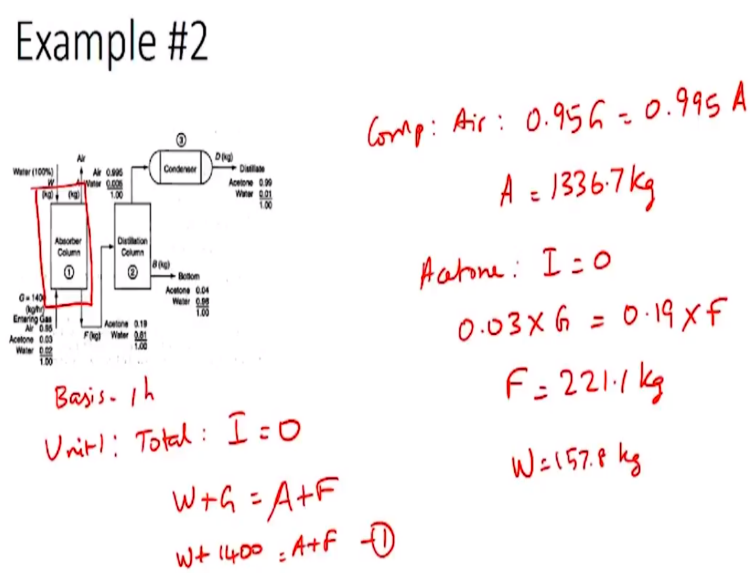
Material and Energy Balances
Prof.Vingesh Muthuvijayan
Department of Biotechnology
Indian Institute of Technology – Madras

Module No # 02
Lecture No # 09
Material Balance Calculations for Multiple Units Without Reactions - Part 2

Welcome back to the lecture on material balances on multiple unit processors without reaction in the last lecture we saw an example where we use the overall system to perform the calculation and then used individual units and performed material balance calculation. Here are more example problem so here is one example problem where you will try to approach the problem like differently.

(Refer Slide Time: 00:42)



The problems statement is you are asked to design an acetone recovery system have the flow sheet which is shown below. All the concentration shown both gases and liquids are specified in weight percent in this special case to make calculation simpler. You are asked to calculate A, F, W, B and D per hour you are also given that G is 1400 kilograms per hour. So the problem gives you many information the first thing we need to understand for solving any of the multiunit processors where do we start what system do we choose?

So here unlike the previous problem we do not want to start with the overall system because not all information of the streams is more. If you were to choose the overall system then we would have many unknown which we cannot solve for with the equation which we have. So for this reason we have to attack the problem in slightly different way. Let us see where we can start so we have an absorber column which is called as the unit 1 which has water stream and gas stream entering and you have air stream and another stream called F which are leaving the system.

Now can we use this unit 1 as the system to radicle what information would we have we can write total balance equation and component balance equations. So how many components balance equation will be able to write so for most systems except for a splitter I need any other system you would be able to write as many independent balances as the number of components. Here how many components do we have?

We have air, acetone and water which means we can write three different balance equations and there are three different unknown which need to be solved which are W which is mass of water entering A which is the mass of air leaving and you also have to calculate F which is the mass of the acetone water mixture which is leaving. So this composition which is given here is the composition of air which is leaving the system.

Now let us go about solving this problem as in any material balance problem the first step is to identify a basis. So here we will use a basis of 1 hour because problem statement asks us to calculate the mass flow rate masses per unit hour. So we have used one hour as the basis and let us continue solving the problem. As I explained earlier we will use this system which is unit 1 as a system to start with you will write a balance of unit 1 which is absorber column.

