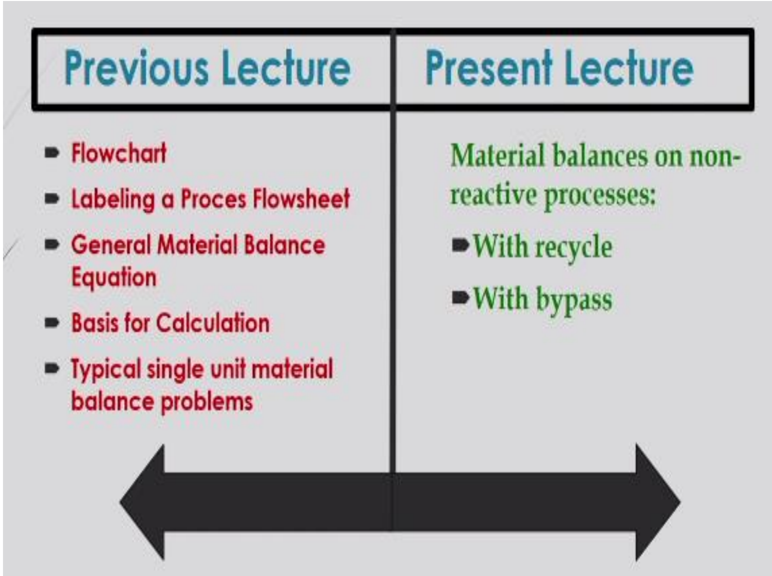
Basic Principles and Calculations in Chemical Engineering
Prof. S. K. Majumder
Chemical Engineering Department
Indian Institute of Technology – Guwahati

Module – 3: Fundamentals of Material Balance
Lecture – 3.2
Principles of Material Balances on Processes
With Recycle and Bypass

Welcome to massive open online course on Basic Principles and Calculations in Chemical Engineering. So, we were discussing about fundamentals of material balance under module 3 and under that module 3, we have discussed the principles of material balance and their knowhow for the calculations of the chemical engineering processes based on that fundamental principle of material balance. Now in this lecture, we will try to discuss about material balances on the processes with recycle and bypasses. and

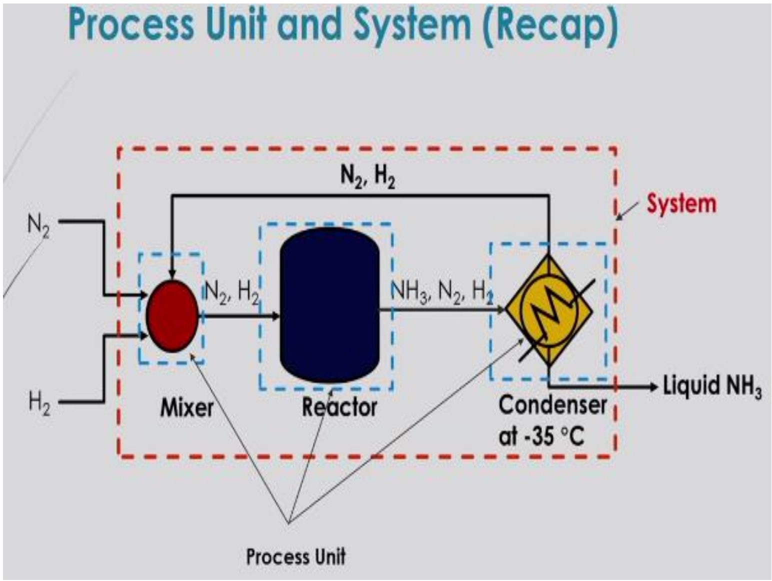
(Refer Slide Time: 01:09)



So in previous lecture, we have discussed the flowchart, labeling a process flowsheet, general material balance equation, basis for calculation, typical single unit material balance problems, based on those general material balance equations. We have given a lot of information, even we have done some problems how to do the material balance and on compound basis total material balance and how to specify that stream by their quantity in terms of flow rate and also in terms of mass fraction or mole fractions.

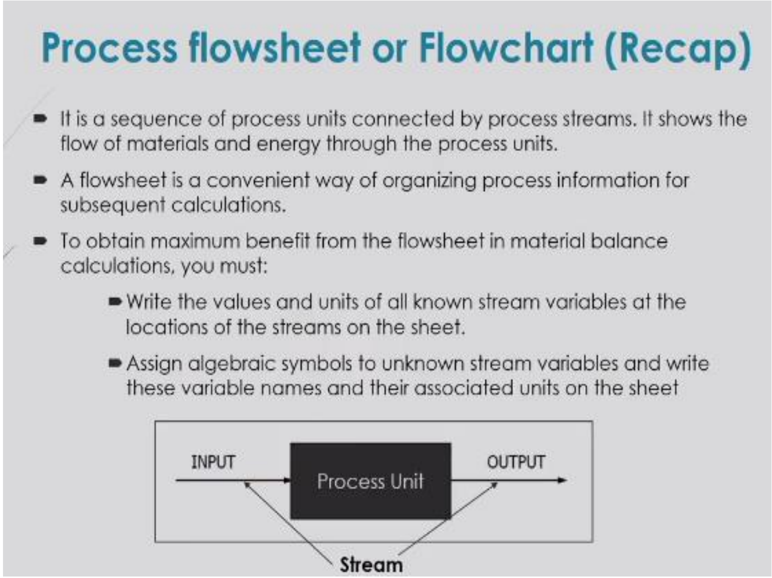
So, here also we will continue that material balance problems on nonreactive processes with recycle and bypasses.

(Refer Slide Time: 01:54)



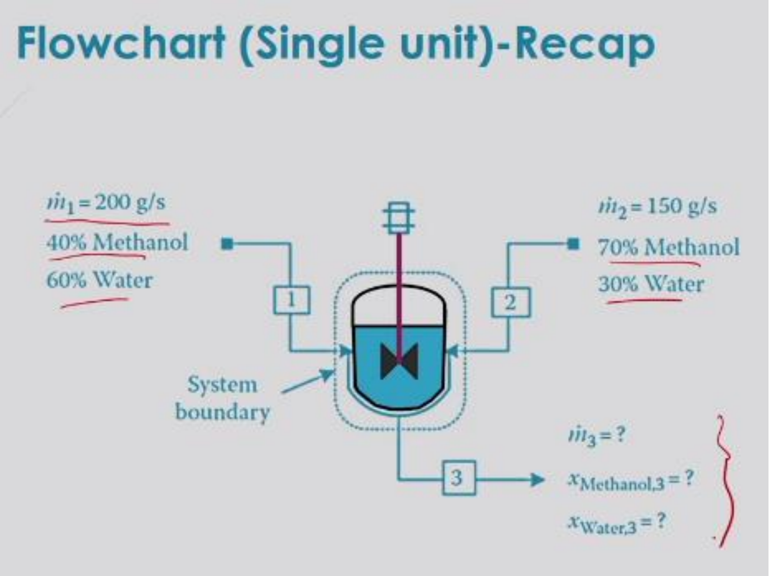
So, we have discussed that before going to that do the material balance equation, we have to specify the systems on which actually we have to do the material balance of the compounds or components or atoms and also total material balance there.

