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

Module No # 05
Lecture No # 24
Recycle with Reactions

Hello everybody welcome to today's lecture on recycle system with reactions in the previous lecture we had discussed recycle systems without reaction. And today we will talk about a reactor in addition to the fresh feed we will also have a recycle feed why do we have to do this?

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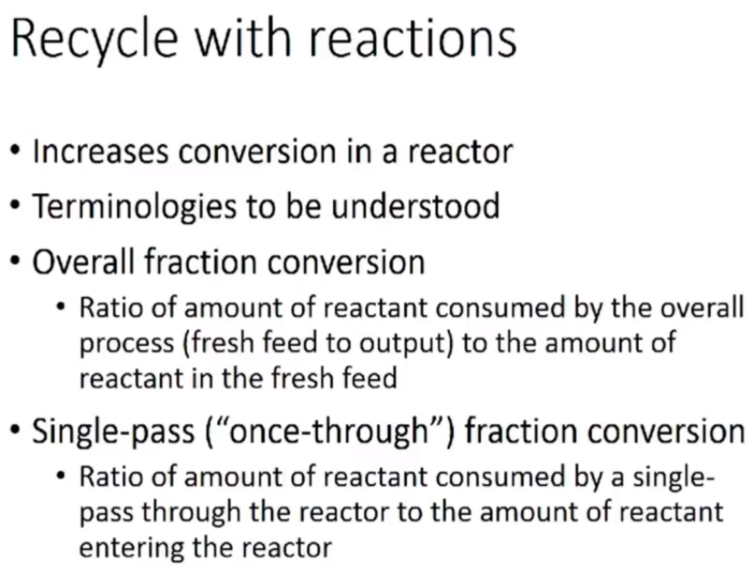

This would increase the conversion in the reactor the unused reactants which get recycle will have a chance to go through the reactor one more time which would mean more of the products would be formed and hence the conversion would increase for the overall process. We need to know how the terminologies are defined for such recycle systems with reaction so that we can apply them.

The principle for material balance itself would be similar to what we have done for recycle without reaction however when we talk about recycle with reactions there are certain terminologies which we should be familiar with. Overall fraction conversion is the ratio of the amount of reactant consumed by the overall process we should be the fresh feed to the output to the amount of reactant in the fresh feed.

So here you are considering the overall process as a single system and calculating the conversion you can also be given something called given pass or one through conversion so this would be ratio of the amount of reactant consumed by a single pass through the reactor to the amount of reactor entering through the reactor. So here you are taking the reactor as system and you are not considering the other components in the system.

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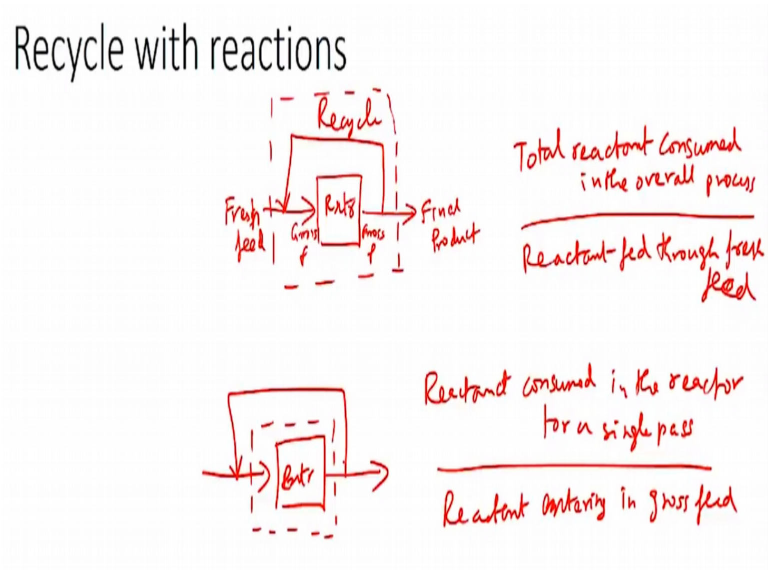

Let me explain this with simple (()) (02:02) feeds which would help you understand the process better. For system with the recycle this would be a simplest system so here what you have is a fresh feed which gets mixed with the recycle feed to enter as the gross feed you have the gross product out of which some aspect is taken out as the recycle feed and the rest is sent out as the final product.

