Chemical Reaction Engineering 1 (Homogeneous Reactors)
Professor R. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology Madras
Lecture No 26
Reaction Design for MFR and Combination of reactors

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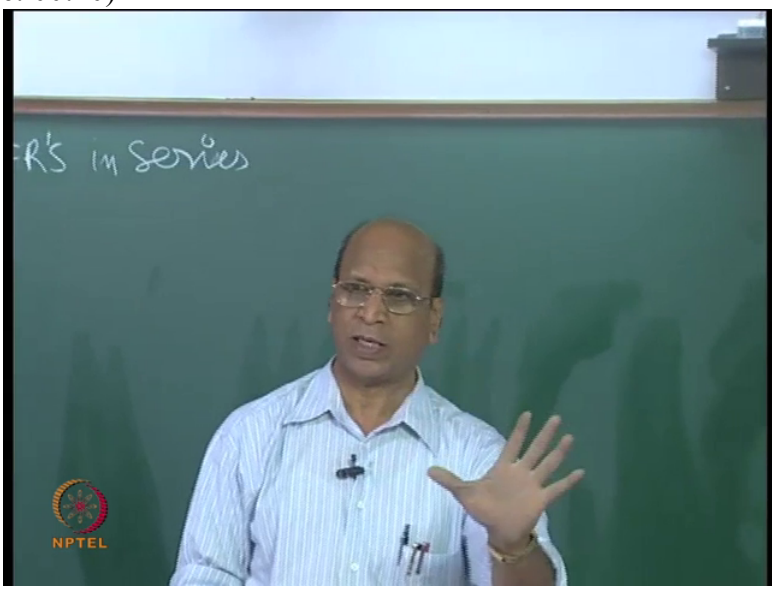

About 1 reactor, about 1 mixed flow reactor. But we also have that definition of saying that when you have infinite number of tanks in series, you will get plug flow.

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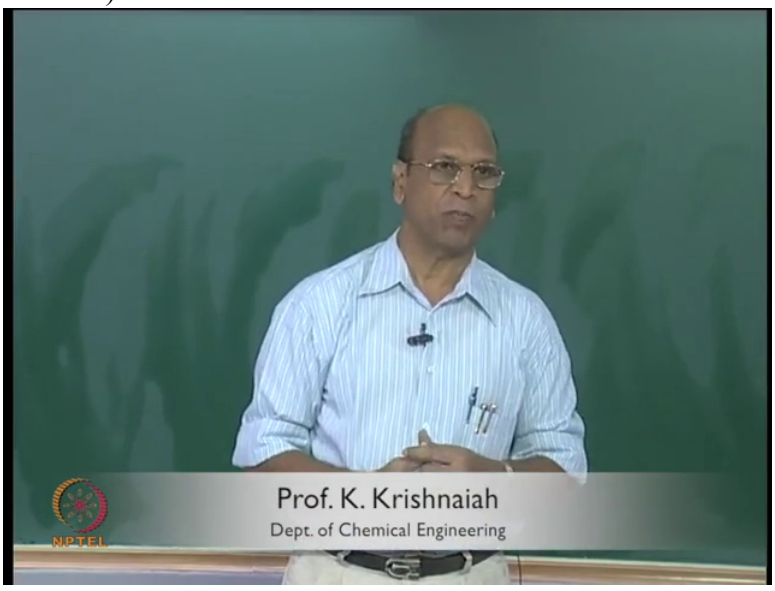

You will now again see that from the actual reactions. So that you have the calculators, at least few of you.

Yeah I think let us solve one problem then you will know

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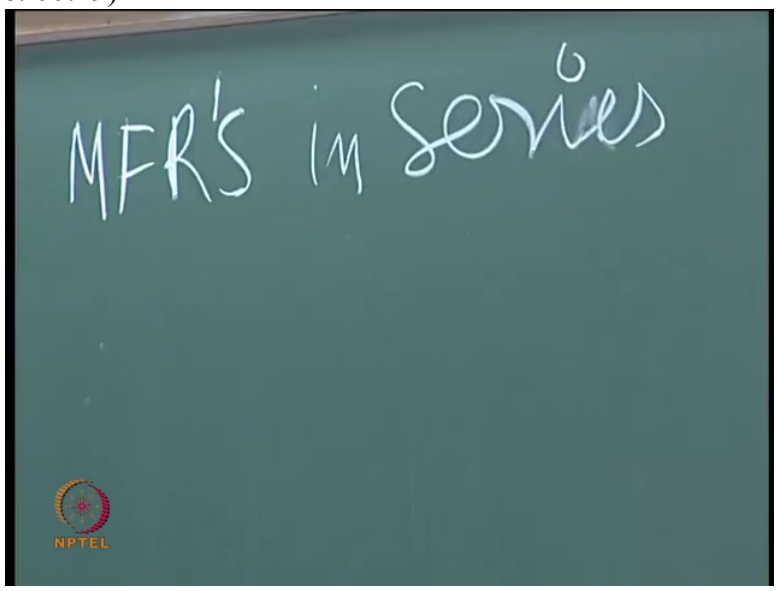

how beautifully what we said is right. So here, we would like to, Ok first order reaction, again simple, first order reaction, so then I have to first draw the tanks in series. Ok.

I have N, this may be i minus 1, sorry, i, this is 1, 2

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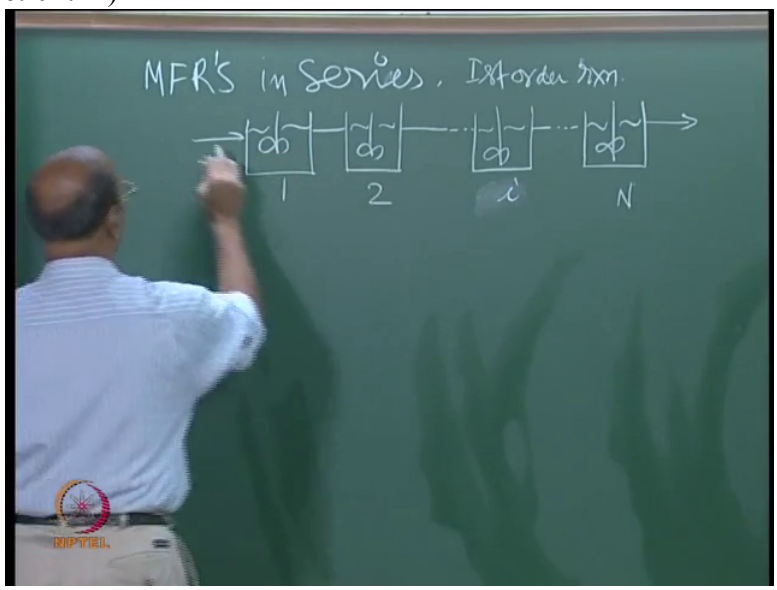

and here I have C A naught entering, this is C A N, and here may be v entering, v liquid phase reactors first order because C S T R most of the time we use liquid phase reactions and to

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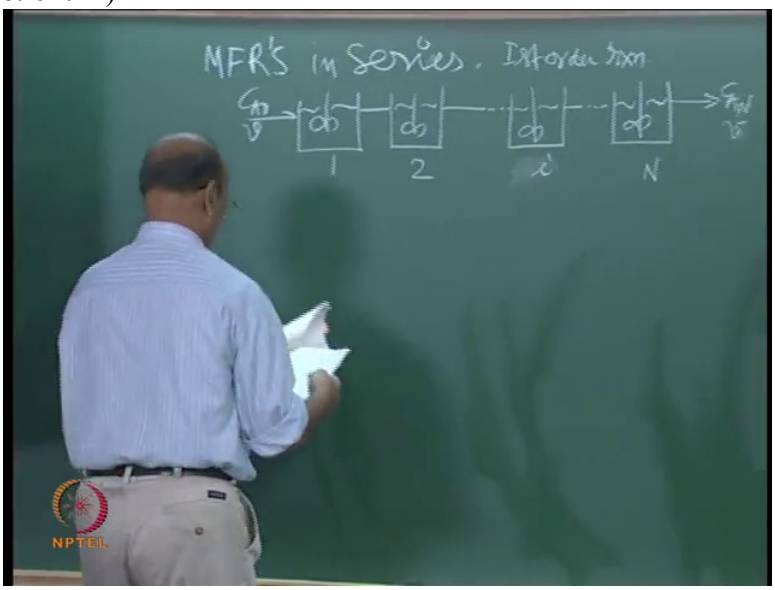

write this, I have V 1, V 2, V i, V n where all of them are equal.

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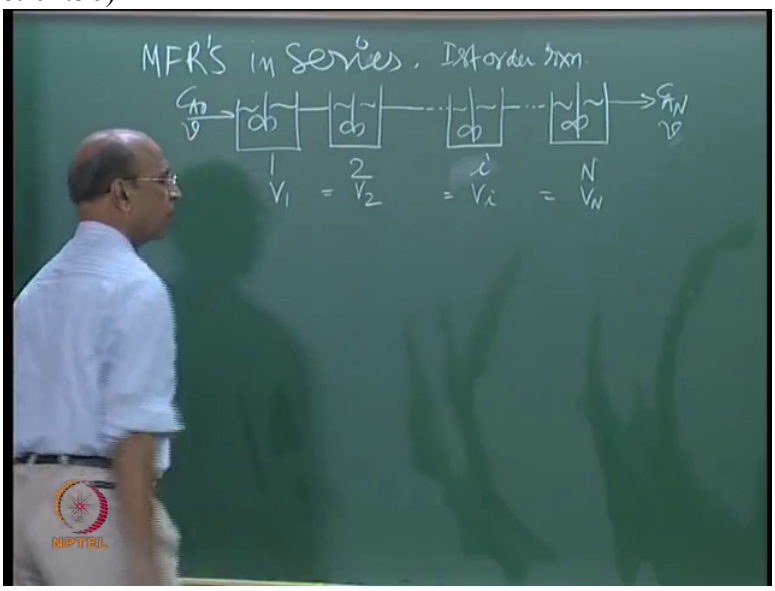

That means equal volumes we are taking, equal volumes we are taking. So now we will define our tau, tau of i as volume of i divided by

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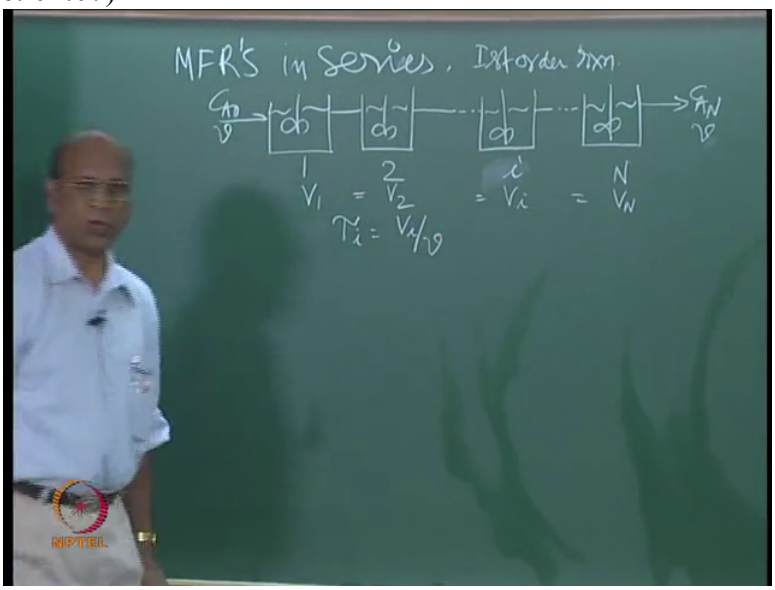

volumetric flow rate. V is constant throughout. Actually try to find out what is the total, tau equal to N into, in one tank i, in one tank I have V i by v,

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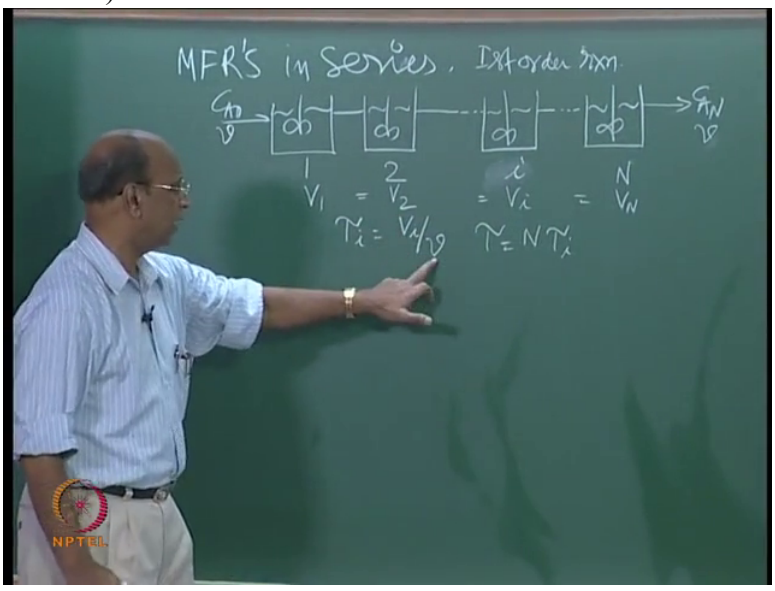

and in these many tanks

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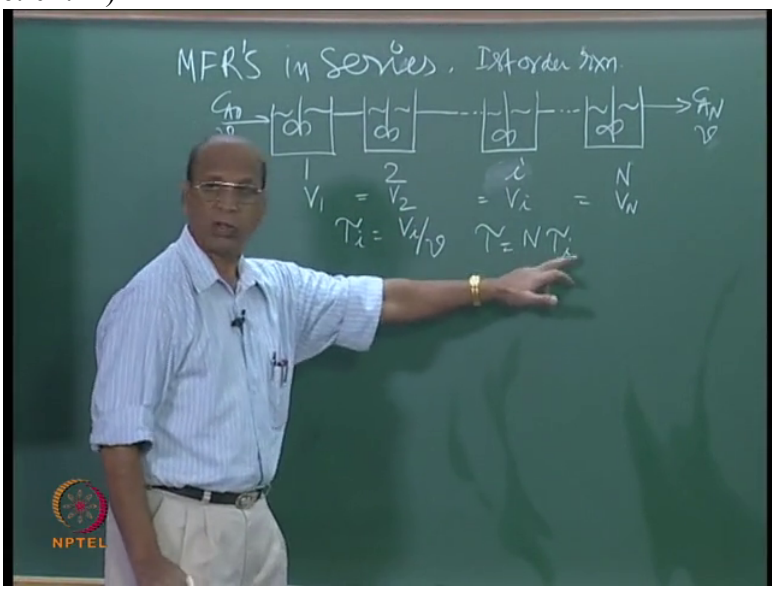

we have total.

So this is nothing but N into V i, by v, by v.

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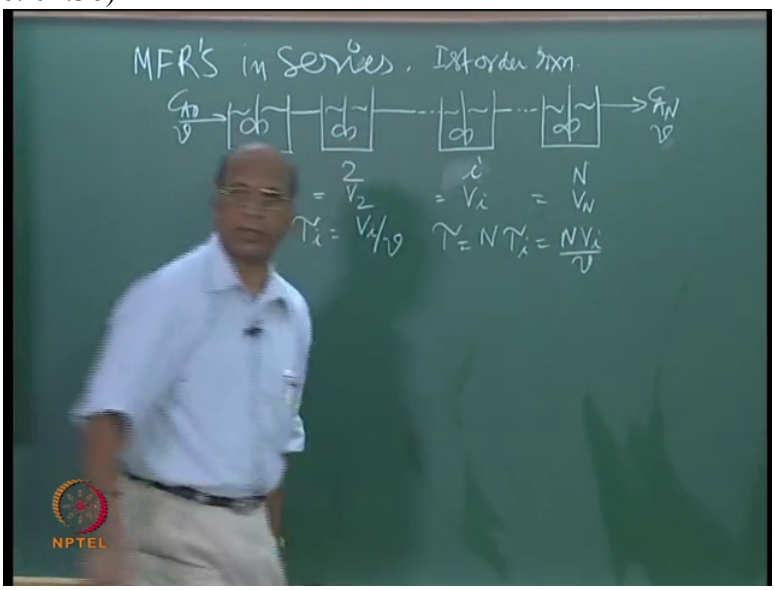

So this N times V i also I can take total V, where V equal to sigma of V i where i equal to 1 to N.

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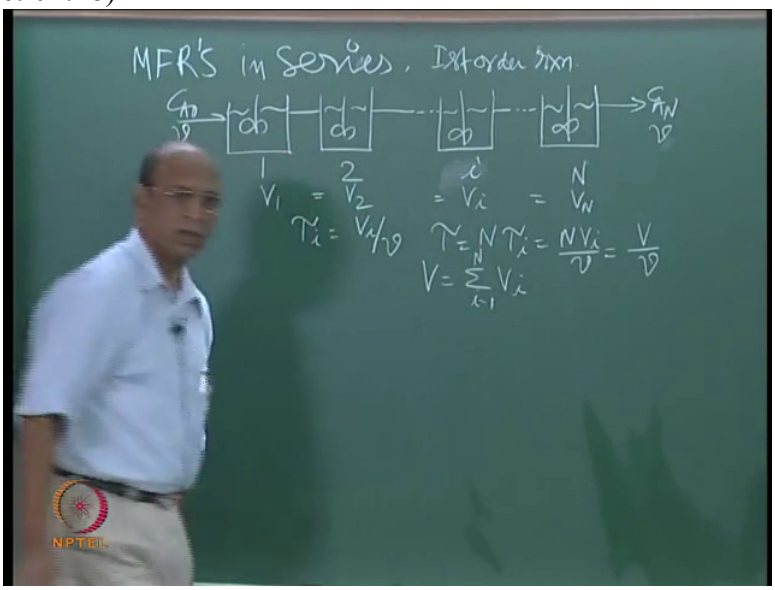

Ok so this is what is again convenient, you know writing,

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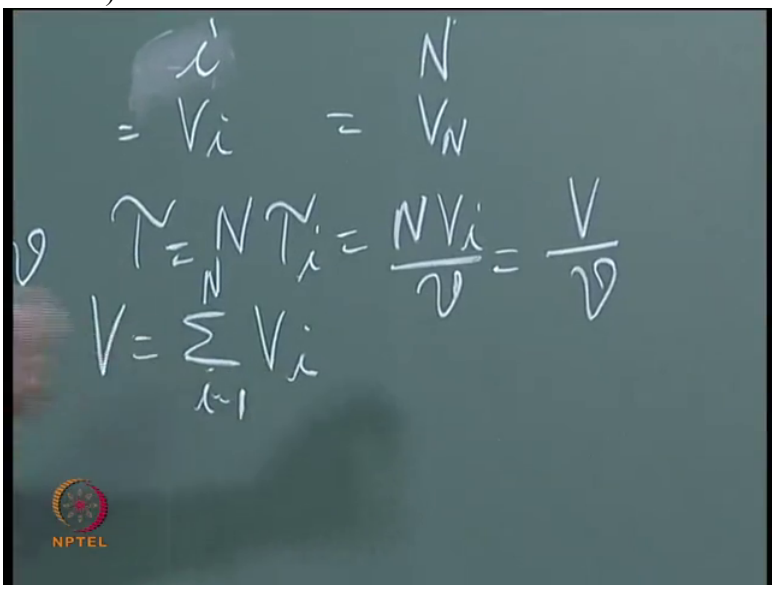

right? So this was summation, Ok, good.

So this is the one, just to start with and let us have that we have first order reaction, Ok liquid phase and we would like to write the balance for this, idea is to find out what is C A N by C A naught which is nothing but X A N equal to what?

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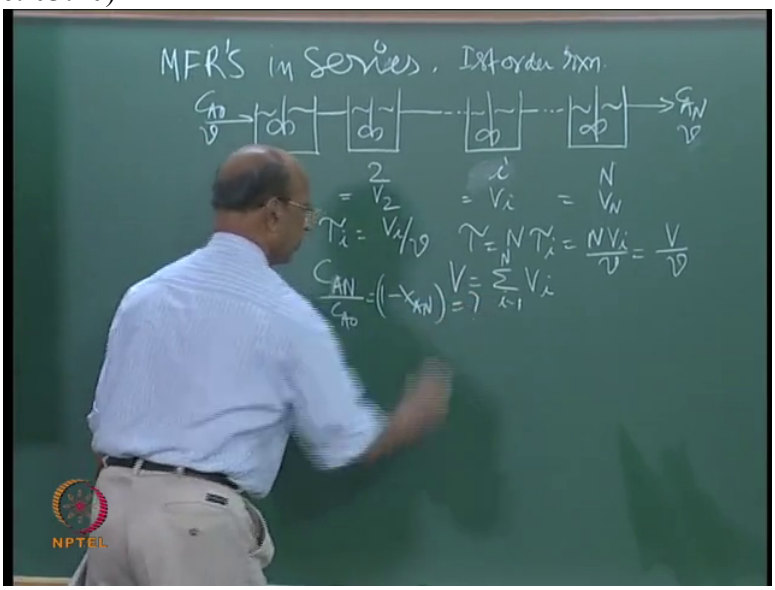

Ok, conversion.

I would like to find out what is the conversion that is coming out, C A N by C A naught, Ok good. So that means I have to now write this equation as, other symbols also, this one is

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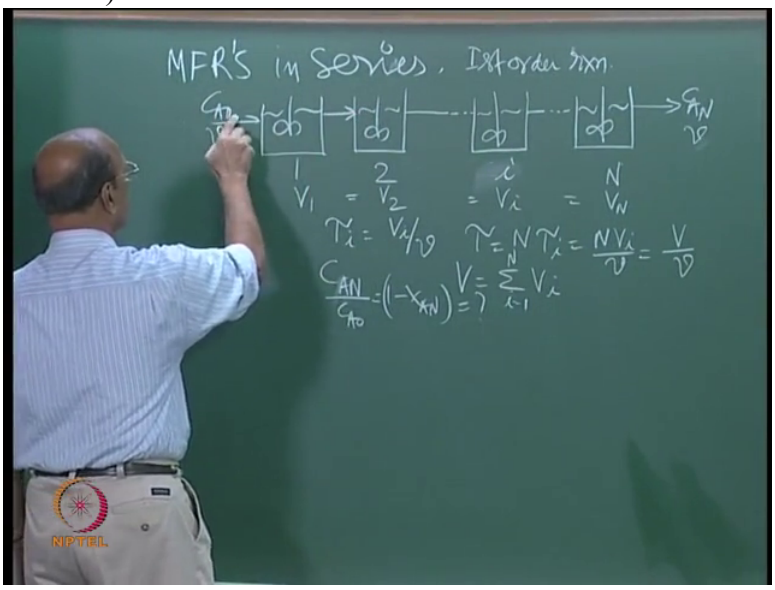

C A naught and coming out is what,

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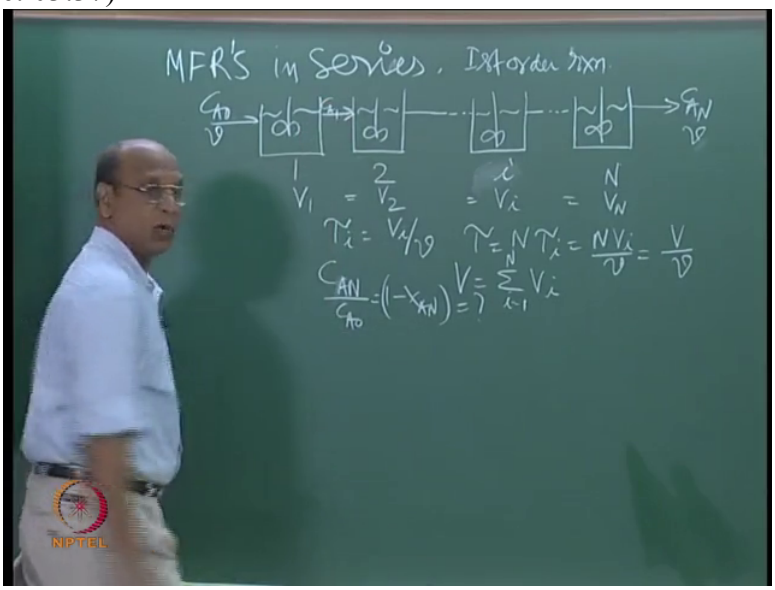

C A 1. And then C A N is entering here, this is C A 2.

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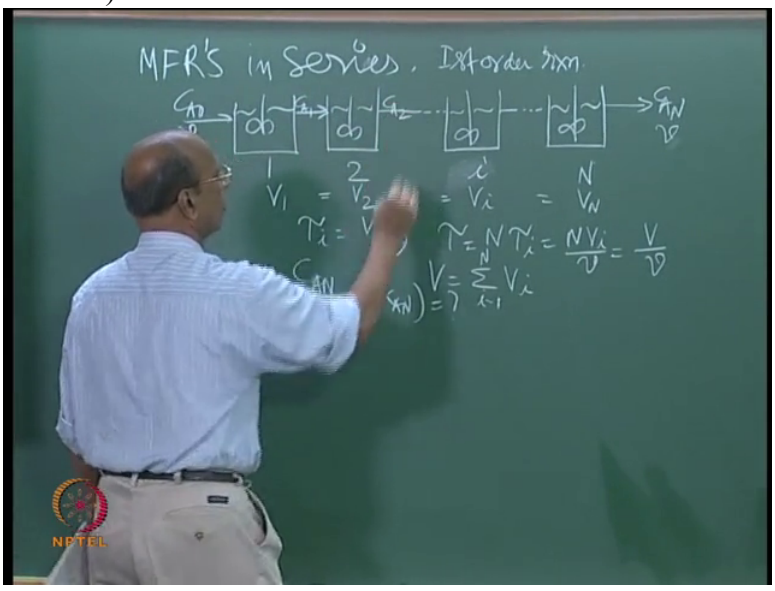

And here I have C A i minus 1, and this is C A i. And here I have C A n minus 1,

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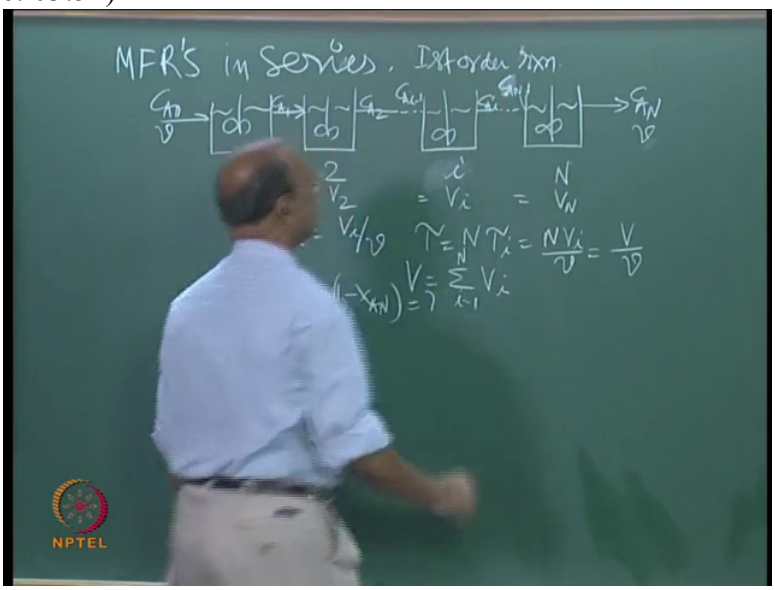

yeah.

So those are the all things. Now let us write the material balance, for first reactor it is v into C A naught, v C A 1 leaving, this is input,

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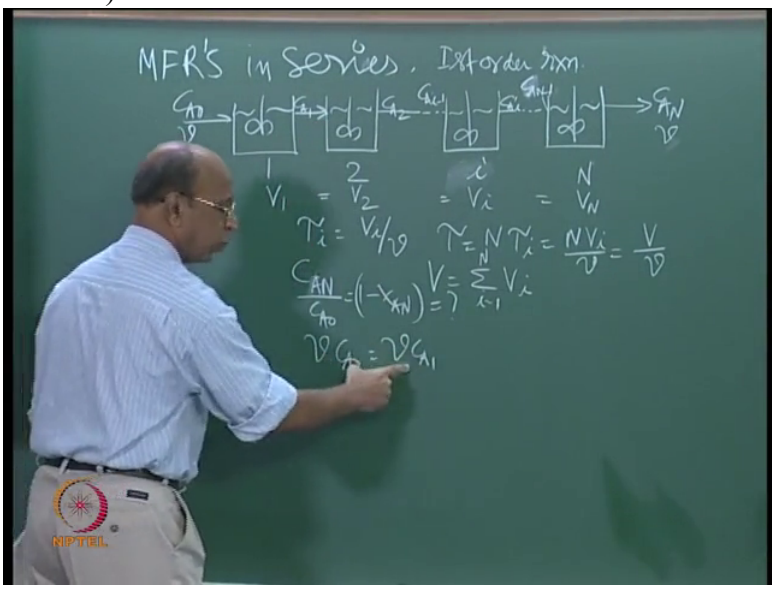

output, reaction, accumulation and this is steady state. Ok, I have to also, M F R in series, first order; I can also write here steady state.

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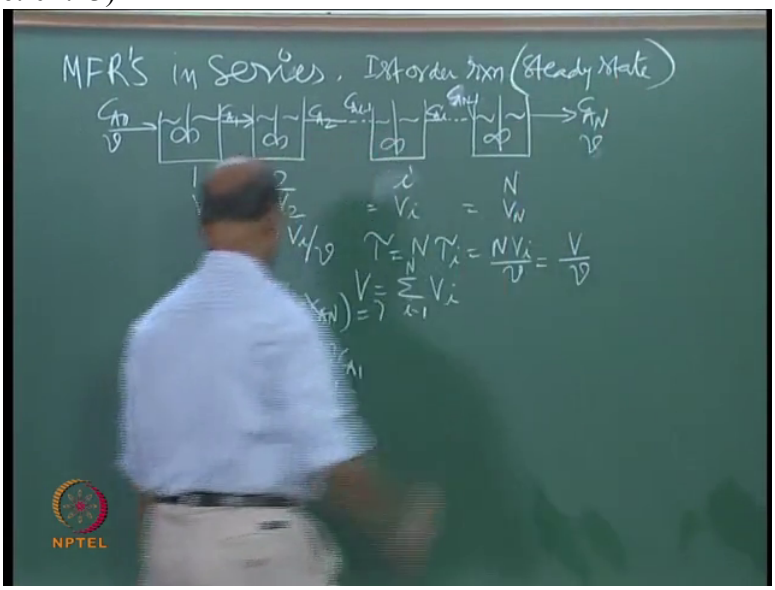

Ok, that is why accumulation term will be zero. This is, I have minus r A into, that is k C A, k C A 1 into V, it is not total V, actually it is, I will write here, this is V dash, this is also V dash. Now all this equal to V.

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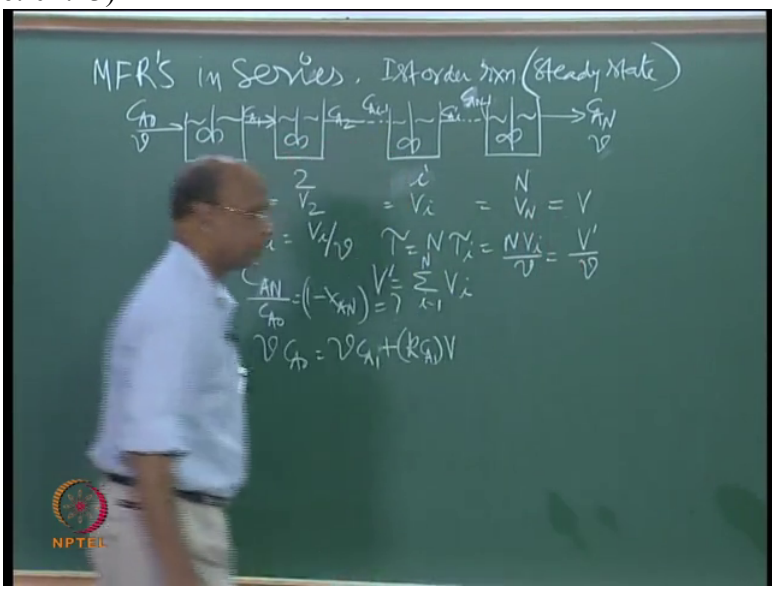

Each one equal to V, Ok. So V dash equal to sigma of V i that is Ok. Or sigma of V out, I can write all these. Or N into V. Ok, good.

So now this I will write for one reactor because now each one has V. All these are equal to, I mean for easy thing. So can you tell me what is C A, 1 by C A naught?

(Professor – student conversation starts)

Student: 1 by N plus

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Student: V by

Professor: 1 by

Student: 1 plus k into tau

Student: k into tau

Professor: Yeah, so now tau 1 also I will take that, you know this is V.

Student: Tau

Professor: Tau, right, so then I have to write this one as tau dash then. Ok sorry, that one as tau dash, no. Ok. That one I will define tau as k tau where tau equal to

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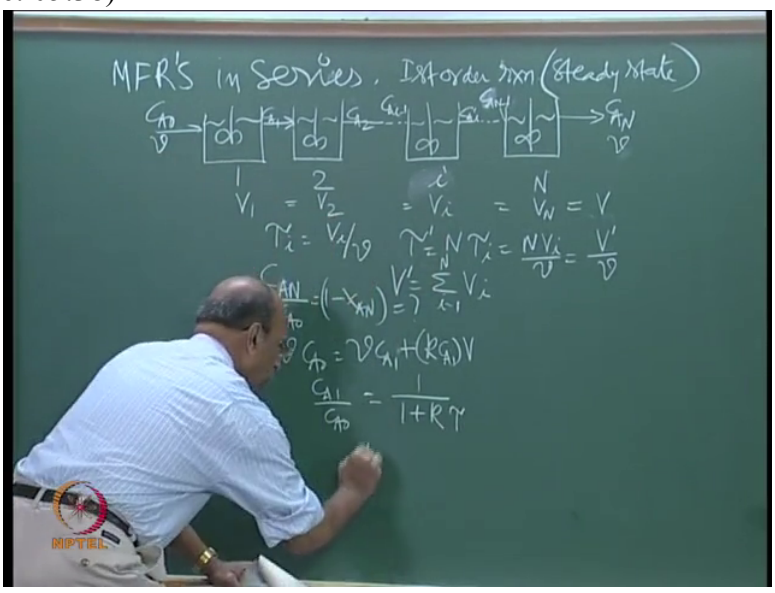

V by v.

I think you make that correction,

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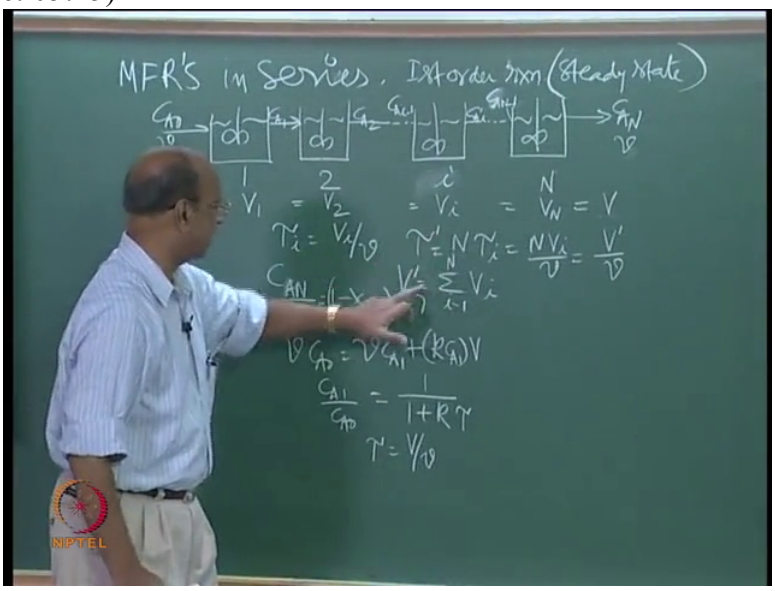

dash, dash and all that. Ok, so this is equation 1, equation 2, this is Ok, no equation. Yeah, similarly for second one, this is for N equal to 1. For N equal to 2, can you

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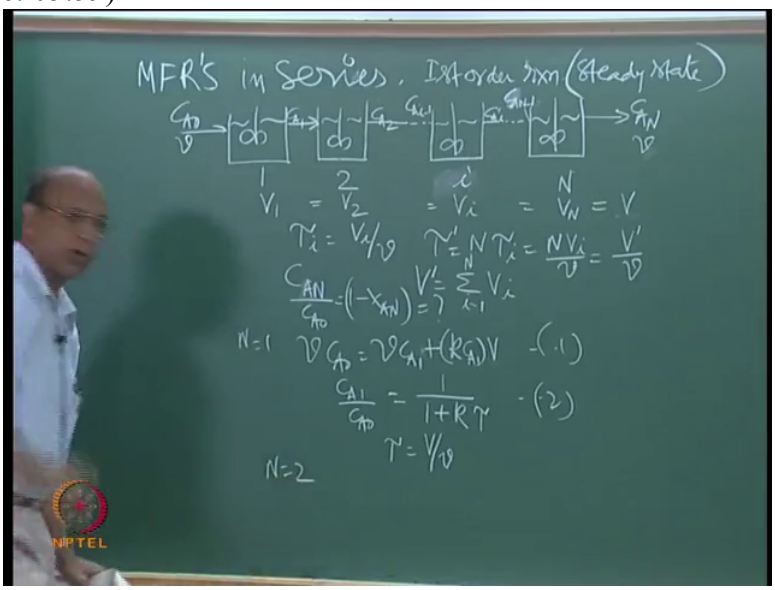

write on your own now? Can you write on your own now? Or otherwise you tell me, I will write.

