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

Module No # 05
Lecture No # 25
Recycle: Tutorials

Hello everybody welcome to today's tutorials on recycle based problems we have looked at recycle for systems with reaction and without reaction. We have performed some example problems which are simple. So today we will solve two problems for tutorials so that we can learn how to approach these recycle problems in a step by step fashion.

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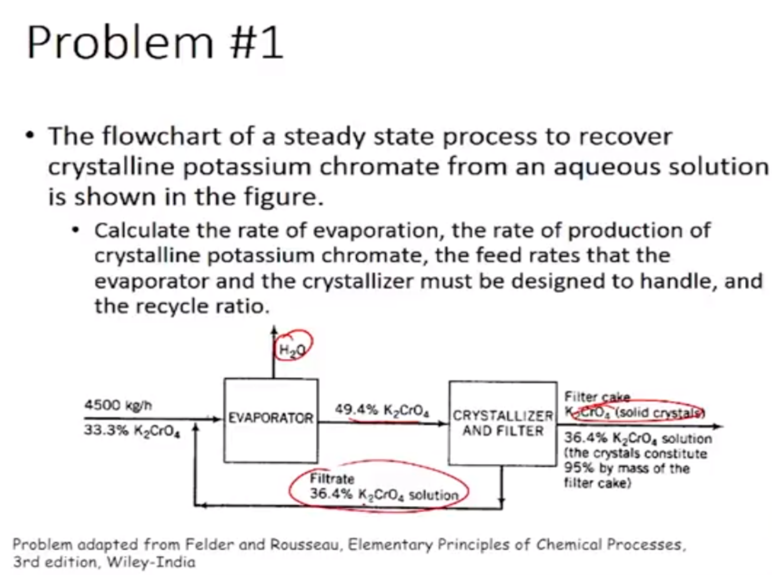

Let us look at the first problem the flow chart of a steady state process to recover crystalline potassium chromate from an aqueous solution is shown in the figure. You are asked to calculate the rate of evaporation, the rate of production crystalline potassium chromate the feed rate that the evaporator and crystallizer must be designed to handle and the recycle ratio. So have a look at this flow chart what you see here is 4500 kilograms per hour of 33.3% potassium chromate solution entering as fresh feed.

So these gets mixed with the recycle stream which is the filtrate and it forms a gross feed or the total feed so this would be the feed rate to which the evaporator must be designed to handle. So we need to calculate this particular stream and we also need to calculate this stream which is the feed rate to the crystallizer and filter which is the what the crystallizer needs to be designed for.

So in addition to these things we also need to calculate the rate of evaporation and the rate of production of crystalline potassium chromate which would be these and with all these we also need to calculate the recycle ratio which means we need to know how much of the filtrate is actually coming back to the recycle. And we will have to calculate the recycle ratio as recycle divided by fresh feed.

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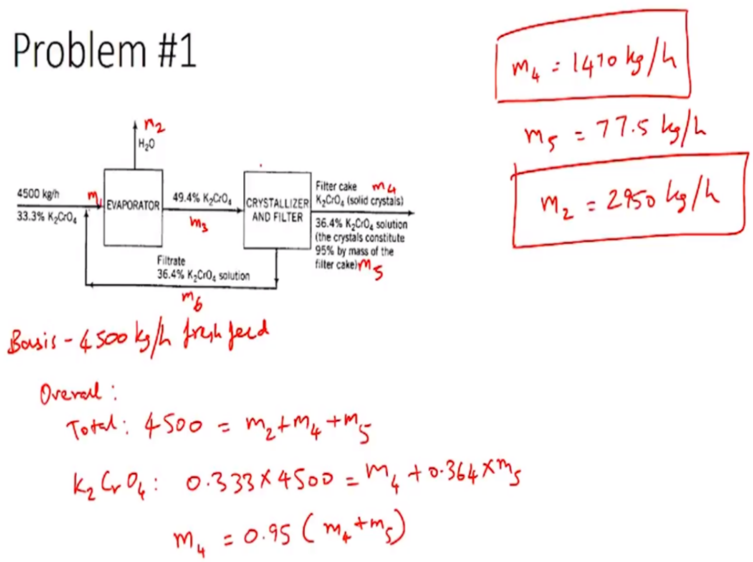

So let us start performing the calculation required so just like any material balance problem the basis would be taken from the information given. So you have 4500 kilograms per hours of fresh feed entering so the basis would be 4500 kilograms per hour basis of fresh feed. Now let us label the terms which we need to calculate.