So what you have here is the fresh feed and this would be the gross feed and again this would be the gross product and this is the final product and this clean is the recycle. So this is the standard flow sheet for any process with recycle so in this case we are assuming a reaction to happen which means this would be a reactor. So when we were taking about the overall fraction conversion we would assume entire process as 1 single system.

So this is the overall system for the overall system what we have is fresh feed which contains reactants entering and you have the final product which is leaving. So all the reaction which is consumed within this process is taken in the numerator and the reaction which is fed through the fresh feed is taken in the denominator to calculate the overall fraction conversion. So this would be total reactants consumed in the overall process divided by reactant fed through fresh feed.

So this is the overall fraction conversion the other conversion which we looked at what was single pass or one slow conversion let us again draw the similar reaction in similar process where you have the reactor and a fresh feed and a recycle feed fixing to form the gross feed. For the single pass or once through conversion we are accounting for reactant which are passing through the reactor only once which means the system chosen for studying would be the reactor alone.

So here what you have is the reactant entering through the gross feed is pass through the reactor only once and leave as the gross product. So the reactants which are entering into the reactor get converted or consumed to form the products so here your single pass conversion then becomes reactant consumed in the reactor for a single pass divided by reactant entering in the gross feed.

So now what you have here is the single pass conversion so you can clearly see that the reactant which is entering this reactor which is the reactor which is system we have chosen passes through the reactor only once. So whatever conversion happens is because of single pass through the reactor.

So that is why is called as the single pass conversion if you have clear understanding of these terminologies we can go ahead and perform material balance calculation for system with recycle and reactions.

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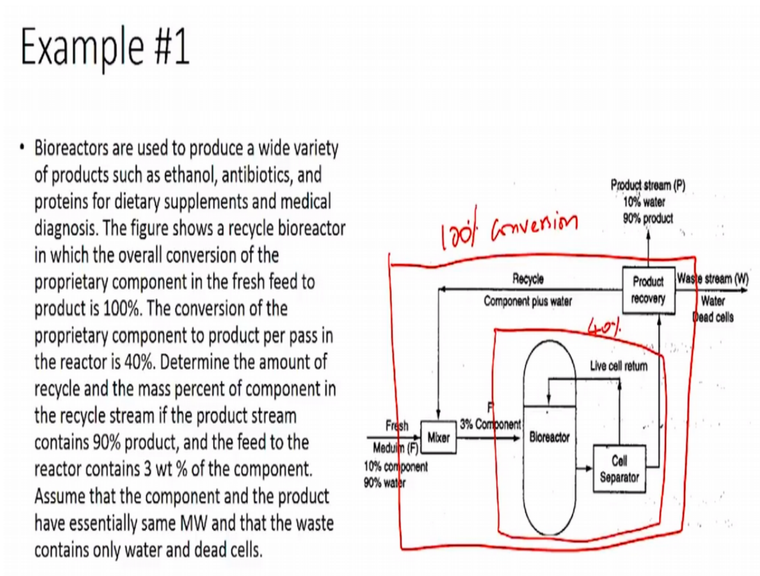

Let us look at a few example problems which will help us fully understand such problem here is the problem statement bioreactors are used to produce a wide variety of products such as ethanol antibiotics and proteins for dietary supplements and medical diagnosis the figure shows the a recycle reactor in which the overall conversion of a proprietary component in the fresh feed to product is 100%.

The conversion of the proprietary component of the product per pass in the reactor is 40% so the problem statement tells us that there is a proprietary component which is entering into the system which is the reactor and it is getting converted to form some product. We have been told that the overall conversion which is for the overall system would be 100% and we have also been given that single pass conversion is 40%.

You have been asked to determine the amount of recycle and mass percent of component in recycle stream if the product stream contains 90% product and the feed to the reactor contains 3% of the component assume that the product have essentially the same molecular weight and the waste contains only water and dead cells. So here is the flow sheet for this process so let us try to convert whatever information we have into this flow sheet.

