Course on Industrial Biotechnology
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Mod02 Lecture07
Reactors Analysis

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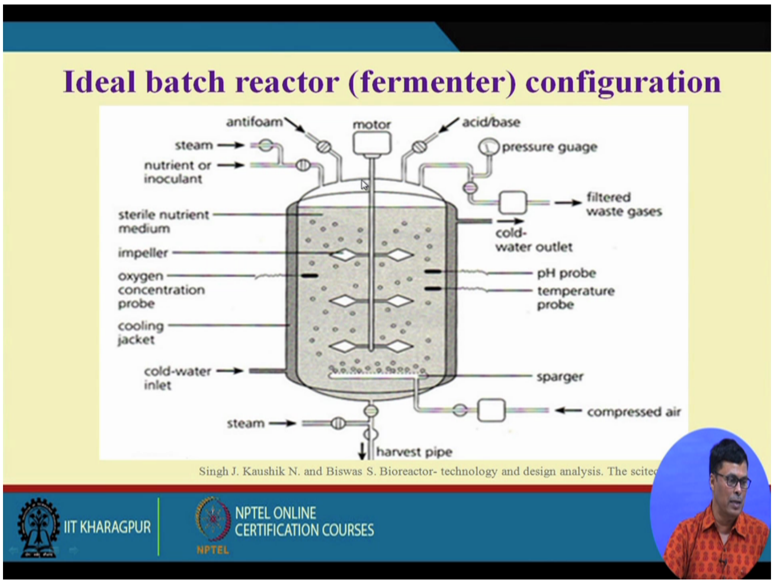

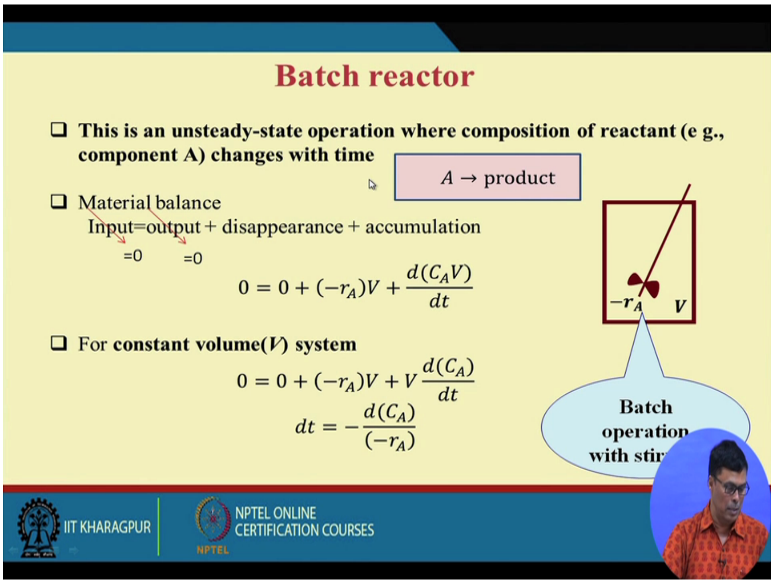

My next presentation is the reactor analysis, because up till now I discuss the different types of reactor that we have. Now let us see how we can analyses the reactor, this is very important, because analysis of the reactor is very important and the we will try to cover this and before we go for that we should know that what are the things actually present inside the reactor that is you see that inside the reactor there will be stirrer I mentioned and this is call

(())(0:50) and this is the impeller and do you know (())(0:52) what is purpose of the (())(0:54) is to maintain the homogeneity in the reaction mixture, because you know so that, because particularly if you look at the microbial cell, they are the insoluble solid and if you don not stir it then what will happen?

The that insoluble solid material will settle down and if they settle down then reaction will take only at the bottom particularly of the reactor that the reaction will not take place throughout the reactor. So for doing so we should have a stirrer. Now then I was talking that you know that one problem that we have with this biological system is the foam formation and why the foam formation take place, because most of the fermentation process they are aerobic in nature. Aerobic means your microorganism grow under anaerobic aerobic in presence of oxygen and I mention that it is little bit different as compared to the human (()) (1:50) system.

Human system we take oxygen from the air but microorganism, they take the oxygen which is dissolve in the liquid. So naturally until and unless the liquid that oxygen direct dissolve in the water, the microorganism cannot (())(2:08) utilized for the growth and metabolism that is very important. So you have to start this that air continuously so that dissolve oxygen concentration increases that is the major (())(2:21) this process.

Now when you do this (()(2:23) that the during the fermentation process some protein formation is there. The when protein and their air come contact with each other they forms the bubble that is call foam formation and if the there is a foam formation then what will happen? It will accumulated at the top of the fermenter. Now if you allow to accumulate then what will happen? It is slowly it will go up and touch (())(2:49) here, there will be mechanical seal and this mechanical seal is a very crucial for any biochemical industries, because I told you in a very first lecture that basic difference between chemical and biochemical process is that we may in the biochemical process mostly we maintain the sterility in the reaction mixture, because why is sterility, because we want to grow a desired organism inside the microorganism we do not like to grow any other organism other than our desired organism in the mica (())(3:20) in the reactor.

So there should not be they should be perfectly air tight and to make it perfect air tight this with the air seal is a this is designed and if you allow the foam to grow then it will enter into the mechanical seal and as soon as it entered into the mechanical seal, a mechanical seal will be ruptured and the contamination will take place. So what we use? we used the antifoam oil we put a sensor here as soon as the they touches the sensor the foam touch the sensor then (()) (3:58) this is connected with some pump antifoam oil tank, pump connected with antifoam oil tank that will drag the antifoam inserted into the fermenter so that that is the your foam will be subside (())(4:10).

