Chemical Reaction Engineering 1 (Homogenous Reactors)
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Lecture No 59
Direct use of RTD to predict conversion (Macro and Micro-fluid as well as Macro and Micro-mixing Concept) Part 2

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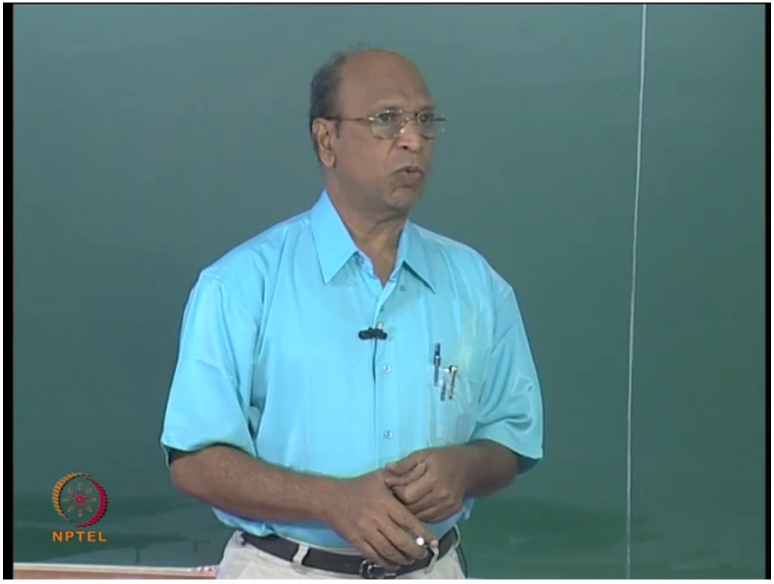

Yeah we will start now. I think yesterday evening what we have discussed I do not know how far it has really percolated into your brains, Ok because I think your brains do not have porosity, right. It is solid rock so, but I think percolating into solid rock is very difficult.

So that is why again I will quickly do that. I think this is what what we have discussed in the last class that is direct use of R T D to estimate conversions. That means no modeling in between, can we use R T D information directly to get the conversion, Ok.

So any, the meaning of that is that, any real reactor, that means with all diseases like dead space, bypass and all kinds of things, Ok good. Then we also discussed that why first order reactions only, it is possible for them, for the first order reactions to get the conversion directly using the R T D, Ok. Now I think that you understood. Right, because that is a linear process. And also R T D is also a linear process.

But on the other hand, first order reactions require only information on timings. Ok. So a packet how much time it has spent inside the reactor and there the conversion depends on the time it has spent inside the reactor. So then you can calculate from R T D those timings and then club with kinetics, that will give you totally the information on, Ok, so the information on conversion.

So for first order

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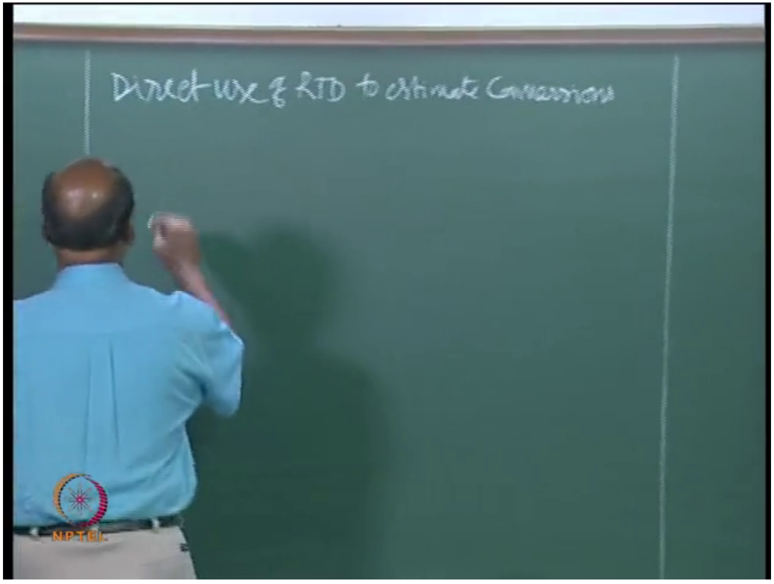

reactions, first order reactions we have R T D plus kinetic, Ok, kinetic information, that is first orders only will be giving performance, performance of reactor.

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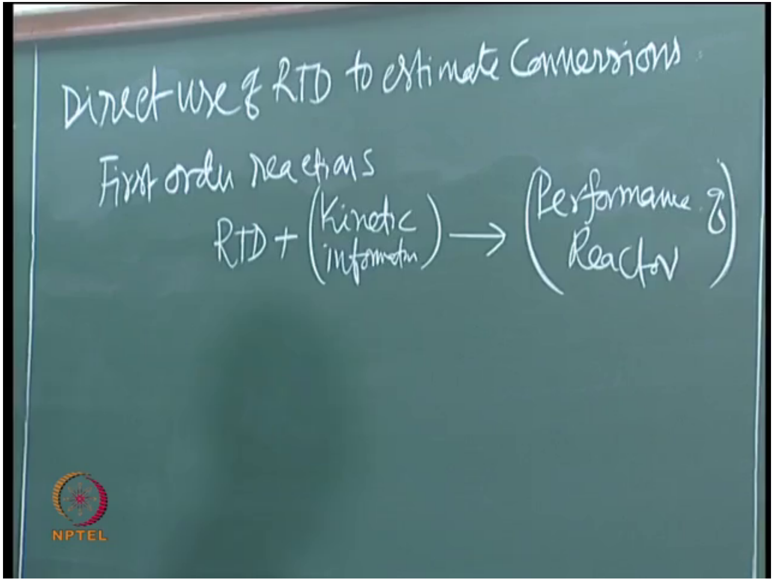

This is only for first order reaction.

And we have also derived the, I mean I simply wrote an equation without derivation, what is happening in first order reactions is because R T D gives me the fraction that is coming between time t and t plus delta t.

In that fraction, how much time this particular fraction has spent inside the reactor and at the exit of course, when you are taking and what is the conversion in that particular fraction, right? So how do I write that? And then we are averaging all the fractions.

Mean conversion or mean concentration, Ok, mean concentration of, we are only deriving an equation for first order thing now, in exit stream equal to, concentration of, concentration of reactant remaining in the element of age between t and t plus delta t, that is one thing,

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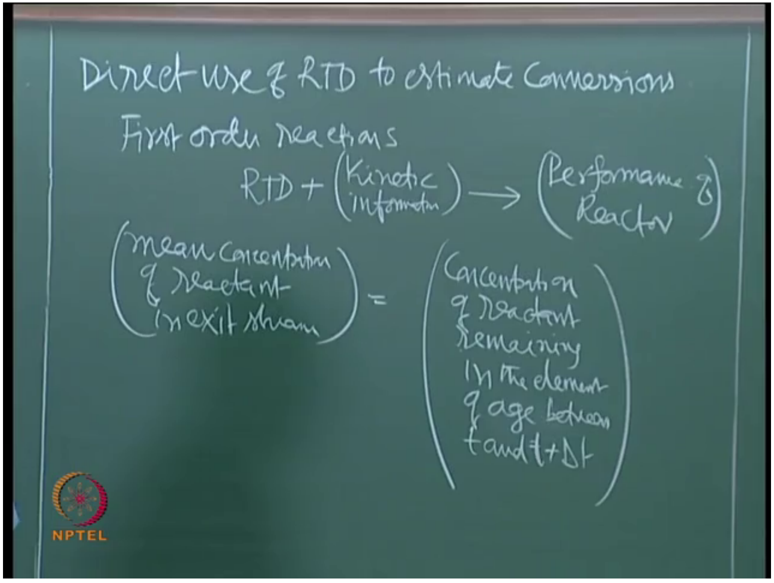

Direct use of RTD to estimate Conversions

First order reactions

RTD + (Kinetic information) → (Performance of Reactor)

(mean concentration of reactant in exit stream) = (Concentration of reactant remaining in the element of age between t and t+Δt)

that is the fraction, you know, that is concentration remaining in that fraction, and, sorry concentration remaining in that packet

And then we have fraction, of, just move the boundary a little bit, fraction of exit stream, exit stream which is of age between, can anyone fill up that, between...

(Professor – student conversation starts)
Student: Same
Professor: Same thing, t and t plus delta t. Ok, what is this?
Student: E t d t

Professor: Very good. This is E t d t, or delta t, Ok.

(Professor – student conversation ends)

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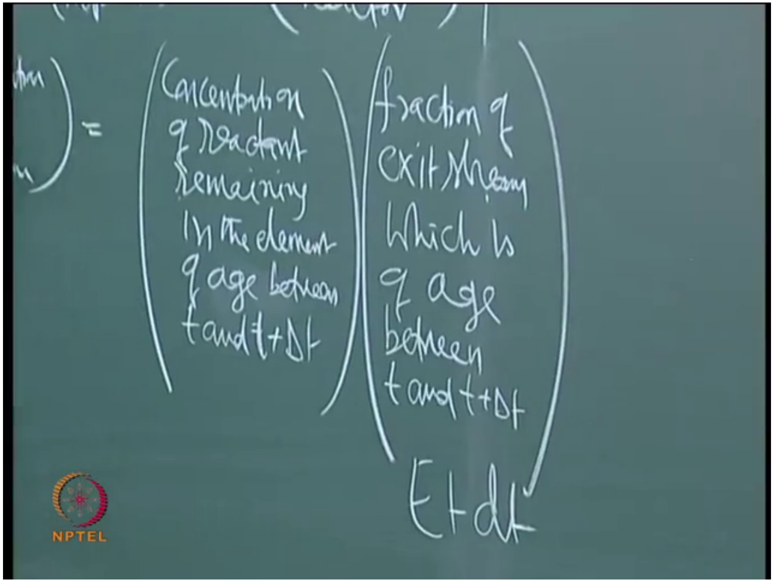

$$ \left(\text{Concentration of reactant remaining in the element of age between } t \text{ and } t+\Delta t\right)\left(\text{fraction of exit stream which is of age between } t \text{ and } t+\Delta t\right) $$

E t dt

And what is this one?

(Professor – student conversation starts)

Student: I t....

Student: 0:04:55.8

Student: That I

Professor: Where is I t, it is the concentration of the reactant remaining in that element.

Student: 1 minus

Professor: It is C A by C A naught of that batch, of that fraction.

Student: Sir E of t

Professor: E of t, yes, E of t d t. And the sum of all these will give us the mean concentration C A bar by C A naught, the sum over that.

(Professor – student conversation ends)

So or other words, what we have written

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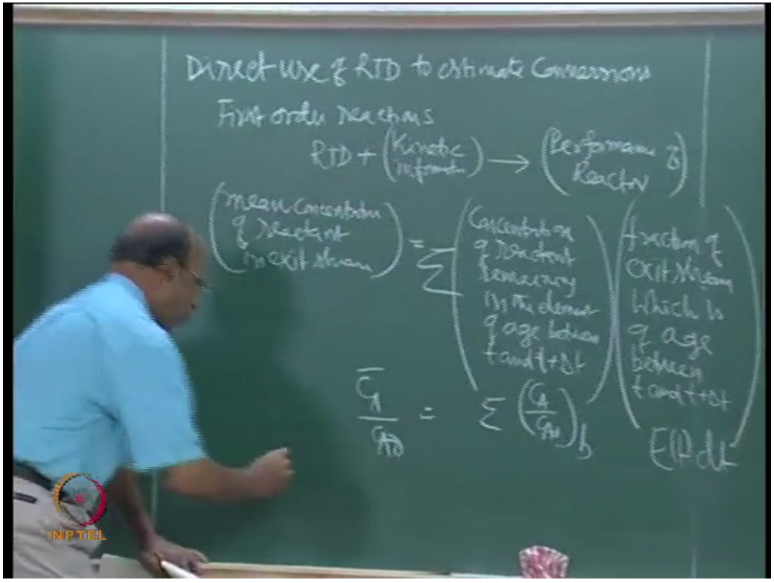

Direct use of RTD to estimate Conversions

First order reactions

$$\text{RTD} + \begin{pmatrix}\text{Kinetic}\\ \text{information}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Performance of}\\ \text{Reactor}\end{pmatrix}$$

$$\begin{pmatrix}\text{mean Concentration}\\ \text{of reactant}\\ \text{in exit stream}\end{pmatrix} = \sum \begin{pmatrix}\text{Concentration}\\ \text{of reactant}\\ \text{remaining}\\ \text{in the element}\\ \text{of age between}\\ t \text{ and } t+\Delta t\end{pmatrix} \begin{pmatrix}\text{fraction of}\\ \text{exit stream}\\ \text{which is}\\ \text{of age}\\ \text{between}\\ t \text{ and } t+\Delta t\end{pmatrix}$$

$$\frac{\bar{C}_A}{C_{A0}} = \sum \left(\frac{C_A}{C_{A0}}\right)_b E(t)\,dt$$

yesterday was, integral form, C A bar by C A naught equal to integral zero to infinity, C A by C A naught batch E t d t, so this is the expression.

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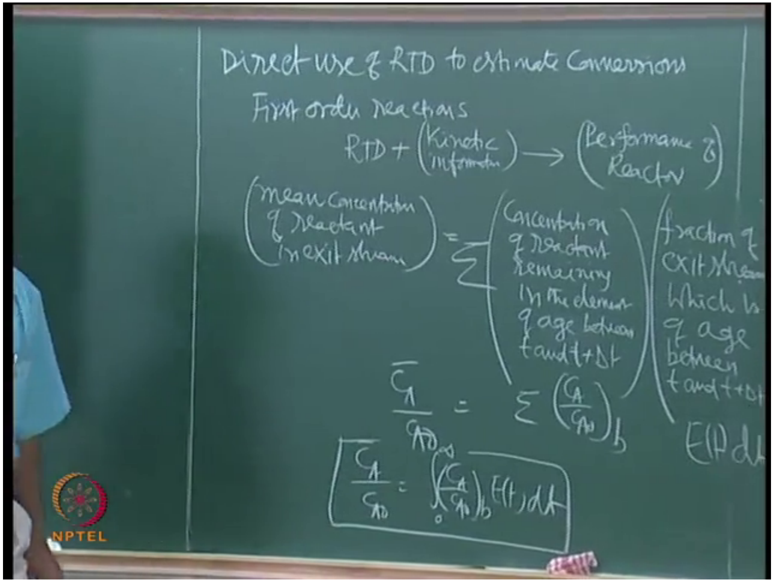

$$\boxed{\frac{\bar{C}_A}{C_{A0}} = \int_0^\infty \left(\frac{C_A}{C_{A0}}\right)_b E(t)\,dt}$$

Good. And now because we are writing specifically for first order, Ok, so now I know C A by C A naught batch for first order, right?