We have been given that the overall conversion for the system is 100% conversion so this system which we have chosen which includes all the component as the overall system as a conversion of

100% of the proprietary component. We have also been told that there is 40% conversion for the proprietary component which passes through the reactor as single time.

So which means this particular system which we choose where the component actually passes through the reactor only once is called as the single pass conversion and here the conversion is 40% only. So we have these two information in addition we have been told that the product stream contains 90% product and you have 10% component which is entering into the system so you also have 3% component in the feed which is entering the bio reactor which is the gross feed.

All this information has been represented in this flow sheet now let us try to perform the required material balance calculations to calculate the required answers.

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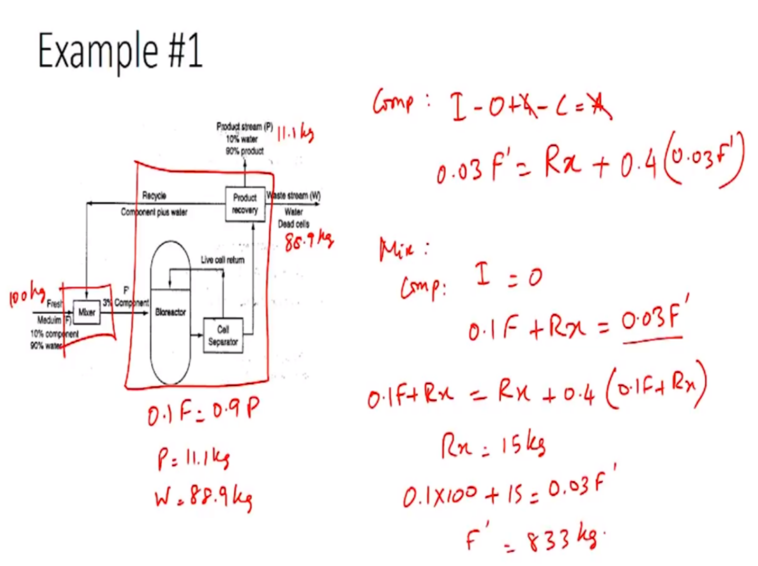

As with any material balance problem we first need to identify a basis for this problem. The problem system has not given any mass or flow rates hence we can assume a basis I have assumed a basis of 100 kilograms of fresh feed. So we have also been told that the molecular weight of the proprietary component and the product can be considered to be equal. This means the reaction would basically be proprietary components C gets converted to product P.

So this can be stoichiometry that can be assume indicating that one mole of proprietary component produces one mole of product. This assumption is valid because we know the molecular weights of these two component are the same. So now let us consider overall system and start writing the overall equation. For the overall system the total balance equation would be input = output because we are assuming the steady state which means accumulation goes to 0 so you have F = P + W.

We have assumed F to be 100 kilograms so implies P + W = 100 kilograms we can also write component balance for the overall system if we start with input – output + generation – consumption = accumulation. Accumulation goes to 0 because there is no the system at steady state and for this system we have chosen there is no component which is leaving the system everything is getting converted to the product obviously component is not getting generated because it is the reactants.

So you are left with input = consumption so we know that the 0.1 is 0.1F we now need to know what is the consumption is? So what would be the consumption ? We have assumed that the stoichiometric is 1 mole of component produces 1 mole of product. So the amount of product which has been formed is 0.9 times the product based on the stoichiometry we have assumed we know that 1 mole of proprietary component gets converted to one mole of product.

So we know that product formed = 0.9 times P so this should also be equal to the component consumed so therefore consumption terms would be equal to 0.9P. Substituting the value for consumption in the component balance equation we would get 0.1F = 0.9P as F is 100 kilograms based on the basis we can calculate the P as 11.1 kilograms. Substituting this value for P in the total balance we would get W2 be 88.9 kilograms.

So we have calculated the product stream as 11.1 kilograms and waste stream 88.9 kilograms for a fresh feed of 100 kilograms. Now that we have calculated this we now need to identify what information is required form the problem. The other thing which we need to calculate is information about the recycle stream. As we need to calculate the flow rate for the recycle stream and the composition of the recycle stream it is important for us to identify an appropriate system.

