Basic Principles and Calculations in Chemical Engineering
Prof. S. K. Majumder
Chemical Engineering Department
Indian Institute of Technology – Guwahati

Module – 3: Fundamentals of Material Balance
Lecture – 3.1
Principles of Material Balance and Calculation

Welcome to massive open online course on Basic Principles and Calculations in Chemical Engineering. So, we were discussing about fundamentals of material balance in module 3. In this lecture, we will try to discuss about what are the basic principles of material balance and how to calculate the balance equation based on these principles.

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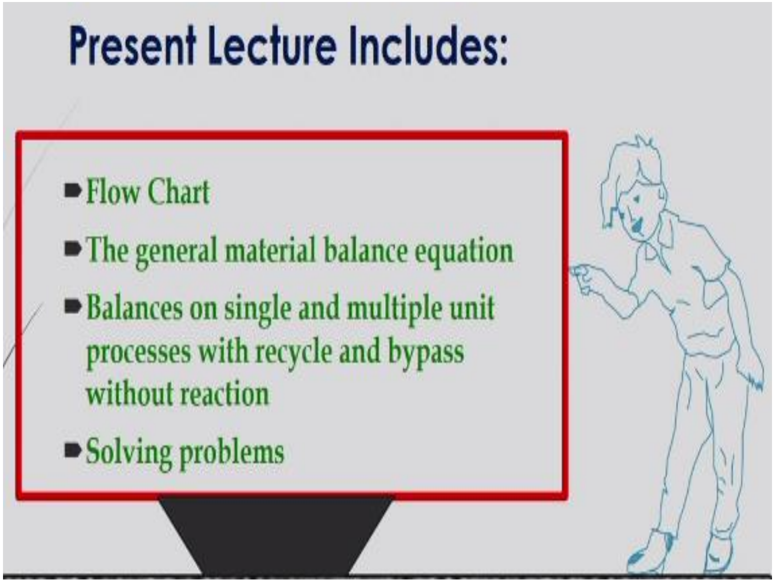

So, we will discuss here some flow chart of this chemical engineering processes, general material balance equation, balances on single and multiple units where chemical engineering processes are being carried out with recycles and bypass without reaction, and also how to solve the problems of this chemical engineering process based on the material balance equations.

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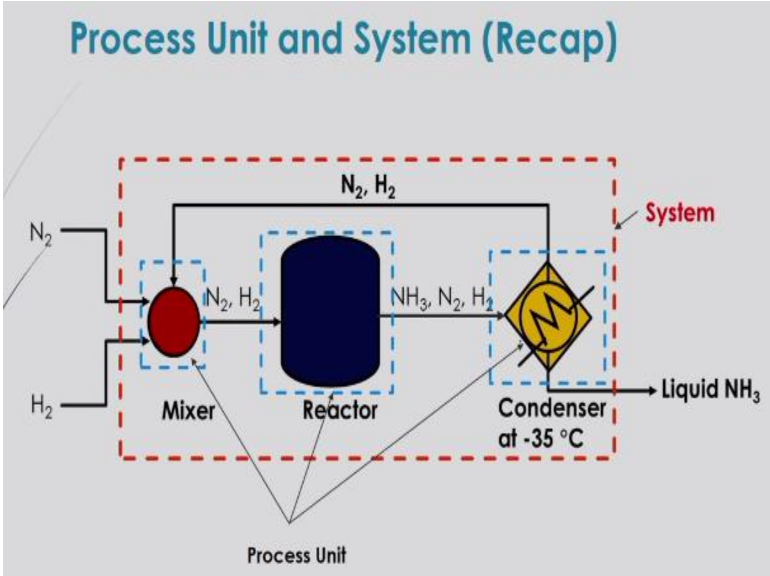

Now, see here in this slide, one process unit and systems is given as we have already described in our previous lecture, that if you are having this process unit like this, one mixer, reactors and condenser for a particular processes like ammonia is to be produced from the hydrogen and nitrogen gas and for that nitrogen and hydrogen gas will be mixed in a mixer and after that at a certain pressure, this mixture of this nitrogen and hydrogen gas to be sent to reactor where this nitrogen and hydrogen gas would be reacting to each other at a certain temperature and pressure and forming ammonia gas.

Unreacted nitrogen and hydrogen gas along with this ammonia will be coming out from this reactor. After that, this ammonia gas will be condensed at minus 35 degree Celsius to get this liquid ammonia. Whereas, other composition of this mixture like nitrogen and hydrogen that is unreacted from this reactor will be sent back to the mixer as a recycle and this will be running continuously and accordingly we can get liquid ammonia for a certain amount of nitrogen and hydrogen gas supplying.

So, this is the process. You will see that to assess this process based on the material balance equation, you have to first think about each unit of this whole processes. Here, you are having this unit mixer, reactor, and condenser. In each unit, you have to do a material balance like this, what will the amount of materials is coming in and what is the material that is coming out, that what amount of material is coming into the another reactor that is coming out from the previous unit, and then after that you have to assess that second unit like reactor.

Again based on that material balance equation, what is that input and output, and then output from this unit will be going to the another unit as an input and thereafter processing it will come out as output and some portion of that, it will be sent back to that initial unit as a recycle. Now, you have to do that material balance individual to that unit, what would be the input and output or you can do that material balance just combining two units as a single unit there and also you can assess based on that.

Now, this is required because you know sometimes you will not be having that unknown, that means variables like input and output or you can say that a streams composition only by doing the material balance for the single unit. There you have to sometimes required to do the material balance just by combining 2 units or maybe more than 2 units there. So, we have already described these things in our previous lecture. So, as a recap, we can consider here again.

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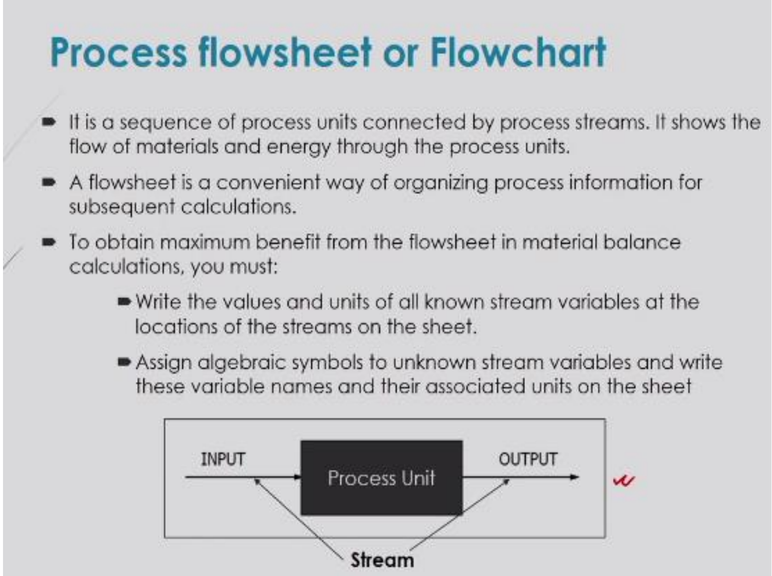

Now, to do the material balance, you have to do the process flow sheet or process flow chart, where you have to represent that whole process by a sequence of process units that will be connected by processes streams and this process flow sheet based on that sequence of process units connected by processes streams, shows the flow of materials and energy through the process units and this is actually the convenient way of organizing that process information for the subsequent calculations.

To obtain the maximum benefit from this flow sheet in material balance calculations, you must write the values and units of all known stream variables at the locations of the streams on the sheet. Like here, you will see that one process unit here shown in this slide like mixer or divider or reactor or condenser or evaporator or separator, like this different type of process unit. So, you have to express this process unit like this block diagram here and this is called flow sheet here and this block diagram will be connected to this flow streams of input and output.

From this process in this process unit, what would be the amount of input and output that will be retaining in that input and output streams there. So, that is why write the values and units of all known streams variables at the locations of these streams here, in input and output streams here in the sheet shown here, and if you do not have that values input and output, you can also write just by defining a particular symbol or defining terms there for that particular variables and then keep it there by question marks there what should be the value there.

After that, we will be using what can be used for material balance and unknown values to be then obtained by solving that material balance equations, and then what you have to do? Assign algebraic symbols to unknown stream variables and write these variables names and their associated units on the sheet as well as you have to write should be the unit for that inputs and outputs there that you have to write on the flowsheet there. So, this is the basic principles to express that process by a flowsheet.

So, what does it mean? You have to express that unit of that process by a block or it is like a box like this or you can simply express other notations also there or other pictures also there and there you have to, then write down that streams what is coming and streams what is coming out and then express all the known values and unknown values of about the streams there. So, this is the basic way to express that.

