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

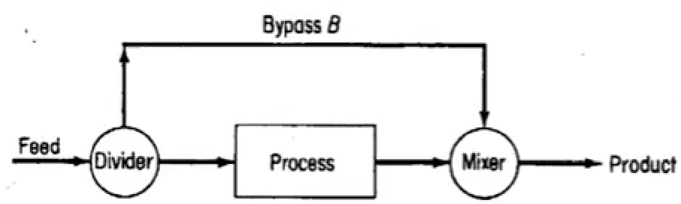
Module No # 06
Lecture No # 26
Bypass

Hello everybody, welcome to today's lecture on bypass so we have now looked at different processes in material balance system. We looked at recycle which is a critical aspect in bio process and chemical industry. Similar to that there is another process called bypass so the term is similar to what you would think of from a literary stand point bypasses is basically bypassing a process so that is what it is.

(Refer Slide Time: 00:47)

Bypass

- Skips one or more stages and goes directly to another downstream stage
- Used to control the composition of a final exit stream



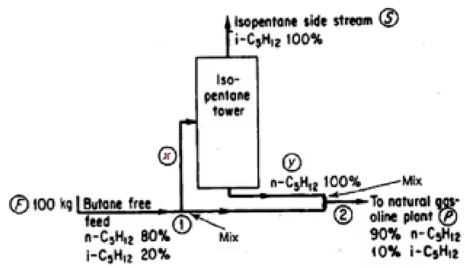
So bypass is when you have a stream which skips one or more stages in a process and goes directly to a process down the line. So this is called as bypass and this primarily used to control the composition of final exit stream. So if you look at the process shown here what you see is there is a divider it would either be a splitter or it could be some kind of separator which takes out one stream and passes it across the particular step and then mixes it to the output of the process so this type of a system is called as a bypass system.

So this again has a stream which is flowing without accumulating just like recycle you have a stream of components flowing in the bypass stream without accumulating during steady state process. So having taken that into account let us look at some example problems which gives us clarity on how to approach such problems where you have a process with bypass.

(Refer Slide Time: 01:48)

Example #1

- In the feedstock preparation section of a plant manufacturing natural gasoline, isopentane is removed from butane-free gasoline. The process and the components are shown here. What fraction of butane-free gasoline is passed through the isopentane tower?

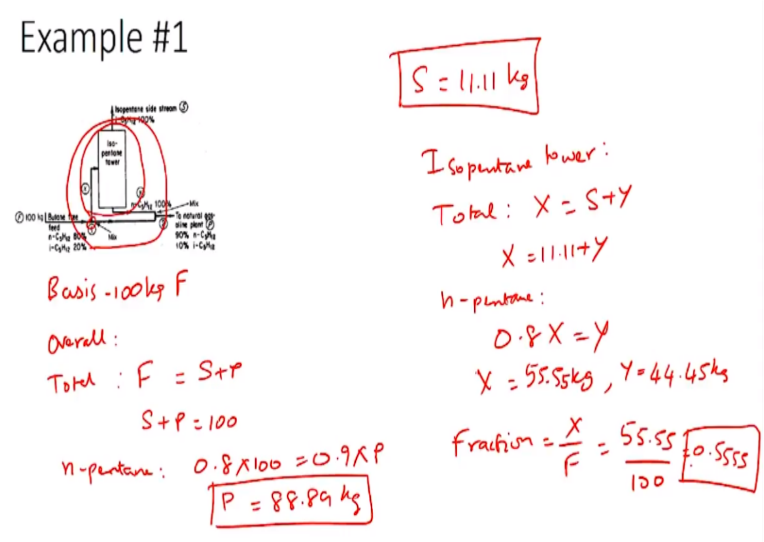


So here is an example problem in the feed stock preparation section of the a plant manufacturing natural gasoline isopentane is removed from butane free gasoline. The process and the components are shown here that fraction of butane free gasoline is passed through the isopentane tower. So what you have here is a feed of 100 kilograms of butane free feed and that enters into the isopentane tower.

Some this stream is actually taken account and it bypasses the isopentane tower and it is mixed with the bottom stream of the isopentane tower. So now taking this flow chart into account let us try to perform the material balance calculations to calculate the fraction of butane free gasoline which is passed through the isopentane tower. For this we need to know what fraction actually enters into the isopentane tower which is X and also we need to know how much skips the isopentane tower.