Then we have other arrangement you can see here that in the fermenter I can tell you there sparger that is very important thing that we have we pass the compressed air and there should be sparger here and we have some jacket that jacketed system for passing the hot and cold liquid to maintain the temperature inside the reactor. This stirring also help for maintaining the temperature inside the reactor then we this this air what we pass this we usually the sterilized air should not contain any kind of contaminance and it goes like this and when it goes like this you can see, it passes through a filter and why it pass through a filter? The reason is that if there is the (()) (4:10) there is a power failure then what will happen? There is a air the compressor will be stop there is no air flow and there is a possibility that the back suction of air and so if you do not have a filter here then what will happen the a unsterile air will go inside the system and system will be contaminated. So there should be a filter that we have at the exit that air steam that is going out of the reactor. Then we have steamy we passed in that is suppose we (())(5:34) two type of sterilization we have one you call in-situ sterilization another is in-vitro sterilization.

In case of a lobotary we usually we recommend we have the small reactor we can do this sterilization in-vitro, but in case of big big fermenters usually we go for the in-situ sterilization means the wherever the fermented is located there we do the sterilization, there we this is the steam inlet, we pass the steam and high temperature high pressure development take place with that we maintain the temperature and sterilize as per our requirement.

Then we have different monitoring system we have temperature monitoring system with the help of thermostat we can monitor the temperature we have pH probe we can monitor the pH of the reactor and there is oxygen probe that is they determine (())(6:33) the dissolve oxygen concentration. So these are the different arrangement we have in the reactor, we have the proficient for acid and base addition in the reactor to maintain the pH of the reactor, the reason is that your microbial system are very sensitive to the environment as your pH changes that the growth of the organism might be hampered. So if we want to control the temperature, pH then we have this kind of arrangement (())(7:00) by the vessel addition system.

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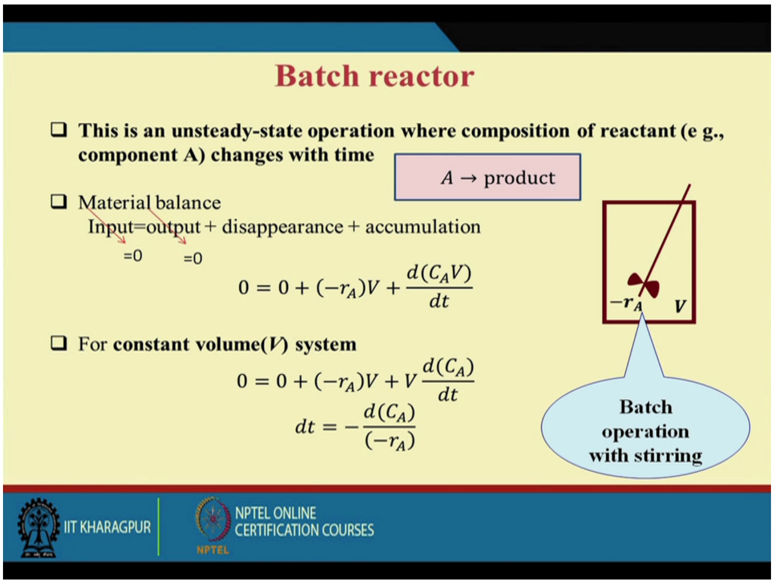

Now let me showed that reactor analysis and for the reactor analysis we use the basic formula, this is call that material analysis, this the rate of input equal to rate of output plus rate of disappearance plus rate of accumulation. Now this is the equation is a such thing that here we consider one particular parameter to write this balance equation, because as for example, in a reactor, we have substrate, we have product, we have in our microbial system, we have cell mass. So we have different type of we have energy some may be some kind of energy point of view it is might be interesting.

So we can write the balance equation with respect to any such parameters, suppose as for example if we want to write the balance equation we can write the balance equation with respect to substrate we can, so this is balance with respect to substrate we call substrate balance, they if it is with respect to product we call it product balance if it is with respect to cell mass we call it cell mass balance. So we can write the different type of reactor.

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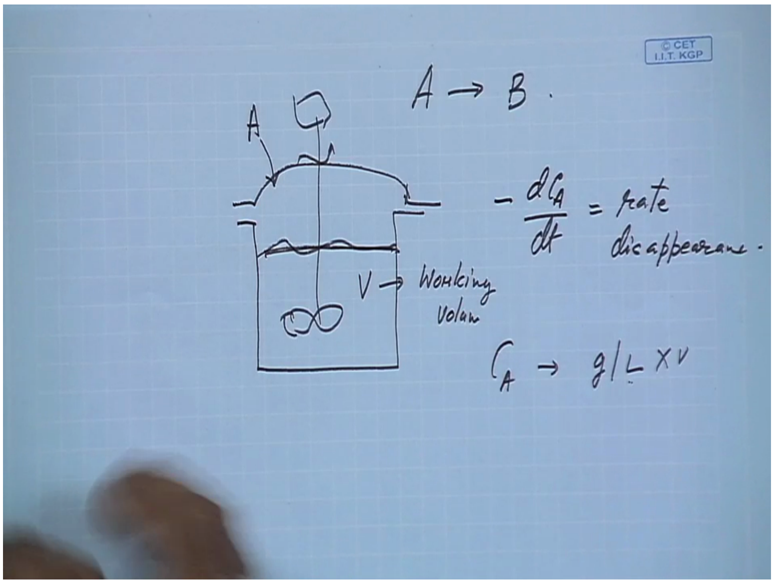

