Material and Energy Balances

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Lecture No # 23
Recycle without Reactions

Hello everybody welcome to today's lecture on recycle so usually in most of the industries the streams which leave a reactor or the particular process is not been converted into the desired products or not been fully purified and the process might still have to be done multiple times. So in such a scenario setting up multiple processes or equipments for the same process would not be cost effective.

So what people do is the stream which are leaving the process would be sent back into the process for further process so this kind of setup is called recycle. We will talk about recycle and how it is useful for chemical and biochemical industries and we will solve some examples problem to try and understand the fundamentals of recycle when it comes to material balance calculations.

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Recycle

- Reactions almost never go to completion
- Unconsumed reactant → Wasted resources
- Separate the unconsumed reactant
- Recycle back to the feed
- Recycle ratio – mass of recycle/mass of fresh feed
- Can be done for non-reacting systems also

So what happens is reactions if we consider reactors reactions never go to completion in most cases you would always have incomplete or partial reactions that is why we learnt all the terminologies associated with them and we were performing calculations related to that. So in this case what happens? The unconsumed reactant which leaves the reactor is a wasted resource if you just discard it you are actually throwing away money because you have spent lot of money to procure these reactants.

So would you not want to waste them so instead what you do is you can try to separate this unconsumed reactants using some downstream operation and send this back to the feed. So now your feed not only includes the fresh feed which has been purchased but also includes the recycle which has been taken from the process and sent back into the system. So this particular process is called as recycle and it helps in reducing cost associating with the process.

A term recycle ratio is used to define how much of component is being recycle so it is defined as the ratio of mass of recycle to the mass of fresh feed. So this can be done for non- reacting systems also for example distillation is one system where you can consider having recycle we will look at different examples for such a scenario.

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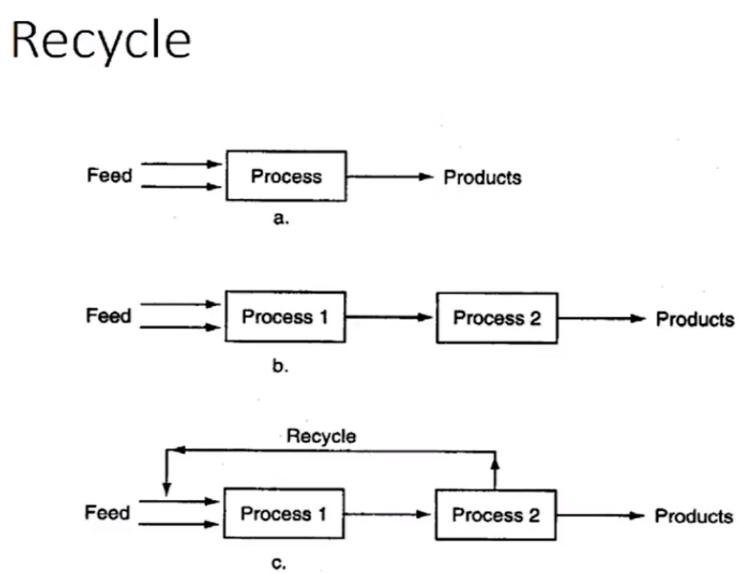

So look at this process the first process shows two different feeds entering into the process and leaving a products. So you have another system where you have two process connected to each other the first one has two inputs and one output and the output for the process one goes into the second process and products are formed.

So what you can do here is the output of the products process two can actually have the separation system where products are removed and the unreacted reactants or the material which needs for the processing and then be recycled back into the feed for the process one. So this is a flow chart representing how recycle system work.

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Processes with recycle

- Always a multi-unit process
- Overall system will include
  - The process of interest
  - A separation process for obtaining the recycle
  - Mixing point where recycle is mixed with the feed to the process
- Material circulates without accumulation
- What does this mean?
  - Accumulation will be zero for any system chosen

So when you talk about process with recycle we need to understand that they are always multiunit processes. This is because the overall system which we consider would have the process of interest and it would also have a splitter or separate which helps in taking some of the product stream leaving the process and sending it back to feed and then it would have a mixing point where the recycle is mixed with the fresh feed which is sent to the process.

