**Material and Energy Balance Computations**
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**Lecture –12**
**Material Balance of Multiple Units (Contd.,)**

Hello everyone, welcome back once again in the NPTEL online certification course on Material and Energy Balance Computations. We were discussing the material balance of multiple units and its fundamentals and will continue the same from the last week that we were in the last lecture that we take. So in the last lecture, we have solved one problem. We have seen how the Concept of Material Balance on a single unit can be applied on the multiple units.

Why it is subdivided into systems in order to simplify the problem or to understand it in a better way. And the same thing now we will see in form of a text because in the last problem that I solved there the flow chart itself was given. But now usually the problem statement are not given in such a way that you have to come up with your flowchart and subsequently levelling that flow chart.

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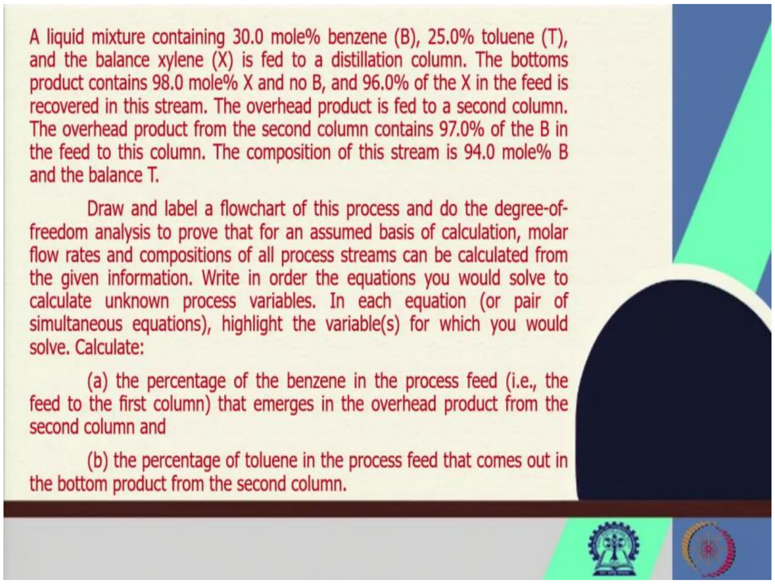


So, let us look at a problem statement that looks like something and it reads like something like this. So a liquid mixture containing 30 mol % Benzene 25 % toluene and the balance xylene is fed to a distillation column. Now let me tell you here the purpose of distillation column is to separate components from a mixture using its relative volatility. Now, for the time being, you consider that this is a process unit where separation of components are happening. So here we have a mixture.

The mole fraction or the mol % are given. So whenever a problem statements is like this that you have 30 mol % Benzene. And again explicitly is not mentioned 25 % or 25 mol % toluene it is not explicitly mentioned here. But you can consider that these are now given in mol % because one is already mentioned as the mol %. So you have 30 mol % benzene 20 mol % toluene and balance xylene.

Now these are the abbreviated form that we will use it while solving the problem. So B stands for benzene, capital T stands for toluene, and X stands for this Xylene. Now, this mixture is fed to a process unit called the distillation column. The bottom that means the bottom product contains 90 mol % Xylene and no Benzene. And 96 % of the Xylene in the feed is recovered in this stream. The overhead product is fed to a second column.

The overhead product from the second column contains 97 % of benzene in the feed to this column. The composition of the stream is 94 mol % benzene and the balance toluene. We have to draw and level a flowchart of this process. We have to perform degree of freedom analysis to prove that for an assumed basis of calculation, which is not mentioned here. That is why we have to assume molar flow rates and compositions of all process streams can be estimated or calculated from the given information.

So, which means we have to prove that overall process the degree of freedom is zero. We have to write the sequence of equations which would solve the problem. That means the equations involving these unknown process variables and in which order you would solve it in that order you have to write the equation and highlight the variables against or say in every equation that which one would calculate from that equation.

Highlight the variables for which you would solve that equation. You did not do any calculation at this stage or just mark it like that. That this is to say you got an equation which is 100 $x_1$ + 500 $x_2$ is equal to something known in the right hand side. So you have in this equation two unknowns. But you mark that which one you would calculate from this equation. Remember the order of equations preferably should be in the order that you would solve as minimum as possible the simultaneous equations.

