**Mass Transfer Operations 2**
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**Lecture 16: Leaching: Multistage Operation**

Welcome back to Mass Transfer Operations 2, we are discussing on leaching process and in the last class we discussed about the single stage operation. Now we will be discussing on the multi stage operation.

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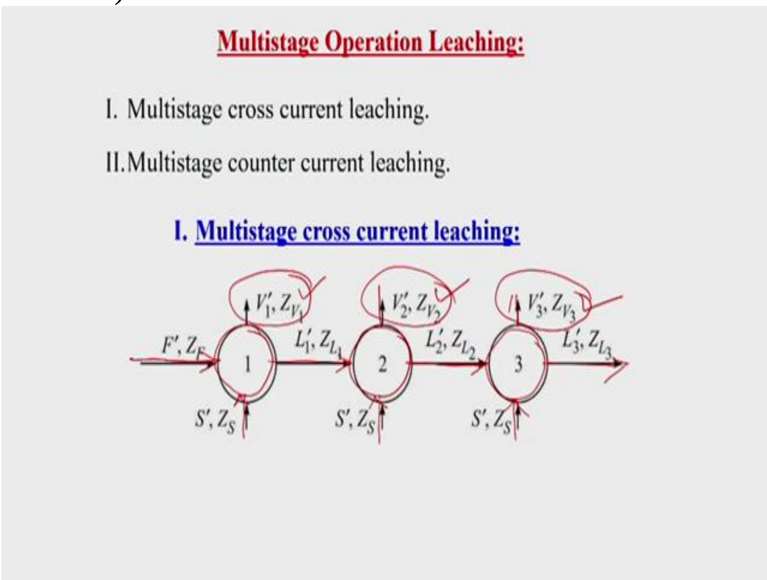


So, in multi stage leaching operation, we have these two different types of processes, one is multi stage cross current leaching and other is multi stage counter current leaching, in multi stage cross current leaching say feed will be entering from the say in the first leaching unit, where we can say this one solvent will be added there and say the under flow of these first process will be used as the feed to the next stage and whatever the overflow we have that will be collected for the further treatment, like this for the second stage again solvent will be added from here and this one under flow will be generated and overflow will be there this overflow also will be collected and this overflow from the first extraction unit, overflow from the second extracts unit will be collected together.

So, for stage three like this, again solvent will be added and extracting solvent and then it will be divided into two parts like this is under flow and this is overflow, this third overflow will be added with the first and second so we will be getting this total overflow from the first leaching unit, second leaching unit and third leaching unit and whatever the under flow will be obtain from the last stage that will be so, we can see this one, mostly free of the target component and the operation is similar to that we already discussed in case of this liquid, liquid operation or extraction process.

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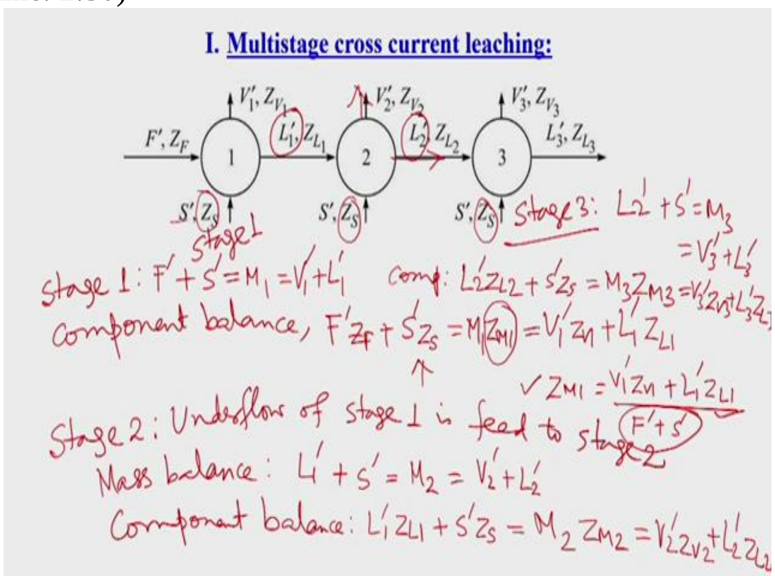