So thereby you get at least three separate single units system combining together to form the recycle system. So we need to understand that the feed which comes in before the recycle the feed which is sent before recycle is fresh feed and this fresh feed which mixed with the recycle forms the total feed or the gross feed which enters into process and then goes through the process and product are removed.

Here one terms which we need to understand is material circulated without accumulation what do I mean by this? Accumulation will be 0 for any system which is chosen.

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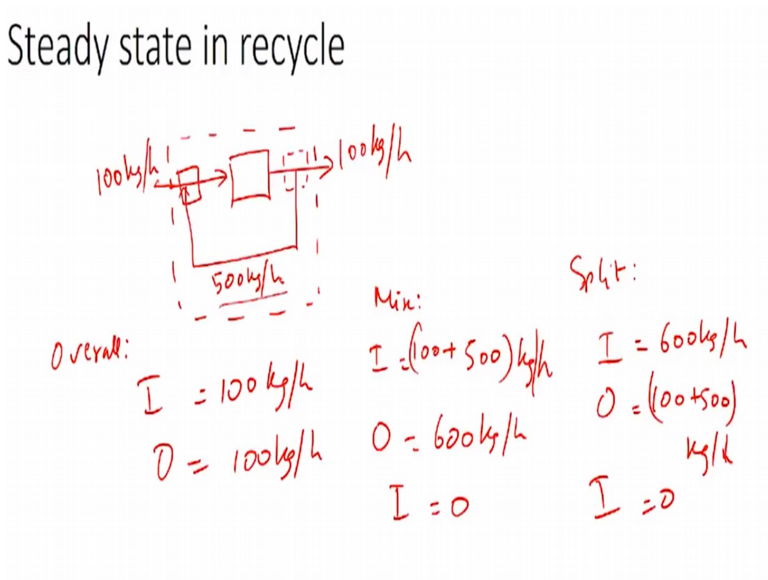

Let us consider a simple system for recycle so you have a input and an output for a process and a splitter used to separate out some of the product which is leaving the system and sent back into the recycle. Now if you were to consider mass flow rates during the initial during steady state what happen is you will have 100 kilograms per hour entering and 100 kilogram per hour leaving the system.

But the recycle stream could be anything if the recycle ratio is 5 you would have this has 500 kilograms per hour of recycle can be sent back again. So now what you do is you consider this overall system so the stream which is crossing the boundary are input which is 100 kilograms per hour and output which is again 100 kilograms per hour. So this means there is no accumulation inside if you were to consider a different system so let us say you consider the system so this is for the overall system.

So if you were consider a mixing point so the mixing point would then have two inputs which is input being 100 kilogram which is the fresh feed and 500 kilograms which is the recycle feed entering into the system and output would be the gross feed which is basically the summation of these two which is again 600 kilograms per hour. So there by this is also input = output so similarly if were to consider this particular system which is the splitter what you would have observe is the splitter would also have an input which is equal to the mass of the gross feed.

So which would be 600 kilograms per hour which is the gross product which is come out and your output would be the summation of your final product and your recycle stream there by being 100 + 500 giving you 600 kilograms per hour again input = output. So I have considered a simple process where there is no reaction so I have not ignored the generation and consumption terms but what you can see here is everywhere input = output.

Because of this we understand that accumulation is 0 so this is despite the fact that there is 500 kilograms per hour of recycle stream which is circulation within the system however this is not considered accumulation because it does not build up over time it does not change with respect to time.

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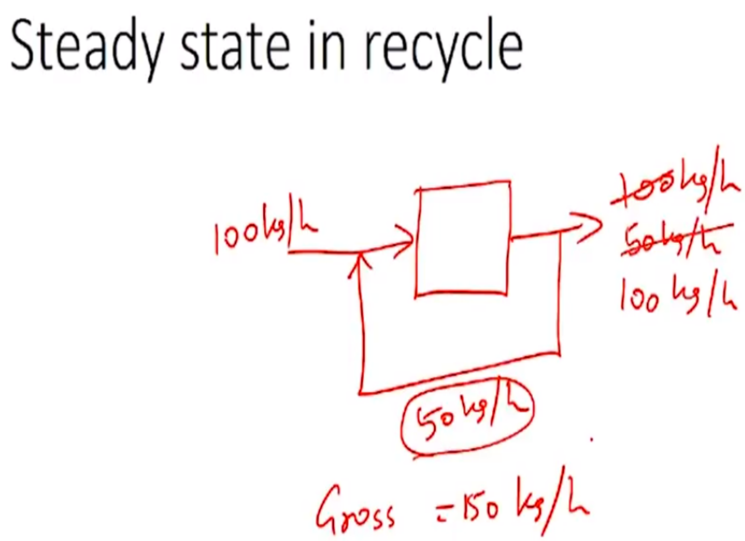