Student: 0:06:10.1

Professor: V into C A 1 equal to V into

Student: C A 2

Professor: C A 2 plus k C A 2, C A 2 into V again, correct no? So what is this equation in terms of

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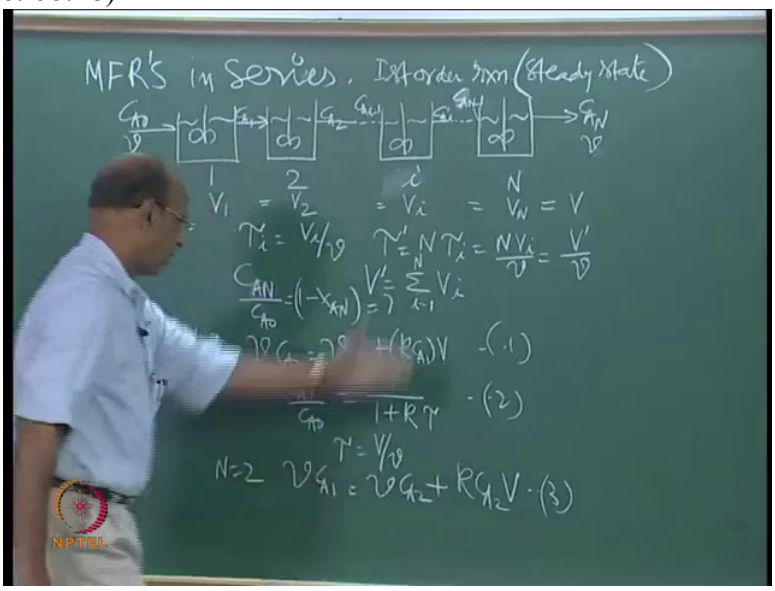

C A 2 by C A 1 equal to?

Student: 1 upon k tau.

Professor: So again for C A, for second reactor also you have 1 by 1 plus k tau,

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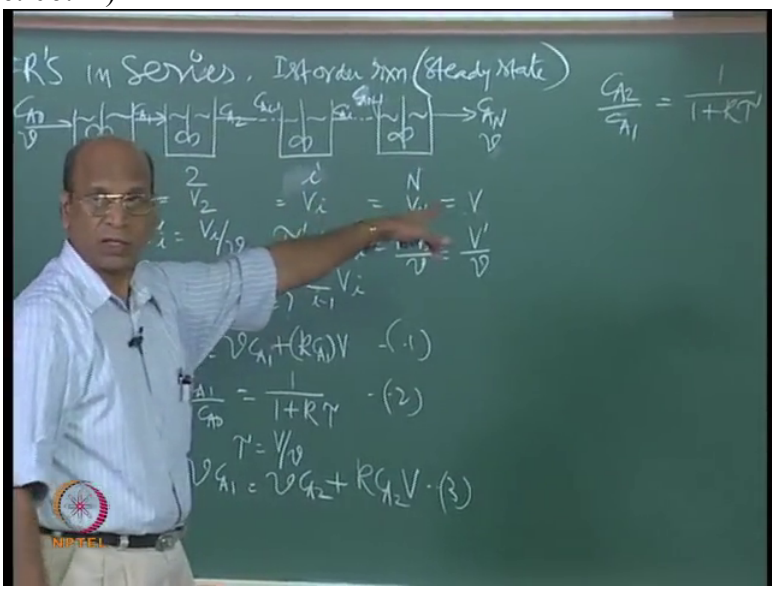

but this side the concentration. Ok. Similarly now we do not have to write for everything. Now this is C A 3 by C A 2 will be again 1 by 1 plus k tau. So similarly when I

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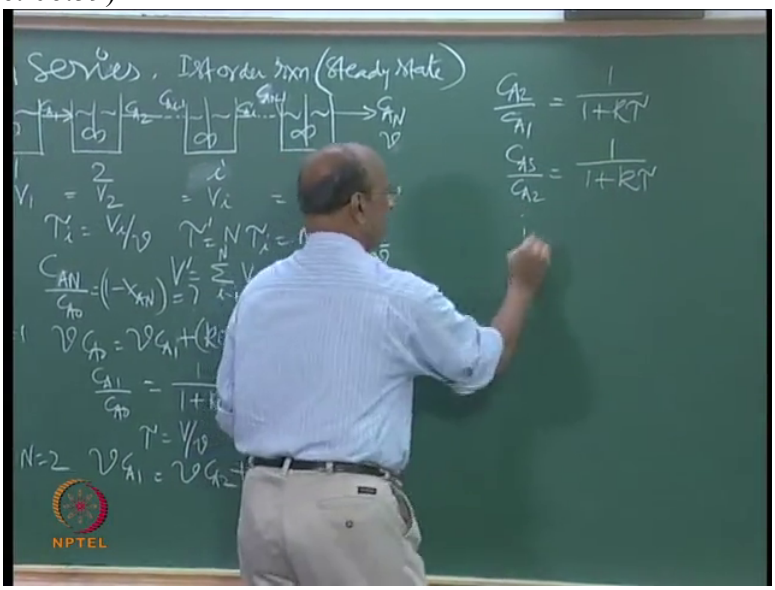

write all these, I have C A N minus 1 by C A N equal to 1 by 1 plus

Student: 0:07:09.8

Professor: Right, thank you, thank you, thank you, thank you, very good. N minus 1 equal to 1 by 1 plus k tau.

(Professor – student conversation ends)

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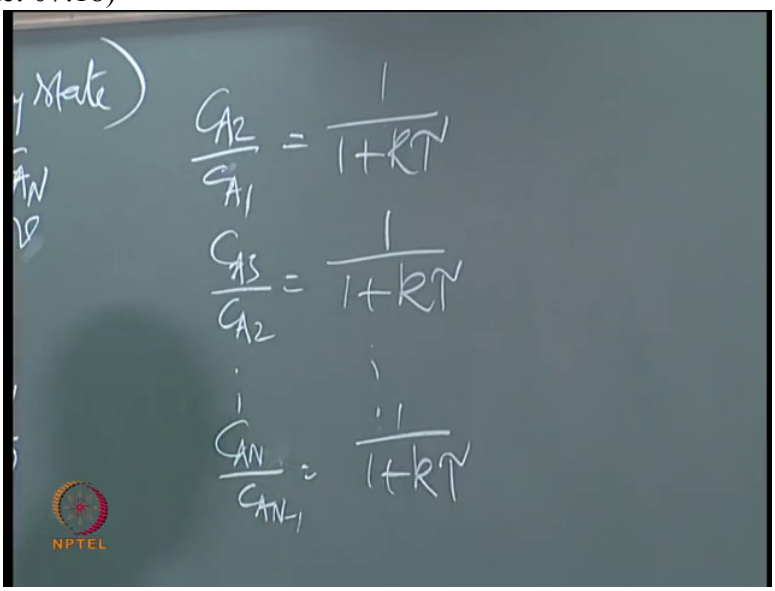

So now I would like to only find out this one. C A N. So I can now multiply all these, you know,

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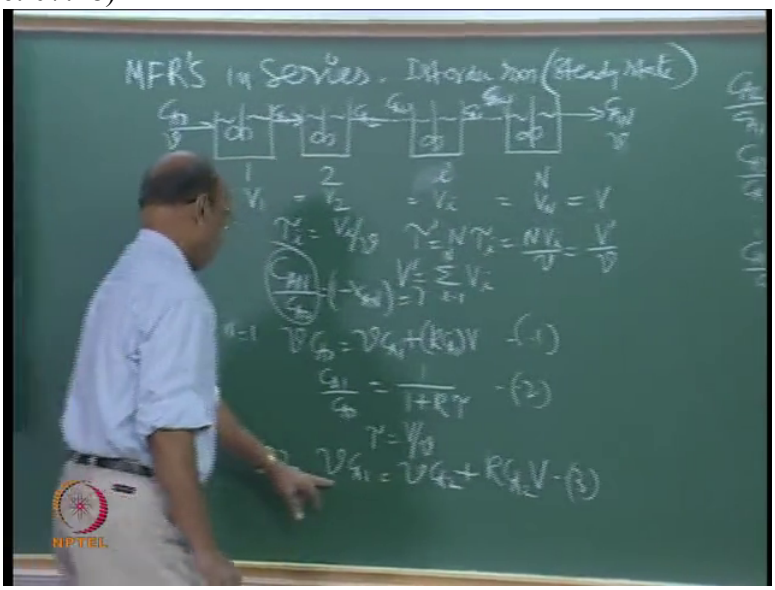

in fact I have C A 1 by C A naught, C A 2 by C A 1, so like that we have C A N by C A N minus 1,

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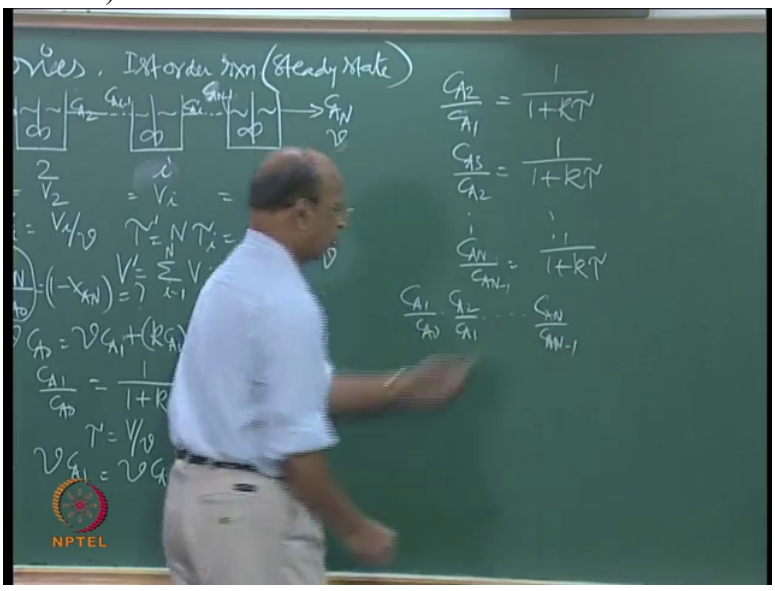

and here I have C A N minus 1, so you can cancel, or if you want you can write one more, this is C A 3 by C A 2, so like that you will get this one as C A zero, which is equal to, now I have N number of terms.

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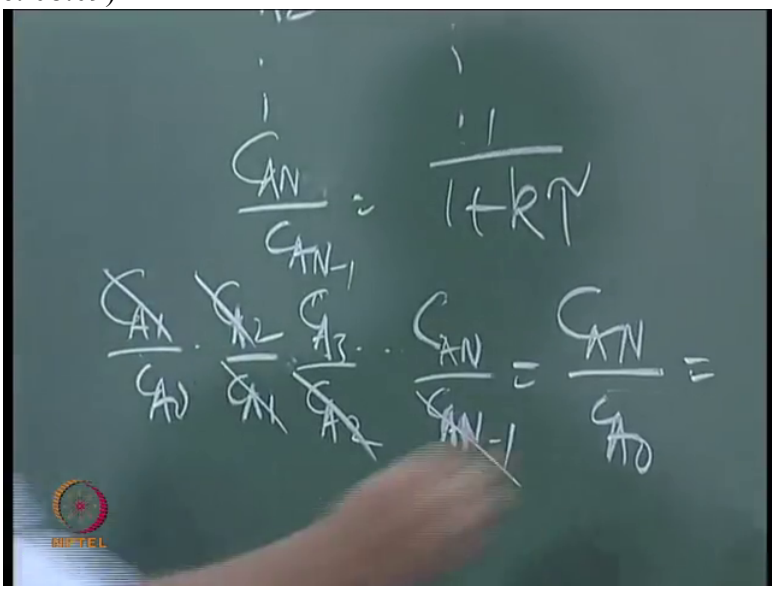

We will have 1 by k tau to the power of N, Ok.

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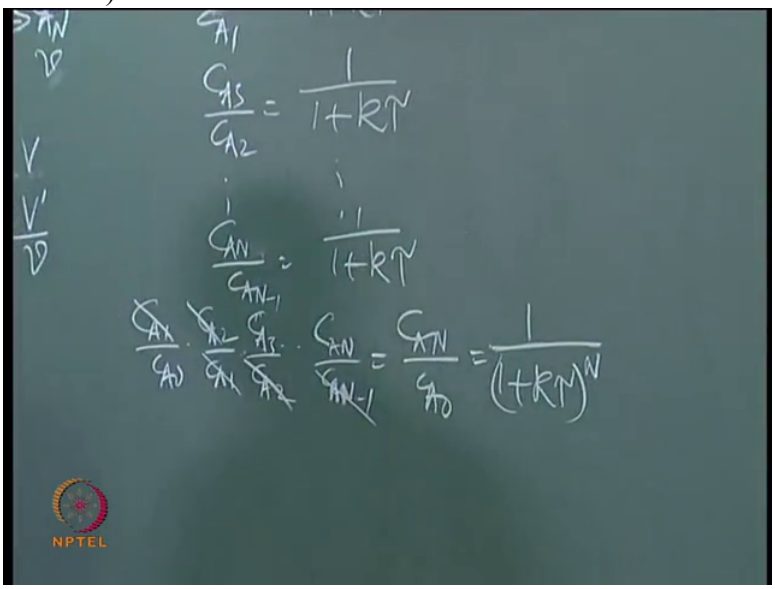

So if I write the equation, this is 4, 5, 6 this is 7.

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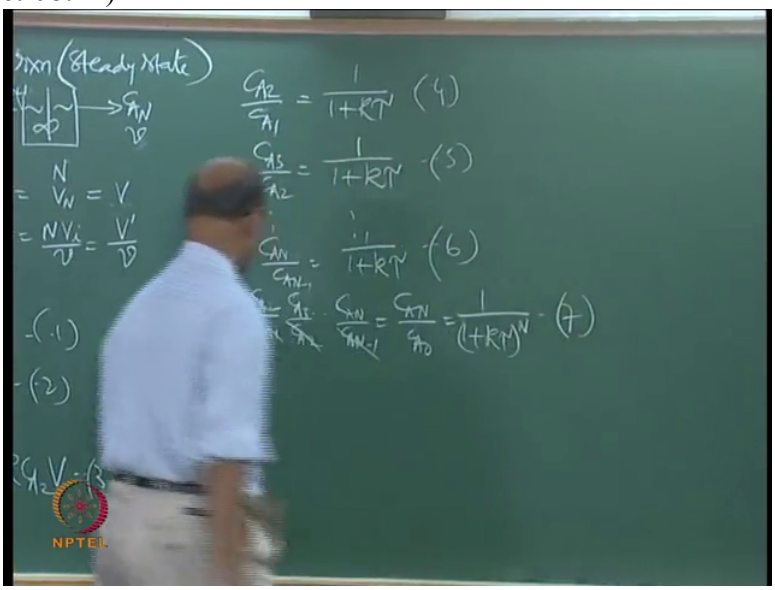

Ok, so this equation also C A N by C A naught can also be written in terms of total time, 1 plus k tau dash by N, correct,

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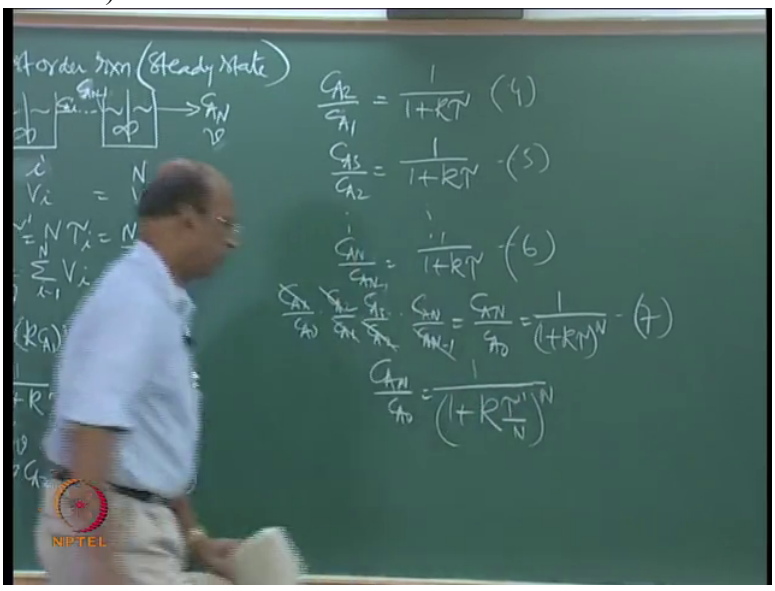

tau i equal to tau. And tau dash equal to N tau,

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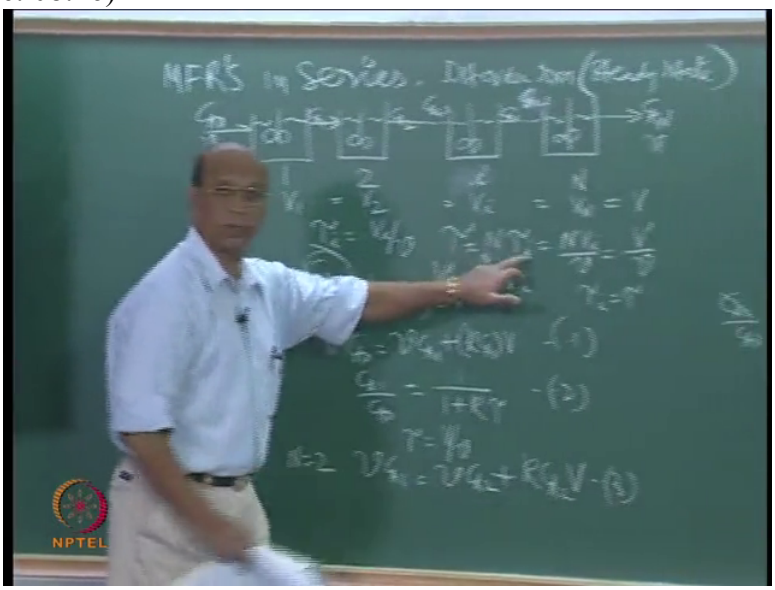

Ok. So that is the one.

So this equation we can nicely convert into k tau dash N equal to, yeah, so 1 minus X A to the power of minus 1 by N minus 1, this one I have written here. This is also equal to

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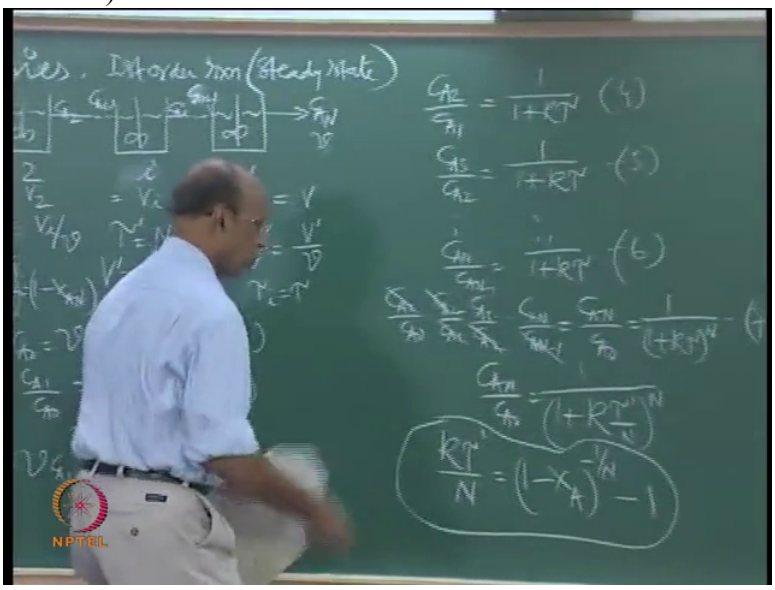

1 minus X A N, right so this is equation 8.This is equation 9.

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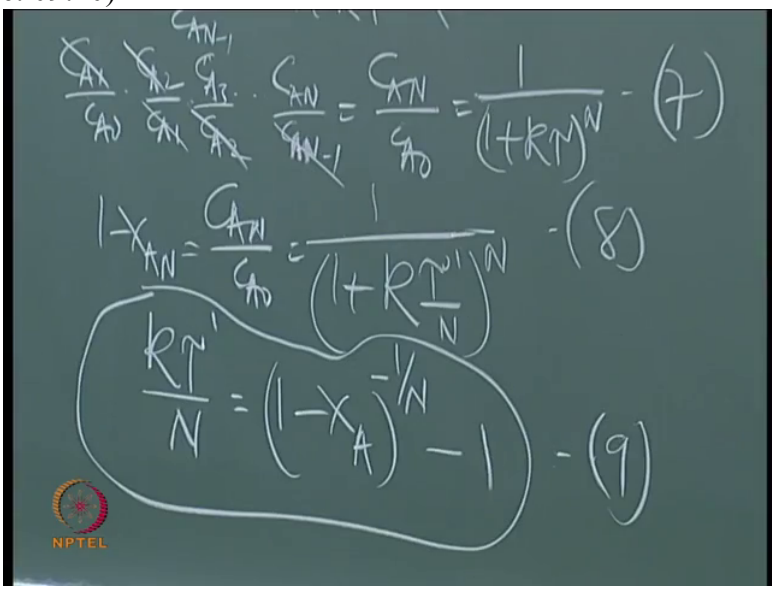

Must be X A N only.

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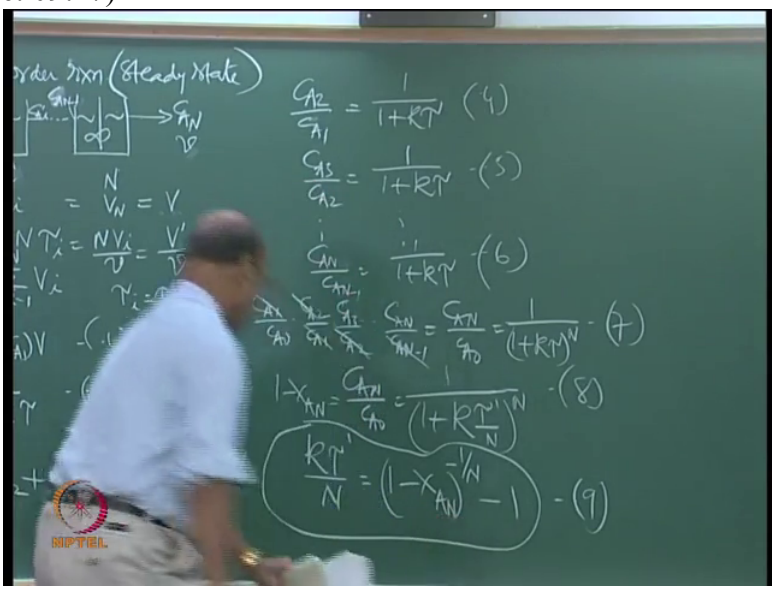

(Professor – student conversation starts)

Student: 0:09:25.6

Professor: So this equation for N equal to 1, what is the equation? So that means I have only just 1 reactor, N equal to 1, means all these things are not there.

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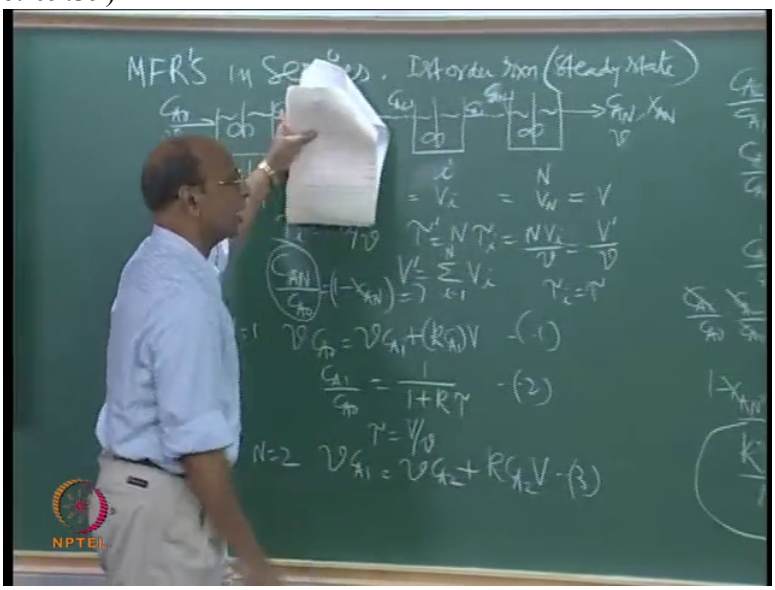

So for N equal to 1, k tau dash equal to, 1 by, 1 by 1 minus X A, X A 1

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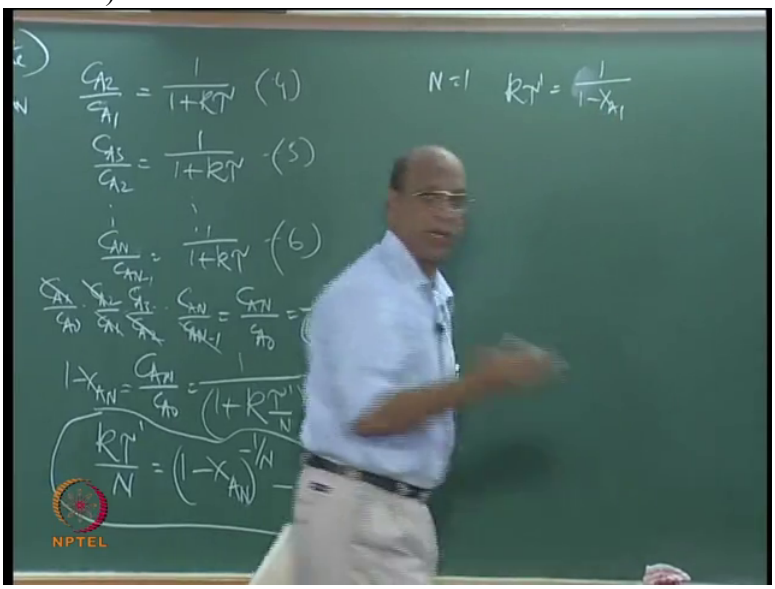

for example, Ok, that is all,

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I think this is minus 1

Student: Minus 1.

Student: Yeah, correct Sir.

Professor: I am simply substituting that one there

Student: Yes sir

Professor: Now tell me for 95 percent conversion, for X i equal to,

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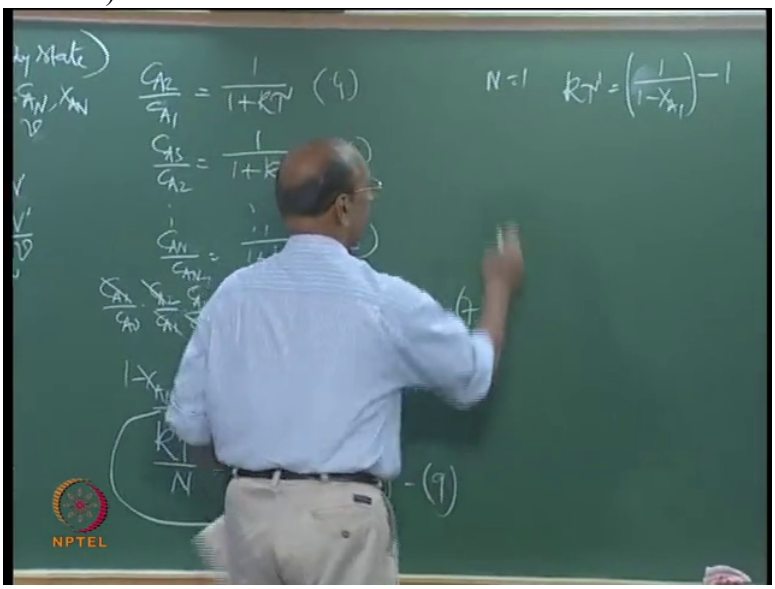

or X i 1, from this, I am talking about, I am talking about 1 reactor where I have

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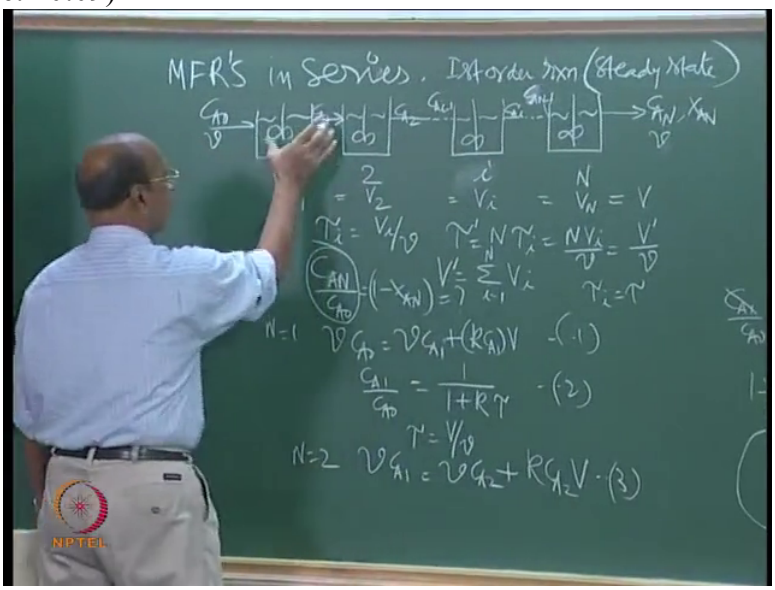

95 percent conversion. What is the volume of the reactor? That means of course k value I do not have to separately give. I mean, assume that unity also.

So I have X A equal to point 9 5. What is k tau dash? It is the measure of volume.

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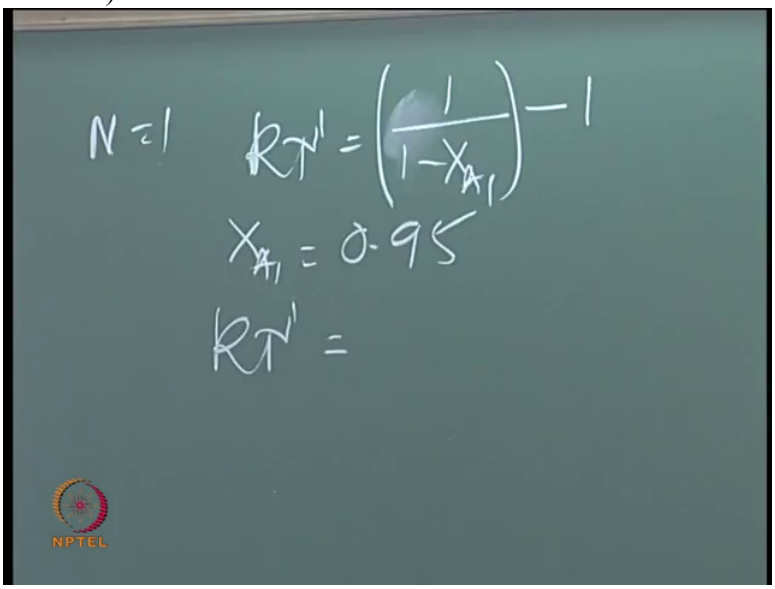

90? Oh he said 90, not 9 9 0.

Student: 9

Professor: Ok, so this is 9. So for N equal to 2,

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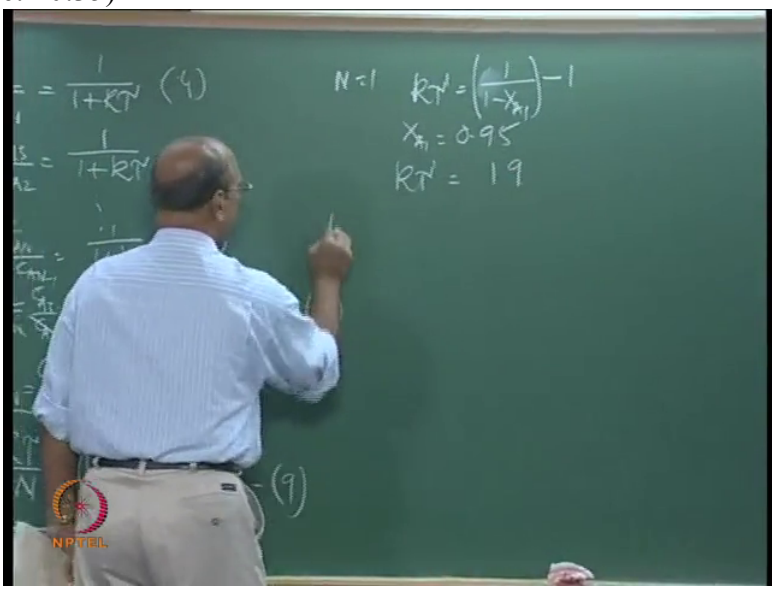

tell me now, k tau dashed by 2, because N is there, N equal to 2, but now this one is

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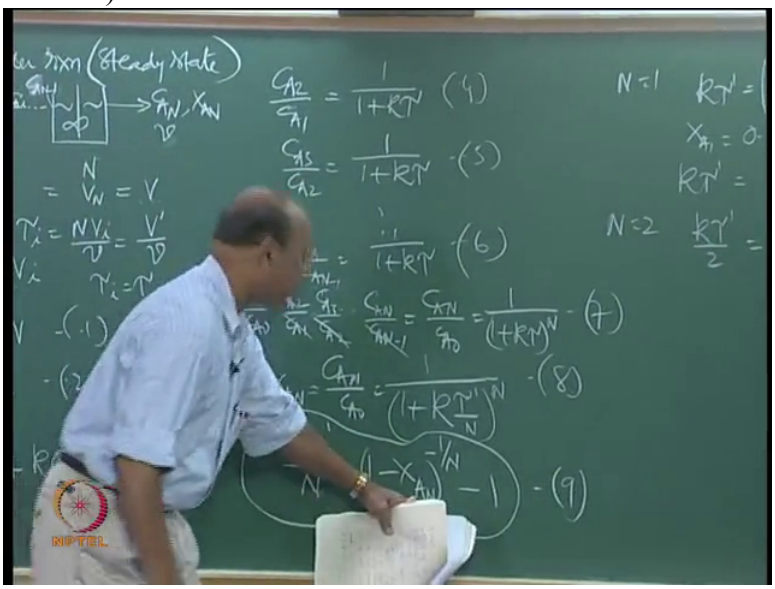

1 by 1 minus X A 2 to the power of, oh that is all. Correct no, minus 1, half, 6 point, yeah

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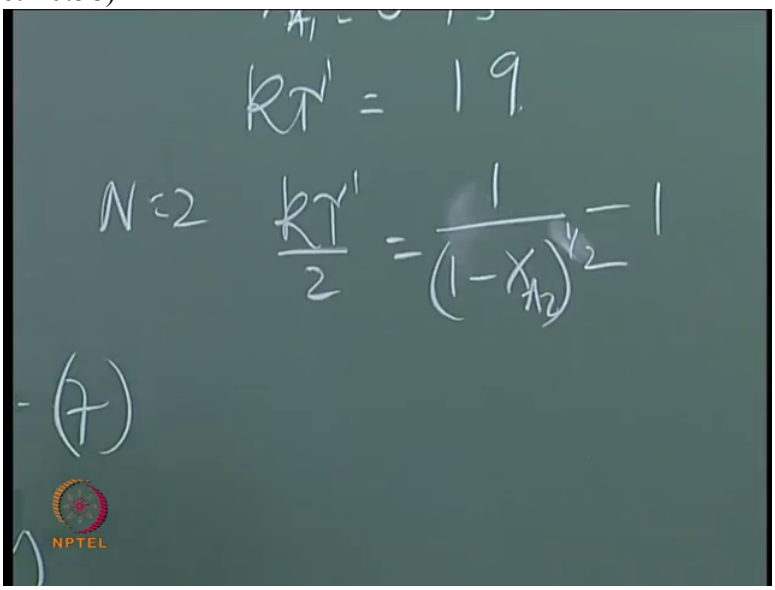

any other things? Always Pooja and Debian only telling. From there, that corner? Ramkrishna you do not have calculator? 0:11:09.4

Student: Yes sir

Professor: Tell me.

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Student: Sir, 6

Professor: 6? You rounded off?

Student: 7

Student: 6 point 9 4

Professor: How did you, I mean mental calculation?

Student: Yes Sir.

Professor: Approximately, approximately I think. Ok good. So this will be k tau dashed is 6 point 9 4.

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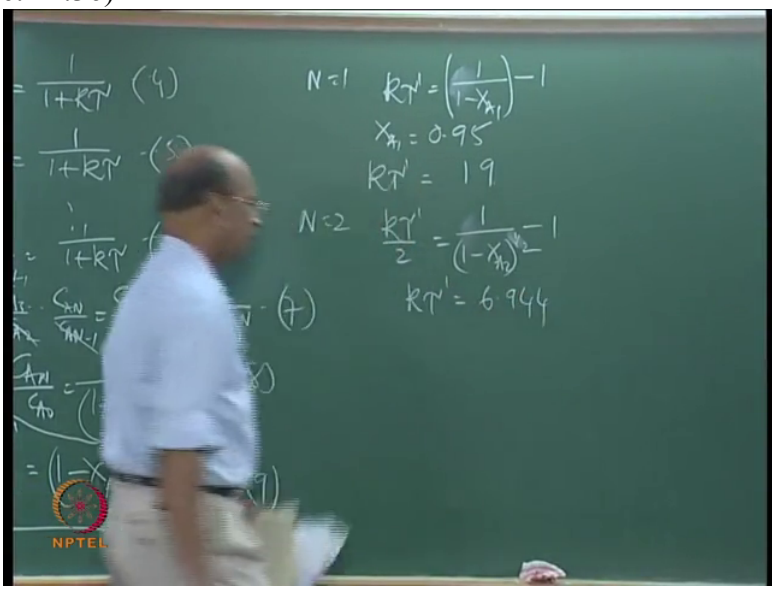

Now tell me for N equal to 3, k tau dashed for this system is 5 point 1 4,

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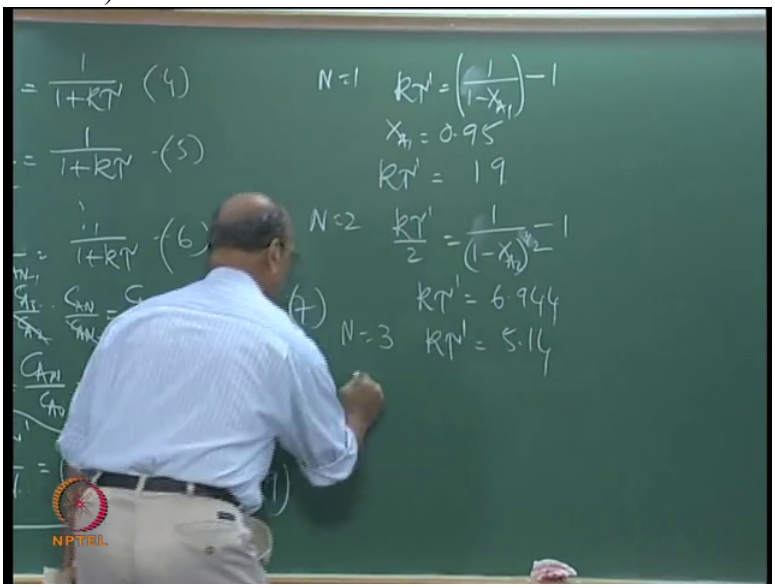

Ok 4, N equal to 4?

