP)	Surface tension σ (dyne/cm)	MW			R /	
Component	Density (kg/m ³) 790	Viscosity µ (cP) 0.316	Surface tension σ (dyne/cm) 24.1	MW 58			Ĕ	<u></u>
Component Acetone Water	Density (kg/m³) 790 996	Viscosity μ (cP) 0.316 0.89	Surface tension σ (dyne/cm) 24.1 72	MW 58 18			Ę	

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And for the sieve tray design, also I have just noted down a few design parameters etcetera. In case you are interested, you can take it up. One thing I was thinking the initial problem that was given, if you are at all interested, you can just after you are found the number of theoretical stages, you have optimized everything, you can just try it out considering a packed bed and using these particular equations. And you can see what you are getting for yourself.

What the time being as far as I am concerned, it is important that you have known the things that I have covered which will be important for your assessments, considerations for the choice of solvent and then, how to select the dispersed and the continuous phase, how to find out the number of theoretical stages, how to estimate the column diameter and the important part is for column diameter, the total flooding velocity is important and certain considerations in deciding the packed tower materials etcetera and also, you need to remember that for the sieve trays, normally we do not use any weir here.

This is the this is something which is different from the vapor liquid contactors. The tray spacing, the active area and the down comer area, the ratios are also different from vapor liquid contacting devices. So, these are the few things that you need to remember and in any case, if you need any further clarification, you can get back to us; we are going to clarify the doubts. I will also give you a small hint. The particular portions which are

important for assessments are marked in red font in all the slides. So, you can just keep that in mind, while you are preparing for the assessment.

Thank you so much.