How is this steady state achieved while keeping material in circulation without accumulation inside the system. So let us consider the initial transient phase where you have the unsteady state of the process. So what you have here is the initial phase is you have this particular process where you have 100 kilogram per hour entering and 100 kilograms per hour leaving the system.

So without recycle this is system is in steady state now if I where to take 50 kilograms out of the product and send it back here so what i have here is 50 kilograms per hour as recycle. So this will not become 50 kilograms per hour so now the process is at unsteady state what happens immediately after this over a period of time is this 50 accept to this 100 and your gross feed becomes gross now becomes 150 kilograms per hour.

So which means the gross product should also be 150 kilograms per hour thereby if you were to continue taking only 50 kilograms in recycle this product stream which you recover is 100 kilograms per hour this happens over a period of time. So this initial period were you have unsteady phase would be a transient phase of the process. So finally you reach stead state like this and you can continue doing this to make sure that this particular value for recycle is built up to achieve the required recycle ratio.

In the example we saw in the previous slide we had assumed a recycle ratio of 5 thereby this was being 500. So if you consider that what we would be doing is instead of leaving this as 100 kilograms leaving we can still take out 50 of this and send it back which means recycle stream will not become 100 and your gross would become 200 thereby your gross product would also become 200 making sure that your final product would again be built up if you were to continue having only 100 kilograms per hour recovered as recycle.

So by doing this repeatedly we can actually build this recycle stream to the particular desired mass we want so that we have desired recycle ratio and this is done without affection steady accumulating does not happen for any of these processes. As I already explained if you consider any system within this process you would find that there is no accumulation assuming there is no reaction would always have input = output.

If you understand this particular concept it beings in lot of clarity when it comes to recycle systems with that let us move on to how we would solve the recycle problem.

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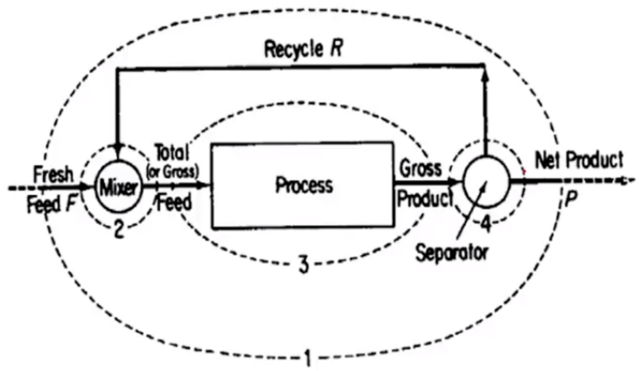
Pick a good system for analysis



As I already mentioned any recycle system is a multiunit process just like any other multi unit process identifying the right system to study is a very crucial aspect for performing calculation.

So if you consider this example where you have a mixer and splitter and the process with the recycle stream you end up having multiple system which you can consider you can consider the overall system which basically engulfs the mixes process and the separator or you could consider the mixer as the system or the process as the system or the separator as the system or combination thereof.

So identifying which system you want to start with will help in solving the problem so this would be similar to solving any multiunit any other process.