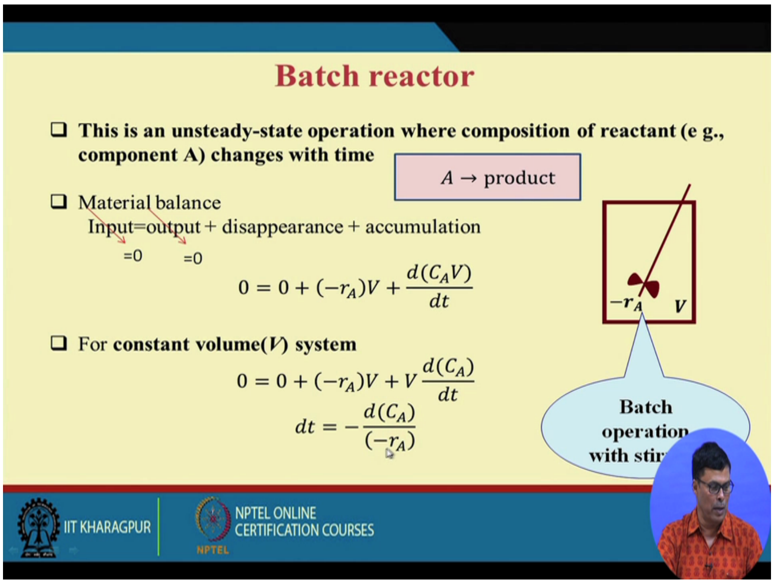

Now first things that (I have) I am going to show you the batch reactor and if the batch reactor if you look at, it is very simple that is the, it is like this. It is the reactor we have we have stirrer here, this is the motor and it is rotating like this. So suppose A it converted to B this is like this. So we put this substrate A at a time we put all the material inside the reactor like this and allow the reaction to take place and when the reaction is over we take it out. So what we, so there is, now if you look at this equation, equation is the rate of input equal to rate of output plus rate of disappearance, rate of accumulation.

Now here what is happening rate of input is zero, because it will taking the substrate at a time, rate of output you are not taking any output from the system, so rate of output will be zero. What is the rate of disappearance? It is we have seen when A is converted to B how we can write rate of disappearance? Minus dca by dt, this is the rate of the rate of disappearance**.**

So we can easily write this, so this now why you why we are writing we are multiplying by volume, because if you look at the concentration, this concentration is what the CA is equal to may be gram per liter. The gram per liter means per unit volume, but you know in that reactor when you have reactor, you have some working volume. This is call v is call working volume. This is call working volume, so naturally the this is to be multiplied by V and so that you can you in the in the calculation you can have all these changes that we have in this volume. So that is why it is multiplied by minus rA is multiplied by V.

Now this is the d CAV by dt, this is the rate of accumulation of A that is it taking place in the system that you know with respect to time how much is the air accumulation take place. Now for constant volume if the V we assume to be constant liquid volume is constant then we **we** can have this equation dt equal to dCA by minus rA.

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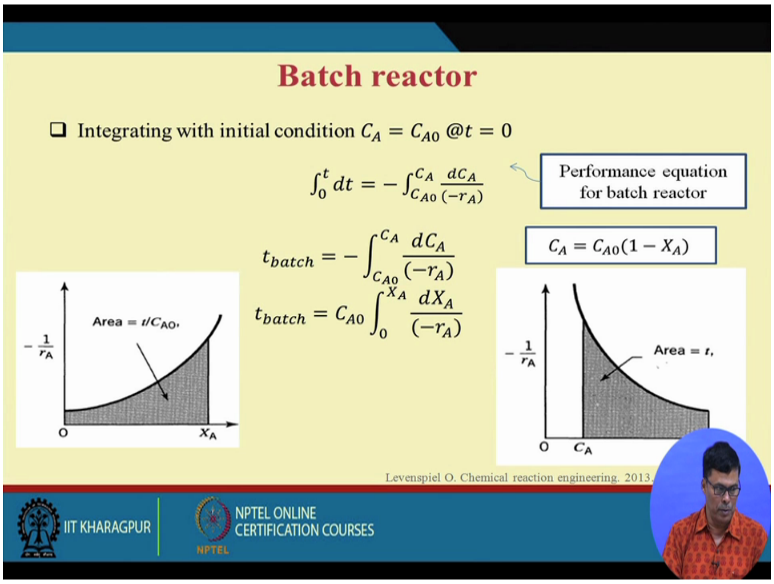

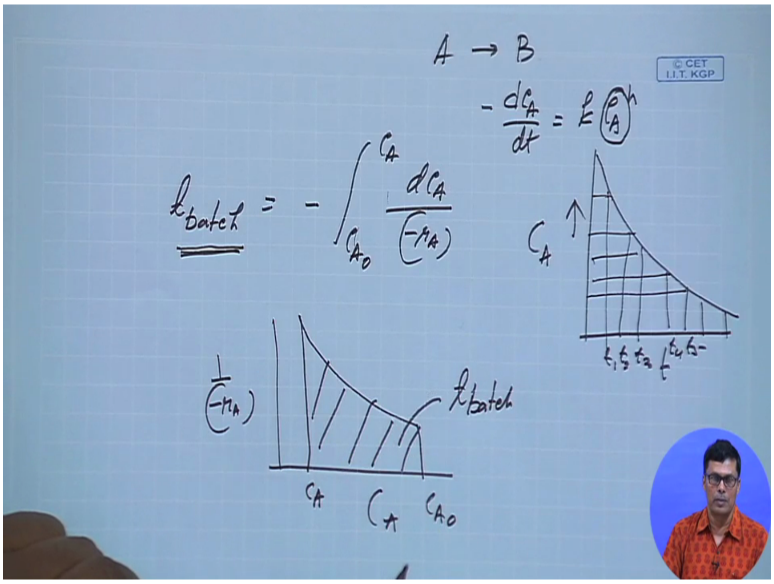

Now if you if here you see that you have the at t equal to zero CA is equal to CA0 then your integration is zero to t and you have CA0 to CA dCA by minus rA. Now here this is equal to tbatch, tbatch is the time required for the carrying out the batch reaction to convert substrate CA0 to CA and this is the equation. Now here I want to point out couple of things that when you write tbatch minus CA0, CA minus rA. Now one thing is that if you look at the profile concentration of profile CA concentration with respect to time, this is like this.

