Chemical Reaction Engineering 1 (Homogeneous Reactors)
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Lecture No 31
Recycle Reactors (Autocatalytic reactions) Part 2

Autocatalytic reaction and recycle reactor, Ok. Yesterday we have

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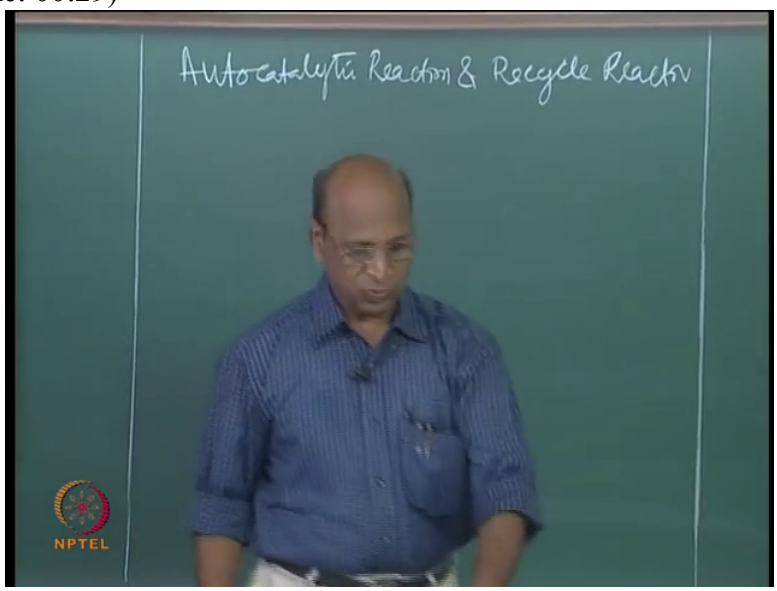

written an equation, very nice condition. So what is the condition for optimal recycle ratio? For optimal R what you have to follow is 1 by minus r A at X A 1 must be equal to X A 1

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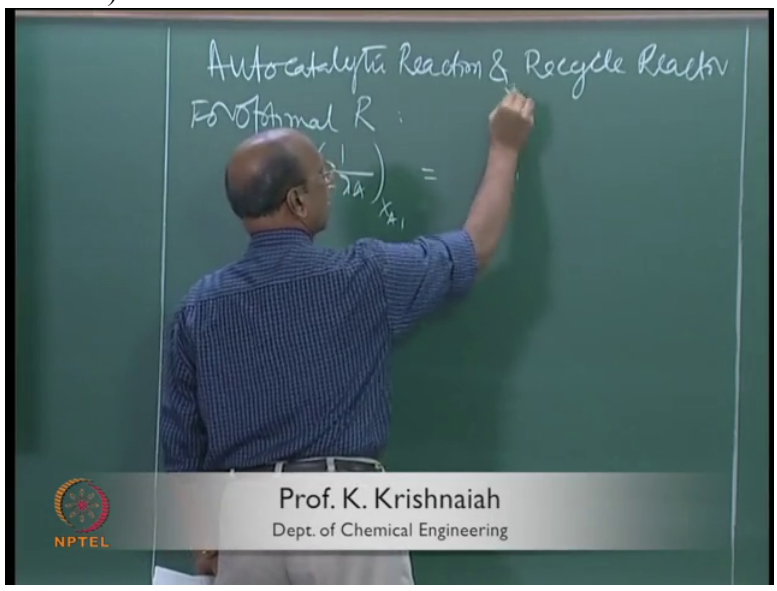

X A f d X A by minus r A whole divided by yeah, so that is the condition, right.

And actually how do you get this optimal recycle ratio, if I ask you to find out, Ok for 90 percent conversion you get me the optimal recycle ratio. How do you do it? What is the normal procedure?

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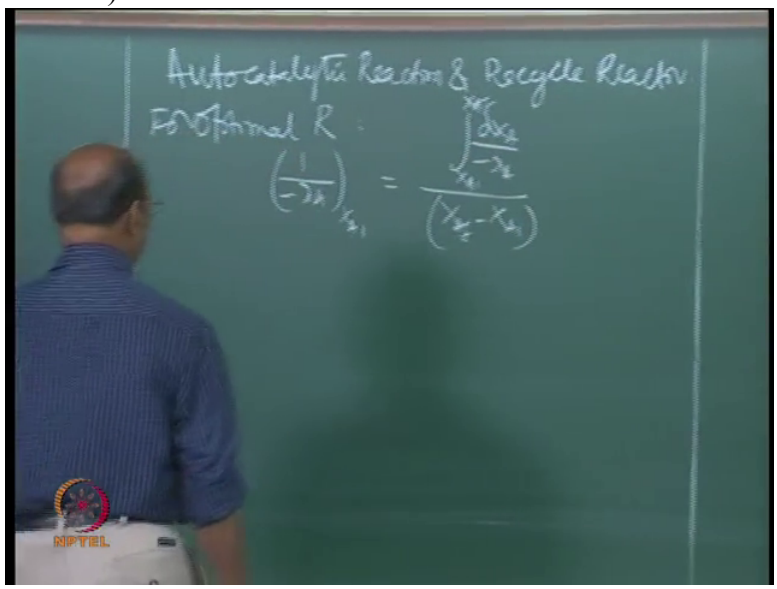

The normal procedure is the analytical procedure where we have V by F A naught equal to zero to, no not zero, X A 1, X A 1 is R equal to, that you remember, d X A by minus r A, Ok. So this minus r A now depending on the

(Professor – student conversation starts)

Student: That should be R plus 1 into integral,right?

Professor: Yeah, right, right, right. Very good. Yeah like that you have to catch the teachers,

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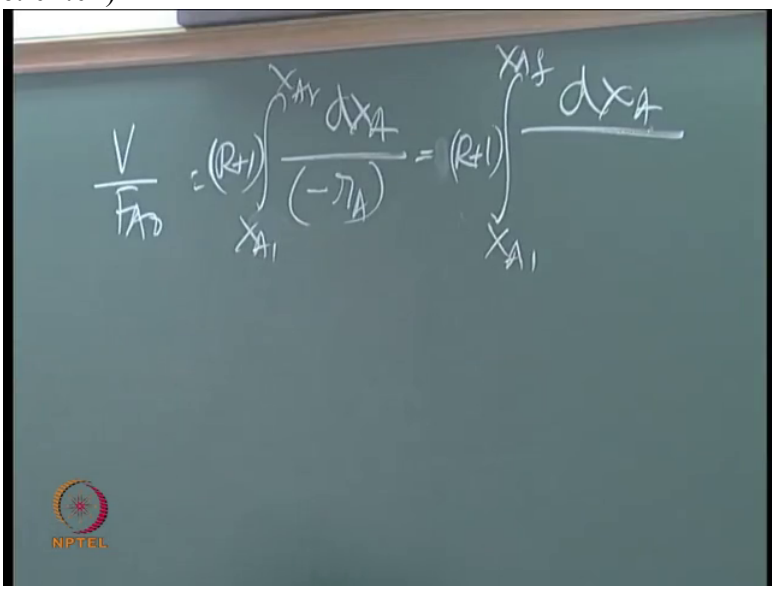

yeah, this one, this is the one.

(Professor – student conversation ends)

And now if I have a scheme autocatalytic reaction no, autocatalytic reaction A plus R going to R plus R, the rate expression for this is k into

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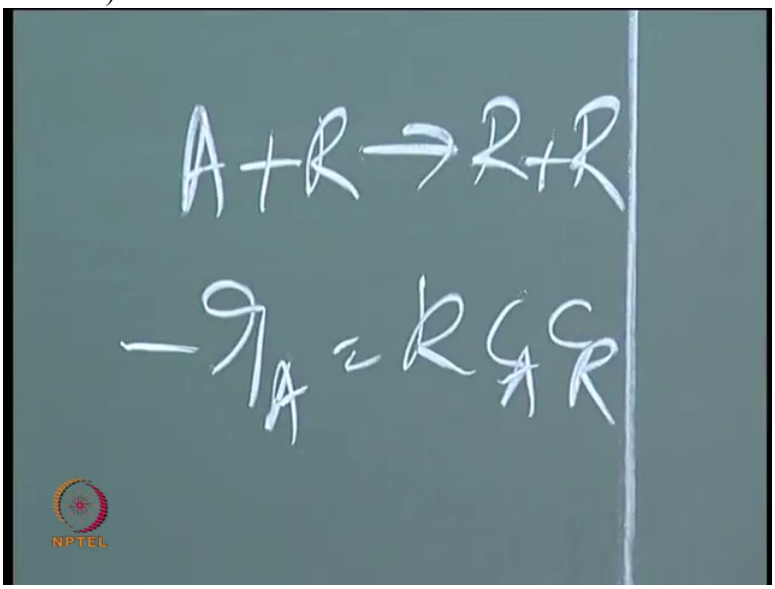

C A C R, that has to be substituted here, you cannot integrate straightaway this, so then you have to write this R in terms of C A.

What is the relationship? Generally the relationship is total concentration C both together, C A naught plus C R naught also equal to,

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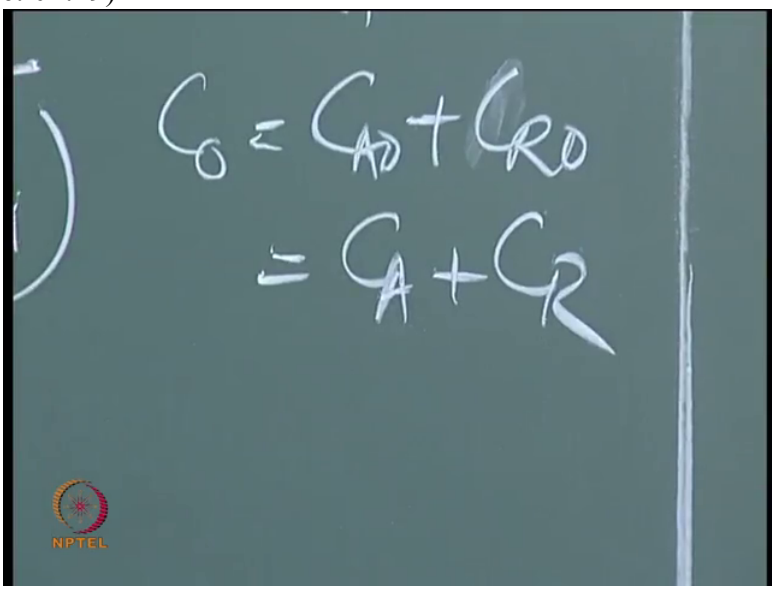

that is simple material balance, Ok. Yeah, so now either you take this C naught, you have C R equal to C naught minus C A. So that you substitute here.

So now this you have to optimize, that means V by F A naught, you have to integrate this one first. So you have to integrate and that integrated expression

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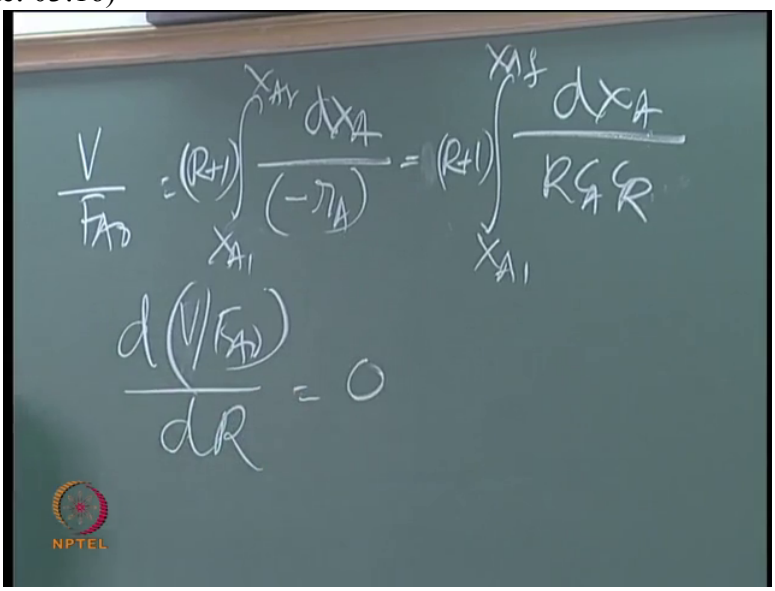

you have to take first derivative equal to zero. Integrated expression, right? So that means this you will have some integrated expression, I am not giving there because I think even though I

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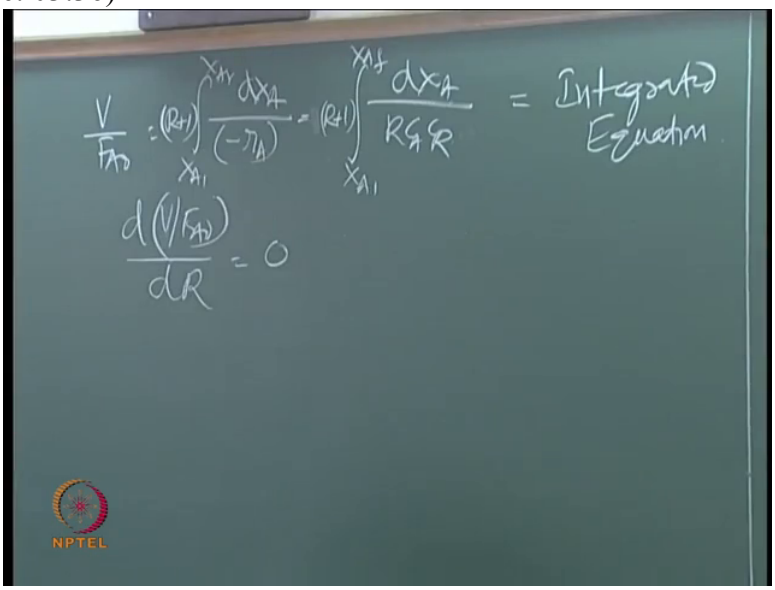

give more work, I think you are not working at all, I think.