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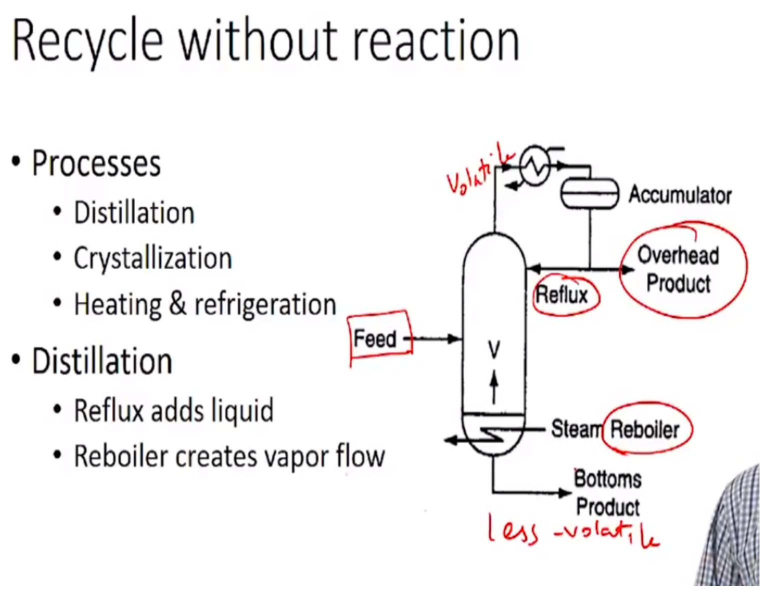

Let us consider recycle system without reactions some processes where you have such recycle without reaction which would be distillation, crystallization, heating and refrigeration and so on. So in distillation we already saw that separation is not complete you always have some preparation and you would have mixture leaving both in the bottom and in your distillate so it is important to recycle to ensure that you get the higher level of purity.

Crystallization again is a process you might want to send it back in so that the saturation solution can be further cooled to get more crystals out heating and refrigeration are system where you perform recycle to ensure that the energy which is present in these materials which are leaving which is utilized to ensure that the process uses the energy rather than waste it by throwing it out of the system.

So let us take distillation as an example so here is a process which describes distillation what you see here is a feed which is entering into the system which is the distillation system the feed entering into the distillation. So you would usually have two particular products leaving so you have 1 which is the bottom product and other which is the distillate product or the overhead product leaving the system and this is basically cool down to make sure that some of the volatile components are condensed to form the liquid and this liquid is sent back in the name of a reflects.

Similarly the bottoms product which contains the non volatile components or the less volatile components to be more accurate it would be less volatile component this leaves us as the bottoms product and this can actually be recalculated back into the distillation column to something called as re-boiler. So this re-boiler make sure that the liquid stream present in the bottom gets evaporated so that the vapors are sent back in by doing this repeatedly you ensure that there is a high percentage of separation and you get a highly pure product.

So by doing this you would get highly pure product which is the overhead and you bottoms products would also have more of the less volatile component and making sure that your separation is quite efficient.

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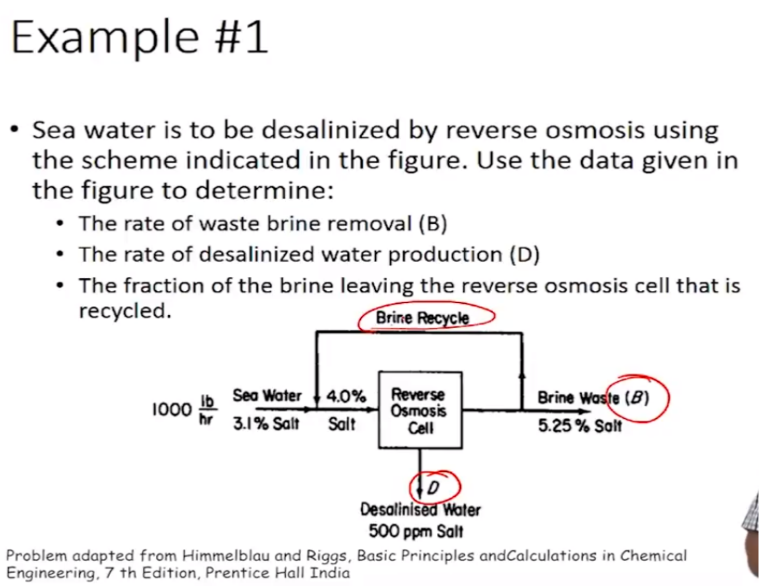

Let u see a couple of example problems which should help us in understanding this and understanding how to perform material balance calculations for such a system.