(Refer Slide Time: 02:17)



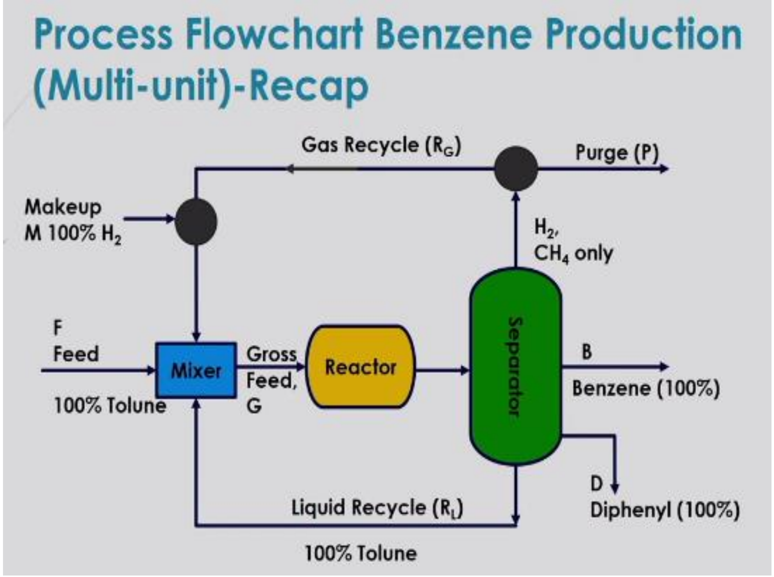
In the process flowsheet how it can be that specified the input and output streams based on their flow rate and also mass fraction and mole fractions there.

(Refer Slide Time: 02:33)



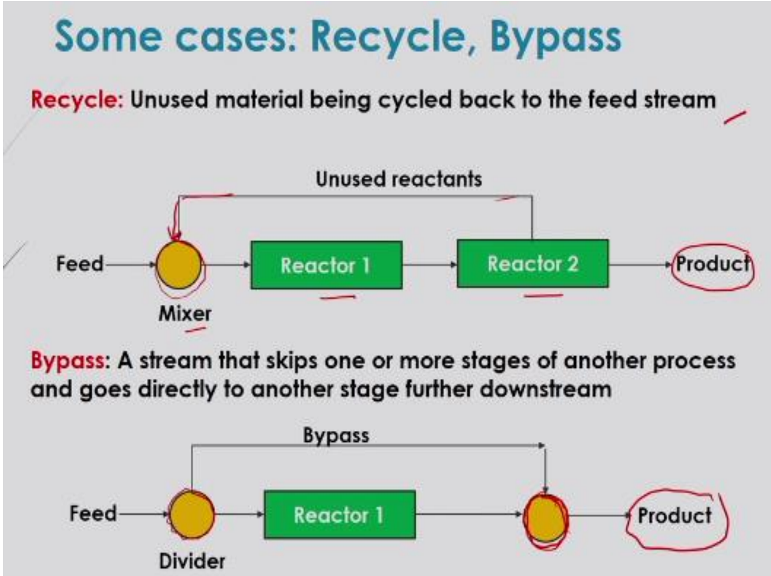
Like here, flowchart is actually discussed for the single unit, how that flow streams are specified by their quantity, like here in the slides that in the mixer that inlet stream and there will be 2 outlet streams or there will be 2 inlet streams and 1 outlet stream. So, in the streams that how that components rate of that flow is specified there it is already discussed in the previous lecture there.

(Refer Slide Time: 03:11)



So, this is also for the multi unit system that how that material balance can be done after the specification of the flow rate and mass fraction of the compounds that is flowing through the streams.

(Refer Slide Time: 03:27)



Now, in this lecture we will discuss something about the recycle, bypass, even makeup are what are those process system for that are to be considered for the expression of that particular processes. They are suppose recycle, here sometimes that in a process unit that some unreacted portions will be there in the outlet streams and those unreacted or extra amount maybe reused for that process. So, it will be recycled to reuse in previous units where to be actually utilized there.

So, in this case one example like this that for the recycle unused material beings recycled back to the feed stream and in this case suppose there are 3 units, one is mixer, another is reactor, and another is reactor 2. Now, in this case, the feed is going to the mixer or this feed will be mixed with that unused reactants that is coming out from that reactor. Then this unused reactants will be mixed in that mixer with the feed mixer with the feed.

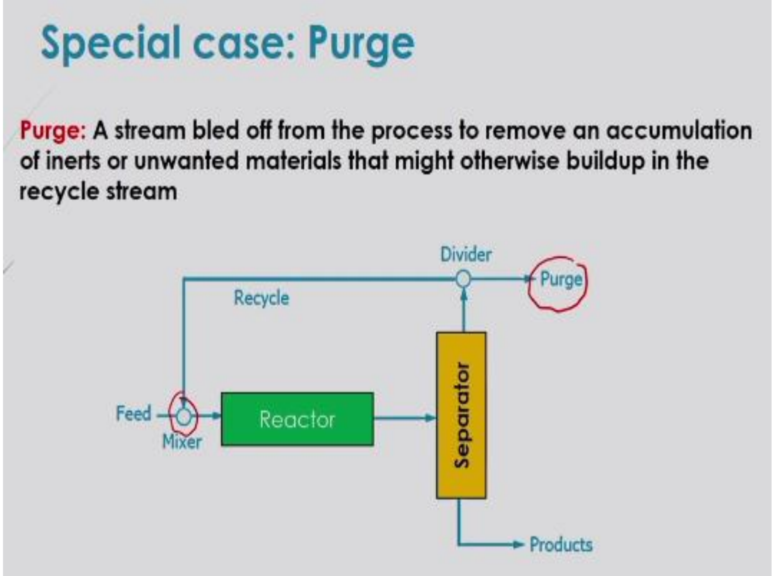
After that, this mixer will be sent to the reactor 1 and then after reaction in the reactor 1, that outlet the streams of that reactor 1 will contains that some products as well as unreacted compounds of that reactor 1. After that, it will be sent to the reactor 2 for further reactions, even after further reaction, you will see that there will be some unreacted amount and some products will be there. So, the products will be separated and it will be taken out as a product whereas unreacted materials can be reused and it will be sent to that again mixer.