Student: 2 point 2 2

Student: 4 point 4 5

Professor: 4 point

Student: 4 5

Student: 4 point 4 5

Professor: 4 point 4 5.

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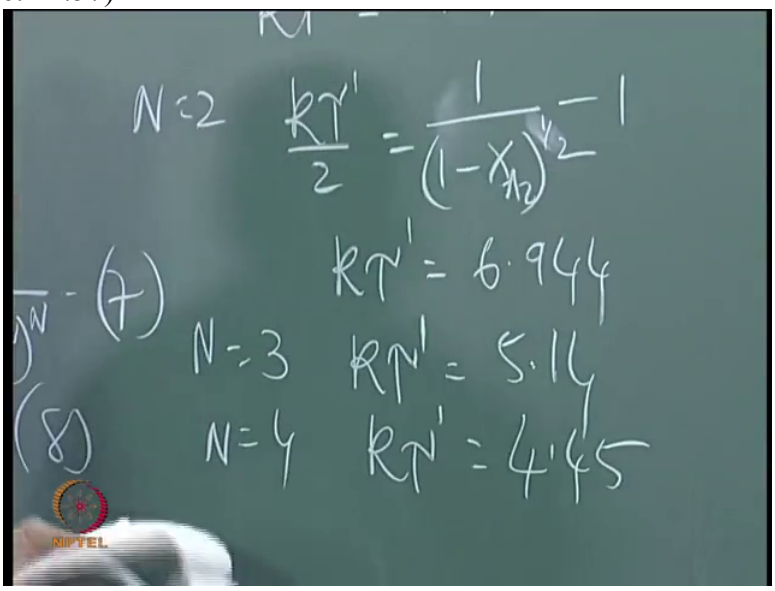

Ok so now, N equal to 6?

Student: 3 point 8 8

Professor: Excellent, 3 point 8 8. Ok, N equal to infinity

Student: (laugh)

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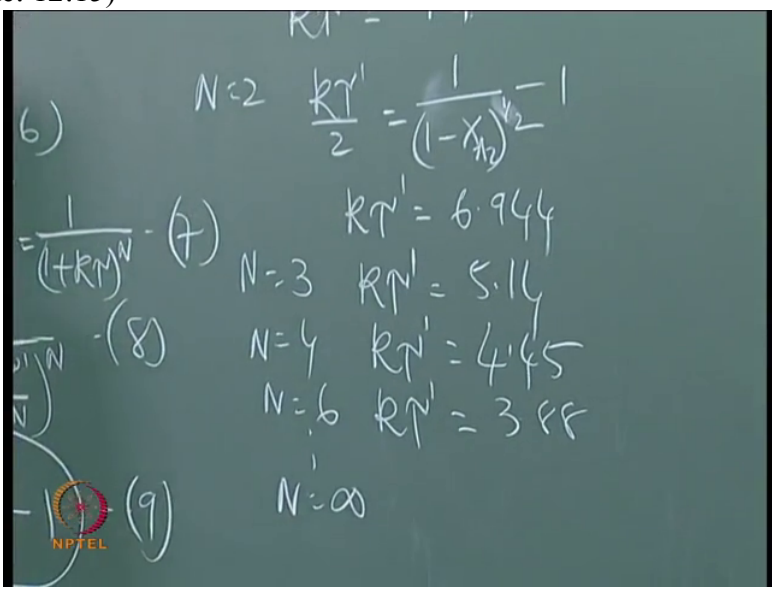

Student: Zero

Professor: Yeah I know this answer which is wrong. What do you mean by N equal to infinity?

Student: 1 Sir

Professor: Yes? You are talking mathematics, I am talking physics.

Student: Infinity

Student: P F R

Professor: Excellent, P F R. So what is the conversion in a P F R for first order reaction? N equal to infinity means you are straightaway going to mathematics. Only one person sitting there who is thinking like me, Physics, right? So N equal to infinity, when infinity number of tanks when you put together, we know that that is going to plug flow. So now what is the equation for first order reaction liquid phase, you know equation for plug flow?

(Refer Slide Time: 13:03)

Student: l n 1 minus X A

Professor: Equal to

Student: minus k tau

Professor: Yeah, exactly that is the one. Ok, for N equal to infinity, we have l n 1 minus X A equal to minus k tau,

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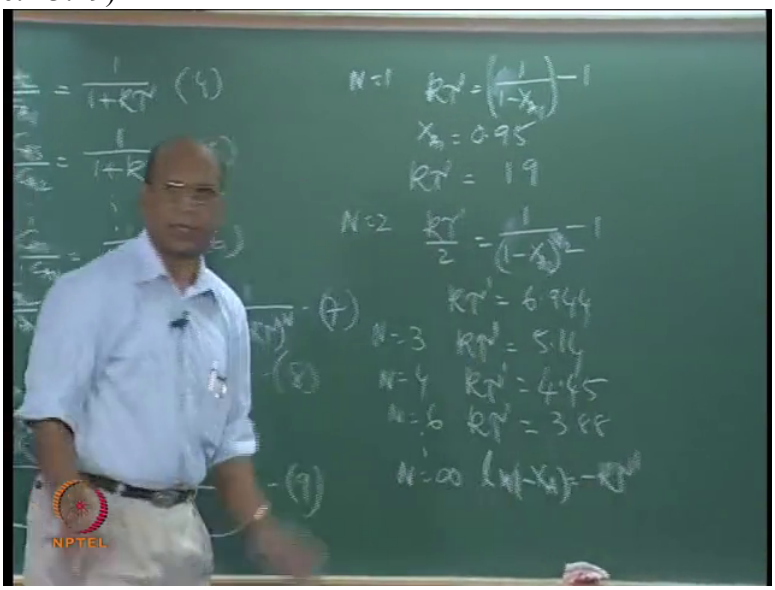

k tau dash because that is the total volume there. How much is that? 2 point

Student: 2 point 9 9 6.

Professor: Excellent, 2 point 9 9 6 that is 3. So k tau, here k tau dash equal to 3. So what can you predict from this? We have all the results. Which one

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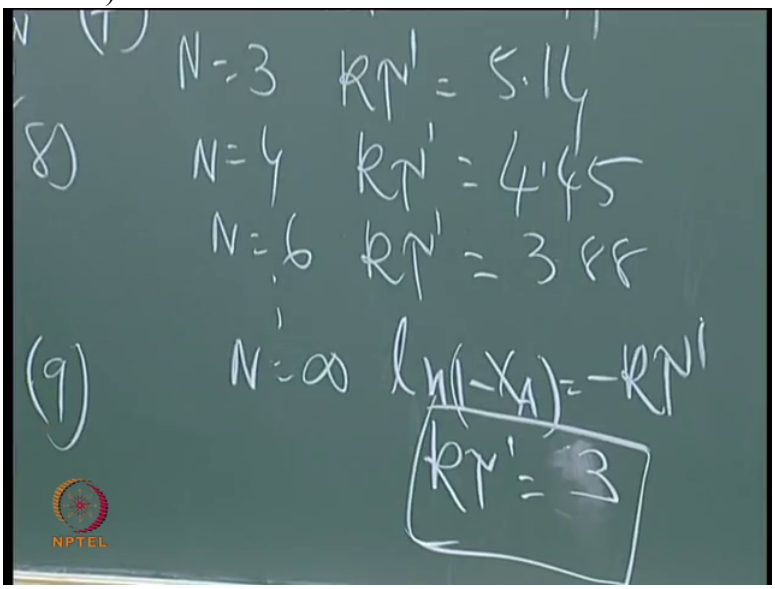

is decreasing? k is decreasing. k is constant for, you know entire reaction you know whether you have....

Student: Tau

Professor: Yeah I mean k tau is a measure I say, when you say, by the way what is the name of k tau, number?

Student: Damkohler number.

Professor: What s the general definition of Damkohler number? What is the spelling of Damkohler number? Damkohler?

Student: k o h l e r

Professor: Yes. In fact there is that umlaut there, kohler, Ok, Germans, Damkohler number. Yeah what is the definition? k tau C A naught

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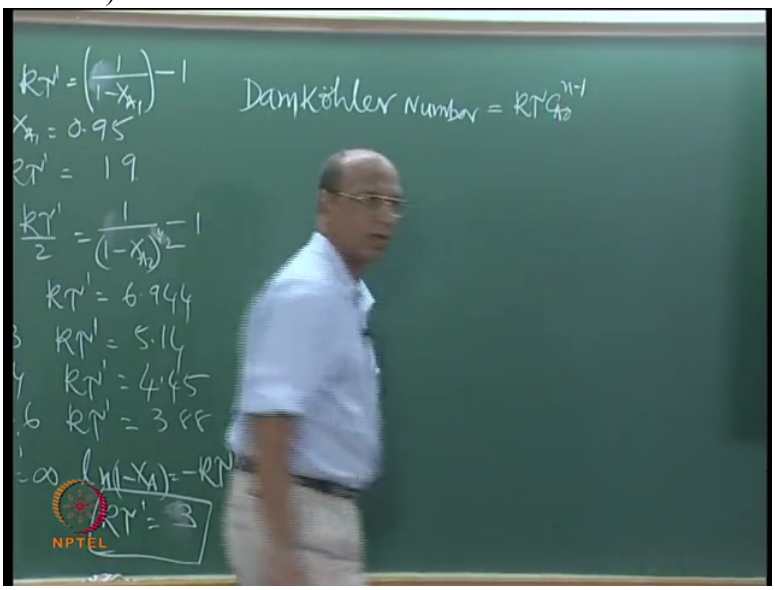

n minus 1. So for first order it will be k tau, for second order it will be k tau C A naught, that again naturally it falls. If you see the second order equation for plug flow what we have written you know, just before that, that is k tau C A naught for second order. For first order it will be k tau. For zeroth order,

Student: k tau by C A naught.

Professor: k tau by C A naught. That is Damkohler number. That gives a measure. For example what is the meaning of having large k tau?

Student: Volume is large

Student: Volume is increasing.

Professor: When I say that

(Refer Slide Time: 14:58)

I have large k tau that means that I am going to get large

Student: Volume

Professor: Conversion.

Student: Conversion

Professor: Conversion. Because no, no you know Damkohler

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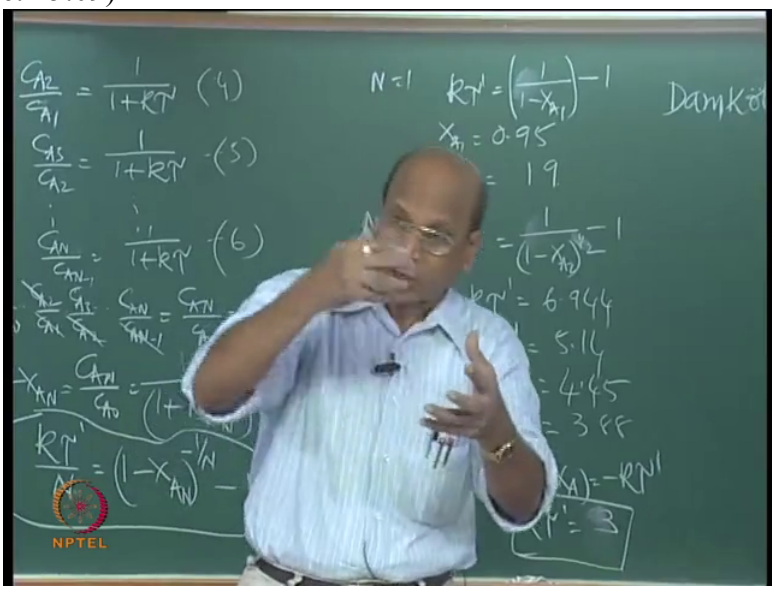

number. So I say that this reactor has large Damkohler number means in that reactor we have conversion more, Ok, good.

(Professor – student conversation ends)

So now here, coming back to these results what do you learn? Beyond this you cannot go,

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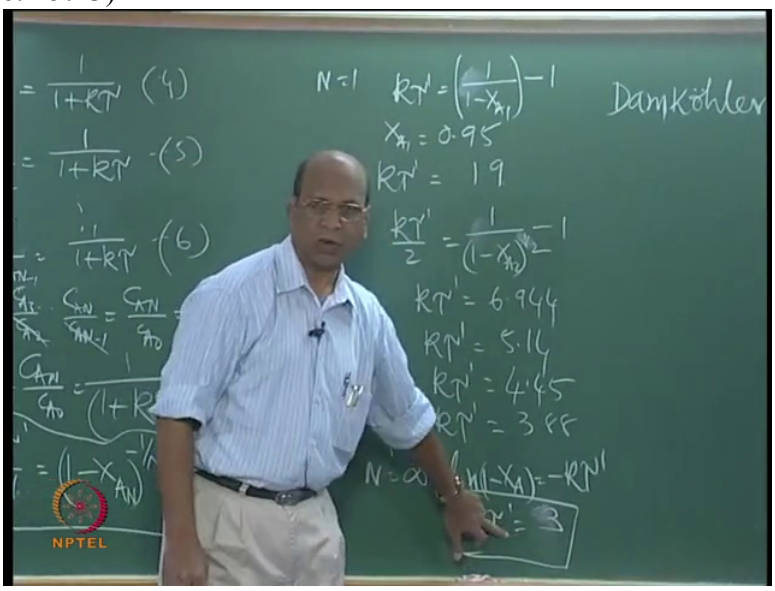

Ok. If k equal to 1, as you know, as for easy thing, and you know here I may take this one is 19

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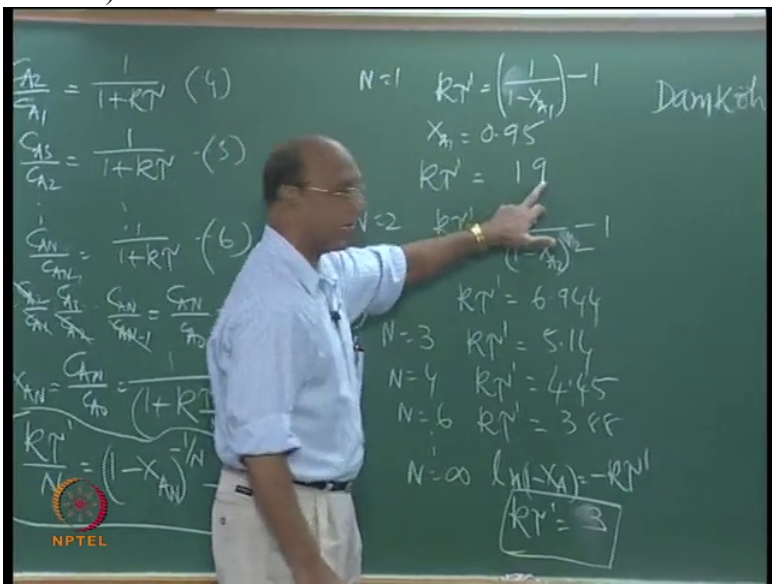

meter cube, as an example, if k equal to 1.

Ok.19 meter cubed here, so that means in the second reactor, that means if I use 2 reactors for the same conversion, one reactor I have used, 95 percent conversion. What is the volume I have to use? 19 meter cubed I have to use.

The moment now I take 2 reactors, same conversion 95 percent, you know the total volume itself

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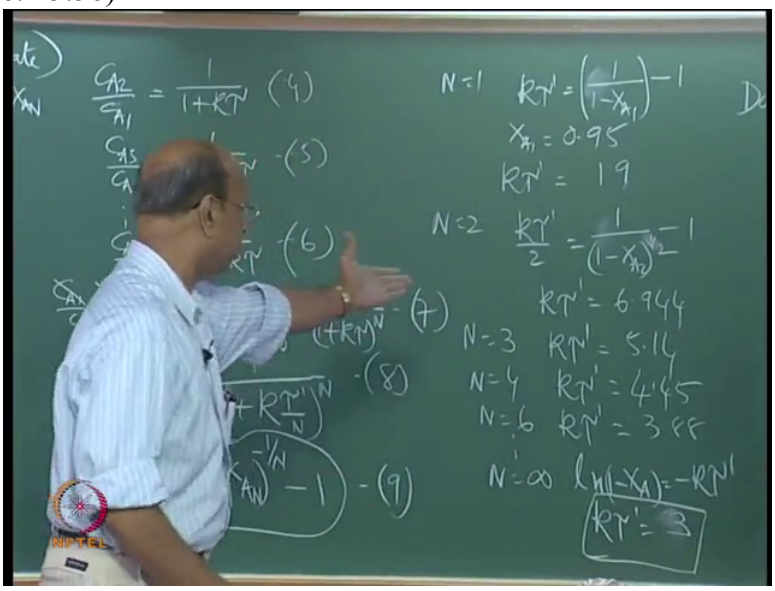

has become 6 point 9 and each volume, volume of each reactor, only 2 are there, Ok 6 point 9 means Ok 7, 3 point 5. Engineering approximation. 3 point 5 meter cubed of 2 reactors if I take then I will get 95 percent conversion.

Now next one, 5 point 1 4, k tau dash

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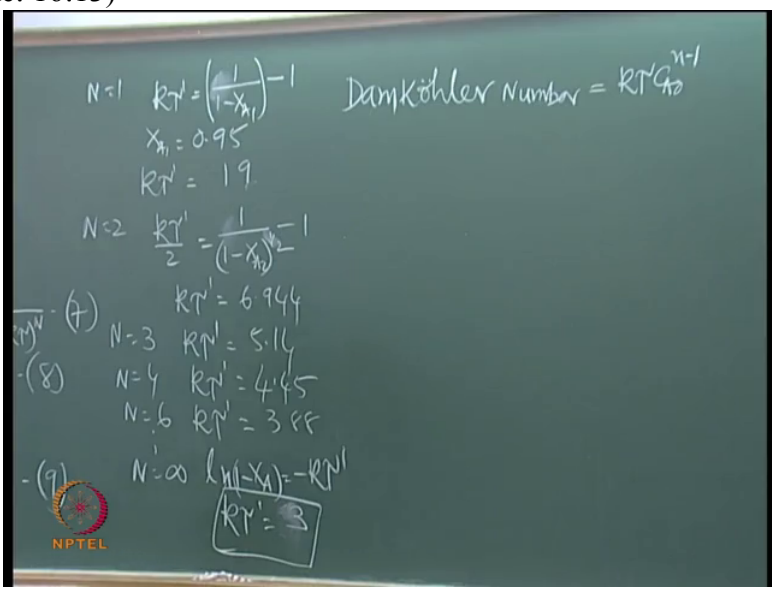

is total, tau dash means N into tau, yeah you already multiplied by 2 because in the denominator this you have,

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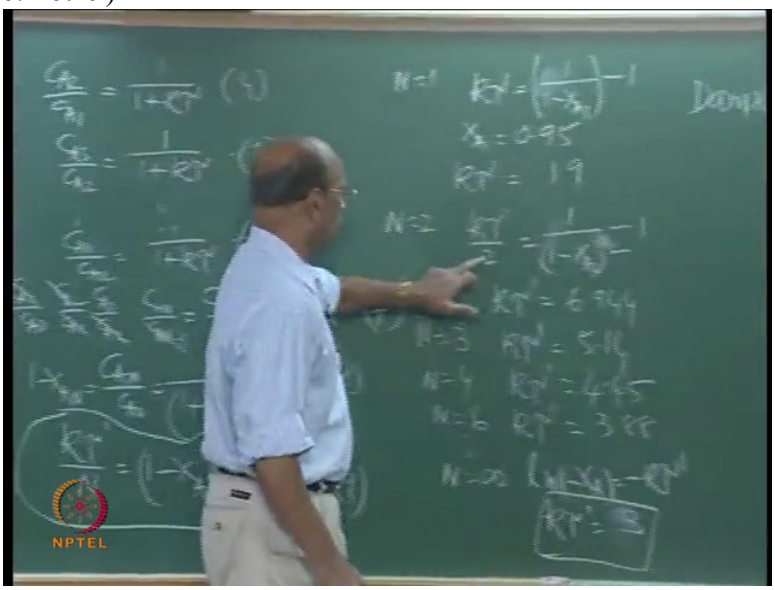

so you multiplied by 2 and then you get, otherwise if you write only k tau dash by 2, that will be 3 point 5 approximately.

Then this will be

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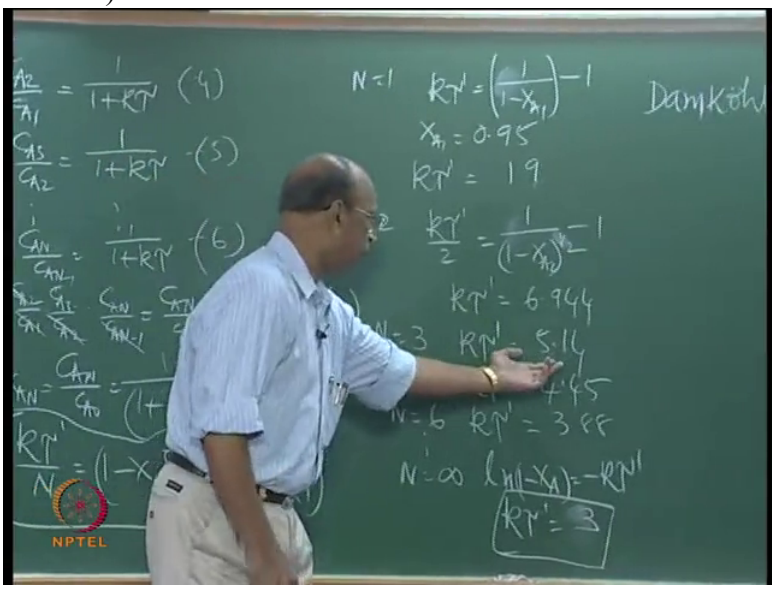

5 by 3, how many 1 point 5, 1 point 6, 1 point 6 or so. You see now. So this is 19 individually, so like this with 1 point 6 or

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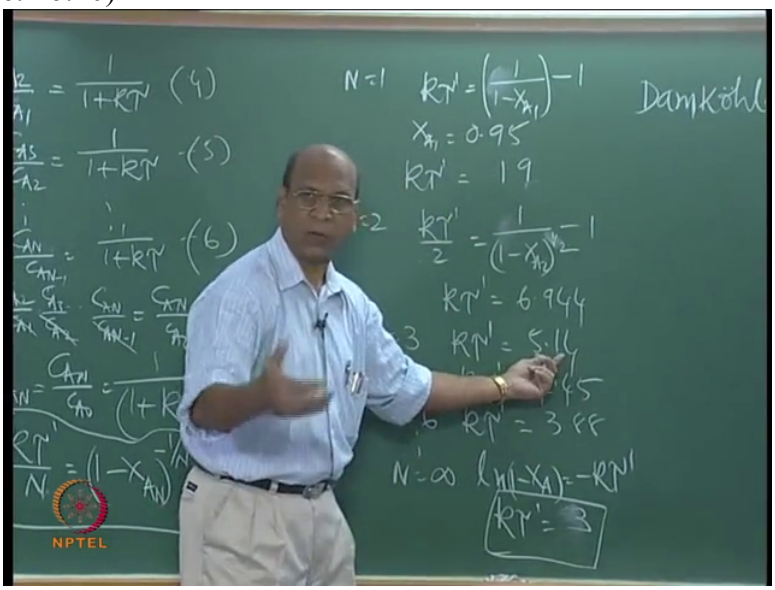

1 point 6 5, I have to use 3 tanks in series. What is happening to the volumes? Decreasing. So when you put infinite number of tanks like that, what will be the volume? Almost zero.

What is the meaning?

(Professor – student conversation starts)

Student: Plug flow

Professor: Not plug flow, each cross-section, each cross-section. Cross-section thickness we cannot define, almost zero. Not that there is no reactor. That is too much approximation (laugh).

(Professor – student conversation ends)

Ok we have a reactor with 3 meter cubed finally,

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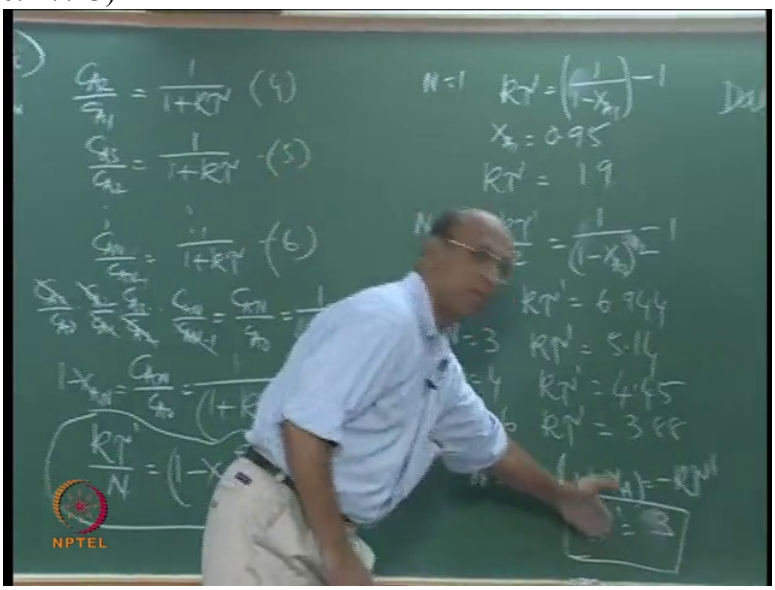

total volume. In fact, this divided by infinity. 3 divided by infinity, so 3 divided by infinity is still some number, it is not zero. Ok? Very, very small one, which is equivalent to our one cross-section.

See beauty again 0:17:34.4. Now the reason, why from 19 to

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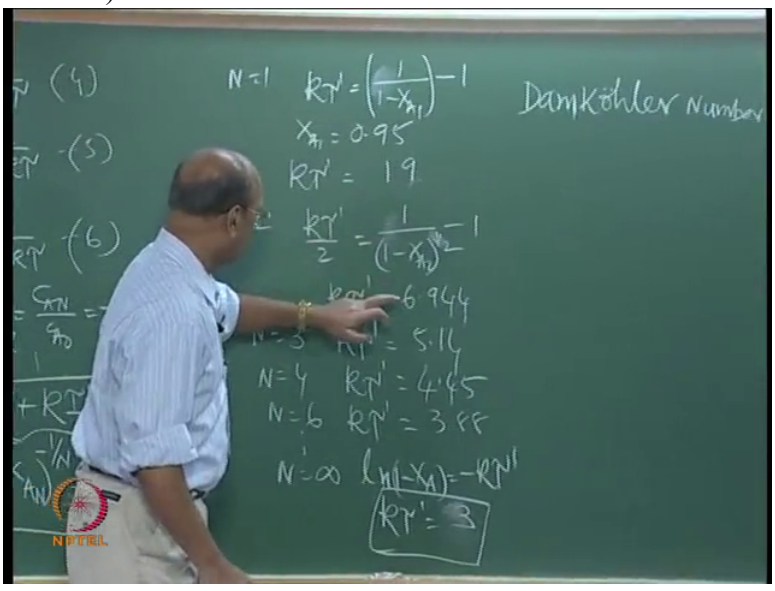

second reactor 6 point 9, there is here steep fall. If I plot this k tau versus N, k tau versus N, this is steep fall, from 1 to 2. From 2 to 3, not much, from 3 to 4, not much. You see here, in fact after 3, no after 6, where is 6,

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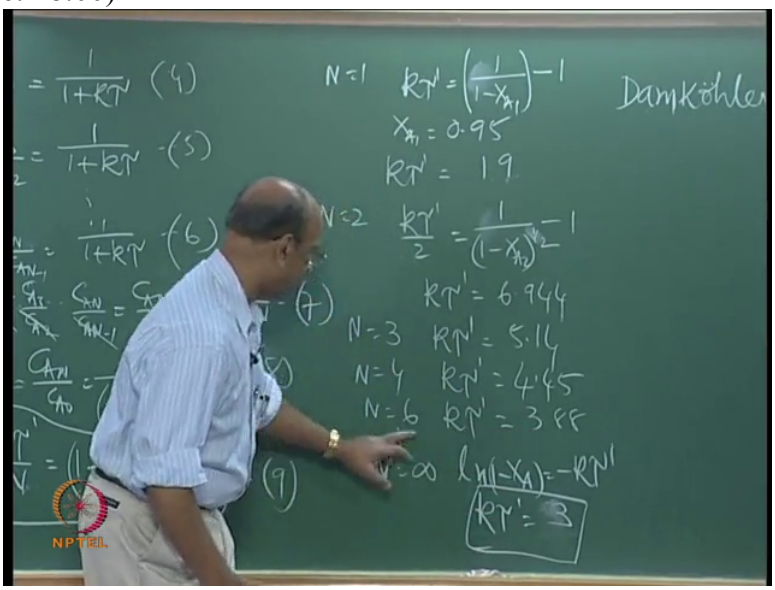

yeah after 6, I have to go infinity, 6 is almost 3 point 8 8 total. And for infinity

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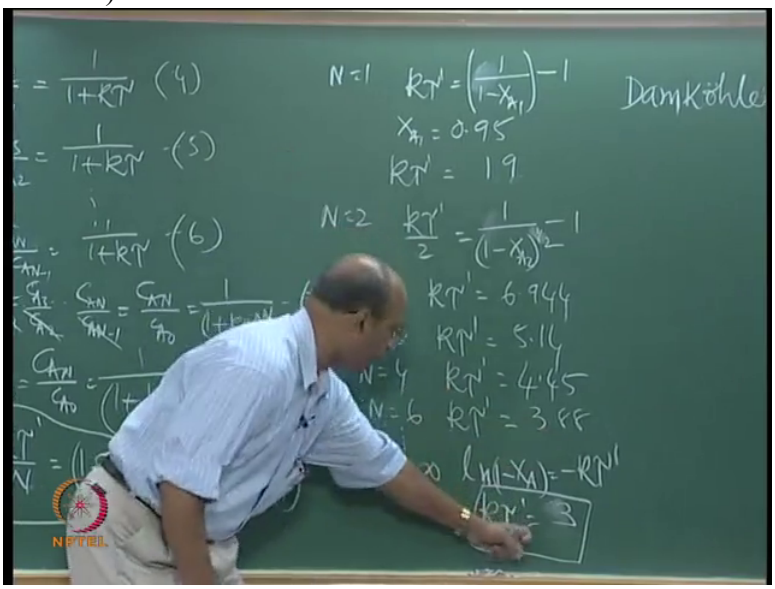

number also we have almost 3, Ok.

So that is why, why the first reactor has tremendous effect? You see the moment you say higher rate, the volume should be smaller. Correct no? That is why Abdul, I think you know we have to really think about that. Because when you say high rate what do you mean by high rate? volume should be less. Is there anything else?

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(Professor – student conversation starts)

Student: So many unreacted component escapes

Professor: Yeah

Student: The availability of

Professor: You by definition

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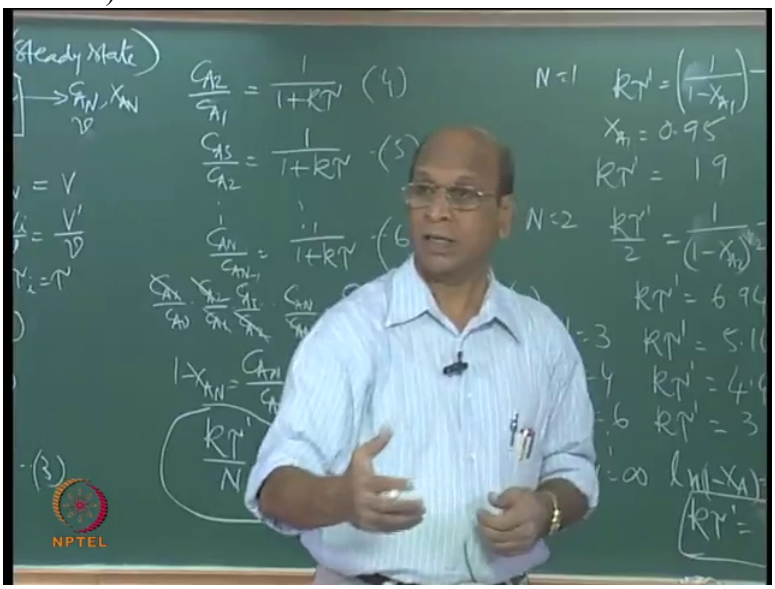

this mixed flow reactor has bypassed. By definition itself. You are saying that you have perfect mixing and through R T D you can find out, in one mean residence time, what will be the, this is what is mean residence time, no? Tau.

(Professor – student conversation ends)

Tau equal to

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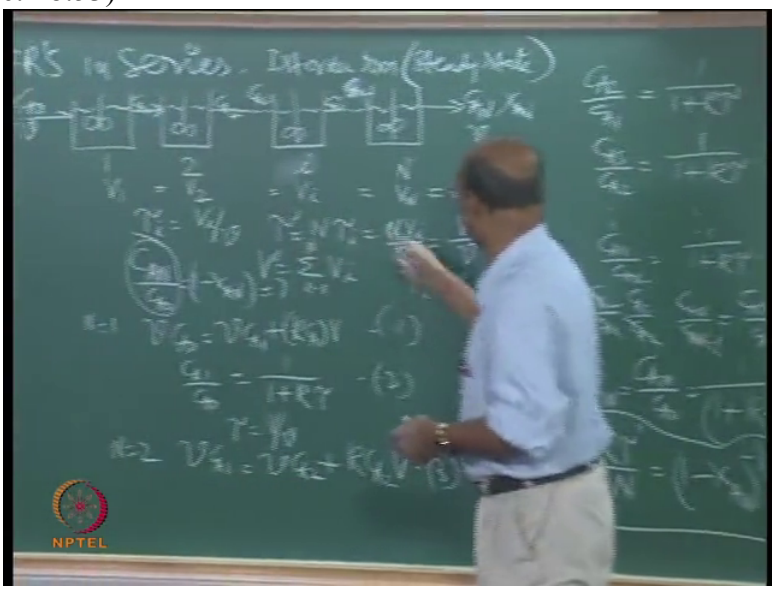

volume by volumetric flow rate of 1 reactor, there is only one reactor. So what happens is the moment you put the liquid continuously there is lot of fresh liquid which is going out with the old liquid. That is what I explained also, what is mixing, perfect mixing. It is not instantaneous reaction. Please remove that concept from your mind, instantaneous reaction. Continuously you are feeding. Mixing is instantaneous,

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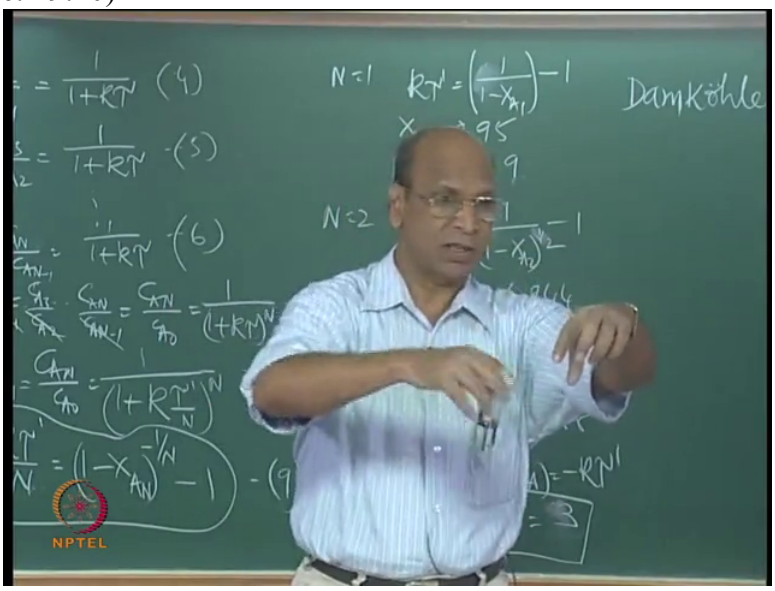

not reaction. Mixing is instantaneous. So when mixing is instantaneous, concentrations will come to some steady state concentration which is outlet concentration. But that does not mean that everything converted.

And the whole, when I look at the outside, or inside also same, there are molecules which have just entered, there are molecules or packet of molecules we cannot say, packet of molecules which have entered long time back, average of all that is 95 percent conversion. Average of all that.