Sea water is to be desalinized using reverse osmosis the scheme is shown here in the figure here you asked to show the data given in the figure to determine the rate of brain which is being removed and rate of desalinized water which is being produced and the fraction of brain leaving the reverse osmosis cell that is recycled.

So we need to calculate how much brain is being removed which is B and how much desalinized water produced which is D and we also need to find the fraction of line which is leaving the reverse osmosis cell that is being recycled so we need to know what the recycle stream would be. So let us see how we can go about we calculating these values.

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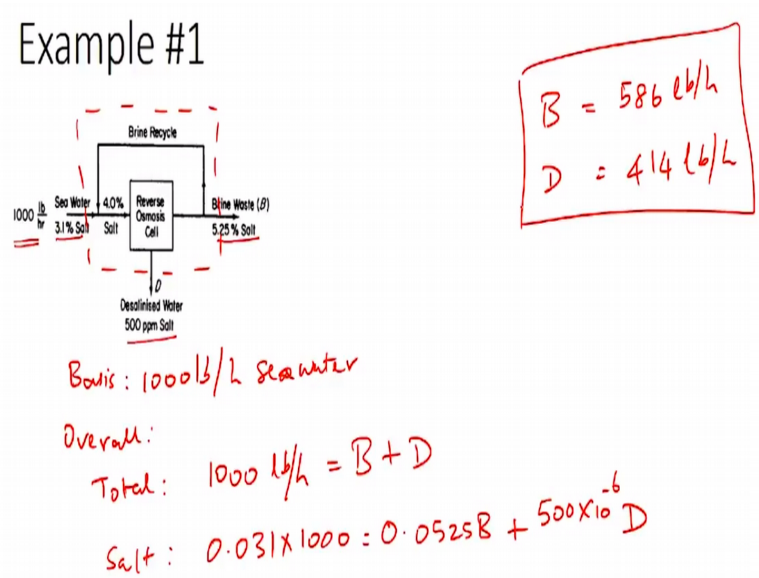

Just like any other material balance the first step for solving this material balance problem would be identifying the basis so in the problem statement it has been given that 1000 kilograms sorry 1000 pounds per hour sea water containing 3.1% salt is entering which means our basis will be 1000 pounds per hour of sea water fed. This would be the basis we start with.

So now the next step is to identify the right system to study we have the information about the concentration of salt in the fresh feed. We also know the concentration of salt in the brain waste and the concentration of salt in the desalinized water. So this means using this particular system as the overall system would be a good way to start so now assuming the over system as the system of interest let us start writing the balance equations.

We can write a total balance equation which would be 1000 pounds per hour the feed which is coming in will be equal to B which is the brain water waste leaving + D which is desalinized water which is leaving the system. So the next balance we can write would be the salt balance. So if you were to write the salt balance it would be 0.031 times 1000 equals 0.0525 times B + the concentration of salt in the dieselized water which is given as 500 PPM which means it would be 500 times 10 power -6 times D.

So now we have two equations and two unknowns solving them we can get B and D so B would be equal to 586 pounds per hour and D would be equal to 414 pounds per hour. So with this we have calculated the amount of mass of dieseline water and the mass of brain ways which is leaving the system.

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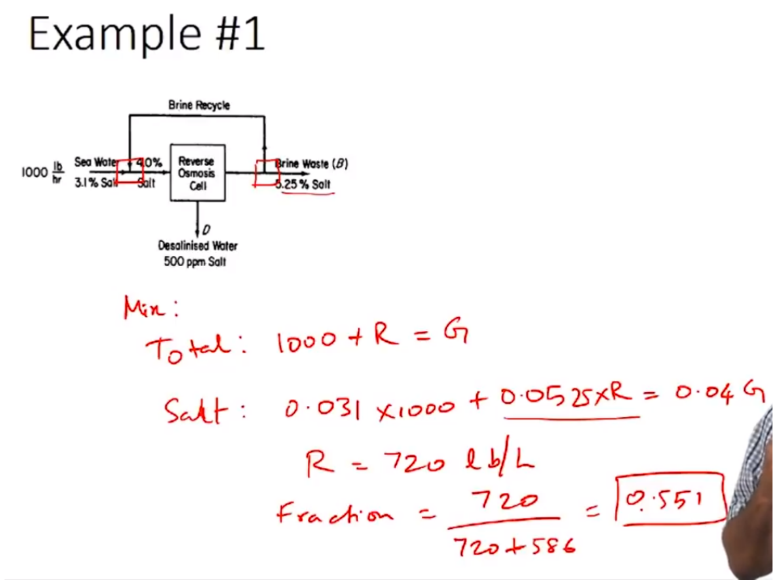