In the mixer, the feed mixer will be mixed in there and then again it will be sent to the reactor. So, this streams that these streams will be regarded as recycled stream. Similarly, some process also will be in such a way that some stream that skips one or more stages of another processes and goes directly to another stage for the downstream. Like here, here feed is coming to one process unit, it is called divider. Now, in this case, this divider will allow the streams divided into two parts.

One parts of that feed mixer will go to the reactor 1 for its process, and from that reactor, it will go to separator for the separation of the products, but here you will see that some feed mixes sometimes to process in this separator or some other units, some portions of the feed mixer required to directly sent to its process unit here. It is sometimes required for maintaining that flow rate as well as that component at a certain amount there, and after that, the product will be coming out.

So, this type of process will be actually regarded as with bypass process. So here in this case, a stream that escapes one or more stages of another process and goes directly to another stage for the downstream for its processing.

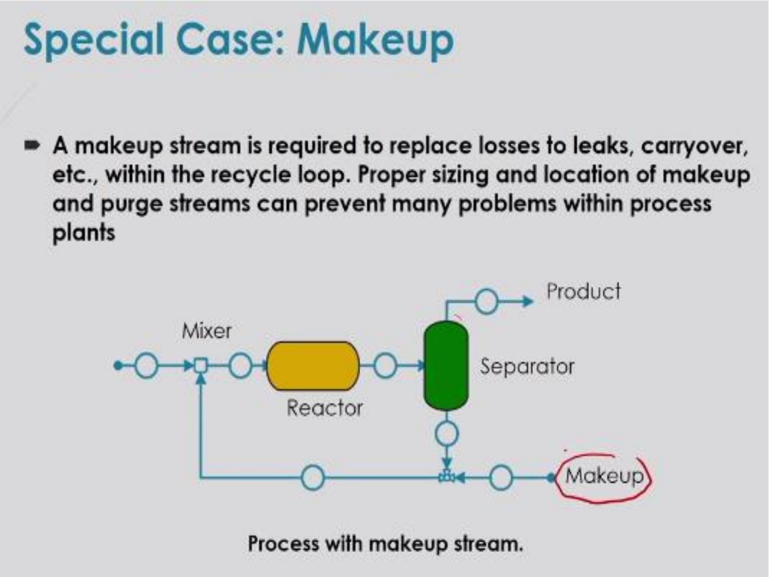
(Refer Slide Time: 07:05)



Special cases like purge sometimes it is required. In that case, a stream sometimes will be taken off or bled off from the process to remove and accumulate it unwanted materials or you can say that some inert materials that might sometimes otherwise buildup in the recycle streams. So, that unwanted material as inerts materials that can be taken out from the outlet streams of that process unit there. Here in this case see feed is coming through the mixer and it will to go to the reactor and after that products will be separated into a product stream and unwanted materials.

So, in this unwanted mixer of this materials, some will be used and reused and it will be recycled back to its mixer here, but some inert materials which will not be actually used for other processing that can be taken out as a purge there. So, this type of process also will be in the chemical engineering process. So, how to do that material balance based on this recycle bypass, even purge, that will be considered here.

(Refer Slide Time: 08:19)

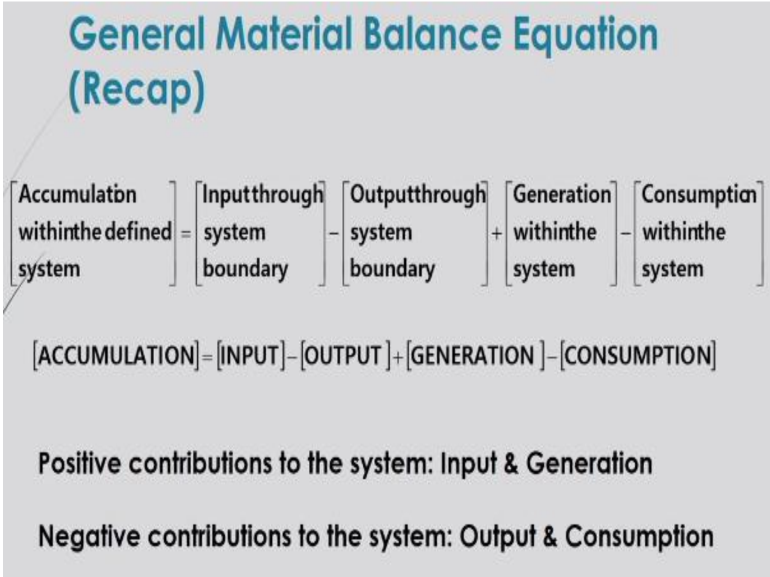


Another this makeup also sometimes some amount of components will be shortage in the flow stream. So, you have to give input as a makeup there in the stream. So, a makeup stream is required to replace losses to leaks, there sometimes there will be some leaks and there will be some losses of that material. So, to fill up those leaks or other carryovers though in that case, you have to give some makeup in the recycle loop. So, that will be considered as a make up here.

Like this in this stream, you will see that process with makeup streams here, the feed will be going to the mixer along with that recycle of this separator here and in that whenever you are recycling there from the separator, you will see that some loss amount will be there, so that that particular flow streams will not be maintained. So, there of course you have to give input as a makeup there to maintain that components here in the mixed stream.

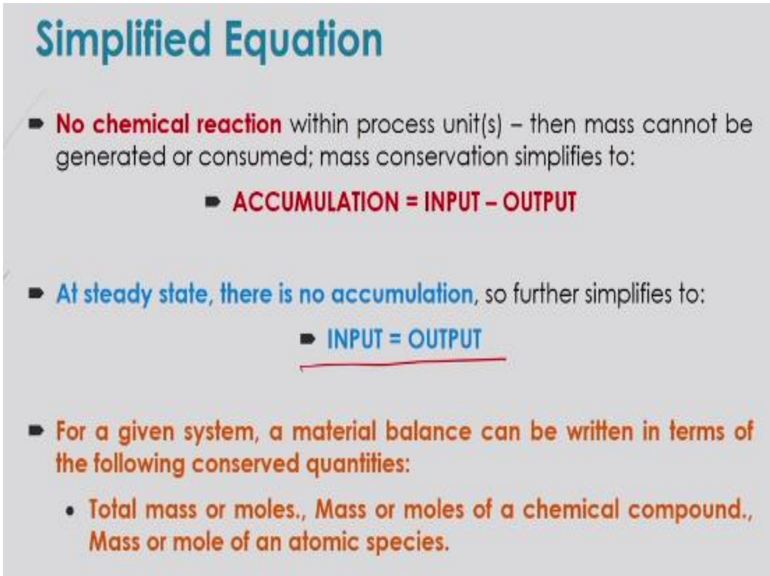
So, after that mixing, then it will go to the reactor again, that product streams of that reactor. It will be separated in the separator and product will be coming out from the separator and the unreacted compound to be recycled back to the mixer along with the makeup.

