Material and Energy Balance Computations
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Lecture –06
Fundamentals of Material Balance

Hello everyone, welcome back once again to the theory lecture classes of material and energy balance computations. Now we are in module two, i.e., the Fundamentals of Material Balance and how we apply that in a single unit. So in today's lecture, we will focus on the fundamental concept of material balance. Now the necessity of material balance, we are pretty much aware that for any process when we have the inlet and outlet, the mass neither be created nor be destroyed except in certain cases.

For example, the nuclear reactions where we will not discuss those topics. So, in general, universally say the mass can neither be created nor be destroyed. So that means when we have an input and output in a process, this mass of certain components of the species that are involved that has to be conserved. For example, say you are giving a input to a unit or say the process for its conversion, say 100 kg of a certain material, you are giving as input.

Now cannot expect the output to be of 1000 kg if any other substance is not mixed with the input. So, if there is a single stream or say multiple streams, for example, 100 kg of component A and 200 kg of component B is mixing in a unit and getting reacted, you cannot expect that the product would be of 500 kg. Similarly, by the molecular weight, the concept of molecular weight and its understanding, you are now aware that when some say in carbon dioxide, you have one mole of carbon in one mole of carbon dioxide.

So now you basically cannot expect or without analysis, you can understand that when CO_2 is coming out from a system the same amount of mole of carbon is also coming out of the process. So this is when we have this balance we typically say this is the mass balance or the material balance. Now in the next couple of lectures, we will focus that on a particular case, that is the single unit that is when there is only one operation or one chamber where a couple of streams are mixing or reacting or say separating.

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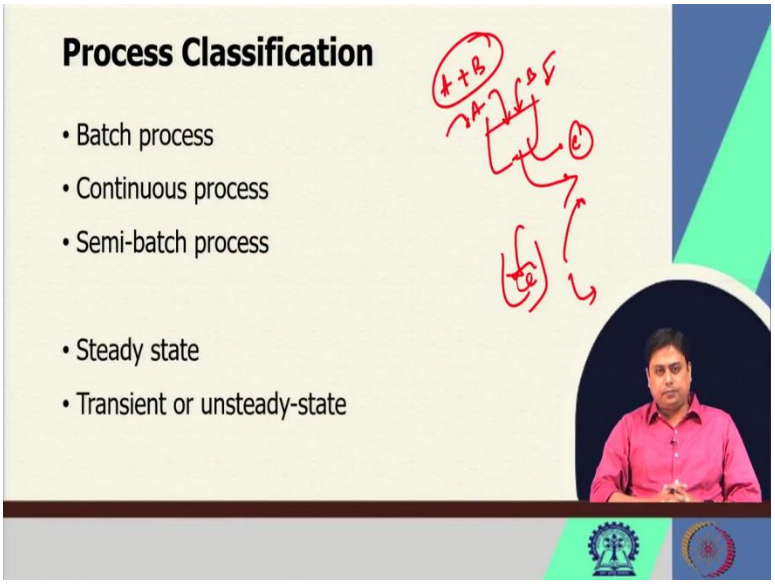

So, before we proceed on this now, we have to understand that, what are the modes of operation through which a process can happen? Those all broadly classified as the batch process, Continuous process or semi-batch process, what does this mean? This means that say you have a component A and it is being reacted with B. Now, this reactive mode of operation can be that you put the two things in a vessel this A and B, you then leave it for some time and then after a certain period, you take out the product.

Say some product is coming out as C. This is called the batch process. That means you leave it for some time without further addition or without further taking out of the product from that process or withdrawal of the product from the process you leave it for some time you just put a batch operation for the reaction to happen. On the other hand, the continuous process is something like that you are continuously pouring this material A in the vessel. B is also coming continuously and you are taking out the product as soon as it is created in a continuous manner.

So that means in one case you put all those things together and leave it for some time, in another case you are continuously putting the streams and also taking out the product at a regular period or regularly you are taking out that outlet stream. The semi-batch operation is something in between these two that is the mix of batch and continuous process. So for example, say you have an alcohol bottle. You leave it open to the atmosphere, some amount immediately be vaporized but then you mix water in that vessel and you mixed it or say some reaction happened.

And again, after some time, you are taking out the product. So which means initially, when you leave it open, there is a continuous withdrawal of the vapour, and after that when you mix some amount of water in that leave it there for any reaction or any mixing to happen and then you take out some product or the mixture. So that means we can classify a process either in a batch mode or in a continuous mode or in a mix of these two of the hybrid of the semi-batch mode.

Along with these processes, in fact, all these processes there are classifications based on the time. So for example, a steady-state process, unsteady-state process, and transition process. So in the steady-state process, what happens that the process variables that means say the concentration, flow rate, temperature and all these process variables that we have learnt. These process variables are not changing with time. So when that is achieved that that condition is assumed to be, call the processes as steady-state.