Next step is to calculate the fraction of the brain leaving the reverse osmosis cell that is being recycled for this we need to get the information about the recycle stream we need to know the mass of the recycle stream. So how do we calculate that what system can we used there are two systems which can be chosen where the recycle stream will cross the boundary.

Those would be the mixing point and your splitter considering that we can take only we can write only one balanced equation for the splitting point it would be wise to start with the mixing point because we would have two unknown to start for in this particular equation.

So let us look at the mixing point as the system of interest for the mixing point we can write balance as 1000 + R which is input would be equal to the gross water slat water which entering into the reverse osmosis cell will let us call that G and you would have a salt balance that we can write the salt balance would basically be 0.031 times 1000 + 0.0525 time R would be equal to 0.04 times G.

So you have two equations and two unknowns so using this we can solve for R which is the recycle stream R would be 720 pounds per hour. So in this equation I hope you understand why I chose to write 0.025 times R this is because of the fact that have a splitter here.

So if you remember from the earlier lectures for a splitter the concentration of dissolved components does not change because only the stream is being split into multiple streams which means the concentration of dissolved components will be the same or the composition will be the same in all the streams which are entering and leaving the splitter. This means the concentration of brine water which is 5.25% salt would be the same in the brine recycle also.

So the brine recycle would also contain so contain 5.25% salt and consideration that I have written 0.052 times R as the amount of amount of salt which is entering through the recycle stream. So now that we have R we can calculate the fraction recycled as 720 divided by 720 + 586 where 586 is the amount of brine which is leaving the system so the total basically is 720 + 586 giving us a fraction of 0.5551.

So more than 55% of the brine waves which is actually being produced form the reverse osmosis cells is being recycled so only less than 45% is being thrown out as brine waste. So hopefully you were able to follow this problem and you where able to understand the logic behind choosing the systems and understanding the composition which have to be used for the salt concentration with that let us move on to the next example problem.

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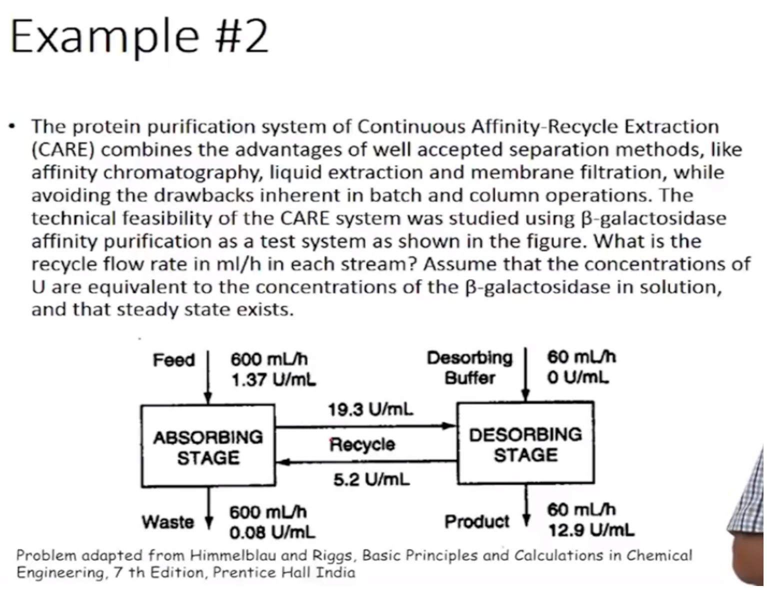

The protein purification system of continuous affinity recycle extraction combines the advantages of will accepted separation method like affinity chromotograpy liquid extraction and membrane filtration while avoiding the drawbacks inherent in batch and column operations the technical feasibility of care system was studied using beta galactoisidase which is an using an affinity purification as the test system based on this process given below.