(Refer Slide Time: 09:46)



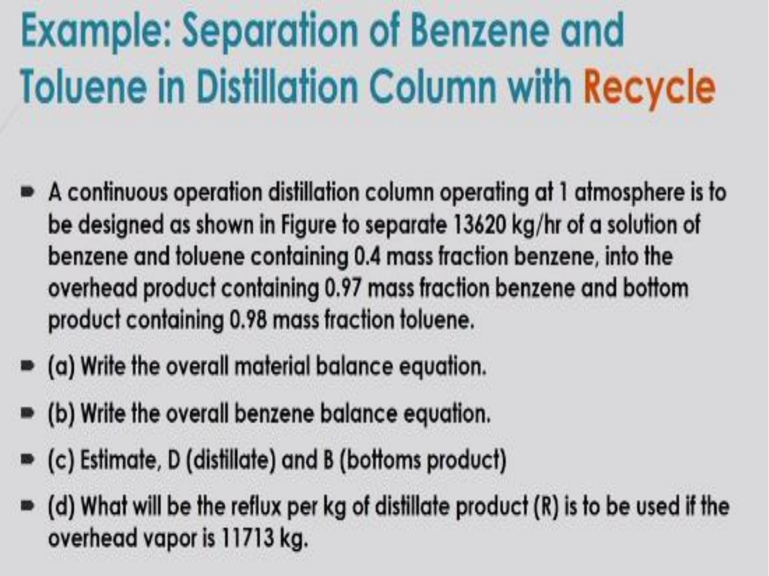
Now, if we recall that general material balance, we know that there will be some accumulation. That accumulation will be is equal to input minus output + generation minus consumption. So, this again general material balance equation will be used for calculation or you can say do the material balance based on that bypass, even purge or you know that recycle processes there.

(Refer Slide Time: 10:17)



These things we have already discussed. Even if there is no chemical reaction, even at a steady state condition, then you can say that the final equation of material balance will be is equal to input minus output. So, in this lecture, we will also again that consider that nonreactive systems where consumption and generation terms will be 0, whereas at steady state, we will consider that accumulation will be is equal to 0. So, simply we can do that material balance as input minus output.

(Refer Slide Time: 10:51)

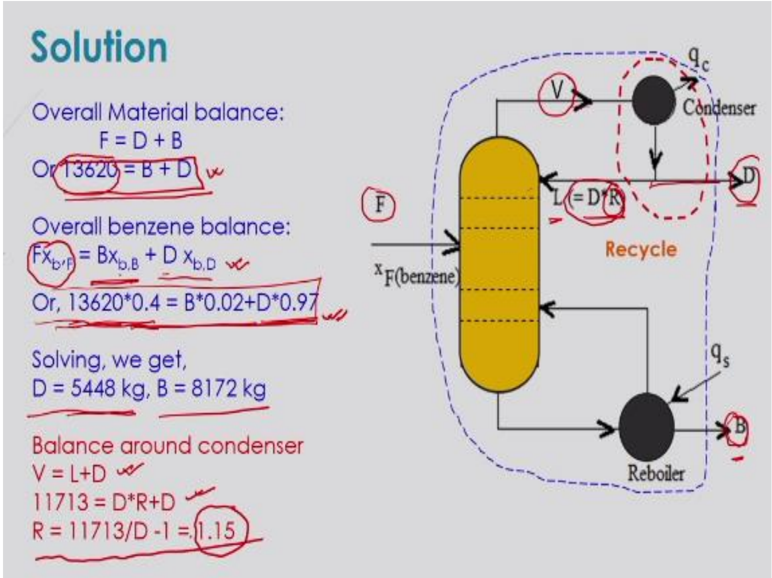


So, as we know that the principles of that material which whenever you are going to do that medical balance, you have to do either by mass or mole basis. So, either one you have to follow or you can do that material balance based on compound balance or you can do the material balance based on atomic species balance, and whenever you are going to that compound balances, to solve those equations based on that compound balances, you need to have sometimes the total material balance.

So, you have to do also the total material balance. So, we have already discussed all those things. Now, here we will discuss the example with recycle stream. Let us have this example of separation of benzene and toluene in distillation column with recycle. In this case, suppose a continuous operation distillation column that operated at 1 atmosphere, which is to be designed as shown in figure of the next slide.

To separate 13,620 kg per hour of a solution of benzene and toluene that contains 0.4 mass fraction benzene that will give you the overhead product that will be containing 0.97 mass fraction benzene and bottom product will be containing 0.98 mass fraction of toluene. Now, in this case, you have to write the overall material balance equation, write the overall benzene balance equation, and estimate the distillate and also bottom products. Now, what will be the reflux per kg of distillate product to be used if the overhead product is 11,713 kg.

(Refer Slide Time: 12:46)



So, in this case very interesting that see this schematic diagram of the process here. In this case, this distillation column is used and feed coming at a certain rate with benzene composition as xF, and after distillation, you will see that the benzene and toluene mixer will be separated out and from the top portion you will see that heavy product as you can say that the benzene will be coming out from the overhead of this distillation column is a vapor, and after that, it will be condensed and after that condensed the liquid benzene will be collected as a distillate.

Now, from that condensed or as a liquid distillate portion, you have to some portion of that liquid benzene you have to sent back to the distillation column for the process. Now, that is called that recycle of that distillate here in the distillation column. So, these some portions should be taken out as a distillate and some portion of its vapor phase as a liquid form, it will be sent back to the distillation column, whereas from the bottom, the liquid toluene will be taken out as an amount of B and there will be some composition of this B there.

Now, in this case since it is a recycle problem, you have to do the material balance and also that you have to do the overall benzene balance equation and also from that you have to calculate what should be the distillate and what should be the bottom product as B. In this case, what should be the overall material balance? So, we knew that the basic equations of the material balance they are accumulation will be is equal to input minus output + generation minus consumption.

In this case since there is no reaction is going on, so you can simply omit that consumption and generation terms and also since this is a steady state operation, also you can neglect that accumulation term. So, finally, it is coming as input will be equal to output as per equation. So, overall material balance if we consider that as an input what would be the flow rate of that feed that will be F and what would be the output from that it will be D and also B.