But I have written yesterday only e power minus k t. But that means what? It is first order A going to R, right? But there are so many first orders. Like for example A going to R, parallel reaction and A going to S. A going to R, R going to S, Ok. So the same thing is it valid for all first order reactions, like series reaction, parallel reaction and also reversible reaction, both are first order. Is it valid? Zero extension of brain?

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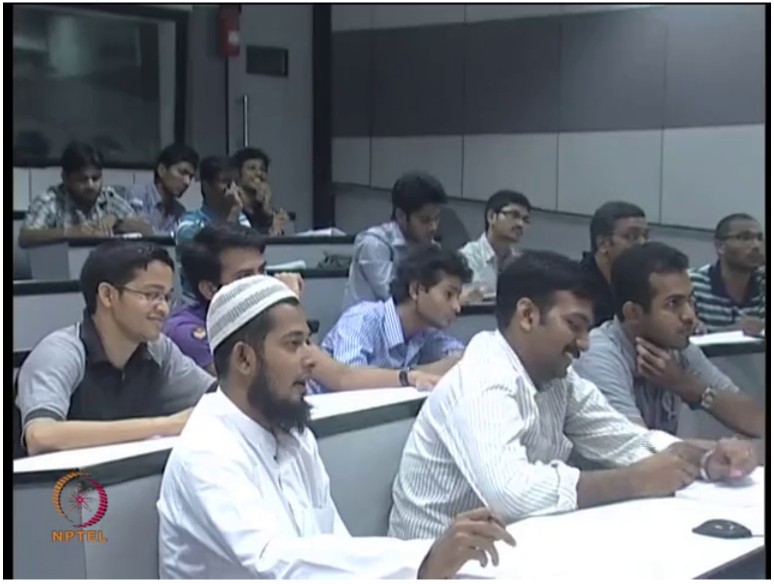

Why no? Anyone yes?

(Professor – student conversation starts)

Student: Valid, Sir

Professor: Why valid?

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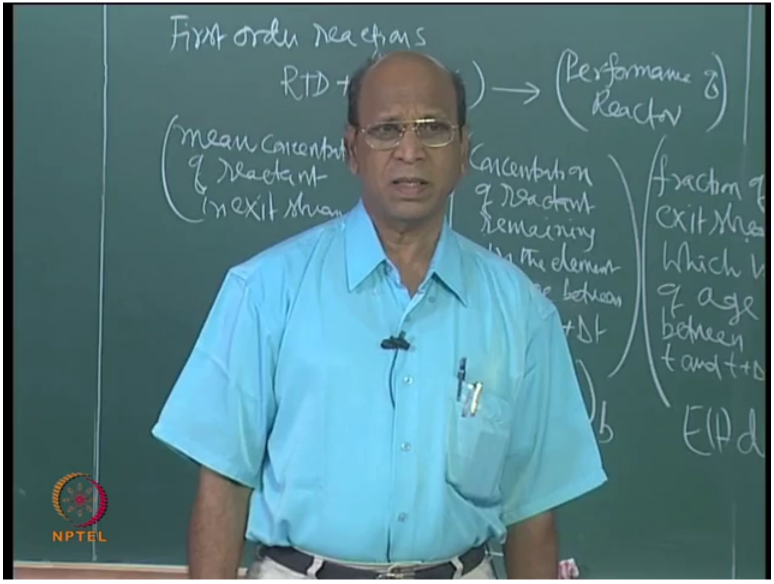

He is swallowing whatever you explain. But you explain

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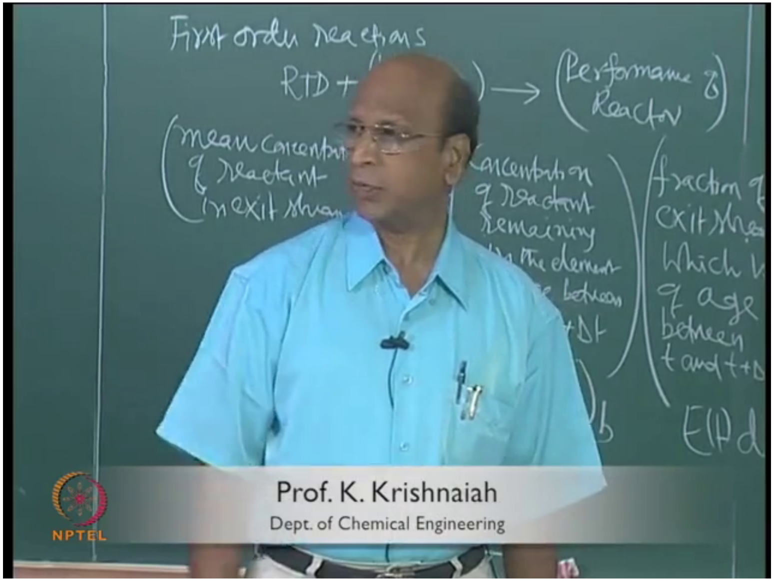

if there is anything?

Student: It is linear; the rate equation is still linear.

Professor: Yeah. Why do you say that? Because you have even reversible reaction, you have k 1 C A minus k 2 C A, it is a first order, linear process only. All linear processes, right.

If A going to R and A going to S what is the rate equation? Yeah, minus r A equal to k 1 plus k 2 C A. Because the power of C A is always 1, it is linear. So please remember, for any linear process, whether it is parallel, whether it is series or whether it is reversible, all processes it is

Student: First order

Professor: Ok and that is why what we do is, please take this, you know example, Levenspiel there is example, I do not remember now that example, Ok. So there is the, let me check whether I have in my notes. So that example please see...it is not here, yeah, it is not here. Ok.

(Professor – student conversation ends)

Please see that example where he has used for first order reaction and then calculated conversion. So what he does is this is e power minus k t for first order reaction and simply A going to R, right. So then this equation also, C bar A by C A naught is sigma of e power minus k t E t, E t delta t,

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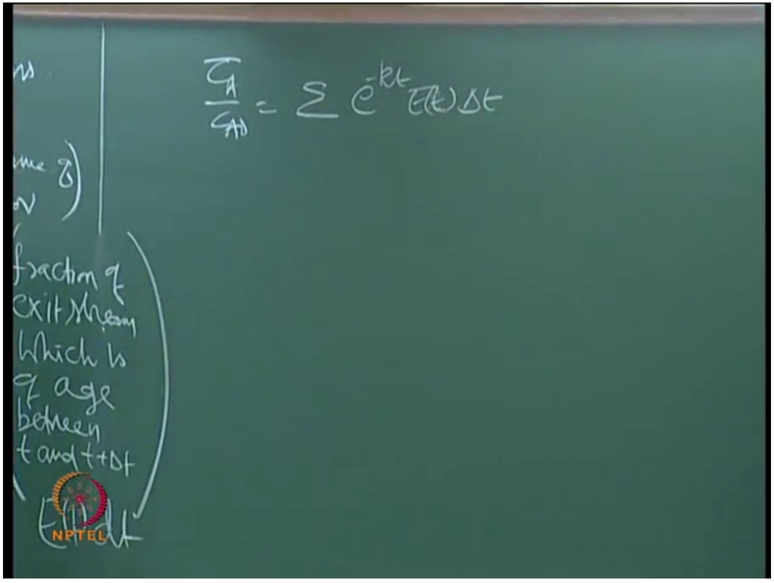

right? So I know this E t delta t and corresponding timings.

And I can calculate this and then you will get the average conversion

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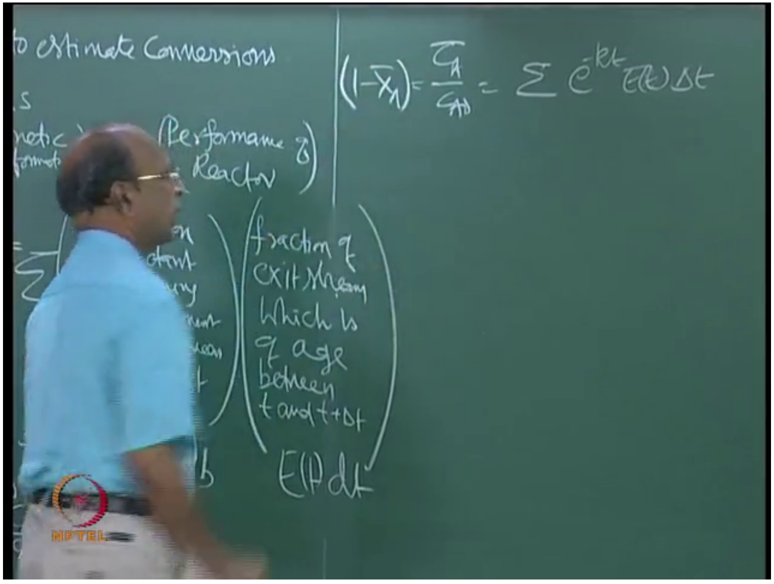

as 1 minus X bar A, right this is for first order. And even I can put here, for second order, sorry

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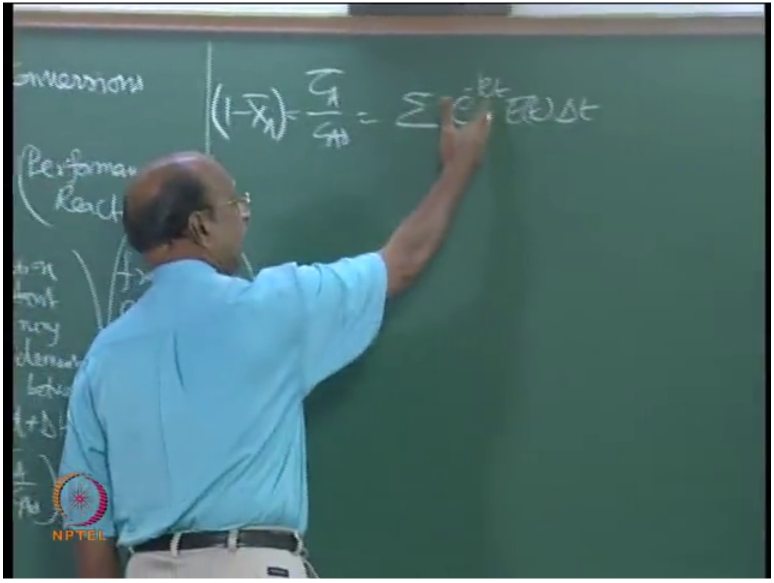

reversible reaction both first order. A going to R Ok, k 1 C A, so all that information you can put here, depending on parallel reaction, series reaction, and reversible reaction and all that. But still this is valid.

So please make a note that this equation is

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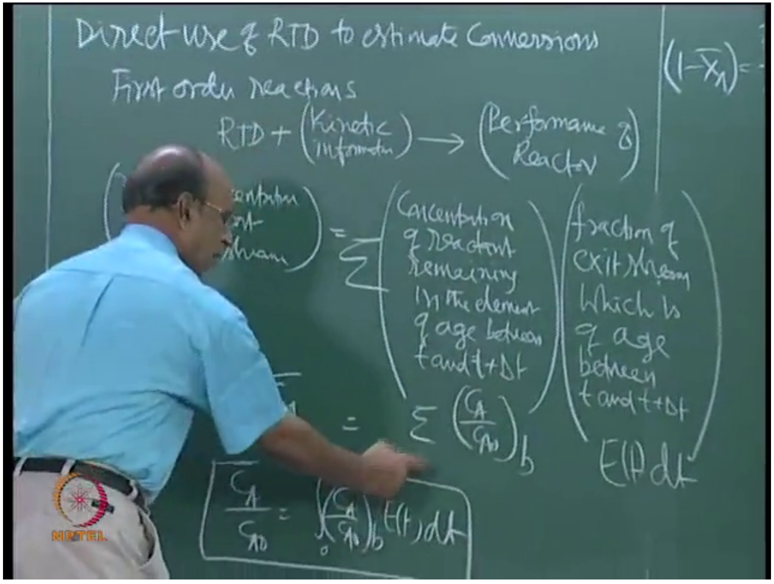

valid for all linear process such as parallel first order, series first order, reversible first order. Anything else? First order is first order whether it is gas phase, liquid phase or solid phase or any other phase if you want to create. In all these phases, provided it is homogenous reaction there is no external mass transfer coming into picture.

In fact by the by, even mass transfer, is it a linear process or non-linear process?

(Professor – student conversation starts)

Student: It is a linear process.

Student: Non linear.

Professor: What is a mass transfer process?

Student: Linear process

Professor: What is this, I say. Absolutely,

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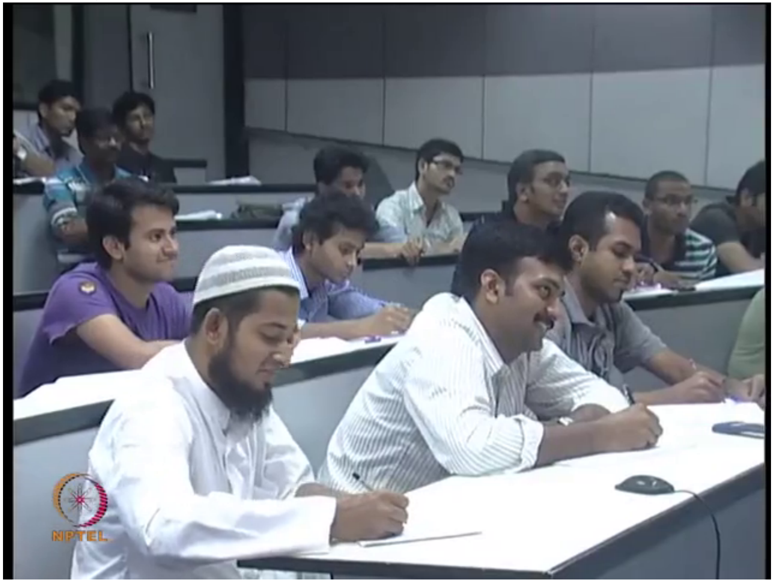

day by day, bread is shrinking you know, the brain is shrinking and I think it is not expanding.