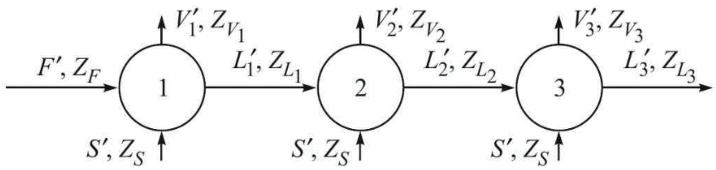

Stage 1: $F' + S' = M_1'$; $L_1'Z_{L_1}' + V_1'Z_{V_1}' = M_1'Z_{M_1}' = F'Z_F + S'Z_S$

Stage 2: $L_1' + S' = M_2'$; $L_2'Z_{L_2}' + V_2'Z_{V_2}' = M_2'Z_{M_2}'$

Stage 3: $L_2' + S' = M_3'$; $L_3'Z_{L_3}' + V_3'Z_{V_3}' = M_3'Z_{M_3}'$

The extracting solvent with the target component. So, that is why it is called cross currents so, here it is moving from one state to another operation and the feed under flow of one process is the feed to the next process. So, this is for multistage cross current leaching process.

## Problem 2:

It is planned to carry out extraction of 1000kg crush oil seeds in a three stage cross current unit using 500 kg solvent in each stage. Calculate fraction of oil that can be extracted by Ponchon – Savarit diagram. Equilibrium data are as follows:

| Over flow (100 kg), solution | | | Underflow (100kg), slurry | | |
|---|---|---|---|---|---|
| ***$W_A$ (kg)*** | ***$W_B$ (kg)*** | ***$W_C$ (kg)*** | ***$W'_A$ (kg)*** | ***$W'_B$ (kg)*** | ***$W'_C$ (kg)*** |
| 0.3 | 99.7 | 0.0 | 67.2 | 32.8 | 0.0 |
| 0.45 | 90.6 | 8.95 | 67.1 | 29.94 | 2.96 |
| 0.54 | 84.54 | 14.92 | 66.93 | 28.11 | 4.96 |
| 0.70 | 74.47 | 24.83 | 66.58 | 25.06 | 8.36 |
| 0.77 | 69.46 | 29.77 | 66.26 | 23.62 | 10.12 |
| 0.91 | 60.44 | 38.65 | 65.75 | 20.9 | 13.35 |
| 0.99 | 54.45 | 44.56 | 65.33 | 19.07 | 15.6 |
| 1.19 | 44.46 | 54.35 | 64.39 | 16.02 | 19.59 |
| 1.28 | 38.50 | 60.22 | 63.77 | 14.13 | 22.10 |
| 1.28 | 34.55 | 64.17 | 63.23 | 12.87 | 23.90 |
| 1.48 | 24.63 | 73.89 | 61.54 | 9.61 | 28.85 |

## Solution:

The quantities are expressed on solid free basis

$F'$=195 kg, $Z_F = \frac{805}{195} = 4.13$, $S'$=500kg, $Z_S$=0

*Stage 1:*

$F' + S' = M_1' = 195 + 500 = 695$ ; $Z_{M_1}' = \frac{805+0}{695} = 1.16$

Tie line through $M_1$ is $L_1'V_1'$. ($Z_{L_1}' = 1.96, Z_{V_1}' = 0$ )

$L_1'Z_{L_1}' + V_1'Z_{V_1}' = M_1'Z_{M_1}'$

$L_1' \times 1.96 + 0 = 695 \times \frac{805}{695} \Rightarrow L_1' = 411 \therefore V_1' = 284$ $[L_1' + V_1' = M_1']$

*Stage 2:*

$L_1' + S' = M_2' = 411 + 500 = 911$, $Z_{M_2}' = \frac{L_1'Z_{L_1}' + S'Z_S}{L_1' + S'} = \frac{411 \times 1.96 + 500 \times 0}{911}$ = 0.884

The line $L'_2V'_2$ passing through $M'_2$ is drawn

From graph, $Z_{L'_2}$ = 2.02, $Z_{V'_2} = 0$

$$L'_2Z_{L'_2} + V'_2Z_{V'_2} = M'_2Z_{M'_2}$$

$$L'_2 \times 2.02 + V'_2 \times 0 = 911 \times 0.884; L'_2 = 398.5$$

$$\therefore V'_2 = 911 - 398.5 = 512.5$$

*Stage 3:*

$L'_2 + S' = M'_3$= 398.5+500=898.5

$$Z_{M'_3} = \frac{L'_2Z_{L'_2} + S'Z_S}{L'_2 + S'} = \frac{398.5 \times 2.02 + 500 \times 0}{898.5} = 0.896$$