Now we have seen when A converted to B (he) we what is the rate of reaction? CA equal to KA into CA to the volume that means it depends on the concentration of A, CA. So as the time passes on you can see at different time, this is t1, this is t2, this is t3, this is t4, this is t5, so at different time you have different substrate concentration and since you have different substrate concentration, your rate of reaction will be different, rate of reaction will not be constant and since rate of reaction is in the constant.

So your, so that is why we have here we have the integration sign we have here we have the integration sign, so this is like this. So question comes then how we can find out the volume of the that a time of the batch process, the how we can find out we can plot that if I plot 1 by rA into CA like this and if your plot is like this the correlation is like this then if it is CA0 here and this is CA then the area under this curve we considered is the tbatch, this is considered as tbatch. So this is how we can find out that we can easily find out the graphically there how the batch time can be calculated like this. So this is how batch time can be calculated.

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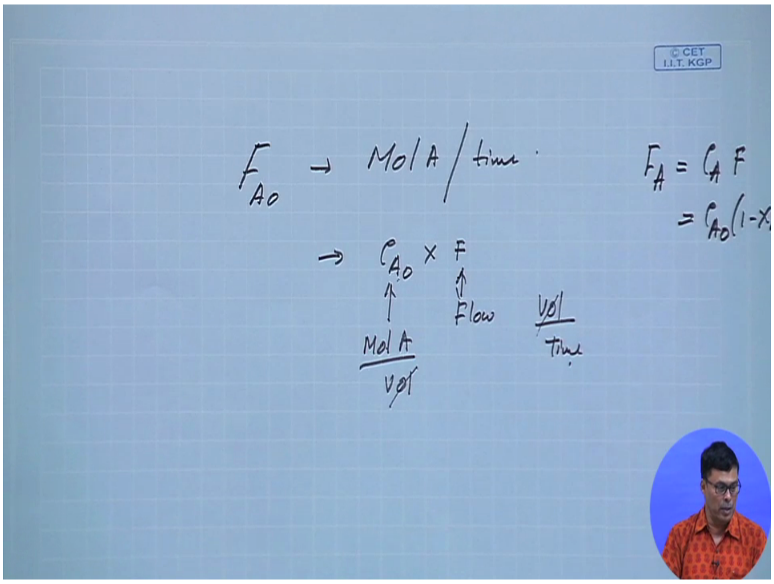