(Professor – student conversation ends)

Ok,

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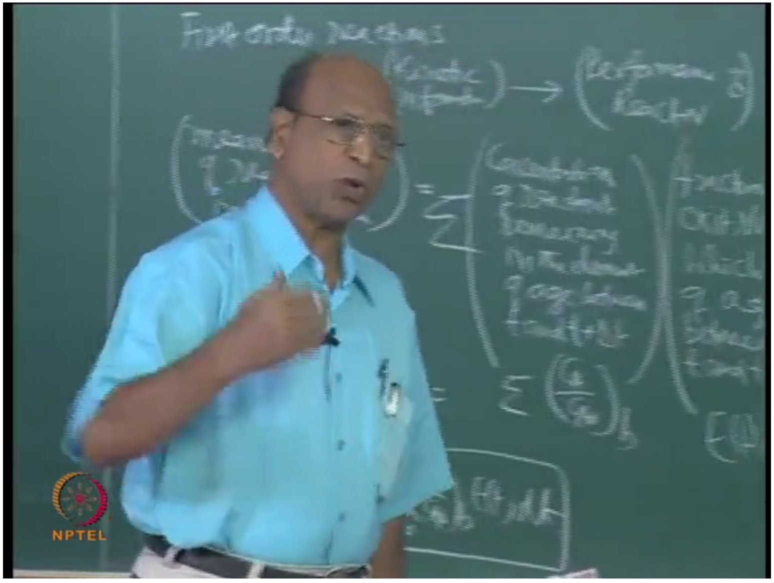

I think, more and more you read, I think less and less you are able to understand, I think. That is what is the problem. All of us could have stopped our studies in school itself, would have been very, very intelligent people, Ok. Yeah, really, by the time you reach the highest degree, brain is zero. You do not know what to say.

Yeah, today I saw, I think Rahul sent to me that Einstein quotation where I think, about technology, Ok when technology surpasses human interventions, Ok, so that means you are accepting technology means no calculating 2 into 2 how much means you have to remove either cell phone or calculator or computer, laptop and then only calculate 2 into 2 equal to 4.

Ok, then the next one is when technology surpasses human intervention, it produces idiots. Same words he has used. Idiots. Same word he has used.-Idiots is there, sentence may not be exactly right. Oh, Einstein told when he was, you know when he died, 1965? Gopi when did he die?

(Professor – student conversation starts)
Student: 63
Professor: 63, yes around that. Ok, so Ok around 60s only, I remember that. So I think somewhere before that he told that. Wonderful no? So that is what what we are doing. For anything go and open the calculator or laptop and we do not know how to use our brain, correct no? Abdul, your name...not Abdul, behind? Mehboob, yeah. Ok.
Student: 0:11:26.0

Professor: Yes? Not required, you only click.

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Clicks over, number of clicks, over. Operation is over, Ok anyway, good.

(Professor – student conversation ends)

So this is the one. Please write a, make a note of that. This is, yeah this equation if I say this is equation 1,

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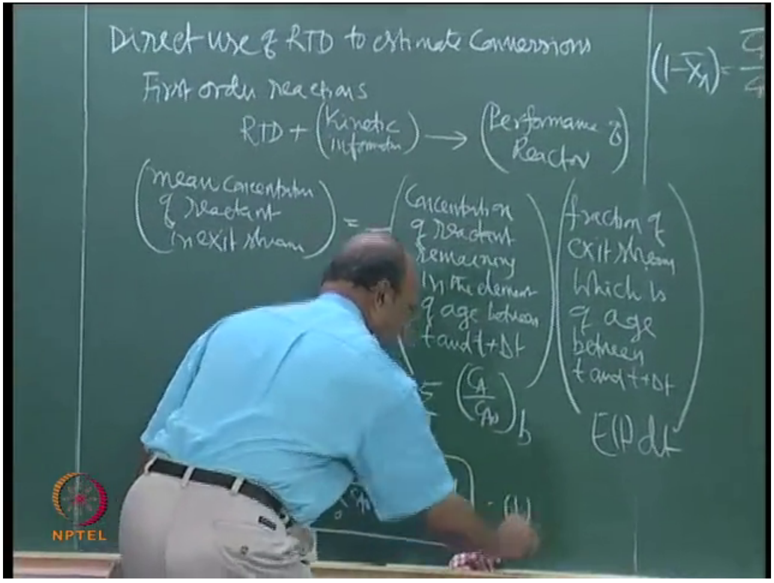

this is equation 2 in terms of

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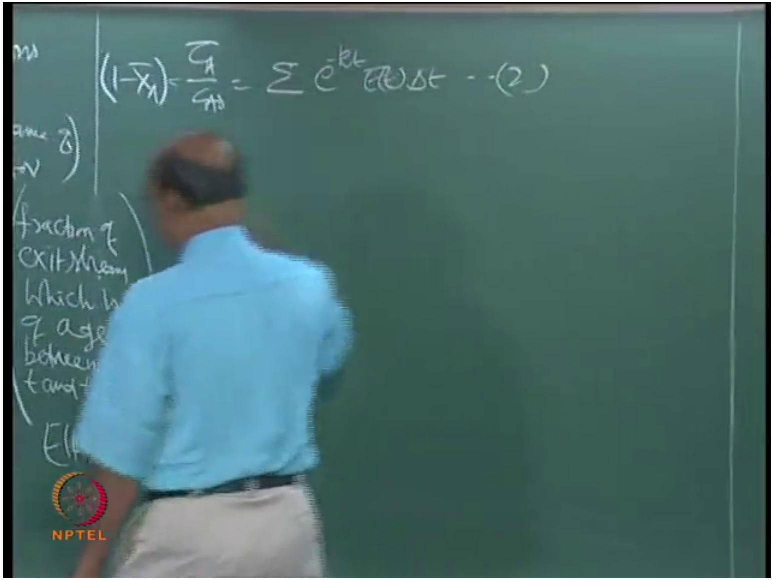

differential form. Equation 1 is valid for all, equation because I think mass transfer process you know, it is N A equal to k C A minus you know the other side, concentration gradient. It is only linear no?

So equation 1 is valid for all first order reactions and I will underline all. Because all means

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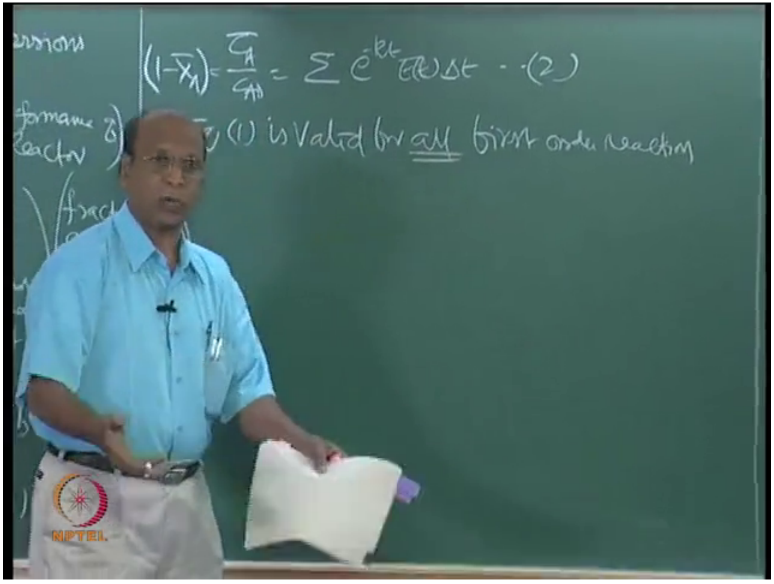

again I have to take...what are all? Yeah, right, all means first order, series, parallel, reversible all that. Ok please write that also. Otherwise tomorrow you may forget. What is this all we do not know. Yeah, good Ok.

The first order reactions are over now. So let us, the next one what we have discussed was using this, yeah asking question, what will happen for other than first order? Yeah and also, I think, time too much, I do not have watch. I am very happy today because I can take any time.

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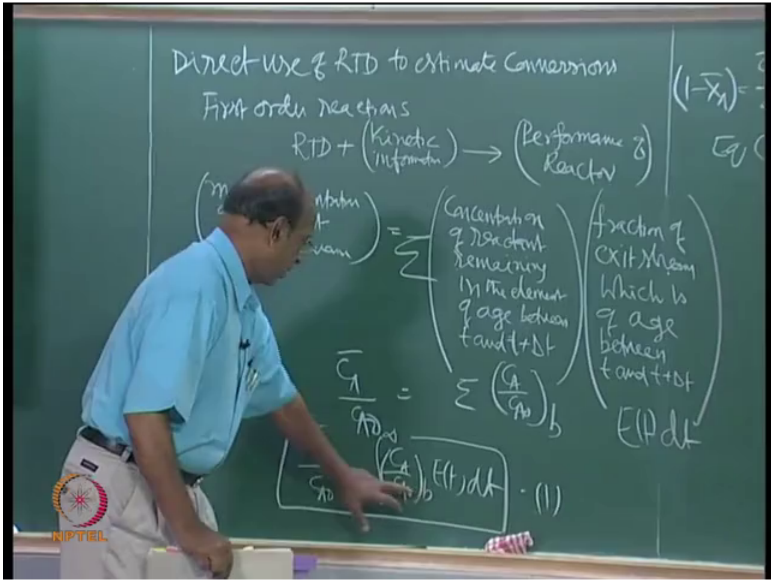

So C A by C A naught batch E t d t, when I have this, and for ideal reactors, what is E t?

For example for plug flow alone, right what is E t and what is, yeah C A by C A naught? For ideal P F R, P F R means ideal, so C A bar by C A naught equal to zero to infinity e power minus k t, yeah this one is direct delta function E t, no delta, this is delta, yeah t equal to t bar P, correct no? Yeah.

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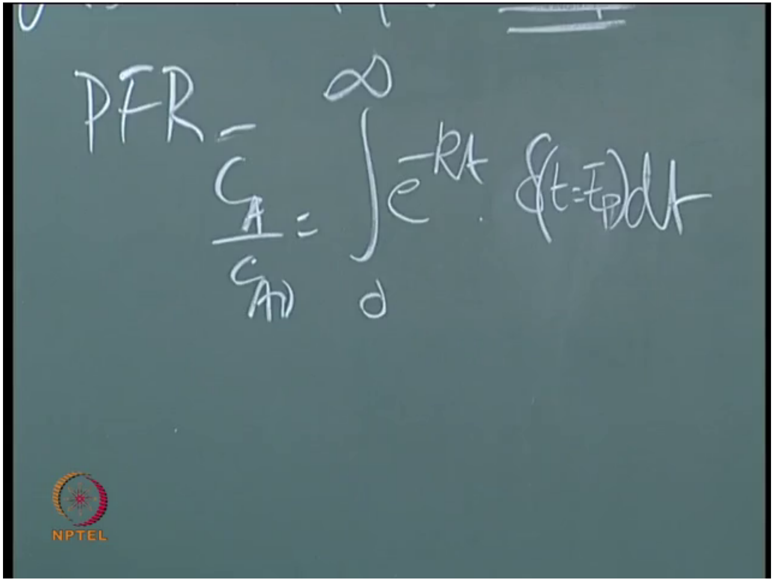

PFR –

$$\frac{\bar{C}_A}{C_{A0}} = \int_0^\infty e^{-kt} \cdot \delta(t - \bar{t}_p)\, dt$$

So now tell me what is the equation for that?

(Professor – student conversation starts)

Student: e to the power k t bar

Professor: e to the power?

Student: k t bar.

Professor: Yeah, you see now even from this you can easily get provided you know actually for first order reaction what is the equation, right?

(Professor – student conversation ends)

So

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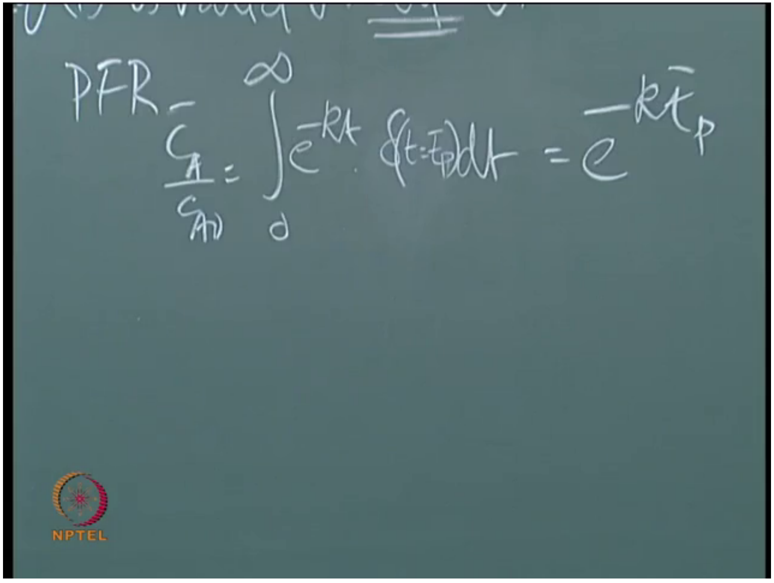

PFR –

$$\frac{C_A}{C_{A0}} = \int_0^\infty e^{-kt}\,\delta(t-\bar{t}_p)\,dt = e^{-k\bar{t}_p}$$

similarly for reversible, parallel, everything you can substitute this equation and you know when this function is valid

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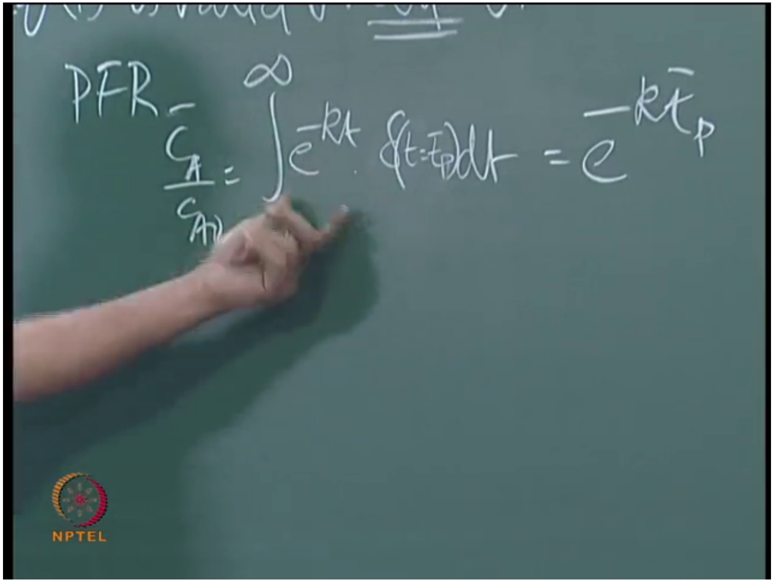

PFR –

$$\frac{C_A}{C_{A0}} = \int e^{-kt}\,\delta(t-\bar{t}_p)\,dt = e^{-k\bar{t}_p}$$

and correspondingly, you know this function, as it is that appears, does not depend on what are also the other functions also you can now calculate.