So let us perform the required calculation to get these values now what would be the system you want to choose for performing these calculations.

(Refer Slide Time: 03:02)



The first step for any material balance problem is to identify the basis in these problem 100 kilograms of butane free gasoline is being fed to the system which means the basis would be 100 kilograms of butane free feed. So we will use the basis as 100 kilograms of F so we can identify different system for performing material balance calculations.

To identify how much of the isopentane side stream which is yes and the natural gasoline which is being sent to the plant P are being produced we will consider the overall system. For the overall system we can write a total mass balance and the enpentane or isopentane balances let us write the total mass balances for the overall system. So the overall system will encompass the splitter and the mixing point and the isopentane tower.

So this would be the overall system that is being taken into account so for this overall system the total feed would be F and your outlets would be S and P you do not have any generation or consumption because it is a non-reactive process which we are having here and you also will not have a accumulation at steady state. So this means the equation become S + P = 100 kilograms we can also write an enpentane balance.

So the enpentane balance would be 0.8 times 100 is the input would be equal to 0.9 times P which is the output so from here we can calculate P as 88.89 kilograms and S would be calculated as 11.11 kilograms. Now we can choose a different system to calculate what fraction to calculate what fraction of this feed enters into the isopentane tower which would be the mass of X where we have to calculate the fraction.

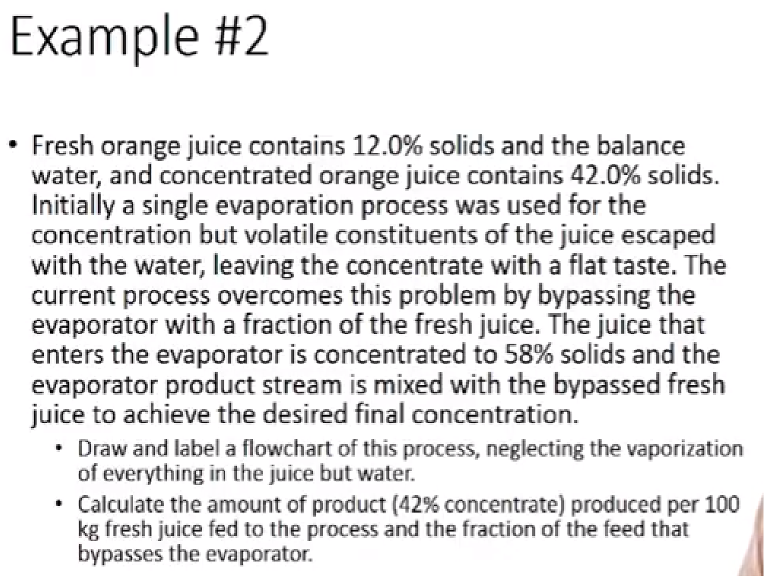
So for this you can use the isopentane tower has the system of interest when we choose the isopentane tower the total balance would become X = S + Y where you have X entering so this is the system we are considering. So we have X entering S is the side stream which is leaving and you also have Y which is the enpentane which is leaving the tower so this would be X = AS + Y and we already know S is 11.11 so this gives you S = 11.11 + Y.

So you can also write an enpentane balance the enpentane balance would be 0.8 times X would be equal to Y. Why did I choose Y times X what you have is the splitter this 0.1 is the splitter. So because you are splitting the stream which is coming in you will get the same concentration of isopentane and enpentane in both the stream.

So this means the concentration of enpentane in the butane free feed and the fraction entering the ispentane tower would be same thereby you have 0.8 as the fraction of enpentane present in this stream. So you have 0.8 X which is the input = to the output which is why the output is 100% enpentane giving you a mass value of Y. So using these two equations we can solve for X and Y so we can get X = 55.55 kilograms and Y would be equal to 44.45 kilograms.

So now we need to calculate the fraction which is being passed through the tower so the fraction would be X divided by F which is 55.55 divided by 100 giving you a value of 0.5555. So the fraction which is being passed through the stream would be 0.5555 okay with that we solved for the required parameters.