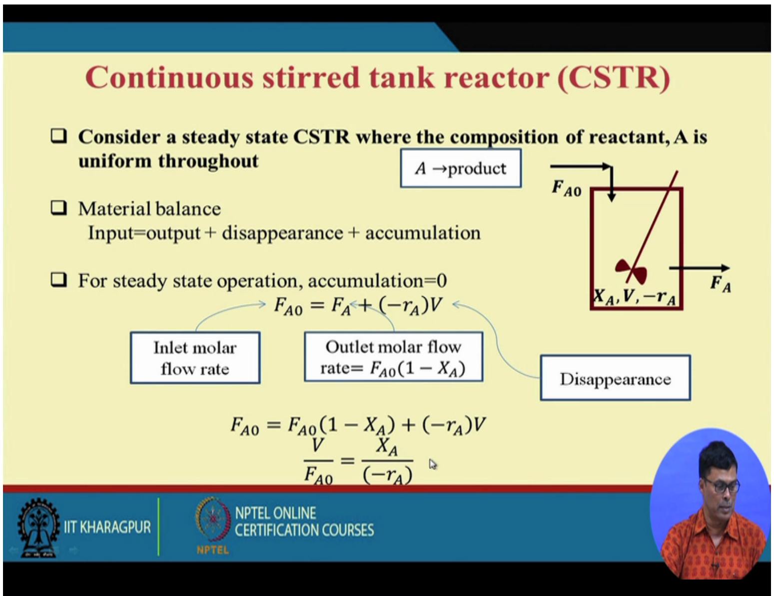

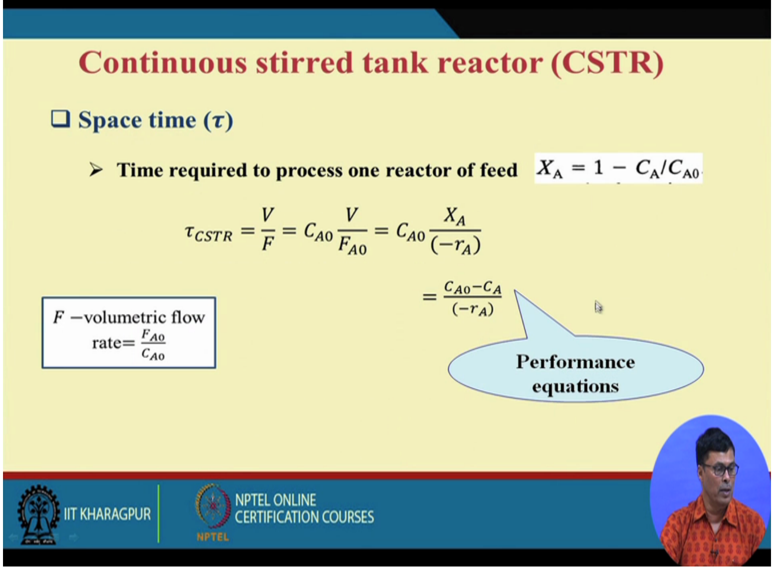

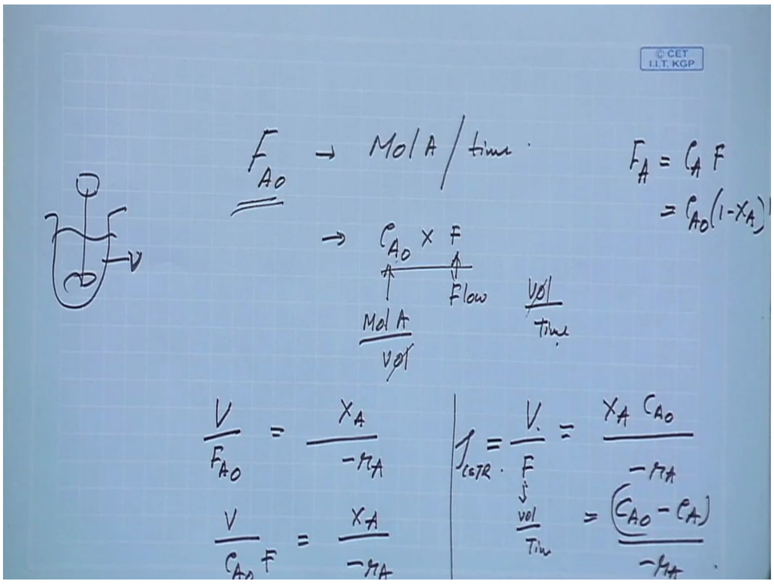

Next let us say talk about the continuous reactor and continuous reactor, basically we have two types. One is call CSTR another we call plug flow reactor. Now CSTR as we know that I told you before also, that it is very easy to operate, because we have a stirrer here main purpose of the stirrer to maintain the uniformity in the reaction mixture and we pass the substrate here and take out the product from here. One end your coating the substrate another end you are taking out the product. So your equation is same your rate of input equal to rate of output plus rate of disappearance, but the but here I one thing I forgot to mention that in case of batch reaction, since the substrate concentration keep on decreases with respect to time.

So this is considered as a very unstable reactor, because it is not a stable reaction, because steady state unsteady steady state condition under no circumstances is possibly (())(14:44) also batch process, since the concentration varying with respect to time so that is why it is a unsteady, it is example of unsteady state reactor, but if you talk about the steady state reaction, the primary requirement for this is that you have to maintain the concentration of the substrate uniform. If the concentration of the substrate uniform then and only then it is possible to have in uniformity in the reaction mixture. So here so here equation is rate of input equal to rate of output plus rate of disappearance plus rate of accumulation, so if you say under steady state operation, the rate of accumulation should be equal to zero. This is the very important the rate of accumulation that should be equal to zero.

Now how we can write it? Suppose rate of input, this is FA0. What is FA0? FA0 is the mol of A per time, I can always write the per unit time. This is mol of A per unit time that is putting in the, but if you write that if you we can this is equal to CA0 into FA what is F? F is the flow rate, F we can no flow rate volumetric flow rate. This is volume per unit time I am right? And this is what this is concentration; this is mol of A per unit volume.

So when you multiply this then volume will cancel then mol of A per unit time. So this FA0 is nothing but FA is a nothing but CA0 in the F. So here you see that FA0, this is the incoming, this is rate of input and output is FA, this is the output is FA and what is the rate of disappearance we have already calculated in case of batch reactor minus rA into V. So we can write this equation like this. What is the FA? FA we can write that FA like this we can write FA is the how we can write FA is equal to CA into F and CA is what? Here CA0 into 1 minus X, XA is (the) what is the that you know that what is the fraction of the substrate that is converted.

So we can if we do that we can replace this equation like this. Then we will come here, this is the F by FA0, XA by minus rA then we can derive from this equation like this. This is very easily we can derive then XA this I told you this is Cao minus CA by CA0 then fraction of A that is converted and finally (what we) what is the previous equation we have? You see we have F by FA0 equal to XA by minus rA I am right? Now what is the I have already shown here FA0 equal to CA0 into F, so I can write V equal to CA0 into F equal to XA by rA, I am right? So here I can write X by F V by F equal to XA into CA0, so this is equal to minus rA and what is this what? This is XA into CA0 is the substrate that is converted that is CA0 into CA divided by minus rA. So this is very simple.

Now here you if you look at unit, this V is the working volume of the liquid. This is your reactor and this is the volume of the liquid this is the volume of the liquid working volume of the liquid. This is the volumetric flow rate. Now what is the unit of volumetric flow rate? Volume per unit time, I am right and what is the unit of the (()(19:07) volume. The volume will cancel, so this will be time and this is called Tau CSTR. What is TauCSTR? This is the space time. why it is called space time the reason is that the how long the liquid recites in the reactor that is the space time, because you are passing a liquid in the reactor, the question comes how long the liquid, because why we are interested the for doing so, because the longer the liquid resize (()(19:37) in the reactor that the longer will be rate of reaction and less time is (())(19:44) in the less will be the reaction time.

So we know that it depends that you know that is very important and if what is our desirable thing is that our that you know space time should be as minimum as possible, because it is directly proportional with the volume of the reactor can you find out, this is directly proportional volume. If the space time is less then volume of the reactor is less is space time of more volume the reactor mode. Now when you do any kind of reactor design then volume is the major construct, because when we produce any kind of product our when ours design criteria is that under what circumstances we can have the minimum size of reactor to get the desired amount of product, because if the reactor size is small our cost involvement in the process will be less so that is very important that is the that is to be that plays very important role.

So I shall show you when I shall discuss the other reactor then I can make a comparative study and show you how we can really go to design the reactor and select the reactor which reactor will be better for our system.