So the let us call the total feed entering the evaporation as M1 and rate of evaporation as M2 and feed rate to the crystallizer is M3 and amongst the product leaving we will call the solid crystals mass of solid crystals is M4 and the liquid which accompanying the filter cake as M5 and your recycle stream as M6. Now that we have label these streams let us look at which system to choose and what balances we can perform.

So for most system we always start with overall balance so we will take the overall system and start writing the balances for the overall system. So the overall system is taken and we can write the total mass balance and mass balance for potassium chromate. So the total mass balance would be 4500 kilograms which is entering would be equal to M2 + M4 + M5.

So M2 is the water which is leaving in the form of water vapor M4 is the potassium chromate crystals leaving the crystallizer and filter and M5 is the mass of potassium chromate solution which is accompanying the filter cake. We can also write the balance equation for potassium chromate K2CRO4 balance would be you have 0.333 times 4500 entering and you have potassium chromate leaving in the form of M4 + 0.364 times M5.

So we now have two different equations it is also been given that 95% of the mass of filter cake is constituted by the crystals the problem statement gives you that. This means you have M4 = 0.95 times M4 + M5 using these two equations we can calculate the values for M4 and M5. So M4 would be 1470 kilograms per hour. So this is the rate of production of potassium chromate crystals and from here we can also calculate M5 which would be 77.5 kilograms per hour.

So this is the amount of liquid accompanying the filter cake. So using the total mass balance which we had we can calculate M2 which is the mass of water vapor which is leaving the evaporated which is also the rate of evaporation that value would be 4500 – 1470 – 77.5 giving you roughly a value of 2950 kilograms per hour. So the next thing we need to calculate is the recycle stream and the feed rate for the crystallizer.

For doing this we need to choose appropriate systems we would not be able to get these values using the overall systems. So what system do we consider? So we can for performing these calculation we could either choose the mixing point + the evaporator or the crystallizer and filter as the systems in this case I have used the crystallizer and filter as the system.

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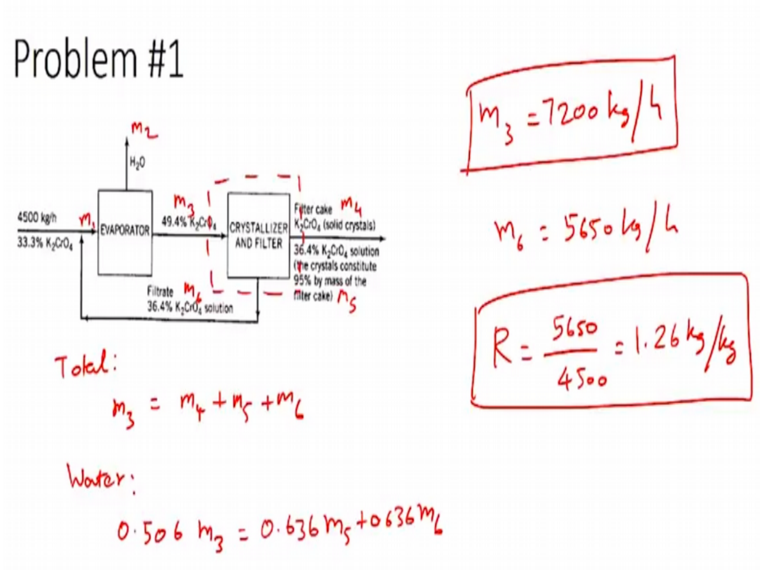

Considering the crystallizer and filter as the system I can write the total mass balance as follows you have M3 entering and you have M4 + M5 + M6 leaving the system. You can also write the water balance for crystallizer so that water balance would be 0.506 times M3 = 0.636 times M5 + 0.636 times M6. So we already know the value for M4 and M5 so using the values we have we can calculate M3 and M6.