So to maintain that 95 percent conversion, I should use 19 meter cubed

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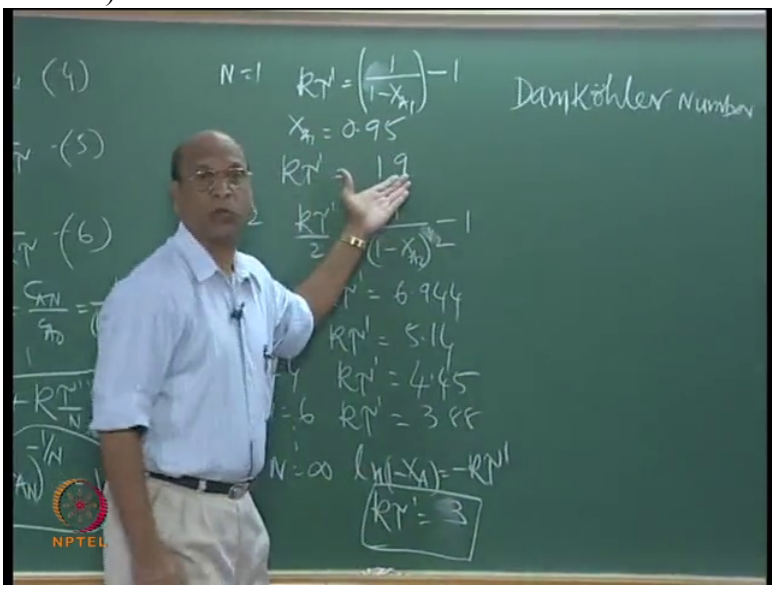

when compared to plug

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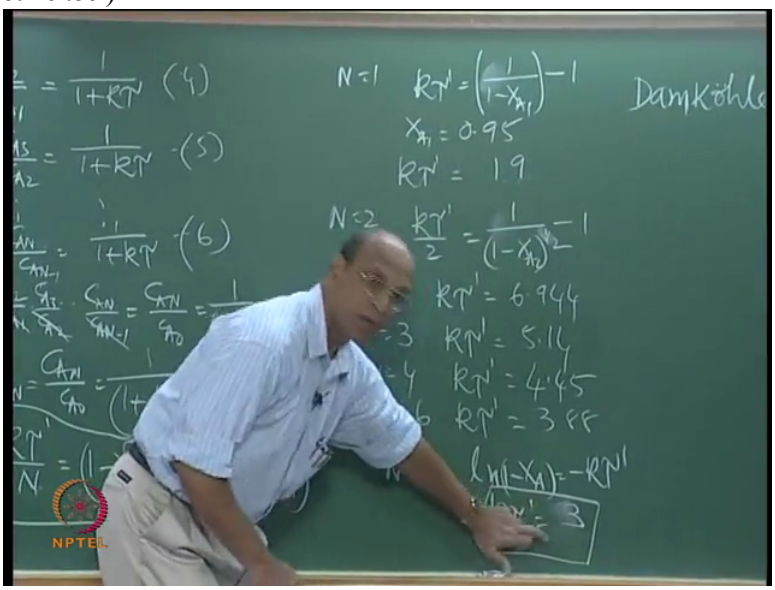

flow reactor, infinity is equal to plug flow

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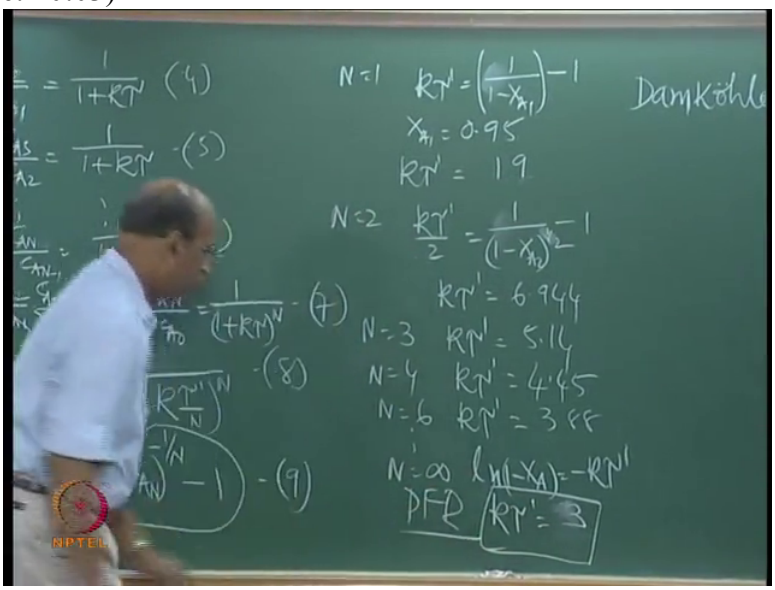

otherwise you would think that there is another reactor called infinity reactor. Ok, this infinity reactor equal to plug flow reactor, Ok, so in this plug flow we have to use only 3 meter cubed. Why?

This is where the beauty of plug flow comes. By definition each and every particle must spend exactly same time. So conversion in every particle, particle means it is containing lot of molecules. So in every packet or particle you have the same conversion. When I take the average and then again mix all that and again take the average conversion, also same.

Where as in the mixed flow I have a particle which is coming with lot of molecules, one quickly coming out, almost spending 1 minute or1 second, where the mean residence time is 10 minutes. So if it is, if I take 1 second, it is true.

The moment you put, when it is continuous mixing, water is continuously entering you know, for imagination I am telling, continuously you are taking out. You put just one drop of ink? Instantaneously it will appear in the outlet. Instantaneously. You can check that.

I think in our lab also when you go, Transfer Operation Lab, there is C S T R tanks in series, some 3, 4 together. So you start the stirrer and you take your ink and you know just drop one ink. Instantaneously it comes out. What is the meaning?

So those molecules which are immediately coming out, they do not have, they have no reaction at all. That is waste for us. That is bypass what we call. So that is why and then you take, there may be another one coming in the second, another particle, not one particle, many particles coming in the second second, Ok third second, fourth second, fifth second, like that you have.

And through R T D studies we can actually calculate from zero to 1, how much fraction of the material coming out, that is what is your V t, d t, the fraction of material coming between time t and t plus delta t is E t d t. That fraction we can calculate.

So I can calculate what is

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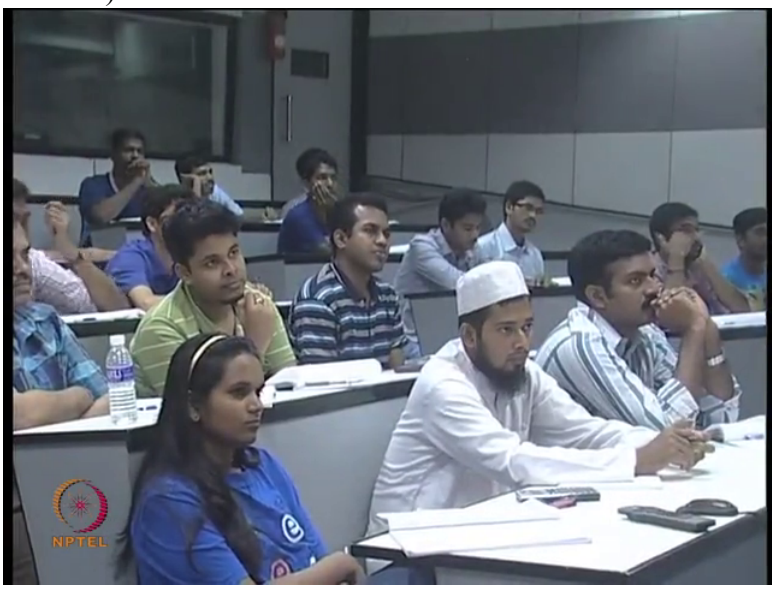

the first fraction, you know zero to 1 minute, or zero to 1 second, the next one is 1 to 2 seconds, 2 to 3 seconds, 3 to 4 second, all that fractions. There definitely the conversion will not be much. Why? The time spent by

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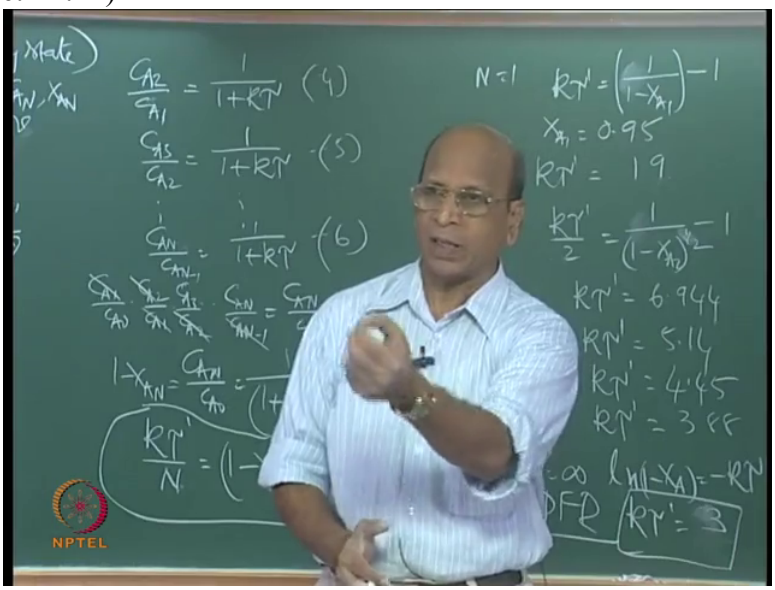

that fraction is only 1 second, 2 seconds, 3 seconds whereas the average residence time is 10 minutes. That also steeply falls.

I do not know whether anyone plotted, you have done experiment in R T D, some of you? Yeah have you done ideal one, single C S T R R T D,

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if you could have done, that is exponential decay. Initially it falls very fast and then slowly

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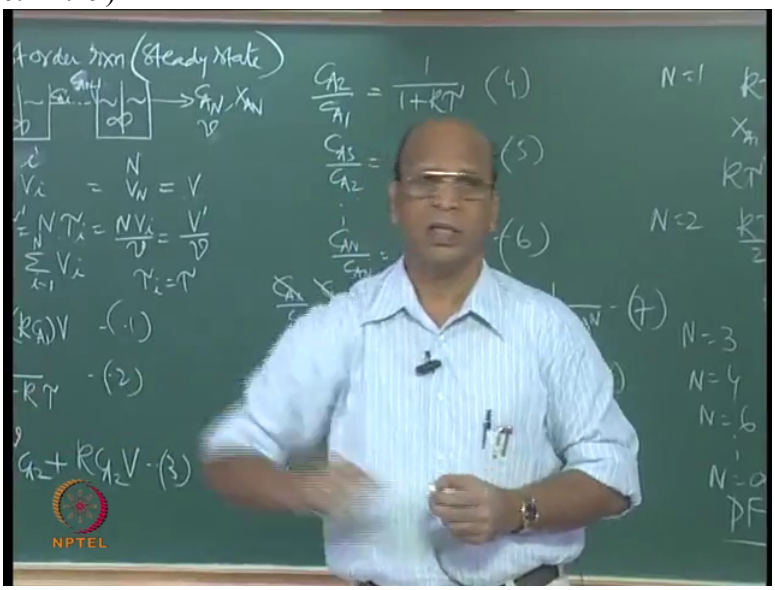

it comes out, the tracer, Ok.

So that means the last portion when I take, not much between you know, may be fifty fifth second and fifty sixth second it is not much, or may be minutes if I take. So that is why it is the Residence Time Distribution which is affecting the performance

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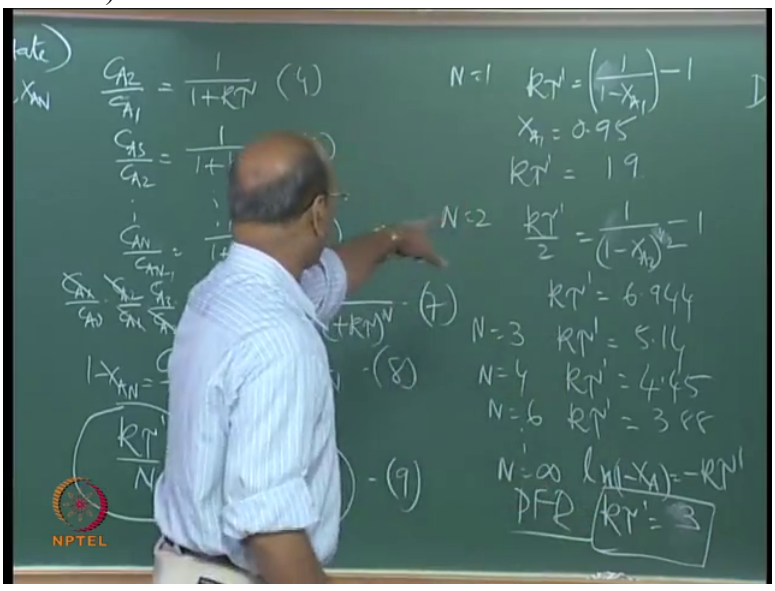

of a mixed flow reactor when compared to plug flow where theoretically there is no Residence Time Distribution, Residence Time Distribution equal to zero.

Right, you understood now? Because please do not say no, the moment you have the reactant going instantaneous reaction, it is not instantaneous reaction, it is instantaneous mixing. And

in that mixer what I see is molecules which have entered just now, molecules which have already converted. So all these average what I am seeing as 95 percent conversion, right?

So that is why the first reactor has tremendous

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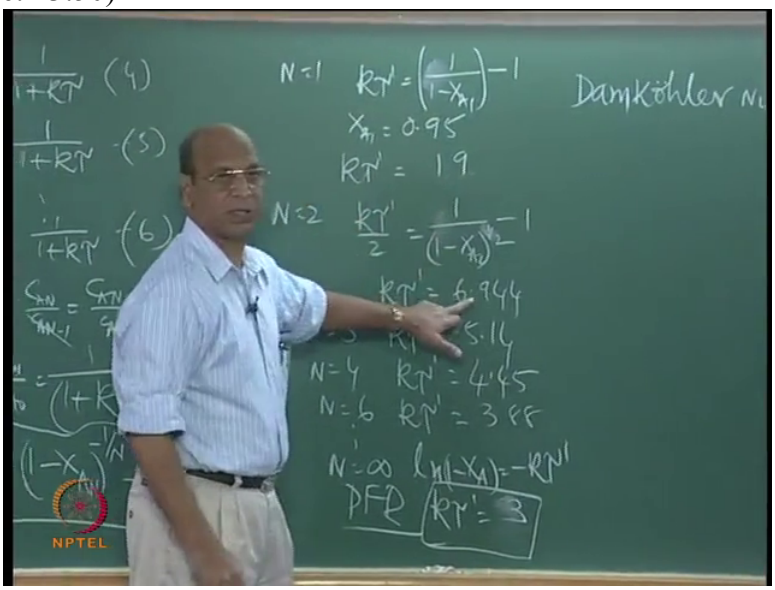

effect. From first to second you won't see that kind of bypass. I mean it is also perfectly mixer. Second reactor you cannot, that means if you find out R T D for 2 reactors we can calculate.

R T D for 2 reactors we can again calculate 2 reactors together. First reactor it entered, second reactor it is coming out, right? And what is the fraction that is coming out in 2 reactors in one minute? It will fall. It will be less than 1 reactor.

So like that, you know second second, third second, fourth second all that I can calculate. So like that I can take 6 tanks R T D, and calculate what is the amount that is coming out of this sixth tank, after 1 minute how much, you will not see much.

So then if I take to infinity, all the molecules would have spent exactly same time. Why? The molecules which have bypassed here

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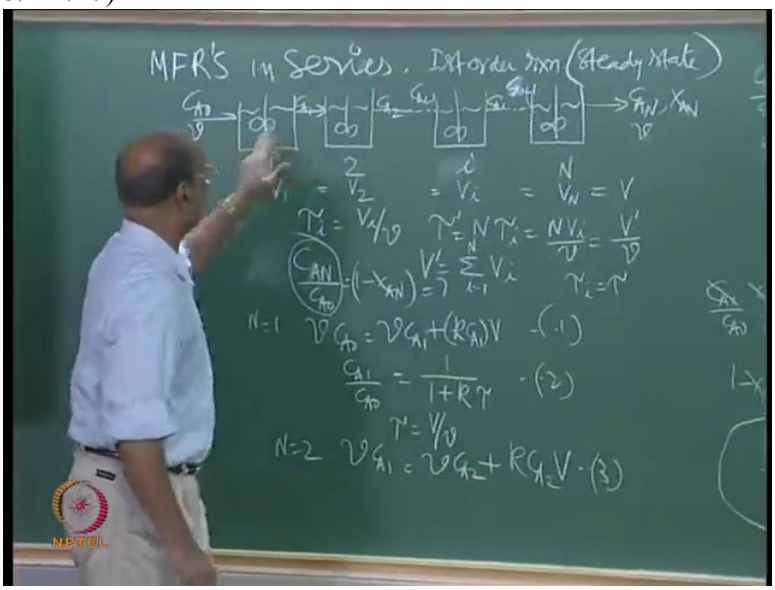

may stay here. Some

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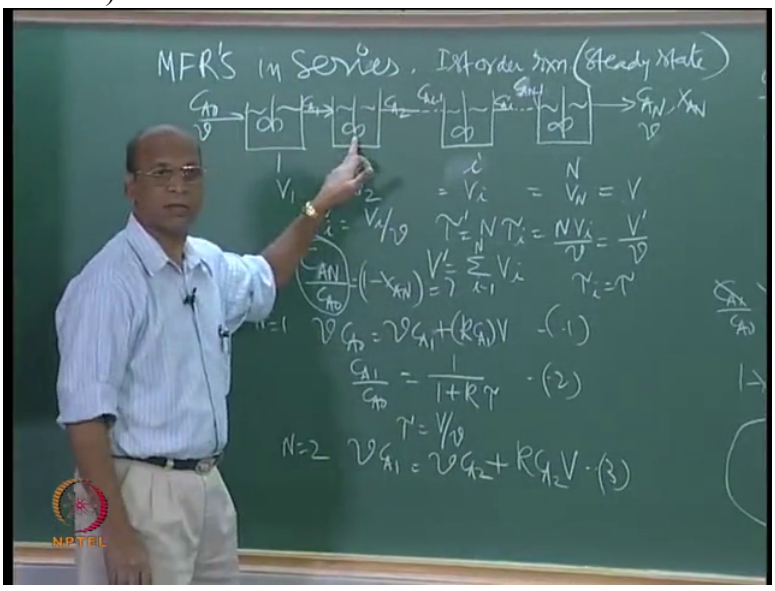

other molecules will bypass. And from here some other molecules bypass

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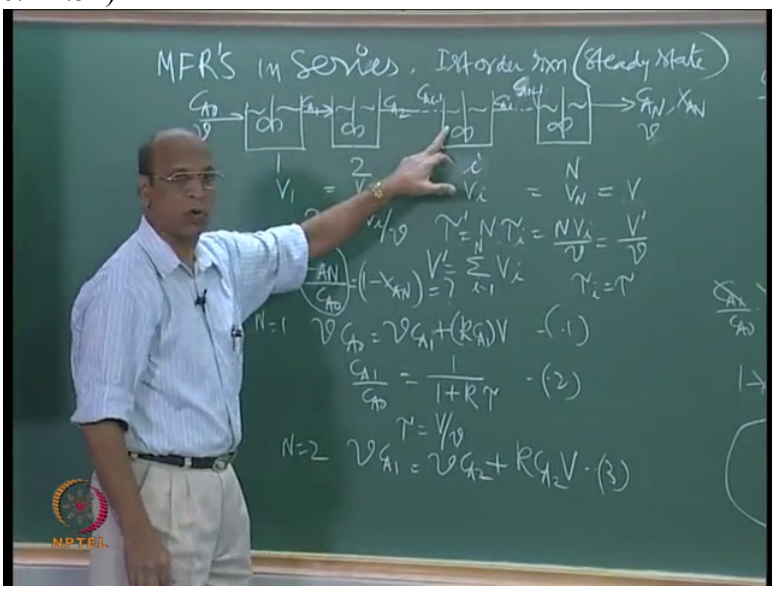

and will go. Some other molecules will stay.

On the average, if I put infinite number of tanks, all these bypasses, and all these staying inside the each reactor, all will be uniform for each and every particle. That is why the residence time of each and every particle, if you have infinite number of tanks in series is exactly same as plug flow.

Then also you can see,

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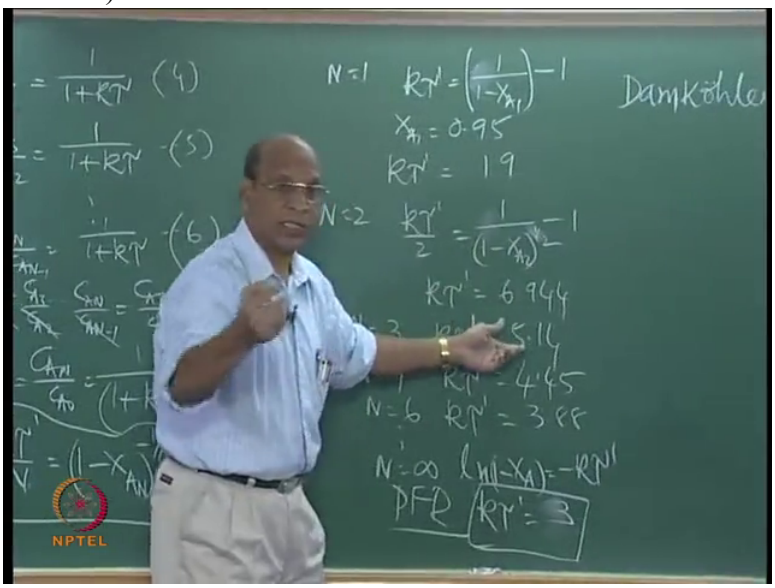

how this volume is going, becoming smaller and smaller and smaller

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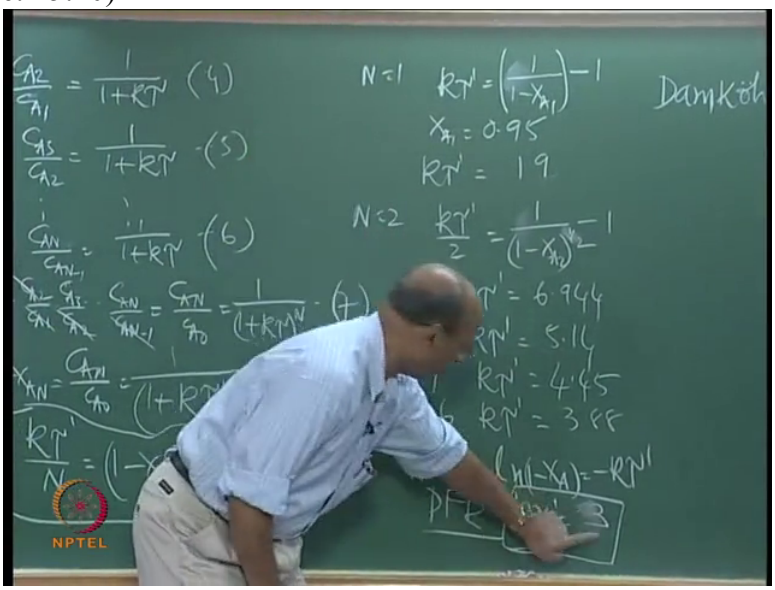

and finally it is going to the size of almost zero, limit tending to zero where that tending to zero is nothing but volume of your cross-section. I think with this you should not forget that. Beautiful concept.

So that is why we know that it is very difficult to operate plug flow reactor because you need very high velocities, Ok what are the Reynolds numbers?

(Professor – student conversation starts)

Student: 500

Professor: Theoretically infinity but practically when you want to see that flat velocity profile which confirms that all the particles are moving at the same speed, that you know flat velocity profile, you need around 40000, 50000, 60000 in an empty tube. You have to also mention empty tube. If you go to packed bed,

Student: 500

Professor: 500, 600. If you go to 4000, 5000, guarantee you know, almost plug flow.

(Professor – student conversation ends)

That kind of more and more Reynolds number I am using, what will happen to my residence time? Less and less. So I cannot use this system for all the reactions where we have more residence time required for conversion.

That is why we go for gas phase reactions where gas phase reacting time is seconds, 10 seconds, 15 seconds, 20, 30 seconds like that. Even then you have there 1 kilometer, 2 kilometer length; they are putting like this, like this, like this, like this. I am not exaggerating. That kind of length will be there.

So if you go to the real, you know may be NOCIL that kind of sold chemical engineering industries you will have this kind of lengthy reactor for plug flow. See now, how beautifully it has come out. The series reaction.

So that it the reason why, because plug flow is not practical most of the time, we try to use 4 reactors, 5 reactors where mixing you can guarantee, temperature control it is beautiful, absolutely no problem and not only that, again you know this is what the expansion of mind should come. You should think also.

We talked about isothermal system, right? So that means even though the concentration is high here,

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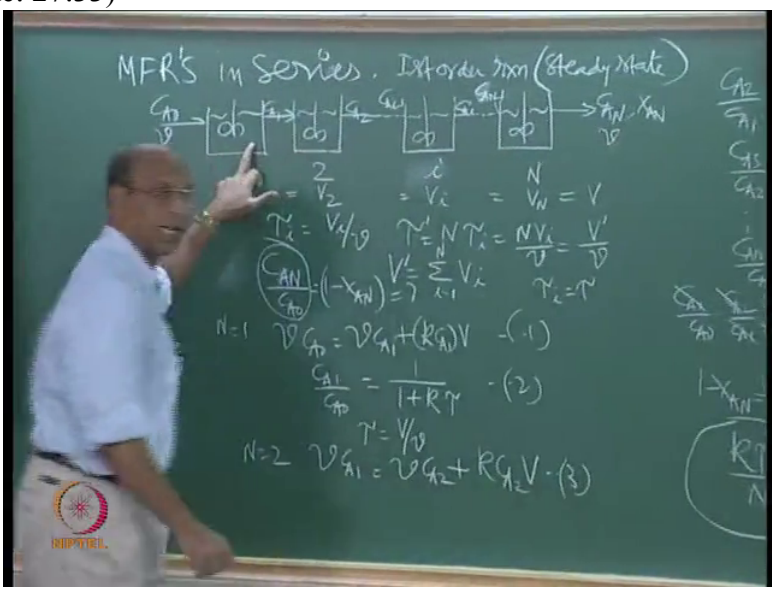

Ok high here and when compared to this one, the rate of reaction will be high here. Because the concentrations are high. On the average again, I am talking.

And here

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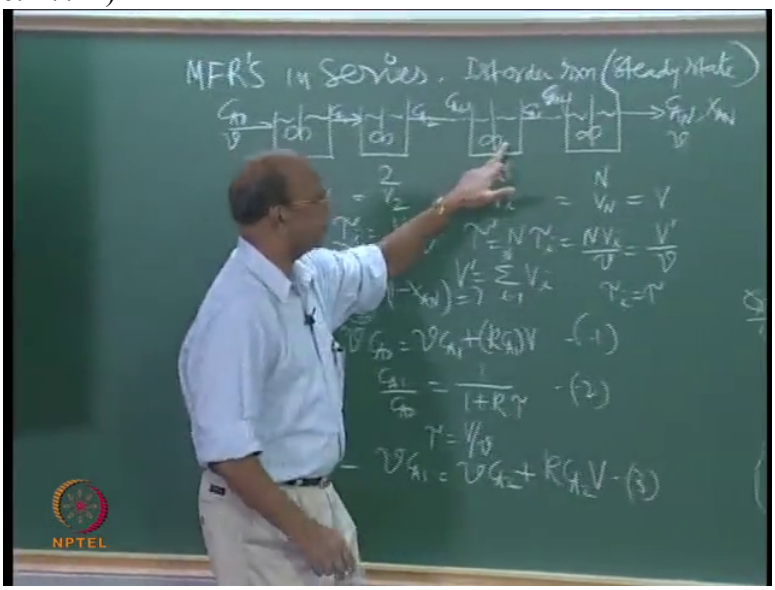

the concentration has fallen, right. But how do I increase the rate here? See for this alone you can have a separate temperature control, you can supply separate heat for this alone because outside jacket now I will maintain. This is at 60,

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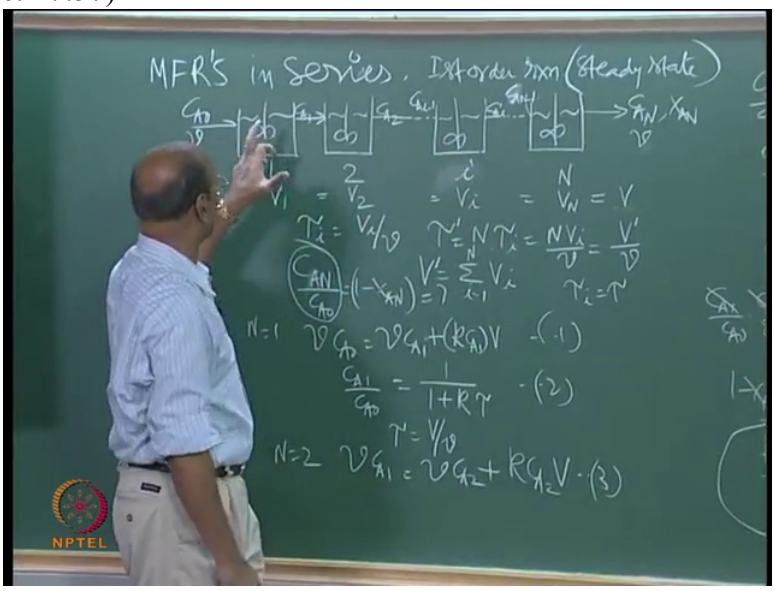

may be 75, 90, 120

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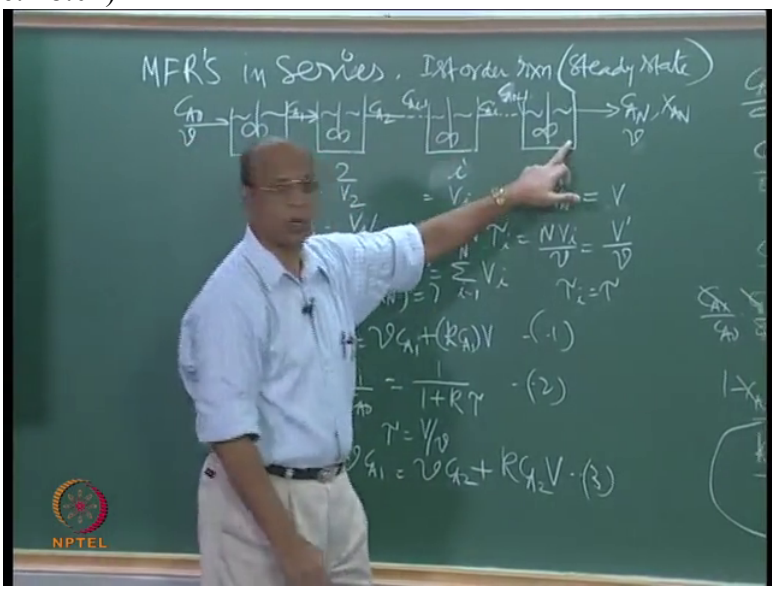

like that you know you are trying to compensate now through temperature, the rate of reaction more.

Then again the total volume will be less. But only thing is you have to see. I mean it is not that easy. You have wonderful ideas. But practically everything is measured in terms of paisa, money. Tension. Temperature fixing means beyond certain things you cannot go. Temperature fixing means what temperature you are talking? 200, 300, 400?

(Professor – student conversation starts)

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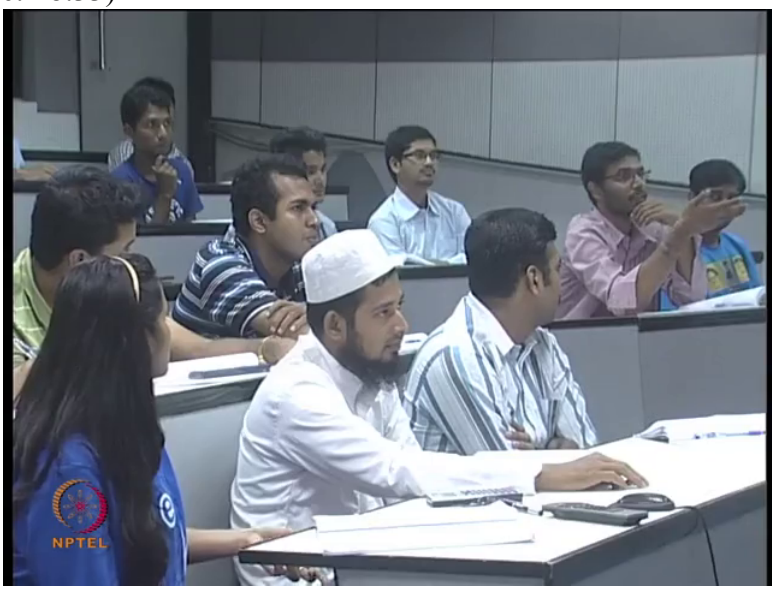

Student: It is starting at room temperature. If it is temperature controlled...

Professor: What temperature?

Student: 40

Professor: 40 degree, you cannot use, that is all, simple. That is why C S T Rs, in biochemical, they cannot use. Right. If they use

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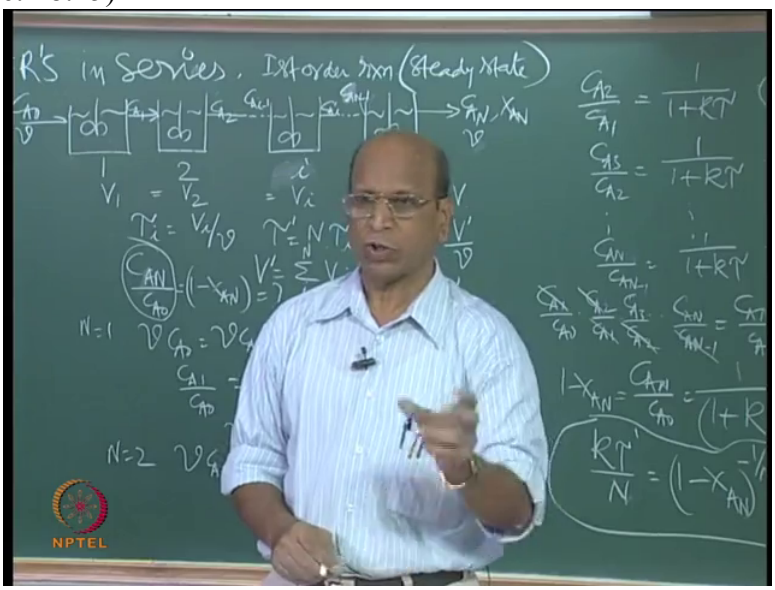

it will be 30, 35, 36, 37, 38 like that only. Because may be 40, 45 many microorganisms will die, no. Yeah if the temperature is 50, 40 and continuously you are exposed there, that is all. Drop dead. Ok, that is all. (laugh) Finished, Ok.

(Professor – student conversation ends)

So that is why if temperature sensitive, we have to use our brain, Ok this is temperature sensitive, I cannot use beyond this temperature. That is very simple question to answer. So that is how you can also try to

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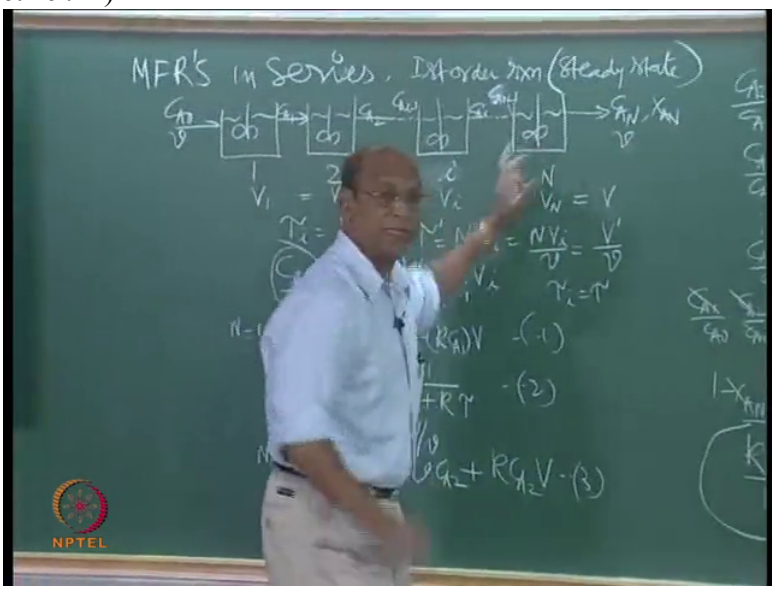

compensate and Walas book gave that kind of problems.

W a l a s, Kinetics for Chemical engineers or so that is the title, he has

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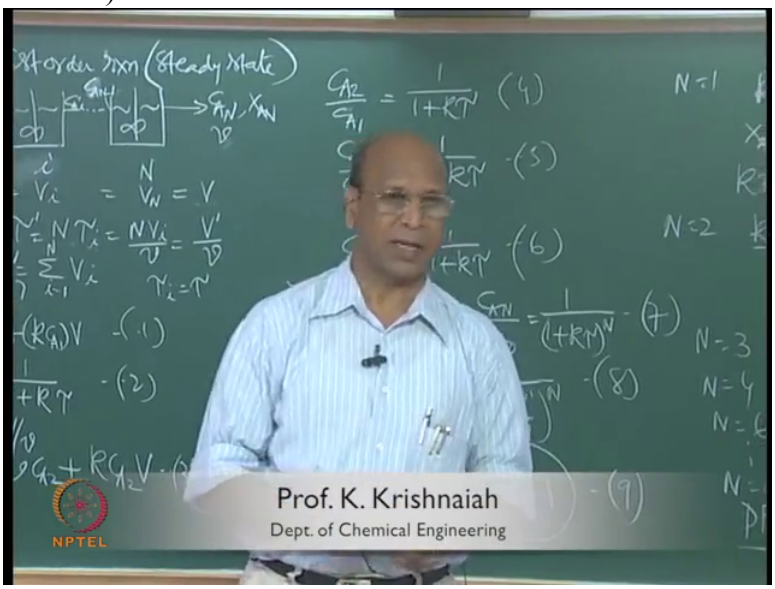

given. He has given you know, 4 or 3 reactors if I remember correctly. So in each reactor the temperature is different. 15, may be 30, 45 like that. So now you, k will change in each and every thing. Concentration whatever we lost, through k we are trying to gain it.