This is the analytical procedure where you first substitute, it need not be always k C A C R,

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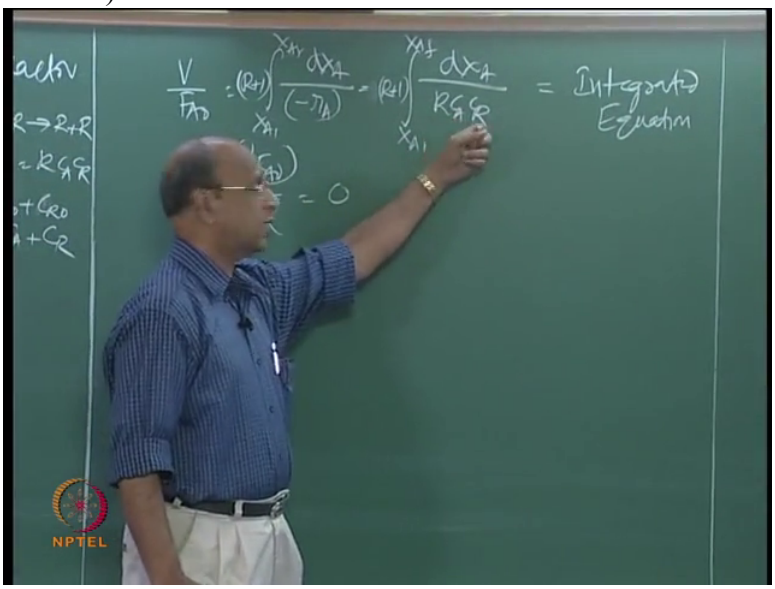

it may be k C A square C R, Ok, that depends on what is the order with respect to A and what

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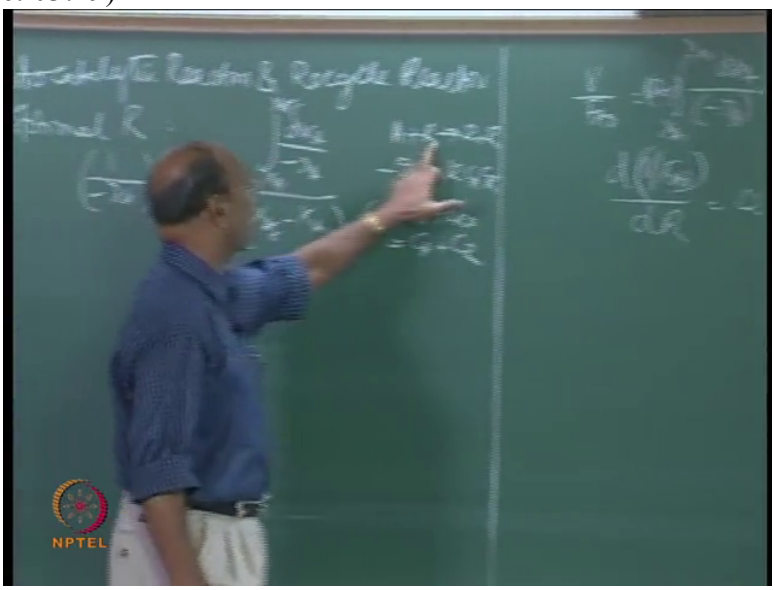

is the order with respect to R and this is also possible that this may be reversible reaction. Then you will have here, minus C R C R, C R square, Ok I mean with respect

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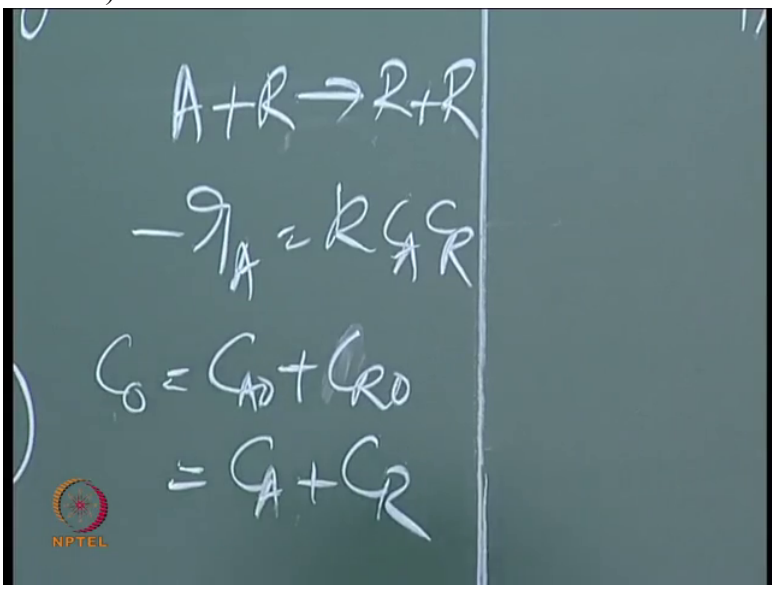

to each first order if you take, good, yeah.

That is why this is one of the biggest headaches in chemical reaction engineering, no. I think the moment I changed either one or two order, you know, this is A plus,

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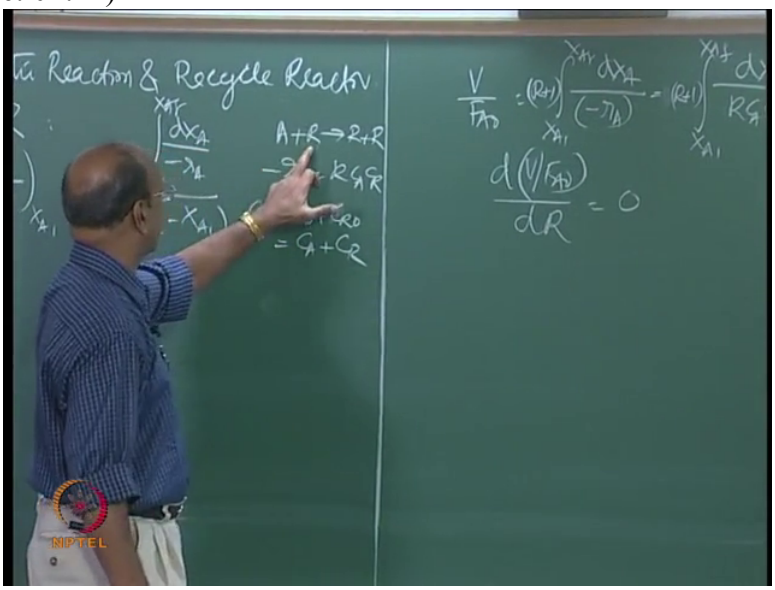

A plus R going to this, right. So if I say elementary only, then it is C A and C R in the rate.

Otherwise if I do not know, if I say that this may be second order, then it will be C A square. So then you will have again lot of problems in the integration, right? So that is why integration, integration, differentiation most of the time in this course you have to do it, right? I think that unsteady state also she is trying.

Anyone has done that unsteady state C S T R? No one, no? This is the problem,

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unfortunate. So this is what is analytic procedure is. Then the moment you have this

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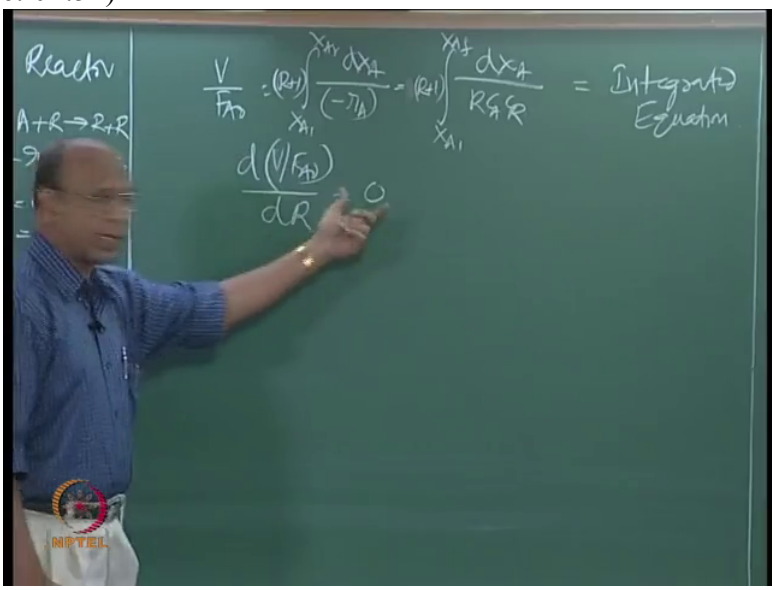

derivative equal to zero, that equation will be only in terms of R and

(Professor – student conversation starts)

Student: X A f.

Professor: Very good, X A f. Ok, So for given conversion of may be 90 percent, or 80 percent or whatever

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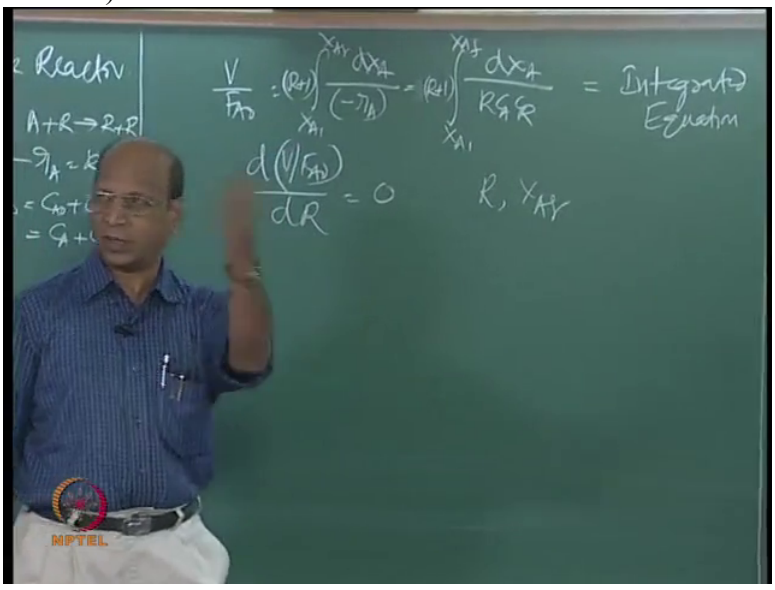

which I ask or which the problem demands, then you will solve that R and you will not get that simple analytical expression. It is mainly trial and error.

(Professor – student conversation ends)

So examination, do not again scold me that you know the question is too long and all that. If your speed is zero, you need infinite time. Correct? You are not able to write at all, your speed is zero, how much time you write? Infinite time you have to write.

Where is infinite time in I I T? You cannot wait, no. You cannot be allowed here to stay infinite time. So that is why I think you have to practice quickly, good. So this is one method. Now I will go to Levenspiel, beautiful method. What is the beautiful method? Graph. Ok. Excellent. This is really very, very nice method. So graphically this is very, in fact it is easy to do it, instead of doing that. But you should be loving to draw the graphs, right? Ok. Yeah.

So for autocatalytic reaction, how do I show the curve? 1 by minus r A versus X A curve? Like this, right? Good,

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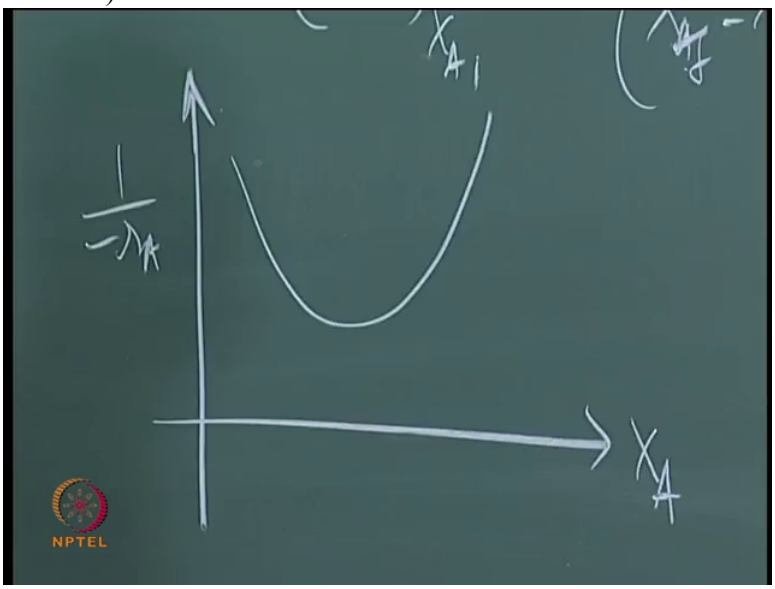

something like this. My X A f is here, because we fix X A f. Then only we are trying to find out R, Ok, optimal R. We are only talking about optimal R. This is X A f, Ok.

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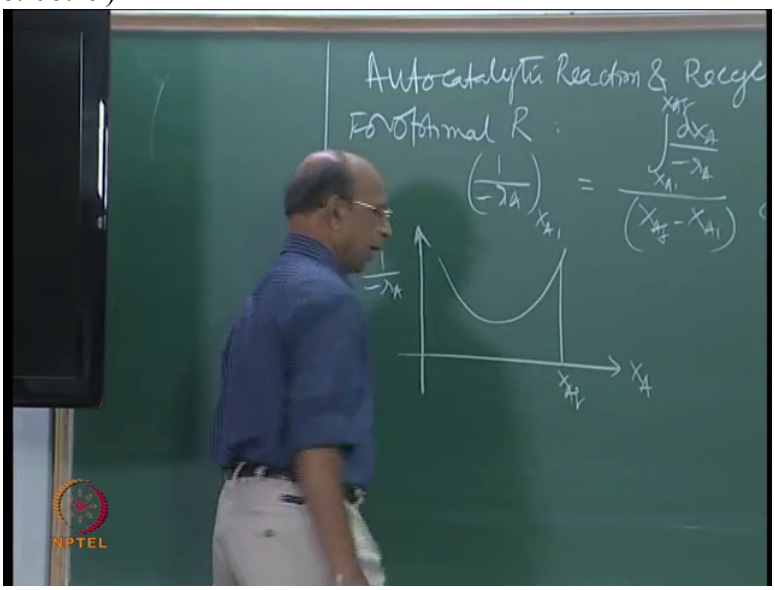

So now for example, without knowing if I say that this is my X A 1, what my condition says? The condition says that the rate

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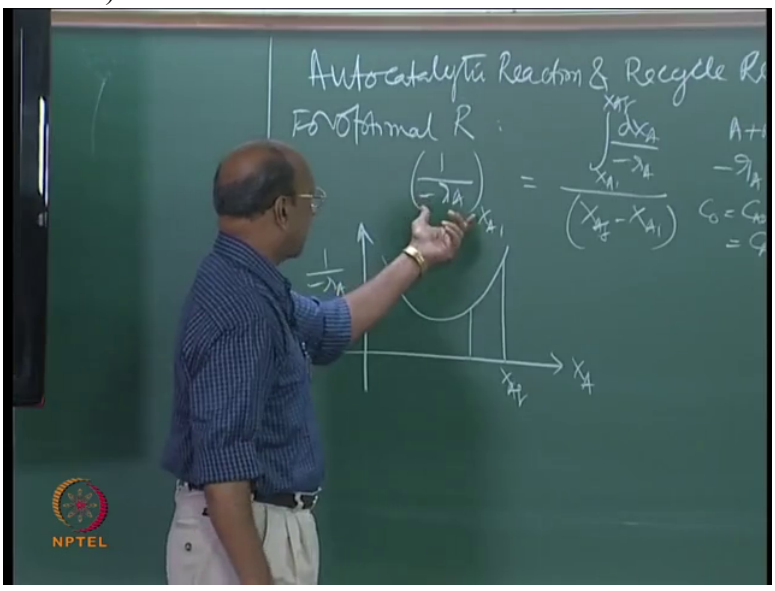

that is entering at x equal to 1, that is at entry, Ok; X A 1 must be equal to the average rate throughout the reactor, Ok.

