Material and Energy Balance Computations
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Lecture –08
Fundamentals of Material Balance (Contd.,)

Hello everyone, welcome back once again in the lecture classes of Material and Energy Balance Computations. We are in module 2, that is, material balance calculation, fundamentals and its application to the single unit. Till the last lecture, we have seen the fundamentals and which will continue in this class as well.

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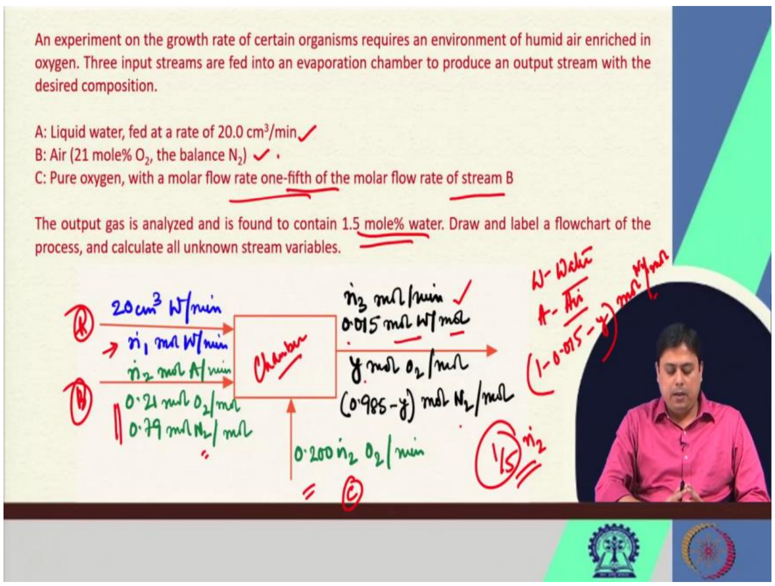

And in the last class, we just stopped at a problem statement where it is mentioned that in an experiment on the growth of certain organisms that requires an environment of humid air enriched in oxygen. Now there are three input streams that are fed into this evaporation chamber to produce an output stream with the desired composition. The streams are the liquid water that has a known flow rate.

Air molar composition is known, and the third stream is pure oxygen with a molar flow rate that has a relation with the molar flow rate that is of stream B. Now, this output gas is analyzed and is found to contain 1.5 mol % of water. Now our task is to draw and level a flow chart of this process and to calculate all unknown stream variables. So, at the same time, we are looking with the fundamentals as well as its application for a single unit in this case.

The fundamental is that we are learning how to draw a flowchart because in the last class, we introduced the term flowchart. We have to level it with the information that is given in the problem statement. So, that we need not look back again and again to the problem statement while solving the problem a clear schematic representing the problem statement should be ready with us with all the desired information or given information levelled on the flowchart.

So, it is not just drawing the flowchart but also to level with detailed information that is given and what is to be calculated or the unknowns. So, in this example, the scenario is something like this that we have an evaporation chamber where we have these three streams that are mentioned here. Now what we see here is that the stream A that is mentioned we take it for liquid water and where the capital W stand for water. It is of known flow rate volumetric flow rate but our molar flow rate is not known.

So, that is why it is given as an unknown variable, but it is clear that easily we can find out this unknown variable $\dot{n}_1$ because we know the molecular weight of water, we know the molar flow rate. So, here it is the volumetric flow rate is given. So we can calculate the molar flow rate. But still, for the illustration, let us take that as unknown as that is seen immediately from the problem statement, the stream B that is air that is also coming into the chamber where the molar flow rate is not known or unknown, but its molar composition is given.

So, which is 0.21 mol of O_2 per mol of this air, where A stands for the air. And the third stream, we have pure oxygen in which the flow rate is mentioned as 1/5 of that that we have for stream B which is 0.200 multiplied by oxygen per minute. So, this is the relation since it is given here we directly write that in this flowchart. Now, what are the unknowns? Unknowns are the output gas molar flow rate which is $\dot{n}_3$.

Now here only, one information is mentioned that is 1.5 mol % water. So, we write that that it is 0.015 mol of water per mol of this output stream and what about then oxygen and nitrogen those are unknown. Now, if we just assume one unknown parameter, say that is for oxygen, we have the molar concentration or the mole fraction y mole oxygen per mole of this output stream. Now since these are the fraction last time also I mentioned that it is basically.