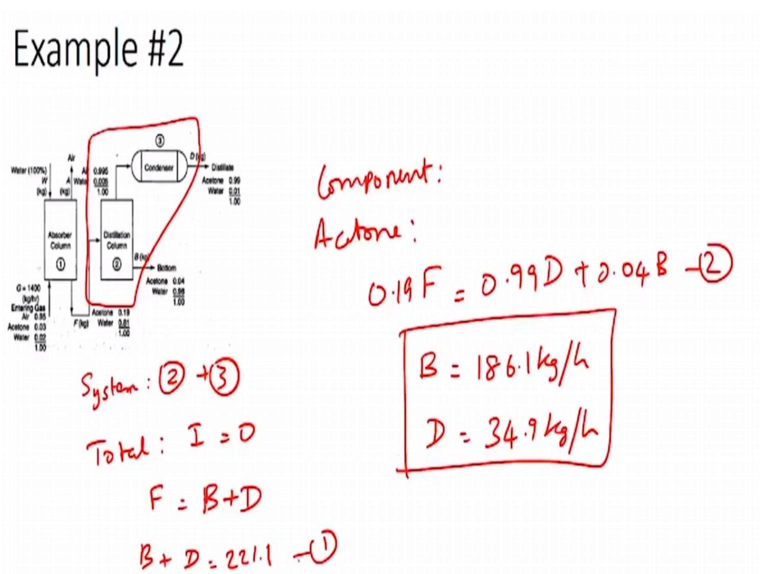
So the total balance for unit 1 would be you have input = output as it is a non-reactive processor at steady state so you have two units which are W + G giving you an output stream which are A + F. We already know G so we can write it down as W + 1400 = A + F. Now we can write components balances let us start with the component balance for air so component balance for air would be 0.95 times G = 0.995 times A.

Air is entering through the gas phase which is G and leaving only through A so this is a equation we start with. So using this equation we can calculate A which is the mass of air leaving the system as 1336.7 kilograms. You already know G as 1400 so substituting for G we can calculate for A we can now write a balance equation for acetone balance would be acetone entering through gas and leaving through the acetone water mixture.

So acetone balance which is input = output would then become 0.103 times G which is 1400 = 0.19 times F as we already know the value for G we can calculate F as 221.1 kilograms substituting the values for A and F in this equation 1 which is the total balance we can calculate W as 157.8 kilograms. So now if we go back and read the problem what we would see is we have been asked to calculate W, A, F, D and B.

One stream which we do not need to get any information about is this particular so this means we can actually calculate only B and D for the second part of the problem we do not need to worry about this particular stream so what does this mean for us in which choose the system based on the information given in this flow chart.

(Refer Slide Time: 06:16)



We do not have the composition of this particular stream as we do not know the composition or the mass flow rate of the stream it would be very difficult to estimate what this particular stream would be. Thankfully the problem does not expect us to calculate the stream so instead of trying to identify this particular stream we can now choose a system which would be basically (()) (06:40) the stream how would we do that?

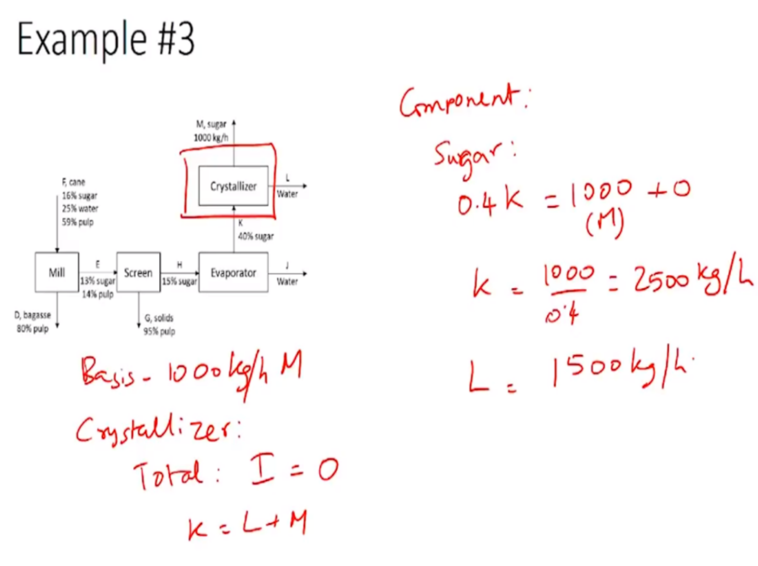
What would be system we can actually draw? System boundary that we can draw to do this so let us not worry about the stream so what we will do is we will choose a system which is the distillation column + the condenser. So the system would basically looks something like this so now you have now crossing the system and entering into the system and you have D and B leaving the system this means we need we calculate information about B and D using the information we have about F.

So let us start solving the problem so we can write total balances for the system chosen so the system of choice here is units 2 + 3 so for that let us write a total balance. So the total balance would be input = output which is F = B + D we already know the value of F so we can substitute it here and get B + D as 221.1 now we can component balance is so we can write the component balance for acetone this is the component balance for acetone which would be 0.19F = 0.99 times D + 0.04 times B.