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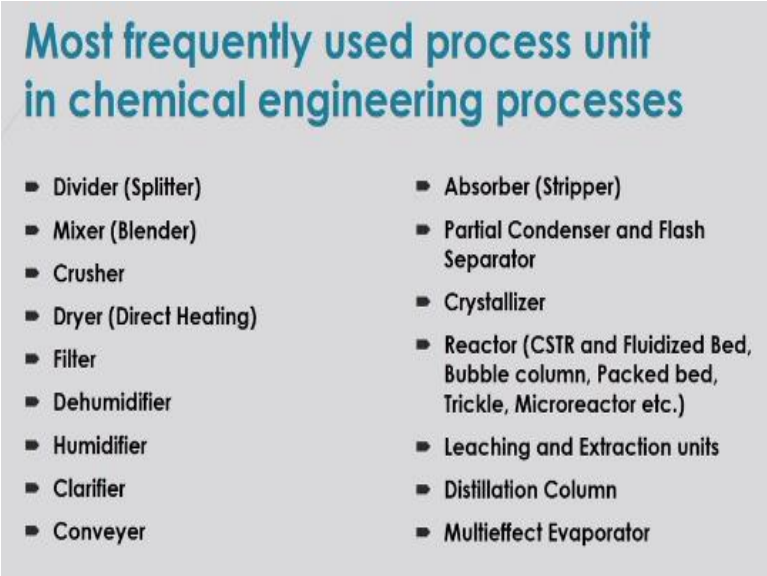

What are the different process units in chemical engineering processes? Here subleased some list are given there like divider. This divider actually basically used to divide the flow streams into two parts where one part will be sent to one unit and another part will be sent to another unit or it can be sent to utilizing for other purposes like this. The mixer, two streams will be coming to that, even more than two streams also will be coming and it will be mixed together and that mixer stream will be sent to some other unit for the process.

Crusher, it is one unit where you will see that bigger size of particles will be crushed into finer particles. Dryer, where you will see that the wet materials to be dried up to a certain equilibrium of moisture. Then filter is another one important, here what is done that some fine particulate materials to be separated from the mainstream or main solution. Dehumidifier, they are sometimes you have to need to increase the moisture there or reduce the moisture there in the flow streams.

So, dehumidifier and humidifier are used for that controlling that moisture there. Clarifier, here also to separate that fine particles by just floating in a particular process unit that is called clarifier. Conveyer, it is basically used to transport the materials from one position to another position. Absorber is used to absorb some unwanted materials in a certain liquid or solid materials. Partial condenser and flash separator is being used for condensing the vapor. Flash separator is being used to separate that vapor from the liquid mixer there just by boiling that liquid mixture.

Crystallizer is generally being used for making that liquid to solid material there. Then reactor is basically used for reaction purpose and reactants will be taking part to give you that another product. There may be different types of reactor will be there, CSTR, fluidized bed, bubble column reactor, packed bed reactor, trickle bed reactor, microreactor reactor; all those things you will know also in chemical engineering process like if you do the course like fluidization engineering.

There you will see different types of reactor like fluidized bed reactor, bubble column reactor there and also other operations like absorption, even reaction purpose like CSTR, packed bed column, trickle bed, even now a days that as a process intensification microreactors are coming. So, these are the process unit where you can do that chemical engineer process for a particular process yield.

Leaching and extraction units also are being used for extracting oil from the solid materials that is called the leaching and then extraction is also another important like one material is to be extracted from another materials, maybe liquid-liquid extraction, maybe liquid-solid extraction there. Distillation column where crude petroleum will be separated into valuable products just by boiling that crude liquid just based on that boiling point differences.

Multieffect evaporator there you have to sometimes evaporate that liquid materials to its vapor form to get vapor forms and maybe multieffect evaporator will be there. There may be successively more than one evaporator will be there to get that desired fractions of materials in the vaporized form there. So, these are the several process unit which are being used in conventional chemical engineering processes. So, for those, processes unit, you have to do the material balance based on that material balance principles.

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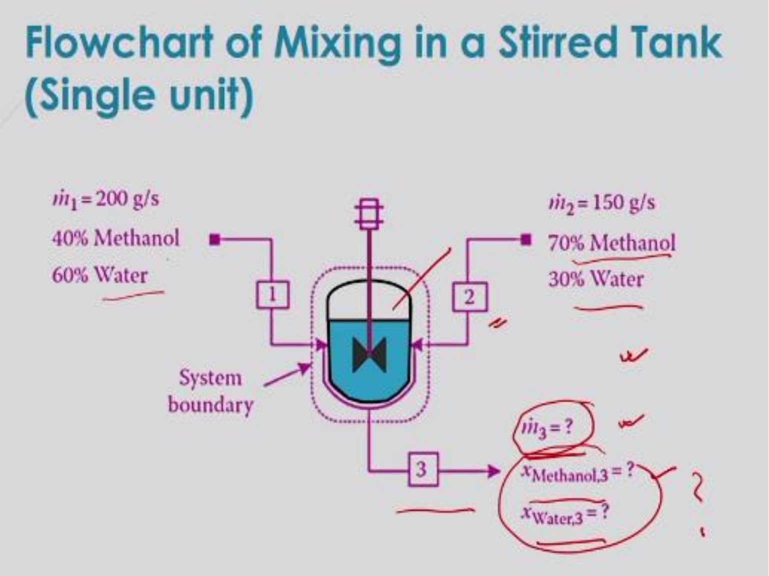

Now, if we look at the flow chart of mixing in a stirred tank reactor, what we can have here. So, this is a typical flowchart as given here in the slide. You will see that this is basically a CSTR and where we can see that mixing of this liquid streams are being done. In this case, here you will see that methanol and water as feed one that is in this stirred tank and also methanol and water other propositions from the other streams as from 2 here it is coming and then after mixing, you will see from this stream 3, this mixer of this methanol and water will be coming out from this stirred tank unit.

So, here this is one process unit, this is called stirred tank and this stirred tank is being used for mixing purpose. Your 2 streams are coming into this stirred tank and after that it will be mixed and it will be giving product, that is mixed a product, with a certain proportions of that composition. Now in the inlet, you will see composition of this methanol and water will be 40%, 60% whereas other portions of this stream is coming into the stirred tank with the composition of 70% and 30%.

So, after mixing, you will see that as an output, this mixer will be coming. What will be the total amount of mixture as coming out from the stirred tank and what will be the composition that you do not know? So, if it is not known to you, just you have to write that it is unknown to you, that is m3 dot here it is shown it is and also x methanol and x water, this is the mole fraction of methanol and water in these streams, it is unknown to you, that you have to find out and that can be obtained by doing material balance.

So, the flow sheet basically is that representation of this input and output there in this process unit with the known values and unknown values by its, you know what is that, is symbols of that feed and also that output amount there.

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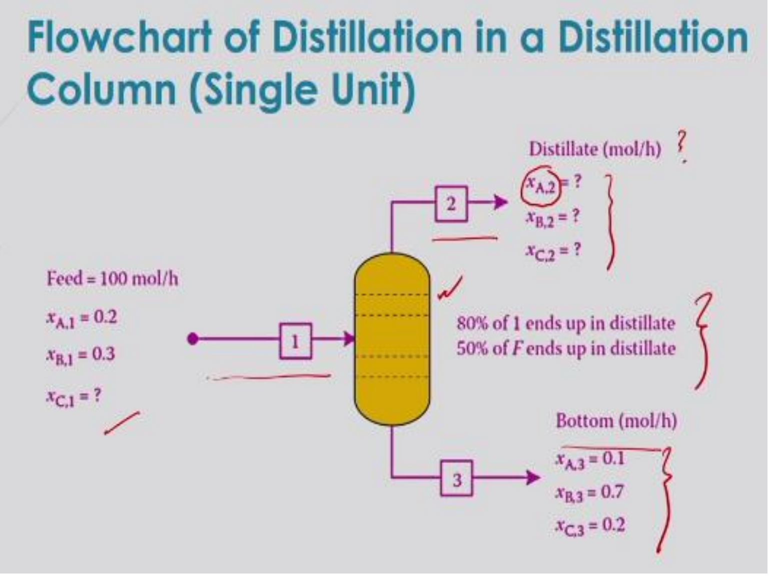

Similarly, we can represent this flowchart distillation in a distillation column like this here. Here in the distillation column, mixture of that compounds like A, B, C with the certain feed flow rate will be coming to that distillation column here and from this distillation column after processing that there will be two output, one will be as distillate, another will be as bottom product. Now, from this distillate, what will be the amount that is not known to you and what will be the composition in the distillate that is also known to you.

If it is not known, then you have to express that composition as mole fraction of A, B, C here, and in the bottom part if it is known to you that mole fraction of A, B, C that you have to express even if you do not know that you have to express by this symbol that you have to find out from the material balance equation. Based on that problem, you have to express all those known and unknown variables in the inlet and outlet and then you have to assess this based on this known and unknown values based on this flowchart.

