Material and Energy Balance Computations
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Lecture –11
Material Balance of Multiple Units

Hello everyone, welcome back once again in the NPTEL online certification course on Material and Energy Balance Computations. We are now in module 3, where we will learn today material balance calculations on multiple units. Till the last class, we have seen the fundamentals of material balance calculations. What is degree of freedom analysis? Why is it necessary? And we have also seen its application on a single unit process.

Now the point is hardly any application in any commercial process is a single unit process, but that is still necessary to understand because that is the building block of the multiple units. So today, we will see very basic things about this material balance on multiple units.

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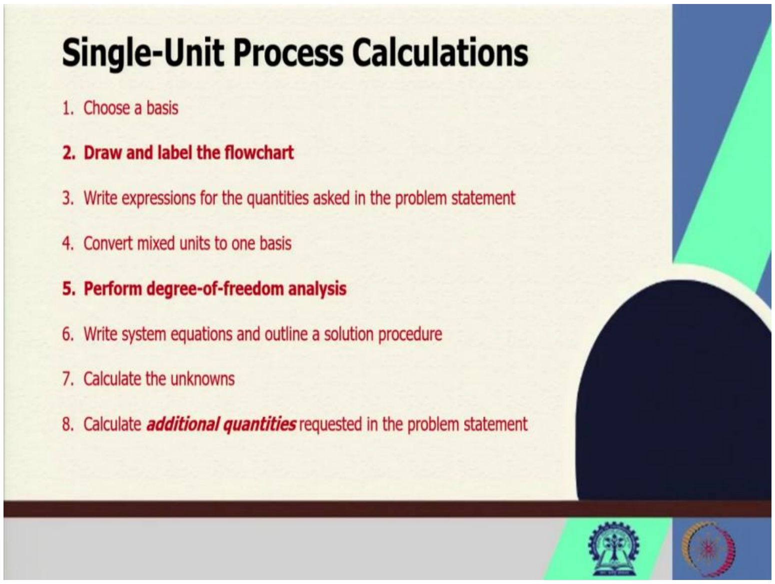

So, when we are talking about multiple units and before we go into that. Let me once again quickly reiterate what are the steps we have to follow for a single unit process, because this again, the single unit is the building block of the multiple units. So in such a problem, the methodology would remain the same. The only thing is that now we have multiple, single units of single individual units which are interconnected. So for any problem, if the goal is not specified clearly, that is the basis of calculation, then we have to choose a basis.

We have to draw and level the flowchart, and we have to write the expression for the quantities that has been asked in the problem statement because this is what we need to achieve. Then we level the flowchart with the consistent units. So, flowchart and levelling together, but once we have seen or we have understood that what is the goal, that what we need to achieve in the final process then we have to recheck, and we have to make the units consistent by converting the inconsistent units if necessary.

Then we do the degree of freedom analysis. Then we write the system equations, and we understand or realise that what is the outline of this solution procedure could be and then we solve the unknowns. And the final step, which is mostly forgotten sometimes, it is that we have to calculate the additional quantities that has been fixed in point 3 that what is the problem statement asking for.

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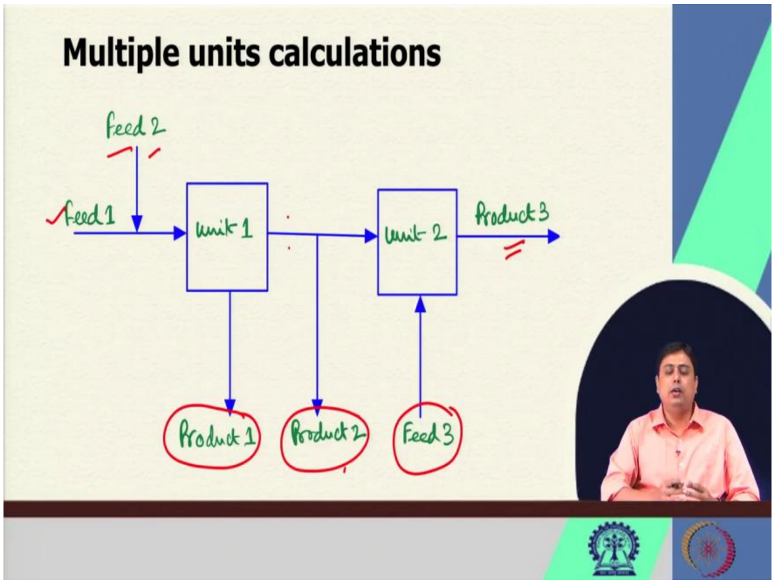

So, now coming to the multiple units, the same methodology can be implemented, but before that, let us understand that why and how we do this implementation for the single units on to the multiple-unit calculation. So here, say we have two unit processes that are combined like this that we have a feed that is feed 1 comes into unit 1 where some process is happening, before that it is mixed with feed 2.