So here, how did you get average rate graphically in recycle reactor earlier? I have to give connection, no, recycle reaction earlier. Anupriya, I think you have solved that problem. Two areas you had taken and

(Professor – student conversation starts)

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Student: Area under the curve

Professor: Is it like this sometimes?

Student: Area is

Student: Loose connections will be connected.

Student: The area that is left out is compensated by

Professor: Yeah, so we will take, you know average rate will be, yeah something approximately, Oh may be slightly above I have to put. Yeah, so this area when it is equal to this area, this is the average rate, Ok.

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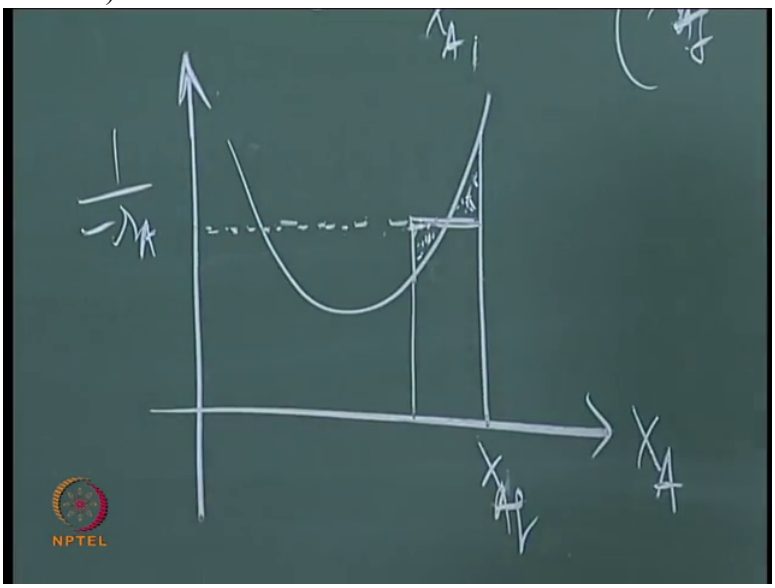

That is the average rate for the entire reactor. Then what is the rate that is entering, entering the element, entering the plug flow element?

Student: It should be the average rate only

Professor: No, no in general I am asking, not the condition. You have not come to optimal at all. Ok. I am just simply asking what is the rate corresponding to X A 1?

Student: Same

Professor: Where is X A 1 here? This one is X A 1. Correspondingly this one is the rate that is entering.

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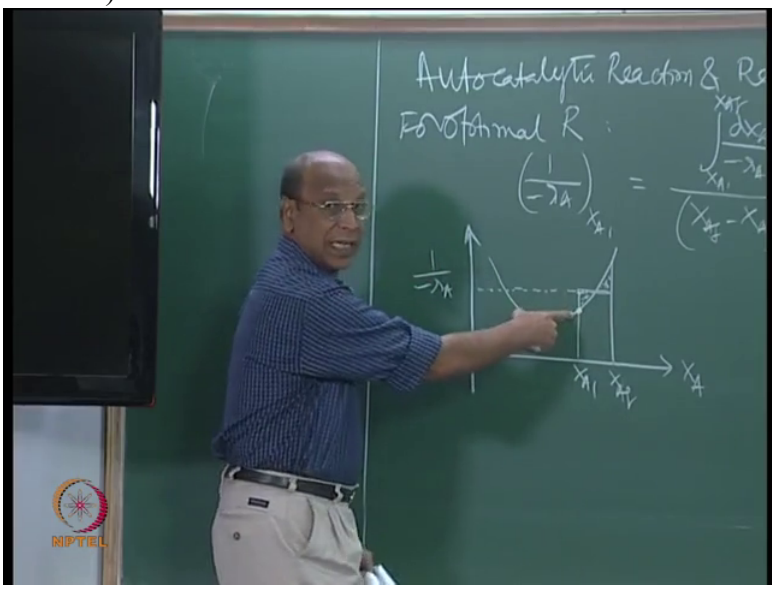

Now this if I say, I mean as per the, yeah, this is point K and this is L and this is this rate P, no, no, no, sorry this is P and Q, both are equal?

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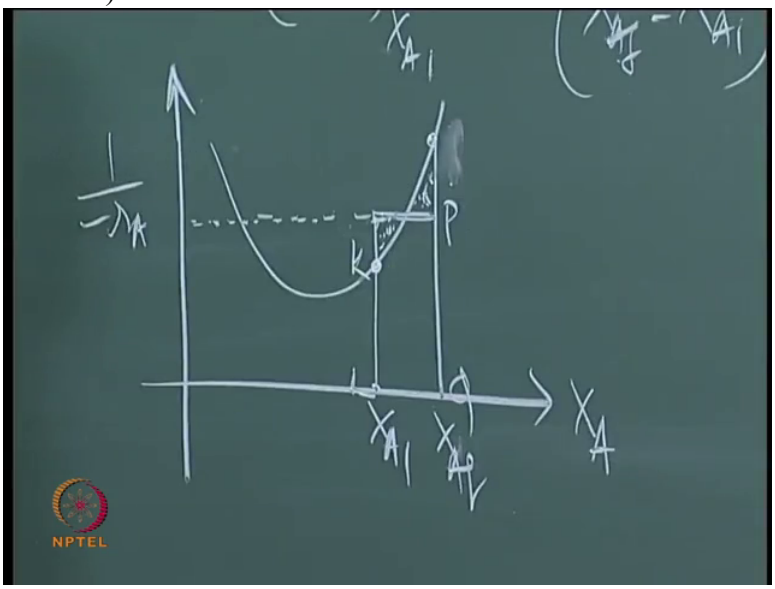

Here P Q is greater than, P Q is greater than K L,

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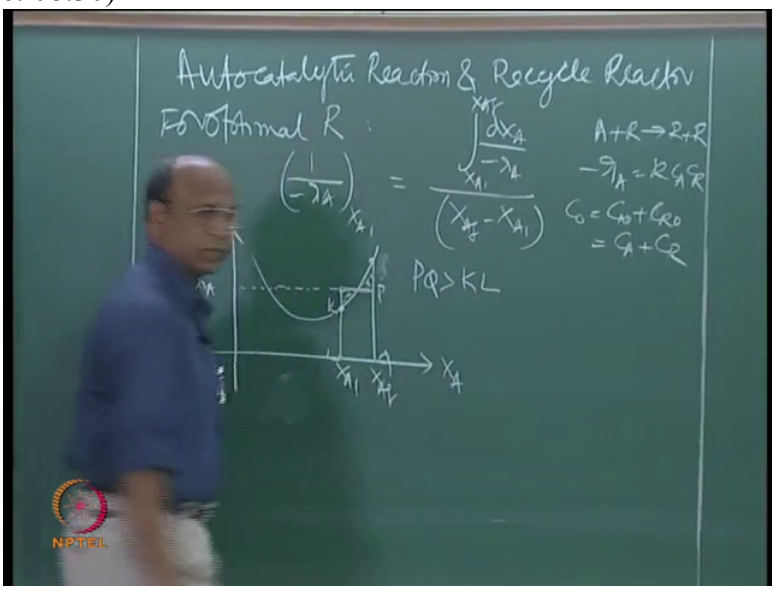

Ok.

So that means recycle is large or recycle is small? I mean compared to optimum. You have optimum, let us say optimum equal to 2; will this be more than 2 or less than 2? You are moving towards plug flow here or towards mixed flow?

Student: Towards mixed flow.

Professor: Yeah towards mixed flow so that means R must be

Student: High

Professor: Yeah, R must be more than optimal value, Ok. So here this is R large. That means this is not optimal.

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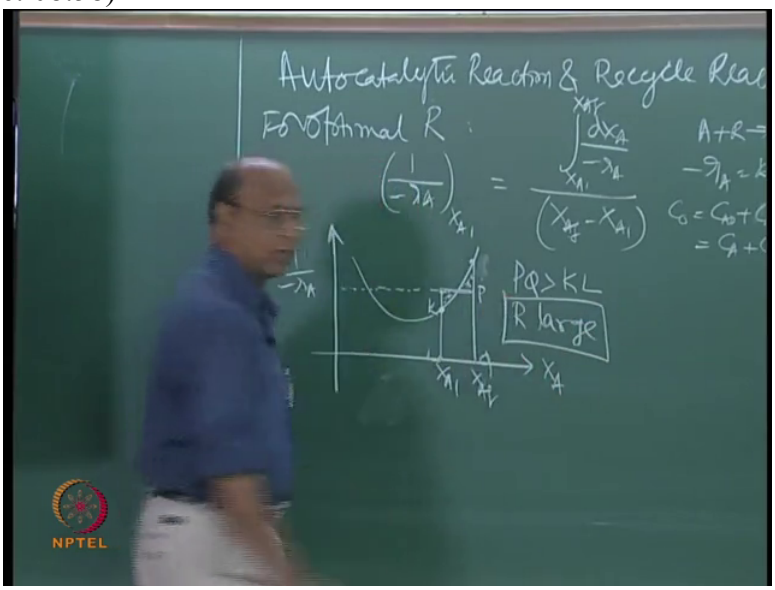

We are all discussing about optimality because yesterday class was continuing, Ok, good yeah. So this is the one.

(Professor – student conversation ends)

So the other possibility is that we have 1 by minus r A versus X A, again same thing, Ok so you may have here somewhere X A f. So I will go somewhere here. This is X A 1. So average rate again I can now get, yeah so again here idea is this rate, this area, this area must be equal to this area.

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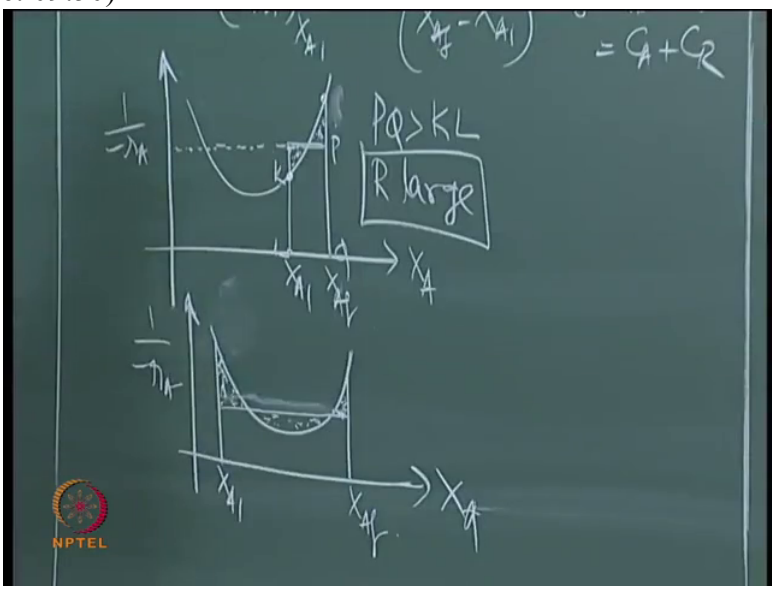

This area and this area I see and this area, then when I have that, I can have here again average rate, Ok. So this average rate again we call, this is P Q, you know average rate.

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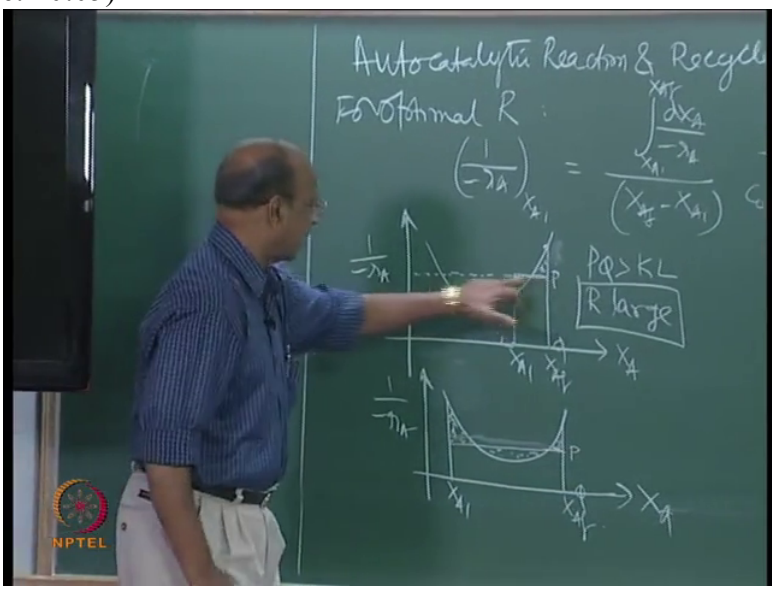

Average rate is you are trying to find out what is the

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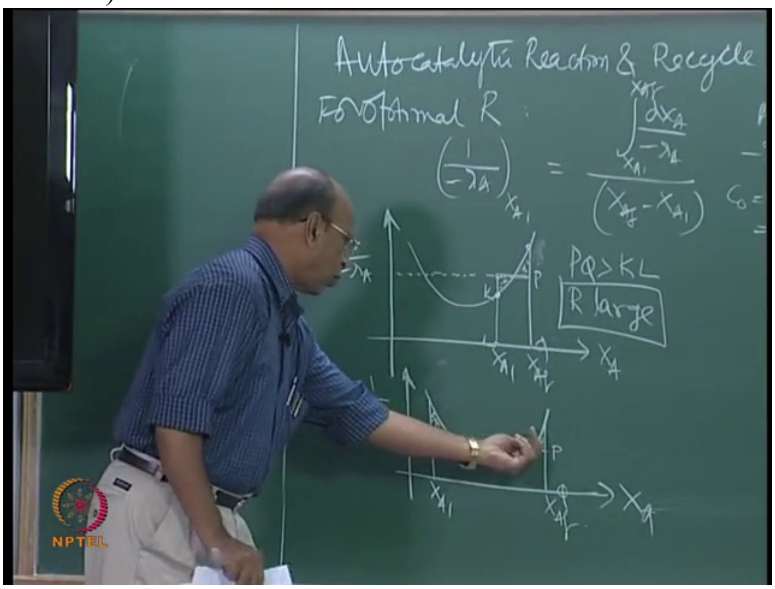

area of this, what is the area of this, so that I will get an average line, Ok.