Tie line $L'_3V'_3$ is drawn through $M'_3$

From graph $Z_{L'_3} = 2.04$, $Z_{V'_3}$ = 0, $(x_C)_{L'_3}$ = 0.055

$$L'_3Z_{L'_3} + V'_3Z_{V'_3} = M'_3Z_{M'_3}$$

$$L'_3 \times 2.04 + V'_3 \times 0 = 898.5 \times 0.896 = 805$$

$$L'_3 = 394.6$$

$$V'_3 = 898.5 - 394.6 = 503.9$$

$\therefore$ Mass of oil leaving with underflow from stages = $L'_3(x_C)_{L'_3}$

$= 394.6 \times 0.055 = 21.7kg$

Fractional oil recovery = $\frac{195-21.7}{195} = 0.89$

$\therefore$Fraction of oil extracted = 89%

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| Over flow (100 kg), solution | | | Underflow (100kg), slurry | | |
|---|---|---|---|---|---|
| $W_A$ (kg) | $W_B$ (kg) $y_B$ | $W_C$ (kg) $y$ | $W'_A$ (kg) | $W'_B$ (kg) $x_B$ | $W'_C$ (kg) $x_C$ |
| 0.3 | 99.7 0.997 | 0.0 0.0 | 67.2 | 32.8 0.328 | 0.0 0.00 |
| 0.45 | 90.6 | 8.95 | 67.1 | 29.94 | 2.96 |
| 0.54 | 84.54 | 14.92 | 66.93 | 28.11 | 4.96 |
| 0.70 | 74.47 | 24.83 | 66.58 | 25.06 | 8.36 |
| 0.77 | 69.46 | 29.77 | 66.26 | 23.62 | 10.12 |
| 0.91 | 60.44 | 38.65 | 65.75 | 20.9 | 13.35 |
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| 1.28 | 34.55 | 64.17 | 63.23 | 12.87 | 23.90 |
| 1.48 | 24.63 | 73.89 | 61.54 | 9.61 | 28.85 |

So, for that the whatever the equilibrium data points, so, for under flow and for overflow, these are already given here, you see this one I already discussed, this is the similar thing that WV and WC these are given in terms of kg, but whenever we will be plotting this one in the Ponchon-Savarit diagram, then we need to express this in terms of capital Z and, and for that we need to Y and small x and small y. So, we need to convert this one in terms of, suppose this yv will be like this, if we say this is yb that will be nothing what 0.997 like this.

So if we say this is yC that will be 0.0, like this if we say this xv that will be like 0.328. So, if it is a xc that will be 0.00 so, we can now plot this overflow line and under flow line in terms of capital XB, capital XC and in terms of Z value, so we will be able to draw this one, we have already drawn this one, for solving the problem, previous problem.

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## Solution

**Stage 3:** $L_2' = 398.5\ \text{kg},\ S' = 500\ \text{kg}$

$$Z_{M3} = \frac{L_2' Z_{L2} + S' Z_S}{L_2 + S'} = \frac{398.5 \times 2.02 + 500 \times 0}{398.5 + 500} = 0.896$$

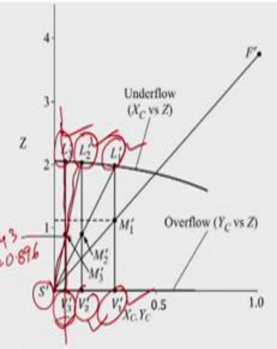
From graph: $Z_{L3} = 2.04$, $Z_{V3} = 0$

$$L_3' Z_{L3} + V_3' Z_{V3} = M_3 Z_{M3}$$

$$L_3' \times 2.04 + V_3' \times 0 = 898.5 \times 0.896$$

$L_3' = 394.6\ \text{kg}$, $V_3' = (898.5 - 394.6)\ \text{kg} = 503.9\ \text{kg}$