Then this mixture goes into unit 1, where we take out some product which is product 1. Part of this is further taken to unit 2 and there say, for example, here we have some process parameter change process condition change and we take out again another stream which is product 2. Then this stream goes into unit 2 for further processing, where it is mixed with another feed, which is labelled as feed 3, and eventually we get some product which is product 3.

Now, this is still a simplified version of multiple units that how it can look like there will be multiple streams now involved. Now this feed 2 say can act as a recycle stream from somewhere inside the process. This stream with product 2 stream can further say you can consider it was a bypass off from the system to check the desired quality.

Now the point is that we have now this combination of individual units of the single unit processes interconnected. So we at first, we have to understand that now, we cannot call this as an individual unit balance. We have to do the overall system balance. So the system is now comprised of multiple units or single operation stages. In a more precise manner, if you try to define a system now so this individual units are the parts of a overall system or a system.

Now again a system is further a part of an overall process. So for example, in material balance calculation we will define a system consisting of feed and product outlet. So say whatever the imaginary envelop or boundary we can draw around the say mixing point, splitting point or individual unit where the streams that are coming into the system or actually penetrating the boundary would be considered for the degree of freedom analysis. So for example, let us simplify this explanation with the visual schematic.

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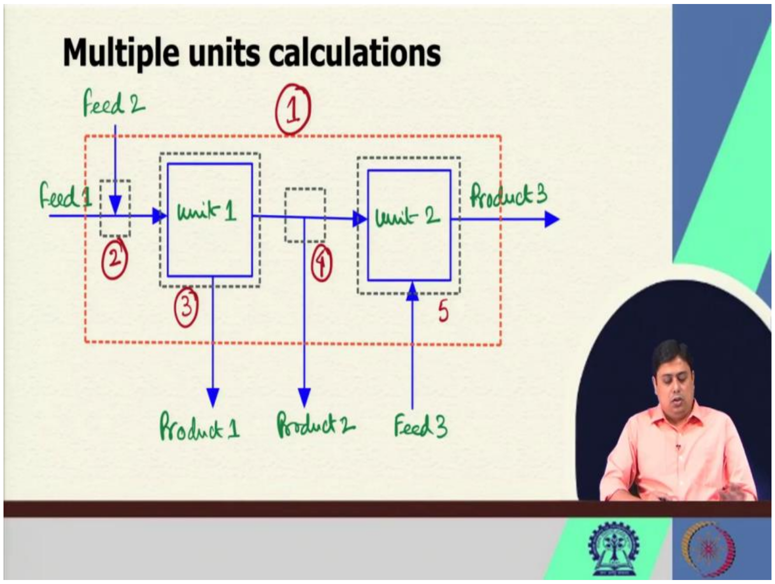

The same system, now say we have drawn a couple of envelopes in order to divide the overall process into a couple of subsystems. Or say now we have systems that is overall system is the bigger envelope or the bigger boundary we can draw is the overall process. Further the mixing point between feed 1 and feed 2 is the mixing point of two streams where we have two inlets and one outlet.

So, this is becoming another system around which we can apply material balance. So these are now becoming a system that is the serial number 1, 2, 3, 4 and 5. So we basically have 5 systems or subsystems inside a overall system. If you say because these are kind of interchangeable nomenclature that if you say that we have five systems then it becomes the overall process. So, overall process consists of 5 systems or overall system consists of five subsystems.

So we can clearly now see that the overall process we have five systems that is the mixing point which is system 2 we had the individual unit, which is unit 1. Again because now you understand that system means an imaginary boundary which we can draw around a unit process. Now for that system the inlet and outlet stream would be the ones that is penetrating the boundary of that individual system.

So for this overall system which is marked by number 1, In this overall system you can now clearly see that we have two inlets. So here we have 1, 2, 3 inlets, basically. So three inlets and we have three outlets because it is the streams that are intersecting this hypothetical boundary. Now for the whole systems the other streams are inside this boundary which are not coming out or intersecting the boundary.