Now the third component or the remaining component which is the n_2 since this is a non-reacting chamber it should also come out we have 1 – 0.015 – y, this is the num amount of mole of nitrogen per mole of the output stream which is 0.985 – y mole of nitrogen per mole of the output stream. So, this is how we level the flow chart because drawing is just for the single unit system it is a box with input and output streams.

Now once it is drawn and levelled like this we need not consult the problem statement repeatedly while solving the problem. So, now let us say solve the problem. Now we have to estimate that what are the unknown stream variables and what are those values.

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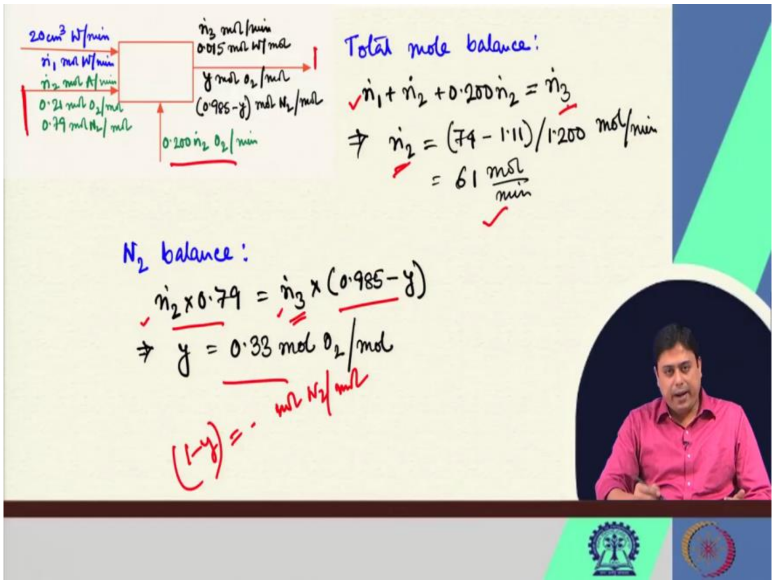

So, clearly if we now look at this chart. So, now let us get rid of the problem statement because we have. Now a detailed flowchart with a level so all the information are now there while levelling we have to consider and we have to remember that the units are consistent or we write the levels having the unit consistency in mind because that helps us in a great extent while calculating the unknowns.

So, for example, here we had in the problem statement the flow rate was mentioned as per minute, cm^3/min. Now that is why all the molar flow rates here are now mentioned with respect to that specification that is per unit time which is here the minute. If we had done it here that $\dot{n}_2$ moles of air per hour or per second, it would not be consistent and during calculation, we have to convert to consistent units.

So, that is eliminated by levelling the flow chart with consistent units, and if the problem statement does not have the consistent units, we convert that and then we place on the flowchart and we level it that eliminates the chances of errors in the subsequent calculation stages. So, once we have the unit consistency as I mentioned in order to find out now the unknowns if we, Now count the number of unknowns. So, here we have one which is $\dot{n}_1$, $\dot{n}_2$ this is the second we have then the third is $\dot{n}_3$, the fourth one is the y or the mole fraction of oxygen. So, these are the unknowns we have. Now, if we look at the unknowns, the first unknown easily can be calculated based on our current understanding of the molecular weight and the volumetric flow rate it is 20 cm^3/min of water.

Now here comes the application of the density because that we need in order to convert it to the molar flow rate. So, 20 cm^3/min multiplied by the density gives us the mass flow rate, multiply or here we divide it by the molecular weight because one mole contains 18 gram of water that gives us the molar flow rate that means the moles of water flowing per minute in the system and that gives us the value of $\dot{n}_1$.

Now it is convenient that if we immediately replace this value on the flow chart like if we now write instead of $\dot{n}_1$ by just striking out this with a known value because this is what we have just calculated. This eliminates the problem of understanding or looking at again on the flowchart and realizing that how many unknowns we have so that those many equations we have to solve. And this is very important when we have multiple units, which we will discuss later and a more complex system.

But this is relatively easier and straightforward process because we are discussing a single unit. So, we have got the first unknown variable. Now the system is a non-reactive system, and it is at a steady-state. So, which means our balance equation boils down to input = output. Now if we write it for the water balance if we look at the process and write the water balance, what do we have here? That this n_1, which we just calculated was coming in the system, the molar flow rate of n_1 should be going out of the system.