Now, very interesting that before going to that material balance, you have to fix it up that boundary of that process based on which that you can do that material balance. Now, overall material balance to do that, you can give this boundary you can of that whole processes, that is denoted in blue dotted line here in the slide, and based on which you can calculate. Now, if you know that F value and if you substitute that F value as per problem, then you can say this will be is equal to B + plus D, but this B and D is unknown to you, B is for bottom product and D is for distillate.

Now, if you do the overall benzene balance that means what would be the amount of benzene and overall it is going to the distillation column and also overall what would be the output of that benzene product it is coming out from the distillation column. From this boundary of this blue dotted line, you can say that some input of that benzene will be is equal to F into XbF. What is F, Fis the feed rate and XbF is that mass fraction of the benzene in the feed stream and B, B is the bottom product flow rate and xbB is nothing but that mass fraction of benzene.

This b is benzene, small b is benzene, and here capital B is for bottom product. So it will be mass fraction at the bottom product of that benzene and + D into xbD, D is the distillate flow rate and xbD is nothing but that mass fraction of that benzene in the distillate stream. So, we can have this total amount of benzene is going to that system, that is in the distillation column is simply F into xbF and what will be the mass of that benzene is coming out from that distillate and from the bottom stream, that is that you have to add it up.

Now, from the bottom part, this mass fraction of the benzene if it is xbB, it is unknown to you. So, it can be calculated as B into xbB and in the distillate stream that amount of benzene that is coming out that will be is equal to D into xbD. So, from this material balance, you can write this equation. After substitution these F value it is given to you as in your problem and the feed benzene fraction is given as 0.4, that is 40% benzene, it is given in the problem.

So, we can write this equation here and then you do not know the amount of B, but you know that in the bottom product the benzene mass fraction is given as 2%. So, it will be as B into 0.02. Similarly, in the distillate flow rate, you will see that there will be mass fraction of benzene is 97%. So, we can write simply that D into 0.97. So, from this equation, you can have this based on that mass fraction of benzene in the bottom and distillate product and also in the feed streams, then you can write this equation here.

Now, you got one equation from your overall material balance like this and another equation you got overall benzene balance as like this. Now, if you solve these two equations, you just see there are two equations but you will see that two unknowns are there B and D and also two equations are there. So, simply you can solve these two equations, and after solving, we can get this D will be is equal to 5448 kg and B will be is equal to 8172 kg okay. So, what would be the amount of D, what would be the amount of B, simply you can calculate now.

Now, after that, the problem is that what amount of liquid that will be sent back to that distillation column as a recycle stream that you have to calculate. Now, if you consider the system unit or you can say process unit as a condenser and there if you do the material balance, you will see that what should be the inlet and outlet from which you can calculate what will be the unknown value of liquid there that is coming into the distribution column.

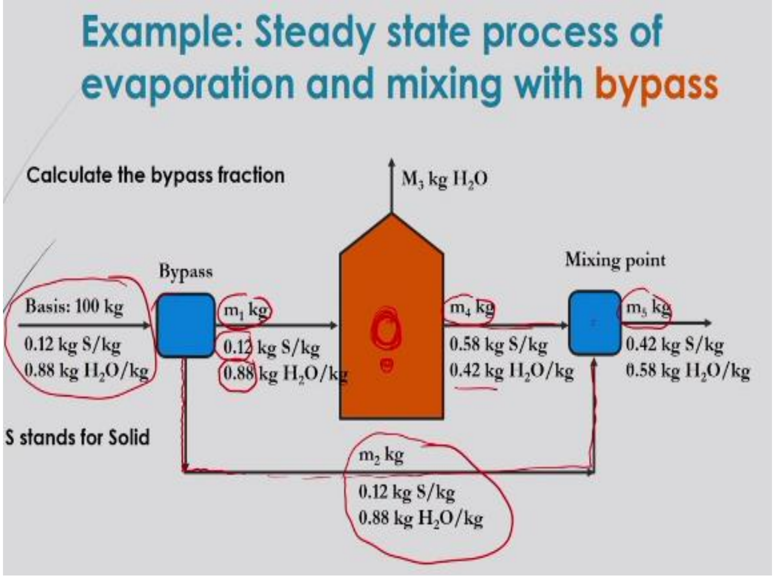
Now, if you do the material balance around that condenser, we can write here, again if you do the overall material balance around this condenser, we can write this V will be equal to L + D. What is V, V is actually amount of that is vapor mixture it is coming out from the distillation column and after that it will be condensed out and then it will be coming out as a liquid stream there and some portions will be sent back as a liquid here. So, in that case, we can write here V that will be is equal to L + D.

So, this is input and these are output there. So simply we can write V is equal to L + D. Now, if you substitute the value of V, V is given to you and D now you have calculated from here, so, it is 5448, but here this, what is the value of L here, L is given here that it should be some fraction of D. So, that fraction maybe you can say that it will be is equal to D, some fraction it is regarded as R that is called recycle faction and then that recycle fraction if you multiply with that distillate, you will get that what would be the amount of recycle is coming to that distillation column.

So, in that case, we can represent that L will be is equal to what, D into R, now this R is called recycle fraction or you can simply it is denoted or you can say it is the reflux there. So, what should be the R from these two equations, you can simply obtain this R will be is equal to this. So, it will be around one point one five. So, in this way, you can calculate that what would be the recycle stream and what is its amount and how to do the material balance.

So, here very important that you have to do the overall material balance first of all for whole system and after that for the recycle portion from where that you know that feed will be recycled that unit also you can do the material balance or you can say that that recycle amount where actually it is going to insert as a feed in this process unit, there also you can do a material balance, so from which you can easily solve the problem for that recycle amount.

(Refer Slide Time: 23:04)



Let us do another example with bypasses stream. Now here in this case see one schematic diagram of the process. There you will see that some slurry as a mixer of solid and water as a slurry some amount, it would be passed through some mixer. So, some amount of solid and some amount of water will be put into a mixer and from which some portion of that slurry, it will be sent to an unit that is called evaporator and there that the slurry will be evaporating and there that water moisture or water it will be evaporated out.

Then you will see that slurry will be more thicker and thicker whenever water will be coming out from that evaporator, and after that from that evaporator with a certain degree of thickness of that slurry system. It will be sent to a mixing unit again and after that some amount of that slurry will be taken out, after that you have to analyze what should be the solid amount along with that water there, and in this case, you will see that whenever you are sending that slurry before entering to that or before allowing it to the evaporator, you know that same some amount of slurry just skipping that evaporator directly to that mixing unit here.