Same thing, you can also put here, for M F R, Oh my God! I am taking lot of time. C A bar by C A naught is equal to zero to infinity e power minus k t, what is for E t, M F R? e power minus t by t bar m by T bar m, Ok d t. If you integrate that and put the limits between zero to infinity, what is that you should get here? 1 by 1 plus k t bar m that is what is for first order, Ok, good, very nice. Ok.

So now the next one

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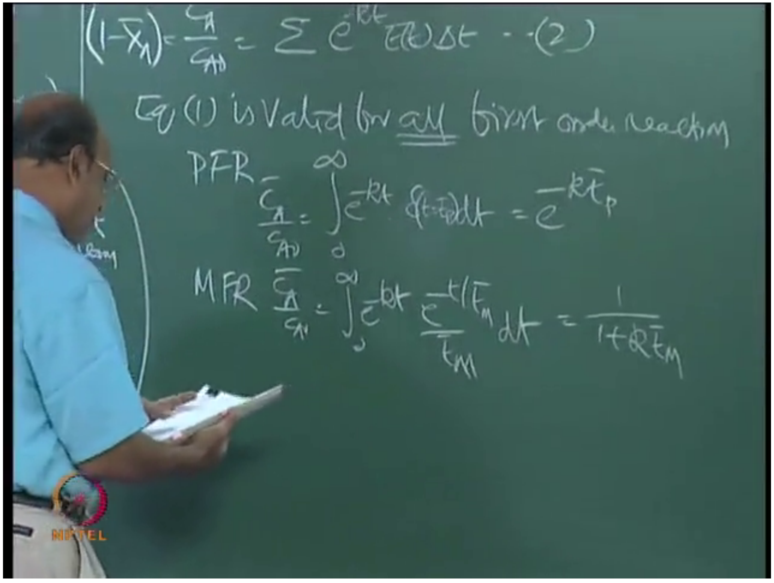

$$(1-\bar{X}_A) = \frac{C_A}{C_{A0}} = \sum e^{-kt} E(t)\Delta t \quad --(2)$$

Eq (1) is Valid for all first order reaction

$$\text{PFR} \quad \frac{\bar{C}_A}{C_{A0}} = \int_0^\infty e^{-kt}\,\delta(t-\bar{t})\,dt = e^{-k\bar{t}_p}$$

$$\text{MFR} \quad \frac{\bar{C}_A}{C_{A0}} = \int_0^\infty e^{-kt}\,\frac{e^{-t/\bar{t}_M}}{\bar{t}_M}\,dt = \frac{1}{1+k\bar{t}_M}$$

is these models what we have discussed, why only for first order, it is a linear process and also first order requires only the timing and that timing is supplied by R T D so that is why I think we can use this very happily without any problem. Ok, good.

But now what will happen if I go to other than first order reactions? So for that, we took that model, very beautiful model, for other than first order reactions we are just explaining with model 1, which we have discussed already.

But still I have to give some idea no because yesterday this is t bar P, no t bar 1 I shall right, t bar 1, this is t bar 2 and the other model 2

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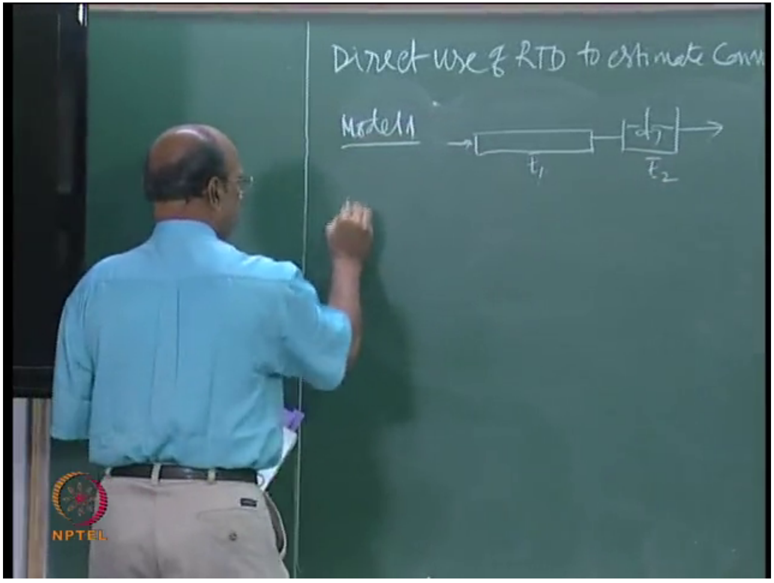

is just reverse of this, yeah, so same thing. This is t bar 2, t bar 1,

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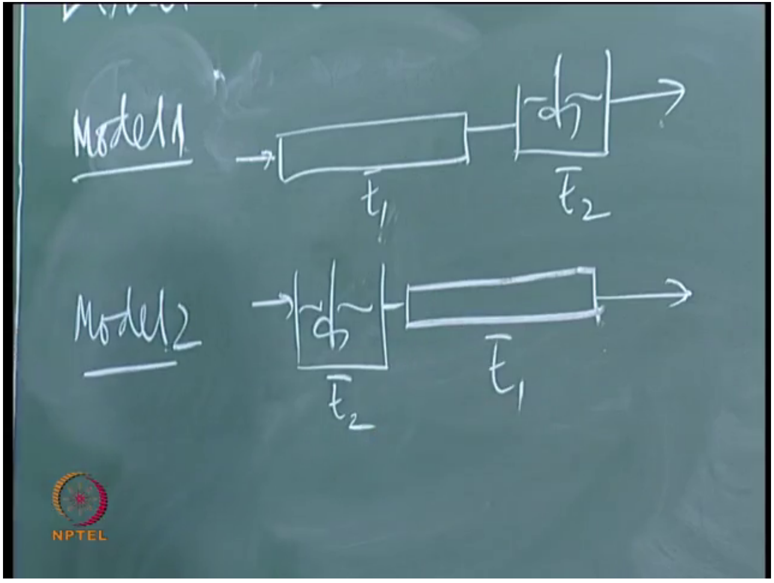

right and we found that for first order,

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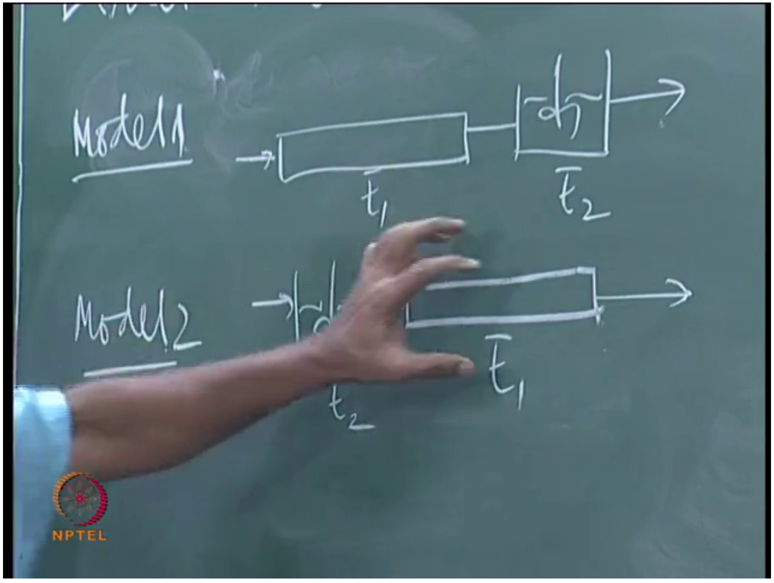

yeah Ok, most important thing. E t versus t, this is t bar 1, right.

So if I do not give this picture,

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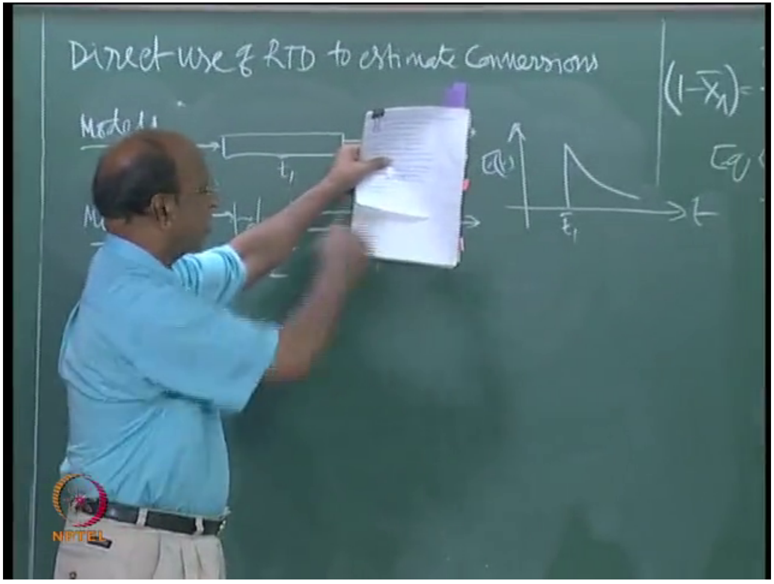

these 2 pictures and if I give only this E t, you know that yesterday we have discussed that. This E t can represent model 1 and also can represent model 2 and not only that, it can represent many other models which I will show you later, a little bit later, Ok. It can represent so many models.

R T D cannot supply all the information. That means again what is information again actually you need? If I go to n equal to 1, model 1 and 2, model 1 and 2 gives same conversion. This is again reiterating what we have told.

The meaning of this is

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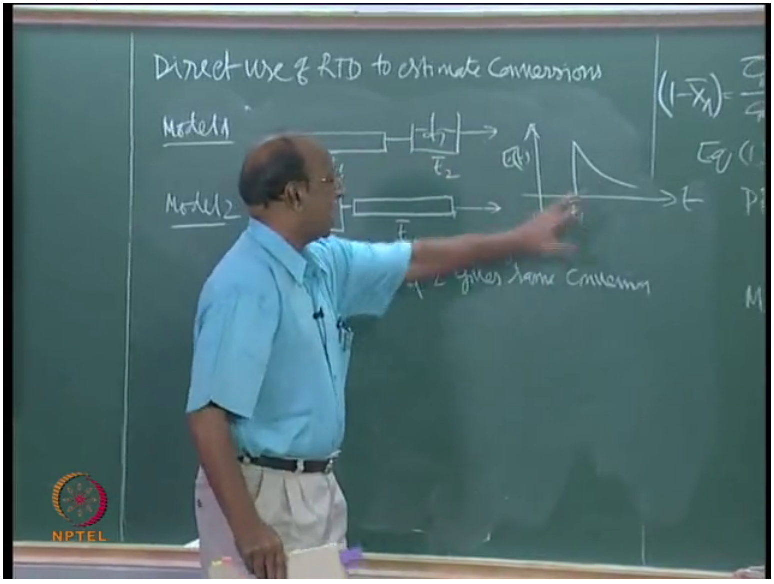

if I know R T D, it does not matter whether we have late mixing or early mixing because R T D tells me the time and for first order we also require only the time of that particular fraction how much it has, you know, the time it has spent inside the reactor, excellent.

So now for the, this n equal to 1, right. So n greater than 1...because I am worried about my time. I think when I again started so again I will end up with the same thing what I have told you yesterday.

So n greater than 1, we have seen that model 1 gives more conversion than, Ok more conversion, why than because it is understood. Correct no, model 1 gives means model 2 does not give. That is all, that is all, Ok. So for n less than 1,

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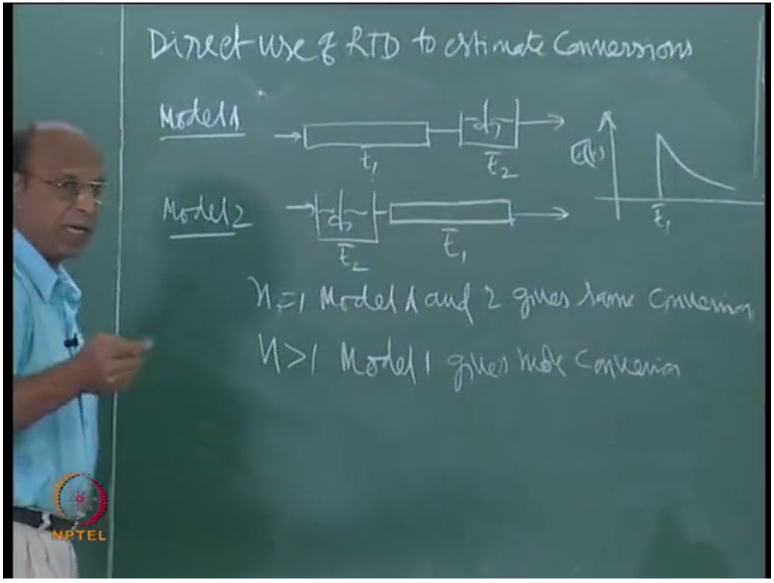
Direct use of RTD to estimate Conversions

Model 1

Model 2

n=1 Model 1 and 2 gives same Conversion

n>1 Model 1 gives more Conversion

even though we have not proved, you will get the reverse.