This is for ease of calculation. When you cannot avoid simultaneous equations, you have to state that that we will solve this set of equations in order to find out these two variables or unknown variables. And then the calculation part comes that we have to find out what is the percentage of benzene in the process feed. That is the feed to the first column that emerges in the overhead product from the second column.

And the percentage of toluene in the process field that comes out in the bottom product of the second column. That means you have a process unit where overhead means say you have a process unit, something is coming out from the top, something is coming out from the bottom. This is called overhead product and this is called the bottom product. So, again try to visualise the problem and at the same time try to draw it this flowchart so that you need not look at this complex problem statement again and again when you will solve it.

When calculate these steps now, this is the point where the flowchart and its levelling becomes important because now you can see that it involves only two process unit and it is now complicated enough. The problem statement is complicated enough to remember what is the molar fractions molar compositions and the relation between the two streams because it is mentioned there that there are certain composition that is coming out with respect to the feed composition.

So until and unless we draw the flowchart and level it in detail we have to consult or we have to read the problem statement again and again. So for that for any problem in fact at this stage you read the problem statement couple of times and then draw the flowchart level it in full details.

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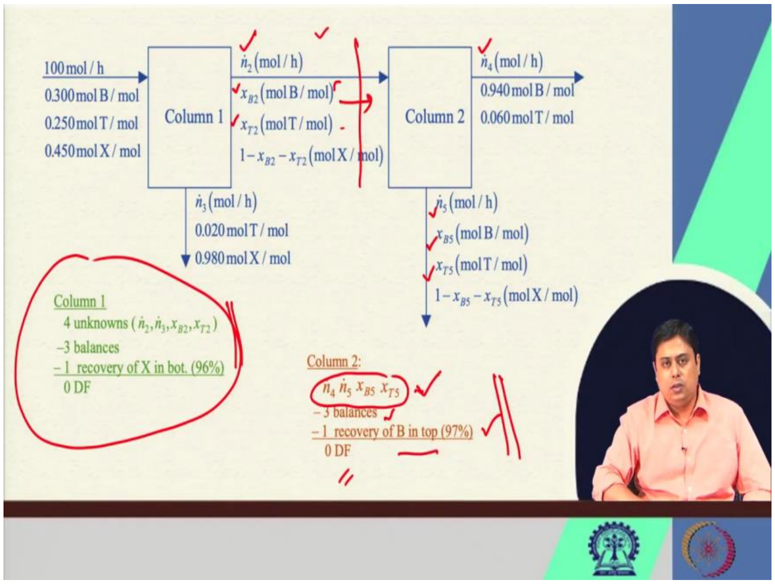


So if you try to draw the flowchart, let me help you here that you get something like this. Now here if you see, it is mentioned that true that for a assumed basis of calculation. We have to calculate or we have to show that the molar fractions molar flow rates everything can be calculated. So let start with the basis of calculation that we have 100 mol/h. And why it is not chosen as 100 kg/h.

Because we have the molar fractions known, the molar composition is known. So, the logical basis of calculation is 100 mol/h. If you had taken 100 kg/h then the conversions of this mole fractions to wait for fractions would be an intermediate step which you can avoid if you choose appropriately the basis of calculation and in this case it is 100 mol/h. So you have 100 mol/h that is coming into a distillation column.

And its composition is known we had 30 mol % benzene, 20 mol % toluene and rest is xylene. So that means 0.3 mole of benzene per mole of this stream, 0.25 mole of toluene per mole of this stream the rest which is 0.45 mole of xylene per mole of the stream. This is coming into a column where you have the overhead product and the bottom that is the bottom product. There in the bottom product if you look at the problem.

Still but once again, it says that the bottom contains 98 mol % xylene and no Benzene. And 96 % of xylene in the feed is recovered in this stream. So these 2 piece of information are provided. So if you are unknown here is m3 mol/h because we do not know how much molar flow rate it is coming out. There you have the molar composition as 0.98 mole of xylene per mole of this stream that is the $\dot{m}_3$ and the rest is toluene.

Because it is clearly mentioned there is no Benzene that means on the other stream, you would have all the three components. That if your unknown is $\dot{m}_2$ molar flow rate there you have say $x_{B2}$ mole of B per mole, 2 stands for this stream that is we are considering here 2 this is 3 this is 1 in this manner. This is the 4th stream and this is the 5th stream. So $x_B$ and $x_T$ in this stream 2 and the rest would then be Xylene. These are unknown to us.