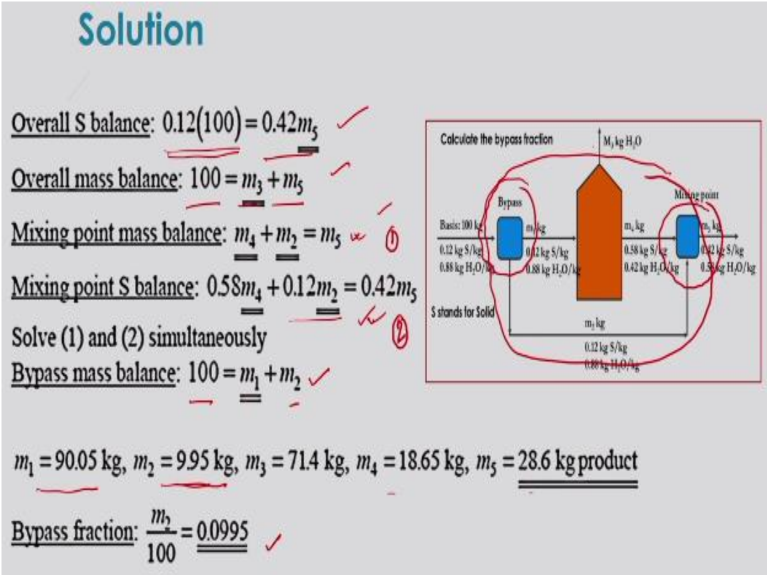
So from this here, you can say one divider you can use and from the divider, some amount of slurry will be sent to the mixing unit just by skipping of this evaporator there and some fractions that will be directly sent to the evaporator and after that removing of moisture or water by that evaporation, you will see that slurry will be again sent to the mixing point there. So, in this case very interesting that slurry whenever it will be sent to that evaporator. After evaporation, some amount of water will be removed by that evaporation process.

Now, before going to that evaporator, that slurry contains maybe you know will be some amount there, maybe some fraction of solid particles and some fraction of water, so that is given here. At the inlet as a basis of 100 kg of suppose slurry which contains 12% of that solid and 88% of water per kg of that basis and it will be used to evaporate by this evaporator and from that some amount will be sent directly to that evaporator and some amount with some composition here, like this it will be skipping that evaporator and sent to the mixing point.

Now, this m1 amount to that fraction of that slurry, the same fraction of that slurry component sent to the evaporator and bypassing to the mixing point. Now after evaporator, you will see that composition, that is a fraction of that component like solid and water will be changing because of that evaporation of water from the evaporator. So, after that you will see that that amount will be as m4 and that fractions it will be change, that the solid fractions will be coming as 58% whereas it was earlier only 12% and water will be as 42%, whereas it was earlier before that evaporator it was 88%.

Then this stream from that evaporator again it will be sent to the mixing point and it will be mixed to that bypass amount in that. So, after mixing of that outlet stream of the evaporator and the bypass amount, you will see that again that composition will be changed. So, in that case composition of that solid will be 42% whereas water will be 58% and the amount will be here only m5. Now, based on this problem, you have to do the material balance and you have to find out the unknown value of streams of like here that is denoted by m1, m2, m3, and m4 and also what is that m5. So, in this way you have to calculate.

(Refer Slide Time: 28:24)



Let us do that calculation here. In this case, you will see that first of all you have to do that overall solid balance. Here S means solid. So, if you do the solid balance, you will see that in inlet condition, you know that what would be the solid in, so there it is you know 0.12 into 100, whereas at the outlet of this whole unit, that is outlet if we denote this here as a boundary of this system. Now across this boundary, we can do that material balance of solid like here 0.12 into 100 that is in and out only here from this mixer and also from this here, but from the evaporator there will be no solid out as an overall system.

So, in that case it will be 0. So, only this as m5 streams, that m5, there only 42% of solid is there, so we can write 0.42 into m5 and also if we do the overall mass balance there, so we can say that 100 kg of slurry is going to that system and only m5 and m3 kg of that component will be coming as a whole from that system. So, then we can write simply 100 will be is equal to m3 + m5. Now if we do the you balance on this mixing unit, on this only mixing unit.

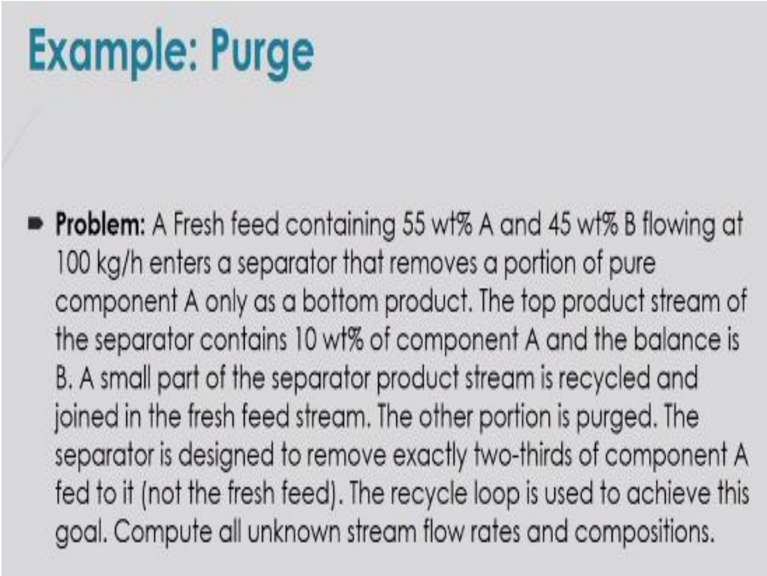
Here we can say that only this inlet is m4, outlet is m5, and also inlet again, another inlet is m2. So, here two inlet and one outlet is there. So, according to that, what would be the solid in and what would be water in and what would be the solid out and what would be the water out that you have to consider. So, in this case if you do the solid balance over this mixing point, what will happen that we can say that 0.58 into m4 + 0.12 into m2 that is m2 as bypass amount, that will be is equal to 0.42 into m5.

So, we are getting these 2 equations here again. Now, if we solve this equation number 1 and equation number 2, then we can easily get that 100 will be is equal to what that amount plus m2. Again the bypass balance, if we do that bypass balance there, we can say that 100 will be equal to m1 + m2 two. Now, if we substitute that value of m1 and m2, then we can say that after solving all these m3, m4 and m5 will be coming out or based on this equation here, all those equations, equation number 1, 2, 3, 4 and bypass mass balance also here, you can easily solve these problems for that m1, m2, m3, m4 and m5 there.