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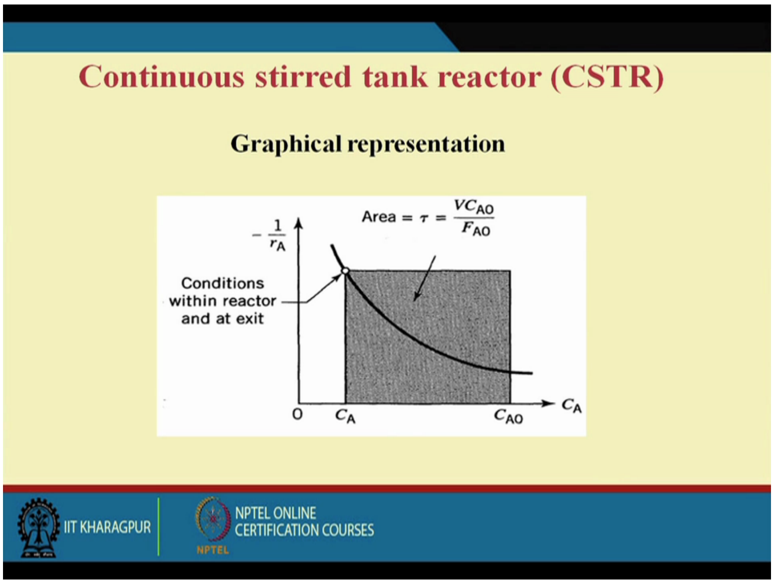

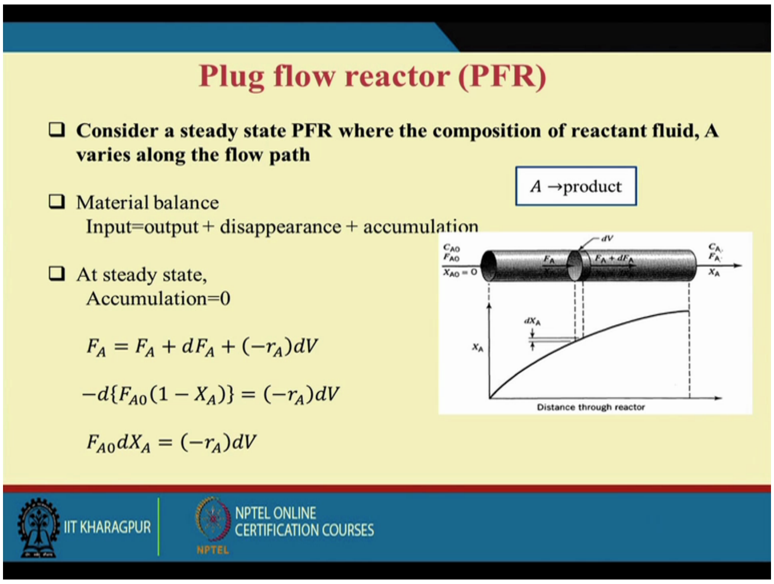

Now next reactor that I continuous system I going to discuss what you call plug flow reactor.

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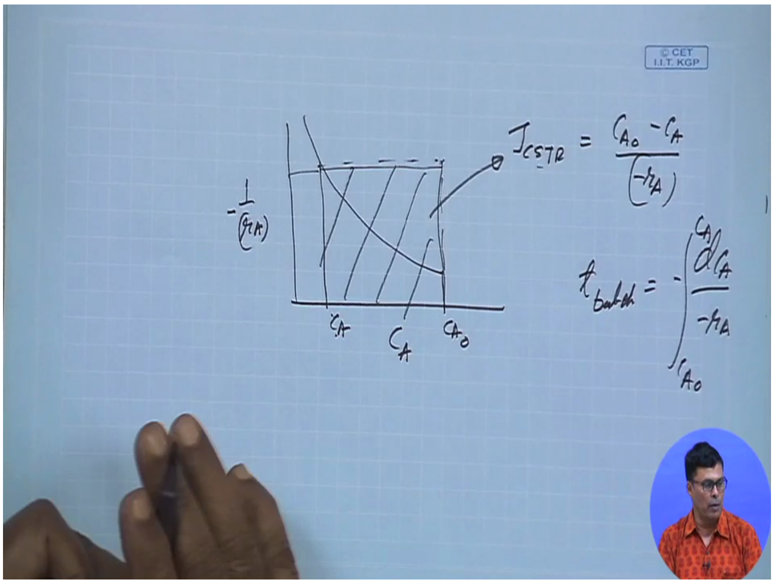