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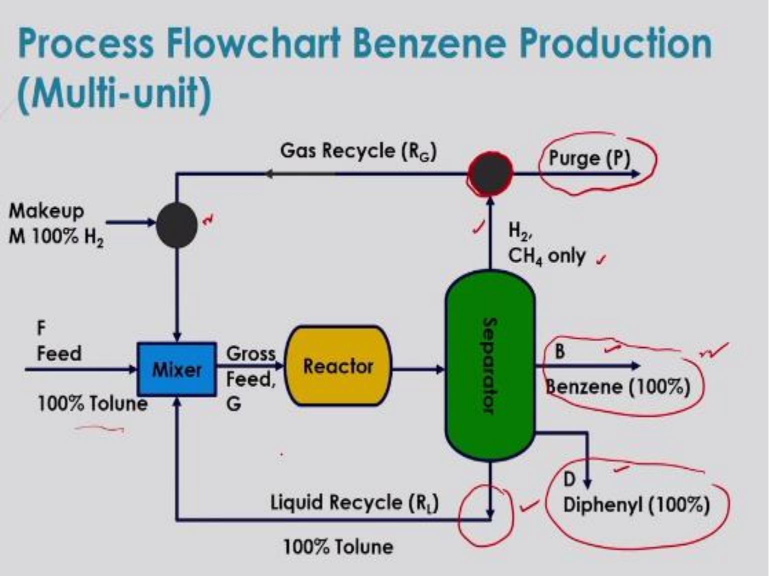

Similarly, process flowchart for benzene production here. This is the multi-unit, more than one unit may be involved in the particular process. Here, you will see that units are like this here mixer, reactor, separator, and also divider is there, and then also mixer is there. Now, in this case, you will see that more than one units and in the flowchart we can represent all those units which are being used for this particular process like this and for each unit, you have to express what would be the input and what would be the output there.

Now, you see that if we consider that mixer, here input is feed as F and here one example like this toluene, 100% toluene it is there. So, mole fraction of the toluene is 1 here. So only pure toluene is being used, other no components of this feed will be there, but whenever it will be sent to mixer, of course this mixer will contain other streams like here gas recycle is being coming to this mixer. Also other stream is coming from the separator as a recycle, as a liquid for Tolune is recycled to this mixer.

Now, all these streams to be mixed in this mixer and then finally as a gross feed G to be coming out from the mixer and then it will go to the reactor. Now, this reactor will have this inlet as a gross feed which is coming out from the mixer, and then after reaction, there will be some generation of the product and then product along with that unreacted reactant, it will be coming out from the reactor and it will go to the separator. Now what is the output of this reactor? It will be input or the separator.

After that, it will be separated and from the separator, you will see that outputs will be here in this one stream, another stream here, another stream here, another stream here. So, there will be four 4 outputs of this separator, one output will give you that separate that H2 **two** and methane and one output will be hundred percent 100% benzene will be there and another output will be byproduct like diphenyl and another output will be considered for the **you** liquid recycle of the Tolune.

So, based on this, you can say that whatever output of this reactor that will be input of this separator and output will be more than one here like this you are shown in this slide. Now, up to separator whenever gas was mixture, hydrogen and methane will be there, that will be coming out from that separator and then it will be sent to the mixer there. Now, you will see that from this hydrogen methane mixer, some amount of that unwanted materials that is to be taken out from that mixer.

So, that will be considered as a purge here. So, to take out that purge, you have to use some divider, so that the divider to be used here as unit from where you can take out this purge sooner P, whereas remaining portions to be sent back to that mixer as recycle. Now, before sending it to the mixer, what you have to do that you have to add some hydrogen gas which is to be considered as a makeup, a 100% hydrogen to be there because some amount of hydrogen may be lost.

Now, to make up those hydrogen gas in this reactor, you have to supply some fresh hydrogen gas. Now that fresh hydrogen gas to be mixed to that recycle gas in that mixer here again. So, there are several units for this benzene production from the Tolune that is represented in this process flowchart and also what will be the composition, what will be the different input and output compounds will be there in these different process units that are represented in this process flowchart.

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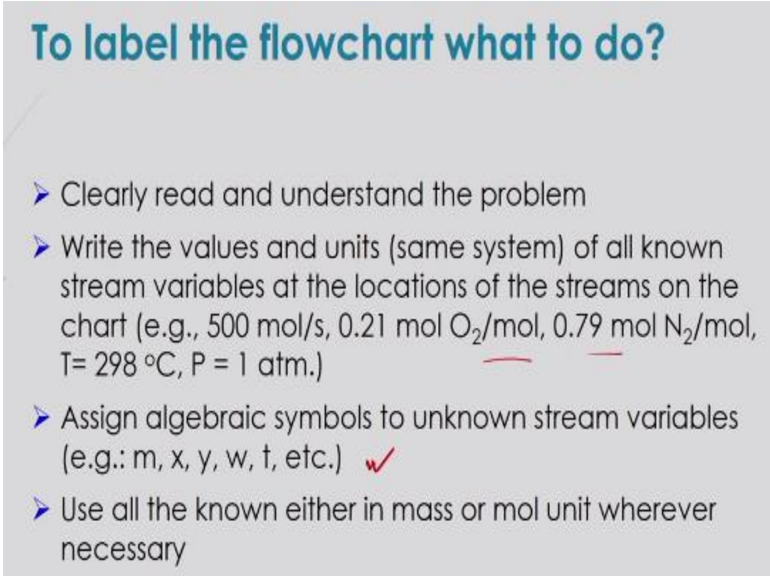

Now, to label this flowchart, what to do? You have to clearly read and understand the problem and then write the values and units, same system of all known streams variables at the locations of the streams on the chart. Like if it is given 500 mole per second or 0.21 mole of oxygen per mole and also 0.79 mol nitrogen per mole of total feed. Then here, what is the temperature, what is the pressure to be also given there. So, all these known values to be written, even unknown values to be written also just by defining some symbols.

Then assign algebraic symbols to unknown stream variables that is here and use all the known either in mass or more unit wherever necessary that you have to mention, either mole or mass that you have to consider, but your consideration should be uniform throughout the process.

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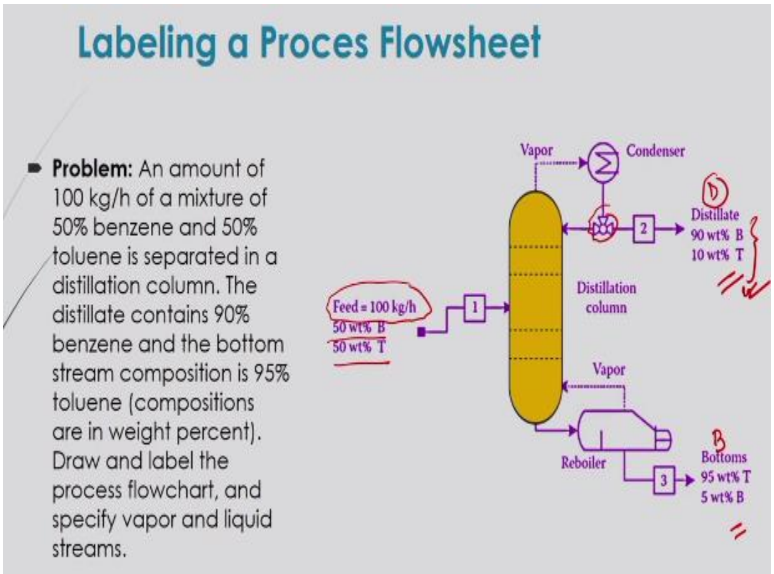

Then, labeling a process flowsheet. Let us consider a problem here. An amount of 100 kg per hour of a mixture of 50% benzene and 50% toluene is separated in a distillation column. The distillate contains 90% benzene and the bottom stream composition is given as 95% of toluene and here all the composition is given in weight percent, not in mole percent. So, for all streams that composition to be considered as weight percent. If you are considering the mole percent, then all the units, all the streams units should be in mole percent there.

Even you will see that whatever feed as input or whatever output amount to be considered also that mass if your composition is mass percent or weight percent and it should be mole or mole percent accordingly also if you are considering all this input and output in terms of molar weight percent. So, here based on this problem, we can then level a process flowsheet by these known values of this here as a feed it is told that that an amount of 100 kg per hour of a mixture of 50% benzene and 50% toluene is separated in a distillation columns.

That means here this hundred kg per hour of feed mixture come into this distillation column with the composition of this 50% benzene and 50% toluene weight percent, and after distillation process, it will be coming out from this overhead as a vapor and then it will be condensed and then it will be separated into 2 parts, one part will go into the distillation column, another part will be taken out as distillate where 90% benzene and 10% toluene, it is mentioned here.

As a bottom product you will see some portions of this bottom product will be re-boiled and it will be sent to the distillation column as a vapor and remaining portions will be taken out as bottom products where 95% will be toluene and 5% will be benzene as weight percent there. Here, what will be the bottom portion, what would be the distillation amount that is as a vapor amount or distillate amount that is not known to you that you have to give or you have to define some symbols for this distillation like this D and as the bottom products maybe you can represent as capital B.

So, out of this distillate, there will be certain fractions of this benzene and toluene and out of this bottom, there will be certain fractions of this toluene and benzene. So, all this inlet and outlet streams are now known, whether it is given or not given. If it is given, you have to directly write this exact amount what is given, and if it is not given, then you have to also define that unknown variables there and form the material balance that you can find out what will be the unknown variables from this material balance equation.

Now, what will be the general material balance equation based on which you can solve these to find out that unknown variables like distillate here, bottom products or for other units like if is there any mixture, what will be the output of that mixed proportions of that compounds that you can find out based on this material balance equation.