This way, you can do either way also, you can do that first material balance of bypass and then material balance of only what is that evaporator and material balance of mixing points separately there. So, you can easily calculate what should be the m1 to m5 there. Instead of solid balance, you can do the water balance also, in that way also you can solve this problem. So, same amount of this stream of m1 to m5 you can get. Now what should be the bypass fraction?

Now bypass fraction is defined here, what would be the input to that bypass and what would be the amount that is coming out from that divider here as a bypass. So, that is simply m2 divided by F. Here m2 is actually this is 9.95 kg as per solution of these equations and then input F is hundred 100 kg. So, simply you can say that bypass fraction will be is equal to m2 by 100, that means here 0.0995 So, you can easily then calculate for the multiple unit and with that bypass how to do that material balance here.

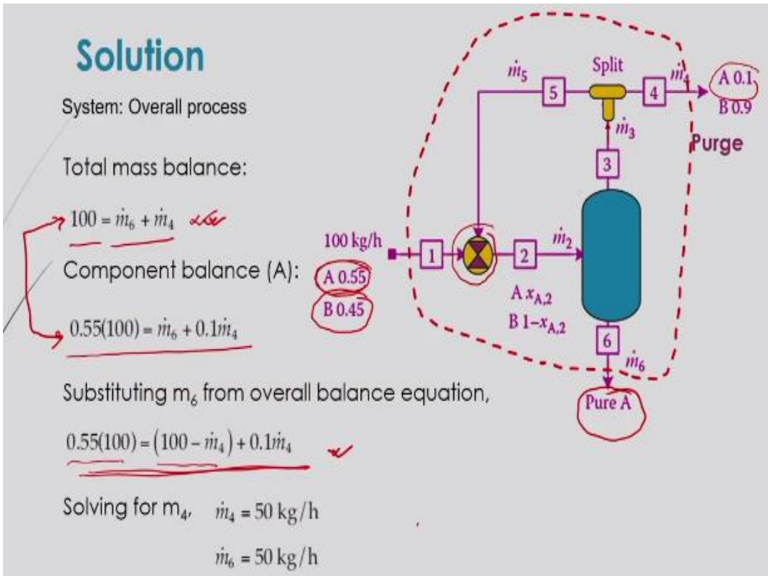
(Refer Slide Time: 33:09)



Now, let us do another example with purge. Now, suppose a fresh feed that contains 55 weight% of component A and 45 weight% of B that flows at 100 kg per hour and enters to a separator which will remove a portion of pure component A only as a bottom product and the top product stream of the separator contains only 10 weight% of the component A and the balance is B. A small part of that separator product stream is recycled and joined in the fresh feed stream, but some other portion is to be purged.

Now the separator is designed to remove exactly two-thirds of the component A that is fed to it, not the fresh feed there. The recycle loop is used to achieve this goal. Now, you have to calculate all unknown stream flow rates and compositions there.

(Refer Slide Time: 34:13)



According to this problem, you can draw the flowchart like this here. Here, you see that there will be some mixer and in this mixer feed stream is coming with the component A and component B with a certain fraction and then it goes to the separator and from the separator two products will be coming out, one will be from the top, another will be from the bottom. Now, from the top portions, you will see that, some fraction of that top portion will be taken out as a purge and some fraction will be sent back as a recycle to this mixer.

Now, this is the problem. According to the value given in your problem, you have to do the material balance. First of all, you have to do the total material balance or overall material balance across the system boundary that is defined by this here red dotted line. Now, if you consider that boundary and in this boundary what is coming in and what is coming out from this boundary. Now, in the boundary, the amount is coming here as a whole 100 kg, whereas the amount is coming out from that boundary as here suppose m4 and here as m6.

Here m4 and m6 rate are not given to you, here it is denoted or it is assumed that it will be only m dot 4 or m dot 6, that is rate, dot means here rate, that is the stream 4 what would be the rate that is coming out as m4 dot. Then in the stream 6, it will be you know m dot 6. So, overall balance or total material balance we can say, it can be written as 100, it will be is equal to m dot 6 + m dot 4. Now, you have to do the component balance or component material balance.

Now, in this case if we consider component A, you can do that component material balance of A. Now, in this case, we can write what should be the amount of that is component A is coming into the that boundary of the system that will be is equal to simply 100 into that is here A 0.55, so 100 into 0.55 and what is coming out from this boundary only for A, it will be m dot 6. Here since it is pure A, all the fractions will be as A, that means 100% A. In that case, the fraction of that A will be 1.

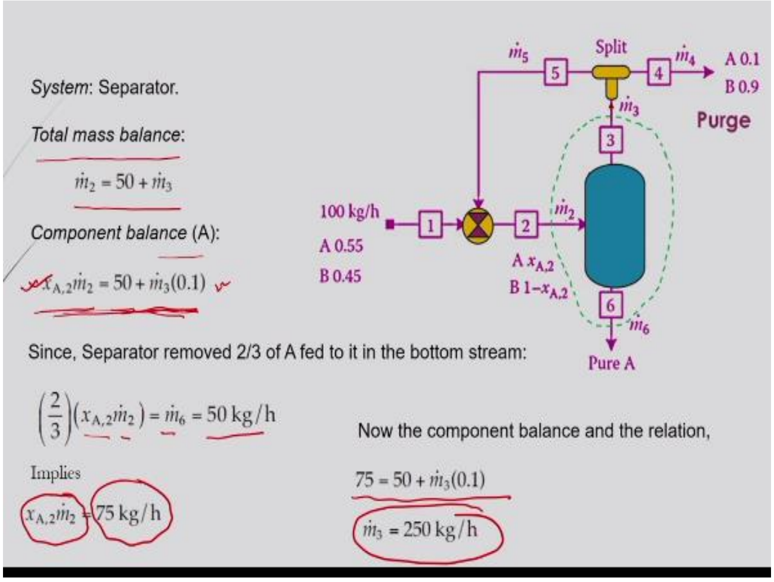
So, here we can directly write here m dot 6 into 1. So, it will be simply m dot 6, and then from this stream4, what is the amount of that component A is coming out since here the mole fraction or mass fraction of this component is given as 0.1, then we can simply write the amount of A is coming out from this stream 4 will be equal to 0.1 into m dot 4. So, based on this, we can write this component material balance here as 0.55 into 100 that will be is equal to m dot 6 + 0.1 m dot 4.

Interestingly in this problem, there is no reaction is going on and the process is steady state, so we can simply consider here input will be is equal to output. Now, from these two equations, you can solve for m dot 6 from the overall balance equation, like this here 0.55 into 100 and m dot 6 will be is equal to what, from this equation you can directly write here 100 minus m dot 4 and then just simply write 0.1 into m dot 4 simply.