Otherwise, it is the unsteady state or the transient process that means the process parameters or the process variable changes with time in the case of the unsteady state or the transition process. So by now with this discussion, you possibly now understand that continuous process that means when there is a continuous inflow and continuous outflow, the chances that we or the process operations that we call that is more of a steady-state scenario. Because then we take out the products.

The batch and the semi-batch that means intrinsically or inherently these are kind of transient or unsteady state process that means because at a certain time you charge everything in a chamber, leave it there, and after a certain time, you are taking it out. It is not a continuous operation, and that means it is not also a kind of a steady-state operation because as soon as you take out something from the chamber, the process variables immediately changes.

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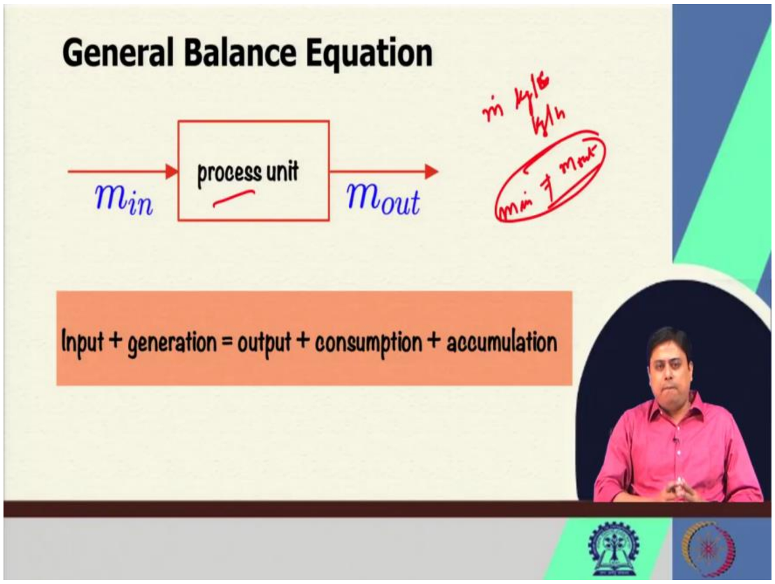

Now when we come to say general balance equations, as I mentioned that when we have a process unit, we have an inflow or the input and outflow or they are the output. Now a certain amount of mass is charged to the process unit or, say, the chamber where the operation is happening, and it is coming out as a product. Now say the typical convention that will follow is that m when I am mentioning only m that means it is the mass of the material, whereas if you write $\dot{m}$, we would say this is the mass flow rate.

So either per second or kg/h, this kind of a unit it would have for $\dot{m}$. So say we are giving either $\dot{m}$ or m that means either it is a mass flow rate or a certain amount of mass we are charging in the process stream, and something is coming out. As I mentioned at the very beginning that if except for certain exceptional conditions this mass we cannot create nor generate. So that means m in should be equal to m out.

Now if this does not happen if there is inequality. That means immediately the flag should be raised that either something is happening inside the process unit that means either the mass is being consumed or it is being accumulated. Either it is generated or consumed or accumulated something is happening or something is escaping somehow because of the leak in the process unit. If this is the condition so we should be aware immediately.

That means in conventional condition or typical condition we should have $m_{in} = m_{out}$. If there is no accumulation, no generation, no consumption and no leak or escape of the material. So that means what we can write as a general balance equation for a material is that there can be a generation if the reaction is happening, or there can be consumption if it is a reactant and there can be accumulation say on the reactor wall somehow the product can be accumulated or buildup can happen.

So, that means the input of a material + its generation = the output of the product or say that material the amount it is coming out from the process unit + its consumption + accumulation. This is the crux of this whole balance that we must look into a species which will have this conservation and this conservation has to be made. That is the input + generation = output + consumption + accumulation.

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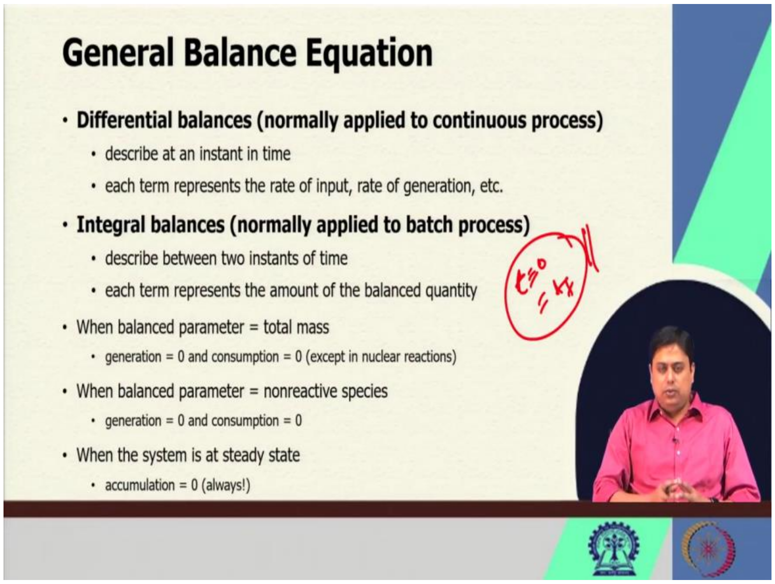