Now I think this is series one, the next one is combination of reactors. I think you know it is only some very simple thumb rules are there. That is why; if you go to really very, very high level everything looks very simple for you. In combination of reactors, how many ways you can combine reactors? Let us say I have only plug flow reactors.

First of all

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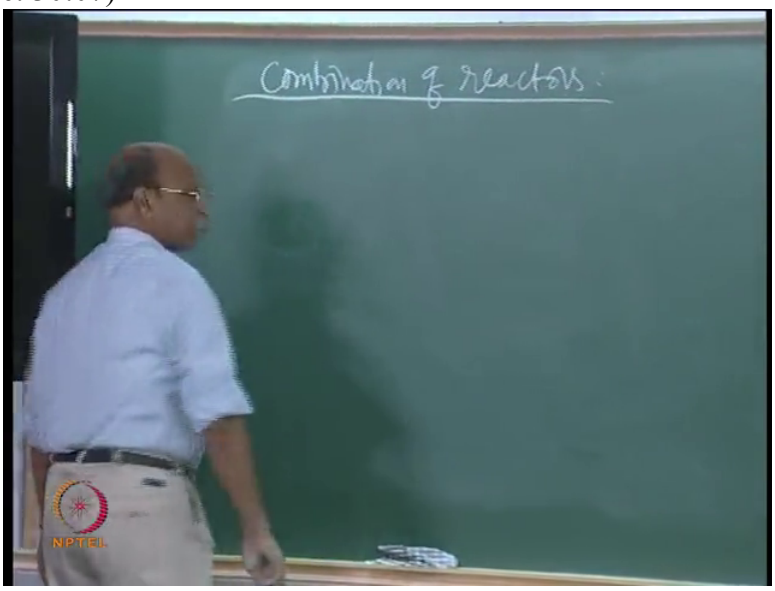

why should we combine reactors? It is a stupid thing no?

(Professor – student conversation starts)

Student: 0:30:14.6

Student: To increase conversions

Professor: To increase conversions you could have designed in the beginning itself, no? Why again adding another reactor?

Student: Sir, volume decreases.

Professor: Let us say, we have P F Rs, first.

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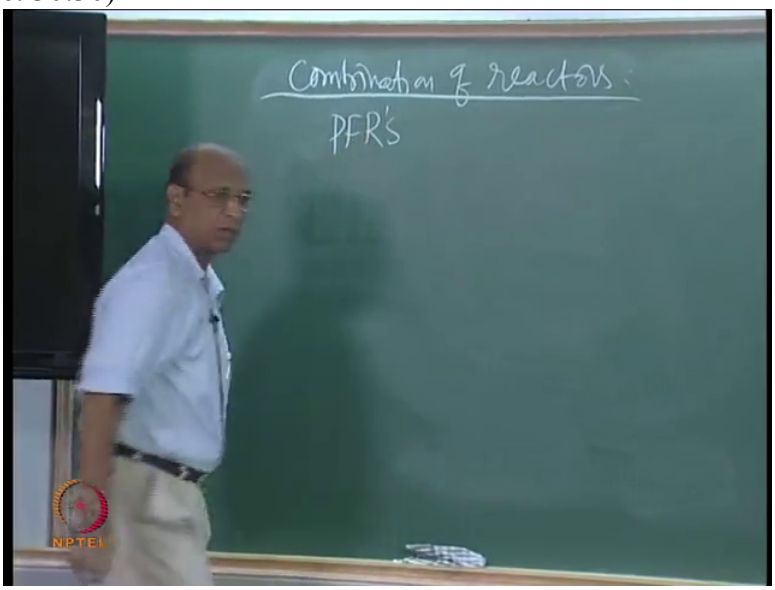

Student: That which temperature sensitive, he was telling, no. In that case, means combination of

(Refer Slide Time: 30:37)

the reactors we can use. In some cases, if it is...

Professor: What is the use? I am getting more volume only. That I can design one reactor.

Student: We can Sir, control the temperature.

Professor: Why do you want to combine? Even at, control temperature, at one temperature, isothermal conditions all the reactors are there. Why do you want to

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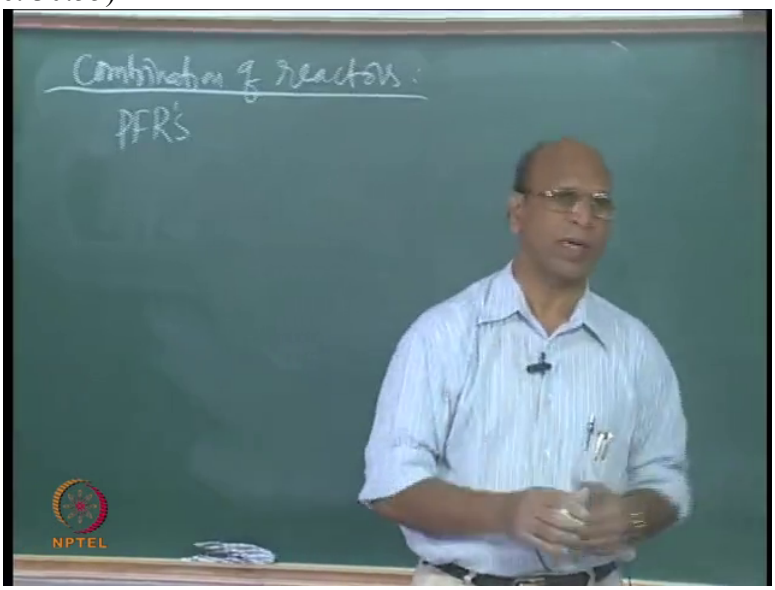

combine reactors?

(Professor – student conversation ends)

I think partially her answer is right, if I want to increase conversion. Already existing, Ok, maybe 100 meter length, diameter may be 2 inches of a plug flow reactor is already existing, right? So that is giving me 90 percent conversion.

But someone tells me, no, no, no I think 90 percent conversion so another 10 percent waste is there. I do not expect, you know, I do not take, buy your product. So it should be, may be 3 percent only you should have the other, unconverted reactants and all that. Then what do you do?

You do not have to design again a whole new reactor, Ok. So then you can add reactor. Where do you, how do you add? Where do you add this? You can put parallel, you can put series. You tell me, I mean why different, different, what do you mean by different, different? There are only two different. One is either series or other one is parallel.

Any other way you can combine? Cross-current also you can put but that will not happen here. For us, cross-current will come later. I will tell you where. Ok, So either series or parallel. Ok, So when you have this conversion, if you want more and more conversion, do you put these P F Rs in series or parallel?

(Professor – student conversation starts)

Student: Series

Professor: Why?

(Refer Slide Time: 32:13)

Student: Easy to understand our real life

Professor: Easy to understand our real life? So that is why you put in series.

Student: It increases the length so that maximum conversion is there.

Professor: Yeah, but even by increasing the length, why do you get maximum conversion?

Student: Volume will increase

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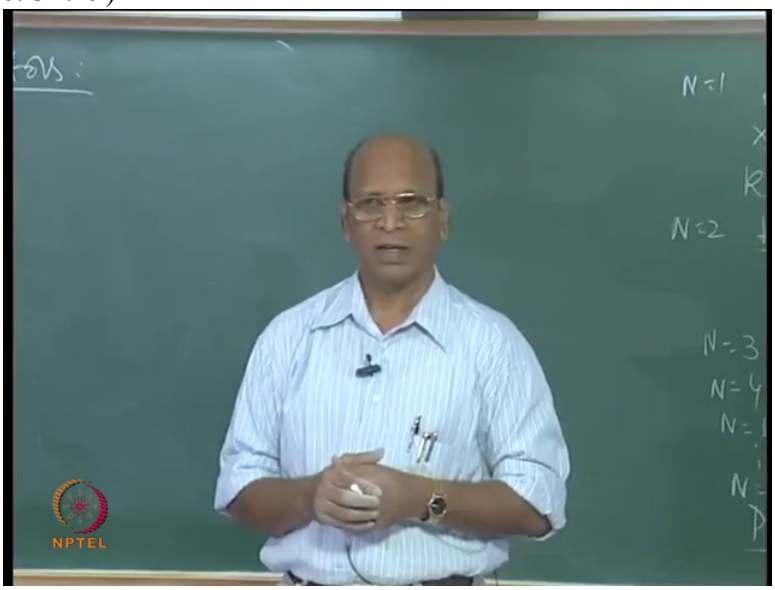

Professor: Yeah I mean answer is right but correct word?

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Student: More time the molecule will reside

Professor: Exactly, more residence time.

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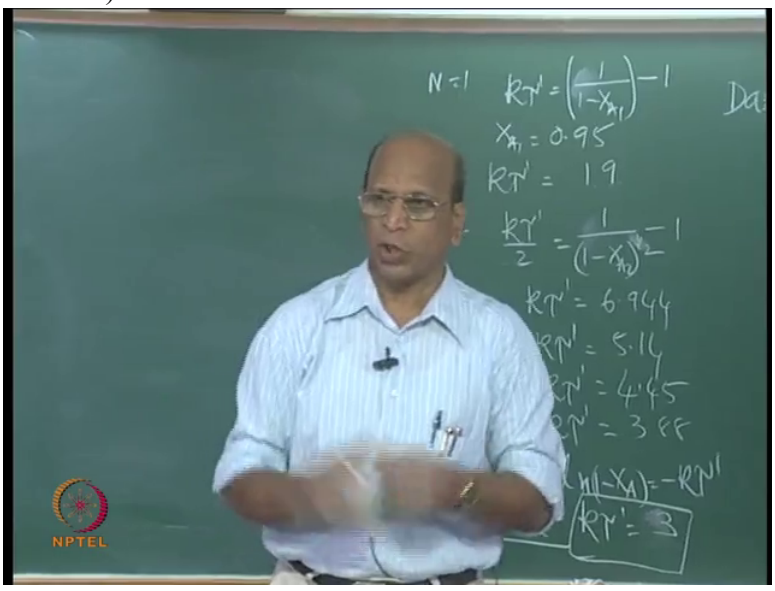

So you are, by putting in series you are putting more residence time.

(Professor – student conversation ends)

So that is why, like story only we can tell this. I think you do not need any, of course if I tell that, I have this much 90 percent conversion, how much length is required for going from 95 to 97, that I think I will give you as a problem.

But right now, I want to discuss all this as a, because you do not need any new equation. I tell you there are no new equations now onwards. Basic equations are already you learnt. The only thing is mathematically you have to; you know, integrate or differentiate and then try to find out what will be that extra information what you require for all this discussion.

So to increase conversion, first objective, thing is to increase conversion. So, Ok reactor should be in series. Ok, this is general. I think even C S T R also, same thing. C S T R also, Ok

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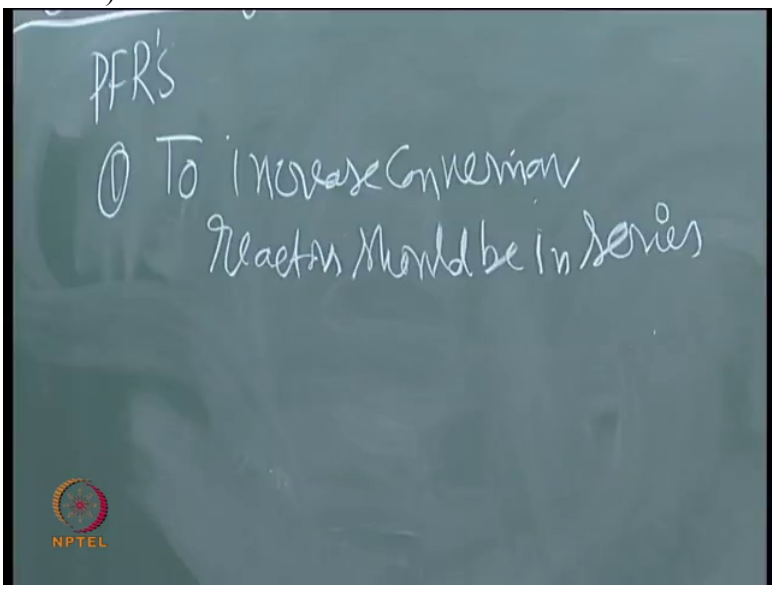

parallely when you discuss that and you are not fixing the conversion, there we fixed conversion and tried to find out how the volume is reducing. But I want to increase conversion.

I have 90 meter cube in the beginning. So another 90 meter cube if I put what will happen? Conversion definitely increases. How much and all that we can discuss later. Yeah, so like that. So that is why, in general, even though it is P F Rs or M F Rs this rule is correct. That means

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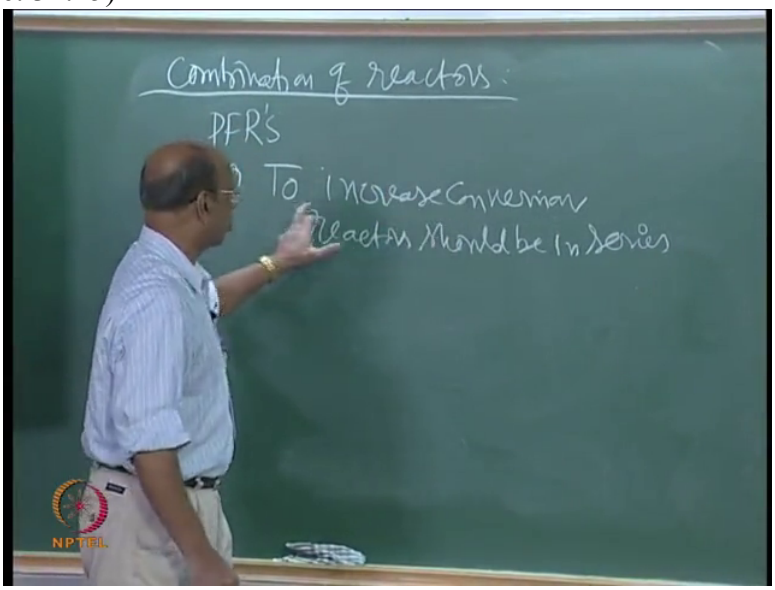

to increase conversion; reactors should be connected in series. Ok. When these parallel things will come? What do you mean by capacity?

(Professor – student conversation starts)

Student: Production capacity is there.

Professor: Like, in our language can you tell what is production capacity?

Student: If you have got the maximum conversion, you do not have

(Refer Slide Time: 34:34)

to go with the series. If you want to increase your capacity.

Professor: Yes, series we have forgotten. I am just asking you when you do you use parallel combination? Is it same time like increase conversion or decrease conversion

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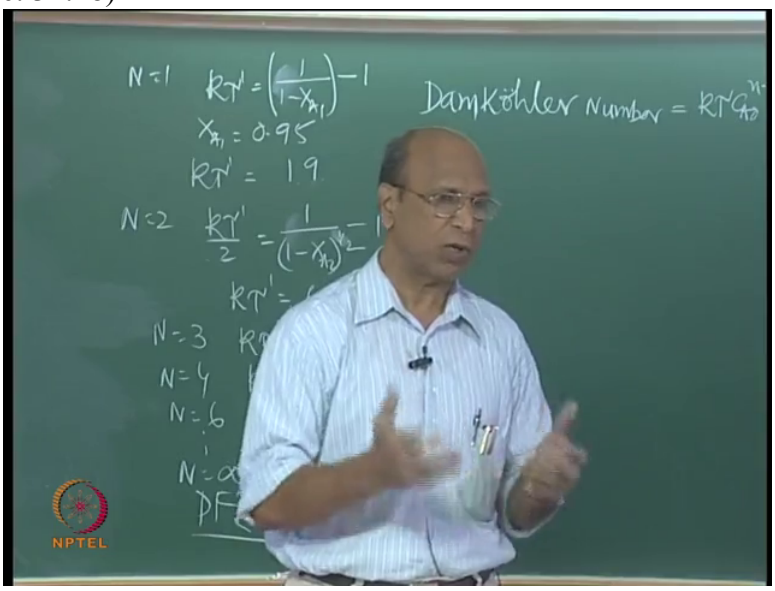

when do you want to use?

Student: Same conversion

Professor: What you said is right but I think some technical words if you use...

Student: High production rate.

Student: Large scale...

Professor: Production rate?

Student: To increase the production rate.

Professor: Yeah, instead of capacity, production rate can be increased.

(Professor – student conversation ends)

So that means if you are able to produce 100 tons

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per day, someone tells no, no, demand has increased. You can go to 150 tons per day. So you do not have to design for the entire, you know, new plant. You have to only put now, parallel

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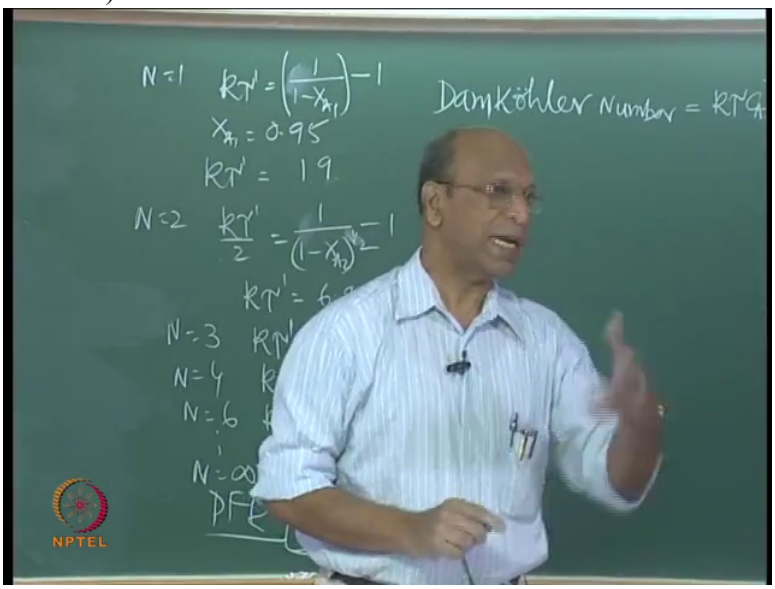

reactor Ok. It is only now 50 tons.

So you have originally, when we were talking of P F Rs, like this 1 reactor which is giving you 90 percent conversion. So this is for 100 tons per day.

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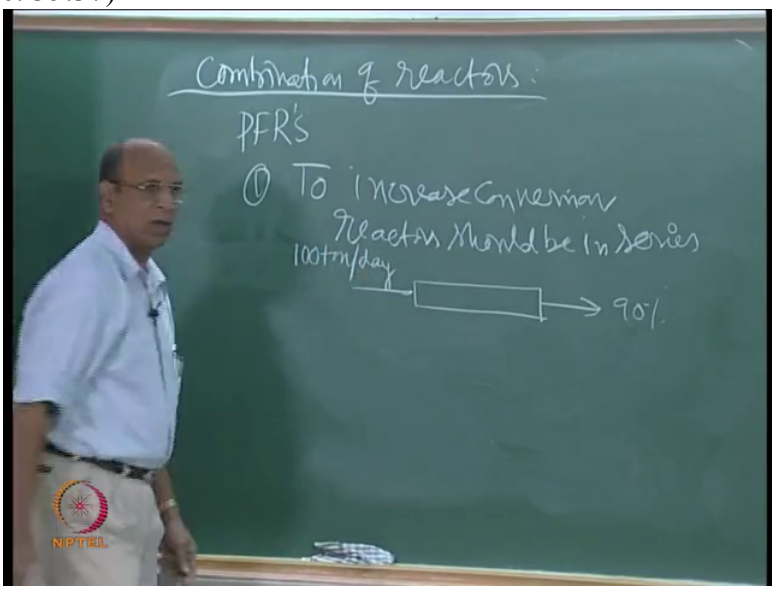

Now we thought now that we can put another parallel reactor for increasing to 150, Ok parallel, so this will be 150 tons per day, not one, both together,

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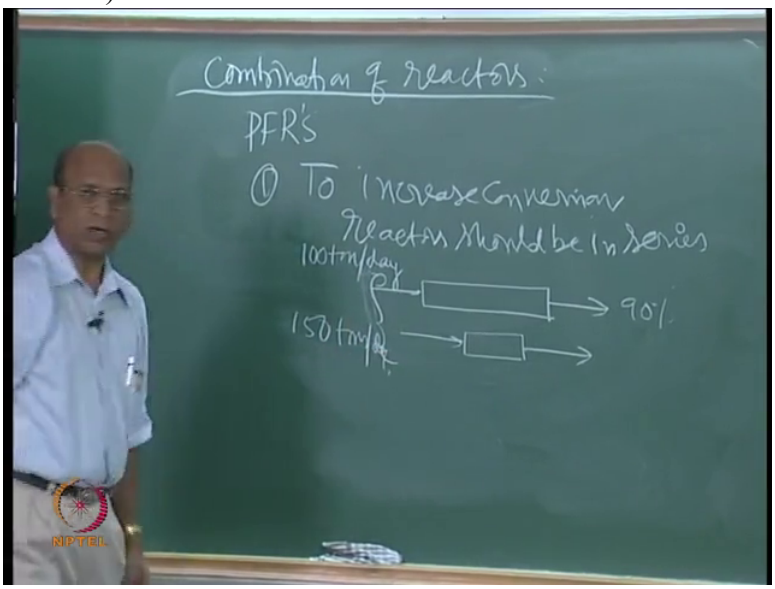

good.

So what is the condition I have to maintain here? Because yeah, so parallely I may, that means I have to again separately put another flow rate and all that here,

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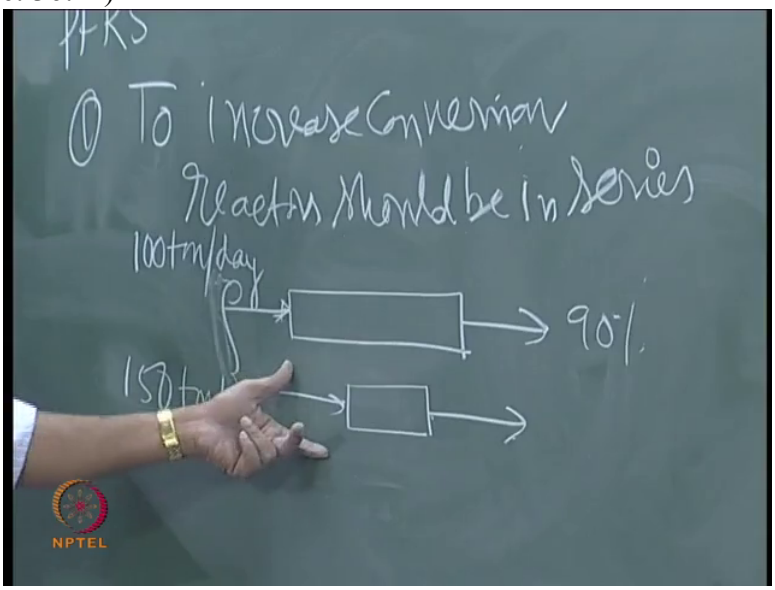

right but is there any condition we require for outlet. What is the conversion, what should be the conversion from outlet?

(Professor – student conversation starts)

Student: Same rate for both

Professor: Why?

(Refer Slide Time: 36:22)

Student: Otherwise we cannot mix both the outlets

Professor: But why I cannot mix? I can always mix. But what do you get?

Student: Conversion would be different

Student: Would be less.

Professor: Different, means more or less?

Student: Less

Professor: That is the condition. That is the condition. So to maintain that condition, no one complained about 90 percent. But only thing is total production rate we should

Student: Increase

Professor: We should increase. So that is why this also should have 90 percent. This also should have 90 percent, total.

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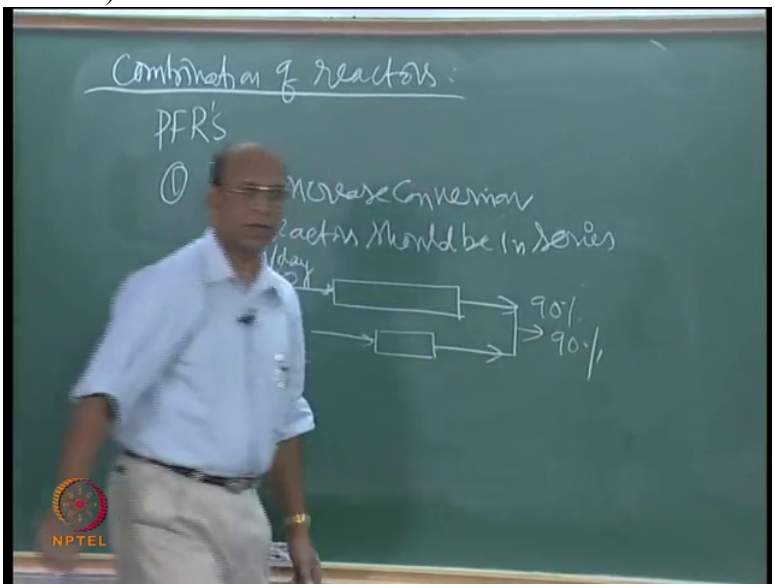

Now you have to calculate back, for 90 percent conversion, how much is the...

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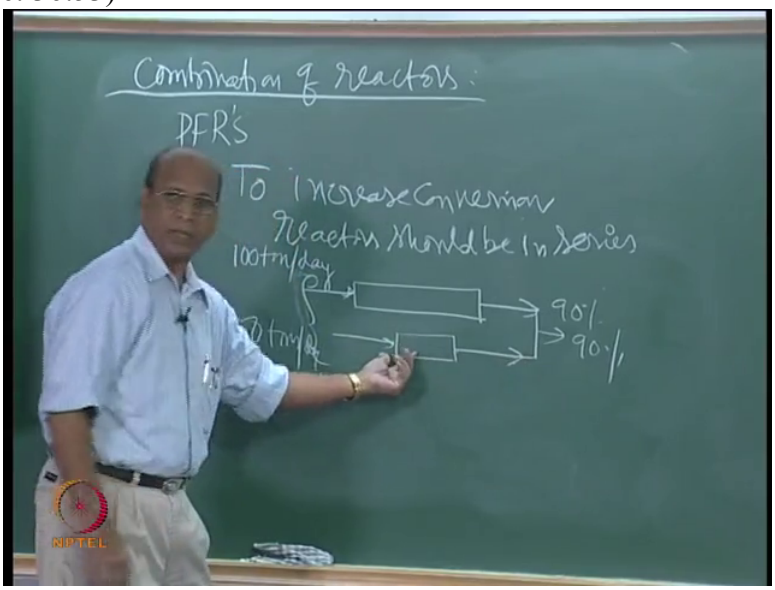

Student: Volume

Professor: Volume required and what are the flow rates?

(Professor – student conversation ends)

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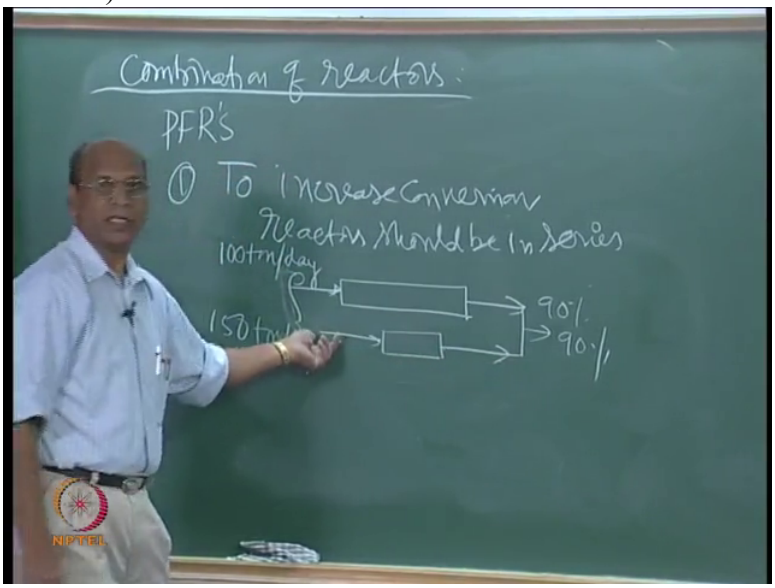

Ok, I mean automatically flow rates will come there, right? So this is one. Now Levenspiel says that you divide this, you know the volumes. I think he gives the example of this is 80 liters may be, this is 40 liters, how do you now

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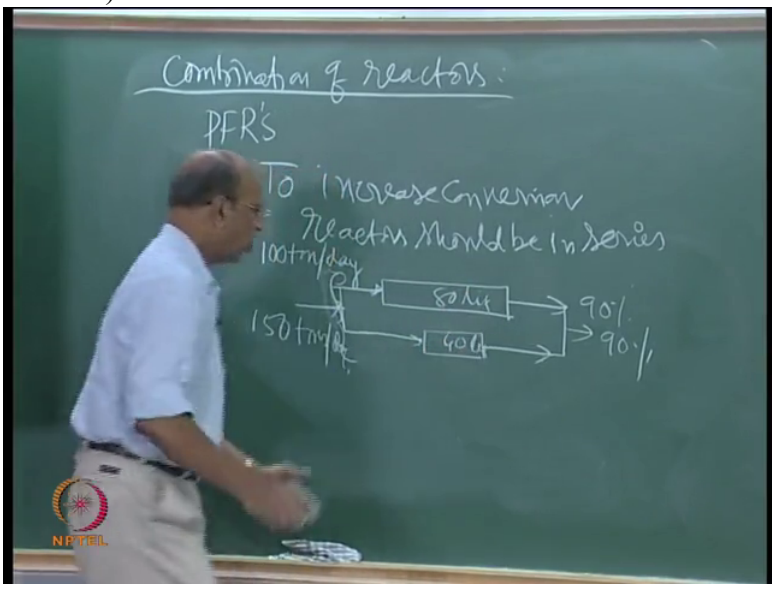

split your flow rates? Because you have only one stream coming here.

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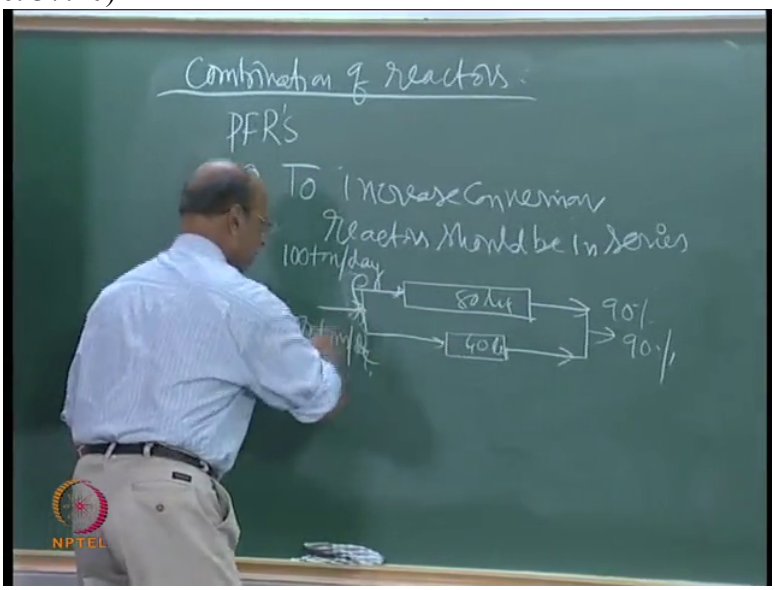

You remember that? V by F A naught, this is V by F A naught 1, this is V by F A naught 2,

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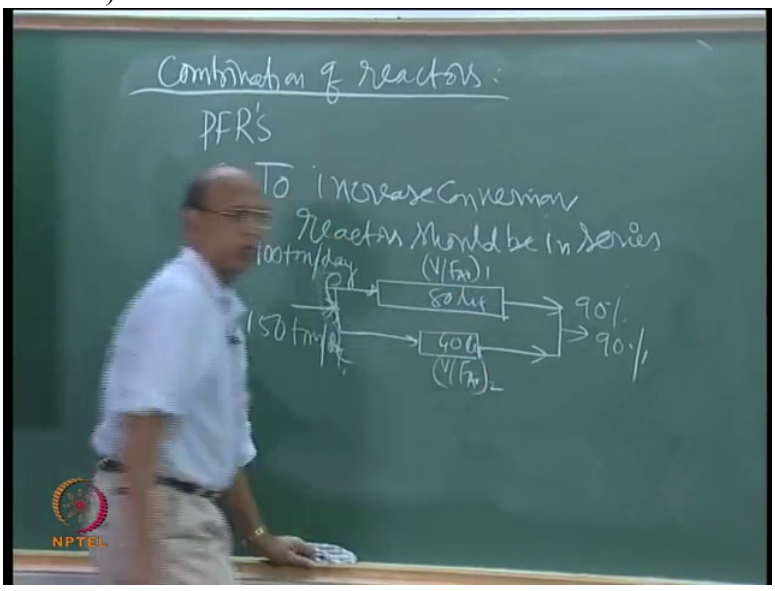

so we have to maintain V by F A naught these two, same. Why these should maintain same?

(Professor – student conversation starts)

Student: That time, the residence time will be same for both

Professor: Yeah, you know the other side, we had integral zero to X A d X A by minus r A, that should be constant.

Student: Constant.

Professor: To maintain that constant you again, yeah you adjust your V by F A naught this side and V by F A naught,

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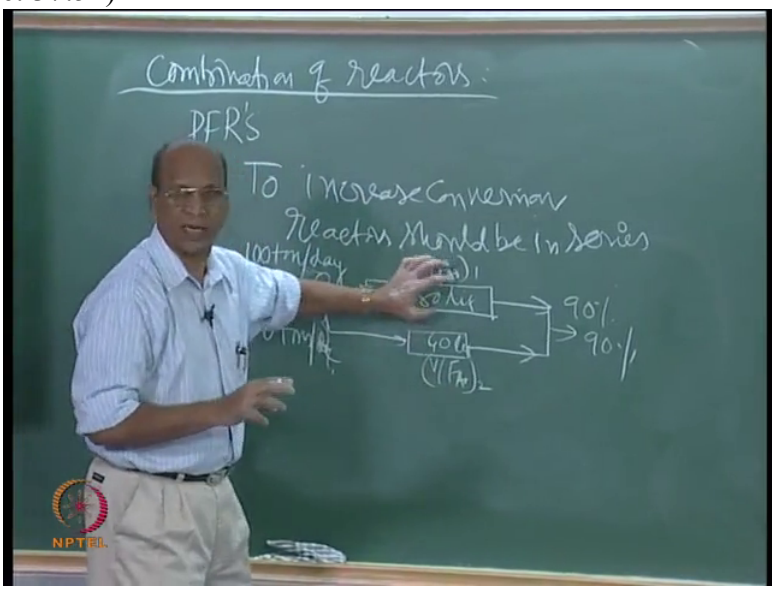

this is there already, the other V by F A naught

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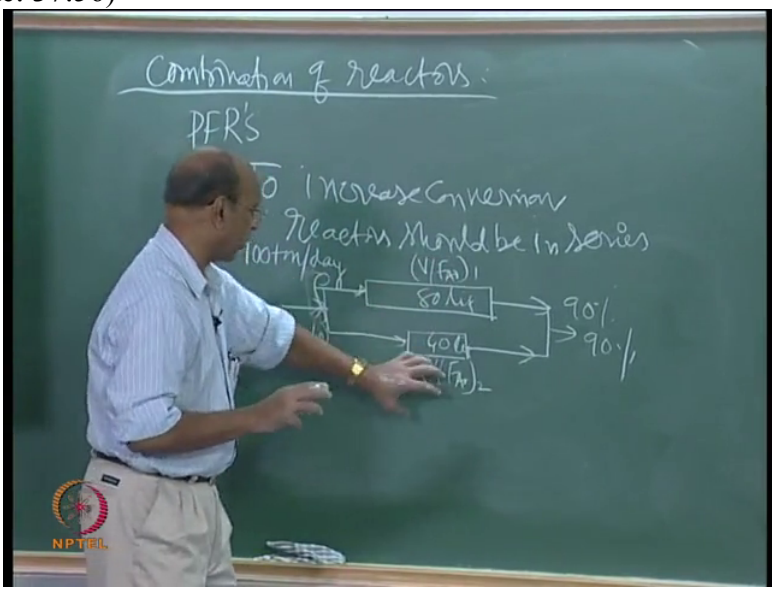

so that you will have, if you know V, only F A naught has to be changed. Because you are taking 40 liters here.

So now, you can take that ratio, how much ratio you have to use to maintain same conversion so that this is nothing but, you know you need that integral same, zero to X A d X A by minus R A. This is equal to, in general V by F A naught.

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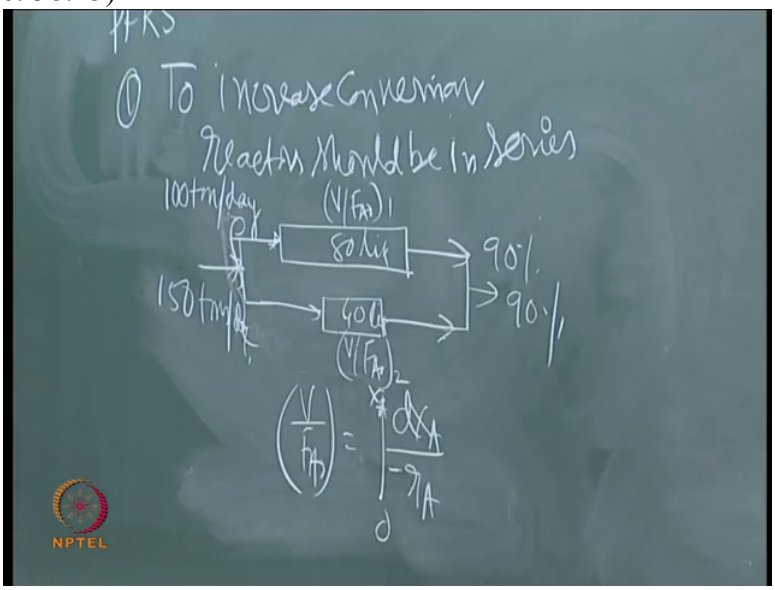

Student: Why we are maintaining same conversion in 2 reactors?