But here do not get confused because it is too much

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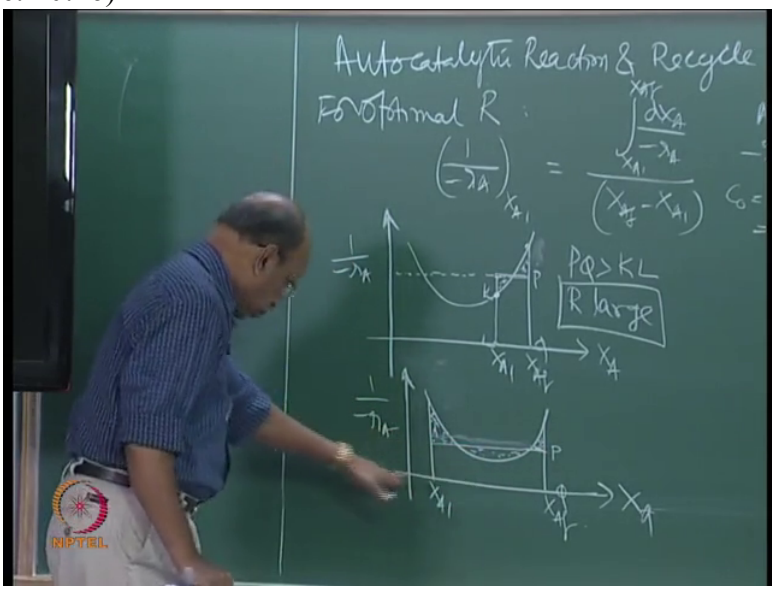

it has gone this side, because of autocatalytic nature, right, Ok. So now this is P Q, where is K L for me? X A 1, this is L, where is K?

(Professor – student conversation starts)

Student: Above that 0:10:31.4

Professor: This one. Now what is the condition? P Q is

Student: Less than

Professor: Less than K L, K L that means what is R value? It will be

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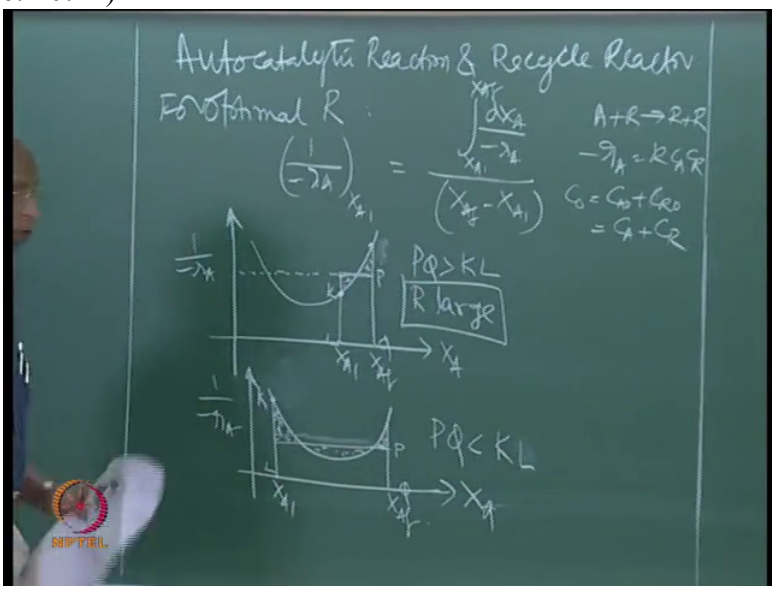

Student: Less.

Professor: Small. That is, R is small R, Ok.

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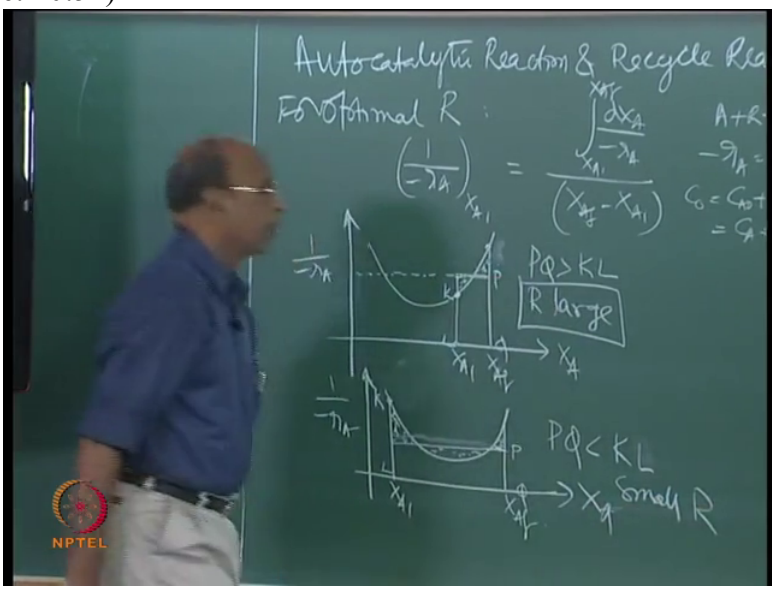

So now we will come to the now, optimal.

(Professor – student conversation ends)

How do you get that optimal? That means this rate P Q also equal to

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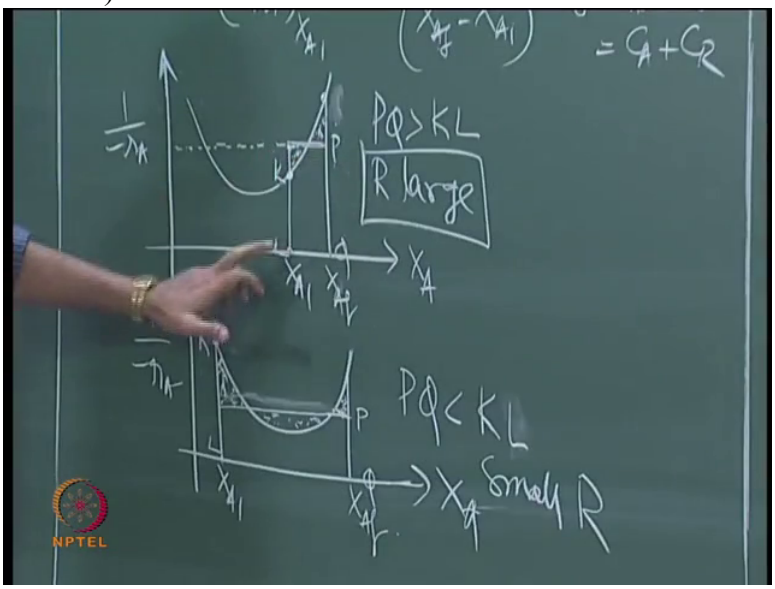

K L. K L is the rate which is entering the plug flow element. Ok. If you have forgotten about that plug flow element, we are talking about, Ok, this one here. This is X A 1, corresponding this when it just entering, what is the rate? That rate is this rate, plug flow

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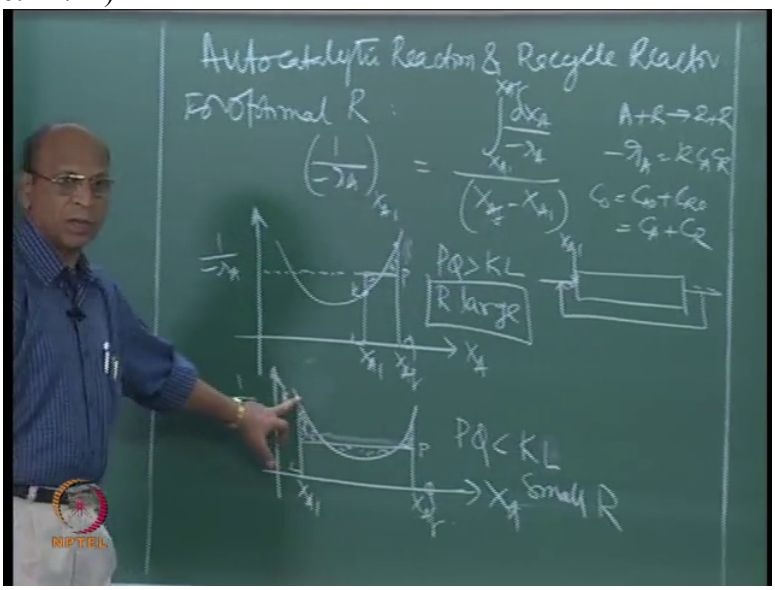

element, right?

And all this one is,

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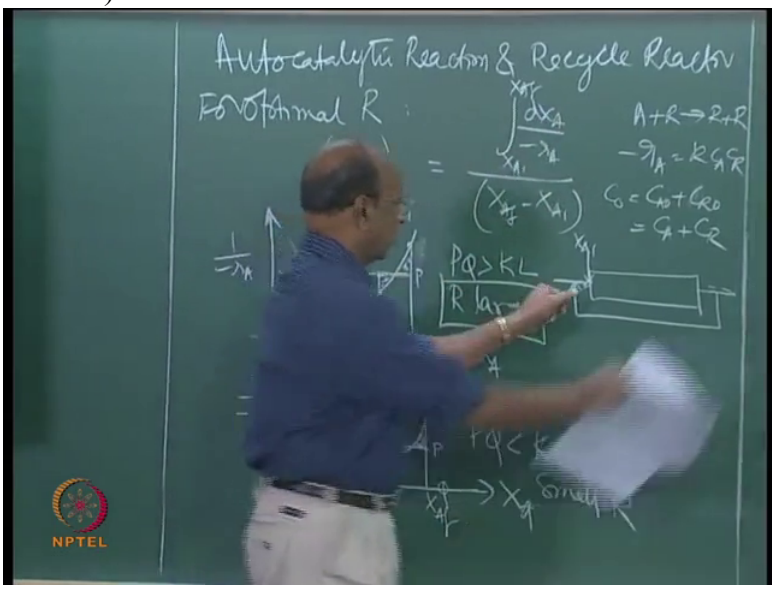

overall from here to here what is happening, Ok. So my optimal ratio will tell me that these two must be same.

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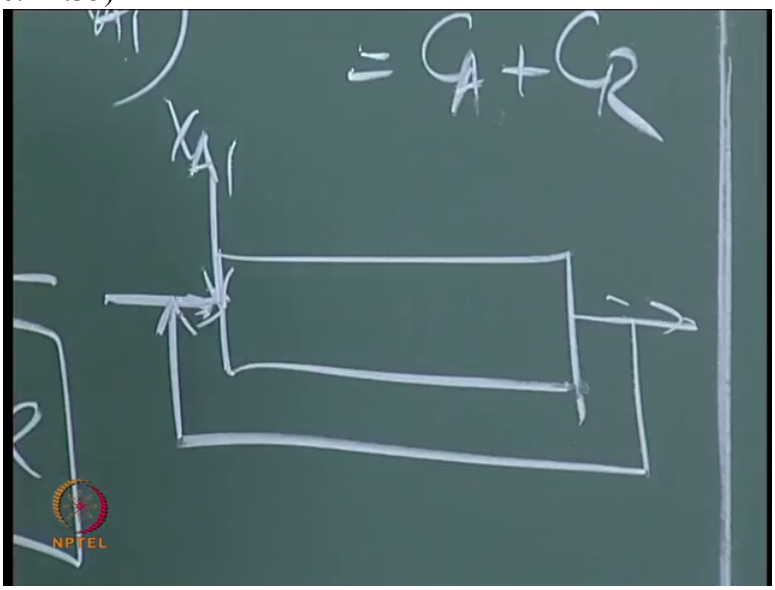

Now you can plot the other graph again X A versus 1 by minus r A, then you will have like this.

X A is fixed, right.