$Z_{V3} = 0$, $(x_c)_{L_3'} = 0.055$




## Solution

**Stage 2:** $L_1' + S' = M_2' = (411 + 500) = 911\ \text{kg}$

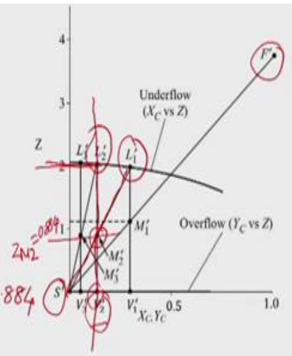
$$Z_{M2} = \frac{L_1' Z_{L1} + S' Z_S}{L_1' + S} = \frac{411 \times 1.96 + 500 \times 0}{911} = 0.884$$

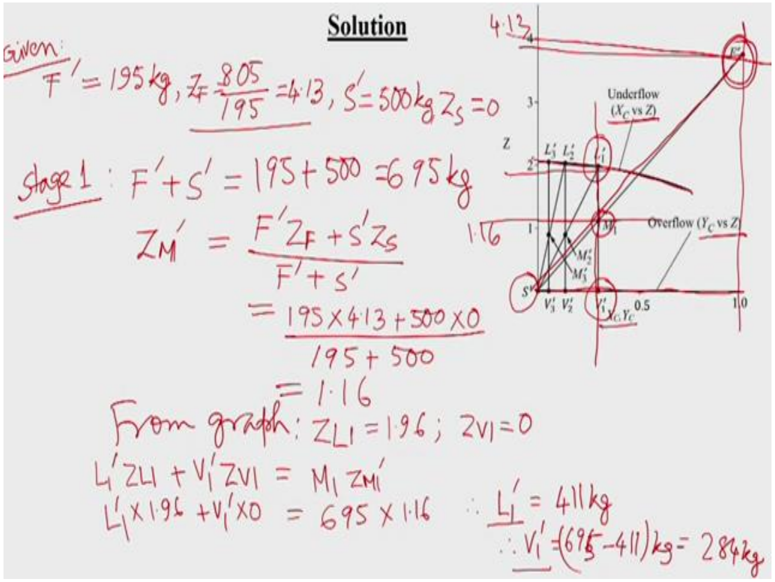
$Z_{L2} = 2.02$, $Z_{V2} = 0$

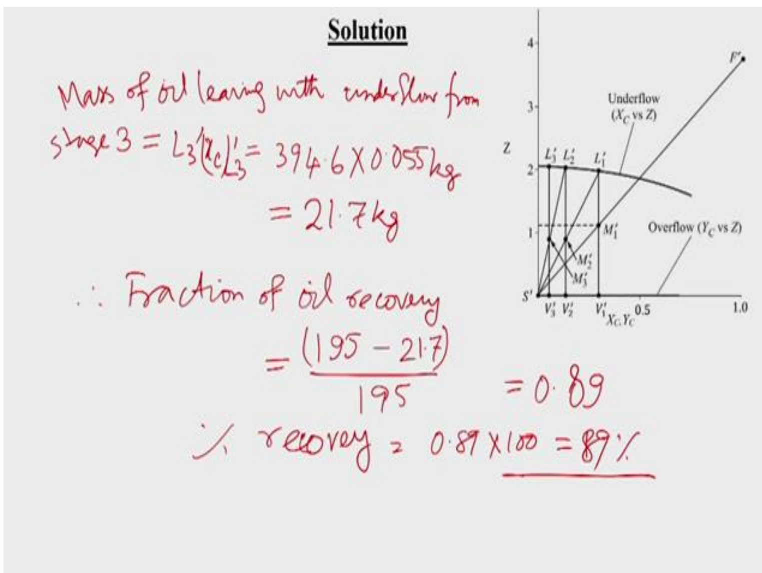
Comp. balance: $L_2' Z_{L2} + V_2' Z_{V2} = M_2' Z_{M2}$

$$L_2' \times 2.02 + V_2' \times 0 = 911 \times 0.884$$

$L_2' = 398.5\ \text{kg}$ $\therefore$ $V_2' = 512.5\ \text{kg}$






So we will be plotting this one it will be like this one. So we are now this over flow line will be this one, it will be like this 0 and this under flow line will be getting this one. So XC versus Z and this XC versus YC. So for over flow that is YC versus Z, for a under flow, this is XC versus Z. And now, we need to get this (())(13:04) for solving this one, whatever we have just we will first get those whatever given F prime that is we can say the solute free basis is as it is 19.5 percent so, it is we can say out of 1000 kg it is 195 kg, oil is there.