So, we did not consider those streams or the unknowns that we would level later on those lines would not be considered for the for degree of freedom analysis. Similarly, say for this unit 2 or say the subsystem 2 in this subsystem 2, we have two inlets that is the feed 1 and feed 2, and we have one outlet that is going into unit 1. So, for system 2 we will consider the variables that will define on these streams only.

We will not bother about the other unknowns that are there after this unit 2 or not attached to or not link directly to unit 2 because its boundary ends here. The system boundary ends there. That means the bottom line is we will consider a overall process by several subsystems. We will analyse overall subsystems or say the systems inside the overall process, and the system is an imaginary boundary around unit process. And its inlet and outlet would definitely intersect the hypothetical boundary of the system.

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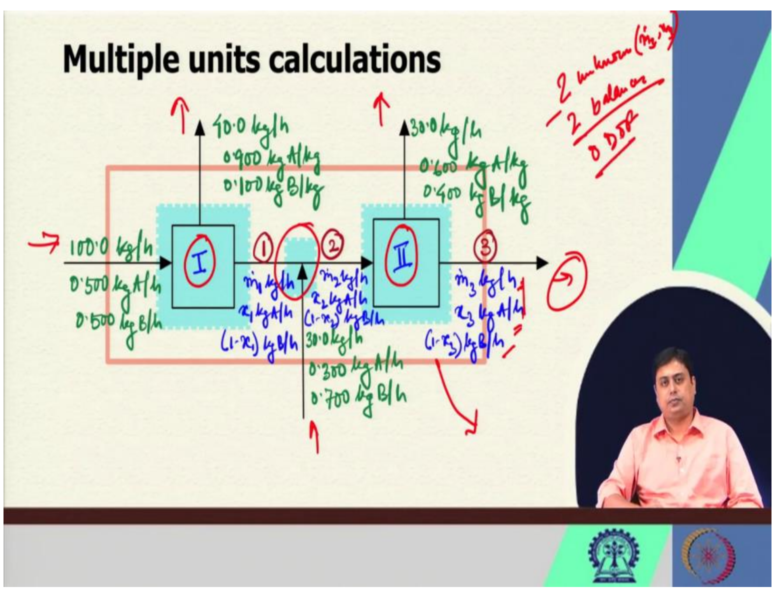

So for example say we have these 2 unit process. So here the problem statement says we have 100 kg/h of a mixture that consists of A and B, these two components. We have 50 wt % of A and the rest B. These are fed into a unit 1 where there are two streams one is taken out at 40 kg/h.

And that stream consists of 90 wt % of A and rest B. This outlet from unit 1 is further mixed with another stream, that is coming at a rate of 30 kg/h where we have 30 wt % of A and rest B.

This mixture is further fed to unit 2 where it is further treated? And we have one stream. That is coming out as 30 kg/h with the composition of 60 wt % A and rest B. The questions are that what would be this composition and flow rate of the streams or the streamlines that are marked by 1, 2, 3 here. So, for this problem, how do we proceed or how do we do that? This is one of the simplest problem on two units material balance.

So, what would be the first step here? The basis of calculation is given because we know the flow rate of the inlet. Mass flow rate is given 100 kg/h so that means our flow rate of 1, 2 and 3 these 3 streams could be in kg/h, and the composition would be in mass percentage because everything is given here in mass percentage. So, now we at first write the unknowns and those are written in blue colour here.

So, at point 1 we have to calculate or on line 1 we have to calculate its mass flow rate which is $\dot{m}1$. We are to calculate its composition by weights which are x_1, if x_1 kg is there of A per hour then naturally, the other one the component B would be $1 - x_1$ kg/h. Similarly the on the same line the other two streamlines have been marked with the necessary unknown flow rate and its composition.

So 2 in the subscript is the mass flow rate and composition for line 2 or the streamline 2 and this is for the streamline 3 where we have subscript 3. Again x is mentioned because it is the wt % or the weight fraction that we are calculating. So we have that means levelled the flowchart with consistent units. Now the next step would be we identify how many subsystems are there are how many systems are there in this overall process.

The overall process is this red enclosure that you see the orange kind of colour. So, this is the overall process. So, that means now here what we can see that we have if you try to now look at how many unknowns for the overall system we have. For the overall system we see that we have 2 unknowns. The two unknowns are m_3 hand x_3 because if you look at this overall process, we have one inlet stream. We have the second inlet stream and other three are the outlet streams.