Model 2 gives or Ok model 1 gives, yeah less conversion. So what we thought if I am talking about n greater than 1, for example second order

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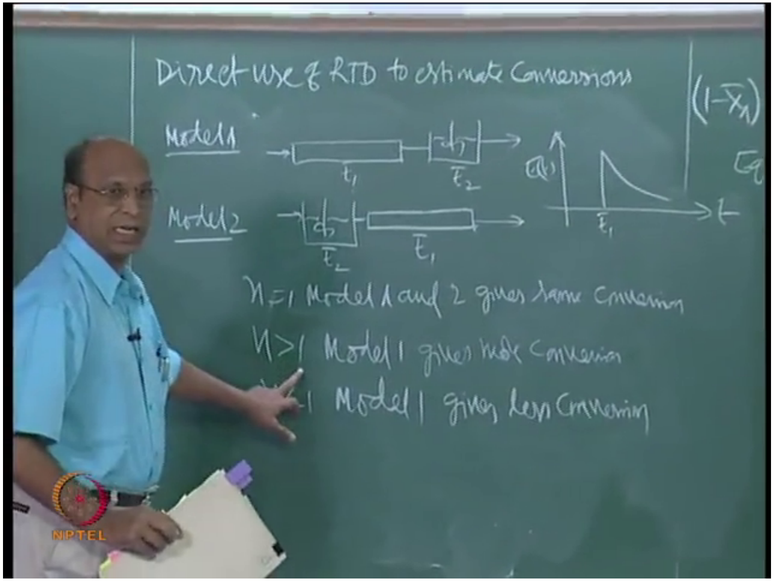
Direct use of RTD to estimate Conversions

Model 1

Model 2

n=1 Model 1 and 2 gives same Conversion

n>1 Model 1 gives more Conversion

n<1 Model 1 gives less Conversion

$(1-\bar{X}_A)$

reaction, right, so it is giving more conversion. The reason is that here we have

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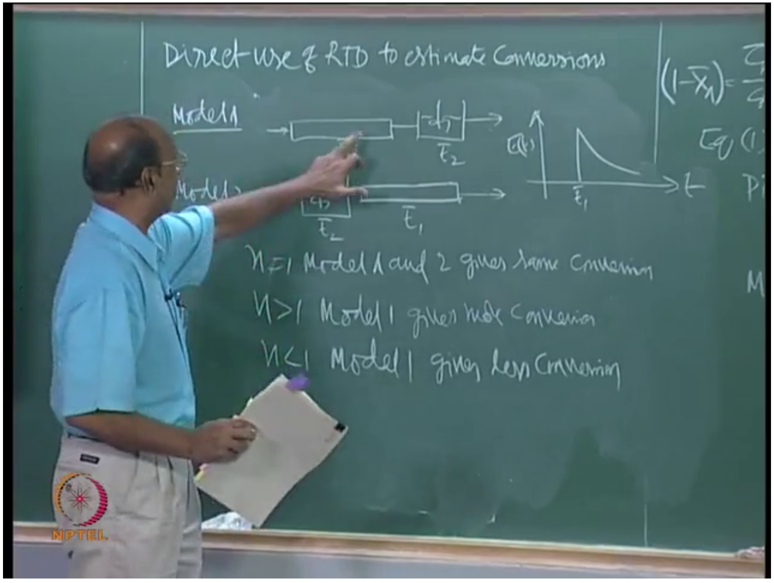

Direct use of RTD to estimate Conversions

n=1 Model 1 and 2 gives same Conversion

n>1 Model 1 gives more Conversion

n<1 Model 1 gives less Conversion

late mixing. And here we have early mixing,

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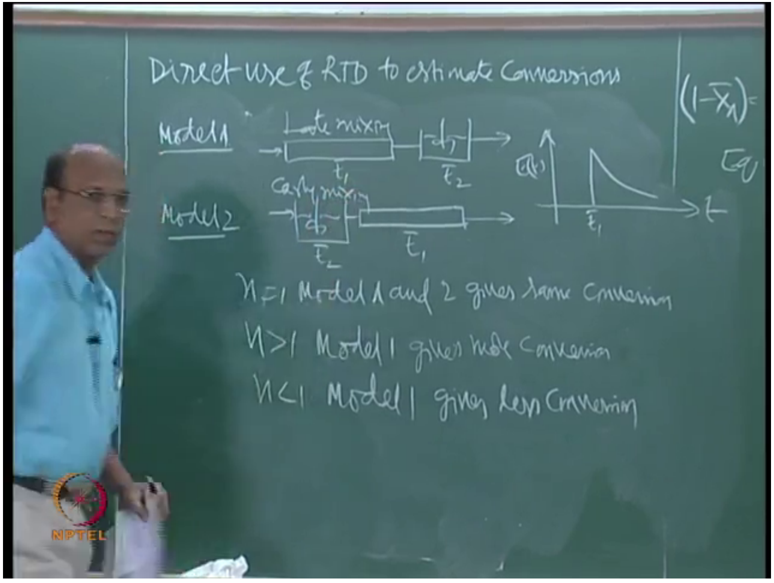

Direct use of RTD to estimate Conversions

n=1 Model 1 and 2 gives same Conversion

n>1 Model 1 gives more Conversion

n<1 Model 1 gives less Conversion

Ok.

So this information should be known. And that information is not given by

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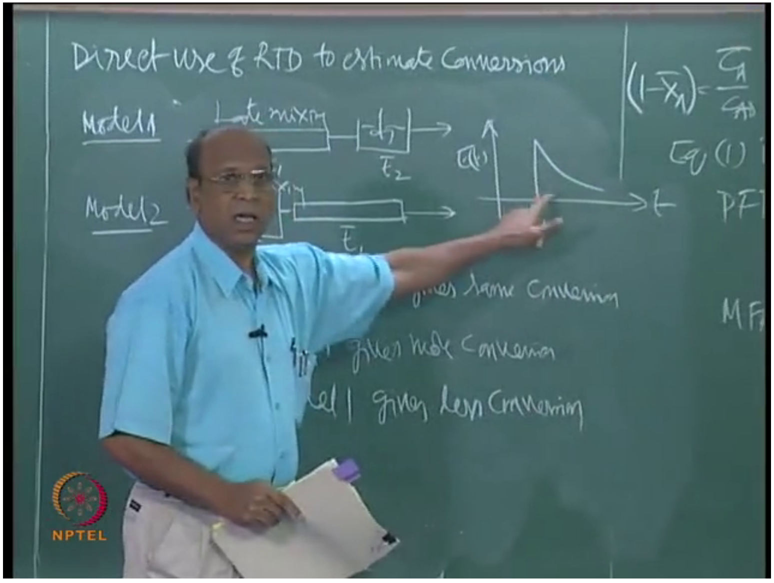

R T D. That is why R T D alone cannot be used

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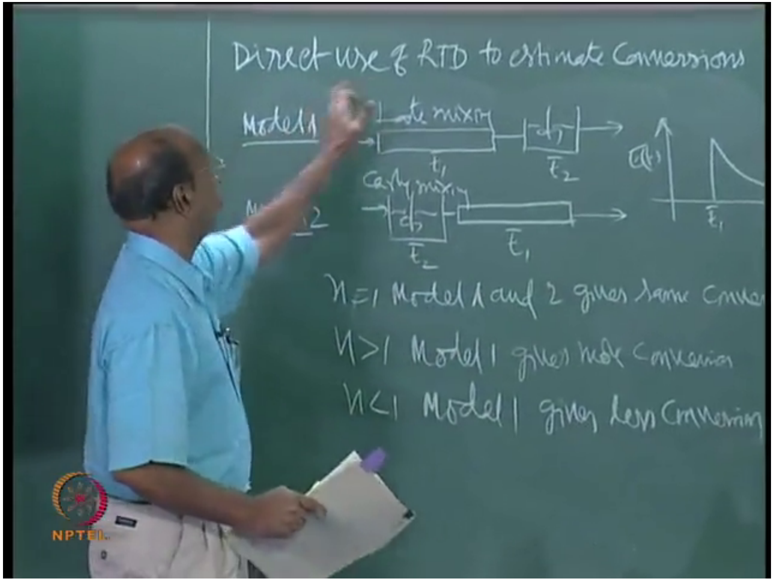

for estimating conversions for other than first order reactions, conclusion number 1. Right.

So now for other, and unfortunately in the industry and also in our profession we have other than first order reactions, many, right? So that is why this, this information we should definitely know. What is the information? Information on late mixing and also early mixing. Oh this one is early mixing.

As I told you

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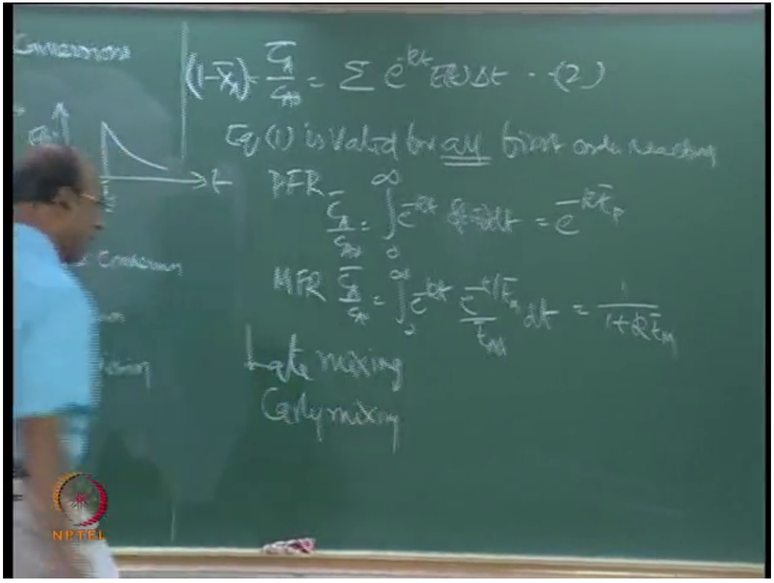

late mixing and early mixing are just vague terms. So that is why now we want to define these mixings, like Ok,

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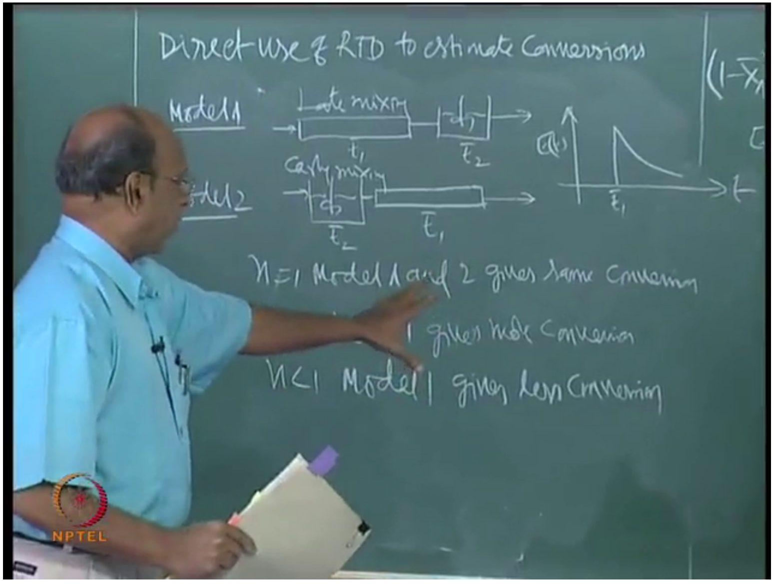

when it is possible to have the latest mixing. So there are two aspects. One is the state of the fluid itself, state of the fluid, Ok,

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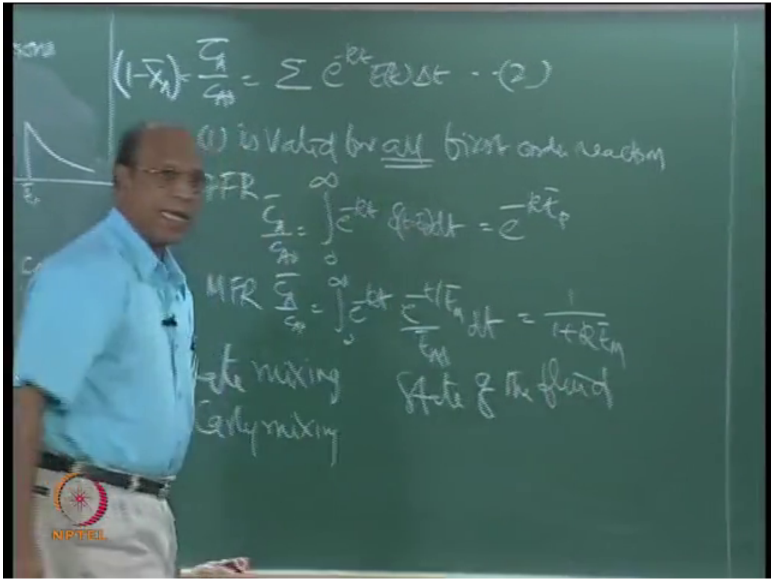

state of the fluid itself can tell me whether the mixing is taking place, latest means you know it is never mixing, Savita. Savita is there? Ok, yeah.

So when we say latest mixing means it is not mixing inside the reactor. After you may break and you may eat and whatever you want, you can do that. Yeah, so state of the fluid

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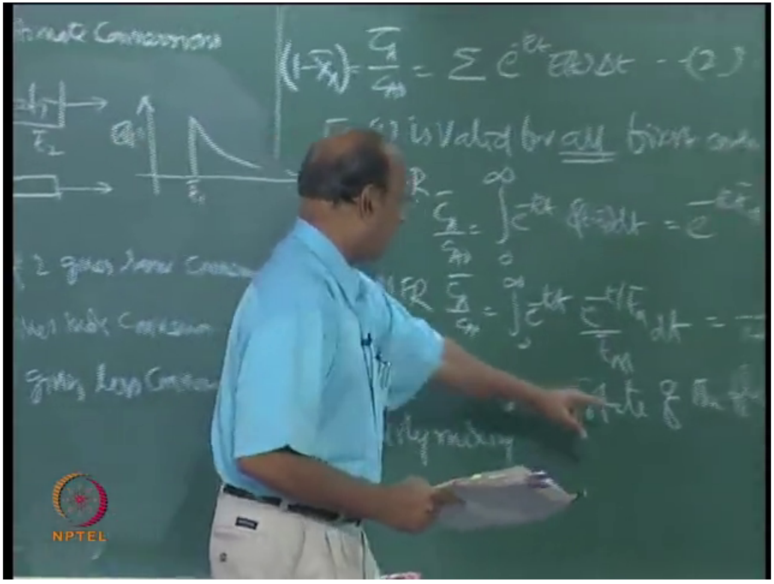

is one parameter. The other parameter is, yeah, the reactor itself. Right, Ok. No, yeah, the reactor itself.