(Refer Slide Time: 07:34)



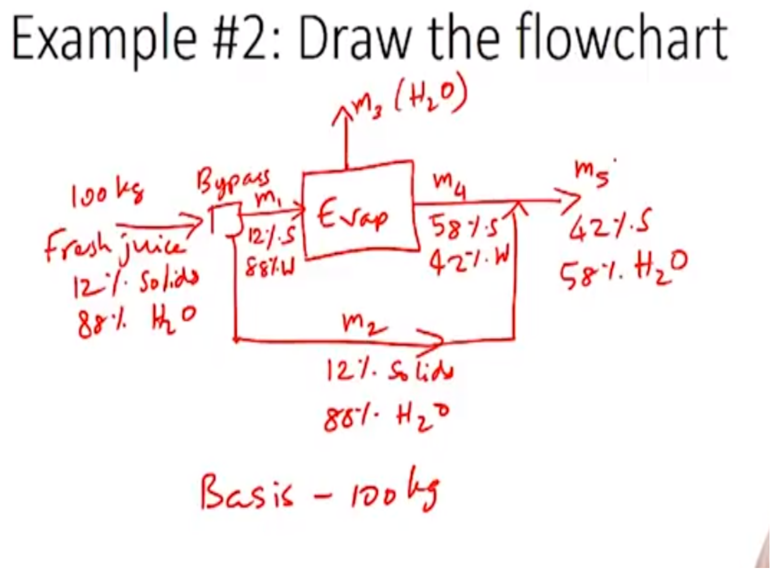
Let us move on to the next problem here is the second example problem fresh orange juice contains 12% solids and the rest is water. Concentrated orange juice contains 42% solids initially a single evaporation process was used for concentration but volatile constituents of the juice escaped with the water leaving the concentrate with the flat taste.

The current process overcome this problem by bypassing the evaporator with the fraction of fresh juice and the juice that enters evaporator is concentrated to 58% solids and the evaporated product streams is mixed with the bypass fresh juice to achieve the desired final concentration.

You are asked to draw and label the flow chart for the process neglecting the vaporization of everything in the juice except for water and you are also asked to calculate the amount of product which is produced per kilogram of fresh juice is fed to the process and the fraction of the feed as to be bypassed from the evaporator.

So now the first step for solving this problem would be to draw the flow chart as we have done earlier understanding all the processes which have been given and drawing the right flow chart with the proper labeling will make our calculations reasonably simple let us start with flow sheet for the problem.

(Refer Slide Time: 08:57)



The problem statement gives us that fresh juice containing 12% solids and rest as water is entering into the system. So let us start with that so the first flow would be your fresh juice so your fresh juice this fresh juice contains 12% solids and the rest 88% would be water so this is now separated probably by a splitter and some of it bypasses the evaporator while the rest enters into the evaporator and whatever is coming out bypassing the evaporated is mixed with the product from the evaporator to produce the final product.

So now this position would be the bypass so this is the splitter considering this to be splitter you would have 12% solid and 88% water in all these stream. This would also been 12% solids and 88% water so the evaporator would have 1 stream would have concentrated juice leaving and you would also have water is being evaporated. So let us assume that you have water leaving and only water leaving as given in the problem.

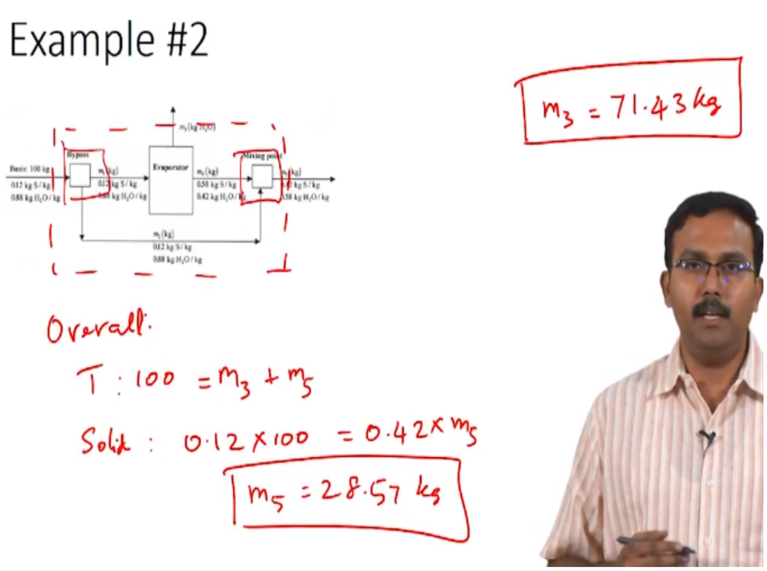
You also have the concentrated liquid which is leaving the evaporator it is been told that concentrated solution or concentrated juice leaving the evaporator would contain 58% solid and rest would be water so the let us call it 42% water and 58% solids. So this is being mixed so that you get the final product which is the desired concentration of the solids. So that would be 42% solids and the rest 58% would be water.