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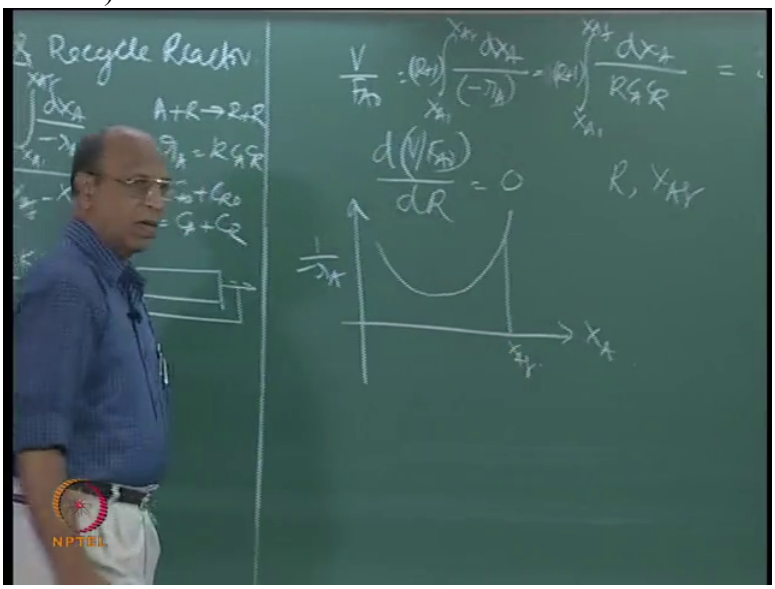

So now we will move like

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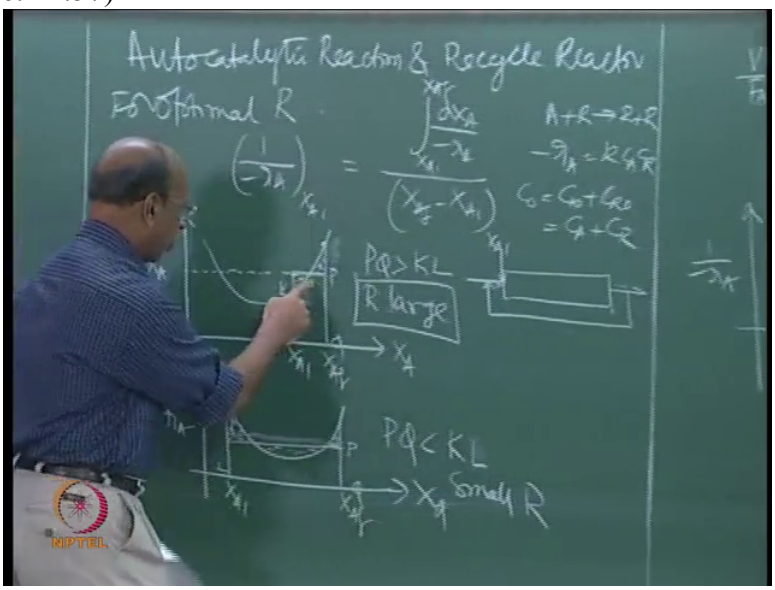

this slowly, Ok this area, you know, this area equal to this area if I take at this point, K L is not equal to K P right? So then I will draw this X A 1 somewhere here.

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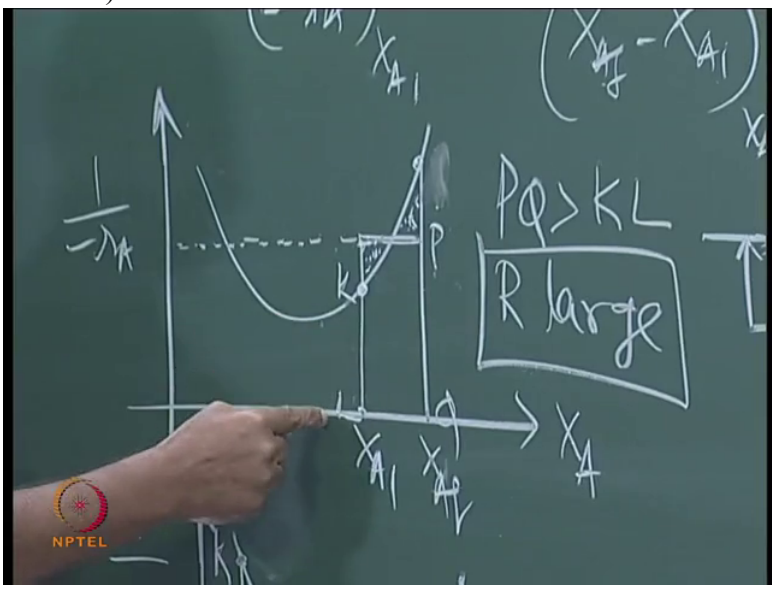

And again take the average line, Ok.

So like that when I adjust my areas, you will get a condition where both P and Q will be same. Ok, P Q equal to K L condition you will get, so that will be, Ok something like this, ultimately this area, yeah so where this area equal to, what you have to do is you have to calculate, you know, imagine,

Imagine a small line you have to draw and find out this area and then afterwards move, again find out this area, afterwards move, find out this area and you will have a condition where this area will be equal to this area and then this will be the X A 1, and this one, this is yeah, this is P Q and this one is K L.

Those who love graphs, they can try this method. And those who like equations, you will take two hours, Ok

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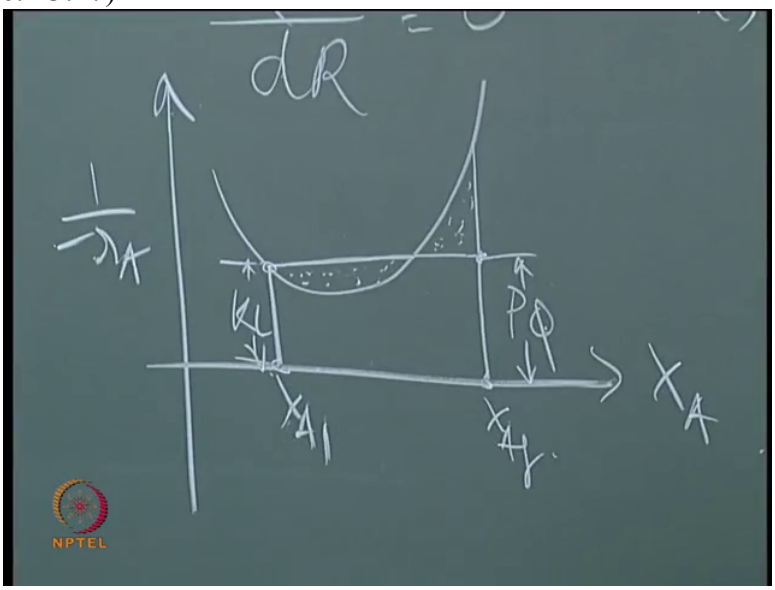

because differentiation and, particularly that equation always you will get one side logarithmic term, other side you will have normal term so then you know to find out, by trial and error you have to do.

Assume R equal to something. Calculate both the terms, by trial and error matching. Or otherwise you can use some other technique; you know to find out what is the intersection value, Ok, yeah. So good. That is nice. So this is one. This is what is the optimal ratio when K L equal to P Q,

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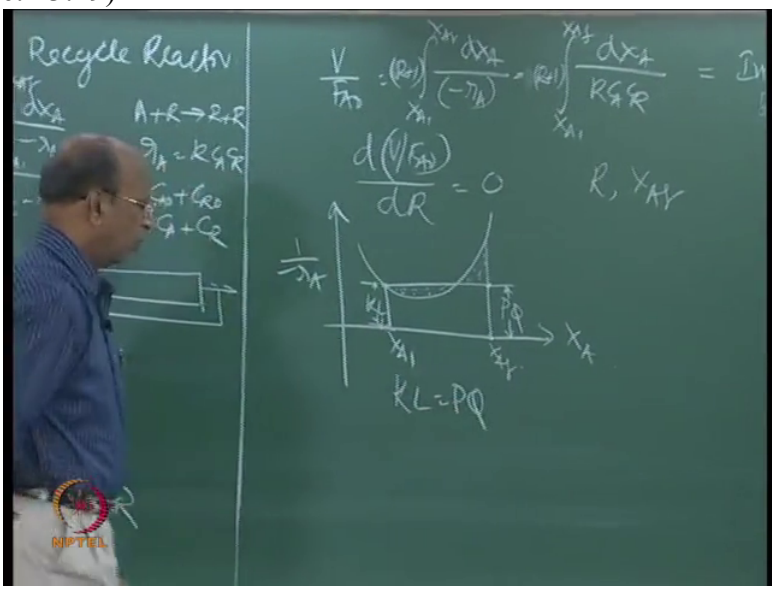

we have optimal R. Ok.

So now how do I get optimal R from this graph

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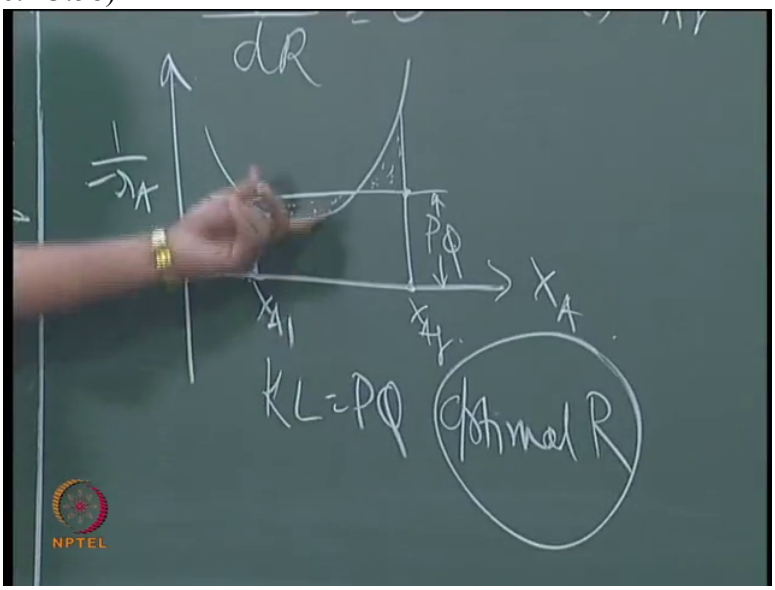

now? Ok I, I managed this area equal to that area. And P Q equal to K L, that condition is there. So then now how do I get now R?

(Professor – student conversation starts)

Student: X A 1 minus X A f

Professor: Yeah, excellent. X A 1, I thought you have forgotten but you remember. This is R by R plus 1 X A f. X A f I know already because I am fixing X A f,

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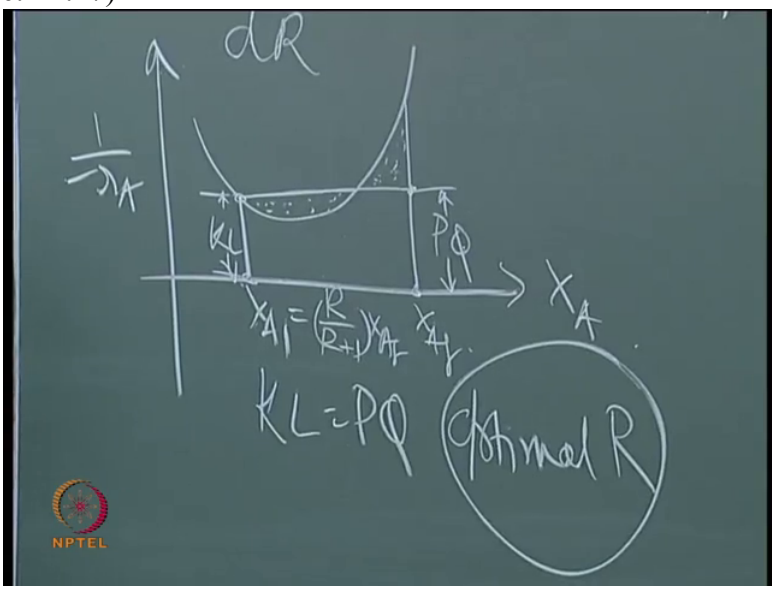

Ok otherwise that is not possible.

So easily one can estimate the optimal R. This is very good particularly for biochemical reactions and you know Monod's equation is an autocatalytic reaction. Not Michelis Menten equation, Monod's equation. Why? Because initially you have...and how do you produce by the by, alcohol? Biologically, yeah?

Student: Fermentation

Professor: Fermentation. What is really happening in fermentation?

Student: Bio molecule, microorganism

Professor: Yeah you take

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sugar source and you grow the microorganisms in that.

(Professor – student conversation ends)

So

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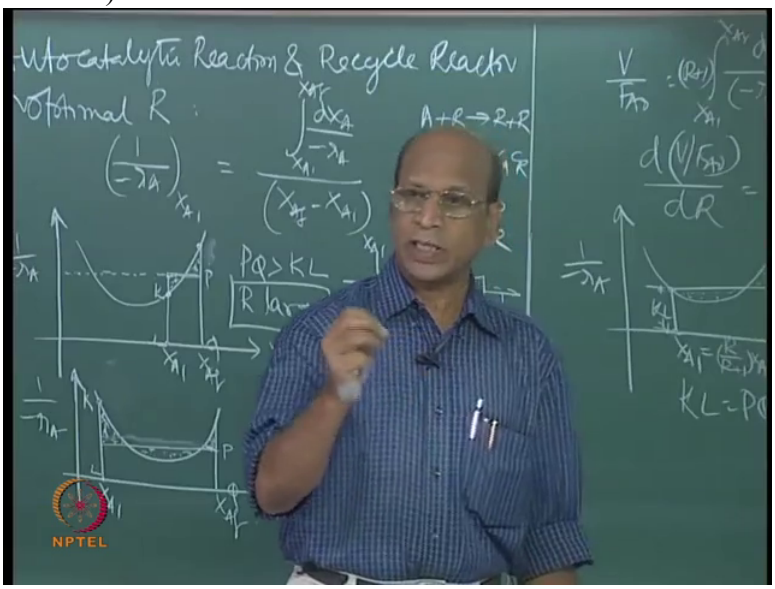

initially you seed, like curd only. You add a small amount of previous curd. That is microorganisms you are putting. So that will multiply, multiply, multiply and then it will make a solid, you know curd, right?

That means you are also taking, you know lot of those microorganisms. You are not separating them again. From curd are you separating? No, actually you should not separate because they are good for the stomach. Yeah, so that is why I think what they call, probiotic? Probiotic, Ok. Antibiotics only we do not like but anyway we have to take most of the time.