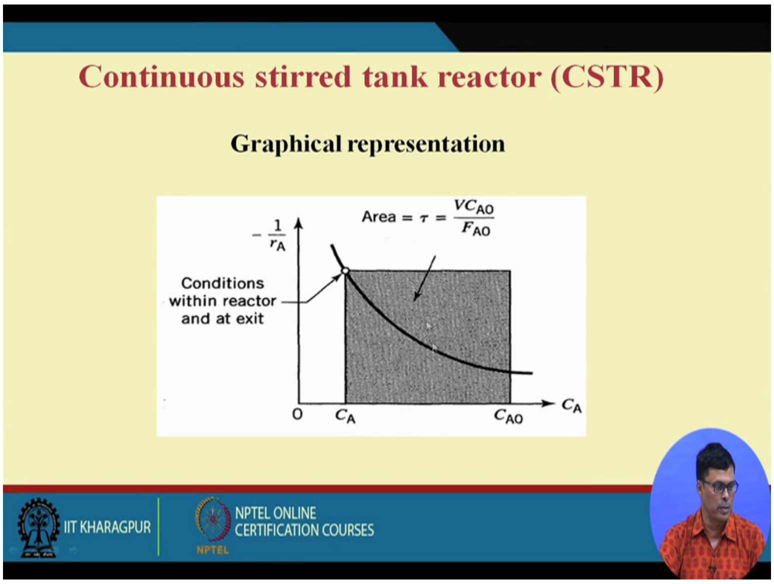

Now before that let me discuss this one, because last time I discuss the batch process that when you plot, because in the TauCSTR you can remember we derive the equation like this, CA0 minus CA minus rA, okay and in the batch process what we have design batch process we have derive this equation minus dCA minus rA, I am right? This is equal to CA0 into by (())(21:41). Now here suppose this is CA and this is this is minus 1 by rA we have this kind of plot. Now in case of CSTR system, because this will be the CA and this is CA0, this is CA. so area under this curve, because as CA what is the rate of 1 by rA this one. So what is that CA0 minus CA that is length minus 1 by rA is this one? So it is a area of rectangle, I am right? This is area of rectangle is nothing, but you have TauCSTR. So this is how it has been shown here in this figure you can see minus 1 by rA where CA you when you plot and if you have this kind of correlation and we will the graphically you can find out also what is the space time that you can easily calculate, okay.

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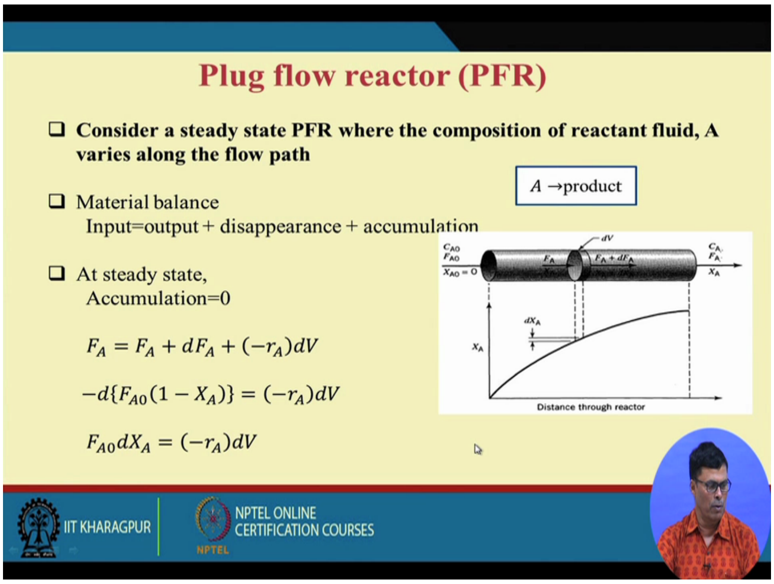

Now let me talk about the plug flow reactor now. Plug flow reactor I told you, it is kind of tubular reactor and you know the tubes that you can (())(22:54) find out that tube the liquid is flowing through one end to other and we plug flow basically we assume this is the velocity gradient across this cross section should be minimum that is the plug flow is the kind of similar to the piston flow. Piston flow is considered as a ideal flow you now that, so this is like this. Here this process also we have the same equation we use that is rate of input plus rate of output rate of disappearance plus rate of accumulation. Now question comes how we can analyze this reactor? That this reactor we can analyze we first we assume here, this is since it is a continuous process. Here also there is a possibility to attain the steady state.

Now to analyze the reactor what we do that we assume a differential segment of this reactor we just cut in portion of the reactor and then we do the balance across this segment, like this here with this segment we know the, let us assume that volume of the segment is dv and FA is the input that mols of A that is entering into the system and whatever change is there dFA. So FA plus dFA is the rate of what is the outcome is going out from the system. Now why it is plug? The in case of product, it should be increase; in case of substrate it may be negative. So it is that is why we considered it that the dFA. Now liquid is flowing like this. Now what is the how this equation we can write. This is FA equal to rate of input equal to FA plus dFA. This is output this is two things we have and rate of disappearance minus rA into dv.

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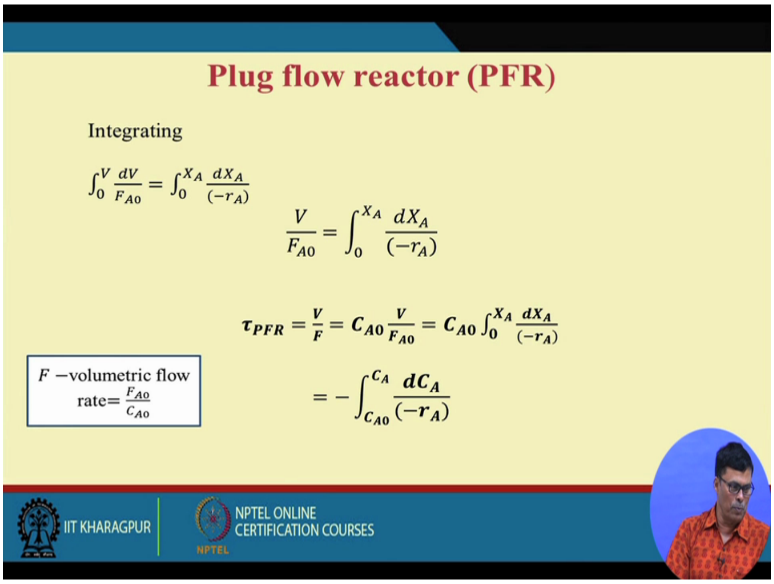