So now that we have all the compositions let us also label the masses for these flow charts so the problem states that we have to calculate the amount of product which is produced for 100 kilogram of fresh juice which is being fed. Hence we will be using the basis as 100 kilograms and we will used this stream entering as also 100 kilograms. So the basis used for this problem would be 100 kilograms.

Now that we have 100 kilograms entering some of it is bypassed and the rest goes into the evaporator let us call M1 kilograms as mass which is entering the evaporator and M2 kilograms as the mass which is being bypassed from the evaporator. So you have M3 kilograms of water which is leaving the system as the evaporated water vapor and you have M4 kilograms of concentrated juice which is leaving the evaporator.

So this concentrated juice M4 is mixed with M2 to produce M5 kilograms of your final product which is the 42% solids containing juice. Now this gives us the flow chart describing the entering process that has been given to us in the problem with this flow chart let us try to solve for the parameters that have been asked for.

(Refer Slide Time: 12:21)



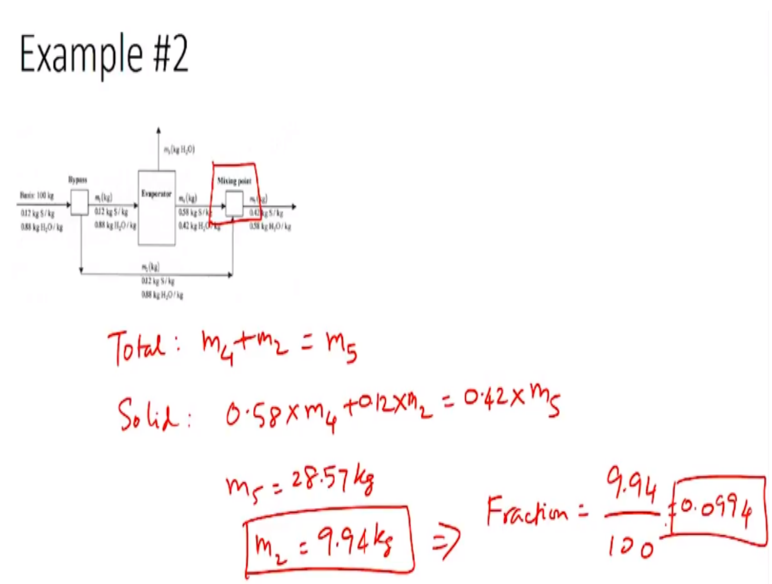
As I had already mentioned the basis is 100 kilograms and now this is important for us to identify which system we want to work with. So as always we will start with the overall system as always we will start with the overall so the overall system would encompass the bypass stream.

So the overall system would have total balances which can be written as 100 kilograms entering through the fresh juice would be equal to M3 + M5 where M3 is the water vapor that is being evaporated and M5 is the final product that has being produced. We also write the solids balance would be 0.12 times 100 kilograms which is the mass of solids entering through the fresh juice and you have solids leaving through the final product which would to 0.42 times M5.

So this gives you a value of M5 which is the final product as 28.57 kilograms so for every 100 kilograms of fresh juice which is being fed we can product 28.57 kilograms concentrated juice containing 42% solids. Now that we have this we can also calculate the mass of water which is being evaporated so the water vapor evaporated would be 100 – 28.57 giving you 71.43 kilograms 78.43 kilograms of water is being evaporated form the system.

So the next step is to calculate what fraction is being bypassed so we have two systems where the bypass stream will cross the system boundary one would be the splitter which is the bypass stream and other would be the mixing point amongst these two I have chosen to use the mixing point because that would give me more independent equations a splitter gives me 1 independent equation so to avoid any chance of higher degree of freedom I will use mixing point as the system of steady.