Now here, the amount of water that is going out is the mole fraction of water in the output stream multiplied by the molar flow rate of the output stream. So, which means after replacing the value of $\dot{n}_1$ with what we have just calculated, we have the value of $\dot{n}_3$ which is now known. So, the remaining unknowns are $\dot{n}_2$ and say the y the mole fraction of oxygen.

So, now if we do the mole balance the total mole balance of the system that means $\dot{n}_1 + \dot{n}_2 +$ this much of oxygen which is $0.200 \times \dot{n}_2$ this is the number the molar flow rate that goes into the system. So, the same number should come out which is $\dot{n}_3$. Now here previously we have calculated $\dot{n}_1$ we have calculated n_3. So, after replacing those values here, which is n_3 is 74 and n_1 is 1.11, we get the value of $\dot{n}_2$, that means now we have 3 variables that we have already calculated after doing the water balance and now the total mole balance.

So, then if we have the nitrogen balance, the nitrogen balance is also something like this like we have done for the water. Here we see that the nitrogen is in-stream B and in the output stream. So, the input stream is $\dot{n}_2$ multiplied by the molar fraction or the composition that is given here or known it is which is 0.79 mole of nitrogen per mole of this n_2 stream $\dot{n}_2$ = the output molar flow rate multiplied by its composition with respect to nitrogen. That now we replace the value of n_2 and $\dot{n}_3$ that we calculated previously that gives us the molar fraction as 0.33 moles of O_2 per mole of this output stream this is for oxygen.

So, which means we can now easily calculate if we calculate $1 - y$ that would be our moles per multiplied by per mole of the output stream. So, that means what we have learnt in this system is that when we have such a system or a problem statement, we draw the flowchart we level it while leveling it we must keep in mind the unit consistency factor. By doing so, we level the flow chart with consistent units, and then we start applying our material balance for each and every species.

And if the system is non-reactive, which currently we are discussing, then the simplified balance equation we apply based on the process, either its batch or continuous operations accordingly our balance equation we write it. And for a steady-state and non-reactive species in case of continuous flow, it becomes input = output. And then we have the balance equation of the species we calculate stepwise different unknown variable.

And the practice should be made that once we know one of the unknown variables from the flow chart and the level we will try to replace that unknown with the known value because that helps us in determining the other variables other unknown variables.

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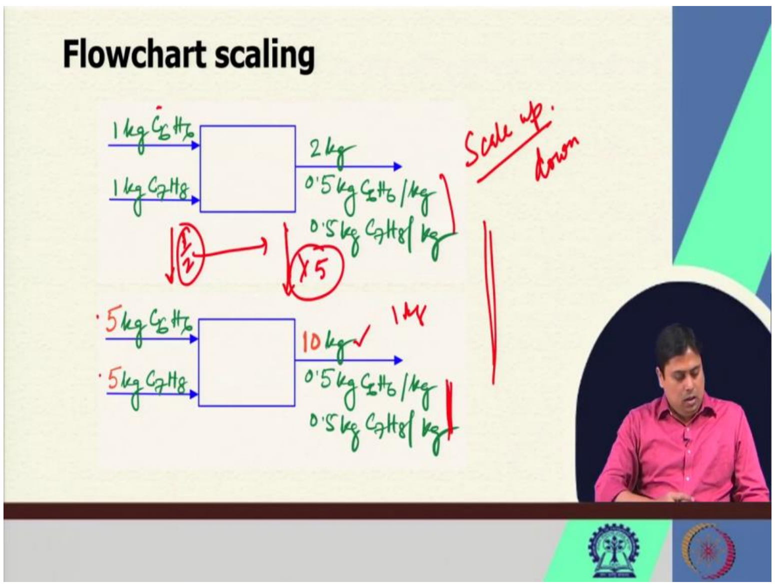

So, now say a flowchart looks like this that 1 kg of C_6H_6 and 1 kg of C_7H_8 is being mixed. So, we have the mixture which is of 2 kg, and we have the mass fraction is 50% by weight with respect to any of the components. Now see this is one of the process and we need to increase the throughput of this process or say for the enhanced production of this mixture to say 10 kg what should be our input streams.