What you said, I will tell, it is not correct, later. Ok. Yeah. State of the fluid itself

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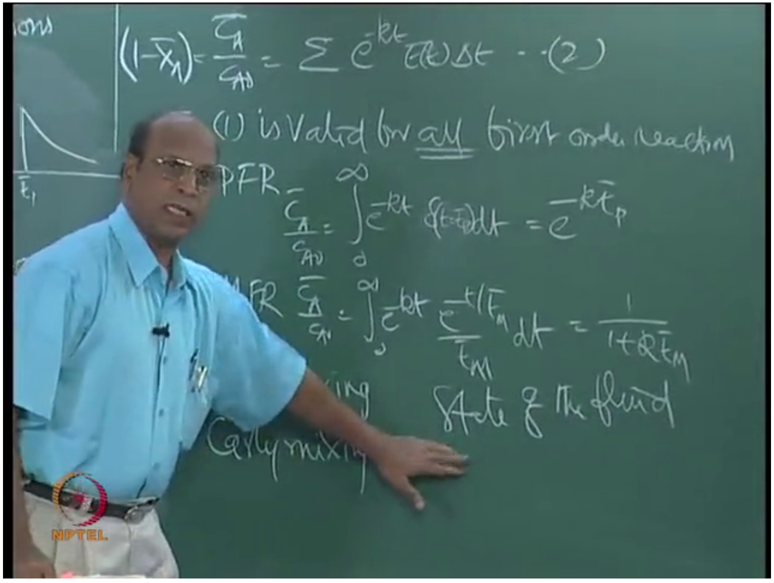

that is one parameter. The other one is how early these things are

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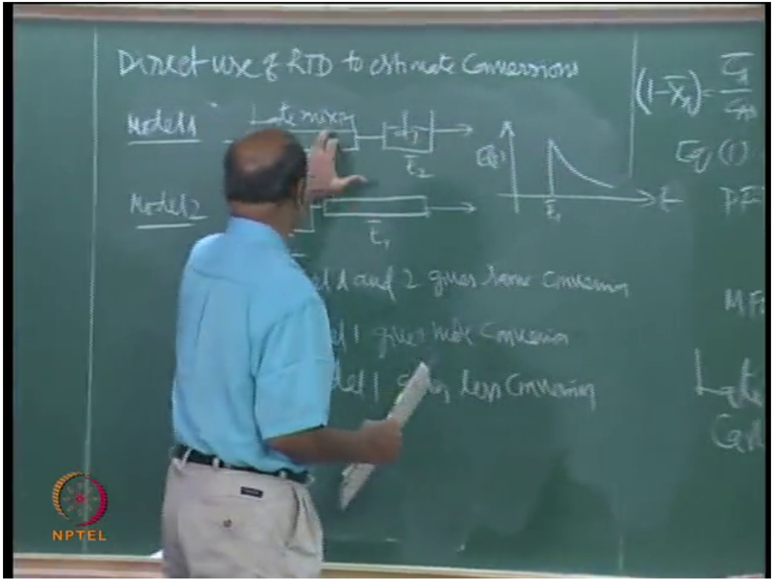

mixing, means how early mixing means it depends on what kind of reactors we have, right. How early when it is mixing means if I take individual molecules together, individual molecules and if I put in mixed flow, then you have earliest mixing possible, right, right? So that is why the first thing what we have to define is

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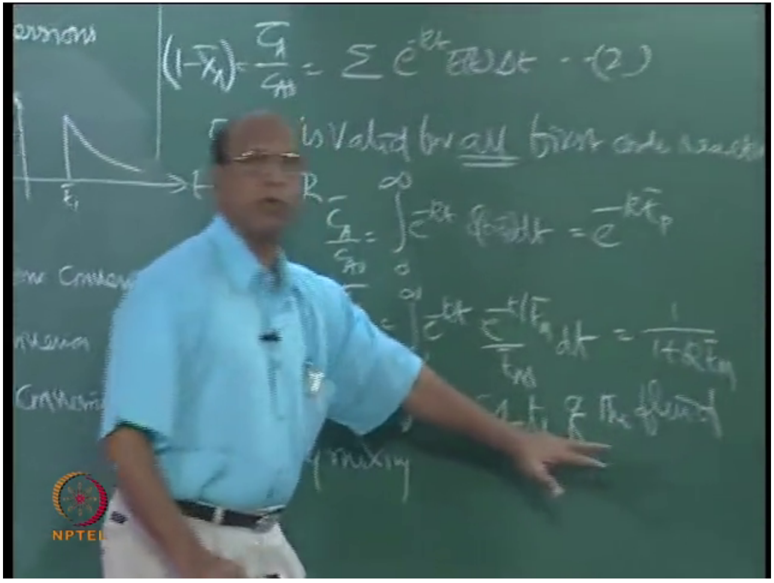

state of the fluid and the second thing what you have to define is earliness of mixing, that means, the earliness what is called that means maximum mixedness that is possible.

Earliness of mixing that means how early it can; these are the two parameters which we have to define. And the state of the fluid tells me whether I have micro fluid or macro fluid,

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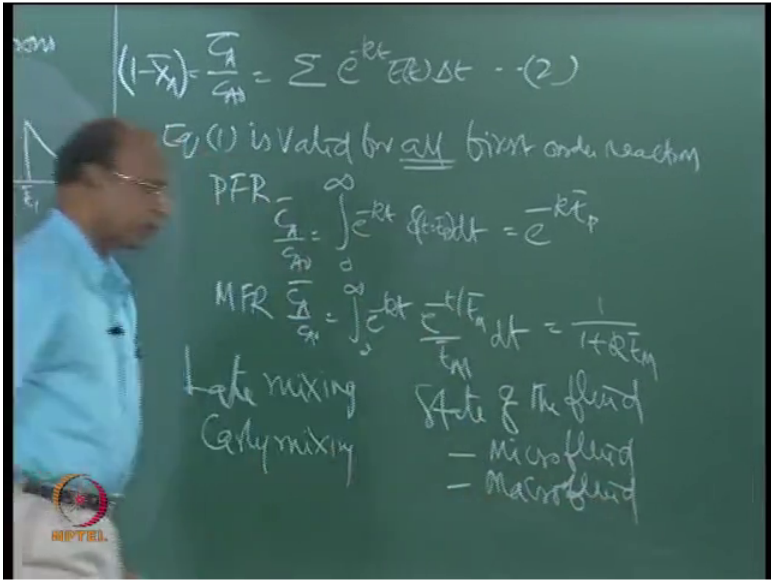

and the definition of micro fluid is the particles are individually capable of mixing, right. They are not forming any aggregates. And any molecule can communicate with any molecule if it is allowed to communicate, right.

But the same molecules, micro fluids, individual molecules, if I put in a plug flow reactor, they never communicate. They just enter, go with all other, you know only that cross-section and then comes out. That is what, right? So that is why we say that first state of the fluid will determine whether I have micro fluid but micro fluid is capable of mixing early, capable of mixing early.

Whereas macro fluid will never mix. So this answer is, the answer to this, late and early, how late and how early, right? The

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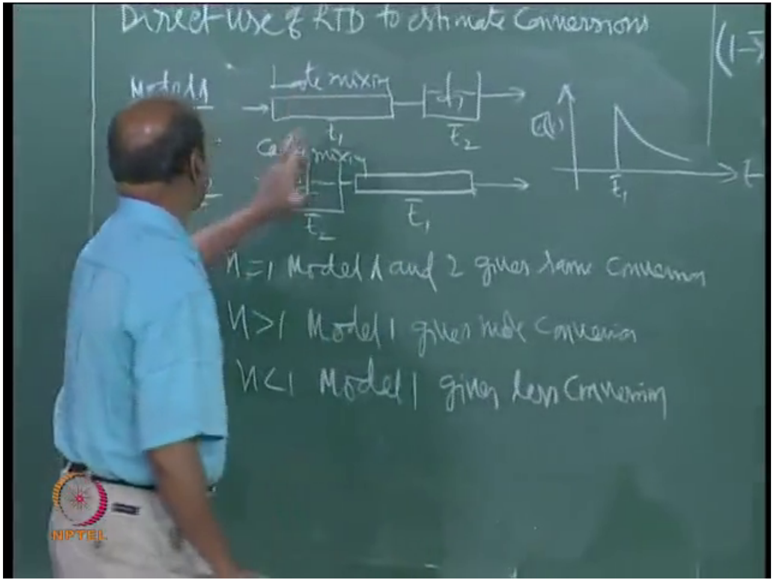
Direct use of RTD to estimate Conversions

n=1 Model 1 and 2 gives same Conversion

n>1 Model 1 gives more Conversion

n<1 Model 1 gives less Conversion

latest one is never mixing. So how do I define that? Using macro fluid.

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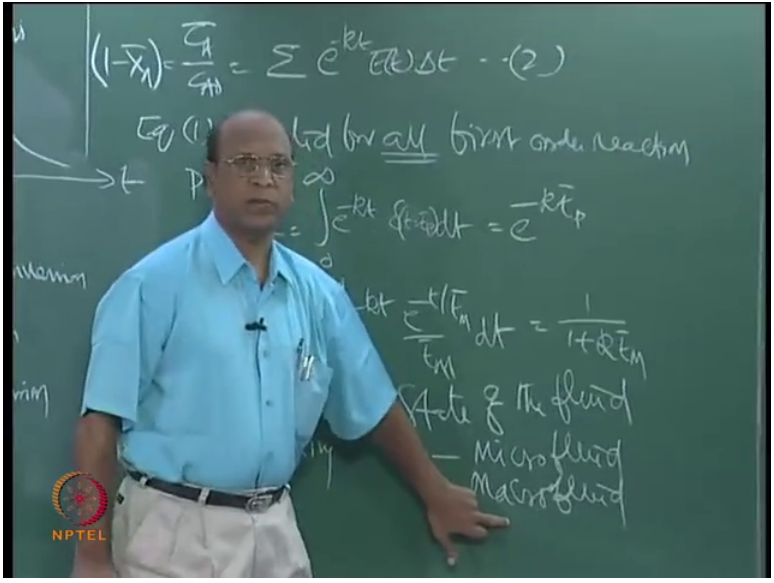
$(1-\bar{X}_A) = \frac{C_A}{C_{A0}} = \sum e^{-kt} E(t)\Delta t \quad \cdots (2)$

Eq (1) ... valid for all first order reaction

$= \int_0^\infty e^{-kt}\,\delta(t-\bar{t})\,dt = e^{-k\bar{t}_p}$

$e^{-kt}\frac{e^{-t/\bar{t}_m}}{\bar{t}_m}dt = \frac{1}{1+k\bar{t}_m}$

State of the fluid

— Microfluid

Macrofluid

Macro fluid are the packet of molecules where I can give no, approximately, which contains approximately 10 to the power of 12 to 10 to the power of 18 moles Ok

And they are independently moving without contacting or without coalescing or without breaking, you know, retaining their own identity from the beginning and then coming out. Now what is the advantage of looking at that? Because whatever conversion is happening, now I know exactly that is happening inside that particular packet.

And this packet is nothing but our batch reactor, Ok, equivalent to batch reactor. So any reaction may take place there, first order reaction may take place, second order reaction may take place, or zeroth order may take place, any order reaction may take place within that particular packet.

That is the reason why we say 10 the power of 12, 10 to the power of 18 because that will give an idea about concentration. So if I have only molecule we cannot say concentration, Ok. So that is the reason why we say, you know that approximate value, good.

So this also we discussed macro fluid and micro fluid.

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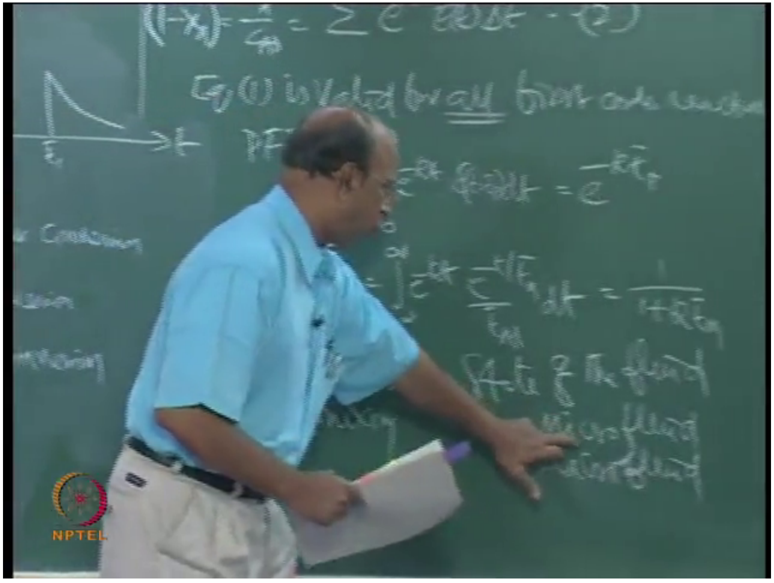

Micro fluid, you know now you have to have the connection. Connection is this tells me early mixing and late mixing.

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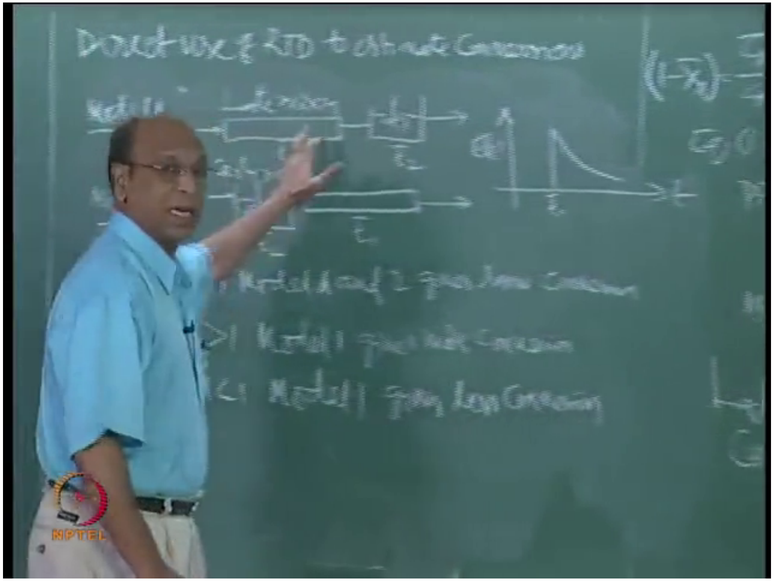

Now vague words like late mixing and early mixing have to be clearly defined. That definition comes from defining state of the fluid.