Now we have two equations 1 and 2 which contain only two unknown so these two equations can be solved simultaneously to get the values for B and D. So B 186.1 kilograms per hour and D would be 34.9 kilograms per hour. So using thought the right systems we were able to solve for all the stream which have been asked for so this is a critical aspect when you are actually going to perform calculating for multiple units.

Whenever you have multiple units the biggest challenge would be to face is to identify the right system to study. As long as you choose the right system then the process becomes as simple as the unit process.

(Refer Slide Time: 09:16)



So let us look at one last example problem before we conclude this particular topic. So here the figure shows the process for extraction of sugar and sugarcane all the known data is given here we asked to calculate the composition of every flow stream and the fraction of sugar in the cane that is recovered so to do this we need to get the information about the all the unknown streams.

We have the stream like D, F, E, G, H, K, L so many different streams have been labeled without information so we have some composition given but we do not know the mass flow rates of this. So here how do we start where do we start so we could look at the simple problem which we have done earlier.

So the first strategy would be to start with the overall system will that strategy wok here probably not because you only have information about 1 particular and every other stream we have no information about the flow rates which gives you F, D, G and J and L so those are 4 unknowns in the stream so it will be impossible to calculate all the four unknowns using the overall system to start with.

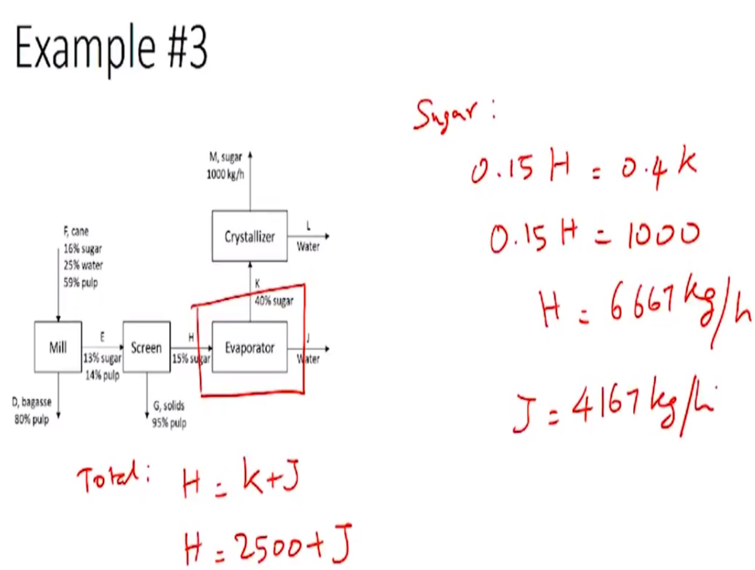
So instead we can start with single systems so where do we start? In the previous example we started with the input stream because we had information about the feed which was entering however here we have information about the product which is introduced so it is been told that we are producing 1000 kilograms of sugar so because we have information about the product stream we can start from the last unit.

So we will start with the we will start with the crystallizer as the system of interest to start the calculation before we start doing the calculation we need to id entify the basis for the problem so here there is only one flow rate which is given which is mass flow rate of sugar leaving through the stream M so our base is for this calculation would be 1000 kilograms per hour M so let us start with the crystallizer.

So we need to know write the total balance and the component balances for the crystallizer the total balance would be input = output assuming that is the process is at steady state and because it is a non-reactive process generation and consumption terms go to 0 leaving input = output. So the total balance then be written as K = L + M we know the value for M we do not know the value for K and L.

Now let us write a component balance the component balance can be write can be for sugar or for water so let us write for sugar. The sugar balance would be 0.4 times K = 1000 which is M + 0 because sugar is not leaving through the stream L using this equation we can calculate the value for K as 1000 / 0.4 giving you a value of 2500 kilograms per hour. So substituting this back to the total balance equation we can calculate L as 1500 kilograms per hour.