So from that we get M3 which is the feed rate to the crystallizer as M3 would be 7200 kilograms per hour and the calculation will give you an M6 values as 5650 kilograms per hour. So this is the rate of recycle. Now that we have the rate of recycle and you already know the fresh feed we can calculate the recycle ratio R as 5650 / 4500 which is the fresh feed giving you a value of roughly 1.26 kilograms per kilogram.

So with this we have calculated all the parameters which have been asked for in the problem. As you saw the most important thing about performing these calculations was that we had to identify the right system so the simple logic we go with this is I use to overall system for the first step and then identify smaller systems for the next step. So this where it is efficiently for the problem statement which we had simply because we had all the information about the composition of streams which are leaving the overall system or entering the overall system.

So for if we have the information about composition of some streams which is crossing the system boundary then we can actually use that system to perform this calculations. So drawing the system boundary in a way that we have the streams crossing the system boundary and have the information for these streams will help us in solving these problems in an easier way.

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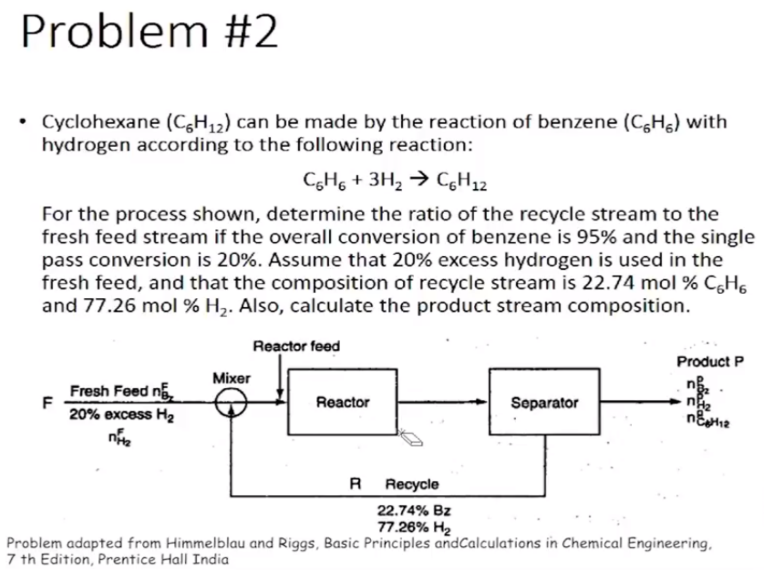

In the previous tutorial problem we looked at a system with reason but without reaction we will solve one problem with reactions and recycle. So this problem as both the reactions and recycle have a look at the problem statement. Cyclohexane can be made by the reaction of benzene with hydrogen according to the following reaction benzene + hydrogen for cyclohexane.

From the process shown determine the ratio of recycle stream to the fresh feed stream if the overall conversion of benzene is 95% and the single pass conversion is 20%. Assume that 20% excess nitrogen is used in the fresh feed and that the composition of the recycle stream is 22.74 moles % benzene and 77.26 mole % hydrogen. Also calculate the product stream composition so in this problem we have been given the overall conversion and the single pass conversion.

Do you remember what these are? Overall conversion is the conversion which is obtained when we account for the overall system. So the system we choose for this would be the overall system and the amount of reactants which is consumed within the system divided by the amount of reactant supplied to the system would be the overall conversion.

If you were to calculate the single pass conversion we would account for only the reactor where the reactants are passing through the reactor only a single time there by we have a single pass conversion or an once through conversion which is also been given here. So for this problem we have told that the single pass conversion is 20% and the overall conversion is 95% using these values let us try to solve this problem.