Now everywhere, the composition is known except on streamline 3 where we have the unknown mass flow rate and the unknown A composition. The composition of component A the weight fraction which is x_3 if we calculate x_3, we can easily calculate $1 - x_3$. So, now the point is now this is the overall system. Inside this we have three subsystems and those are marked as these blue shaded cells. So the first one or if I tell from left to right that we have unit 1 and around which we can apply the material balance.

We have unit 2 the second one and the third one is the mixing point. These are the three subsystems and when will apply degree of freedom around each of these we will realise that which unit we have to start at first for the calculation. The one that would give us the degree of freedom as zero we would start from that point. Because then that means that subsystem can easily be solved.

But before that you apply this overall degree of freedom analysis for the overall process because at first we have to understand whether the information that has been provided is sufficient to solve for the overall system or not. Now here as I mentioned or you can identify that we have only two unknowns for the overall system. We have two components here. That means we have two unknowns minus so here we have two unknowns which are $\dot{m}_3$ and x_3 and we have two components of that means we can write two balances, the degree of freedom is zero.

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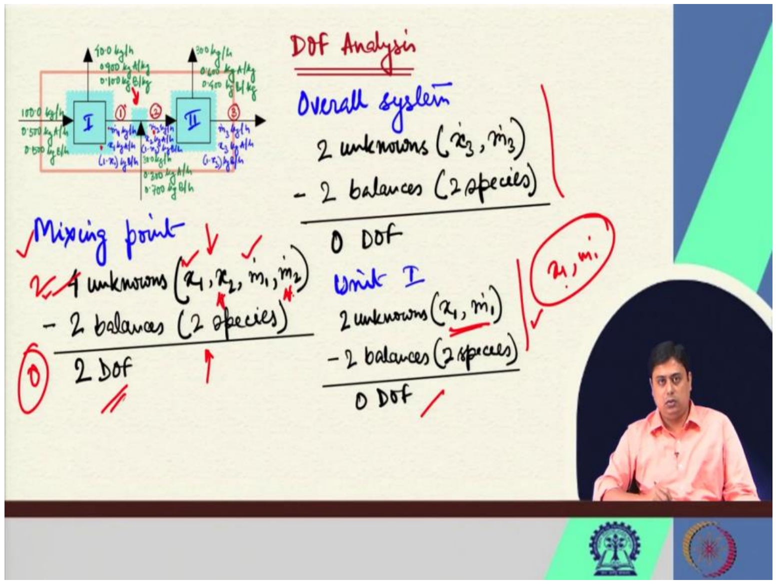

So let us apply that and we see that how it comes out. To say someone without doing the degree of freedom analysis starts at mixing point that means here. He or she started to solve the problem taking the mixing point as his or her first point. There should identify that she had or he had 4 unknowns. That is the x_1, x_2, $\dot{m}_1$ and $\dot{m}_2$ and same here $\dot{m}$ stands for the flow rate. So x_1, x_2 and $\dot{m}_1$ and $\dot{m}_2$. These are the four unknowns.

The maximum number of balanced equations that you write or write for this system is 2 because you have 2 species. You can write the balances for the 2 species or 1 species and 1 overall balance. These two independent balances so that means you have basically two degree of freedom, which means you cannot solve if you start with the mixing point; the calculations at the mixing point but as I said at first you have to look at whether the overall system can be solved or not.

Now in the overall system as I mentioned you see that it is solvable. The degree of freedom is 0 that means it must be solvable. The information that is given are sufficient to solve the problem. Now here are the ones who started in the mixing point they immediately realise. that is not good starting point because there are several unknowns than the known or the known balances. So now if we shift to unit 1 or if you start with unit 1 we see in unit 1 we have this stream1 which is basically where the mass flow rate and compositions are unknowns.

That means in unit 1 we have x_1 and m_1. These are the two things that are unknown. And for unit 1 we can write two balances because we had two components of species. So we can write two individual or independent balance material balances. And since we are still talking about the non-reactive system that means we get the 0 degree of freedom. Now the point if you remember that once we realise that these two unknowns are now known that means x_1 and $\dot{m}_1$ if one solved unit 1 first then these two are known now x_1 and $\dot{m}_1$ known because it can be solved. So once these are known.