So it is solute free basis and then we will say like this previous one, ZF will be like this 805 by 195. So, that will be ZF will be 4.13 like the previous problem and this S prime that is purely free of we can see these solids so, that is whatever we are adding in all these single stages like 500 kg and Zs that is 0.

So, we will be now plotting these S prime here and Zs is equal to 0 so Z equal to 0 and we can say for A prime means this we can say this one for XC and YC whatever the XC value is there so, 195 by 195 so, we can see this one XC or YC whatever we say that is 1 and this Z value is 4.13. So, for that we can say that we are getting these, for this one actually it will be like this, that is 4.13 and this is 1, so we have this A prime and S, then we need to join this A prime and S so initially, we have this over flow line and under flow line.

Now, we need to find what is the M on prime, that this one solid concentration in the mixture for the first leaching unit. So we will be getting this one, so we can start to the calculation in the stage one. So, for that case we can say whatever we know this one A prime plus S prime, so, that is A prime is equal to 195 kg and S prime we have 500 kg so, this is 695 kg so, we have total mixture is 695 kg.

Now, we have this, we need to get this ZM 1 prime that will be getting this one using this formula, whatever we found out now F prime into ZF plus S prime into ZS by mixture, A prime plus S prime. So, it is coming out as A prime is equal to 195 into ZF is equal to 4.13 then plus S prime is 500 into Zs is equal to 0 divide by 195 plus 500. So, it is coming out as so, that will be 805 by 695 so, it is coming out at 1.16. So, now you see Z M 1 prime actually we can say now it is like ZM 1 prime will be like this one.
So, it is 1.16 so, when it cut this F prime, S prime line so we will be getting this M prime composition because I already explained this one that in whenever will be expressing the all the constituents, components in solid free basis then the tie line values will be vertical towards this Y axis, that is why now we are will be drawing one vertical line through M1 then we will be getting this V1 prime where we can see this one solid concentration will be 0 and in L1 prime whatever Z value actually will be getting, will be now, say from this graph we can see this one from, from graph.

Say we need to use this actual graph paper millimeter, millimeter graph paper for getting the exact value that is somewhat below this suppose for L1 prime this solid concentration is below 2. So, now from this graph actually will be getting this Zl 1 that is we are getting as so we can say 1.96 just below this one and we can say ZV 1 that we will be getting as 0. So we will be doing down it using this, we need to find that what is the value of L1 prime and what is the value of V1 prime because we know this component balance for the first operation, like L1 prime into ZL 1 plus V 1 prime into ZV 1 is equal to mixture means M 1 into ZM 1 prime.

So, here we can say this one so, this L1 into L1 prime into Zl1 we got this one 1.96 plus V1 prime into Zv1 is equal to 0 is equal to mixture 1 is like this 1.1, the mixture 1 is 695 into 1.16. So we will be getting from here actually, we will be getting L1 prime is equal to 411 kg. So, therefore, V 1 prime will be 695 minus 411 kg that is coming out as 284. So, now, we got this Ll prime, V1 prime, the amount of L1 prime and V1 prime we got and composition also.

As we mentioned this one that L1 prime or whatever the under flow is there coming out from the stage one that is regarded as the feed to the stage two so, we have this S prime so, now, we need to draw the straight line from L1 prime to S prime. So, one point is there, whenever we used these pure this only one stage, there this feed point location was here, maybe at around where Z was there, Z was around 4.13 now, you see, now it is coming down to around 1.96. Zl1 has come down to around below 2. Now we have this one and again we need to do this for stage two, we have this one, we will be calculating like this so we will be doing the again component balance.

So, here we have L1 prime plus the entry is S prime, so we are adding this one, then M2 and M2 prime is equal to L1 prime whatever we got this one around L1 prime is 411 plus again we are adding 500 kg solvent. So, it is coming out as 911kg. And so, again ZM 2 that is we will be getting from this component balance like L1 prime to Z L 1 plus S prime into ZS divided by mixture, L l prime plus S.

So, here all the parameters are known so we can say this L1 prime is equal to 411 into that value is 411 into 1.96 plus 500 into 0, divided by 911 so, it is coming out as 0.884 we can try this one using again I am telling this one we can try this one using this graph paper. So, this is now 0.884 means ZM 2 that is coming out as 0.884.