Now this equation can be simplified based on certain scenarios because in certain cases, we will have neither generation nor consumption if the species is non-reactive. So we will come to that point, but then this balance that we are writing that can also be classified into 2 types, 1 is the differential balances that we normally applied to the continuous process because it describes the parameters will be right this left-hand side and the right-hand side is at an instant in time.

That means it is each term on the left-hand side and the right-hand side represents either the rate of input or rate of generation etc., which means it will have a unit that is per unit time. By looking at that unit, you can realize whether it is a continuous process or it is a batch process. If it is a continuous process, there will be the units that is kind of per unit time, the variation of per unit time or the mass flow rate molar flow rate etc.

Now since it is coming for this in the context of a particular instant in time, it is normally applied to the continuous process. On the other hand, we can also have integral balance where we describe the process between two instants of time that means taking t = 0 when we charge all the materials into a chamber or a reactor for the reaction to happen. And after a certain time, which we say $t = t_{final}$ we take out the product for the analysis.

So, between t = 0 to $t = t_{final}$ we analyze the process. That means each and every term of this balance on either on the left-hand side or right-hand side would represent the amount of the balance quantity that we are doing or conserving here there will be no link with say per unit time because it is happening in between two instants of time or within a time interval. So that means if our balance parameter is, say, for example, we are balancing the total mass of the system.

And we know then that generation is 0 in that case and the consumption is 0. So that means our previous expression that generation would be zero, consumption would be zero, for the case when we have the total mass balance equation because if that is our conserved quantity. And if this process is steady-state, then accumulation is also zero, and that is always. Because steady-state means that there is no change in process parameters.

That is the molar concentration, flow rate, etc. So which means if the process is steady-state, there would be no accumulation term in the equation. And if the balance parameter is non-reactive species, that means it is neither reacted nor being consumed. So in that case again the generation and consumption both are 0. So our balance equation eventually boils down to input = output in such cases that is for the mass and the non-reactive species for the steady-state scenario.

So this understanding will come pretty handy when we will solve several problems because these understandings we need in order to simplify or in order to interpret the problem statement.

Because it would be mentioned in the problem statement or in the design problem that thus if the process is steady ok or the steady-state process then what would be the amount of either generation or say this or different concentration mass or molar concentration of certain species.

In those cases in the governing equation for this balance equation of the generic balance equations that I should earlier there we can safely place accumulation is zero because the process is steady state. And for any non-reactive species, we can place generation and consumption as zero.

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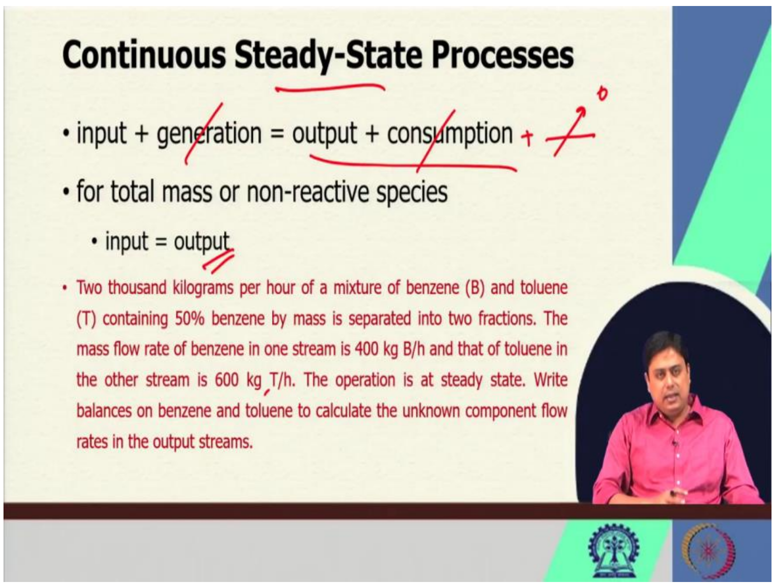

Now say for example, if we now try to look at our continuous steady-state process. So it is a continuous process the classification is continuous, and typically the continuous processes we analyze at its steady state. So that means accumulation is always zero in that case. So that means our generic equation that we have seen earlier, which was input + generation = output + consumption + accumulation.