(Refer Slide Time: 14:40)



So for the mixing point let us try to write a balance equation for this mixing point. So the total mass balance for the mixing point would be M4 which is the mass enteing through the concentrated juice + M2 which is the bypass stream which is also entering the mixing point giving you a value of M5 which is the final product.

We can also write a solid balance the solid balance would be 0,58 which is the mass fraction of solids in M4 times M4 + 0.12 times M2 would be equal to 0.42 times M5. We already know that M5 is 28.57 kilograms so substituting the value for M5 we have two equations two unknowns we can solve for M4 and M2 we would get M2 as 9.94 kilograms. So this is the mass of bypass stream.

This implies the fraction which is bypassed would be 9.94 divided by 100 which is 0.9994 so the fraction of the stream would be bypassed would be 0.9994 kilograms per kilogram.

(Refer Slide Time: 16:14)

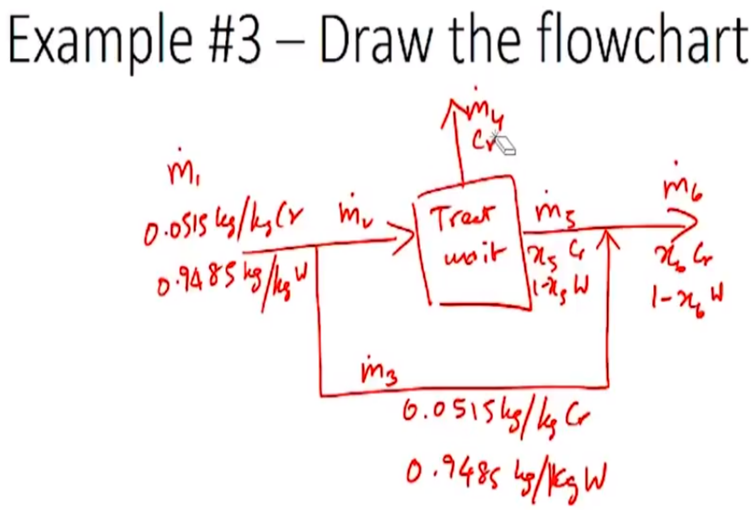
Example #3

- A stream containing 5.15% chromium is contained in the wastewater from a metal finishing plant. The wastewater stream is fed to a treatment unit that removes 95% of the chromium in the feed and recycles it to the plant. The residual liquid stream leaving the treatment unit is sent to a waste lagoon. The treatment unit has a maximum capacity of 4500 kg wastewater per hour. If wastewater leaves the finishing plant at a rate higher than the capacity of the treatment unit, the excess bypasses the unit and combines with the residual liquid leaving the unit and the combined stream goes to the waste lagoon. Draw and label the flowchart for the given system. If 6000 kg/h of wastewater leaves the plant, calculate the flow rate of liquid to the waste lagoon and the mass fraction of Cr in this liquid.

Here is the third example problem a stream containing 5.15% chromium is contained in the waste from a metal finishing plant. The waste water stream is fed to a treatment unit that removes 95% of chromium in the feed and recycle it to the plant. The residual liquid stream leaving the treatment unit is sent to a waste lagoon. The treatment unit has a maximum capacity of 4500 kilograms of waste water per hour.

If waste water leaves the finishing plant at higher than the capacity of the treatment unit the excess bypass is the unit and combines with the residual liquid leaving the unit and the combine stream goes to the waste lagoon. Draw and label the flow chart for the given system if 6000 kilograms per hour of waste water leaves the plant calculate the flow rate of liquid to the waste lagoon and the mass fraction of the chromium in the liquid.

(Refer Slide Time: 17:06)