(Refer Slide Time: 13:15)

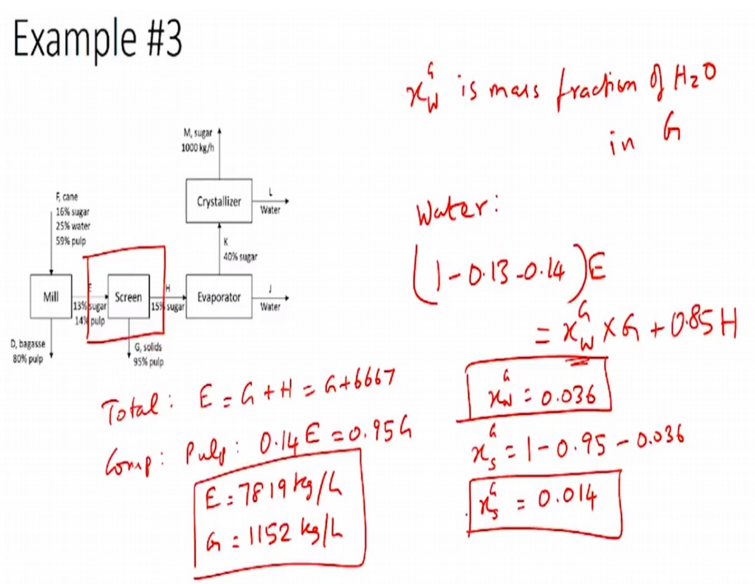


So now we have identified one system and solve the balances for K and L so similarly we can now choose the next system which would be the evaporator. So for this stream again we have the information about the stream K and the information about stream J and the information for also given. So we have the composition for all the three stream however the mass flow rate is known only for the stream K.

So this is exactly the same as what we did for crystallizer so as we did there you will start with total balance for the evaporated system as H = K + J and we know the value of K to be 2500 so this is H = 2500 + J so now we can write a component balance so here we can write a sugar balance so the sugar balance would be 0.15 times H = 0.4 times K. So this would mean 0.15 H = 1000 giving you a values of H as 6667 kilograms per hour.

So substituting back to the values to the total balance equation we can calculate J as 4167 kilograms per hour.

(Refer Slide Time: 14:46)



Now that we have calculate the streams L, K, J and H we can start with the system of stream to identify the mass flow rates of E and G. So for starting that let us first write the total balance equation. The total balance equation for this stream would be E = G + H and then we can write component balances here we would choose pulp as the component balances because we know the concentration of pulp in the input stream E and exit stream G.

So this makes is 0.14 times E = 0.95 times G as we already know the value for H we can substitute this equation as G + 6667 so now you have two equations and tow unknowns you can solve for E and G and you would end up with E = 7819 kilograms per hour and you will get G as 1152 kilograms per hour. Now that we have the mass flow rates we are not done because we need to know the composition of the solid stream G which is leaving the system.

Unlike the other streams which we looked at till now this particular stream as to the water and pulp together why do we say that you have 95% pulp which means the other 5% as the liquid component which is accompanying the solids. This liquid component will not only contain the water but also contain the dissolve component which is sugar. However we do not know the composition of water and sugar in this (()) (16:39).

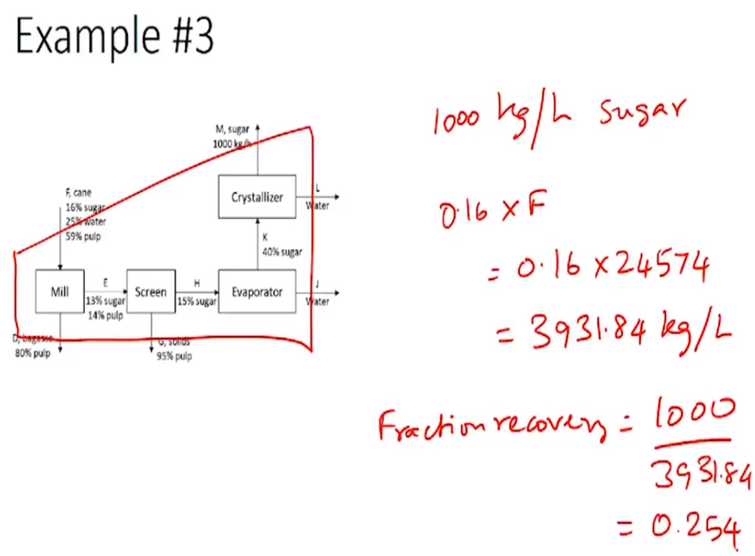
We know that those two add up to 5% so let us assume that the composition of water in this stream G is XWG is the mass fraction of water in stream G. So assuming that let us write the water balance equation so the water balance equation would be 1 – 0.13 – 0.14 times E how did I get this we know that the total mass fraction for any mixture would be 1 and in the mixture which is entering the screen which is E.