So, by these two equations, you can write here this equation and solving here this equation, we can simply calculate what should be the value of m dot 4 here from this equation. Once you know that m dot 4 from this equation, you can easily find out what should be the m dot 6 from your total material balance equation. So, it is coming here m dot 6 will be is equal to 50 kg per hour and m dot 4 will be is equal to 50 kg per hour, both are same.

So, in this way, you can easily calculate what should be the amount of purge that is taken off from the system. So, you had to calculate this bypass amount of m dot 4. So, simply this is the simple example of doing the material balance for the purge.

(Refer Slide Time: 39:38)



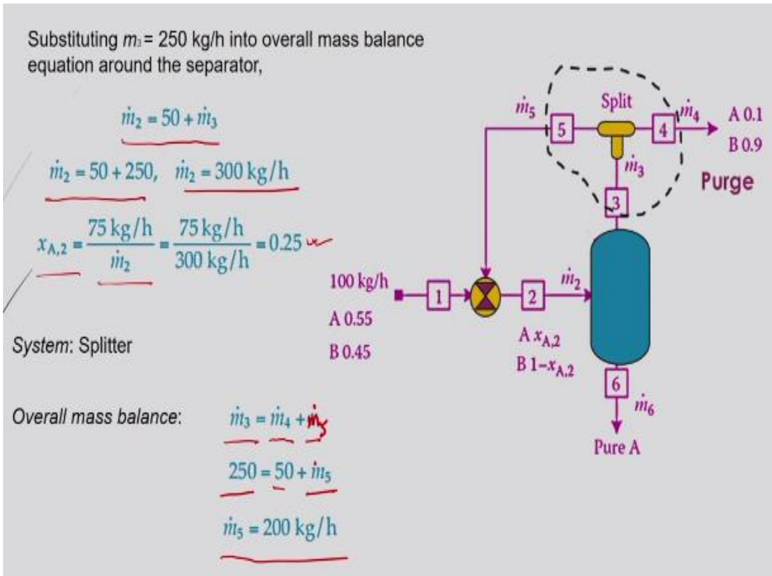
Again, there are some other streams that you have to calculate based on this problem. If you want to find out that other streams and what are those amount, then you have to do the material balance for other systems there, and in that case, if we do the material balance for this unit separator and if we specify here the boundary for this system, then what is the in and what is the out from this boundary that you have to now consider here. Now, accordingly, you have to write to the material balance here.

Here, if you consider this a separator, this input is m2 and output are m6 and m3. So, we can simply write here m2 will be equal to here 50 + m3 three because here m6 is 50 that we got earlier, and then if you do the component balance A again for these streams, then we can write here mA this is stream 2 into m dot 2 that will be is equal to 50 + m dot 3 into 0.1. Here in m3 that component A will be is equal to 10% according to the problem and this m dot 6 here since it is a pure component A simply it will be into 1, that is fraction will be is equal to 1.

So, simply that means here 100% will be the pure component A here. So, accordingly you can write these equations. Now, one condition is that the separator that will remove two-third of A fed to it in the bottom stream. So, in the bottom stream, they told that this component A will be two-third of A that is fed to it. So, in that case, we can write here two-third of xA2 into m2 that will be is equal to m dot 6. So, that will be is equal to 50 kg per hour, which implies that xA2 into m dot 2 that will be is equal to 75 kg per hour.

Now, if we do the material balance and material balance for the component A that already done here, now if we use this equation and substitute the value of mA2 into m2 dot here, then we can simply write this equation from that equation here. Now, from this equation, then we can easily calculate what should be the m dot 3. So, m dot 3 will be coming as 250 kg per hour.

(Refer Slide Time: 42:34)

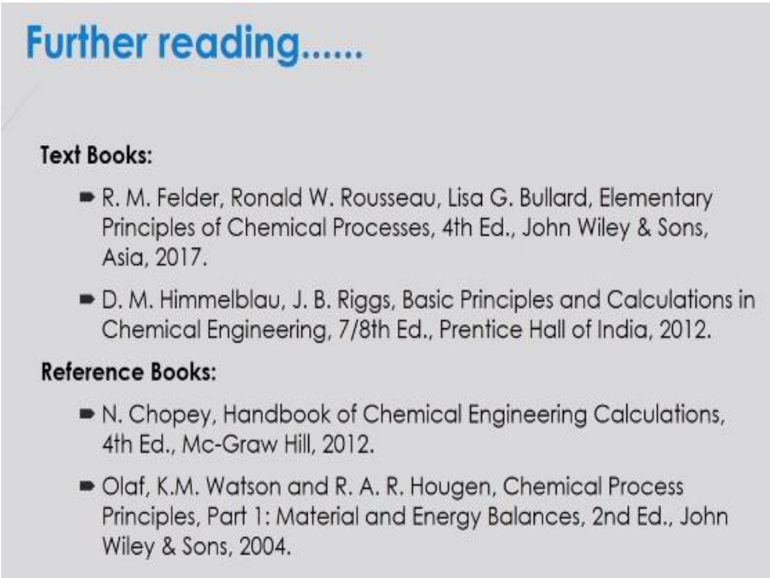


Now, if we substitute this m3 as 250 kg per hour into overall mass balance equation around the separator, then you can write here m2 dot that will be is equal to 50 + m3 dot. That means here, it will be equal to m2 dot will be is equal to 50 + 250. Then m2 dot will be is equal to 300 kg per hour, and then what would be the xA2, xA2 will be is equal to here again from that question earlier, so simply we can calculate from this equation. Now, again if we consider that a split, around the split if we do the overall balance, we can write m dot 3 that will be is equal to m dot 4 + here that will be is equal to m dot 5.

So, we can simply write that here it will be m dot 5. So, here we know that m dot 3 will be is equal to 250 and m dot 4 is equal to 50, and then remaining m dot 5 will be there here. So, that m dot 5 will be is equal to 200 kg per hour. So, in this way, we can do the material balance for that bypass, recycle, spurge, and makeup also. So, in this way, we can do other exercise problem also. We will provide some exercise problems later on after finishing this course.

During that run of that course, we will give some supplementary materials for the practicing and then you will practice and I think will have more idea about that input and output and material balance, how to do that, all these things. So, thank you for your attention.

(Refer Slide Time: 44:41)



Here, I would suggest you to follow that textbook of this given here in the slides for the calculation and also practicing the problem. In the next lecture, we will discuss something more about that material balance that will be on reactive processes. Thank you.