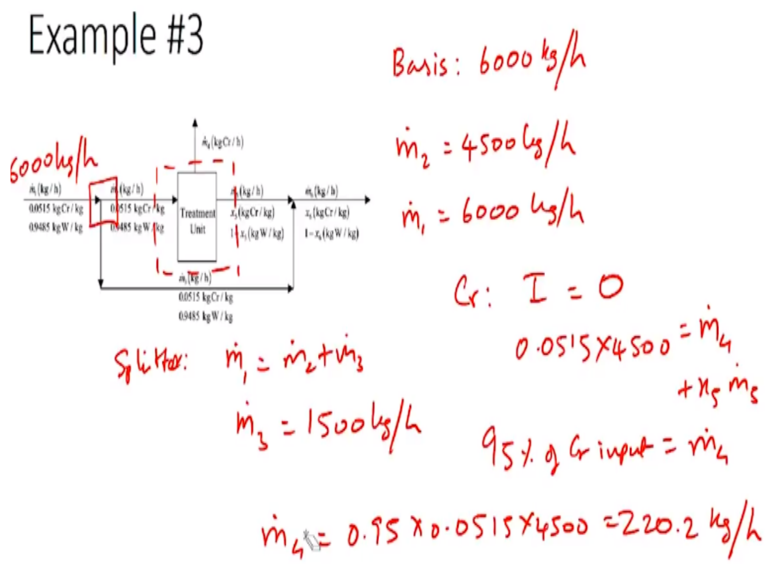
So what we have is a stream which contains 5.15% chromium is actually being sent to a treatment unit. So let us call this as treatment unit so from the treatment unit 95% of chromium is recovered and recycle back into the plant. The rest of the fluid is sent back to sent to the waste lagoon as waste treatment for as waste which is being discarded. So this treatment unit has been designed to handle only 4500 kilograms per hour of the liquid.

In case the flow rate of the liquid is greater than 4500 some of them is removed anything excess of 4500 is removed and it bypasses the treatment unit and it is mixed with the effluent which is sent to the waste lagoon and the combined fluid is sent to the waste lagoon. So this is the flow chart describing the process. So we have 5.15 chromium and rest would have to be water. So would be 0.9485 kilograms of water per kilogram.

So we will also write this in mass fraction so chromium would be 0.0515 kilograms per kilograms of chromium because this is splitter which is being used to bypass to create the bypass stream. The composition of the streams in which is entering the treatment unit and the bypass stream would be same. So this should also contain 0.0515 kilogram per kilogram of chromium and 0.9485 kilograms per kilogram of water.

So this stream would also have the same composition so let the flow rates be labeled as M1.M2.M3. which is the bypass stream M4 dot which is the stream which is being sent back to the plant you have M5 dot which is the stream leaving the treatment unit and the combined unit which is leaving would be the M6 dot so we do not know the mass fractions of chromium and water in these streams.

So we will call that as X5 chromium and 1 – X5 water X6 chromium and 1 -X6 water so the stream which is leaving that is being recycled back only chromium and we know that it is a 95% chromium which is entering the treatment unit that is being recycled.



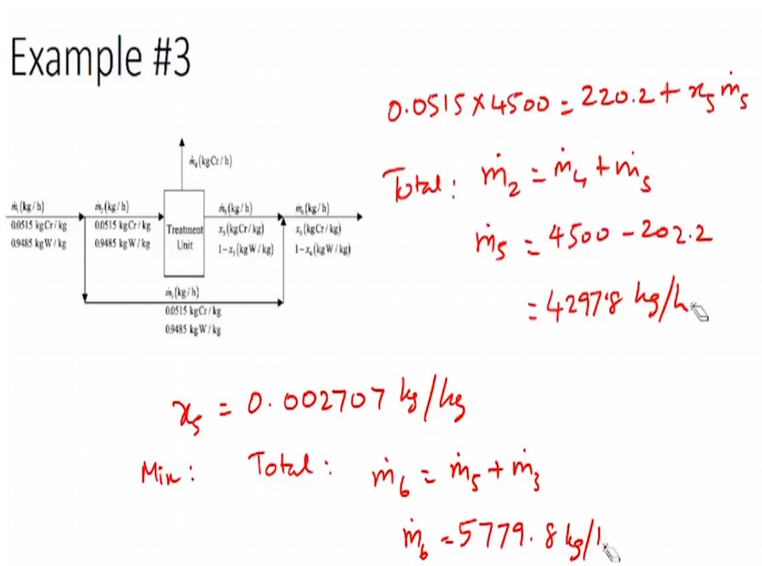
So here we have the flow chart and now we try to solve the material balances so that we can calculate the mass flow rates. So we have been told that the basis to be used for our calculations is 6000 kilograms per hours which is being fed. So this M1 dot would be 6000 kilograms per hour so this means only 4500 can actually enter into the treatment unit. So M2 has to be only 4500 so we know that M2 dot = 4500 kilograms per hour because that is what the treatment plant can handle.