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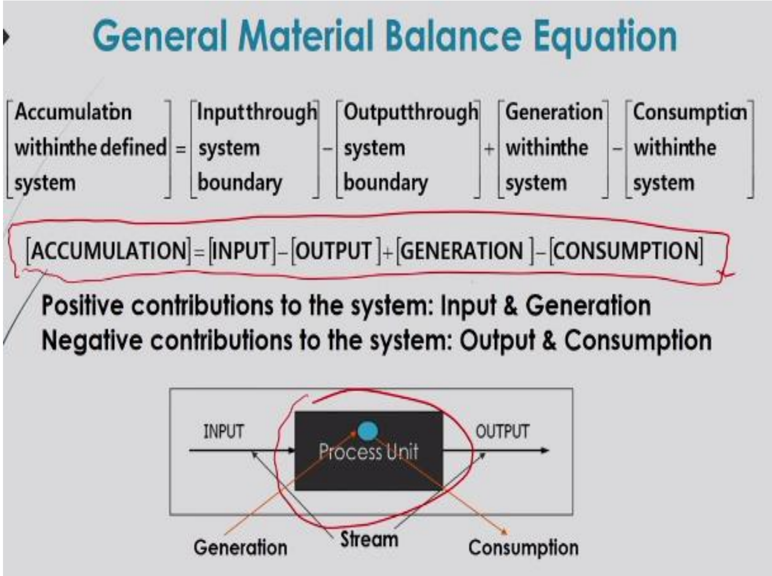

What is that material balance equation? It is given you will see in a particular process unit, suppose there will be some amount of input is coming to the process unit and some amount will be coming out from that process unit. If there is steady state process, that means the input and output proportions are same, they are in the process that you can say that a steady state process, that means it does not change with respect to time. So, in that case, it will be regarded as that steady state process and there you will see that there will be no accumulation of the materials inside the process unit.

So, there will be one important thing that there may be an accumulation, based on that what will be the output and input rate. If output is greater than input, then there may be an accumulation of the materials there. If there is no change of this input and output flow rate, then you can say there will be no accumulation. So, one important term is accumulation. Another is input through the system boundary, if we consider that process unit and if we represent it as like a boundary here around this process unit.

Now, within this process unit, what will be the amount of that material is coming in to that process unit that will be regarded as input. Now, that input, there may be a certain flow rate that is known to you or may not be known to you. So, anyway, it will be regarded as input amount and then what will be the amount that will be coming out from that process unit from the boundary, it will be called as the output through system boundary and it will be regarded as simply output.

Then if suppose the process unit is like reactor where reaction is being carried out, so there may be due to that reaction some amount of materials will be produced, may be generated, so there one term should be coming as generation, so generation within the system, inside the system, inside the reactor here, as an example there will be some generation of materials. So, that the generation within the system to be considered. Then also during that reaction, there may be some reactants that should be taking part for that reaction.

That reactants may be consumed for that giving up product of like some compounds as a generation product. So, in that case, that reactant will be consumed, that consumption of that reactant also to be considered here. So, what do we get that for a particular process unit if we make it or you know that identify with a certain boundary of that process unit and what would be the input is coming that will be input, what would be the output from that process boundary it will be coming as output. If there is not a steady state process, there will be some accumulation.

If there is a reaction is going on, there will be some generation of material. And if suppose there is a reaction, then of course there will be a consumption terms will be there. So, all these 1, 2, 3, 4, 5 terms will be there in the general material balance equation. What are those? In short we can write that accumulation, input, output, generation and consumption. Now, the principle as per this mass conservation equation, we can write that this accumulation will be equals to input minus output + generation minus consumption.

So, there will be no materials generated or destroyed there in the universe. So, that is called conservation of mass. Now, based on that, you will see for a particular process unit that this basic equation for the material balance equation can be expressed like this. Now, here in this case, we are getting some positive terms, some negative terms. In this case, positive contributions to the system, generally input and generation and the negative contributions to the system is generally output and consumption.

So, based on these principles, you have to solve the material balance equation for a particular process in a chemical engineering system.

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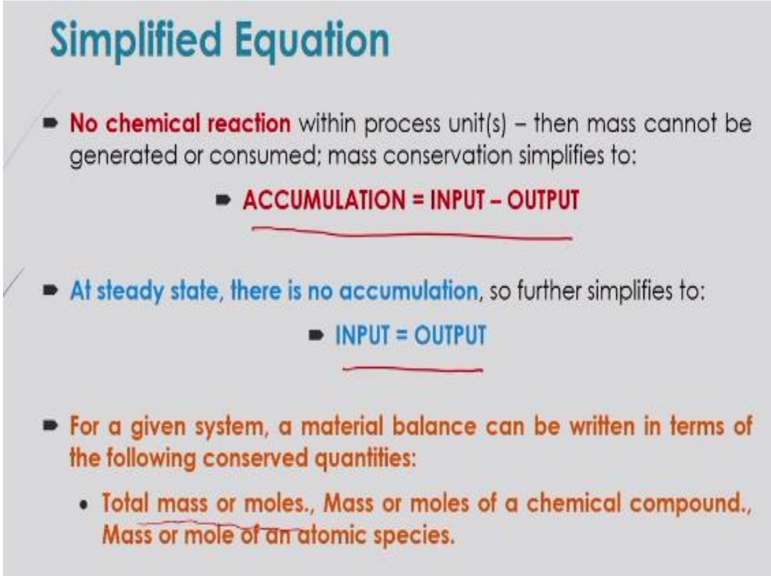

Now, simplified equation can be written as if there is no chemical reaction, we can simply neglect that generation terms and consumption terms. So, general equation can be written as simply accumulation will be equal to input minus output. Now, for steady state operation, there is no accumulation, in that case, then input minus output will be equal to 0, that means input will be equal to output there. Now for a given system, now a material balance can be written in terms of the following conserved quantities.

First of all, you have to do the total mass or mole balance and then individual mass or mole balance of that individual compound there in the system. You can do that material balance based on atoms of that compounds also. So, that is called mass or mole of an atomic species and the equation or balance equation to be considered as atomic balance equation Now, so based on this material balance equation, what you have to do? You have to do the total material balance first, total material balance means what?

In a particular boundary system, what will be the materials in and what will be the material out, irrespective of inside what is happening there, we have not to consider all these no happening inside the system, only just what is the input, what is the output there, that is called total mass or mole balance, and then after that, you have to do the material balance for individual compounds or atoms.

So, there itself you have to consider that what would be the mass of that compound in, and then if is there any generation of that mass inside the unit or if there are any consumption of that materials inside the unit is there or not that you have to consider. So, for that compound balance, you have to consider all those things.

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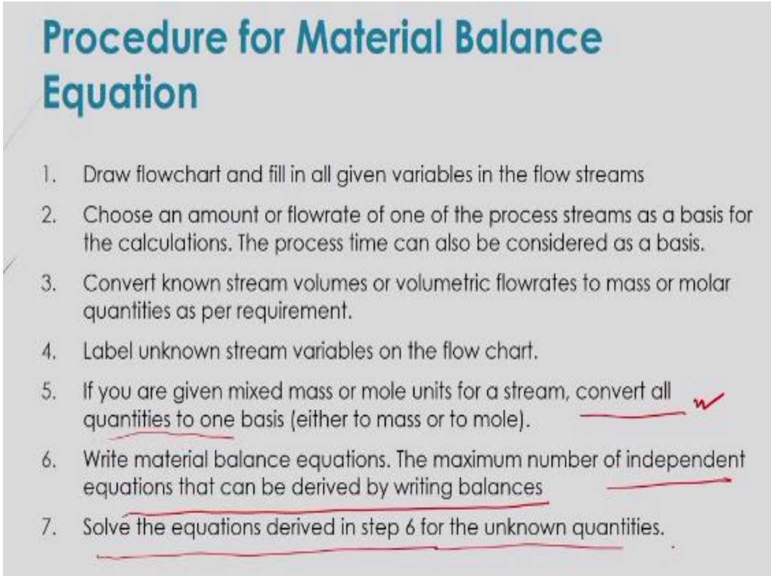

Now procedure for material balance equation is given here step by step. First of all you have to draw the flowchart and fill in all given variables in the flow streams, and then choose an amount or flowrate of one of the process streams as a basis for the calculations. Then process time can also be considered as a basis there. Then convert known stream volumes or volumetric flowrates to mass or molar quantities as per requirement. Label unknown stream variables on the flow chart.

If you are given mixed mass or mole units of a stream, convert all quantities to one basis, either mole or mass. It is very important here, you cannot use this mixed unit there. Write material balance equation. The maximum number of independent equations that can be derived by writing this material balance, and then solve the equations derived in step **six** 6 for the unknown quantities.