Now we identified that point M2 prime, again we need to draw the one vertical line which is parallel to Y axis or Z axis from there the mixture is divided into two parts, that is one part is V2 prime and another part is L2 prime, means the under flow is L2 prime and overflow is V2 prime. So, from here whatever we did for the first stage we will be doing the same thing in the second stage like this.

What we will be doing? We will be doing again component balance and so for the other part of this leaching unit we will be doing Z L 2 will be to some extent greater than 2, so around that value is actually more than 2 like this around 2.02 and, as usual, ZV 2 that will be 0, because it is 0. And now, so we need to do the component balance, so we will be doing component balance for the stage two in the outgoing streams, so that will be L2 prime into ZL 2 plus V2 prime into ZV 2 that is coming out as M2 into M 2 prime into ZM 2.

So here again we will be putting this out of these L2 prime into Z L 2 is 2.02 plus V2 prime into ZV 2 equal to 0 is equal to mixture is 911 into ZM 2 is equal to 0.884 from here actually we will be getting L 2 prime is equal to L 2 prime is equal to 398.5 kg and therefore, the V2 prime will be equal to 911 minus 398.5 kg. So, that is coming out as 512.5 kg.

So, now we have this, now L2 we have L2 prime. So this is now the feed for the third stage, so we will be adding this one like this we can say we will be doing this one now L2 prime is the feed to the stage three. So, now again we will be adding this S prime and L2 prime and then we need to find the what is the composition in stage three.

So, for stage three we have this L2 prime that actually we have, L2 prime is equal to 398.5 kg and S prime that is as usual 500 kg because 500 kg is added in all the stages and ZM 3 is equal to L2 prime into Z L 2 plus S prime into ZS divided by L2 plus S prime. So, it is L2 prime 398.5 into ZL 2 is equal to 2.02 plus 500 into 0 divided by 398.5 plus 500 so it is coming out as 0.896 so, you see this value is ZM 3 is equal to 0.896, once we got this mixture for the third leaching unit so again we will be drawing the vertical line through these ZM 3 to get this V3 prime and L3 prime, so we will be getting this one from graph ZL 3 that is coming out as 2.04 and ZV 3 that is 0.

So, we will be doing now what is called from this component balance we will be getting L3 prime into ZL 3 plus V3 prime into ZV 3 is equal to M3 into ZM 3. So this L3 prime that is we got this one L3 prime into ZL 3 that is 2.04 plus V3 prime we do not know but we know this ZV3 is 0 is equal to M3 is the mixture of these two 898.5 into ZM 3 that is 0.896.

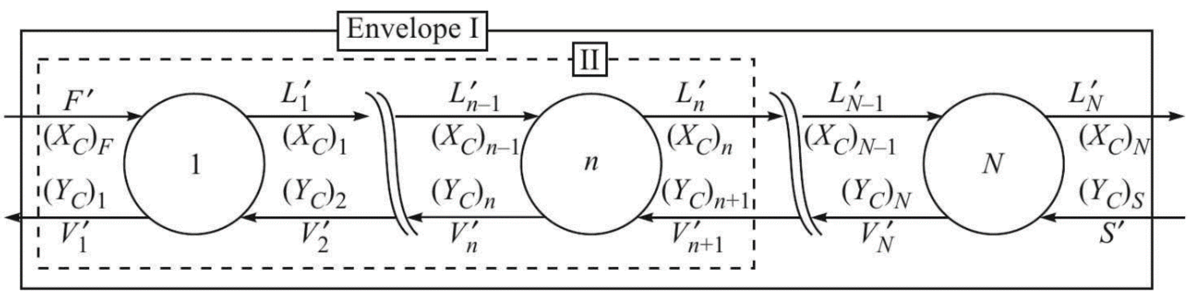
So from here actually we will be getting L3 prime is equal to 394.6 kg, so we will be getting this V3 prime is equal to 898.5 minus 394.6 kg, that is we got as 503.9 kg and say whatever the solute that is leaving from the stage three, so that contents we can say ZV 3 that is equal to 0 and XC L3 prime that is actually we have this 0.055. So whenever, this under flow this V3 prime we have, how much amount of solid actually is left from there we can calculate.