So this is why initially when you put small amount of curd, that means small amount of microorganism, it takes some time that is why that 8 hours and all that is required. Ok it first gets acclimatized to that environment and then once it starts eating food, once the environment is good I told you no,

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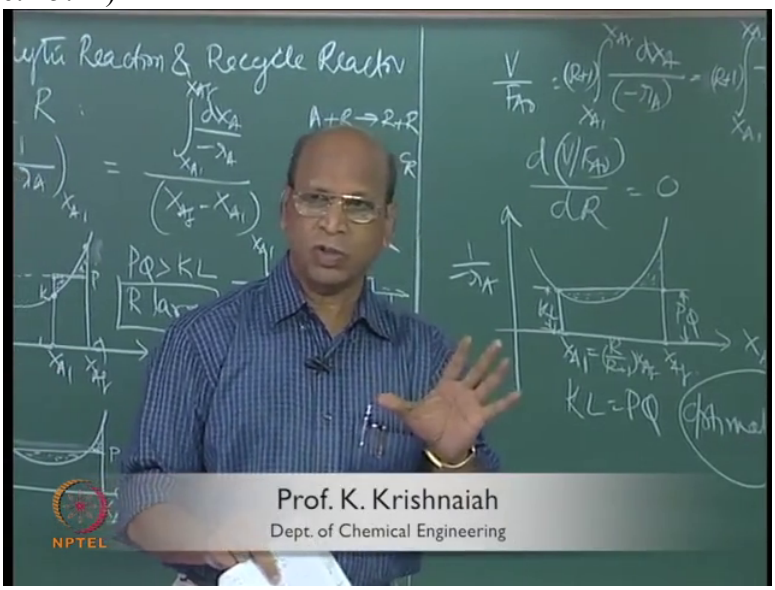

like human beings once you have good food, good house and all that, only production of children, that is all, nothing else.

No, because that is the, because that is the nature of this planet. We do not have to really take it as you know, you know laughing matter, really. Because any life, definition of life is propagating in your own species. That is one of the definitions of life on this planet. Otherwise you would not have been here, I would not have been here, there is no C R T class. No really, I think you know...

(Refer Slide Time: 16:12)

(Professor – student conversation starts)

Student: (laugh)

Professor: If that would have not happened. Right, yeah so that is why

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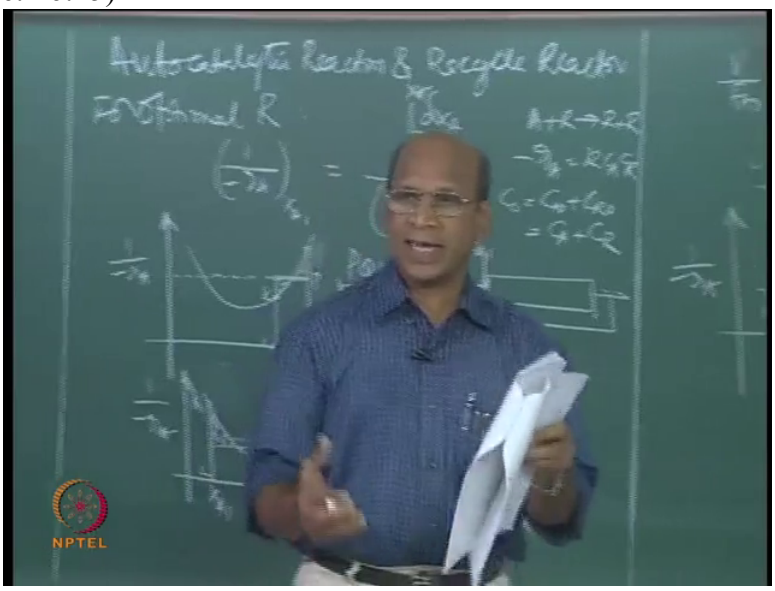

you know initially the, slowly it will grow. And then the rate of reaction, in fermentation if you come, if you forget about curd and fermentation if you come then what happens, initially small amount of microorganisms are there. Then it will get acclimatized and then it is ready now to produce and afterwards it starts producing more and more.

(Professor – student conversation ends)

Now what happens? If it is a batch process, batch fermentation, then you have more and more microorganisms growing and the sugar source, that total amount of food available is only limited. So that is why after some time, the population is more. There is no food. Then people start dying.

Exactly, same thing our planet also is going to go to only that direction. Because we have so many people, 11 billion, by the class is over another 2 millions would have been added, yeah really. Because throughout the world, no.

So that is why initially when I write the rate of reaction it is the concentration of glucose and concentration of microorganisms. Initially microorganism concentration is small,

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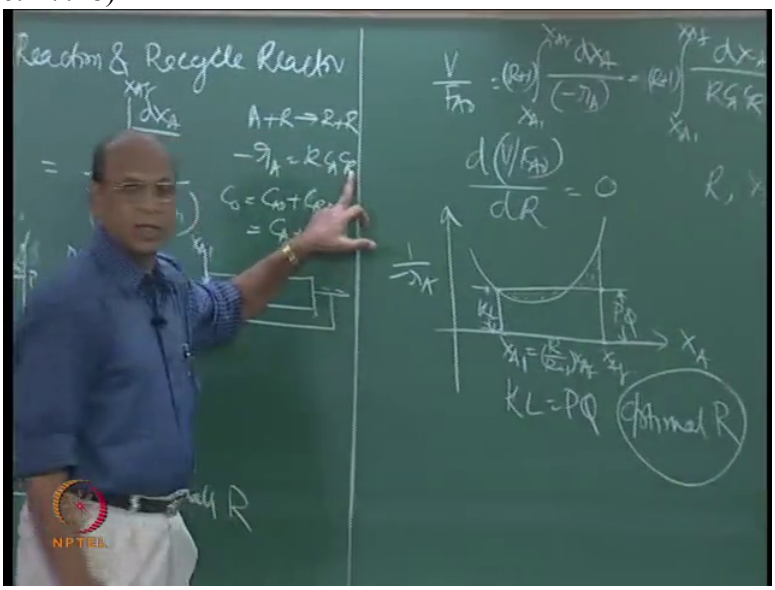

C R, Ok. Then after some time

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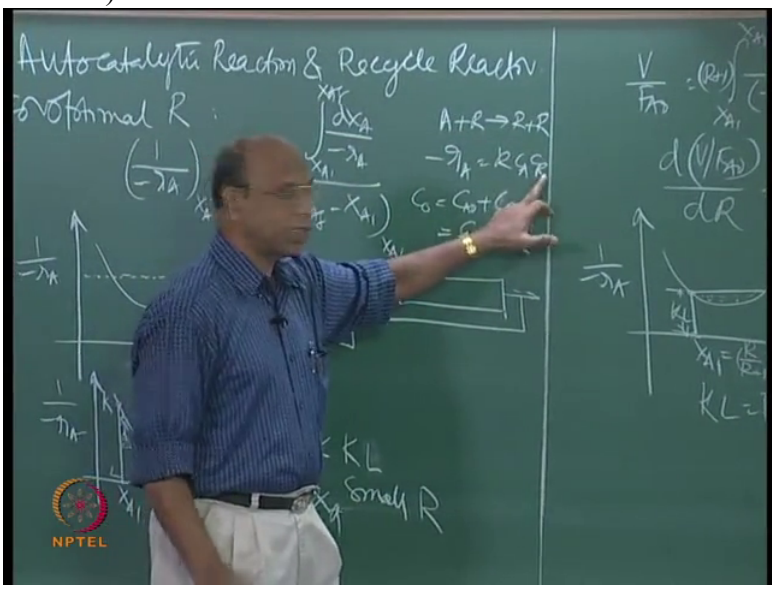

C R will be slowly increasing. C A will be decreasing.

So that is why it goes to maximum rate and then again falls, Ok. Now on this planet we are in this region, no, falling region. Because more people, less food, many people are dying. So that is why it is a beautiful example for autocatalytic reaction. Fermentation. Ok, what do you produce from fermentation?

(Professor – student conversation starts)

Student: Alcohol

Professor: Alcohol, what do you do with that?

Student: (laugh)

Student: Drink

Professor: Yeah, we drink all the time. If I tell you those, you know those at least happy to drink or those who are thinking of drinking, you cannot drink at all. You know what you drink there? It is the waste material of microorganism. What do you call that in English? S h i t.

Student: (laugh)

Professor: Ok, yeah. That is what what we drink happily and then do whatever we want.

Student: (laugh)

Professor: I think, you know if you just imagine that

(Refer Slide Time: 18:17)

Student: May be Sir curd is also same....

Professor: Exactly

Student: (laugh)

Professor: Curd also is same,

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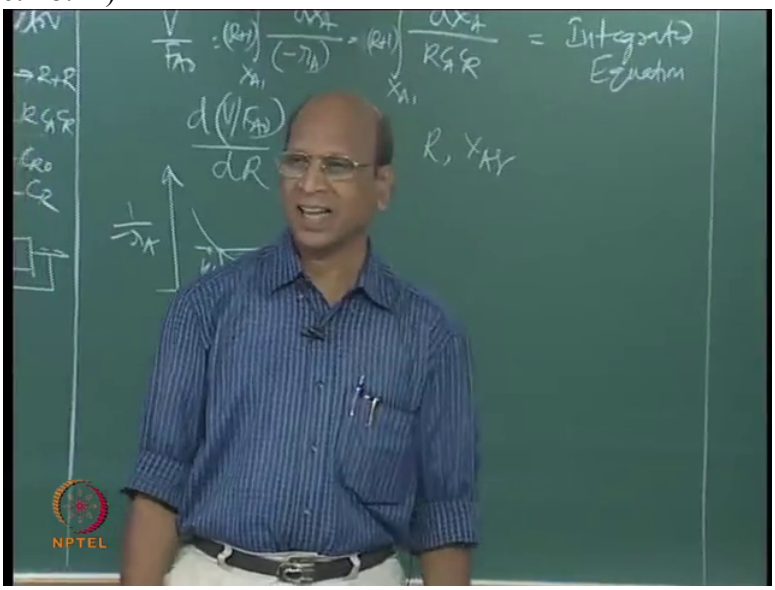

yeah.

(Professor – student conversation ends)

You know microorganisms take the glucose and then they produce the waste product, Ok. That waste product is alcohol. Even antibiotics and all that what you produce through microorganisms, all of it is only waste product. See that waste is so great, saving lives and all that, right? But alcohol taking is not good. I think that is useless material. Really useless material. Do not drink that. Ok, good.

So that is what is autocatalytic reaction, one of the very good examples for us. Ok. There are many other autocatalytic reactions, particularly in organic chemistry reactions. So all of them, they need only this

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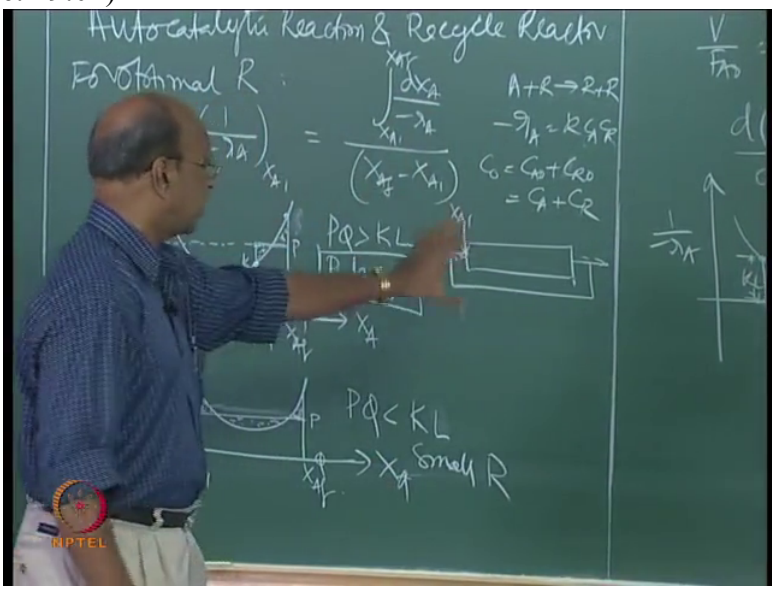

procedure if you want to produce, if you want to use recycle reactor and you want to produce very, very optimal, either design optimal reactor or for a given volume produce maximum X A, Ok, yeah conversion. So this is the one, good.

So what else we have now? I think now, we have to do a problem; very quickly we will do that. Ok and there are 1 or 2 things before doing that problem. You have the recycle reactor. Just forget about autocatalytic reaction. You have the normal reaction. Right.

You have an equation. I also gave the equation for first order, second order. I am sure you would have not derived. And in the examination if I give, again, and only thing is you only scold me. By scolding me you do not get marks, no. Because I think he is giving very tough question paper and all that. What you have to do is you have to solve the problems, not once, many times.

So what I was telling was if you come to recycle reactor, now there are 3 things where for simple orders you can have that equivalence, right? Plug flow I have. And that can be replaced by infinite number of mixed flow reactors. That is one equivalence. Now the same plug flow can be replaced by zero recycle or infinite R will be mixed flow. These are the two extremes.

But in between any time, if I have 3 tanks, can I imagine that it is equivalent to a recycle reactor? Yes, definitely. That is what is the beauty in mixing. That is what all the time we are discussing about recycle reactors where I can control my mixing.

One mixing equal to infinity, you know, single C S T R if I have. Then if I have two, then I am reducing mixing or increasing mixing? Because 2 times you are stirring so mixing is increased. When I take two tanks, two mixed reactors and then put in series, am I decreasing mixing or increasing mixing?

(Professor – student conversation starts)
Student: Increasing
Professor: I am decreasing mixing. So 3, some more decrease. 4 some more. Infinity? Zero mixing, Ok.
(Professor – student conversation ends)

So similarly now I can imagine recycle infinity means perfect mixing. Recycle zero means no mixing, zero mixing. So in between I have various Rs which are now also equivalent to N. Try to find out that. And it is very good for me to give a nice, simple separate test there. Every time I am blackmailing with tests only.

Ok, I may ask, for example, Ok 2 tanks, N equal to 2 means equivalent to how much is the recycle ratio? Or N equal to 3 means how much equivalence in terms of recycle ratio. And when you come to R T D, I hope we will come to R T D, so at that time that is also replaced by what is called a dispersion number. Because some of you know already, that is why I am telling you. Dispersion number zero means which reactor?

(Professor – student conversation starts)
Student: P F R
Professor: P F R. Dispersion number infinity means
Student: M F R
Professor: So now any intermediate dispersion number means equivalent to some R, equivalent to some N. So those are the three equivalences. So wonderful. You can also always

find out what is the dispersion number and normally it should be a plug flow reactor. If it is a single C S T R then I do not have that chance.

(Professor – student conversation ends)

But I can also imagine. I have 5 tanks in series. Now I can imagine that this is equivalent to some recycle ratio, recycle reactor with some recycle ratio or plug flow reactor with some dispersion number. You see the beautiful connections at that level.