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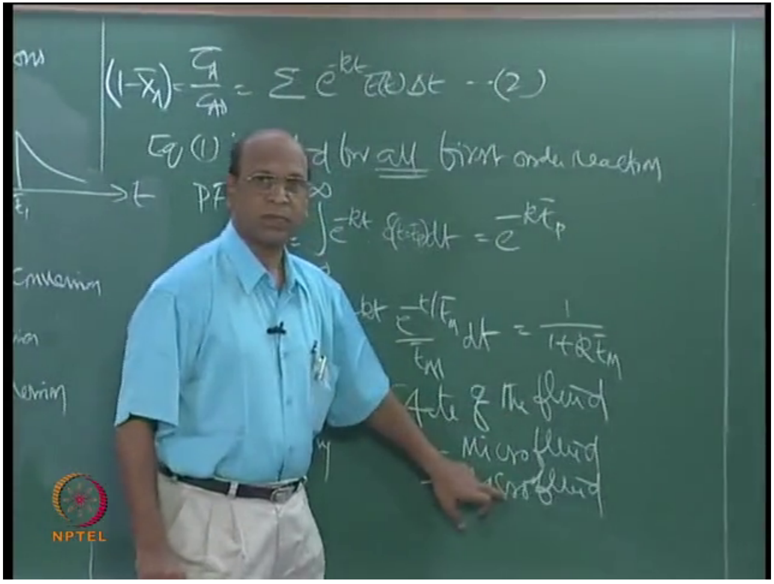

First state of the fluid, Ok, this is one parameter. State of the fluid. And

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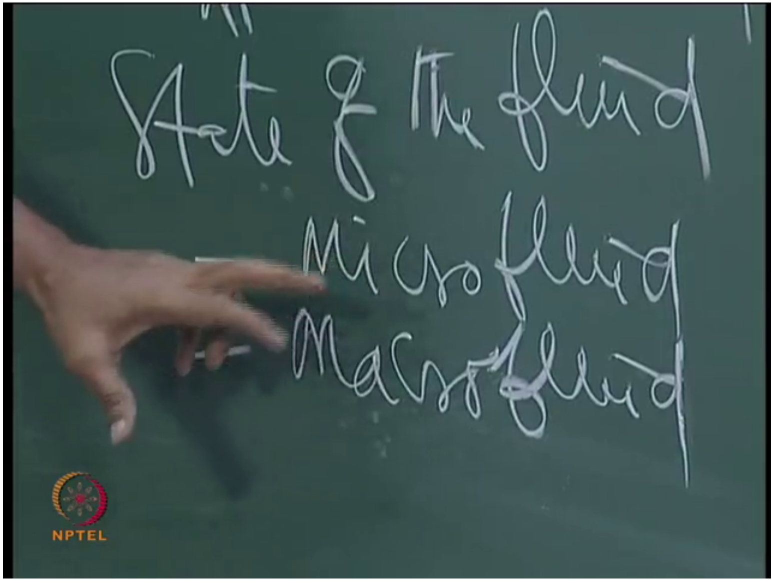

when I take the state of the fluid, what we call this one is degree of segregation. That means

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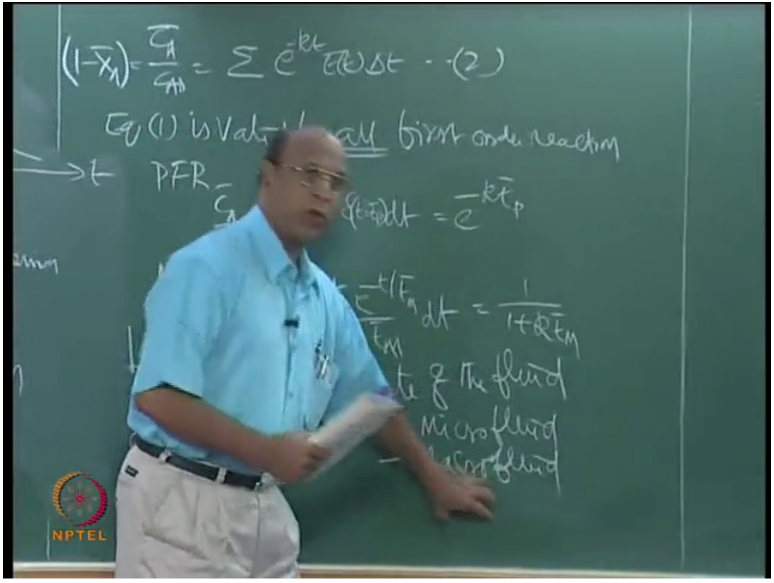

macro fluid is totally segregated, whereas micro fluid is totally mixed. Right. I mean if it is allowed to mix. Capable of mixing. Whereas here, this fellow capable of not mixing, right? That is the extreme, right?

So can you give an example of macro fluid?

(Professor – student conversation starts)

Student: Droplet

Professor: Yes?

Student: Liquid droplet

Professor: Yeah, liquid droplets provided we very strictly follow that no liquid drop is

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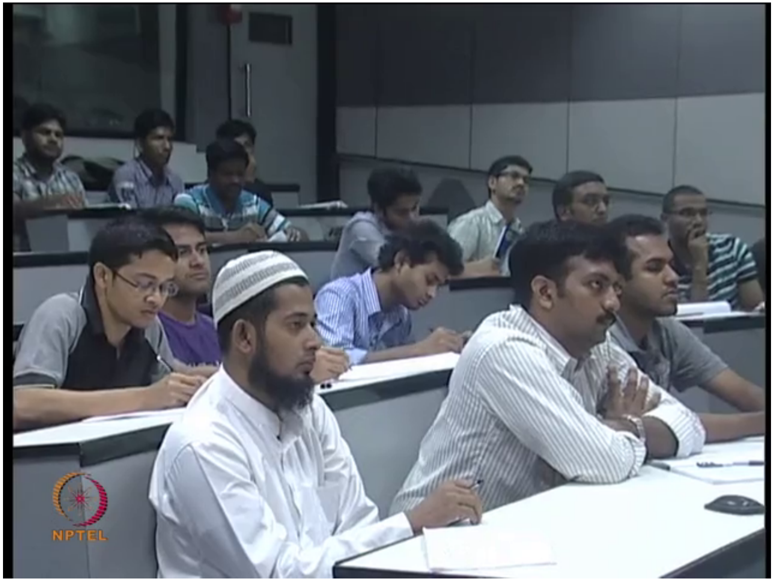

allowed to coalesce with any other liquid drop or even if there is some kind

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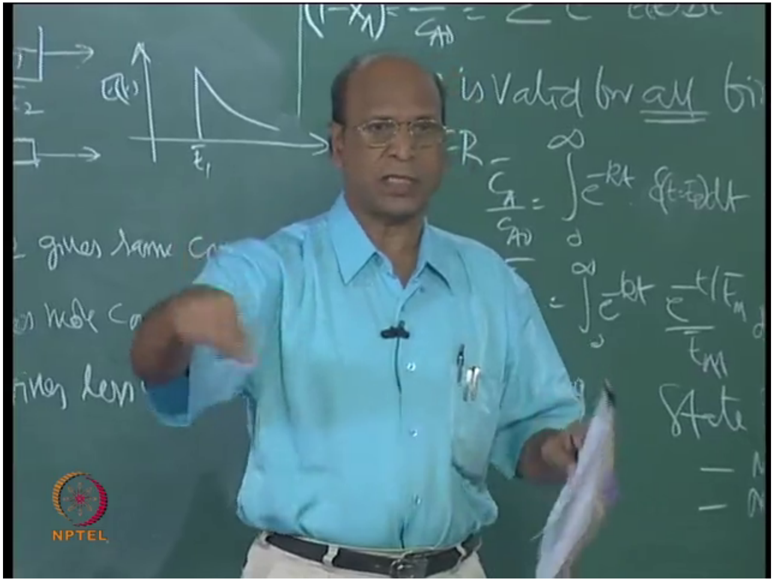

of mixing going on and all that, you know in the overall liquid then even the droplets are not allowed to break, allowed to coalesce and you know those two are important things. And the size is constant during the reaction.

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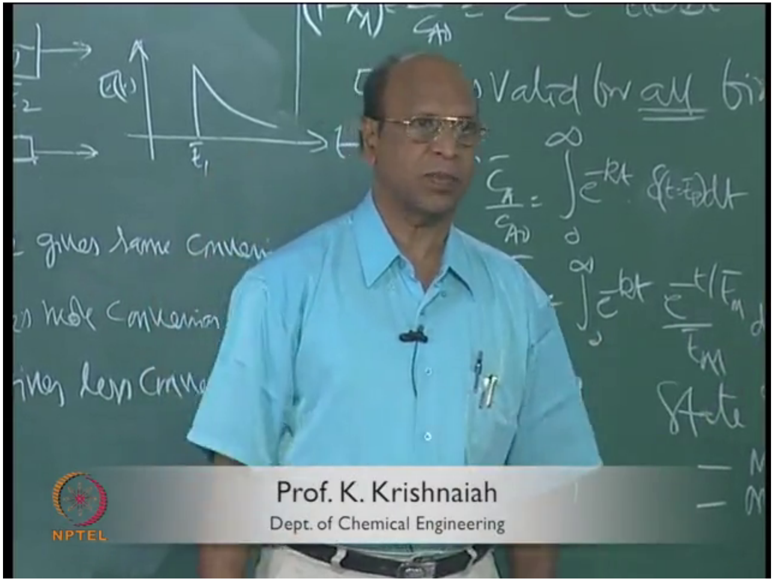

Ok.

(Professor – student conversation ends)

Yeah, I mean in the gas phase reaction slight expansion may be there. But condition is that, within that reactor itself, within that packet itself whatever is happening, happening. Good, yeah. So take care of this late mixing and early mixing, we have now two, two definitions now.

This is micro fluid, macro fluid is giving the state of the thing

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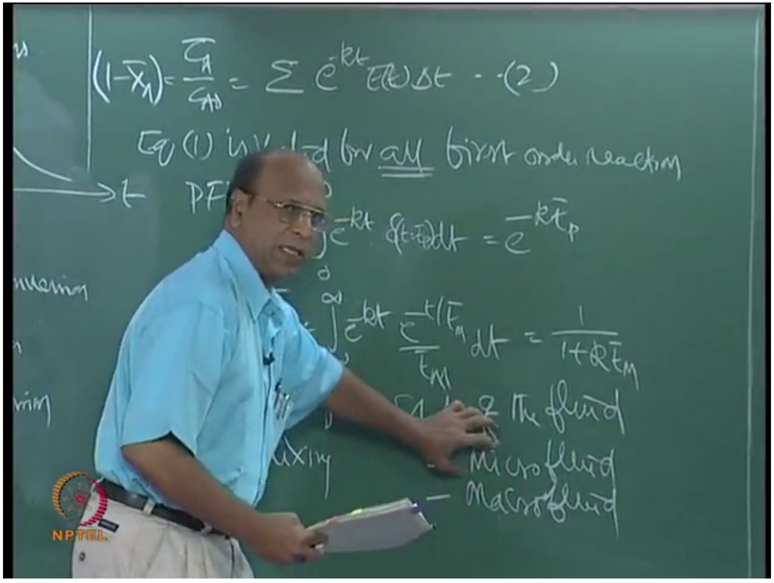

and we also have two more, you know scale of mixing, scale of mixing. Many papers will tell us this is micro mixing, Ok scale of mixing, one is micro mixing and Levenspiel calls this one as degree of segregation. Degree of segregation.

This is definition of Levenspiel book where we have, you know micro mixing. But some papers will give that, you know, it is called micro mixing. But Levenspiel book tells degree of segregation. So when you are seeing the book, degree of segregation means we are talking about micro mixing.

And the second factor is that macro mixing which he calls as earliness of mixing, earliness of mixing, Ok. So actually this macro mixing, earliness of mixing is given by R T D. Yes, what is that?

(Professor – student conversation starts)
Student: 0:26:13.3
Professor: No you have to tell louder
Student: Macro mixing
Student: Level of segregation.
Professor: No, no, see he calls this earliness of mixing

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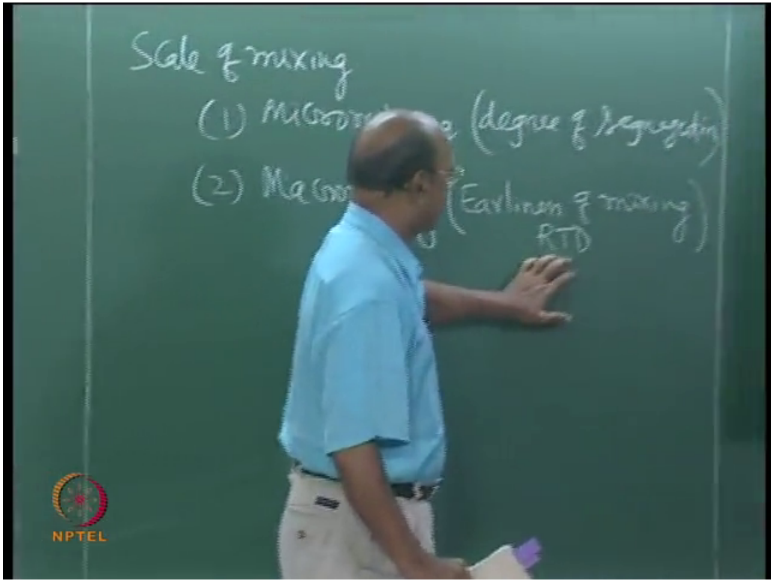

is for macro mixing where macro mixing can represent R T D, right. Yesterday I have drawn the scales also. What was one scale?

Student: Micro mixing.

Professor: This is micro mixing scale, micro mixing scale, that is increasing from this side to this side because here I have segregation. And here I have maximum mixedness.

(Professor – student conversation ends)

Do not confuse with maximum mixedness with earliness of mixing. Maximum mixedness. Yesterday also what I said was right only. Ok. Earliness of mixing, it won't represent that, you know maximum mixedness.

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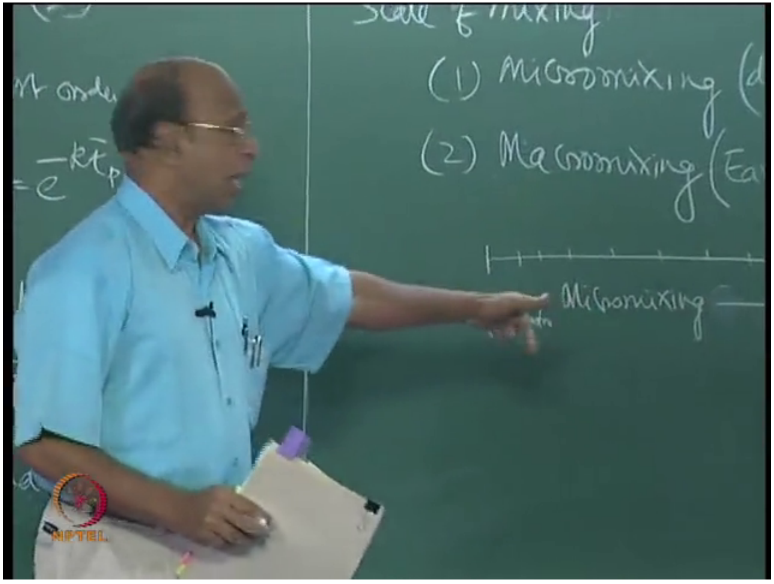

Earliness of mixing is associated with the reactor, right?