Professor: Yeah. Let us say this is 90 percent conversion. This is 70 percent conversion.

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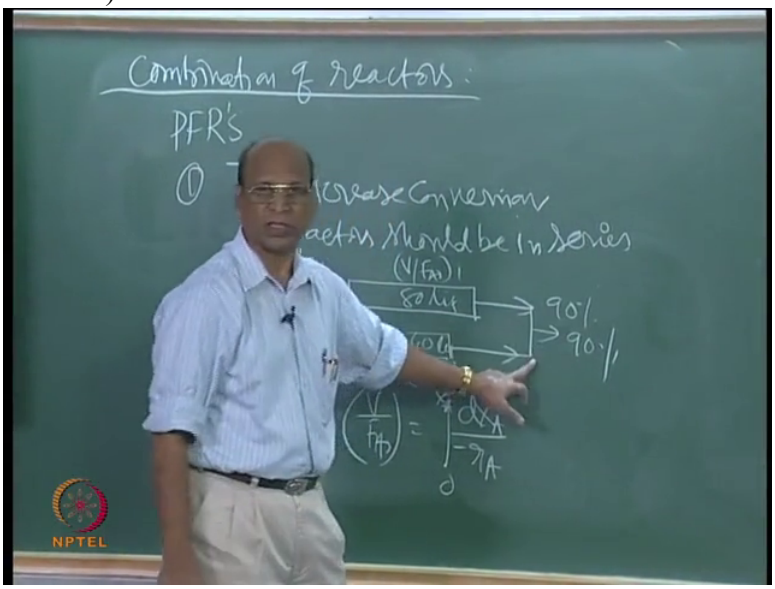

What will happen, no, no, I have to tell, sell the product by mixing those two, right. What will be the average conversion?

Student: Between 90 and

Professor: Depends on weighted average and all that, so it may be between 70 and

(Refer Slide Time: 38:48)

90. So that means your conversion is falling. That fellow may not accept now. So the minimum thing you have to maintain is 90 percent only.

(Professor – student conversation ends)

Otherwise any other conversion, even if you go to 95 percent here,

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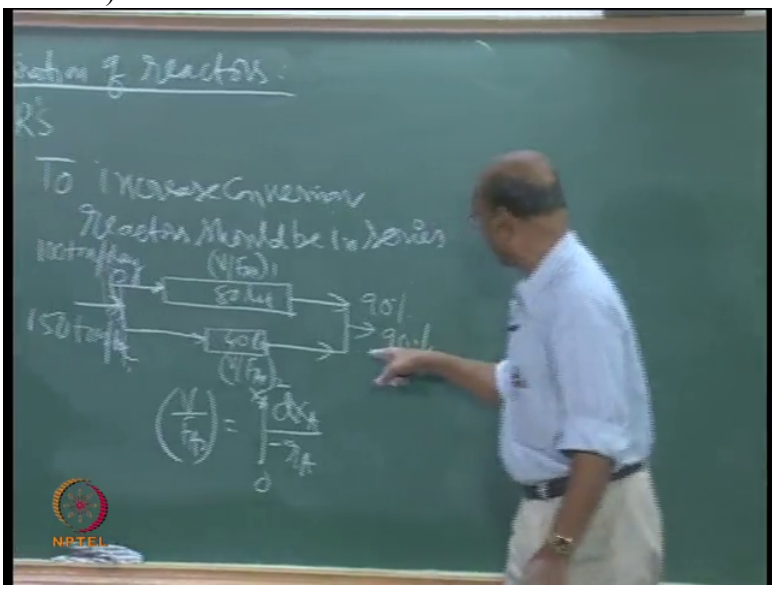

that is 90, so again it is changing. May be higher side but still that is not required, right? Because unnecessarily, you know if it is 90 percent again you have more time required.

So that is why whatever fixed conversion you have, you have to have in the outlet the same conversion so that there will not be any dilution. That you have to adjust. That V by F A

naught is nothing but tau by C A naught. So that is why residence time is automatically adjusted.

So to adjust those timings you maintain the flow rates such that, because you are taking 40 liters, you know it is available with you. Ok. Or some other thing. So accordingly you maintain flow rate such that you will get this conversion, I mean this conversion same. Simple thumb rule. It is not only this. Yeah.

(Professor – student conversation starts)

Student: I can use, I can 0:39:53.5

Student: What is need to parallel

Professor: Yeah, no problem. You know...

Student: In series output of one reactor is input of another reactor

(Refer Slide Time: 40:00)

Professor: That is true

Student: In this case...

Professor: You do not have to put you know, this common point there. Ok but still this condition is same. Even if you put parallel without any touch,

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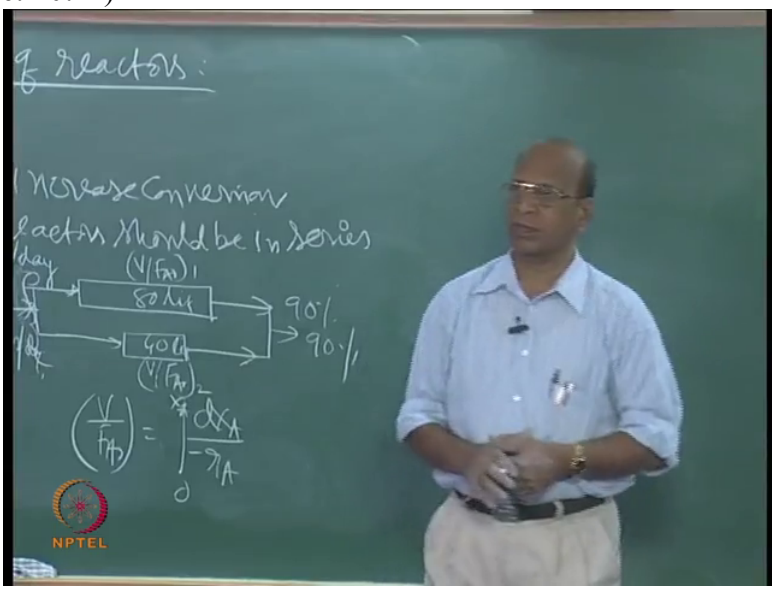

no touch but still what should be the outlet concentration? Still 90 percent. Yeah. Still 90 percent conversion, Ok. So that is what is the condition.

(Professor – student conversation ends)

For all parallel combinations you have to use only same conversion whereas, yeah, here

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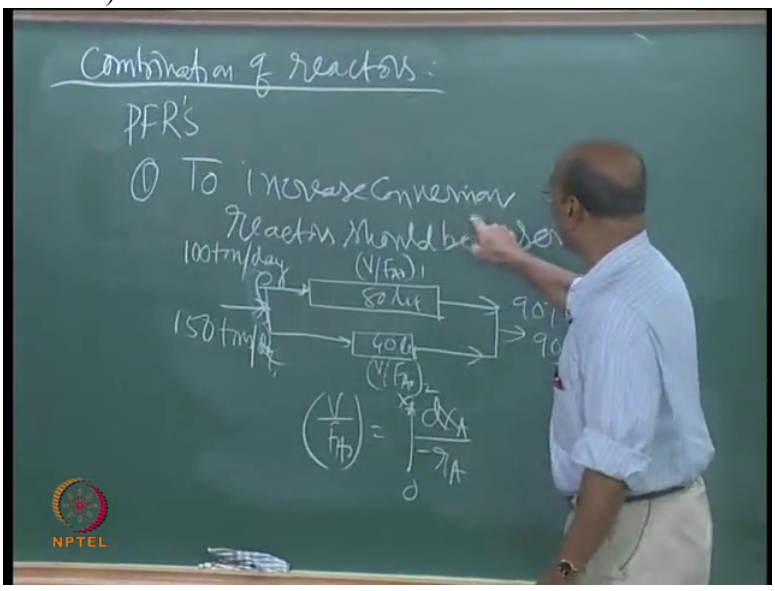

to increase the conversion you go for more, I mean in series, and to increase production, production means you know, production you can increase but you cannot decrease again conversion if you have different conversion. That is all with the combination of reaction, reactors.

If you take individual C S T Rs and individual, you know P F Rs. Now we have another combination. Can I put a C S T R and a mixed flow together? Under what conditions we do that? We know that for all N greater than zero, mixed flow is lousy reaction.

(Professor – student conversation starts)

Student: Sir suppose 90 percent

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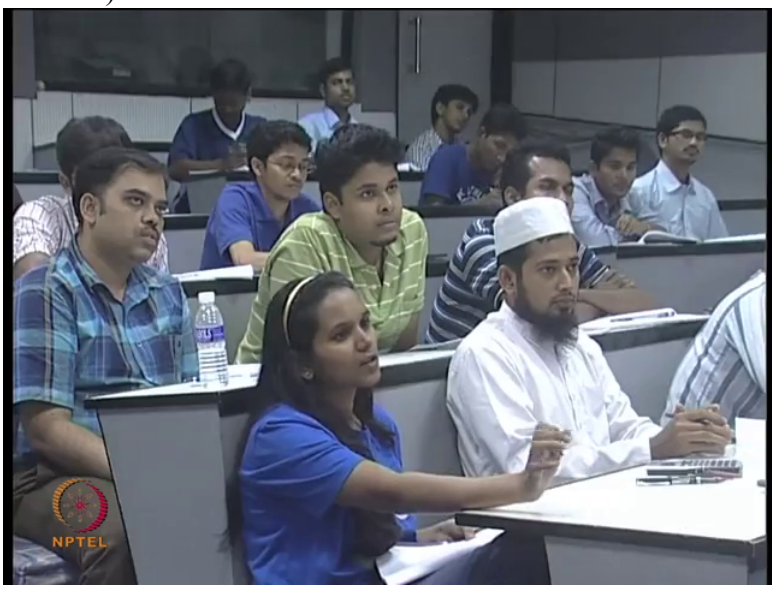

conversion is required, so we use a P F R but it is giving only 80 percent conversion. Sir, if you put C S T R in series after P F R...

Professor: I can put under P F R, why C S T R?

Student: Control temperature of reactor.

Student: Sir V by F A naught

Professor: Yeah but there is another constraint which we are not discussing, you know temperature control means I should go to the other P F R, only M F R.

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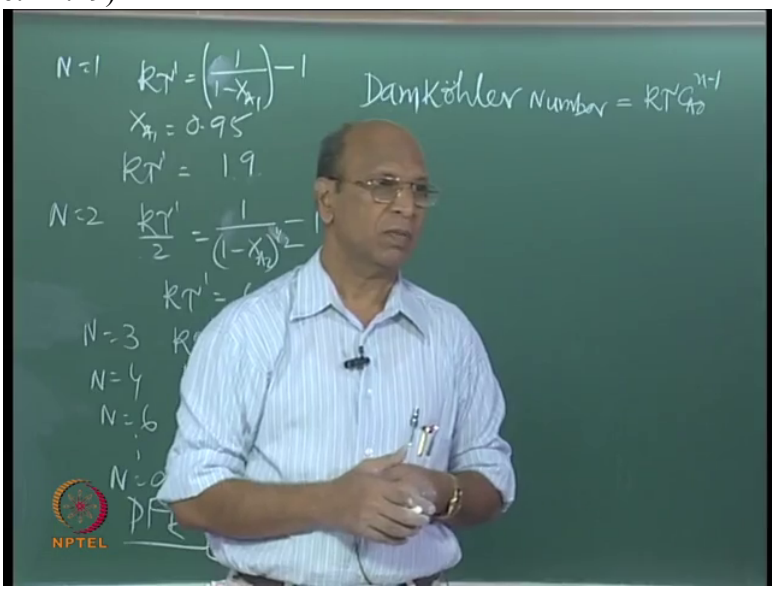

Student: Differential

Student: 0:41:32.5 temperature and pressure

Professor: Yeah

Student: But later we need higher temperature to continue the reaction.

Professor: Yeah

Student: In that case first we do for P F R, then we put it through M F R and...

Professor: That is not that kind of convincing reason

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for us because I can also maintain, theoretically speaking we can also maintain temperatures for you know P F R also, Ok

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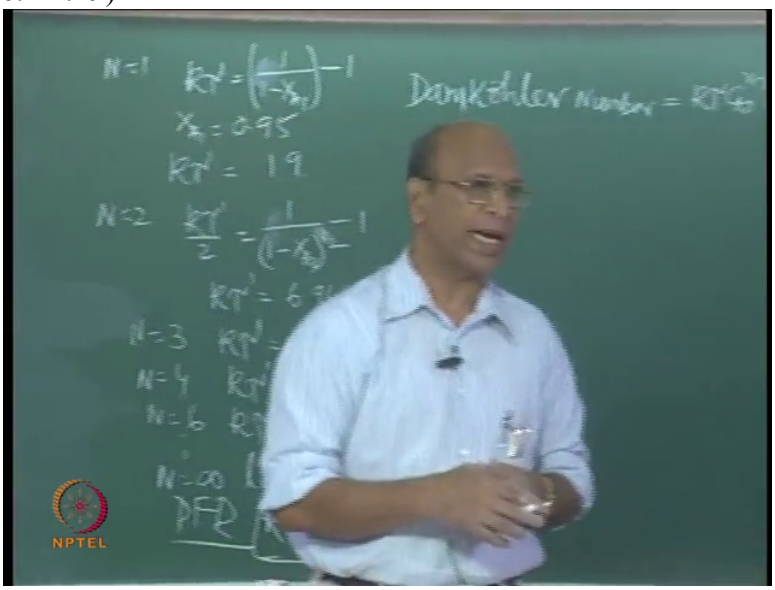

but I think which is convenient is definitely M F R but I know that M F R again gives lower conversion than compared to P F R, correct no?

(Professor – student conversation ends)

I mean I have used extra temperature but in spite of using temperature that cannot compensate P F R except under some conditions where it is a wonderful problem in Carberry where he has done that, you know under some activation energies, adiabatic reactors, I will tell that when you come to non-isothermal reactors. I will also tell that.

Under some conditions you C S T Rs also will go beyond mixed flow reactors particularly if you have adiabatic reactions, under some activation energy conditions. So that is why I think these combinations generally we do not use, C S T R followed by M F R and M F R followed by C S T R for normal reaction. C S T R followed by P F R and P F R followed by C S T R, that is not generally followed but in case he beautifully used that.

(Professor – student conversation starts)

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Student: If we need high concentration we can go for P F R, the later, the

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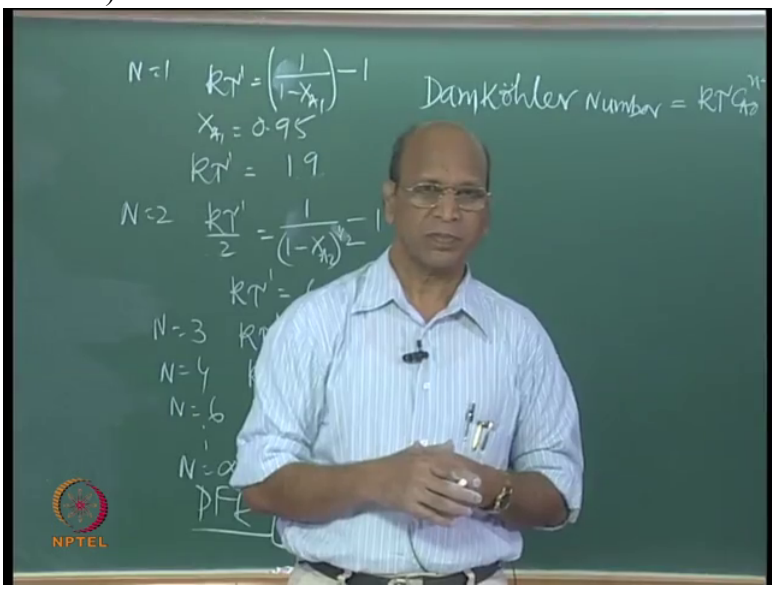

unreacted things can be mixed in C S T R.

Professor: There also I can use P F R, no? Because there also P F R will give better conversion.

Student: Yes Sir but the unreacted conversion will be in the...

Professor: Unreacted means, there is still some concentration going on

Student: Sir for auto-catalytic reactions, you want to mix with the reactants

Professor: Yeah, it is for

(Refer Slide Time: 43:10)

autocatalytic reactions. That is a beautiful combination.

(Professor – student conversation ends)

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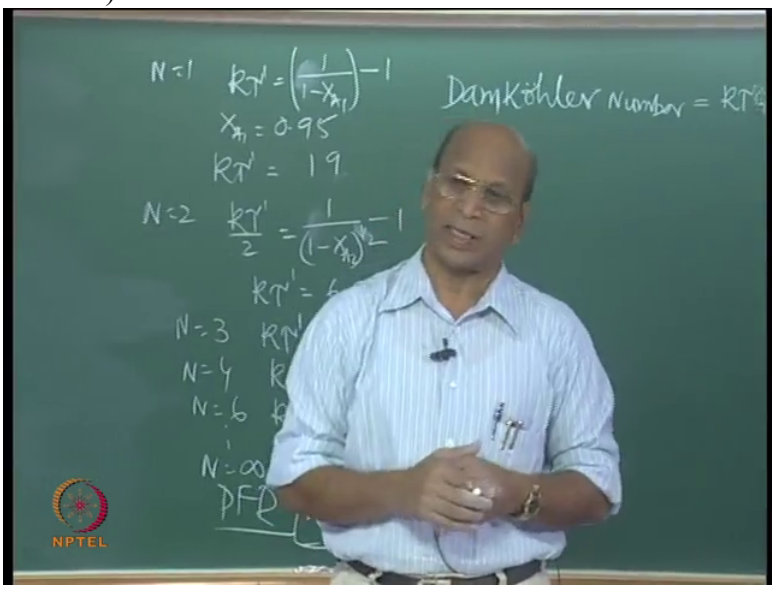

But in spite of that, we have to definitely find out whether, when do you use C S T R, I mean this combination Ok, in spite of that, still we can discuss this.

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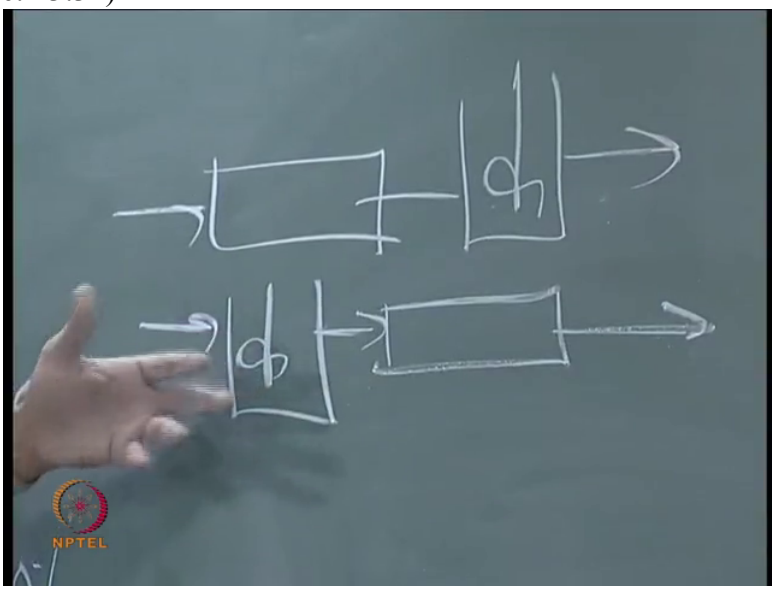

Like for example I have this reaction, Ok this combination going for R equal, n equal to 1,

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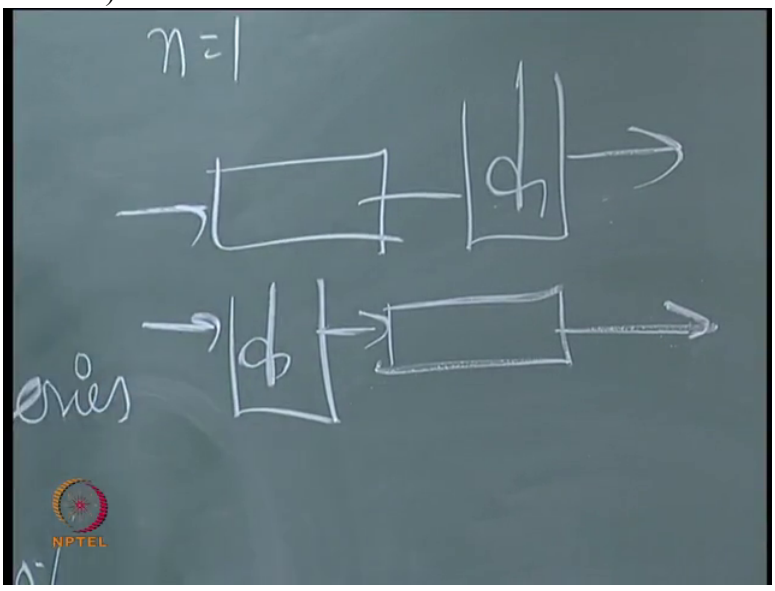

Ok. I have already going on, I think for some reason I have used these two, Ok and then the reaction is going on.

And now I have for first order reaction, so suddenly I got the idea, can I interchange? Interchange means instead of pumping this side, can I pump this side? That is my interchange, that is all. I am not changing again, defabricating and fabricating and all that. Ok. So will the conversion change?

These are all academic questions, nice and academic questions. Ok, so this one, please derive. That means take n equal to 1, constant density system and you know, first

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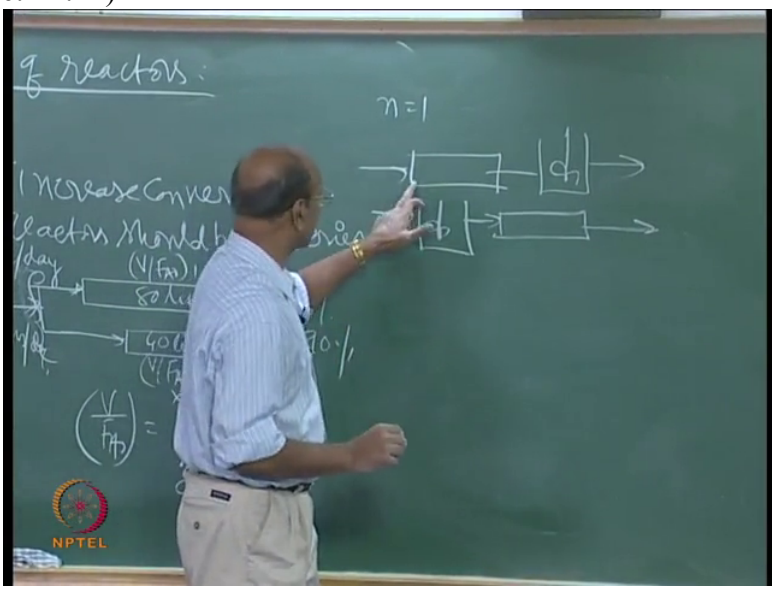

it is going through P F R and ideal, ideal P F R, ideal M F R and in the reverse direction, it is first

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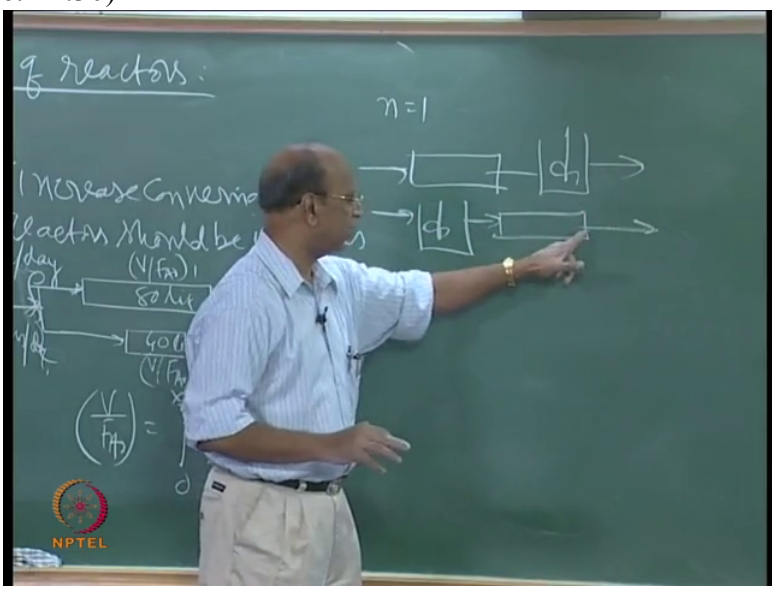

going through, yeah, here C S T R, M F R and then P F R, Ok.

So n equal to 1, constant density system, minus r A equal to k C A, I will simply say that A going to R.

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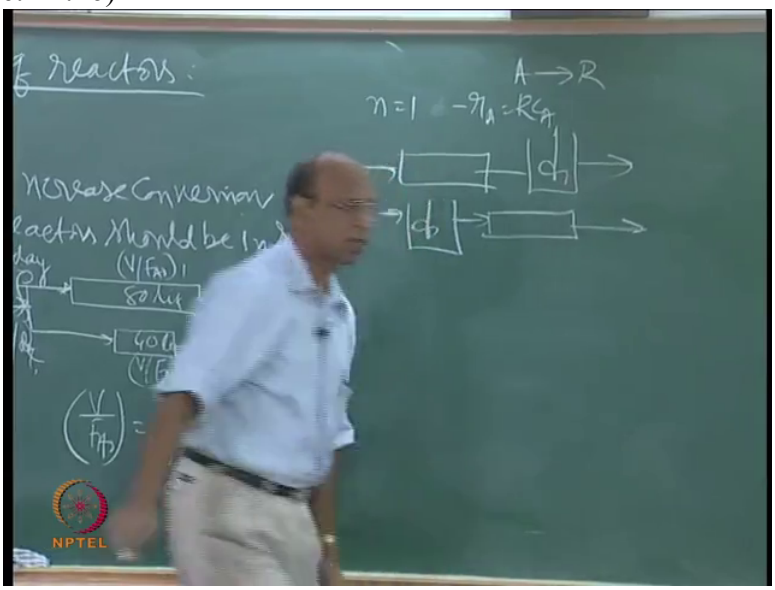

Constant density system or even gas phase also same, because no volume change. Please find out which setup gives, which gives more conversion for n equal to 1, repeat this for

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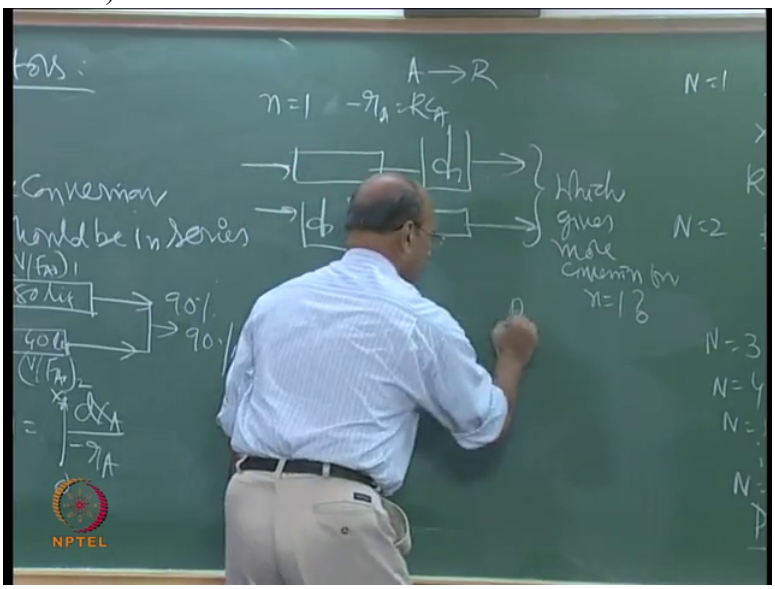

n equal to 2,

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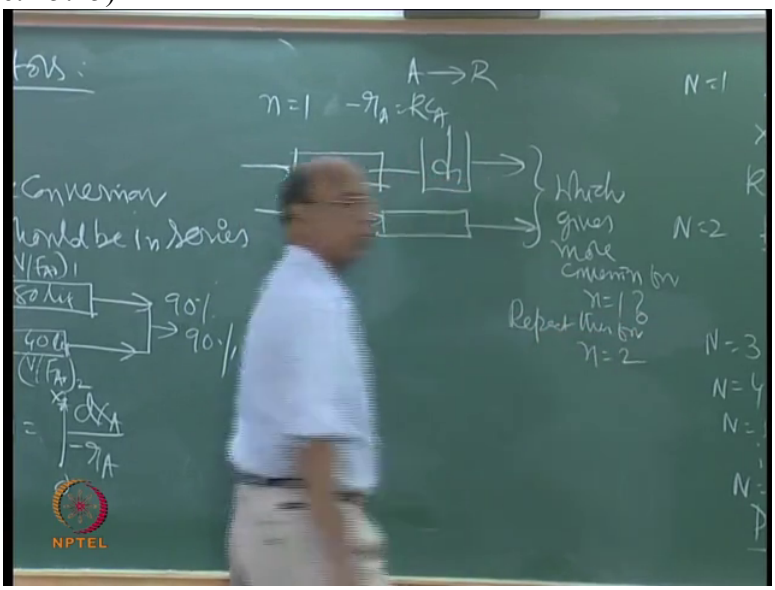

Ok. Yeah and again repeat this for n equal, n equal to half,

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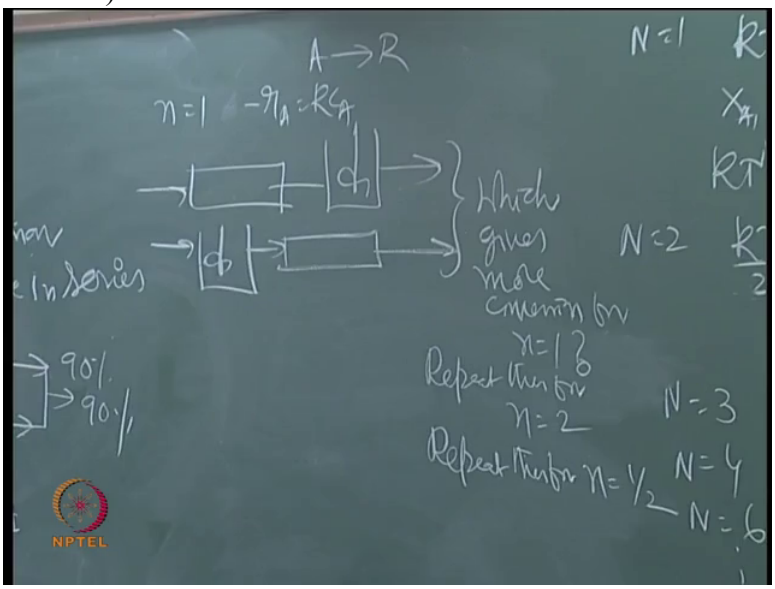

half order reaction. Will you do that? This is fourth assignment.

You also know that you know some kind of optimization between two reactors. If I have 2 reactors, C S T Rs for example, plug flow will be very complicated, but C S T Rs, two tanks I have in series, Ok. So this may be V 1, this may be V 2

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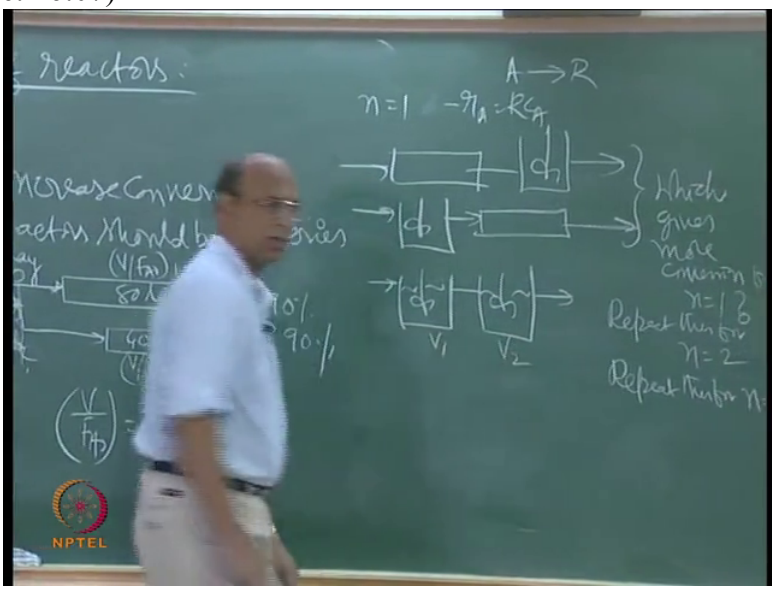

which are not, say V 1 is not equal to V 2,

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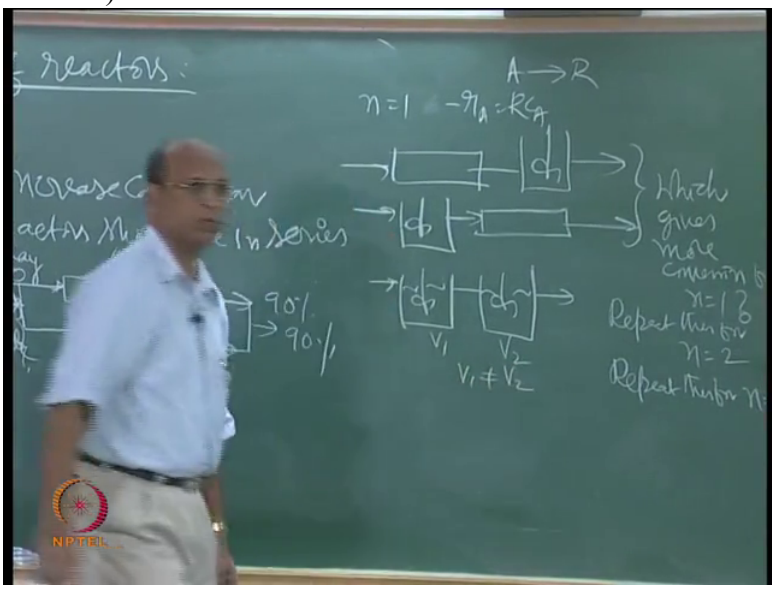

right. Or otherwise I will say that another condition, V 1 is less than V 2.

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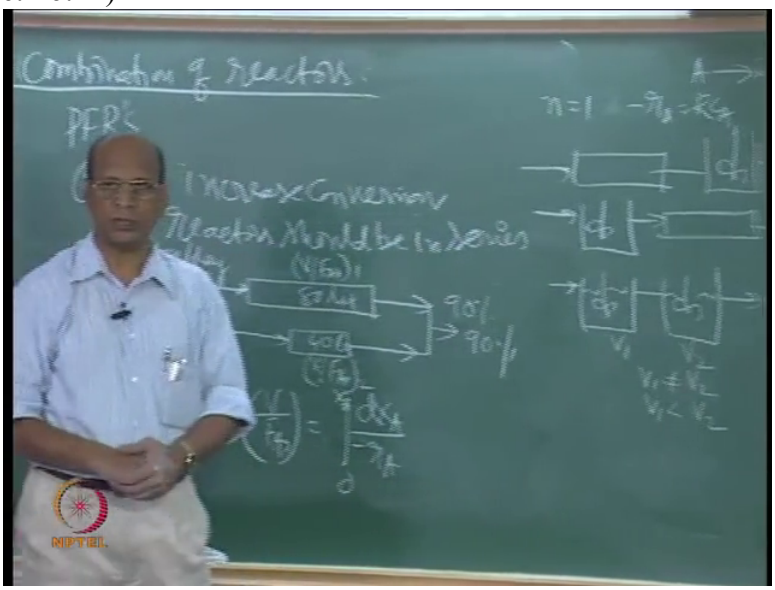

For this one, how do I optimize, that means for given conversion, for given conversion X A, how to minimize the

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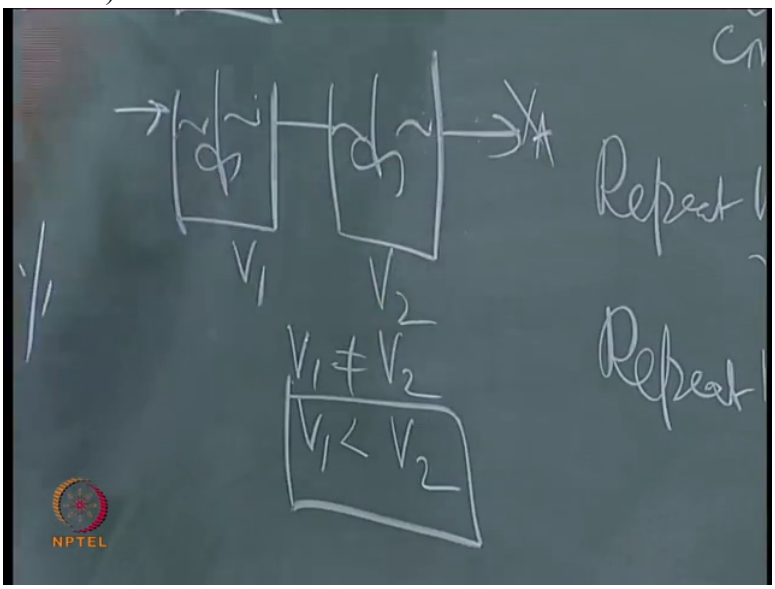

volume, Ok. How do we minimize reactor volumes for given X A, all this you have done,

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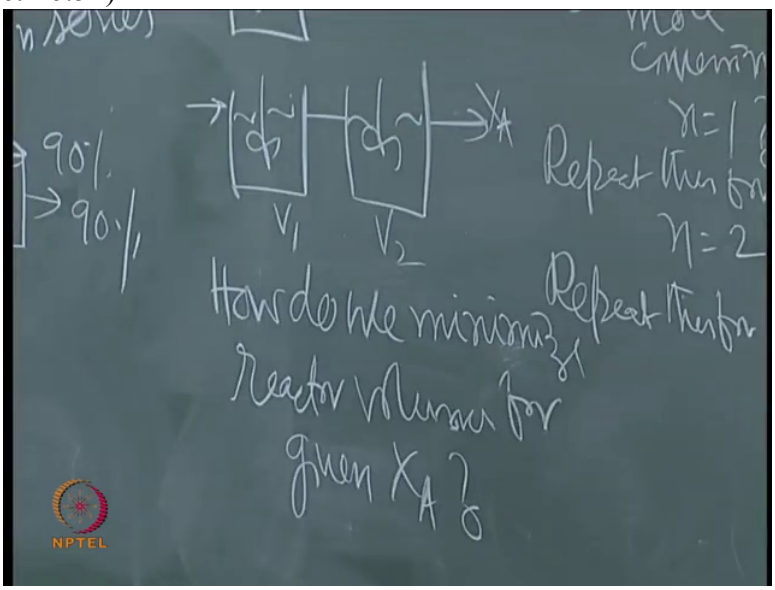

Ok. I will give you a clue for this, which you have done also.