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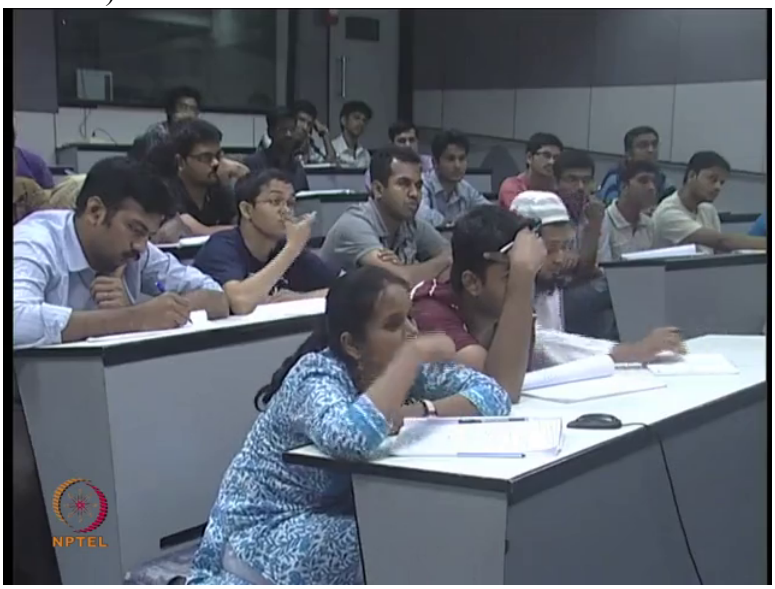

All talking and we are not at all unsteady state people here.

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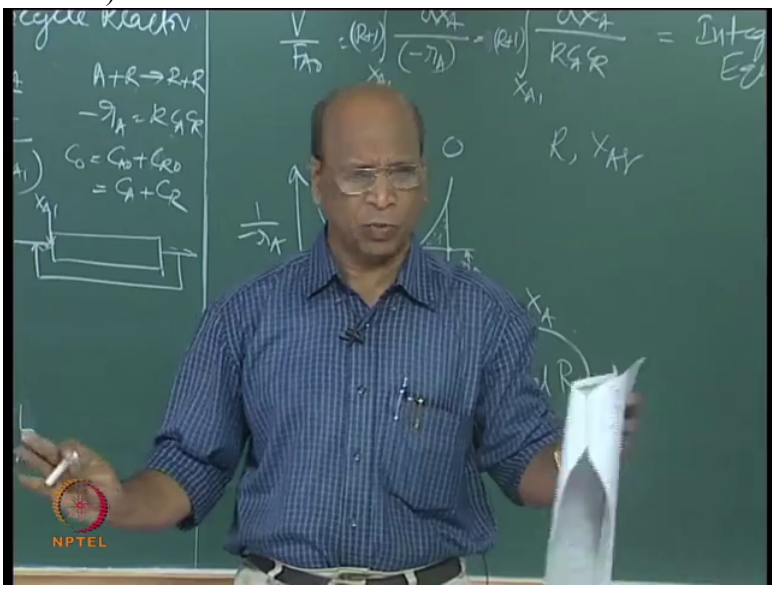

Only one problem I have given on unsteady state, Ok.

(Professor – student conversation starts)

Student: 0:22:50.6

Professor: Dispersion, how, I mean how can you say that zero dispersion is, sorry some dispersion equivalent to unsteady state? That means what you will call...

Student: Dispersion 0:23:00.9 is zero using P F R?

Professor: Yeah but what will you call mixed flow reactor when I have infinite dispersion? Is it called

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unsteady state?

Student: No

Professor: Then why are you not calling there? Only when you say

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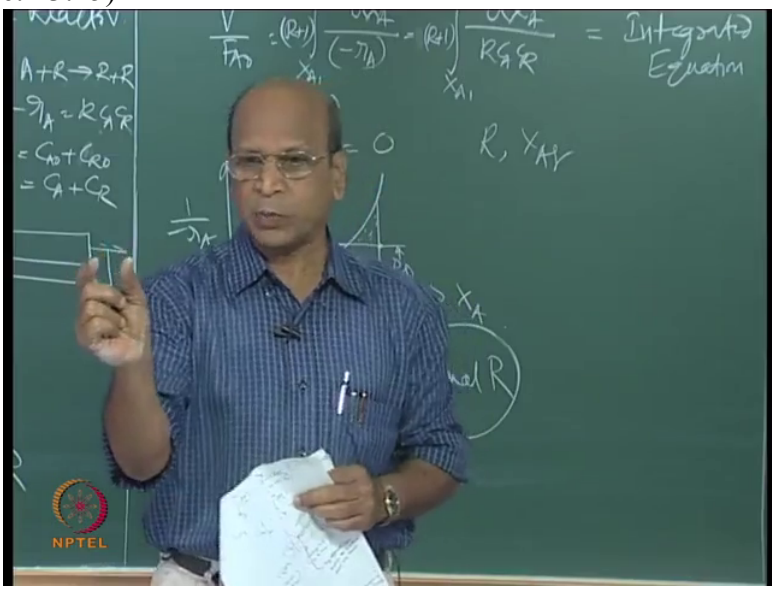

P F R with dispersion how can you say that it is unsteady state?

Student: P F R is ideal

Professor: Ideality is different and what you know what she is asking is different. Unsteady state, steady state is different.

Student: It is not ideal P F R

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then.

Professor: It is not ideal P F R that is all. It is non-ideal P F R with dispersion.

(Professor – student conversation ends)

Because our definition of dispersion is, I mean yeah reactor is,

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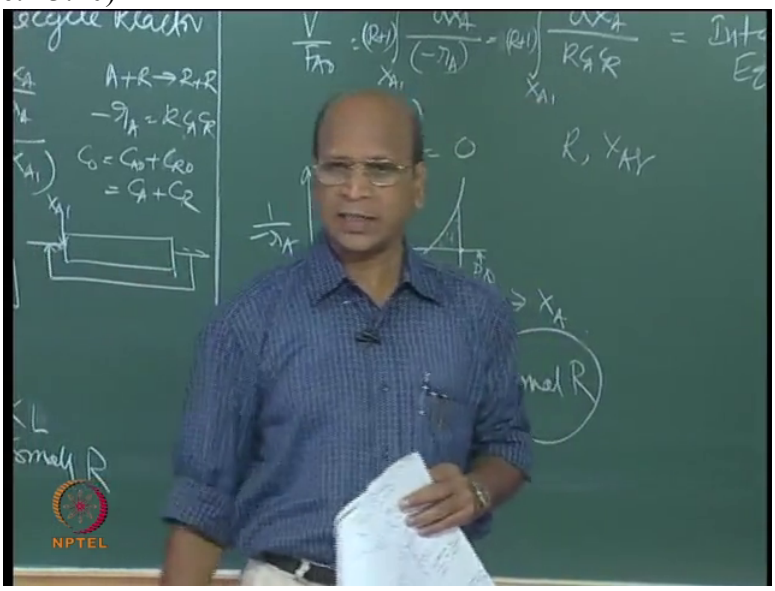

of ideal reactor is dispersion equal to zero. Right, yeah, I think you know I told you all Indians are brothers and sisters. Only she asked. Most of you also may be having the same doubt. Ok. So when you have this dispersion or when you have some kind of dead space or bypassing they are not unsteady state.

By the way what is the difference between unsteady state and steady state?

(Professor – student conversation starts)

(Refer Slide Time: 24:03)

Student: Change in time is constant, that is called steady state.

Professor: Then is it equilibrium then?

Student: No, it is not steady state.

Professor: Then what is exact difference between steady state and unsteady state?

Student: No gradient.

Professor: No gradient?

Student: No change,

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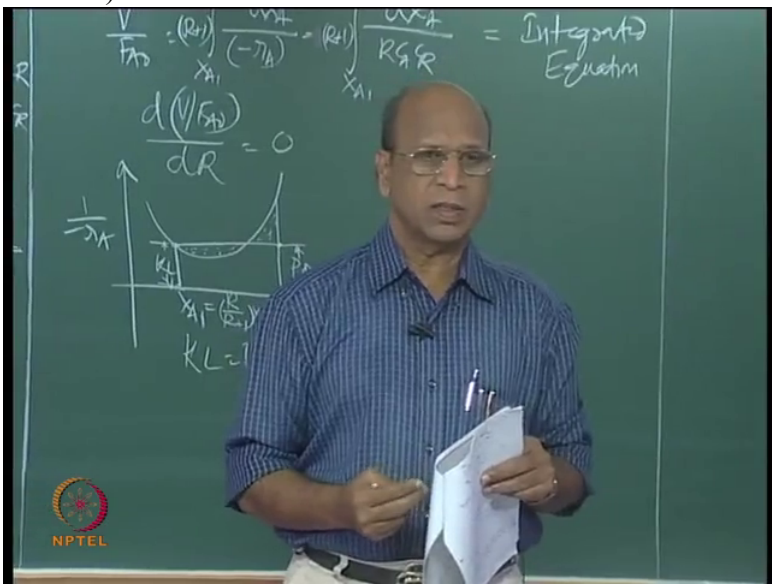

equilibrium

Student: With respect to time there will be no change

Professor: Yeah, at any position when you look

Student: Position

Professor: At any position you look, you know that concentration is same

Student: Is same

Professor: But not gradient zero, there is gradient.

Student: Gradient is there.

Professor: Gradient is there.

(Professor – student conversation ends)

That means along the plug flow reactor I am introducing C A naught, and I am getting C A outside but everywhere inside, I have decreasing, decreasing, decreasing till that outlet concentration. But at any point if I look even 100 years if it is steady state, that concentration is same. At outlet it is same. That inlet it is same. That is what is steady state.

And equilibrium is gradient zero. That is thermodynamic equilibrium. That is like you know; you come and spray some perfume here, right? So after 5 hours if you come then the entire room will be smelling uniformly same, that is what is equilibrium. There are no gradients.

Otherwise the moment I spray here, only I will get maximum smell. Next Pooja may get, that is all. But Gopi will not get. Gopi gets only after 5 years. After, if the diffusion is slow, slowly it is diffusing and then you know and all the gradients died down, so finally it occupies uniform concentration throughout this room. That is what is equilibrium. Please remember.

That is one of the good question that will be asked in good interviews. There are many lousy interviews where they ask how many fathers, how many mothers? If you say 2 mothers, 2 fathers, 2 jobs you will get. Because this is a great, innovation, Ok. So there are many, many lousy interviews also I have seen. I think we are talking about decent interviews in engineering. You will definitely learn a lot. Ok, through interviews also. Good.

That is why please remember this equivalence. If I have 2 tanks how can I replace that by with single R? Or if I have recycle ratio of 5, how do I replace that with, yeah, tanks in series? Equal number of course, equal thing, this is very good problem.

You see that, no, if you had sufficient, if my zeroth test was really successful test, zeroth test, that means all of you had answered, all this things I would have really pushed you Ok, but now I think we have gone to L K G and then from there we started coming. So that is the problem.

Otherwise you know all these wonderful things you will have lots of time to discuss if we had. That is why I am taking more classes and all that to cover that loss. Ok, good. So this is one of the very good problems you have to please try. Ok, good and also it is by trial and error and all that. So please try. Unless you try in your room you cannot solve that in the examination hall. Good.

Now take this problem. We will solve the problem. First we will define the problem. I think affterwards we will see. Tomorrow we will solve the problem. Yeah, problem.

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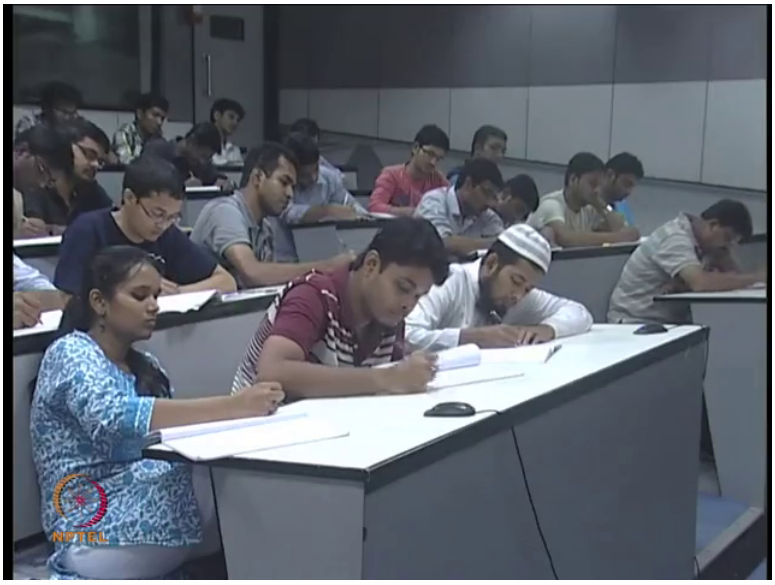

We explore various reactor setups for converting A into R, full stop.

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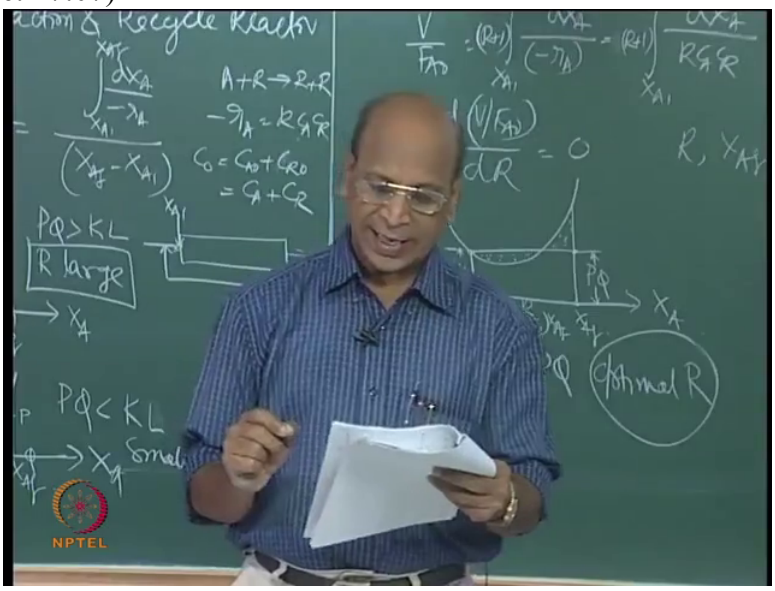

The feed contains 99 percent A, 1 percent R and the desired product is to consist of 10 percent A and 90 percent R, full stop.