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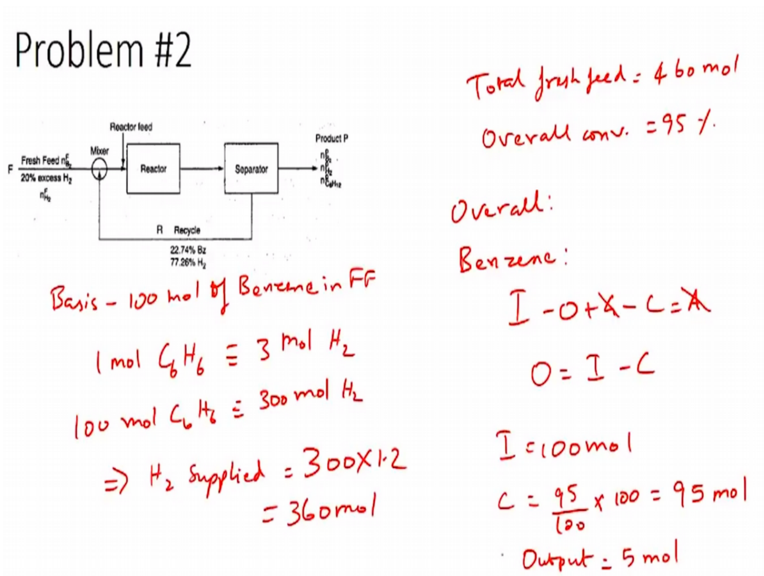

The first step for solving any material balance problem would be identifying the appropriate basis. In this problem there are no flow rates given this means we can choose any basis. Here I have chosen 100 moles of benzene in the fresh feed why I have chosen this? In the problem it also been given 20% excess hydrogen is fed along with the fresh feed this means if I use 100 moles of benzene as the basis I can calculate the number of moles of hydrogen using this 100 moles as the basis.

So this will give me cleaner numbers if I were to use 100 moles of fresh feed then I will end up with more combustion number which can make calculations a little more tedious. For this reason I will be using 100 moles of benzene in the fresh feed as a basis for this problem. So let us start solving the problem basis is 100 moles of benzene in fresh feed looking at stoichiometric we know that 1 mole of benzene requires 3 moles of hydrogen.

So 100 moles of benzene would require 30 moles of hydrogen we have been told that hydrogen is supplied at 20 % excess. This means hydrogen supplied would be equal to 300 times 1.2 giving you 360 moles. So the total fresh feed we have would be 460 moles the overall conversion has been given as 90%. So overall conversion = 95% sorry not 90% 95% so now for the overall system we can write species balances using the moles that we have.

So if where to take the overall system we can write a benzene balance so it would be input – output + generation – consumption = accumulation at steady state there is no accumulation benzene is not generated because it is a reactant however you have input, output and consumption. So your output would be equal to input – consumption we have already used the basis for input as 100 moles of benzene and we now need to calculate the consumption.

We have told that 95% of the benzene entering is converted by the overall which means consumption would be 95% of whatever is entering which is 100 giving you 95 moles is being consumed. Thereby your output would be 5 moles of benzene so your value for NPBZ here would be 5 moles. Now that we have the information about the benzene we can write balances for hydrogen to calculate the amount of hydrogen in the product.

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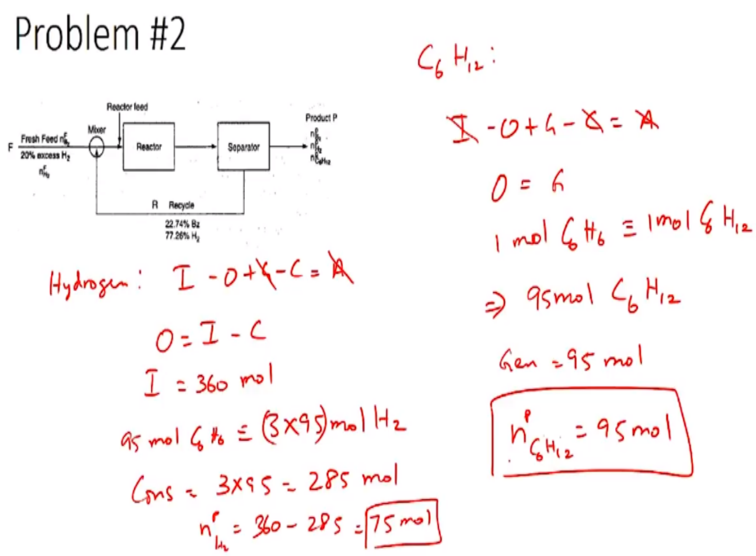

So let us write the balance for hydrogen again hydrogen balance would be hydrogen – output + generation – consumption = Accumulation. No accumulation at steady state now accumulation no generation for reactants so your output is basically input consumption we know that input is 360 moles. We know that 95% moles of benzene is consumed using stoichiometric 95 moles of benzene consumed here would have been 3 times 95 moles of hydrogen which has consumed.