What is the recycle flow rate in terms of milli liters per hour in each of the a stream assume that the concentrations of U are equal to the concentration of Beta galatoisdase in the solution and that steady state exist. So what has been given to us is this particular stream contains a feed into the absorbing stage and the waste and you also have a dissolving stage which have the dissolving buffer and a product which is leaving the system.

You also have recycle between the absorbing stage and the dissolving stage which are happening both ways the composition of these streams are also given. You have been asked to calculate the recycle flow rate in terms of milli liters per hour. If your remember earlier I had mentioned that balance have to be written only for moles or masses we cannot write balances for volumes unless we make one crucial assumption the assumption is the density does not change.

So as long as density does not change we can assume that the volume is also conserved so making an assumption for this problem we would be able to solve for the volumetric flow rate of the recycle state.

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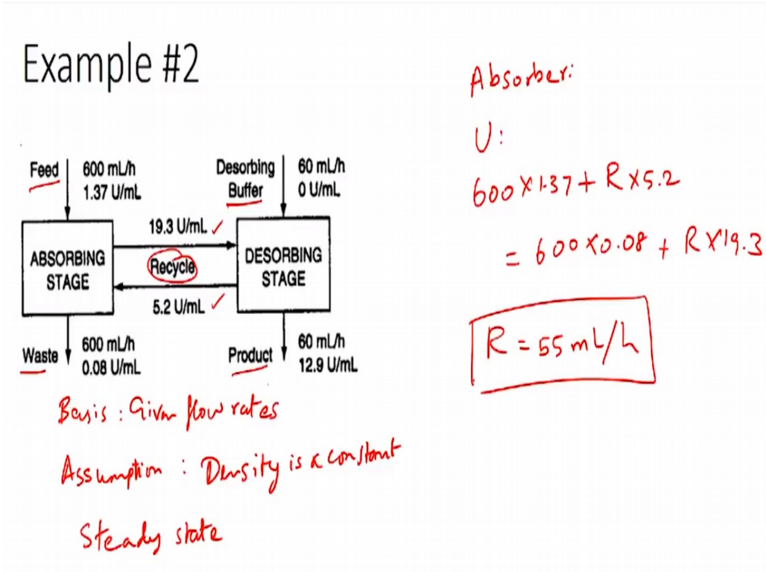

So let us start with identifying the basis so you have different flow which are given so you basis so you have different flow rates which are given so your basis can be basically can be written as various flow rates given which would be the given flow rates as your basis now as I mentioned earlier the assumption we make is density is constant. So the next thing we have been given is steady status maintained so for steady state to be maintained for this processes.

We need to ensure that the flow rate of the feed and the waste are equal for the absorbing stage and the flow rate of the dissolving buffer and product are equal for dissolving stage this can happen only when the volumetric flow rate of the recycle is the same for both these streams. So the recycle flow rate the volumetric flow rate would be equal for these streams with that we know have to choose a system to identify what these flow rates for the recycle would be.

As we want the recycle stream to cross the system boundary we could either choose the absorbing stage or the dissolving stage for as the system for kept performing the calculation in this case I have chosen absorber as the system of interest for performing calculation we would either write a total balance or component balance. So the total balance would not be very useful here so hence we would use the component balance would be trivial so component balance will be useful for calculating he volumetric flow rate of recycle stream.

So we will use the component balance which is the beta galactosiddace which is U so the component balance here would be beta galactosidase enters as 600 times 1.37 + recycle times 5.2 and this leaves as 600 times 0.08 + recycle times 19.3 so using this balance equation we can calculate R which is the volumetric flow rate as 55ML per hour.

So is a simple problem where were able to perform material balance calculation to calculate the volumetric flow rate of recycle entering the leaving the system which is the absorbing state so with that we can come to the conclusion for recycle problem without reactions in the next lecture we will talk about recycle problem with reactions and we will also perform some tutorial problems related to recycle without reactions thank you.