You have 0.13 or 13% sugar and you have 14% pulp which is 0.14 so the amount of water the mass fraction of water would be 1 – 0.13 – 0.14 times E which is your mass flow rate for the stream entering the stream. You have now have the exit streams so the exit stream would contain XWG times G where XWG is the mass fraction of water in the stream G and you also have the water which is leaving through the sugar stream which is or the H stream which is 0.85 times H.

Now that we have all these values the only terms which is unknown here is XWG so we can calculate the amount of water in the sorry the mass fraction of water in the stream G as XWG = 0.036. So how much of sugar is present in your solid stream so that would be given by the mass fraction X as G which is 1 – 0.95 which is the mass fraction of the pulp in the solid stream – 0.036 which is the mass fraction of water in the solid stream.

Giving you the mass fraction of sugar in solids stream as 0.014 so this gives you all the information about these two streams you have calculated the flow rates also the composition of these streams.

(Refer Slide Time: 19:15)



Now we need to perform similar calculation to identify the flow rate and the composition of the gas stream which is the stream D how we go about that we identify nil as the system and once we have identify the millers the system we need to understand that we have all the information about the system which is the cane stream which is the feed stream is entering into the mill we have all the information.

We have all the information about the stream extract stream E which is leaving the mil however we have only one information about the gas stream which is the percentage of pulp. The other 20% basically contains and the dissolve components which is sugar so just like how we solve for the previous problem here also we can make an assumption of the mass fraction of water in the stream to the XWD.

Let us first start with the total balances the total balance for this stream for the system mill would be F = D + E. We already know the value for E which is 7819 so F = D + 7819 now we can write component balances we will start with the pulp balance so the pulp balance would be 0.59 times F = 0.8 times D + 0.14 times 7819 which is E. Using these two equations we have two unknown F and D we can solve for that you will get F = 24574 kilogram per hour and you will get the as 16755 kilograms per hour.

We still need to calculate the composition of the stream which is basically the amount of sugar which is leaving through stream D for that we will use the assumed mass fraction of water and let us write a water balance for the system mill. So the water balance would be 0.25 times F = XWD times D + 1 – 0.13 – 0.14 times E.

So this gives you XWD times D + 0.73 times E now that we know the values of F, D and E we can calculate XWD as 0.026 which means the amount of sugar the mass fraction of sugar which is leaving through the stream D would be 1 – 0.8 – 0.026 giving you a value of 0.174. So this gives you the composition of stream D also. So stream D which is the gas stream contains 80% pulp and it contains 17.4% sugar and 2.6% water.

So with that we have calculated all the flow rates and composition of the streams in addition to calculating the mass flow rates of each of the stream and the composition of the stream we have also been asked to calculate the fraction of the sugar fed has actually recovered through the process.

We know that the total amount of sugar which is recovered is 1000 kilograms per hour so considering the overall system we know that sugar only enters through the cane and it leaves through multiple streams however we are consent only about the crystal sugar which has been recovered which means 1000 kilograms per hour of sugar has been recovered. The amount of sugar which is fed into the system through the stream F would be 0.16 times F which is 0.16 times 24574 this gives you a value of 3931.84 kilograms per hour.

So the total amount of sugar which is fed to the system is 3931.84 kilograms per hour out of which only 1000 kilogram has been recommend. So the fraction recovery would be given as 1000 divided by 3931.4 which gives you a value of 0.254 so about 25% of the sugar which has been fed into the system as actually been recovered so with this we come to the end of the example problems for multiple units processor without reactions.

What you could have learnt is when there are multiple units the system which is chosen for studying becomes the most important thing by choosing the right system the problem can be solved in simple step so we looked at three different example problems in the first one we choose the overall system to start with and in the second example problem we started with the first system in the process.

And in the third example problem we started with the last unit as a system by performing these three different types of calculation I have tried to show you how we can attack such a multi-unit processor. Hopefully this will give you enough experience to solve such problems I strongly recommend that you refer to the text book which you have been recommended and solve more problem so that we can intuitively choose the right system to study.

Choosing the system is very critical and that comes only through practice I strongly recommend you do more problems and gain experience in identifying the right system to start with thank you.