If someone again goes to this mixing point balances you would realise that now basically he or she have two unknowns instead of four. And then mixing point can be solved. Because now, you know, x_1 and $\dot{m}_1$ that means it gives you the sequence to solve the problem that solve unit 1 at first know the values of x_1 and $\dot{m}_1$. Take those values utilise it for mixing point then you can solve that mixing point.

Because once you have it as 2 unknowns you always can write 2 balances there, two independent balance equations, so the degree of freedom would be zero. So once this is zero that means you know x_2 and $\dot{m}_2$.

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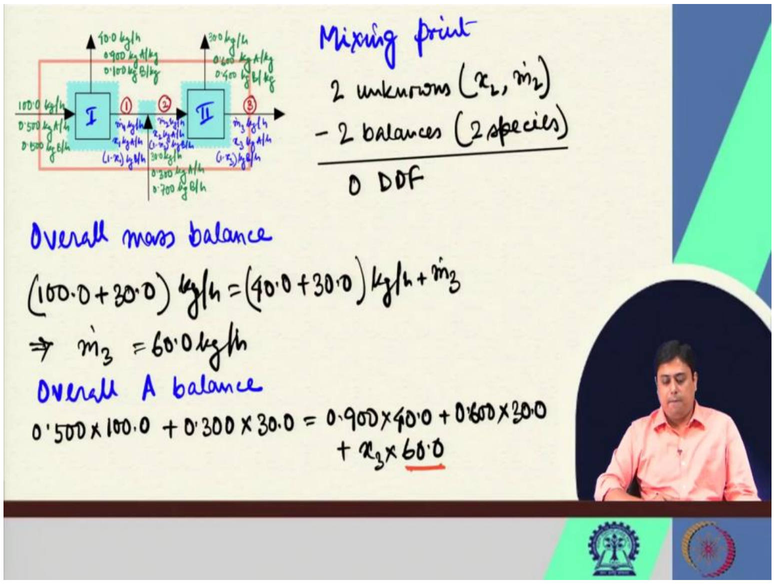

Having that knowledge now if you look at; so this is what I mention that now you have x_2 and m_2

and you get 0 degree of freedom. So, once that is known and you have seen already that in overall balance you can calculate x_3 and m_3. While applying the degree of freedom analysis to the overall process, you see that already you knew x_3 and $\dot{m}_3$. So there is no need to apply this degree of freedom analysis again on unit 2.

Because we are having the combination of overall system, mixing point and unit 1 the remaining is unit 2 that is automatically deducted. So that means now if we do the calculations, so now we have an outline of the solution. So what we do. We start with the same process that we solve the overall system first, unit 2 next, and mixing point at the third step. So we do that we apply the overall mass balance that is the hundred and all the units are consistent kg/h.

So, 100 + 30, this one + this one = 40 + 30 + $\dot{m}_3$ in kg/h. We get the answer; here, only one unknown is there. Again we can apply the component A balance for the overall process. We do that that is the 50 percent, 0.500. So here again, if you realise if you look at the number, you see the significant figures the importance the things that we have discussed earlier are preserved. So that is why it is clearly mentioned 0.500 × 100.0 for this stream.

This one has this composition 30 wt % × its mass flow rate = this individual stream of these 2 outlets + the third one, which is unknown. These are the wt % × their mass flow rate. So you get here; now here you can see this 60 has been taken immediately once it is known. This $m_3 \times x_3$ is basically is this part where m3 is substituted by 60 because we knew once it is calculated we consider that is a known parameter.

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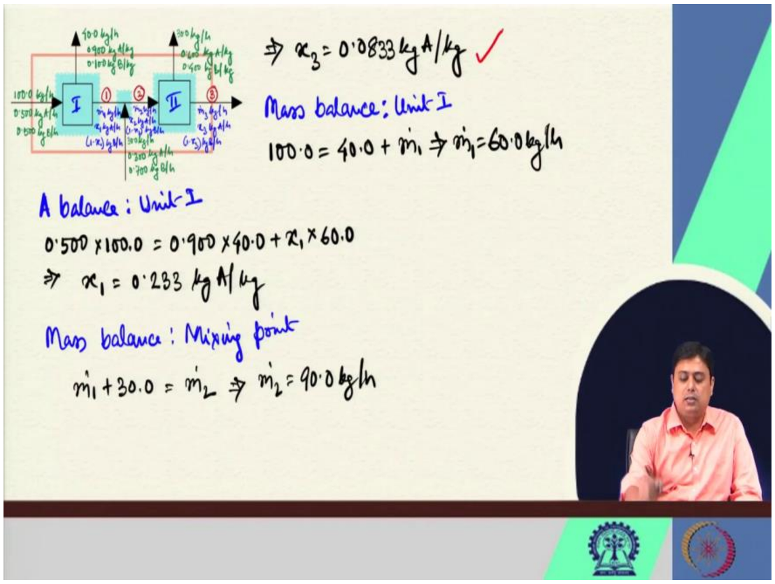