We can say mass of oil that is leaving with under flow from stage three, whatever is leaving with the under flow that is left out and the remaining part that is extracted, that is equal to L3 prime into XC L3 prime. So that is L3 we got this one as 394.6 kg into XC L 3 that is 0.055 kg, so that is we can say it is coming out as 21.7 kg.

So we can say this one therefore, the fraction of oil recovery is equal to, we have in the beginning we have 195 kg and out of these 21.7 kg is wasted from the third stage under flow divided by 195 into 100, we can say this 100, then fraction means this one percentage is equal to 89 percent or if say this fraction, then it is like this 0.89 or percentage recovery equal to 0.89 into 100.

So 89 percent so, we can say the fractional percentage recovery of oil is 89 percent. If we recall that in a single stage leaching unit for the extraction of oil from 1000 kg crushed seed with this 19.5 percent oil, we were able to separate around 75 percent but when we divided this same solvent in three different stages with cross current operation, we were able to extract the 89 percent oil. So, we can see this one almost save 14 percent oil recovery has increased when we are using multistage cross current operation compared to the single stage leaching operation.

### I. Multistage counter current leaching:




So, now we will be discussing about these multi stage counter current leaching process. So, the it is as usual, or it is similar to that of the multistage counter current extraction process, suppose feed is entering from the first stage and where the solvent actually is entering from the last stage or any stage and final under flow is leaving from last stage whereas, final under flow the overflow will be leaving from stage one, it is similar to that of the extraction process and the calculations also is same.

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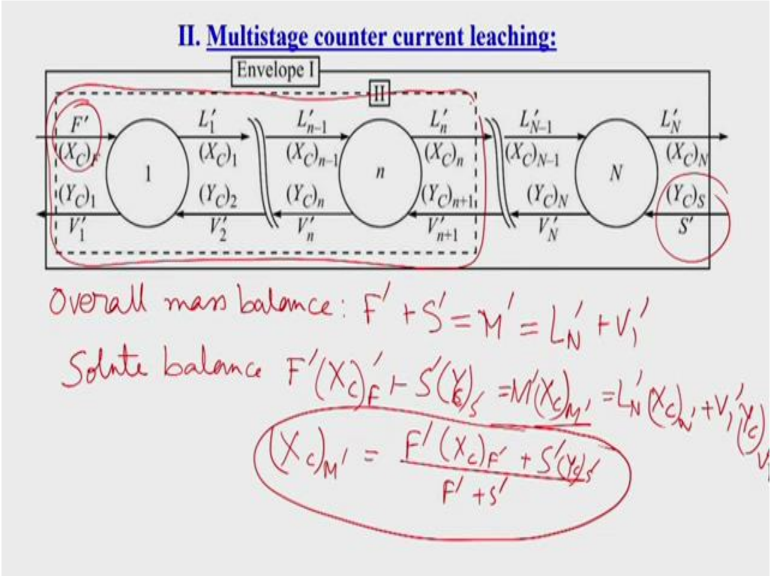


Whatever we discussed in the leaching process, the extraction process the same procedure actually is followed here and the steps also are same. Here only we can say this one for stage one will be doing the calculation only just for the remembrance we are writing this overall mass balance and for the envelope one so, we will be getting F prime plus S prime because this F prime is entering and S prime is entering, so that equal to, in any point it is a mixture and so this mixture one that is nothing but this LN prime plus V 1 prime.

And if we do the solute balance will be like this, F prime into XC F prime plus S prime into YC S prime is equal to M prime into XC M prime is equal to LN prime into LN prime into XC N prime plus V1 prime into YC V1 prime. So from here we will be getting this XM prime or solid concentration in the mixture, this is the hypothetical one. So in any point of time whatever the solid concentration in the mixture will be like this we can say the XC M prime that will be nothing but F prime into XC F prime plus S prime into YC S prime divided by mixture or we can say F prime plus S prime or M prime or LN prime plus V1 prime.

So, that actually will be getting from this equation will be able to calculate the concentration of the solid in the mixture, but I told that this is the fictitious concentration or the solid in the mixture because it is a combination of so many stages, but in case of this counter current leaching process, under flow of stage one will be the feed to the stage two and therefore, it will be moving and whatever the overflow is there that will be also carried forward from one stage to the other stage like this it is flowing in the counter current direction. So, both the under flow and overflow will be utilized for the next stage. So, that way it is happening.