So this system would have to allow recycle to cross the system boundary so for that we could either choose the mixture or this system which includes the bio reactor and product recovery we would not want to choose any other system because information about come of the stream which is engulfed in this system would not be available for us readily.

If we were to choose the bio reactor + the product recovery unit as the system our component balance can be written as you have component coming in from the gross feed which would be 0.03 times F prime this would be so the component balance for this system chosen which is the reactant and the product recovery would be input – output + generation – consumption = accumulation.

Accumulation goes to 0 because it is steady state so you are talking about a reactant which means the generating terms would also goes to 0 you would have input, output and consumption terms. The input term would be 0.3 times F prime which is the proprietary component entering through the gross feed we know that 3% of the gross so using that we can identify the input equals output which would be component present in the recycle stream.

Let us call that R times stream where R is the mass of recycle stream where X is the mass fraction of component in the recycle stream + consumption which would be the single pass consumption of which can be calculated based on + consumptions which can be calculated using the single pass conversion given to us. So the single pass conversion can be given as 0.4 this times the feed which is entering the reactor which would be 0.03 F prime.

So this is the balance equation for the component for the system chosen if we write the balance equation for the component for the mixing point so the mixing point as the system the component balance would be the input = output because there is not generation terms or consumption terms here for non-reactive process and accumulation goes to 0 as it steady state.

So this equation can be simplified as input is 0.1 times F + RX which are the input for the components for coming through the fresh feed through the recycle stream = output which is 0.03 F prime. Now if we were to substitute the value of 0.03 F prime as 0.1 times F + RX into the first equation we have we would get the equation as 0.1 F + RX = RX + 0.4 times 0.1F + RX. As we already know the value for F to be 100 kilograms we can calculate RX from this equation as 15 kilograms.

Now substituting the value for RX here we would be able to calculate what F prime is so this equation becomes 0.1 times 100 + RX which is 15 = 0.03 times F prime giving us the value for F prime as 833 kilograms.

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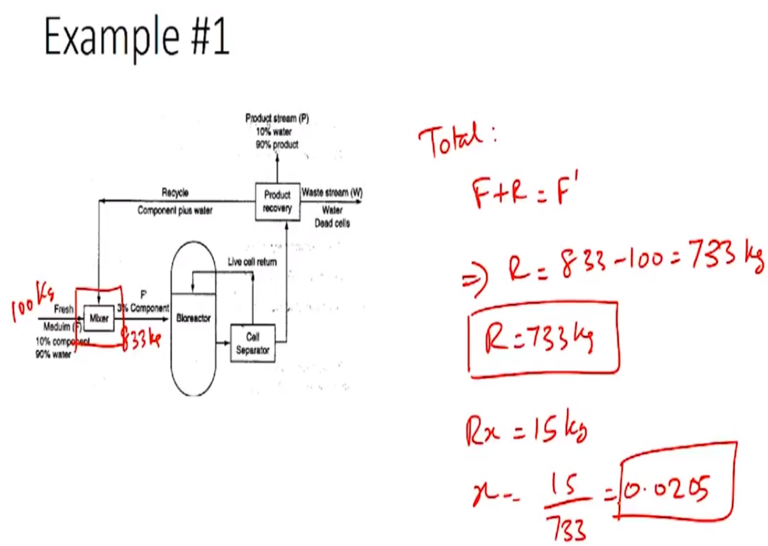

Now that we have the information about fresh feed from the basis as 100 kilograms and the gross feed from the calculations as 833 kilograms we can write the total mass balance for the mixing point to find the information about recycle stream the total mass balance for the mixing point would be F + R = F prime this implies R = 833 – 100 giving a value of 133 kilograms.

Now that we know that recycle stream is 733 kilograms we can calculate the composition of the component in the recycle stream form he value of RX we know RX is 15 kilograms so X = 15 / 733 which is 0.0205 so this is the mass fraction of the proprietary component in the reaction stream with this we have calculated all the required values in the problem let us move on to another example problem which uses similar concepts and which will give us further clarity on performing energy material balance calculations for system with recycle.