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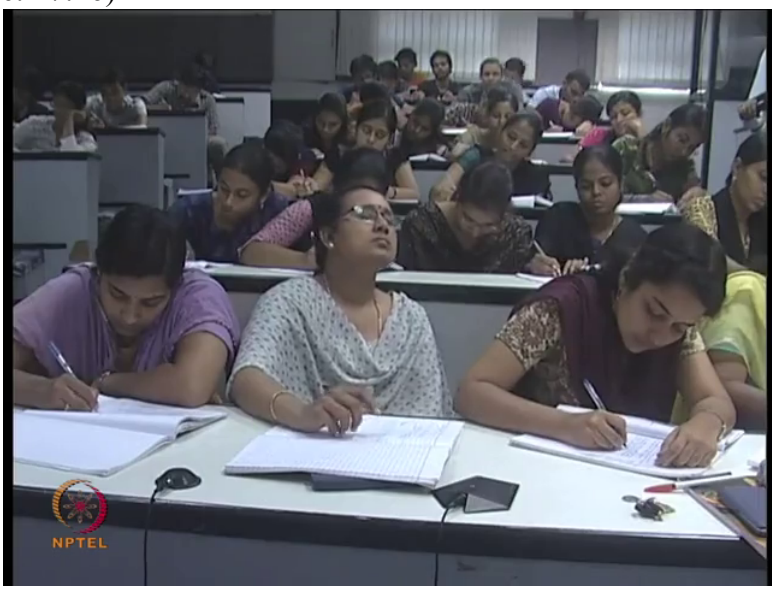

The transformation takes place by means of an elementary reaction A plus R going to R plus R

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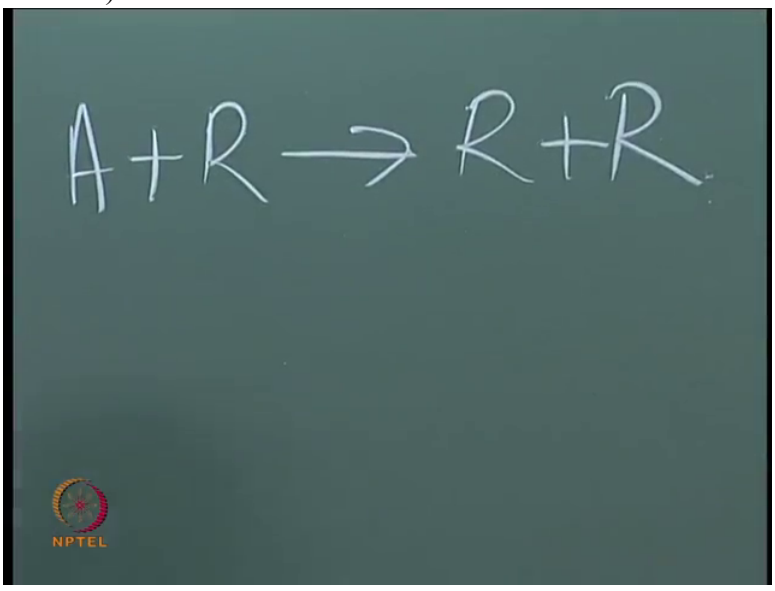

with rate constant k equal to 1 liter per mole per minute.

It is autocatalytic reaction, no?

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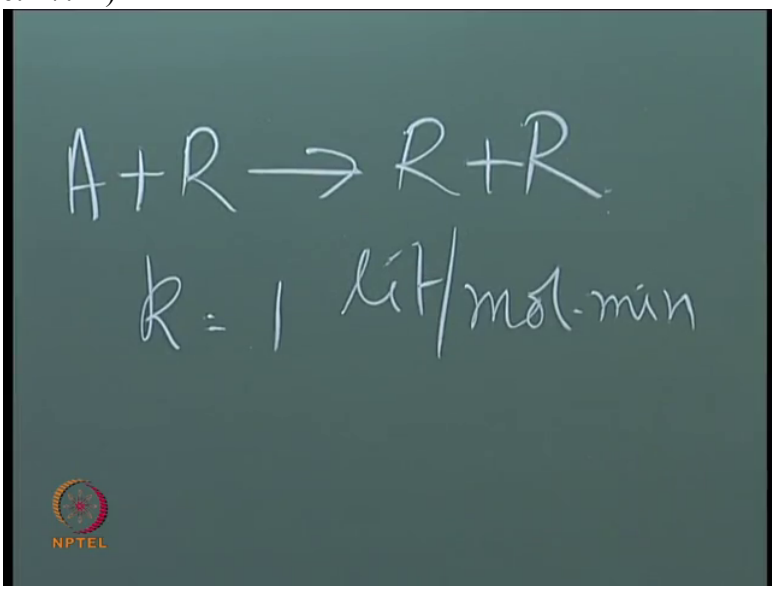

Very good. It is elementary. So you know the exact one, yeah.

So the concentration of active materials is C A naught plus C R naught equal to C A plus C R equal to C naught equal to 1 mole per liter, yeah liter only, yeah, yeah,

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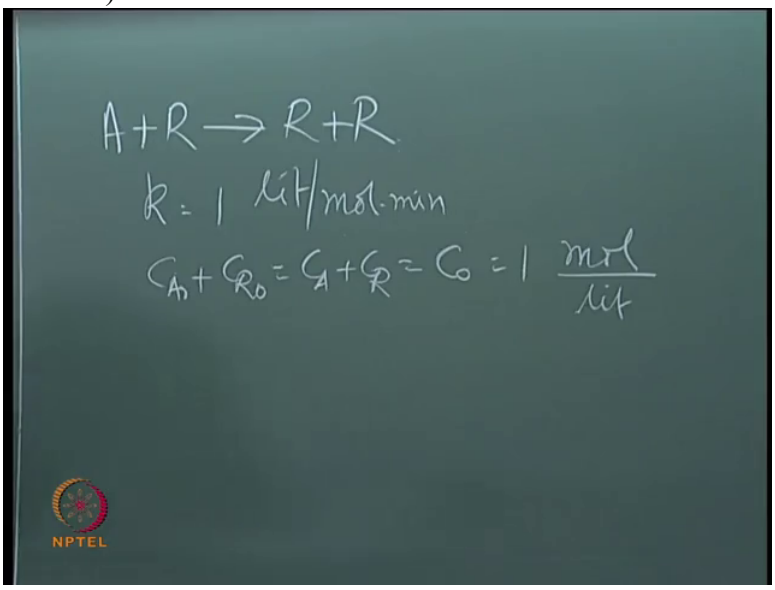

throughout. You can also write there throughout, that means throughout the reactor this material balance is valid.

Ok next one, what reactor holding time will yield, will yield a product in which C R equal to, in which C R equal to point 9 moles per liter. Ok, what reactor holding time, that means tau

you have to calculate. Right. What reactor holding time will yield a product in which C R equal to point 9 moles per liter? What is the conversion? 90 percent, Ok. Because it is 1.
We have to now find out what is tau for a P F R, Ok, P F R and b, M F R

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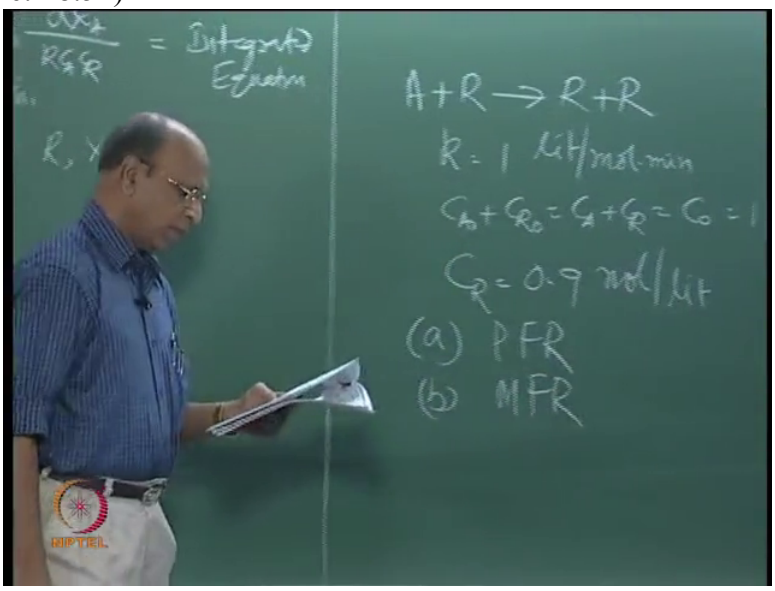

that means one, one reactor. And c, minimize size setup without, without recycle, minimum size, please see the word, minimum size setup, so it is not one reactor, it can be 2 reactors also. Minimum size setup with, without yeah, without recycle, without R. Without recycle.

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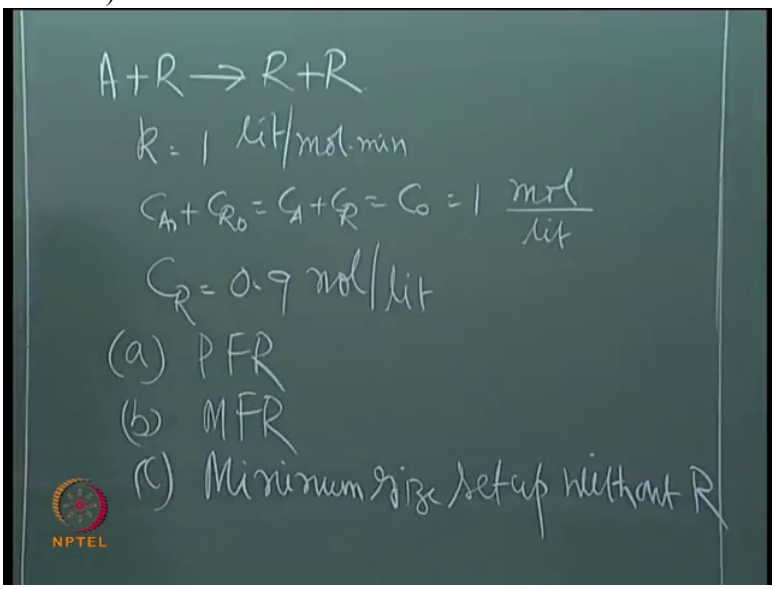

Ok.

Next one is d; please take this, if separator is used to separate 90 percent R and 10 percent A

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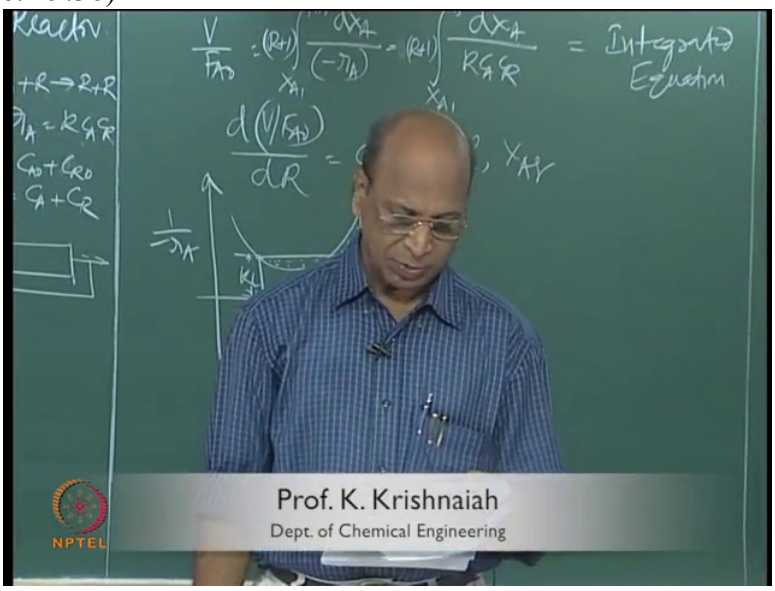

from the reactor, what is the minimum reactor space time or holding time? What is minimum reactor space time? So I think you understood that no, d?

d, what I am asking is this. This is 90 percent; this is 10 percent, Ok. That is separator. Only you have to find out reactor volume,

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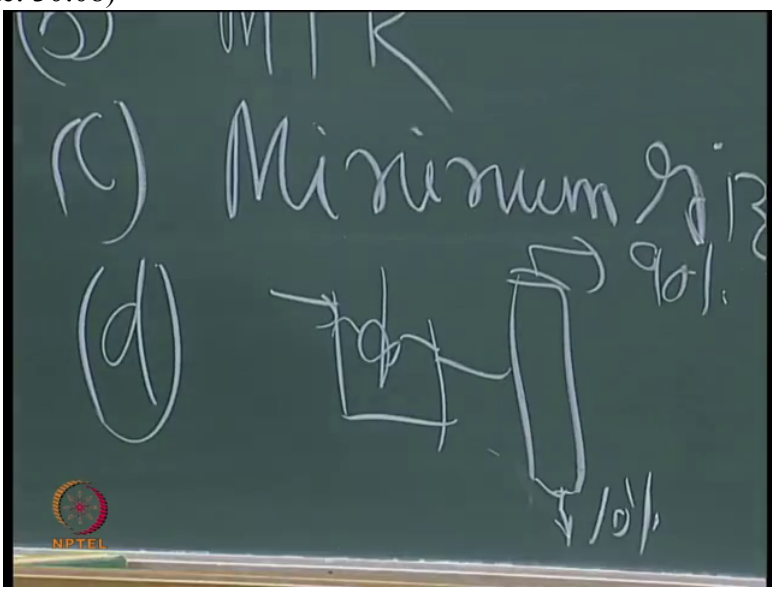

now. Separator is anyway, we are not asking. The other one is 2 reactors. You know till maximum rate and then P F R. There are of course individual rates. I think all these taus, right? This is a very nice problem. I think now we do not have time. Let me see how many of you will come tomorrow with the solution.