So consumption for hydrogen would be three times 95 which is 285 moles so from this we can calculate the output which would be N hydrogen in the product as 360 – 285 giving you a value of 75 moles. Similarly we can write a balance for cyclohexane to calculate the amount of cyclohexane in the product so your cyclohexane balance is H12 balance would be input – output + generation – consumption = accumulation at steady state there would not be accumulation as this is a product there is no consumption of cyclohexane.

So you do not have any cyclohexane entering so you have input is also equal to 0 so which means you output is basically = generation. Using this stoichiometric we know that every mole of benzene consumed there is one mole of cyclohexane produced so this implies 95 moles of cyclohexane would have been produced for 95 moles of benzene which was consumed. Therefore generation would be equal to 95 moles.

So the output in the product which is NC6 the output in the product so the amount of cyclohexane in the product which is NPC6H12 would be equal to 95 moles. Now that we have all the information about the components in the product stream we can calculate the molar composition of each of these and these fractions can be calculated the I would leave that out as an excise per unit.

The other important information which has been asked in the problem is to calculate the recycle ratio. Now for identifying the recycle ratio we need to choose the system where the recycle stream process the system boundary. So what would be an appropriate system where we can choose form the problem we have information about the single pass conversion and based on the calculation we have done we have information about the product stream.

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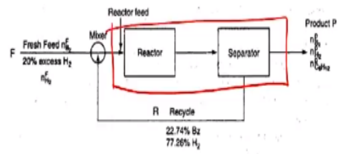
Problem #2



Benzene: $I - O + \cancel{G} - C = \cancel{A}$

$$(100 + 0.2274R) - (5 + 0.2274R) - 0.2\,(100 + 0.2274R) = 0$$

$$R = 1649 \text{ mol}$$

$$\text{Recycle ratio} = \frac{R}{F} = \frac{1649}{460} = \boxed{3.58}$$

Hence choosing your reactor and separator as a system would help you use the single pass conversion and also use the values we have calculated for products to finally calculate the recycle stream. Let us try to write the balance equation for this particular system if you were to write a benzene balance for the system the benzene balance would be input – output + generation – consumption = accumulation.

At stead state there is no accumulation benzene is being consumed not generated you have benzene leaving and entering the system. So your equation is this now you have benzene entering in the form of the total feed. So the total feed basically is 100 moles of benzene in the fresh feed + 0.2274 times R which is the number of moles in the benzene in the recycle stream this together forms the benzene in the gross feed.

And this minus the amount of benzene leaving the system would be the benzene which is unreacted leaving through the product which is 5 moles + 0.2274 times R which is the benzene leaving the system through the recycle stream and the amount of benzene consumed based on the single pass conversion. Single pass conversion has been given as 20% so 20% of the benzene entering to the system would have been converted.

So using that we can calculate the consumption as 0.2 times the amount of benzene entering which is 100 + 0.2274R. So this is = 0 so using this equation we can calculate the value for R as 1649 moles now that we have the number of moles of the recycle stream and we already know that number of moles of the fresh feed we can calculate the recycle ratio as recycle ratio would be equal to R / F which is 1649 / 460 giving you a value of 4.58.

So with this we have calculated the product stream composition the component in the product stream and also the recycle ratio with this we come to the end of this problem and to the end of this tutorial session. I hope you were able to understand whatever we have discussed here and you would be able to perform this calculations with ease.

We will perform more calculation and more example problems for material balances to make sure that we have a full understanding of whatever we discussed till now. In the next lecture we will talk about bypass and purge these are two new concepts which are crucial with respect to recycle. So we will look at these systems and see how material balances can be performed for these systems thank you.