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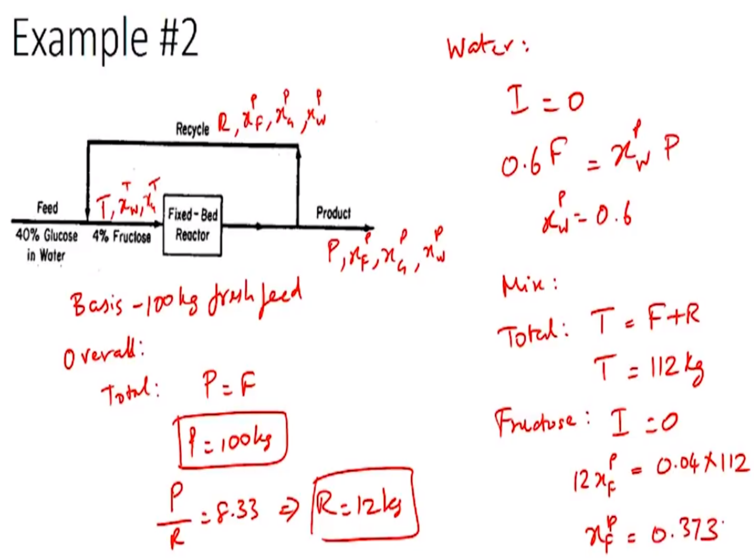

Here is the second example immobilized glucose isomers is used as the catalyst in producing form glucose in a fixed bed reactor. For the system shown what percent conversion of glucose results on one pass through the reactor when the ratio of the exit stream to the recycle stream in mass unit is equal to 8.33. So you have been given information about the fresh feed the gross feed and you have been given the information amount the ration of exit stream to the recycle stream.

With that we need to calculate the percentage conversion for a single pass through the reactor let us see how we about this problem as with any metrical balance problem the first step is to identify the basis for the problem. Here no masses or mass flow rates have been given so we can assume the basis which is convenient for our use. So here i have assume 100 kilograms of fresh feed as the basis.

So basis is 100 kilograms of fresh feed if were to consider the overall system the total balance for the system would be P = F as we know F is 100 kilograms P would also be equal to 100 kilograms the problem statement tells us that P / R = 8.33 this implies R = 12 kilograms. So we now have information about product stream and the recycle stream in addition to writing the total balance equation we also write component balance equation.

For writing component balance equation for the overall system we need to understand what reaction is taking place we have been told that glucose in being converted to fructuous using and immobilize using isomeric. Glucose is $C_6H_{12}O_6$ and fructose is $C_6H_{12}O_6$ is just isomerization reaction which is happening so only glucose is involved in the reaction and fructose is being produced in the reaction.

So hence we know water is not taking part in the reaction if were to write the component balance for water it would come down to input = output so let us do that water balance equation would be input = output. So input water is basically 0.6 times F we need to calculate output water so let us call the mass fraction of water in the product stream as XWP and P. So let us label what these are so P to B the product XFP XGP and XWP are the mass fractions of fructose glucose and water in the product stream.

Similarly we would have R as the recycle stream and XFR XGR and XWR as the mass fraction of fructose glucose and water in the recycle stream. However one important information we have from the flow sheet is we do not have any separate we only have an editing point this means the mass fraction of fructose glucose and water in the recycle stream would be the same as the mass fractions seen in the product.

So this means these values would also be XPF XPG and XPW we can assume the total feed entering is T with X WT and XGT as the mass fraction of water and glucose in the gross feed entering so this information can be used now coming back to balance equation we had we can substitute the values for F and P into the water balance equation for the overall system to calculate the XWP as 0.6 again.

So now the next is to get the information about the mass fraction the product stream recycle stream and the gross feed. So for finding this information we need to choose and appropriate system if where to choose the splitter we would be able to write only one independent balance equation hence it would not help in identifying all the unknowns so we can choose the mixing point instead where we would be able to get more independent equations and hopefully able to solve for the unknown.