So this one let us say,

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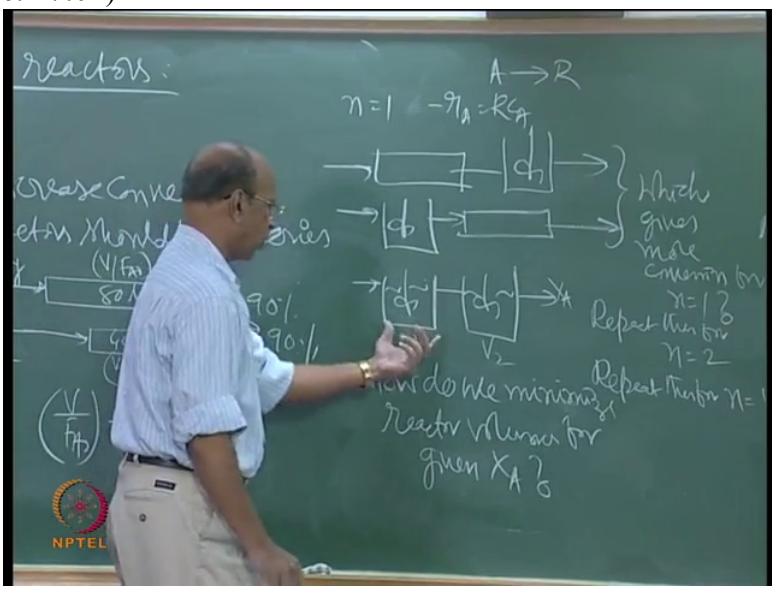

residence time is tau 1 and tau 2,

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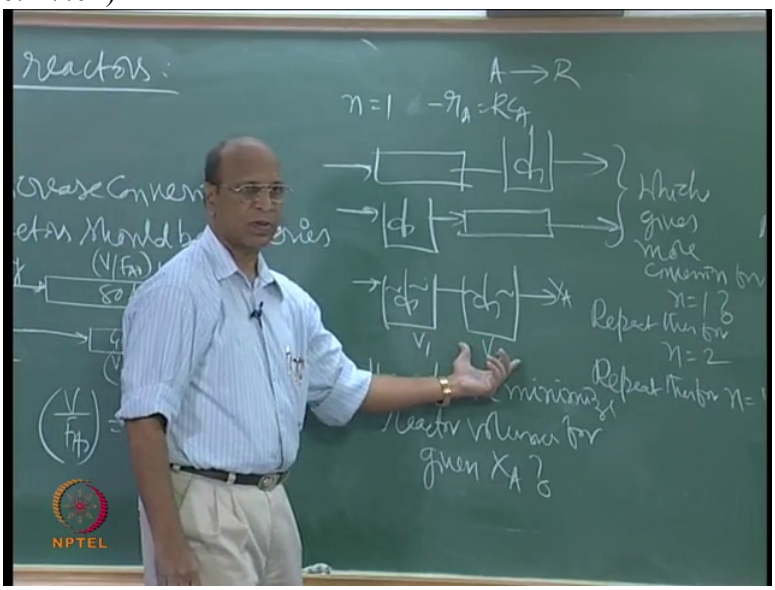

and this is given conversion. Conversion is fixed. For given conversion, what will be the minimum volume of A and B? You can do for first order; you can do for second order. First let us see only for first order, because easy to do, Ok. How do you optimize this? What is the mathematical condition for minimizing the total volume, total volume minimizing for given conversion?

(Professor – student conversation starts)

Student: d V by

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Professor: d V by?

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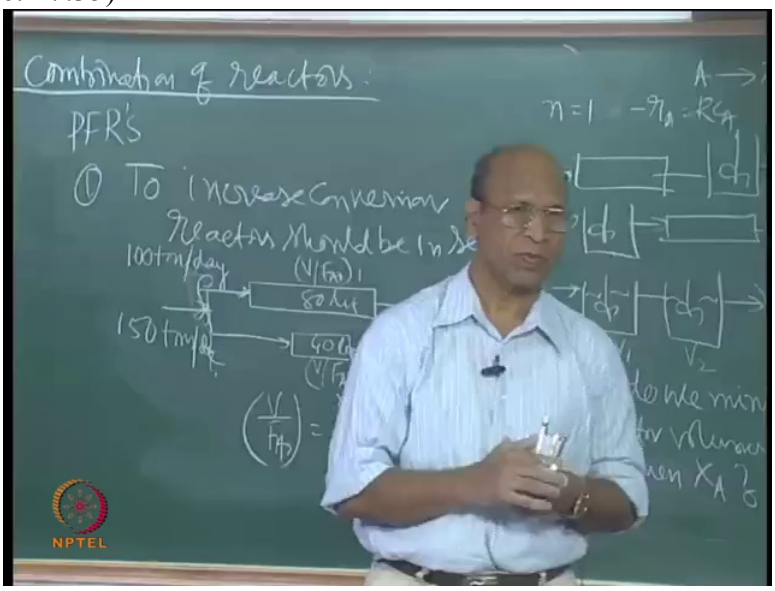

Student: d V by d t

Professor: d V by d t, what is V there?

Student: Volume.

Student: V 1 plus V 2

Professor: V 1 plus V 2. What is d V by d t? What is that t?

Student: Time of reaction

Professor: Where is time of reaction? Because it is steady state.

Student: C A by d t

Professor: It is steady state, I say. Always d by d t?

Student: d X A by d t

Professor: d X A by d t?

Student: d V by d X A

Professor: d V by d X A 1 or d C A

Student: intermediate 0:48:08.0

Professor: Yeah, why intermediate conversion? Because this is fixed.

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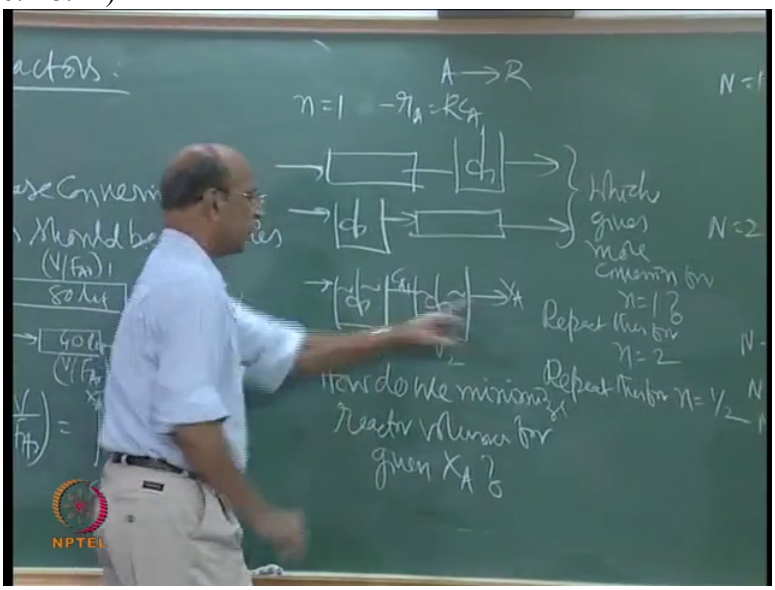

So if I am able to optimize this, how much is coming out of this and then entering, this is already optimal one which is entering the reactor now. So that is why overall also you will get the optimum.

(Professor – student conversation ends)

That is why, total time if it is tau 1, so if I

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call this one as tau 1, and also this is tau 2,

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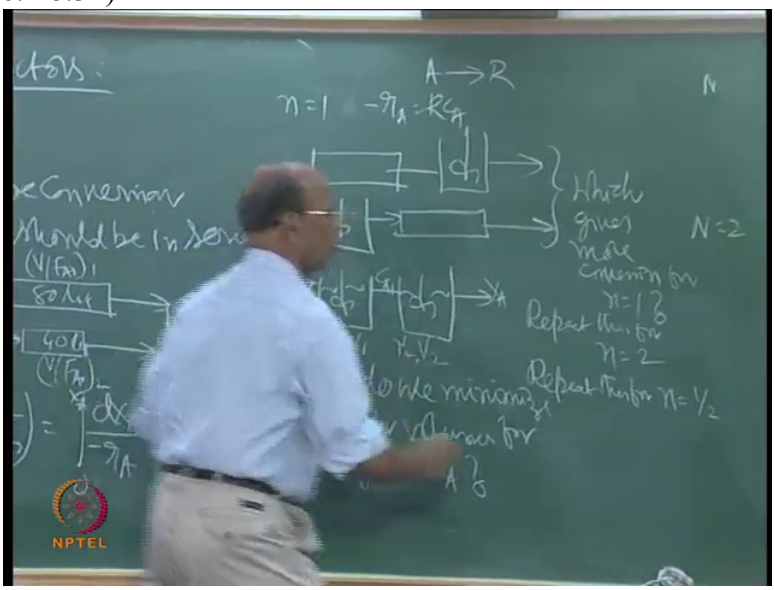

what we have to do is d tau 1 plus tau 2 d C A 1,

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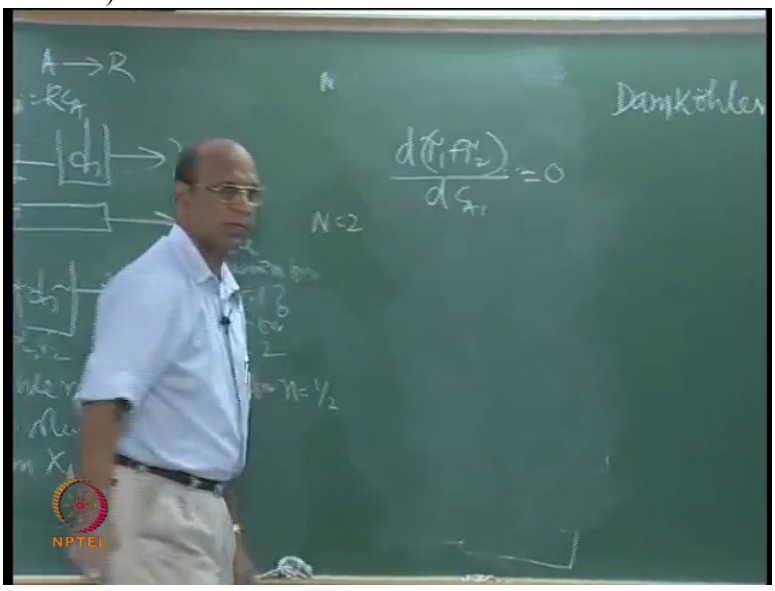

that should be minimum, I mean minimum or maximum then you can calculate from second derivative, Ok. The first derivative should be zero first. Ok.

Why should I have order of reaction? I can have only rate versus concentration data. Because you have gone through kinetics, and then you found out d C, concentration versus time and somehow you plotted d C A by d t and then got rate versus, C A versus minus r A data. You do not want to fit this rate of reaction equation. You do not want to find out any rate, rate equation.

So how do I use this one now for design? Because these are all not new. There is nothing new concept, already what you know I am trying to ask. What is which concentration, I think you know as concentration is increasing or decreasing, you have correspondingly;

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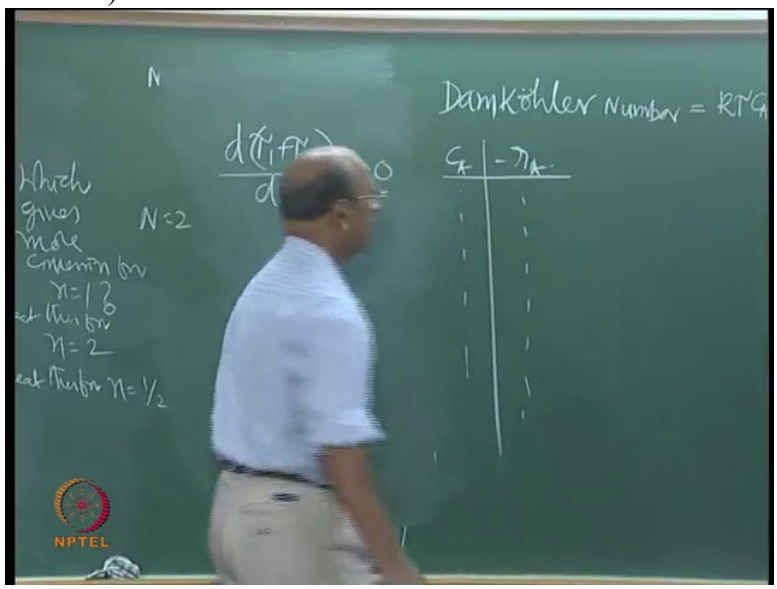

it is simple, N going to, N greater than zero type. How do I find volume of the reactor? Plot what?

(Professor – student conversation starts)

Student: C A 2 minus C A 1 divided by r A will give you tau.

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Professor: You are thinking that you are only trying

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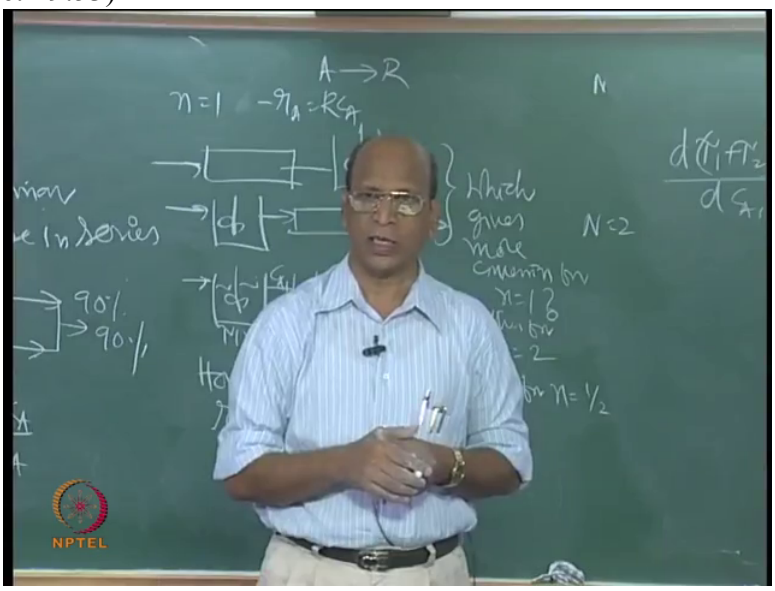

to find out, you know, using mixed flow reactor, right?

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Yeah. In general I am asking.

Student: 1 by r A versus

Professor: Yeah, it is very simple I say. Again how many times we have done that? The simplest thing is 1 by minus r A versus C A, Ok or X A.

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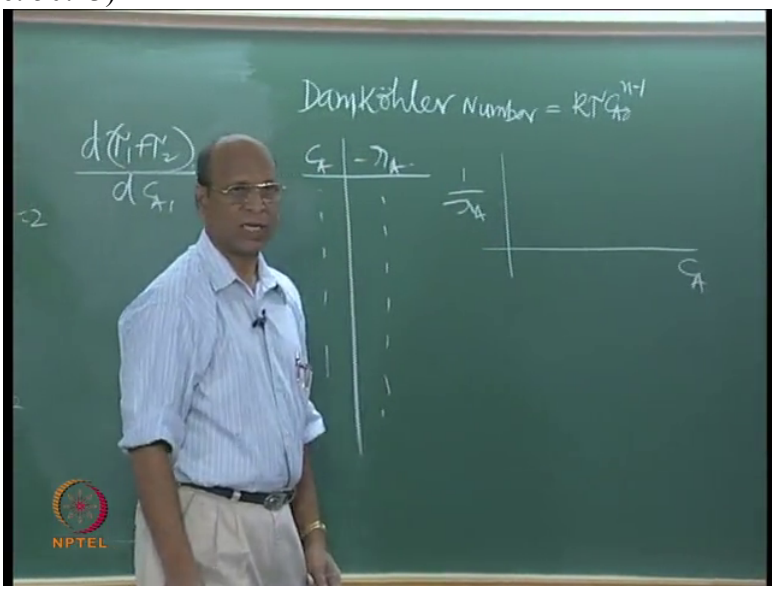

(Professor – student conversation ends)

Ok. X A is easy for us because our equations are X A and this is again special case you know where constant density system, so if I write X A then where it should be, it goes like this,

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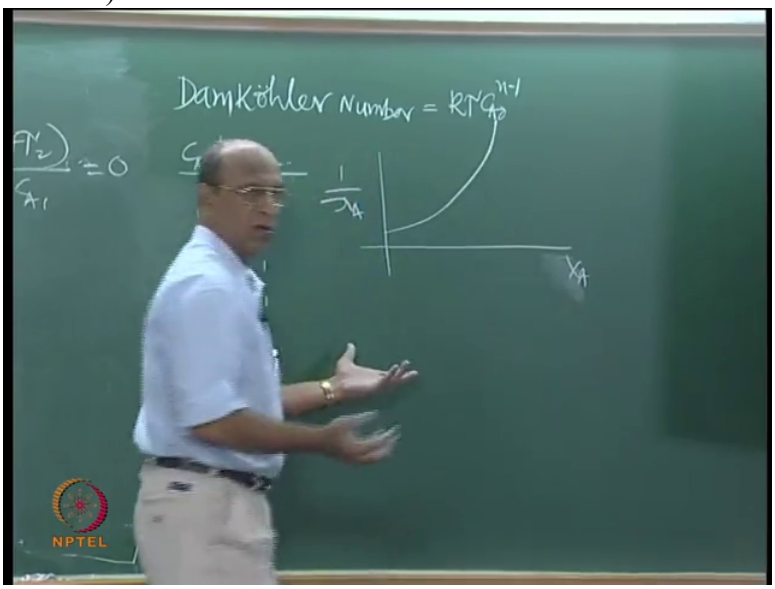

Ok. Yeah, so now for a new reactor I have to fix the conversion. So I have fixed this conversion. This is X A f. And now Abhijeet, whatever you say, Ok, so area under the curve alone will give you

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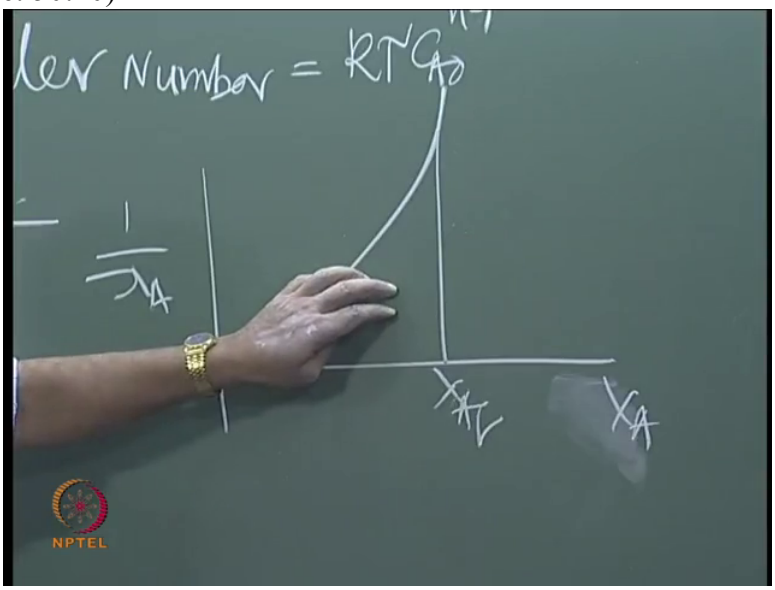

P F R volume and that

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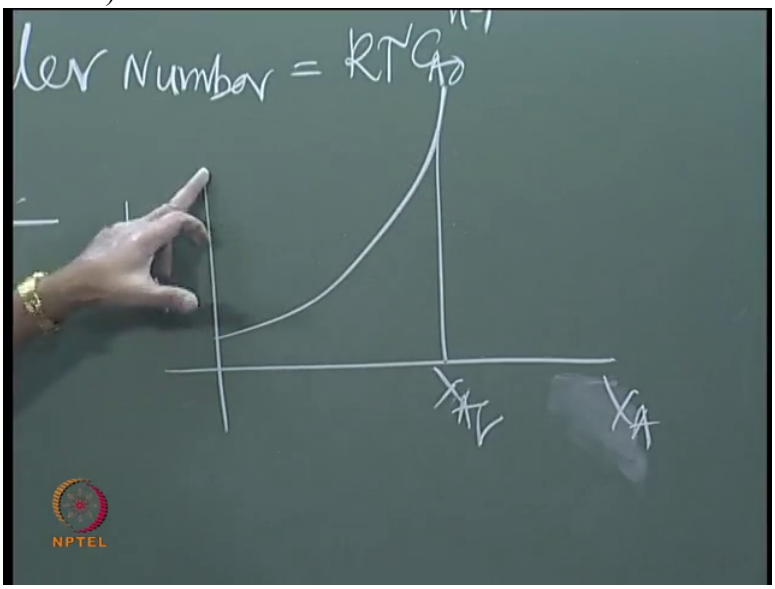

one will give you

(Professor – student conversation starts)

Student: 0:50:49.7

Professor: Even two reactors also you can try, right? So similarly for tanks in series also, this one reactor we are talking. For tanks in series, there is a method of plotting this and then finding what is the, either conversion or volume. Do you remember that method, what Savita, lost?

This you know, no? This is

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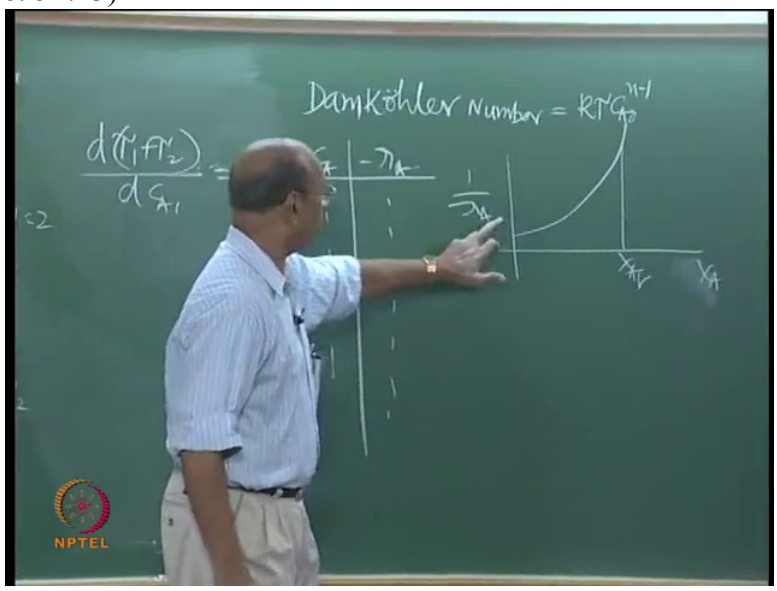

why all design expressions what do you have? Yeah, V by F A naught equal to integral d X A by minus R A. So that is why area under the curve is nothing but d X R A by...

Student: Sir, V by

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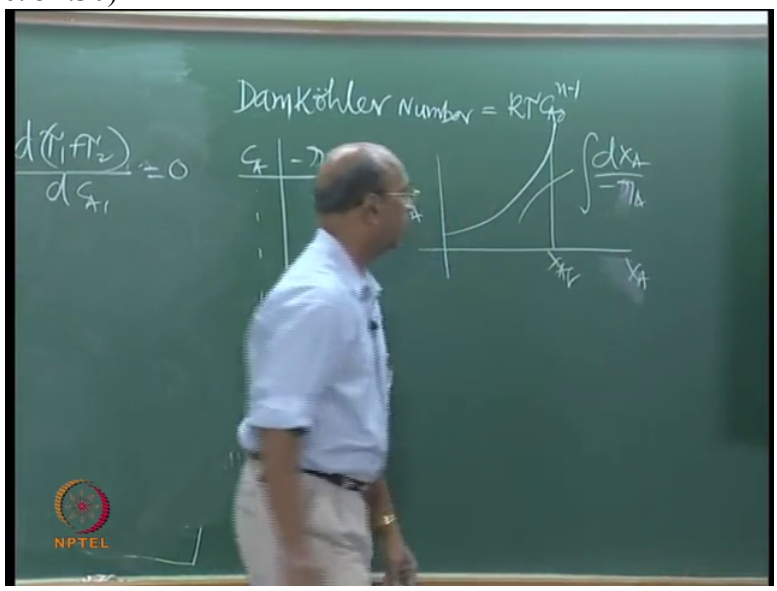

Professor: This is the area. That is equal to nothing but V by,

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it is plug flow.

(Professor – student conversation ends)

So then if I take, because these equations already you know. But only thing is that

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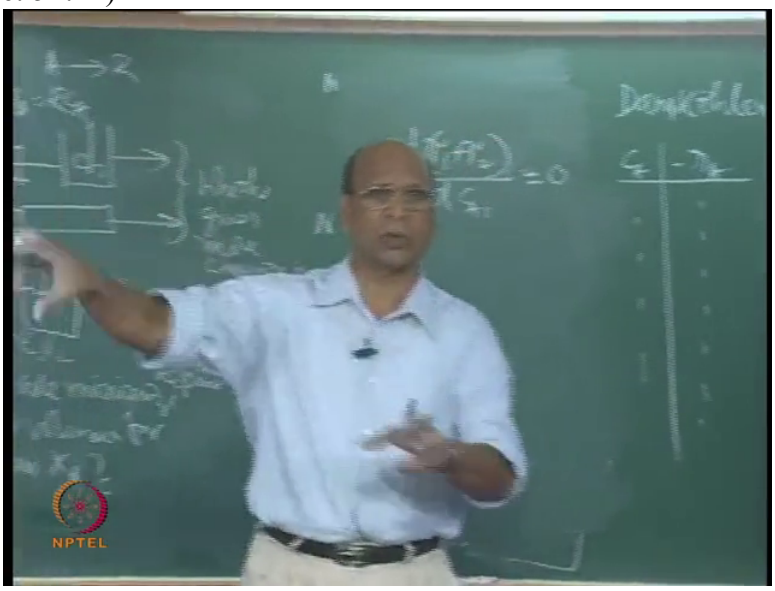

connection should come. Not able to follow still? Yeah, so now if it is, continuous, I mean mixed flow reactor,

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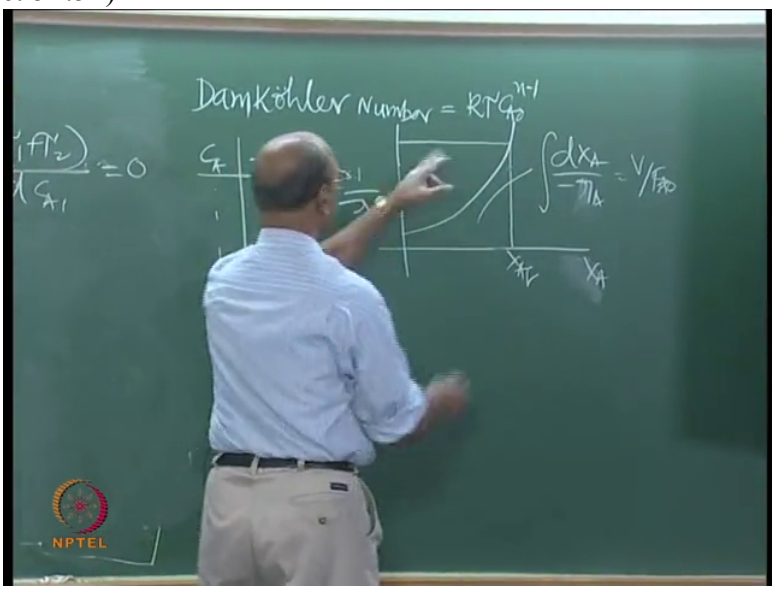

all this because this one is

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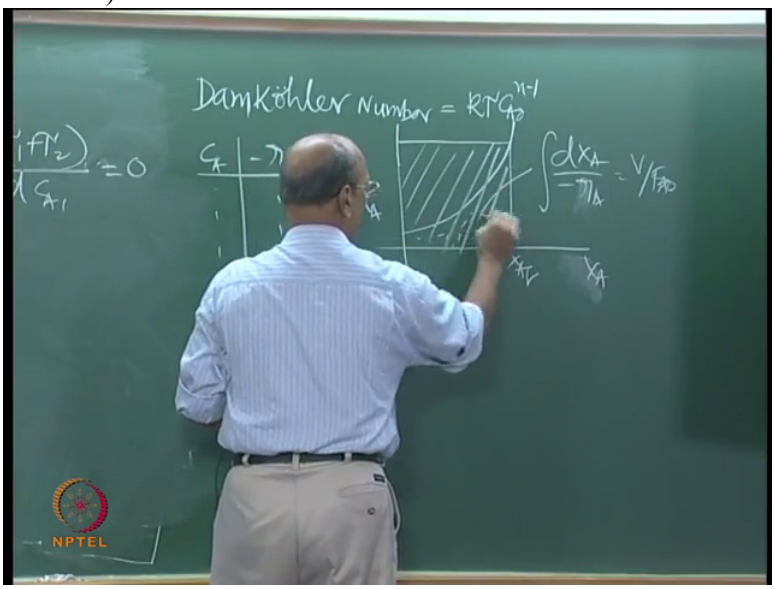

only P F R, Ok this is P F R and this one is

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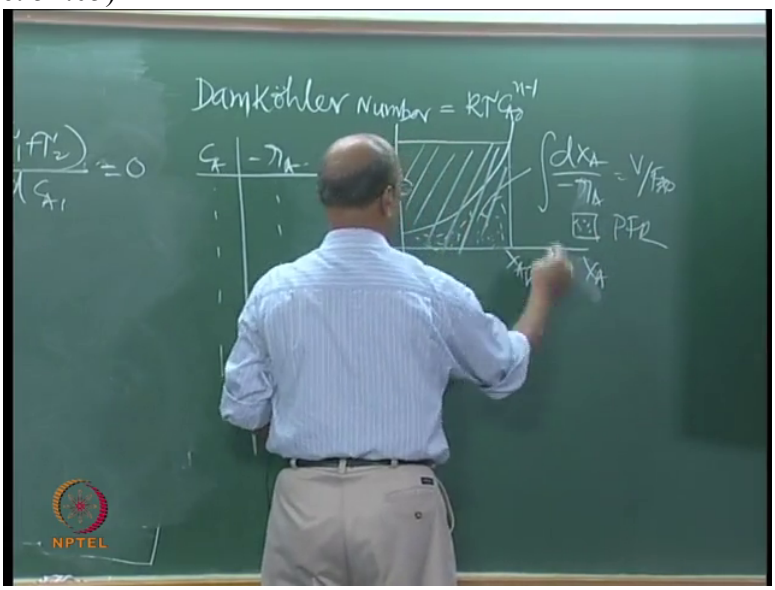

M F R,

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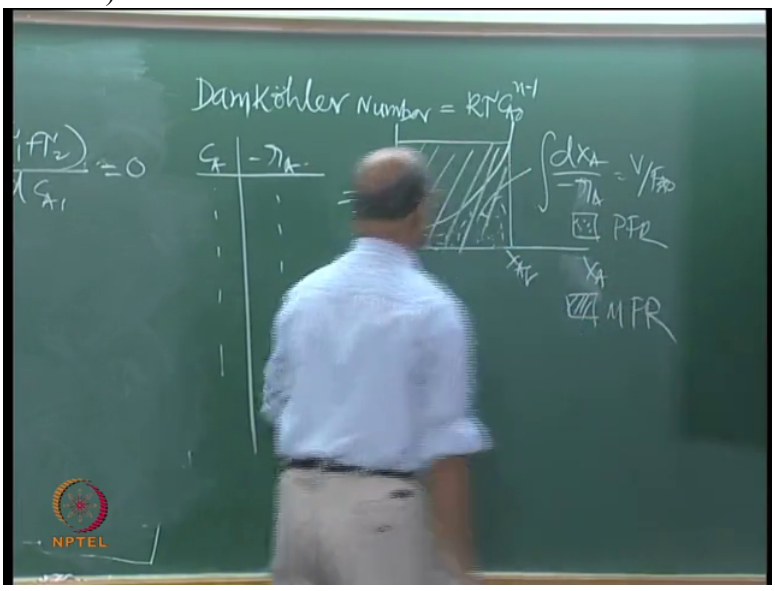

Ok, yeah. So this will be representing V by F A naught

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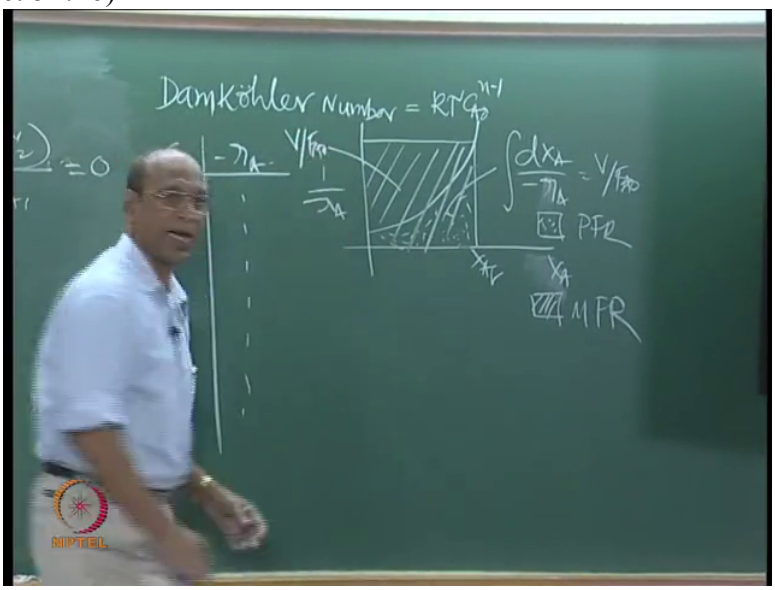

because that equation itself is rectangle. How do you know it is rectangle?

(Professor – student conversation starts)

Student: C A

Professor: Yeah, V by F A naught equal to X A by minus r A, right. So,

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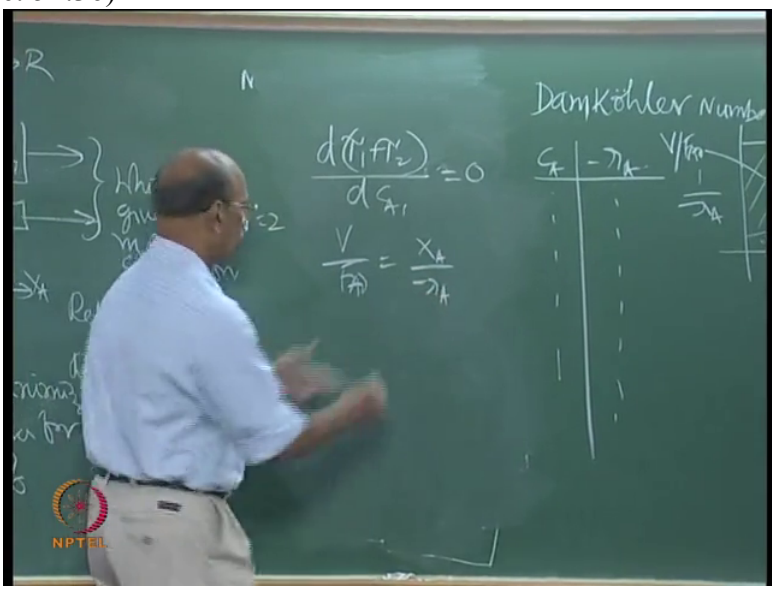

1 by minus r A, I taking as y.