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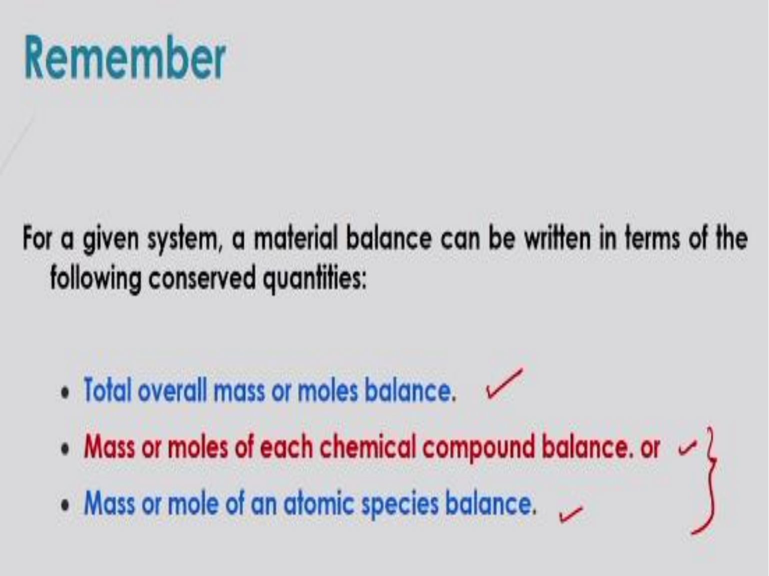

Now, in this case you have to remember that for a given system, a material balance can be written in terms of the following conserved quantities. Total overall mass or mole balance, mass or moles of each chemical compound balance, then mass or mole of an atomic species balance. So, for this, either one you can consider.

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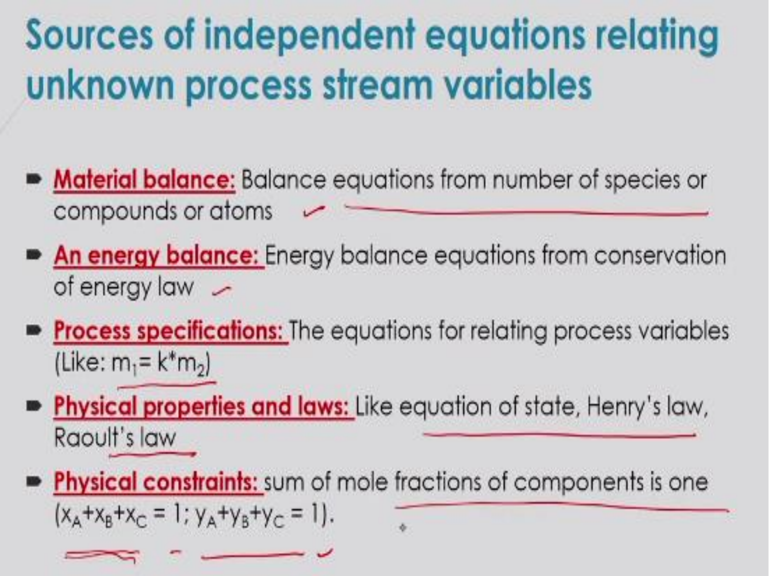

Now, source of independent equations relating unknown processes stream variables. Sometimes you will see that whenever you are doing the material balance for a particular forces, you will see that certain number of equations will be having based on that material balance equation, but there are you will see that more than unknown variables will be there in the process, but you are getting less number of equations based on this material balance. So, what you have to do to equalize this number of equations with the number of process variables?

You have to consider some other relationships is there with the variables or not or some other relationships is given based on the thermodynamic conditions are not that you have to consider or is there any other physical law are actually involving without process variables are not, Is there any physical constraints are there in the systems or not, all those things to be considered. So, they are, suppose if number of variables are greater than the number of equations, in that case you will not get that unique solution or you cannot get the solutions for all variables.

So, for that you have to consider some of the relationship of the variables, that relationships maybe some equilibrium conditions, maybe some that pressure, composition relationships, there may be sometimes some fractions of all compositions will come to that unity that relation is to be considered. So, here some clues are given. Now, material balance, balance equations from the number of species or compounds that will be retained, and energy balance to be written. The process specifications like is there any equations for relating process variables like m1 is equal to k into m2.

Then physical properties and laws like equation of state, Henry's laws, Raoult’s law that we will be discussing in the next even in future lecture also. Sum of mole fractions of components that is 1, that means here some fractions, suppose 3 three components are there and fractions are given XA, XB and XC, so, the summation of all those fractions will be equal to 1.

Similarly, if it is gaseous mixture, then summation of mole fractions of that gaseous components will be equal to 1 like this. So, these are the relationships to be considered, they are for the solving that material balance equation to get that unknown variables.

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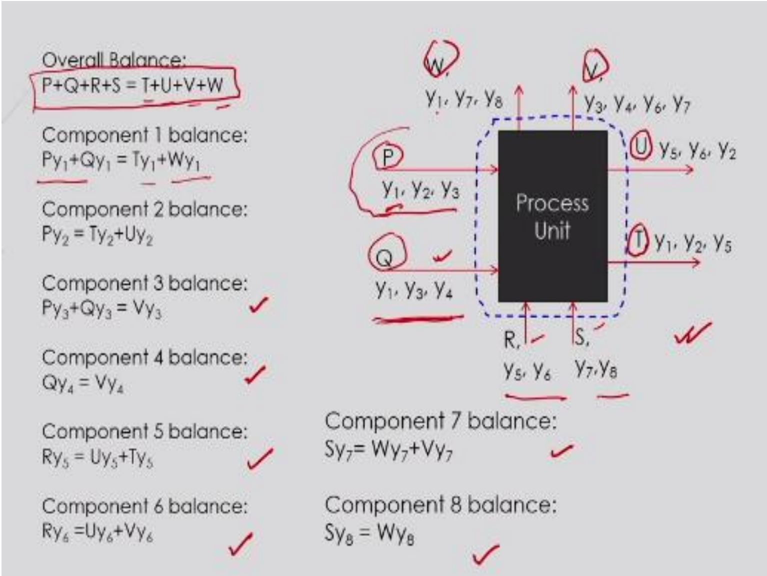

Let us do an example here showing this process unit where how material balance can be retained here. In this case, suppose this process unit will have that 4 input and 4 outputs are there. The inputs are P, Q, R, S and outputs are here W, V, U, and T, and in all these process streams, there will be some compounds like 1 to here I think 7 or 8 here components are there. In the stream here in this inlet, the amount of P will consist of these components here 1, 2, and 3 with the compositions like mole fractions as Y1, Y2, Y3 three.

Similarly, in this systems here, the amount is Q and compositions are Y1, one y two Y3, and Y4 for the compounds 1, 3, and 4. Similarly, for this R and S here for this streams like this and with the composition of 5 and 6 with their respective mole fractions. In the outlet streams also, you will see that there will be an amount of that outlet streams here like U, T, W and V here with compositions are given like mole fractions Y1, Y2, Y5; Y5, Y6, Y2; Y3, Y4, Y6, Y7 and Y1, Y7, Y8 respectively for this streams T, U, V, and W there.

So, in this way, we can express the process by a flowchart or we are mentioning all these input and output variables with their competitions. Now, you have to do the material balance, you have to write the material balance. So, I told that first of all you have to write the overall material balance, that means total amount of material come into the process unit and total amount of material which is coming out from the process unit. So, here as an overall balance, you can write here total amount is coming P+Q+R+S here in this input streams.

Whereas total amount is coming out as T+U+V+W. So, we can write this overall material balance here like this P+Q+R+S that will be equal to T+U+V+W. Next what you have to do?

You have to do the material balance for each compound. Now, like this compound 1 or component 1, you can say compound 1 balance here like suppose compound 1 here, in the input what is the compound 1 here, suppose here Y1, so it will be your P into Y1, this would be your compound 1 in this input.

Here again in this stream, that total amount is Q and whereas this compound 2 with a fraction of Y1. So total amount of this Y1 in this stream will be Q into Y1. Similarly, in the output stream you will see that we are getting this W into Y1 and another stream here suppose T into Y1. So, we can write this amount of P into Y1 + Q into Y1 that will be equal to T into Y1 + W into Y1. Similarly for compound 2, we can write this balance also in this input what will be that here, input here coming as P into Y2.

No other you know Y2 is coming into this inlet condition whereas at outlet conditions Y2 we are having here like this U and in the T streams here. So, here it will be U into Y1 T into Y2 like this. Similarly, we can write here component 3 balance, component 4 balance, component 5 balance, component 6 balance, component 7 balance, and component 8 balance here. So, from this material balance equation, we can solve for this Y1 to Y7 and also we can solve for this P, Q, R, S, T, U, V. W. Now, how many unknowns are there here?

Let it be here what is that unknowns P, Q, R, S, T, U, V, W, here total 8 unknowns are there and also composition like Y1 to Y8, so 16 unknowns are there. So for this, is it possible to solve this 16 equations to get this 16 variables, of course they are, but we are getting only how many equations 1, 2, 3, 4, 5, 6, 7, 8, 9 equations we are getting, whereas we need 16 equations. Another what is that, 7 equations are required to solve this unknown variables.