So let us take the mixing point as the system so for that we can write the total mass balance which would be T = F + R so you have input = output so you have T = F+ R so which means T = 112 kilograms. We also write balances for fructose and glucose the fructose balance for mixing point would again be input = output and input fructose is 12 times XFP and output fructose is 0.0 4 times 112.

So this means XFP = 0.373 now that we have the mass fraction of fructose and water in the recycle stream we can calculate the mass fraction of fructose and water in the recycle stream we can calculate the mass fraction of glucose in the recycle stream also.

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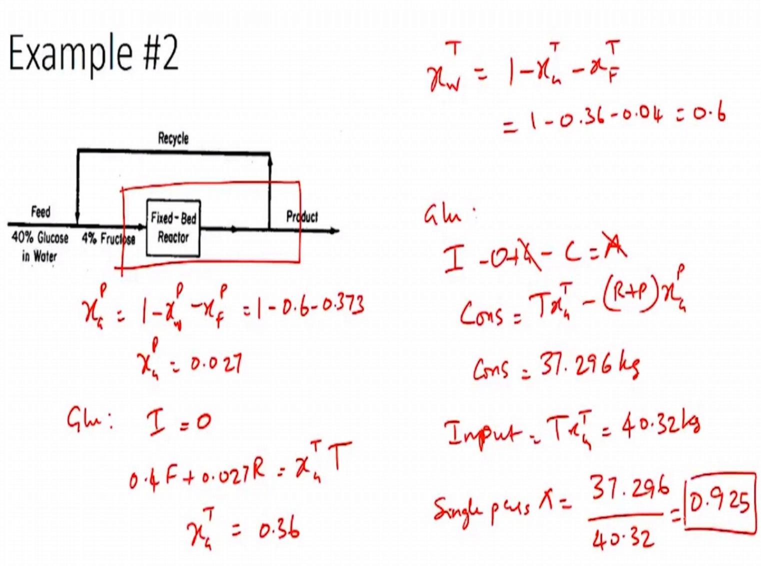

So that would be XGP would be equal to 1- XWP – XFP so this equals 1 – 0.6 – 0.373 giving the glucose mass fraction as 0.027. Now that we have the mass fraction of glucose in the recycle we also know the mass fraction of glucose in the fresh feed. We can write a glucose balance for the mixing point.

So the glucose balance for the mixing point would be input = output and input is basically 4 times F + 0.027 times R equals XGT times T we know the value for FR and T substituting those values w can calculate the mass fraction of glucose in the gross feed as 0.36.

As we have the mass fraction of glucose and fructose in the total feed we can also calculate the mass fraction of water in the total feed so which would be XWT = 1 – XGT – XFT which equals 1 = 0.36 – 0.04 giving a value of 0.36 we still need to calculate the single pass conversion for the system for calculating the single pass conversion for the system we need to identify the appropriate system to study.

So the appropriate system would have to allow the reactants to pass through the reactor only once this means we need to ensure that the total feed is what is crossing the system boundary. So we will choose the fixed bed reactor with the splitter as the system for our study so this would ensure that we have information about the product stream and recycle stream which are the exit streams and we also know the information about the inlet stream which is the gross feed.

With all the information we will be able to calculate the fraction conversion for glucose entering into the fixed bed reactor for a single time. So now let us write the glucose balance for the system chosen. The glucose balance would be input – output – generation + consumption = accumulation at steady state accumulation goes to 0. Glucose is not generated as it a reactants so the equations simplifies to input – output equals consumptions.

So we are expected to calculate consumption so the consumption is nothing but input – output input is T XGT and output is R + P times XGP so substituting the values for TXGT RP and XGP we can calculate the consumption as 37.296 kilograms now that we have the consumptions we need to know how much glucose is entering the reactors glucose entering the reactors which si input would be equal to TXGT.

This is equal to 40.32 kilograms so single pass conversion would be glucose consumed by the single pass which is 37.296 divided by glucose entering which is 40.32 giving a fraction conversion of 0.925 so this is the single pass conversion for the system given with this we have performed some example problems we will get the full understanding of what recycle system reaction would be see you in the next lecture until then thank you and good bye.