So that means on stream 2 we have 3 unknowns. The molar flow rate, the mole composition, the mole fraction of benzene, and the toluene and we have the rest is xylene. It is said that this overhead field is fed to a second column. The overhead product from the second column contains 97 % benzene in the feed to the system. The composition of this stream is 94 % benzene and balance toluene. So that means this stream is fed to column 2 where you have in the overhead 94 mol % benzene.

The composition of this stream that is overhead that is coming out and the balance toluene there is no xylene. So that means in the bottoms now what you have is $\dot{m}_5$ the unknown molar flow rate that is coming out as the bottom product. The other three other in fact the three constituent of these flow that is the benzene, toluene and the rest is xylene. This is how we level the flowchart. And remember there is the relation the information that are given that the percentage recovery and the link between two streams by this 97 % you will see that.

So, for column 1 now as I mentioned before applying this to the individual units or individual system let us have a look at the overall system that whether it is solvable or not. If you look at the overall process and if I make an imaginary system boundary we see that we have one inlet and three outlets. That means this is the inlet and we have 1, 2 and 3 outlets. And if you try to identify the unknowns the number of unknowns we have, here we have 1. Here, we have 2, 3, 4 and 5.

So for the overall process we see that we have 5 unknowns. How many species we have? So that we can write their individual balance equations, we have three species. So 3 independent balance equations we can write and then, what does this mean that the degree of freedom is zero in this case or non-zero? The point is that it is said that first of all you show that it can be solvable at all the streams, the compositions these unknown compositions can be calculated.

But remember in the problem statement, two things are mentioned; one is the information that is provided that its percentage recovery we have the percentage recovery that the 96 % of x in the feed is recovered in the system from the stream and the overall product from the second streams contains 96 % of benzene in the feed to this column. So these 2 streams link information’s are provided. So that means two additional information we can extract from the problem statement.

That means we have zero degrees of freedom. Which means the problem overall problem can be solved or it is a solvable problem. Now coming to the calculation part or even before that We have the steps that we have to solve. And here if we see that first if we applied to column1. Now in column 1, we see that we have 4 unknowns and those unknowns are $n_2$, $n_3$, the composition of benzene and the composition of toluene. So we have four unknowns.

We have three balances. That we can write because we have 3 species. So 3 species we can write three independent balance equations. And in this case as I mentioned earlier, we have one information that is given the problem statement which is the percentage recovery of xylene in the bottom. So that means one another additional information is given that helps us to achieve the zero degree of freedom.

Which means the column 1 can be calculated at first in a standalone manner. And then if we look at column 2 what we see that here we have 4 unknowns in column 2 and those are $n_4$, $n_5$ or rather $\dot{n}_4$, $\dot{n}_5$, $x_{B5}$ and $x_{T5}$. So, these are the 4 unknowns we can identify for column 2 provided we calculate column one beforehand, and we realise that these are now known to us that $\dot{n}_2$, $x_{B2}$ and $x_{T2}$.

So in column 2 we can see that we have now 4 unknowns. We have three species here. So we can write three independent balance equations and 1 percentage recovery of benzene this additional information was already provided in the problem statement. So, therefore for column 2 we have 4 unknowns, we can write 3 material balance equations that are independent and one recovery information that forms our degree of freedom for column 2 as 0.

But we have to be careful here that to write this part as zero. We considered the column 1, all the unknowns for column one that are known. So, which means before coming to the column 2 we have calculated these unknown parameters. So that means we have now understood that what is there in column 1 its unknown variables and the column 2 based on the calculation of column 1.