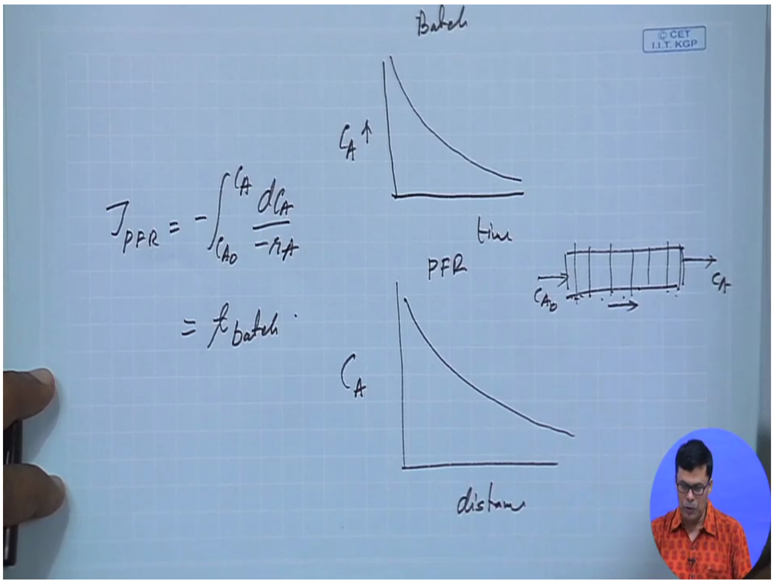

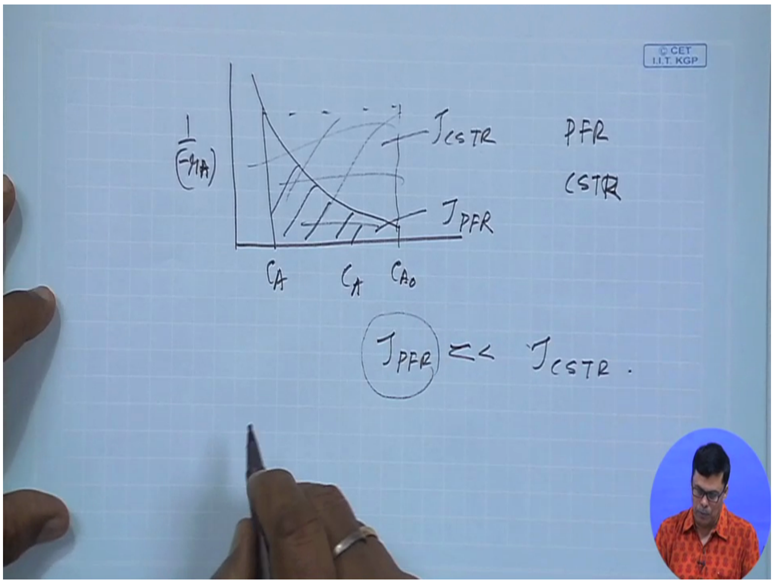

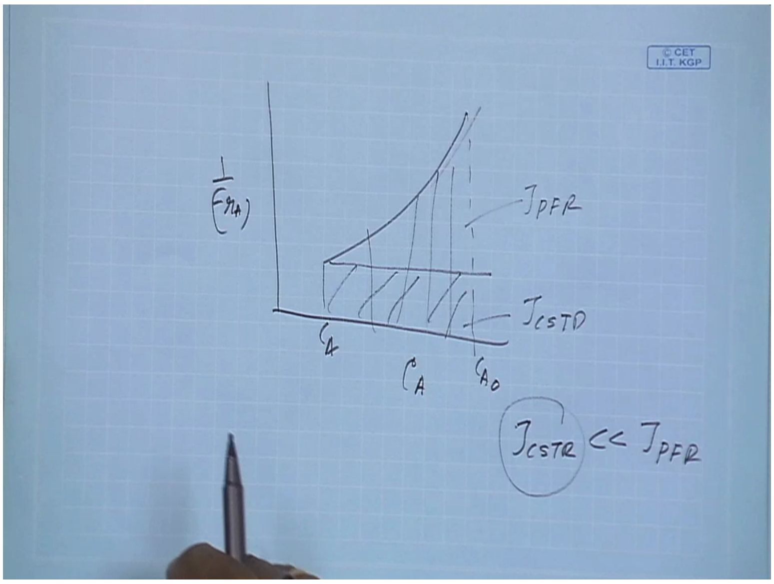

Now if you analyze this system similar as we have done before we can come across this equation very simple equation we can derive and ultimately we can find the same equation that we have seen, in case of batch process, tbatch process we have also seen this. Now question you question may be ask that why we have the similar type of question? The basic main reason is that if you look at in the batch process if you plot CA with respect to time, in case of batch process then what is happening that you know that a substrate concentration keep on decreasing with respect to time. Now in case of plug flow reactor, this is distance, because you know that liquid is flowing from one end to others, this is like this. So this is CA0 and this is CA.

So it is flowing like this. This direction it is flowing, this is with respect to distance. So you can take the sample at different location. Here you can take, so here CA value will be different like this if you plot this you will also find this. So you have you can easily find out similar type of correlations. This with respect to time this is with respect distance that is why that in a Tau plug flow reactor is equal to minus CA0 into CA dCA minus rA and it is same at tbatch. Now I was talking about the selection of the reactor. This is very important, suppose how you select that reactor, suppose I want to operate because the we always separate the continuous system the reason is that rate of product formation in the continuous system is much more as compared to batch process, so suppose we have plug flow reactor we have CSTR and we have we have the correlation between 1 by rA and CA is like this. This is CA0 and this is CA.

Now in case of plug flow reactor, this is Tau plug flow reactor, space time of the plug flow reactor and in case of CSTR this the area under this curve will be TauCSTR. Now Tau plug flow reactor here, it is much less as compared to TauCSTR. So what we will go we will go for Tau plug flow reactor.

Now situation will be different when you have the correlation in other way, suppose we have correlation like this. This is minus rA by CA. Now here we have CA0 and this is CA, now the area under this curve will give you the value of TauCSTR I am right and, but area under this we will give Tau plug flow reactor. Now TauPFR here TauCSTR is much less as compared to Tau plug flow reactor, we will go for TauCSTR if your correlation is like this. This is how we can select the reactor which reactor we should select for a particular process, because our target is to get the minimum time required to get the desired amount of product. Thank you.