Now, of course, for a particular processing unit, you see some amount of input will be there, you cannot have all the unknown variables will be there in the process unit, some input will be there, some output of course will be there, that should be experimentally determined or it will be known to you. So, from those, you can minimize that number of equations and then with other you know that is there any relationships.

Suppose Y1 to Y2 or Y3 to Y5 is there any relationships that physical properties relationships are there are not, then from those relationships also you can reduce those equations and coming into the equality of equations to the number of unit process variables and then you can solve it.

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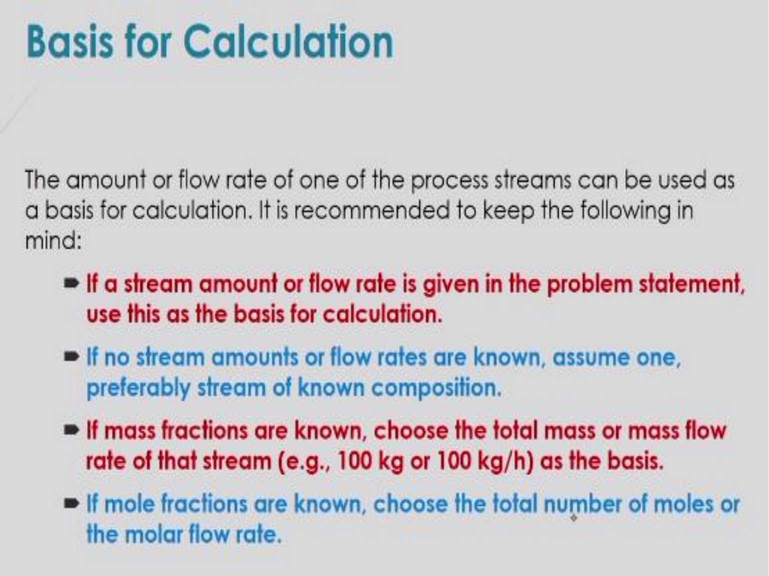

Now, next, what is the basis for calculation? The amount of flow rate of one of the process streams can be used as a basis for the calculation and it is recommended to keep the following in mind. Now, if a stream amount or flow rate is given in the problem statement, use this as the basis for the calculation. If no stream amounts of flow rates are known, assume one, preferably stream of known composition there.

If mass fractions are known, choose the total mass or mass flow rate of that is stream, like 100 kg or 100 kg per hour like this as a basis. If mole fractions are known, then choose the total number of moles or the molar flow rate there.

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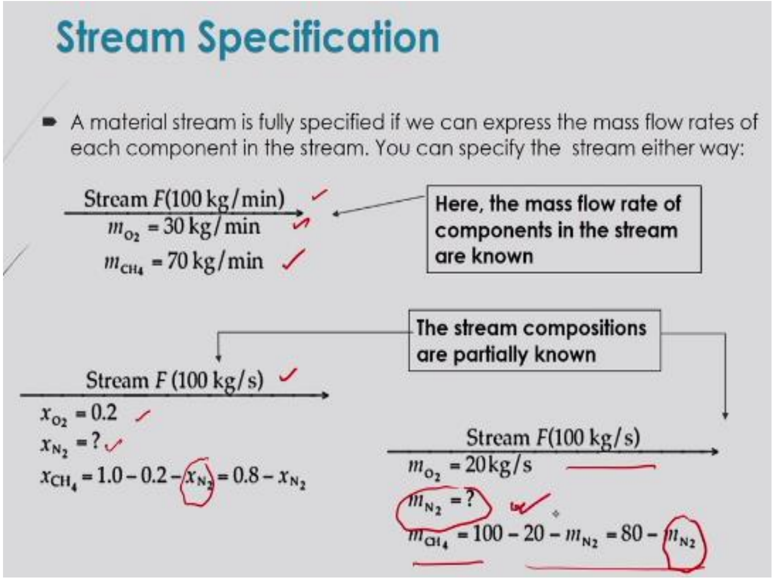

Like here, earlier we have already described this the streams will be you know there will be known values of like this 100 kg per minute as basis and mole fractions will be like this, here oxygen and methane gas is 30% and 70%. Here the mass flow rate of the components in the streams are known and the streams competitions are partially known here, like here stream amount is given, whereas composition of this here nitrogen composition is not known to you, but oxygen composition and methane compositions are known to you, but this also unknown because your XN2 is not given to you.

So, finally, you are getting two unknowns here. And here, stream here again this if it is 100 kg per second the streams, here also you see that the two unknowns are there here. Again if you know this nitrogen mass here, you can get this methane mass from this amount here, from this mN2 and then we can say that only one variable is unknown to you.

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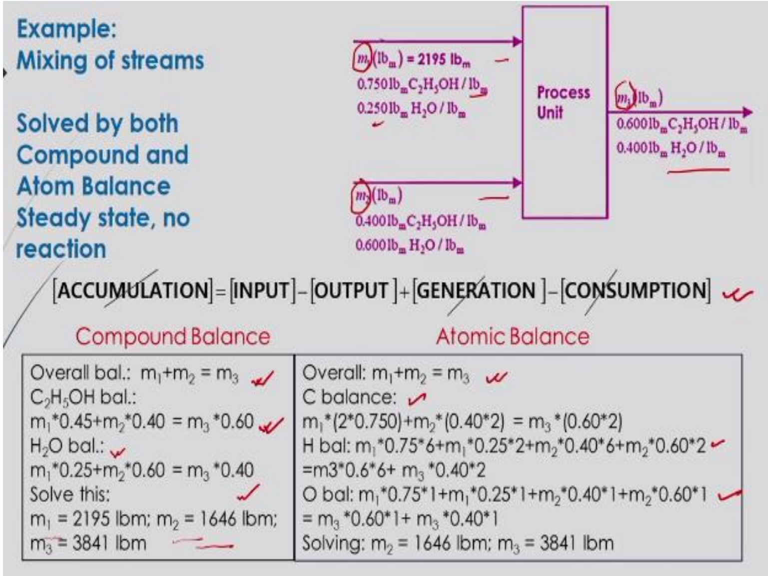

Now, let us do example for the single unit without reaction. Like this here one process unit, some feed is coming in and here another feed is coming in and this amount is coming out. Now, you can solve this problem either by compound balance or atomic balance. Based on this material balance equation, here accumulation will be close to o because this is a steady state process. There is no reaction, so generation and consumption terms will be omitted. So, only remaining is input and output. So, we can write here input will be equal to output there.

So, according to the material balance, compound balance can be written. First of all you have to write the overall balance. Now our overall balance is here. This is streams m1, m1 + m2 that will be is equal to m3. So, this is your overall material balance. Now, compound balance, if we consider here, ethanol C2H5OH, that is ethanol composition. So, in this system, ethanol will be coming as m1 into 0.750 and then in this here it will be m2 into 0.40 and output is m3, that will m3 into 0.60, so this one. So, we can write this ethanol balance.

Similarly, for water balance we can write here, here m1 into 0.250 + m2 into 0.60 that will be equal to m3 into 0.40 like this. Similarly, we can write this atomic balance also. Overall balance from that, then atomic balance like for carbon only, for hydrogen only what will be the balance, for oxygen only what will be the balance like this. Now, solving these equations, you will see that as per compound balance and then overall material balance, you can solve these equation to get these are unknown variables like here.

You will see that after solving these you can get m1, m2 and m3 and similarly based on this atomic balance also, you can solve this and you can get this m1, m2 and m3. Now, here very interesting that you can have the same value of m2 and m3 value, even m1 value, based on that compound balance and atomic balance. So, either you can do the compound balance or atomic balance, just based on this material balance equation.

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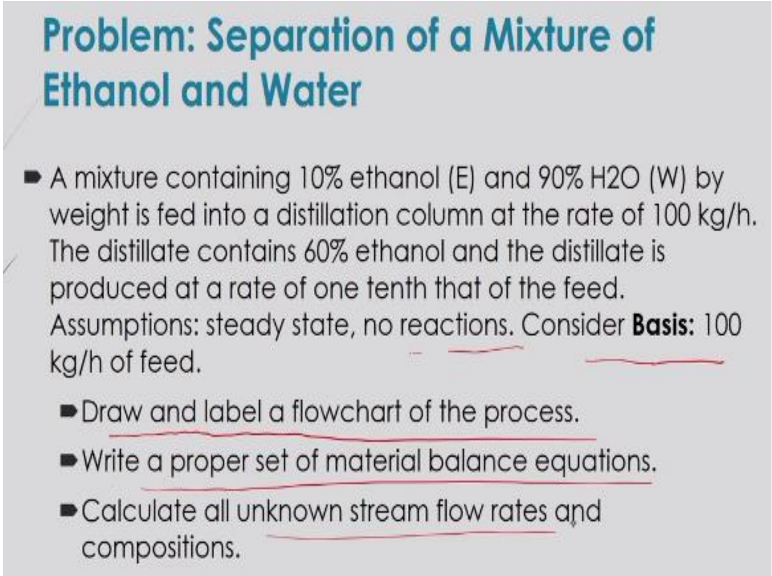

Let us do another example like separation of a mixture of ethanol and water. Now a mixer containing 10% ethanol and 90% water by weight is fed into distillation column at the rate of 100 kg per hour. The distillate contains 60% of ethanol and distillate is produced at a rate top one tenth of that of feed. Assumptions is given steady state, no reactions. Consider that the basis is 100 kg per hour of feed. Now, in this case draw and label a flowchart of the process, write a proper set of material balance equation, and then calculate all unknown stream flow rates and compositions.