So we know M1 dot is 6000 kilograms per hour so if you were to write material balance for the splitter you would have one total balance that you can write for the splitter so this balance would be M1 dot equals M2 dot + M3 dot. So using this you can get M3 dot as 1500 kilograms per hour so we now have M2 dot M1 dot and M3 dot. So we need to know how much is M4 dot and what would be M5 and M6 dot.

So for this we can write a balance equation for the middle balances for the treatment unit so if you were to write the material balance for treatment unit we can write a chromium balance. The chromium balance basically says that the amount of chromium input would be equal to the amount of chromium output because there is not reactions or no generation or consumption and at steady state there would not be any accumulation.

So you get input equals output so that input term would be 0.0515 times 4500 so which is what would have to leave through M4 and M5 so this would be M4 dot + X5 M5 dot so we do not know M4 or X4 M5 however we have been told that 95% of chromium input is actually leaving as M4 dot. So we can calculate M4 dot as 0.95 times 0.0515 times 4500 so M4 dot = 0.95 times 0.0515 times 4500 which is equal to 220.2 kilograms per hour. So that would be the mass flow rate of chromium leaving through the stream M4.

(Refer Slide Time: 22:36)

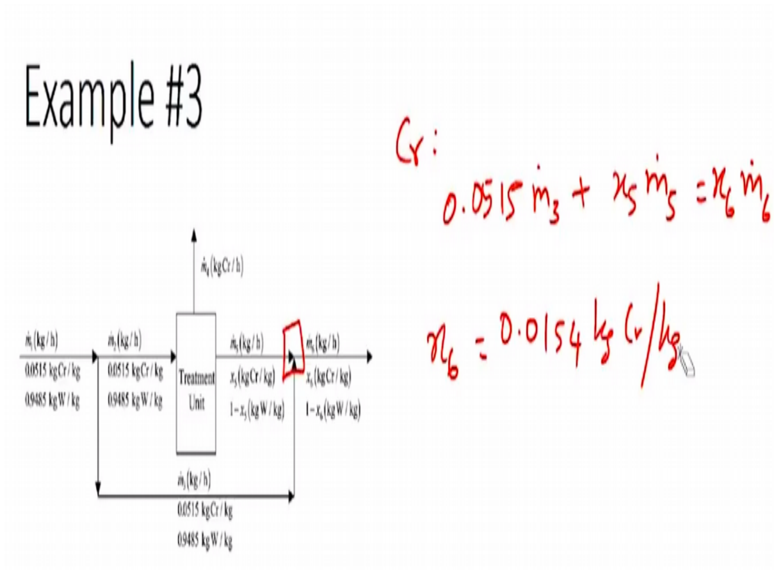


So writing the total balance for treatment we would basically have substituting this M4 dot into the chromium balance we would have 0.0515 times 4500 = 220.2 + X5 M5 dot. So we can also write the total balance for the treatment unit which would be M2 dot = M4 dot + M5 dot so we already know M2 and M4 so we can calculate M5 as 4500 – 202.2 giving you a value of 4297.8 kilogram per hour.

So substituting the value for M5 dot in the chromium balance equation we end up with X5 which is mass fraction of chromium in the stream 5 which is leaving the treatment unit as 0.002707 kilograms per kilogram. So now we have the information about M5 dot and we also have the composition of the stream which is mass fraction of chromium. So we can calculate the mass fraction of water which is just be 1 – mass fraction of the chromium.

Now we need to identify the mass fraction of the chromium and the flow rate of the components in the stream 6 for this we can choose the mixing point as the system and we can write the mixing point balances the total balance for the mixing point would be M6 dot equals M5 dot + M3 dot we already know that M5 dot is 4279.8 an dM3 dot is 1500 kilograms per hour. Using this we can calculate M6 dot as 5779.8 kilograms per hour.

(Refer Slide Time: 24:39)



For the mixing point we can also write the chromium balance the chromium balance for the mixing point would be 0.0515 times M3 dot + X5 times M5 dot = X6 times M6 dot. We already know M3 dot M5 dot M6 dot and also X5 so substituting the values we would get X6 which would be 0.0154 kilograms of chromium per kilogram. So with that we have come to the conclusion of example problems related to systems with bypass.

In the next lecture we will look at performing calculations for a similar system which is called as a purge system thank you and good bye.