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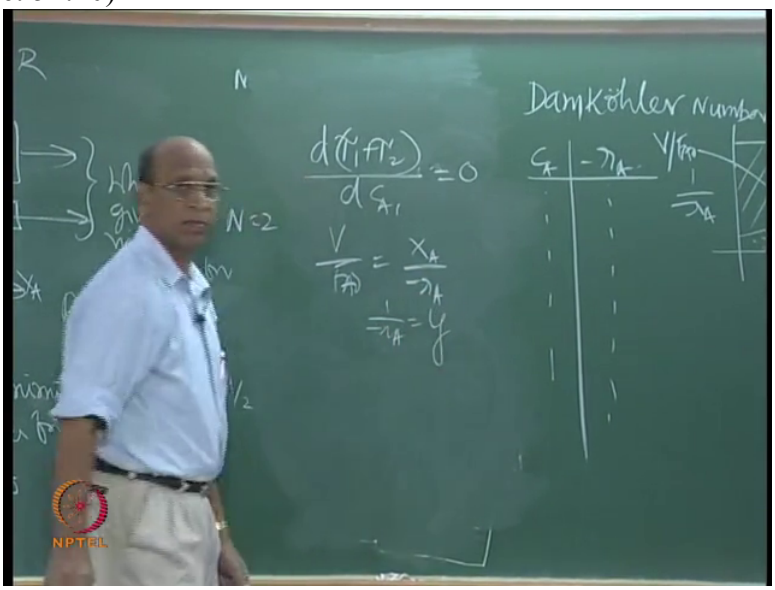

So this is nothing but y into

Student: X A

Professor: X A. So this is y, and this is

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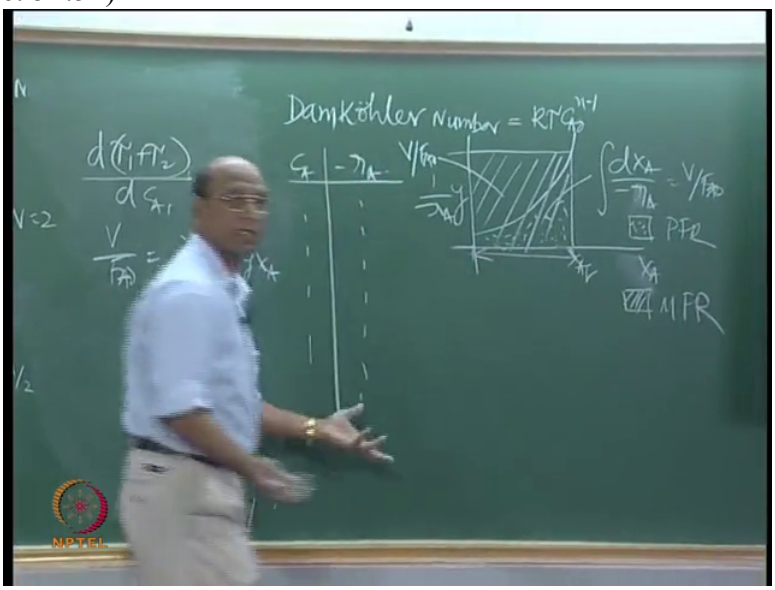

X A. So this versus this will give me the area, that also gives. Yeah, now tell me, Shahid.

Student: Regarding X A.

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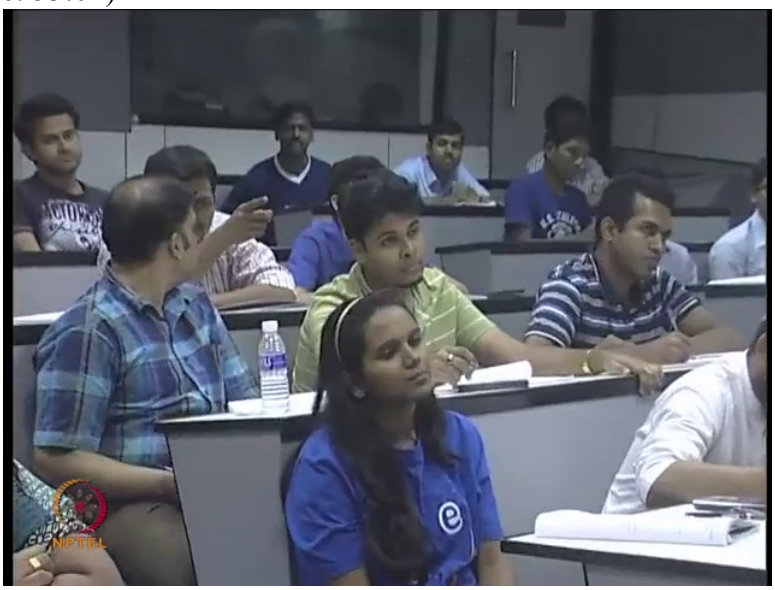

X A I think, C A and minus r A data only given I do not think you can find X A.

Professor: C A and?

Student: Only C A and minus r A data given, plus 0:53:10.4

Professor: Why cannot you?

Student: C A is C A naught, right?

Student: For that you have to go differential method and then you have to collect....

Professor: Where is C A naught here?

Student: That will give you C A naught.

Student: C A naught is the first one

Professor: No, where is C A naught here?

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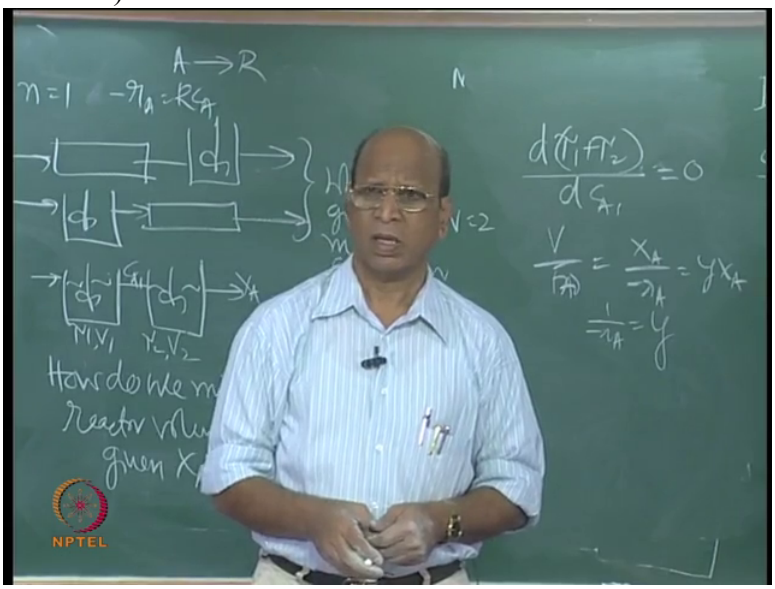

Student: For conversion, plotting 1 by r A to X A,

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you need for X A, like C A is equal to C A naught 1 minus X A right?

Professor: X A you are fixing I said because when you are finding out area under the curve what is the meaning? You are finding out volume of the reactor.

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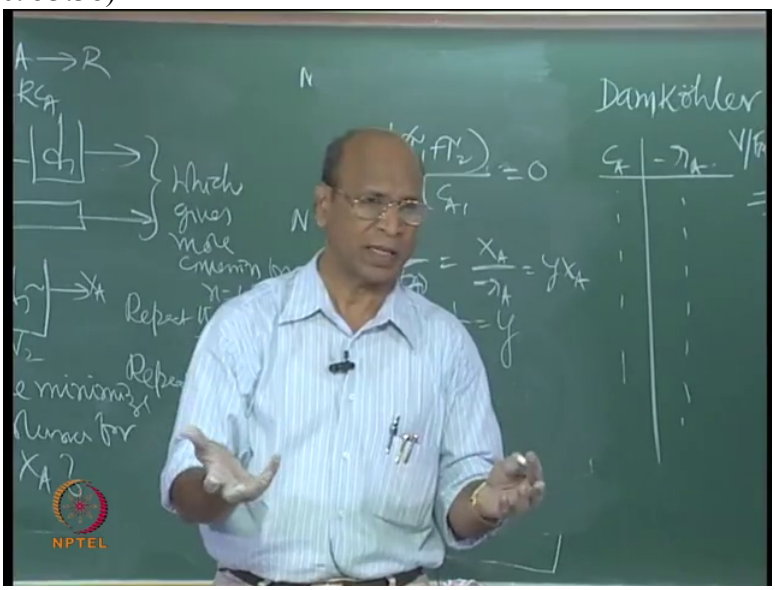

So to find out volume of the reactor, you should know conversion. Conversion means C A. Either one, either this or that.

Student: For example,

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problem number 24, same question is given. C A and minus r A data is given. Then order is not mentioned.

Professor: Order is not required, yeah

Student: Order is not required. But for example, only minus r A...

Professor: What is the problem? What you have to find out?

Student: Sir, if you have to find these volume and such things.

Professor: No, no what is given in that problem?

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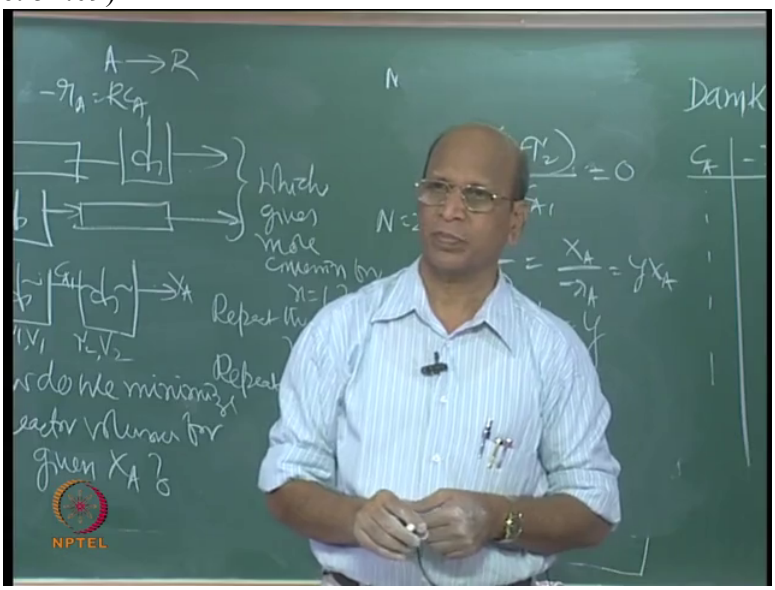

Student: Sir, about rate of the reaction. Problem is our

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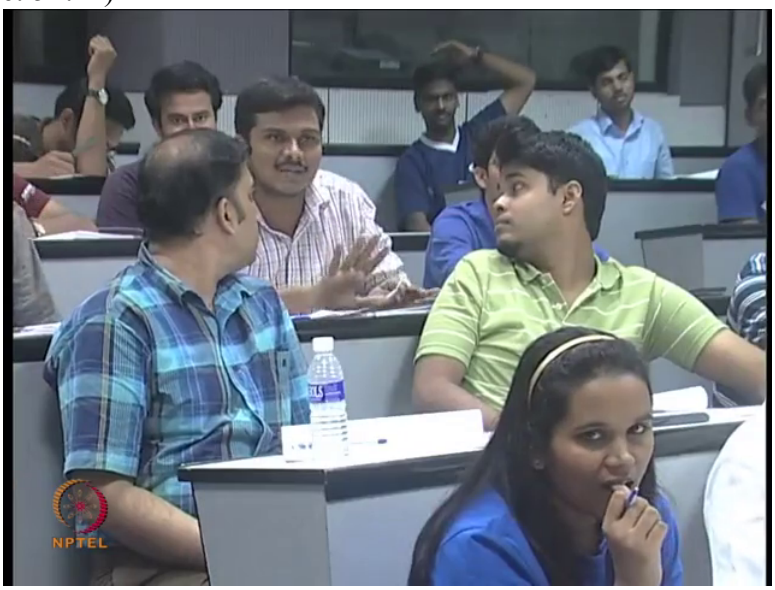

rate of reaction. For example you can only 0:54:13.1

Professor: No, no you see in that problem when I give, there must be objective no?

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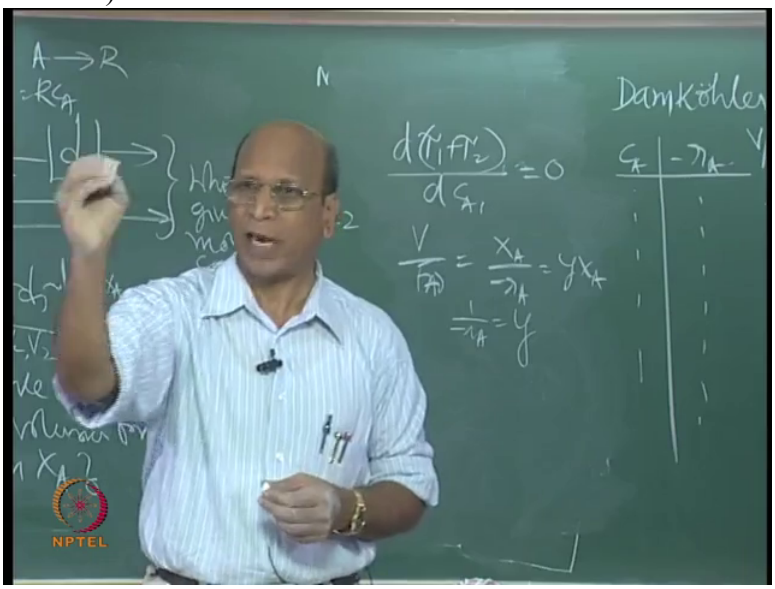

Find volume, find conversion...

Student: 0:54:21.1

Professor: Nothing is given?

Student: No I will read the problem. If minus r A is point, if minus r A is zero point 2 moles per liter second when C A is 1 mole per liter. What is the rate of the reaction when C A is 10 moles per liter?

Professor: Oh no, I think I am not talking about, you are talking about point. You are talking about one point. I am talking about, if you collect data C A versus minus r A, how do you use that for reactor design? That is what my question.
(Professor – student conversation ends)

So there the answer is that, you know you cannot find out. That is all, you cannot find out. It is only 1 point. So answer is known to us because I think some data, Levenpiel's problems. you cannot find out. You have to say that.

He also gives, for order of reaction where A plus B going to something, Ok, what is the order of reaction he asks? You cannot say. Unless otherwise you mention whether it is elementary. So again you know he wants to provoke you. That is why I also want to provoke you. I gave the questions and then you know this one point, answer for that is that you cannot find out.

But I am not...I thought you were asking something great about this, you know C A, minus r A, and that is why I was asking, unless X A is given how do you find out volume? Ok, you are talking about 1 point, where I am talking about a process where how do you find out, you know volume without even finding out what is the rate of reaction,

Ok, yeah, and this is one thing. The other thing is that you have, rate versus, again same thing. This side you plot rate, versus C A, it is not 1 by,

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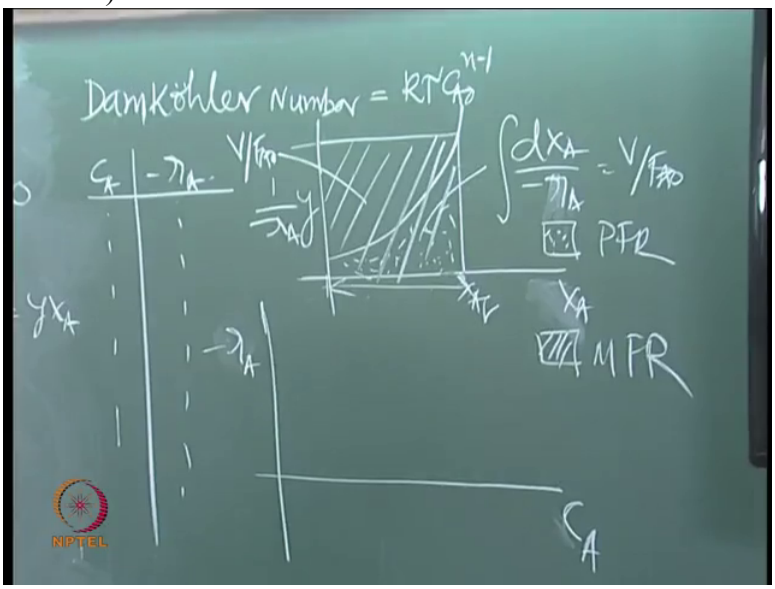

1 by minus r A. It is simply this. Ok, so now when you have the same kind of data, we can also find out what is the conversion if we have 2, 2, reactors in series, 2-2-2, three tanks in series or otherwise given conversion, what will be the volumes, combinations.

You know how to do that? Again same equations, it is only, you know, expansion of the brain, that is all, nothing else, Ok. I think someone was telling tau equal to C A naught minus C A by minus r A is the equation for M F R, correct?

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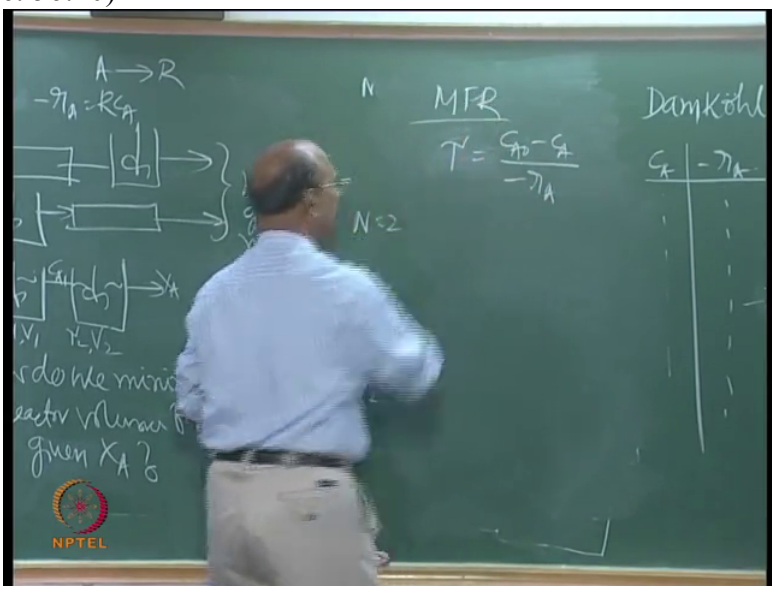

Please check. V by F A naught all that we checked, right so this is the equation what you get. The same thing can also be used to find out, you know the volume and also, if I have another one, this is tau 1; tau 2 equal to this is C A 1. C A 1 minus C A 2, this is r A 1,

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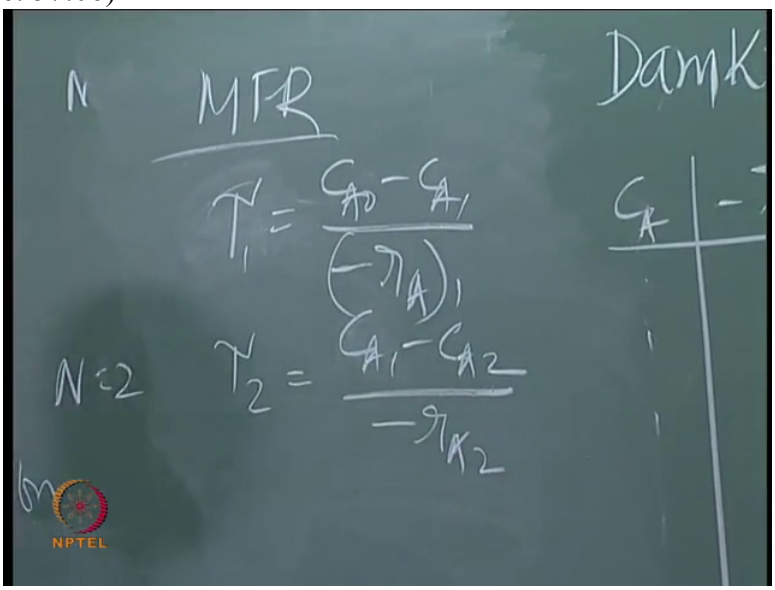

r A 2, Ok. What we do is we try to arrange this equation,

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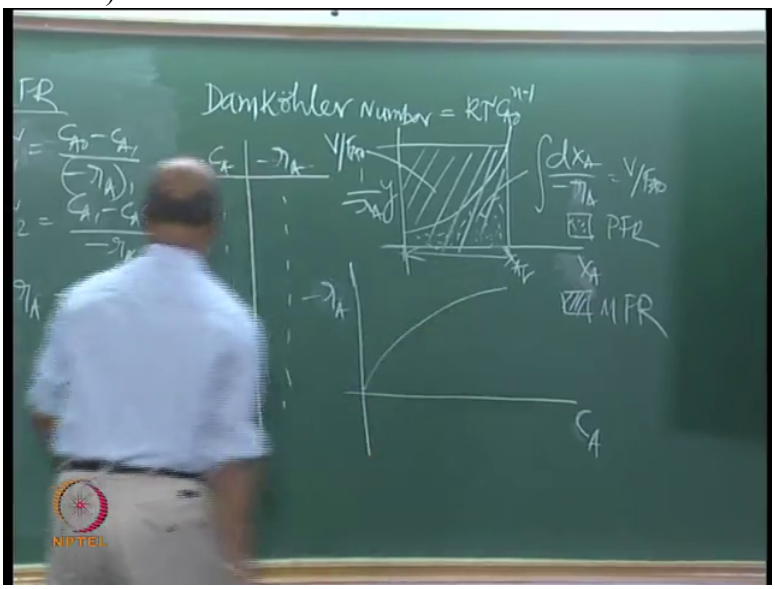

1 by tau 2 equal to minus r A 1 by C A naught by, yeah,

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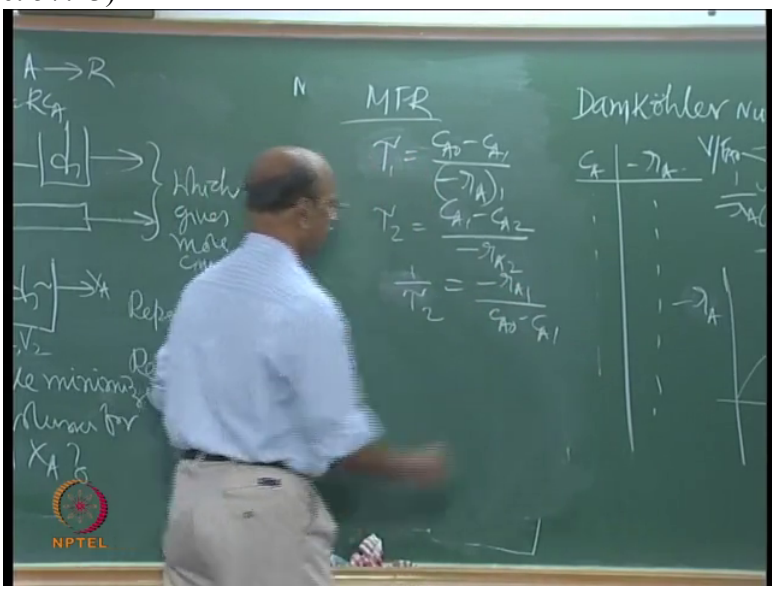

yeah this is the one.

So that means I have to draw, I have to start here C A naught, yeah 1 by tau 1, of course, yeah that is Ok, 1 by tau 1, so this is the one, this is C A naught,

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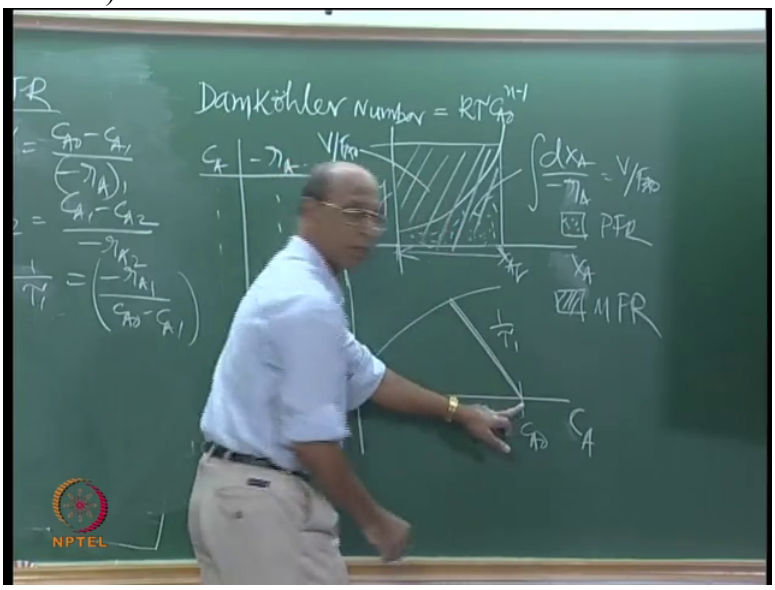

Ok now if I draw a line here, this is

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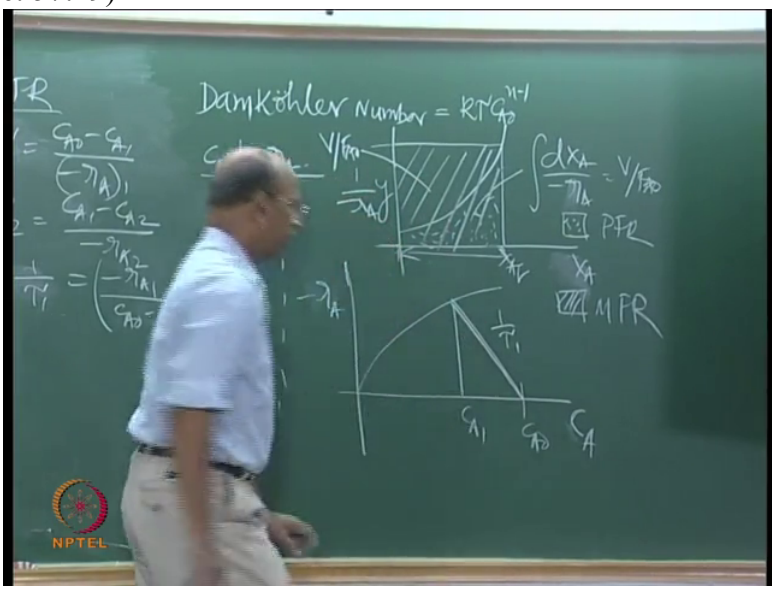

C A 1, Ok, this is negative slope. This is negative slope only, no. That is, Ok minus, that is Ok, the shape itself will tell you it is negative. If it is positive like that, it will be.

So similarly if I have the same thing, go like this, so this is C A 2, this is C A 3.

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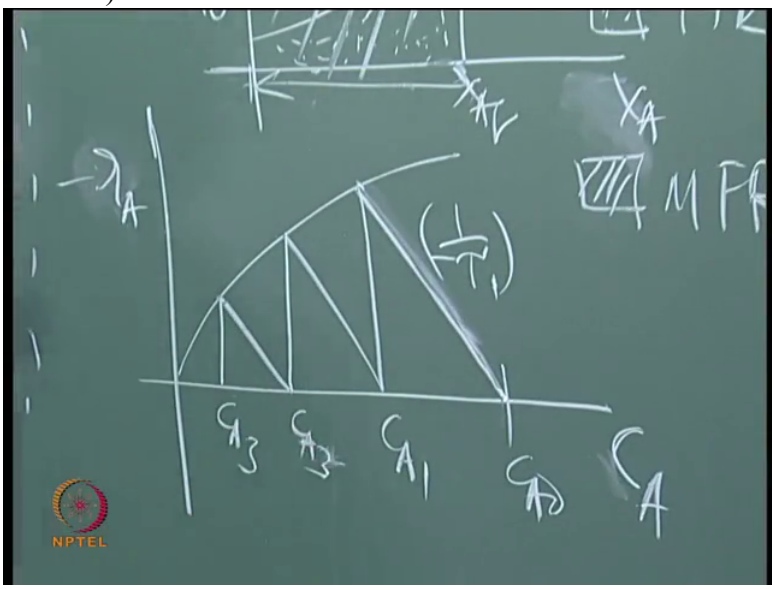

So this slope is nothing but I have you know, this is minus r, this is minus r

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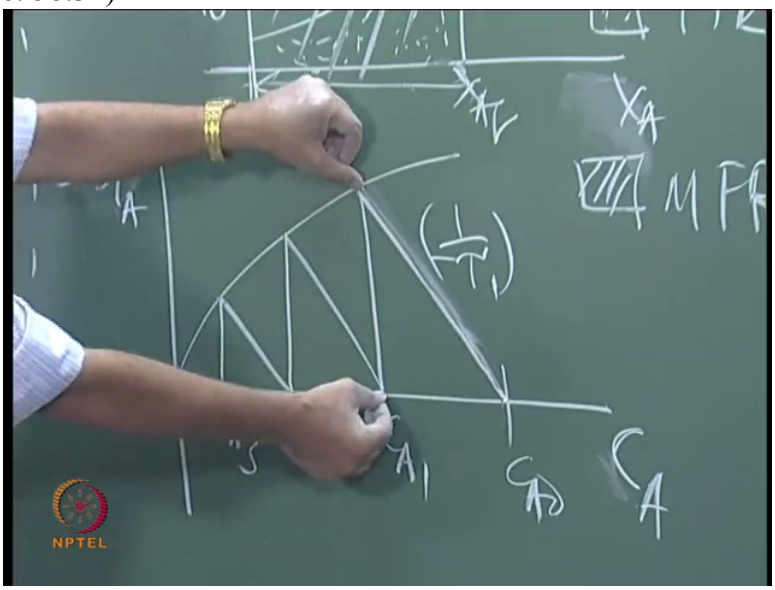

that is this, minus r A 1 and this one, this is the slope. This is the slope, right?

So again you know that I am trying to say is we have not learnt any new equations. Using the same kind of equations, how are we manipulating so that we can get this kind of things. But it is very easy if I know volume of the reactor

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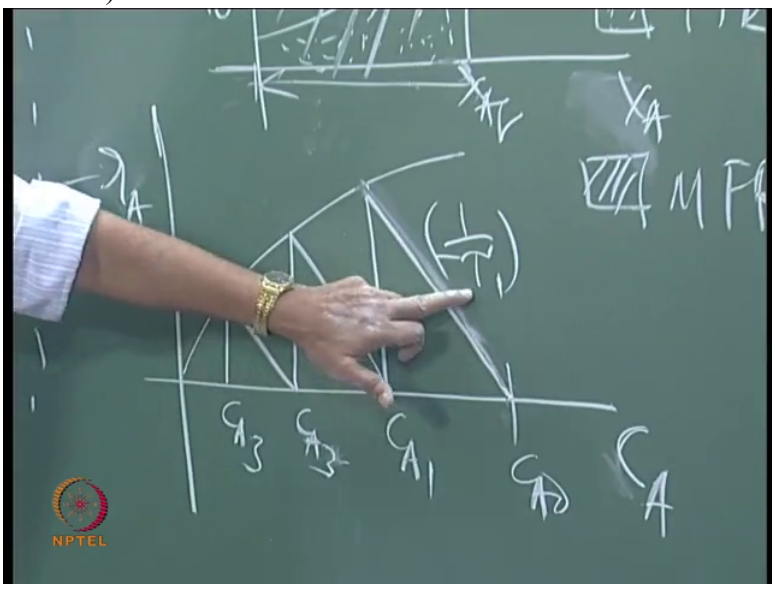

first, and then to find out conversion,

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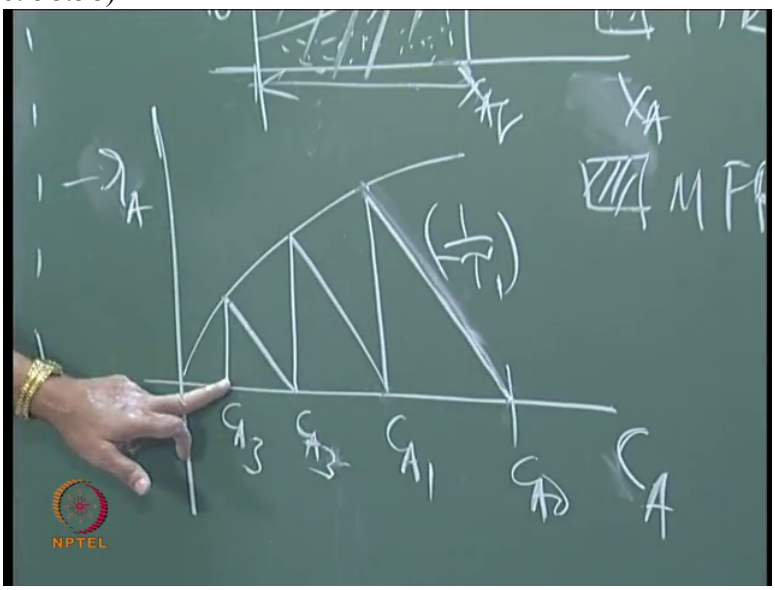

yeah.

But it is very difficult for me to go the other way. That means if I know C A 3, I have to now find out 3 reactors, so that means by trial and error you have to draw the slopes, by trial and error, then only you have to come here, each time you have to draw a slope and then draw these lines and then see whether you are coinciding with C A 3 or not.

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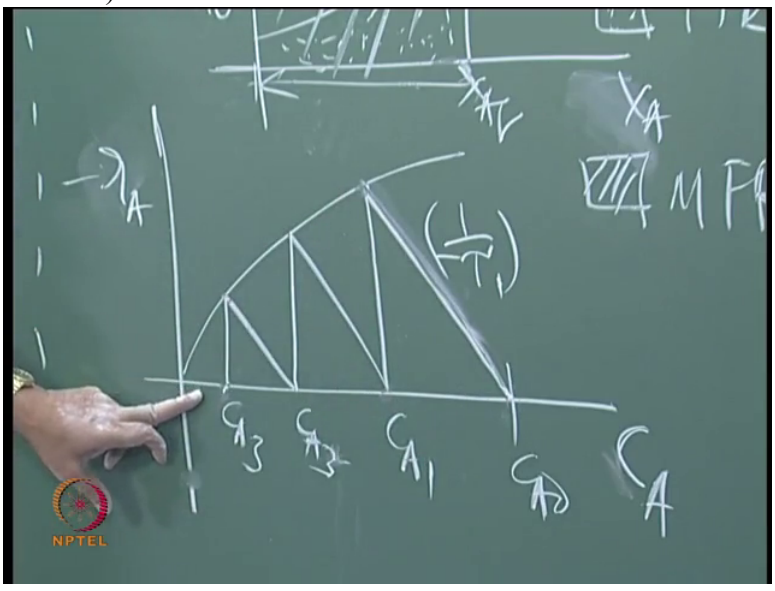

So easy problem is knowing volume, that means knowing tau and finding out conversion. That is easy. You have to write

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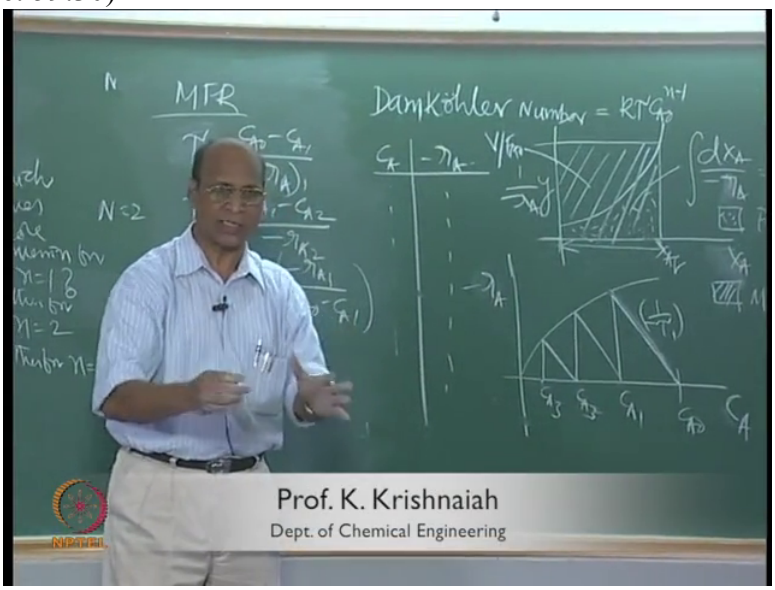

somewhere, knowing tau getting conversion is easy in this problem but difficulty

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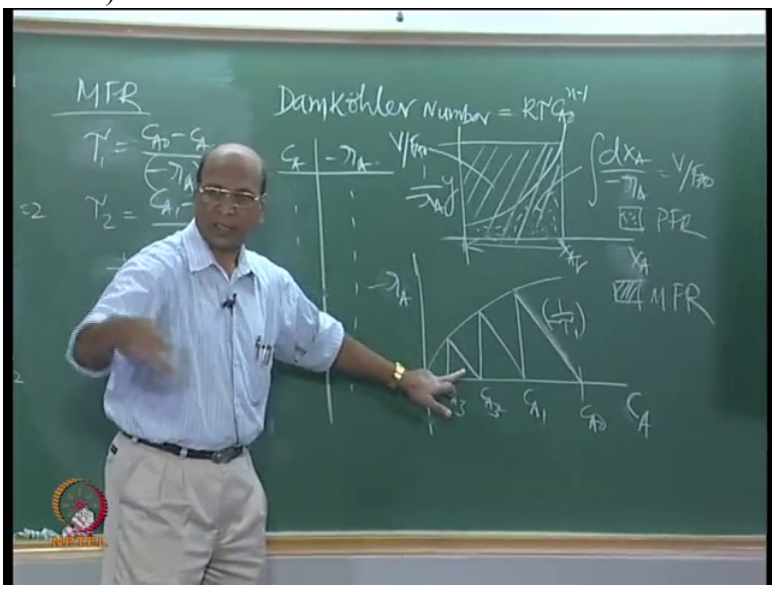

is knowing conversion find out tau, by trial and error you have to do, by trial and error one has to do. Yes, slope, slope you have to change such that finally you end up here

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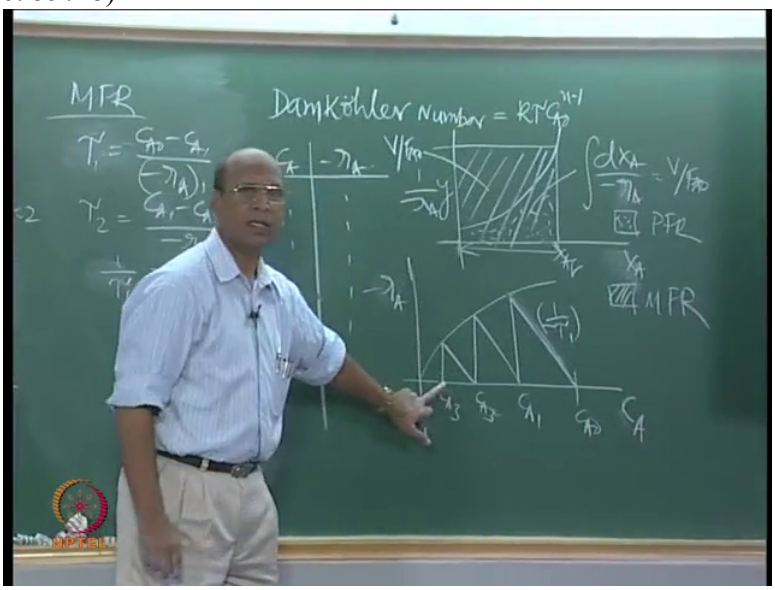

with C A 3, Ok, yeah I think it is full. We will discuss later.