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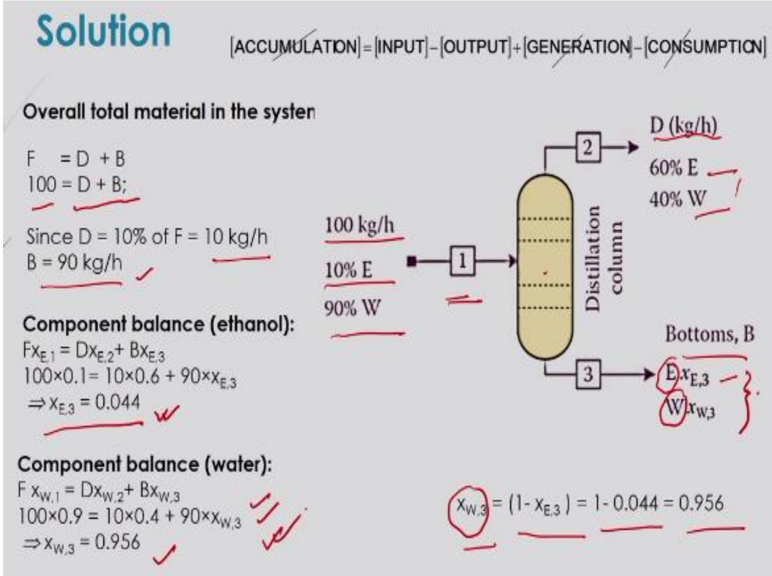

So, based on this problem, we can draw this flowchart here. This is a separation column. In this case, feed as an input is 100 kg per hour, composition is ethanol and water as 10% and 90%. In the output distillate is D and ethanol and water is 60% and 40% in the overhead product and the bottom product is coming as B and composition like this here xE and xW and the amount is E and W there or ethanol and water respectively. Now, based on this problem, we can write the overall material balance based on the material balance equation.

Like what would be the feed in, this is you know F we can write and feed out is D + B here. F is given to you, so 100 will be equals to D + B. Now since D is given as 10% of this feed, so we can write D will be is equal to 10 kg per hour. So, B will be is equal to from this equation, F minus D, that will be coming 90 kg per hour. You can do that component material balance also, like this eternal balance. If we do that, then it will be equal to F into xE1 that will be equal to D into xE2 + BxE3 that is in the inlet what would be the ethanol.

In the outlet also total amount of ethanol what will be that based on which we can write that, we can solve this for a fraction of this xE3 exit, that means in the stream 3, what will be the composition of ethanol there. So, it is coming like this. Similarly, we can do the material balance for the component water here. So, in the same fashion, we can solve this for xW3, that is composition of water in the stream 3 and it is coming 0.956.

Now, you can get this xW3 without doing this material balance of compound for water also because once you know this xE3 in the stream 3, you can get it from the auxiliary equation of that like xE3 + xW3 that will be equal to 1, from that you can directly calculate what should be the composition for water in the stream 3. So, it will be coming 1 minus xE3, basically it is 0.956, which we have got based on this component material balance per water based on this material balance equation.

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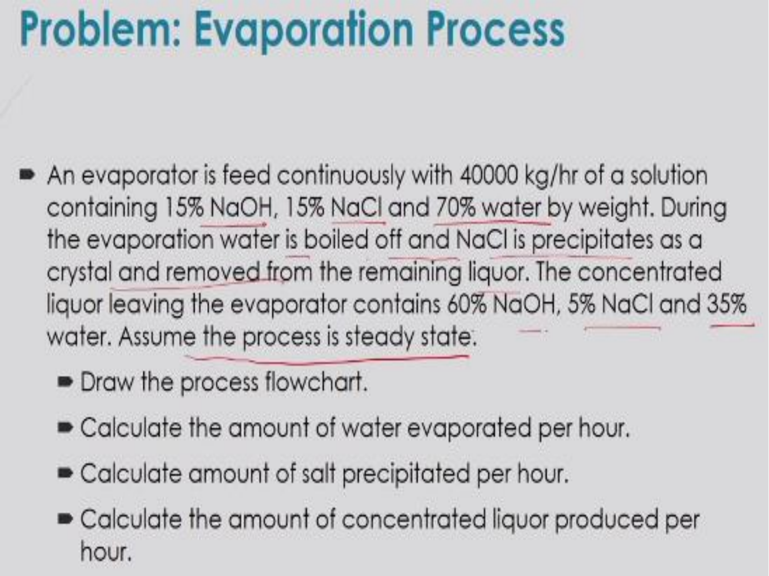

Similarly, you can do that evaporation process to find out that amount of concentrated liquid produced per hour also and also based on these what should be the amount of water evaporated per hour and also what would be the salt precipitated per hour that there. Now, the problem is given that the evaporator is feed continuously with 40,000 kg per hour of the solution that contains 15% sodium hydroxide, 15% sodium chloride and 70% water by weight.

Now, during the evaporation of water, you know that the water is boiled off and sodium chloride is precipitates as a crystal and removed from the remaining liquor. The concentrated liquor leaving the evaporator contains 60% sodium hydroxide, 5% sodium chloride and 30% water. Now in this case, you have to assume that process is a steady state process. So, based on this problem, you have to do the material balance to find out that amount of salt precipitated, amount of water evaporated per hour, and also what would be the amount of concentrated liquor that is produced per hour.

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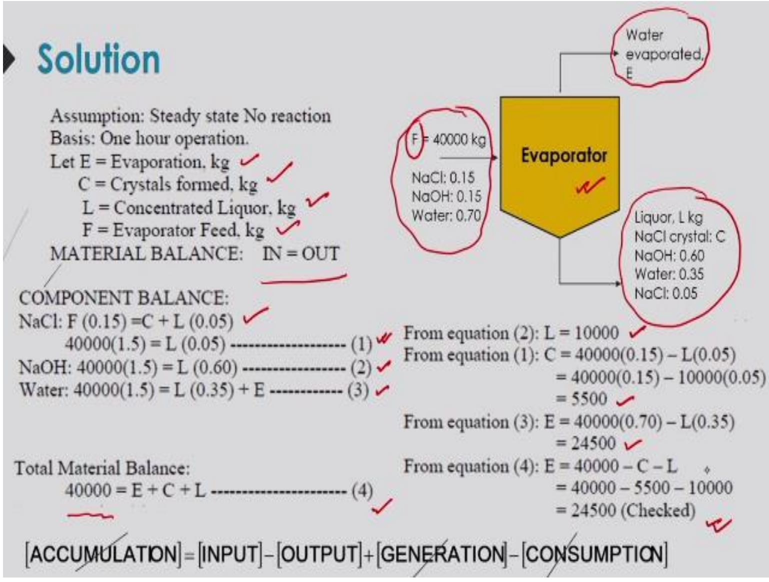

Now, see this you know process flowchart here. In this case, it is an evaporator. What is the input as per problem, it is mentioned here. What would be the output also as per problem, it is mentioned here. What is the output in this system also it is mentioned here. Now, since as per problem it is steady state operation, we can consider that a basis of 1 hour operation, and in that case, what will the evaporation amount that is not known to you, that let it be E and what would be the amount of crystals is formed that is you know C it is assumed.

What will be the concentrated liquor is formed that is L is assumed and what would be the evaporator feed, it is given to you, still we are considering that it is denoted by F. So, based on that material balance since there is no reaction, we can omit that generation and consumption terms, also since it is a steady state operations, we can omit that accumulation term, so simply we can write input will be equals to output.

Now, if you do the component material balance there for the sodium chloride, we can write this equation and finally substituting the value of this F and C value, then we can have this here equation number 1 and similarly for sodium hydroxide balance, you can have this equation number 2. Similarly, for water balance, we can form this equation number 3 and total material balance is basically that, that is F will be equal to E + C + L, that is given in equation number 4.

Now, from equation number 2, we can solve for L, from equation number 1, we can solve for C just by substituting this solution of L, then it will be coming as this 5500. Similarly, from equation number 3, you can solve for E. From equation number 4, we can solve for E based on this value of C and L, that is solved by equation number 2 and 1. Now, we can then have this unknown values of E, even C, L like this. So, based on this problem, then what will be the amount of then water evaporated that we got, amount of salt precipitated that we got, and then amount of concentrated liquor that we got based on this problem.