So we can easily calculate here, what is the value of x_3. Again it is written in such a format that the significant numbers of the figures are preserved. And then the second stage is the application of this material balance on unit 1 because that is there that should come before the mixing unit or the mixing point. So, similarly we apply the overall mass balance here 100 + here only one feet is there, so 100 = 40 + $\dot{m}_1$ that is the two outlet streams. So ṁ1 is known here.

So, we apply component A balance overall balance around this unit 1. So component A balance around unit 1 is this part that we have only one stream that is coming inlet and we have 2 outlets. This 60 comes from here, this flow rate was known as 40 kg/h with 90 wt % and here for this stream 1 we did not know what is the mass fraction, but now we know what is the mass flow rate which is $\dot{m}_1$.

And then we know what is x_1 and then we apply again. Now it is m_1 and x_1 these two are known. So we apply here on the mixing unit this material balance and we calculate the m_2 because here $\dot{m}_1$ + 30 these are the two inlet stream = the stream flow rate of 2. So $\dot{m}_2$ is 90.0 kg/h.

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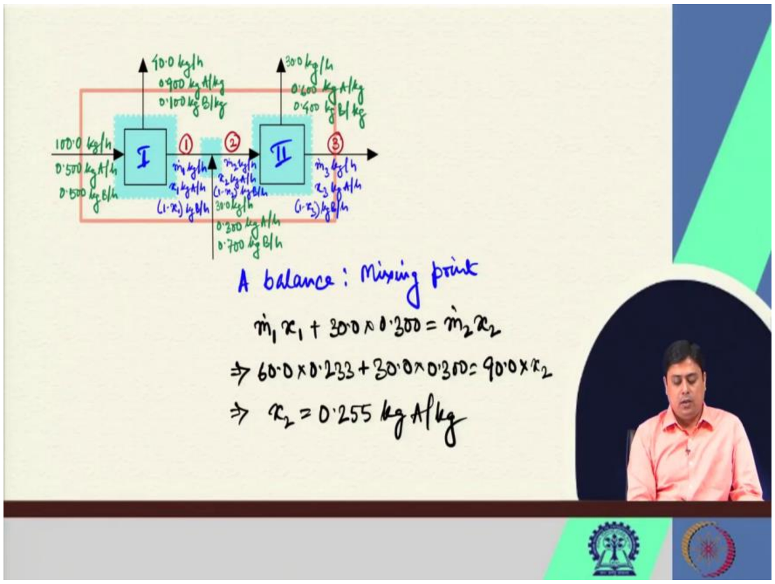

Again we can I apply the component A balance around the mixing point. There we see that we have $\dot{m}_1 \times x_1$ this is the amount of A being fed to the mixing point that this mixing system enclosed by this blue shaded box + 30.0. This is the inlet flow rate of another stream × its composition of A = $\dot{m}_2$ x_2. Remember here $\dot{m}_1$ and x_1 are now known.

So we have and also we know what $\dot{m}_2$ is because we have just calculated that in the last step. So we have x_2, do not forget to write the consistent unit which is kg amount A per kg of the stream this is the weight fraction. So that means after calculating the mixing point, we had realised what would be the value of m_2, x_2. So the stream composition of 2 is known. Before that while applying this to unit 1, we estimated what would be x_1 and $\dot{m}_1$.

So that means the stream composition of 1 is known and even before that while applying this to the overall balance we already calculated $\dot{m}_3$ and x_3. So the composition and the flow rate of stream 3 is also known to us. So, I hope you understand this solution procedure when it comes to the multiple units. We will in fact continue this week by solving couple of examples or we will see couple of problems and how to draw the flowchart.

How to apply this degree of freedom analysis for the subsystems? And subsequently, solve it. Till then, thank you for your attention.