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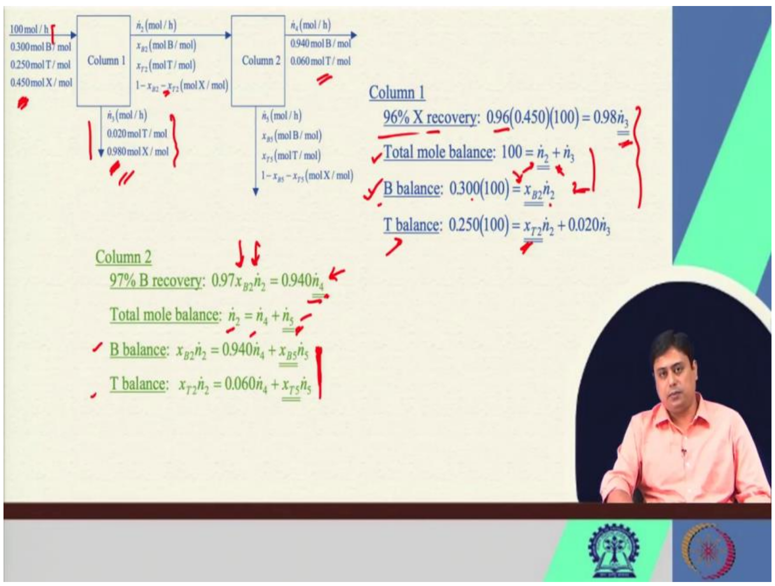


So now if we apply the balance equation on column 1 that is we have the 96 % recovery which is 96 % of this known stream, the xylene that is coming out from the bottom. This is the 0.98 $n_3$. So the first one we get from the xylene recovery. Now here you can realise that this $\dot{n}_3$ is the only unknown. So we can highlight that that this is the unknown variable that will be calculated from this equation. If you look at the total mole balance, we see that $\dot{n}_2$ and $\dot{n}_3$ gives the 100 here. That is the inlet.

Now in the previous step, if you see that we have calculated $\dot{n}_3$. That means, it is known now, so that means in this equation, the only unknown would be $\dot{n}_2$ and that is why it is highlighted. If you apply benzene balance for column 1 we see that the benzene composition here is no benzene. It is there only in one stream in the output so which is $x_{B2}$ and $\dot{n}_2$. We have just calculated $\dot{n}_2$. So, here $x_{B2}$ would be the only unknown parameter.

And the third one if we apply which is the toluene balance because we have already applied mole balance, total mole balance, benzene balance. So, the remaining part is either xylene or toluene. But the point that we are avoiding xylene because it is appearing in all the three streams. And in fact that toluene is also there in all the 3 streams. So any one of these we can apply but before applying to either toluene or xylene we have applied to benzene because it is not appearing in the others streams.

So it is there only in two streams that is why it has been applied or it has been written at the first step before toluene or xylene stage. Similarly, we write toluene balance here. One can write this xylene balance as well and calculate this composition because the others are now known, others are known from the previous step. For column 2, now we have the again benzene recovery relation that is given the problem statement.

From there we write this expression. Now, here again remember the $\dot{n}_2$ is now known $x_{B2}$ we have already calculated so $\dot{n}_4$ is what is the unknown here we have. Now, in this case, the total mole balance is $n_2 = n_4 + n_5$, now these all are molar flow rates so it is written in $\dot{n}_3$, $\dot{n}_4$, $\dot{n}_5$. So now you see again in this case these two terms are unknown variables or by now it is known so we calculate $\dot{n}_5$.

Because from the previous stage we have seen that $\dot{n}_2$ is known to us. And from this step, we have found that $\dot{n}_4$ is known to us. So $n_5$ is what is unknown in this equation. Similarly, we write benzene and toluene balance or any other two compositions between benzene, toluene and xylene and you would find out the rest of the variables like this stepwise manner. So, this is the sequence that can be followed for solving this problem.

But remember here that this is not only the process or the sequence of the equations that have written can be just in only one type of this format. You can come up with your strategy but this is one of them which will lead to one of the easier ways to solve the problem as I mentioned that instead of this writing benzene, toluene balance one can easily write the benzene xylene balance or toluene xylene balance.

But the logic of choosing benzene in this case was that there was no benzene in the third stream. So you had to solve only two components or two streams. Similarly, in column 2, one can easily apply the xylene balance instead of the benzene and toluene, and that would be in fact say the more easier way because here, there is no xylene in the overhead stream. I hope this sequence of solving the equations or writing the order and to identify the variables is clear to you.

Because identifying this variables or unknown variables in each equation and realising that it is now known before you go to the next step and considering that it is known variable for the next step. You can avoid the solution of simultaneous equations. We will solve a couple of more problems in the next lectures. Till then, I want you to practice this problem statement and solve this, which I have not shown you the solution and will solve in the next class. Thank you for your attention.