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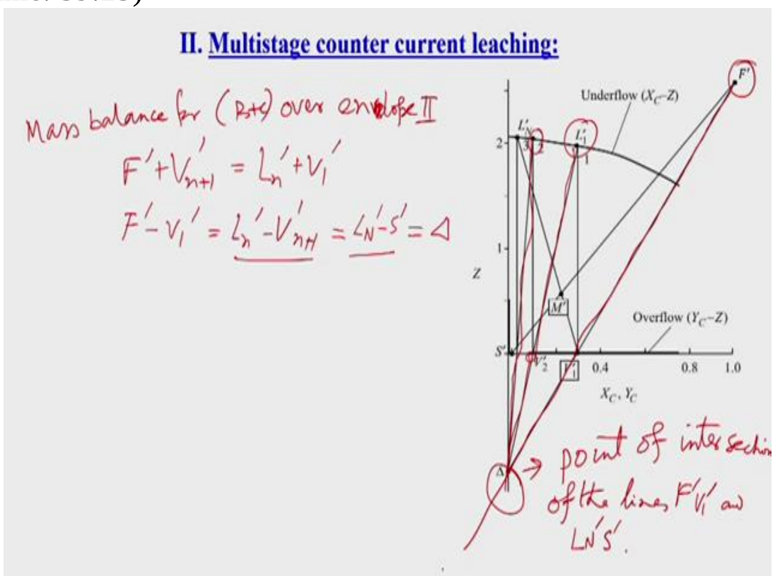


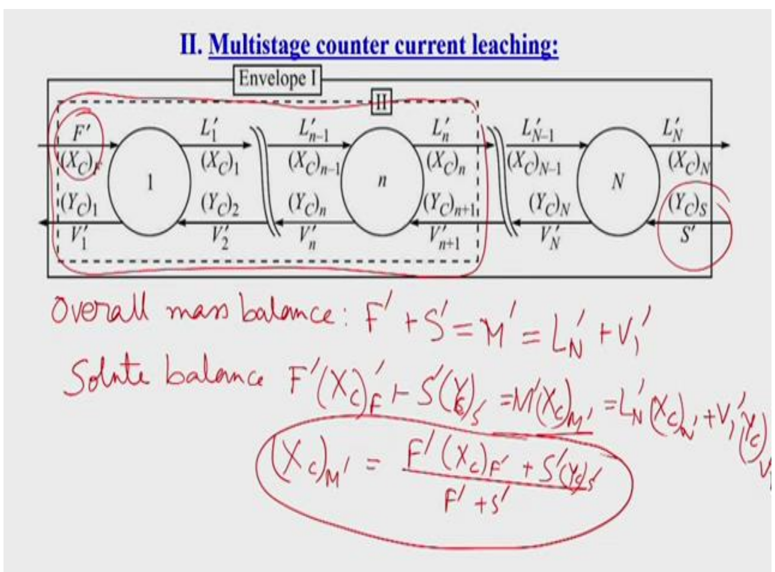


And so we can do the mass balance actually, mass balance for B and C, carrier solvent as well as target component mass balance for B plus C over envelope 2 so, that will be like this previous we can see this one for this envelope actually and if we take a small portion of this, the process so, there actually we can do the mass balance like this F prime plus V prime n plus 1 that will be Ln prime plus V1 prime.

From there we can say F prime minus V1 prime will be nothing but Ln 1 prime minus V prime n plus 1 and that is equal to Ln prime minus S prime. So that is coming out at the delta we have already derived this one for the multistage counter current extraction, the same concept here is also that the concept of delta means if we extend these F prime and V prime to a point and if we extend these any of these L prime and V2 prime to this and that way, so, we can say L2 prime then we can say V3 prime and that way when it will meet a point or the difference between the two streams, in terms of flow rates the difference between the two streams for any of the stages like this for any of the stages, what is the difference between the two streams which is entering and which is leaving.

So, from there we will be getting this delta. So, the same concept we adopted for the extraction process also, so, delta is point of intersection so, that is the point of intersection of the lines F prime, V1 prime and Ln prime and S prime like this. So, whenever this all the feed line and overflow that will be extended and then it will meet a particular point that is delta.

So, in the next class will be discussing about the supercritical fluid extraction and the equipment for leaching. Thank you