This accumulation term is zero here because of the steady-state process, and if the total mass or non-reactive species are being balanced, then the generation and consumption both are zero, and we have input = output. So say if you look at this problem statement. It says we have 2000 kg/h of a mixture containing benzene and toluene, where we have 50% benzene by mass is separated in 2 fractions.

The mass flow rate of benzene in one stream that is being fractioned I mean which are now a product as fractionation is 400 kg B stands for benzene per hour, and that of toluene in other stream is 600 kg/h. So here T stands for toluene, the abbreviated form of toluene. The operation is at steady-state. So we have to write a balance on benzene and toluene to calculate the unknown component flow rates in the output stream.

So, for that what should we do? This is although a very simple problem. It need not require any explanation. You can easily do it. But let us say how we apply whatever this generic equation that we have understood. So for any such problem now this problem statement is very short. But typically any problem statement in this material and energy balance computations that is being commercially applied or process design purpose would be very large.

So, how do we at first understand the problem, or how do we realize that what are the data that is given here? For that the very basic thing that we should do is draw a flowchart.

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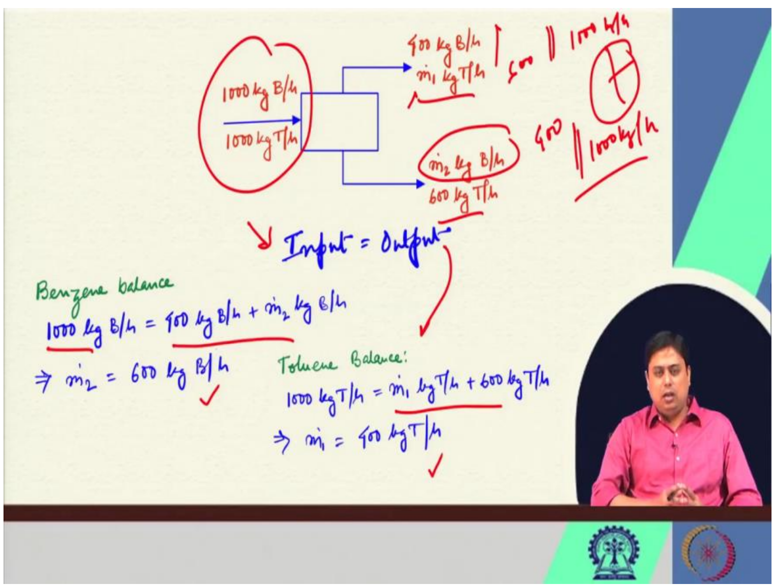

The flowchart levelling and all these details I will come after a couple of slides. But say schematically we present or now understand the problem like this that there was a stream that contains 2000 kg mixture flow rate where we had benzene as 50% by mass which means we can write we have 1000 kg B/h and 1000 kg T/h that is coming as a mixture. It is being separated in two streams. In one stream, the concentration or the flow rate here it is mentioned that we have 400 kg benzene per hour.

And in other case, we have 600 kg toluene per hour. It is separated in two fractions. So that means these are the 2 known as we have here. Because in this stream, there will be a certain amount of toluene and in the other stream where the toluene the flow rate is known. There will be a certain amount of benzene. So that means our job is now to calculate the values of $\dot{m}_1$ and $\dot{m}_2$. Now again the dot represents the flow rate per unit time.

So, how do we do that? Clearly, there is no reaction happening. It is a continuous process. The process is at steady state, it is also mentioned that our balance equation is simplified to input = output. Now, this we apply to say each and every species. So first of all we can apply that to the benzene balance. So if we applied this balance to the species one species, which is benzene what we can write that this is the input that we are having on the left-hand side.

And on the right-hand side, we have the output which is the combination of 2 output streams. That is the 400 kg + $\dot{m}_2$ so which means we can easily calculate what is the value of $\dot{m}_2$ which is in this case it is pretty simple because it is a very simple problem. And then we can apply the same equation or the same balance for the toluene as well. So we have 1000 kg toluene that is the input per hour, and on the right-hand side, then we have the output, the combination of two output streams.

And the calculations are simple, which means we now have the values of $\dot{m}_1$ and $\dot{m}_2$. Now since this is a very simple calculation. As a step to have confidence on this calculation, we can quickly cross-check whether these are ok or not or fine or not. So, how do we do that? We immediately replace these values here. This is 600. That means this stream is of 1000 kg/h, this stream we have also 1000 kg/h.

That means the total output is 2000 kg/h and total input is 2000 kg/h which is conserved or balanced. So, that means there is no calculation error here. So this is the way that this is the convention that we will follow, and this is one of the very preliminary concepts of this material balance. And one of the examples that we have seen now is that or in this class is that it is of applications to the continuous steady-state process.

So, in the next lecture, we will see how we apply to a batch process. And you will see a small example related to that application. Till then thank you for your attention.