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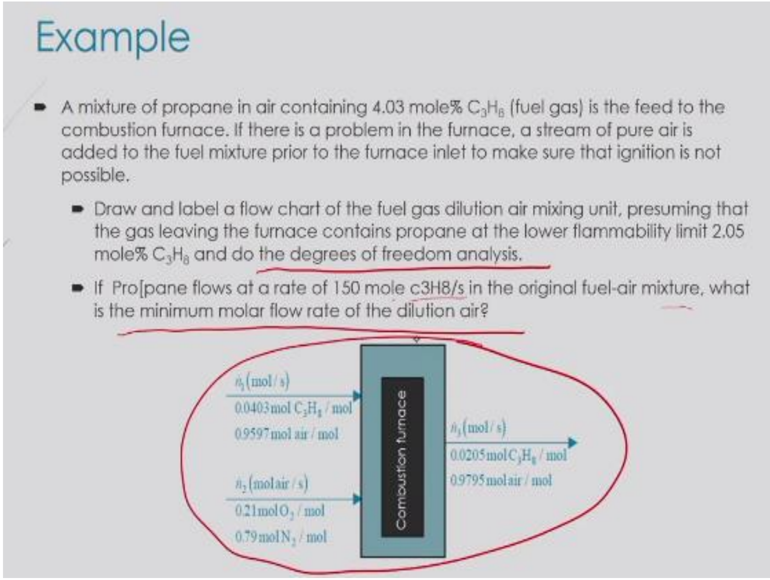

Another example like this here. A mixture of propane in air containing 4.03 mole percent fuel gas here C3H8 is the feed to the combustion furnace. If there is a problem in the furnace, a stream of pure air is added to the fuel mixture prior to the furnace inlet to make sure that ignition is not possible. Now, in this case draw and label a flowchart of the fuel gas dilution air mixing unit, presuming that the gas leaving the furnace contains propane at the lower flammability limit of 2.05 mole percent C3H8 and do the degrees of freedom analyzes, that degrees of analyzes will be done later on.

But in this case you have to do the material balance just by drawing that label, a flowchart of the fuel gas dilution air mixing unit. If propane flows at a rate of 150 moles there in the original fuel-air mixture, then what is the minimum molar flow rate of the dilute air that you have to find out. Now, according to this problem, this flowchart is given here in this slide.

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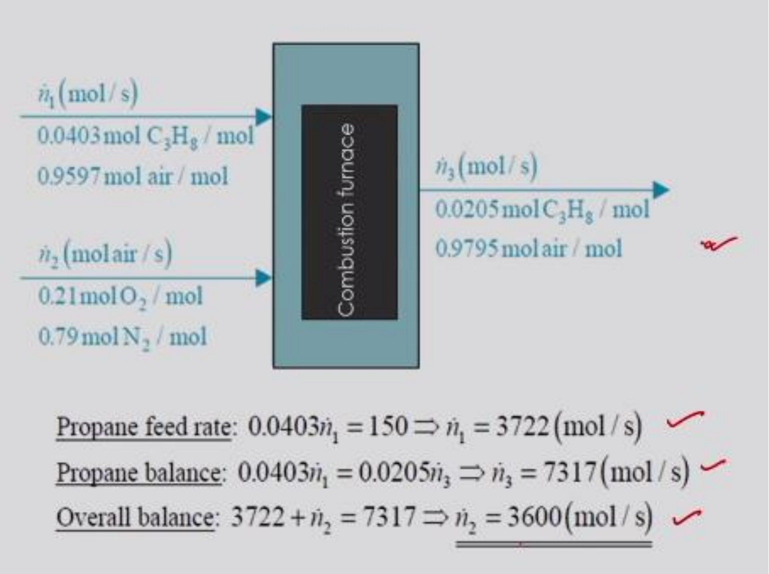

Now, based on this problem, you have to do first what would be the propane feed based on these material balance, what would be the propane balance and if you write this and then you can get this n3 value as part this diagram given and overall material balance based on which you can find it out what would be the n2 value there.

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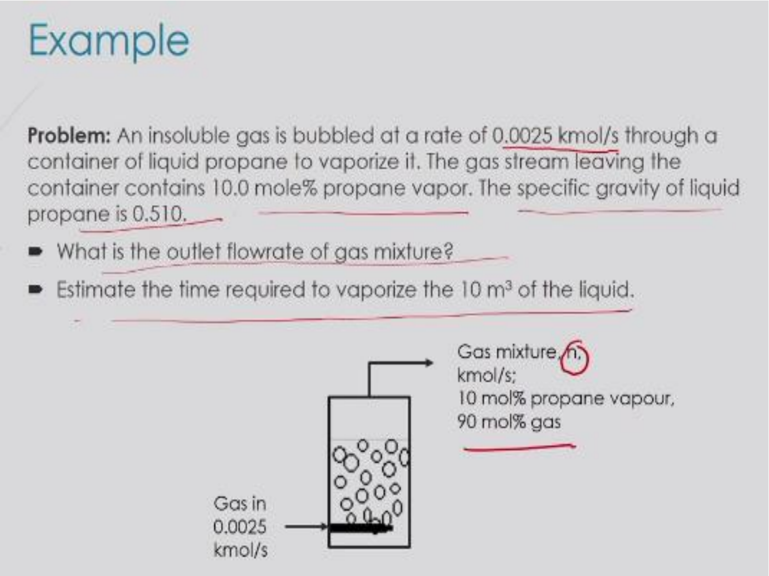

Another example is given like an insoluble gas is bubbled at a rate of this 0.0025 kilomole per second through a container of liquid propane to vaporize it. The gases stream leaving the container contains this mole percent of propane vapor. The specific gravity of the liquid propane is given. What is the outlet flow rate of the gas mixture? Estimate the time required to vaporize the 10 meter cube of the liquid there?

Here also, you will see that some input will be there and you know that initially that some amount of liquid will be there whereas gas will be you know inlet at a rate of this 0.0025 kilomole per second and gas mixture which is coming out that is not known to you, that can be denoted by n, and in this case 10 mole propane vapor and 90 mole percent gas will be there.

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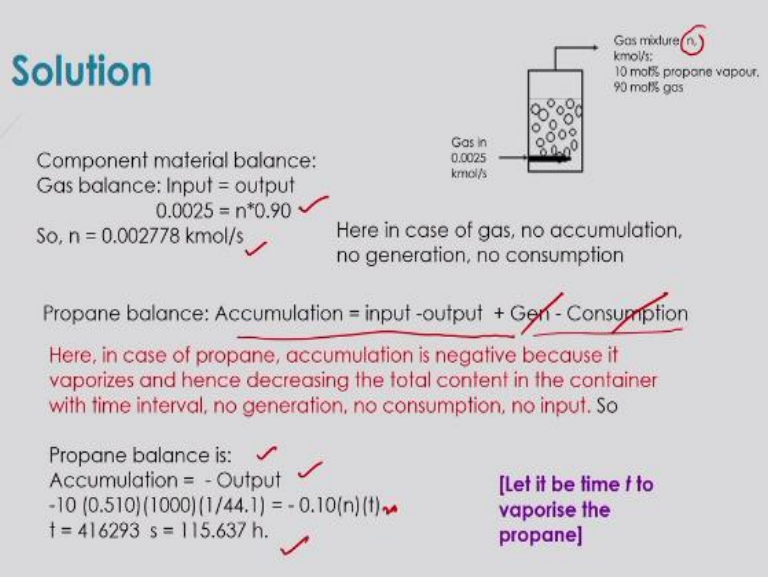

According to that, what will be the component material balance? Now, gas balance will be is equal to simply input will be equal to output since there is no reaction. So, in that case since output is total amount is not known to you, it is assumed that it will be n. So as per that gas balance, this n will be coming like this. Now propane balance if you do, the accumulation will be equal to input minus output + generation minus consumption.

Since there is no reaction, we can omit this generation and consumption terms, but here accumulation will be there because your output rate will be not equals to that input rate there. So, in case of propane accumulation is negative here, because it vaporizers and hence decreasing that total content in that container with time interval, no generation, no consumption, no input. So, we can write this propane balance, so here accumulation will be equal to minus output.

So, based on which you can write this equation and solve for this time t will be is equal to this 115.637 hour okay. So, based on which you can solve this problem.

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Further reading......

Text Books:

- R. M. Felder, Ronald W. Rousseau, Lisa G. Bullard, Elementary Principles of Chemical Processes, 4th Ed., John Wiley & Sons, Asia, 2017.
- D. M. Himmelblau, J. B. Riggs, Basic Principles and Calculations in Chemical Engineering, 7/8th Ed., Prentice Hall of India, 2012.

Reference Books:

- N. Chopey, Handbook of Chemical Engineering Calculations, 4th Ed., Mc-Graw Hill, 2012.
- Olaf, K.M. Watson and R. A. R. Hougen, Chemical Process Principles, Part 1: Material and Energy Balances, 2nd Ed., John Wiley & Sons, 2004.

So, we have described this material balance equation, how to write the material balance equation with example, also how to formulate that process with the flowchart and based on the flowchart with known composition and unknown composition, writing the material balance equation. Based on that material balance principle, we can solve those known values and unknown values. So, in this way we can do the material balance for the chemical engineering process.

So, we will discuss more about that material balance based on that chemical engineering process where you know reaction will not be taking part, but there material balance will be more than one unit there. So, we will be discussing in the next lecture based on that material balance equation with nonreactive processes. So, thank you for giving your attention.