Now such kind of process we typically call as balanced process because after leveling the flowchart, we see this composition on both the sides that is input and output are quite balanced with respect to both the species. So, when the process is balanced then what we can do we can easily scale up or scale down the process. For example the same flow chart we can either multiply by a factor or divide by a factor to all the streams except the mass or the molar fractions.

Because those remain identical, those remain the same because the composition does not change, but this flow rate be it either kg/h or if this is the batch system it is the amount being fed into the system or into the unit. There we see that if we multiply. So, this process by a factor 5 everything remains similar. Everything means this molar composition the stream wise compositions, but if we had to have a higher throughput from this unit, this is called the scaling up of the flowchart.

And this can only be done for the balanced flowchart when you have both sides that means the input and the output sides are balanced with respect to each species, then easily you can multiply the stream flow rates by a certain factor or divide it by a certain factor or constant factor in order to have the scale-up of the process or scale down if it is say divided by 2 or multiplied by half any such cases.

In that case, it would be 0.5 if I divide it if I scale it down we would have 0.5, 0.5 kg of these streams, and we will have 1 kg of the output stream where the mass fractions would remain identical. This comes handy when say as I mentioned, we have to do scale up or scaling down an operation. In the initial lectures, I mentioned about stepping up the production rate or stepping down sometimes whenever it requires in such cases this kind of understanding or knowledge becomes handy.

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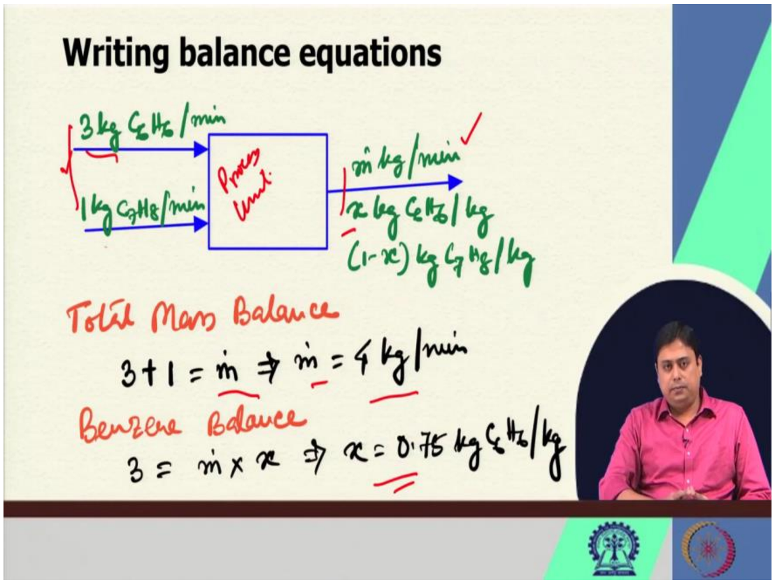

Now if we try to look at the balance equations, how do we write the balance equations that we have seen while solving this problem statement. That when there was a process we level the flow chart we try to write the species balances. For example, we started with water in this case, then we went for total mole balance then we did nitrogen balance. So, the logical question could be that what led us to this kind of sequence?

Why not we started with the total mass balance or nitrogen balance cannot be done? Yes definitely it can be done, but this sequence actually comes from the understanding of certain things. Say, for example, another example is giving here is given here. So, 3 kg of C_6H_6 per minute is coming into a system or a process unit where it is mixed with 1 kg of C_7H_8 per minute that is the mass flow rate of these components.

And our output is the mixture that is of ṁ kg/min, which is unknown and the molar composition and see here since it is the mass fractions. So, we are talking about the mass fractions. So, mass fractions or mass composition of this stream are unknown. So, what we do the immediate sequence of solving this problem could be that we know the total mass has to be balanced. So we do the total mass balance.

We find what is the mass flow rate of the output stream?. Then we apply the benzene balance because this is the input this is the output ṁx is the output. So, we calculate the x. So, the question remains the same that why not we solved say the benzene balance or say here the C_7H_8 the toluene balances here at on the at the first place. Now for that, we need to understand that what is or what are the unknowns we have in a problem statement, how many equations we have, and the equations that we will solve how many variables it contains.

So, in the next class, we will take it forward from this position that what is the sequence of solving or writing at first the balance equations or the species balance equations in a system. And what should be the logic behind choosing whichever should come first. So, till then, thank you for your attention.