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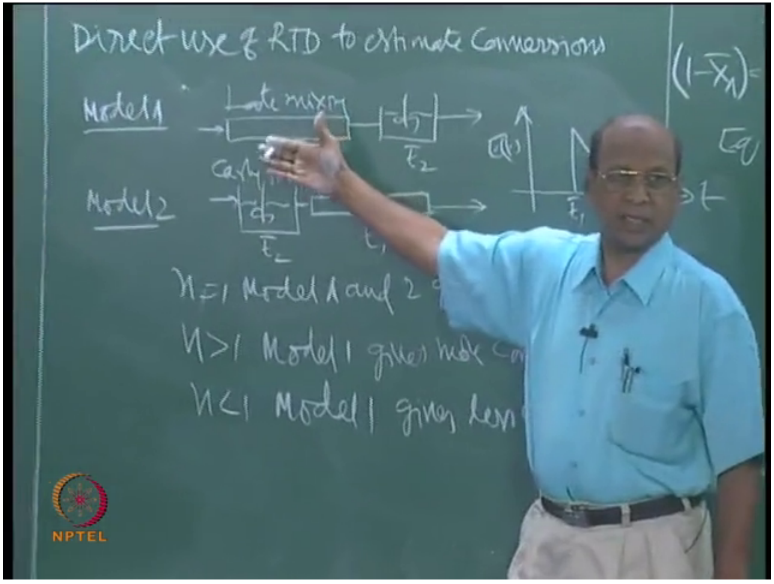

Reactor means R T D comes into picture, right?

So

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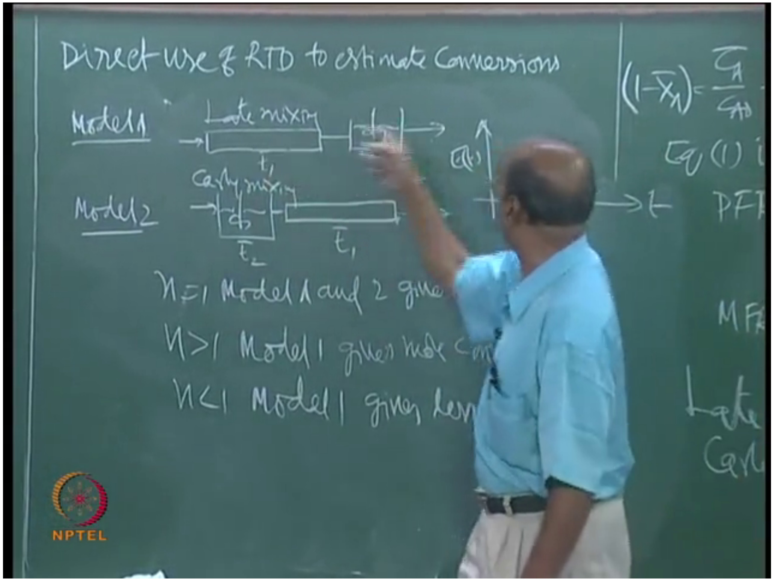

this one has this R T D but this is late mixing, right. And this has early mixing but this also has the same R T D. So these words are used, yeah, earliness of mixing represents, Ok,

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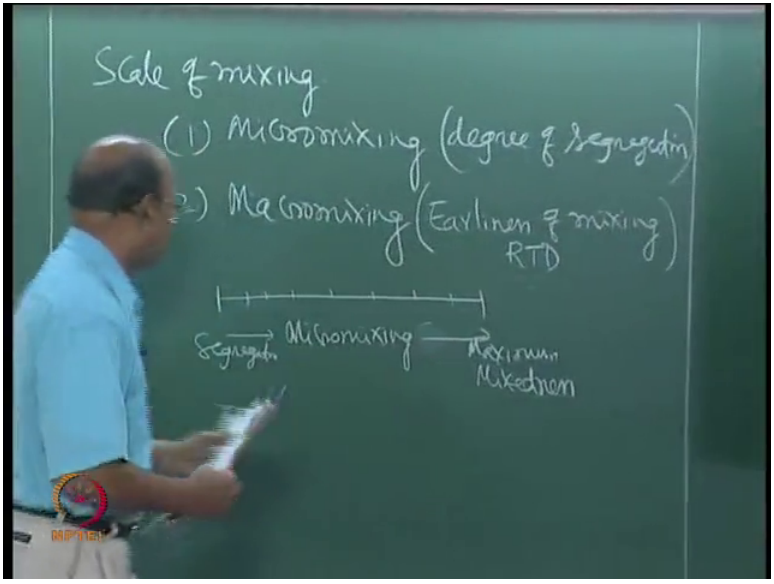

so this is macro mixing

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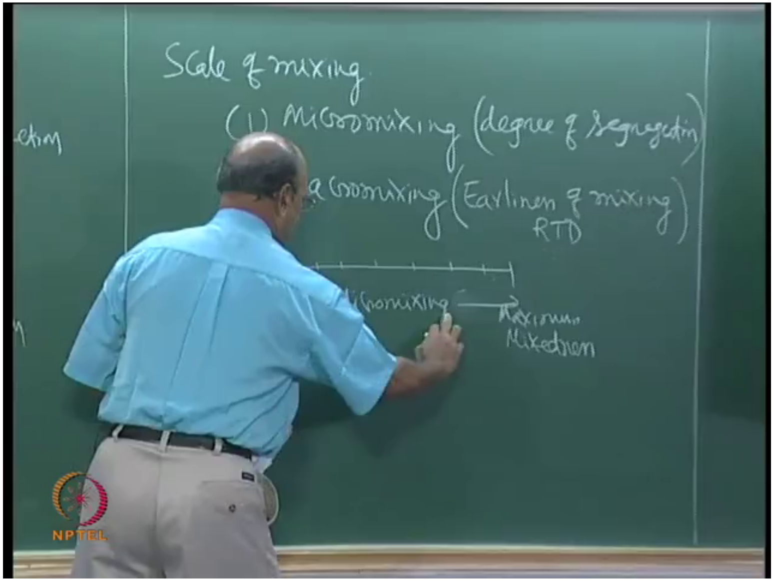

and I have also written there, if you remember, if you see my notes, here I have degree of segregation. This is Levenspiel's meaning, Ok.

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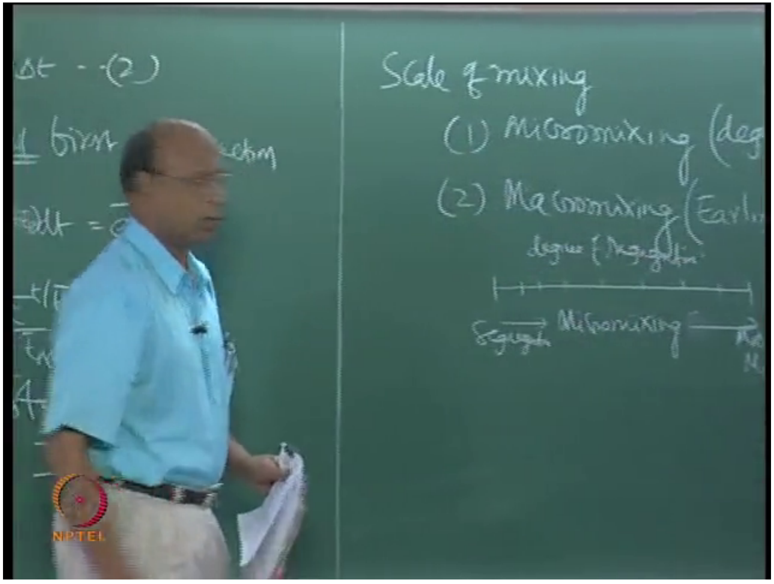

So that is what is the degree of segregation. And here what is the segregation?

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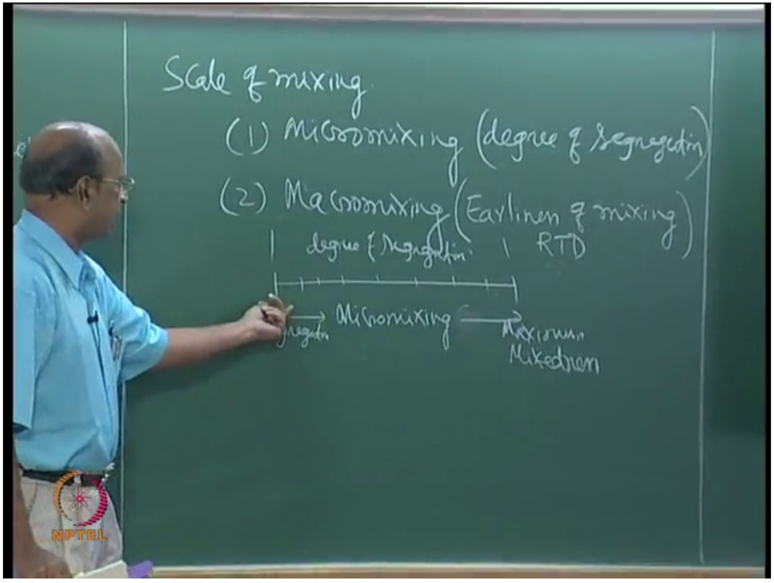

Infinity, maximum. And here we have segregation equal to

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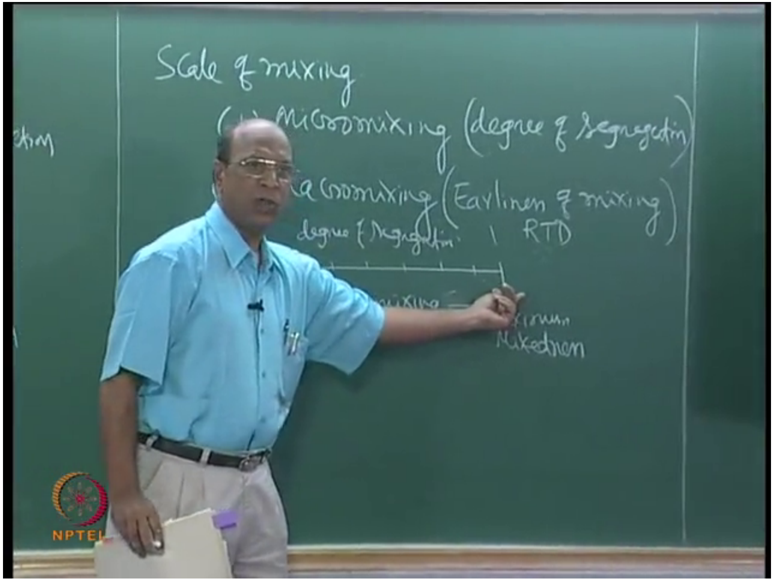

zero. That is what is the degree of segregation what we have. And the other scale also what we have, Rahul you have watch? Can you put that, your watch there? Yeah.

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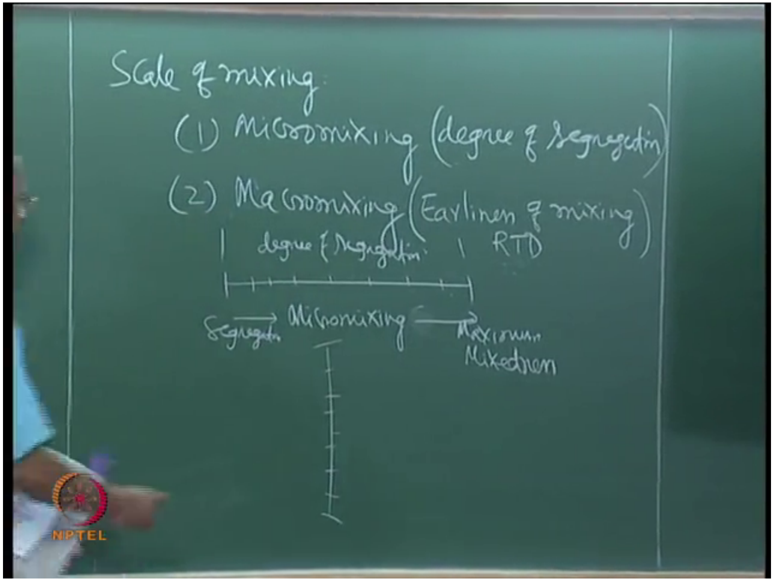

here we have P F, here we have M F. Right that is what. And we call this one as macro, Ok macro mixing. Macro mixing, that is the scale, right and I also wrote here, this represents R T D and I think that side I have written I think Residence Time Distributions.

Ok, this represents, yeah and any way these two are the extreme R T Ds for us where this P F tells me that R T D equal to zero and this tells me R T D equal to zero to infinity, so everything covered. This is zero, that is zero to infinity. So any other system may be intermediate R T Ds, whatever many other systems what we have.

So that is why we can call also, in between we have intermediate R T Ds, intermediate R T Ds and here we have intermediate mixings, here. Intermediate mixings. Ok. Intermediate mixing states, Ok. What do you mean by intermediate mixing states here?

This side, yeah this side I have individual

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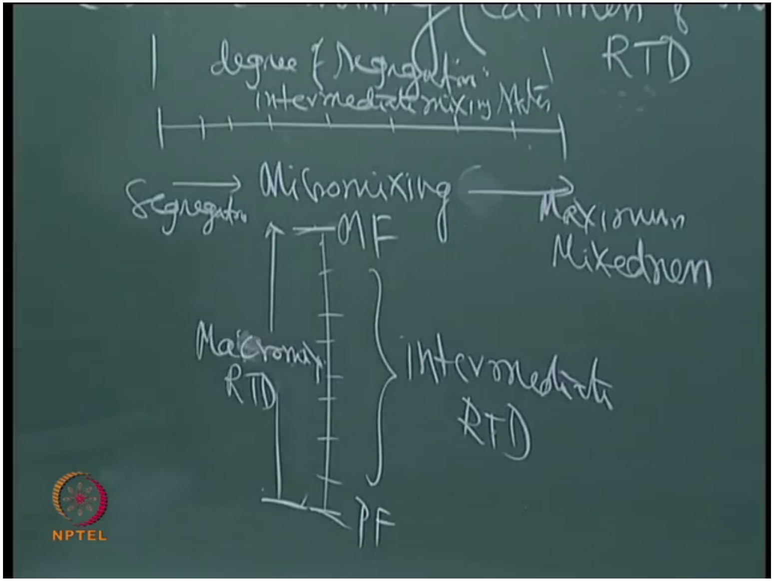

segregated packets, this side I have

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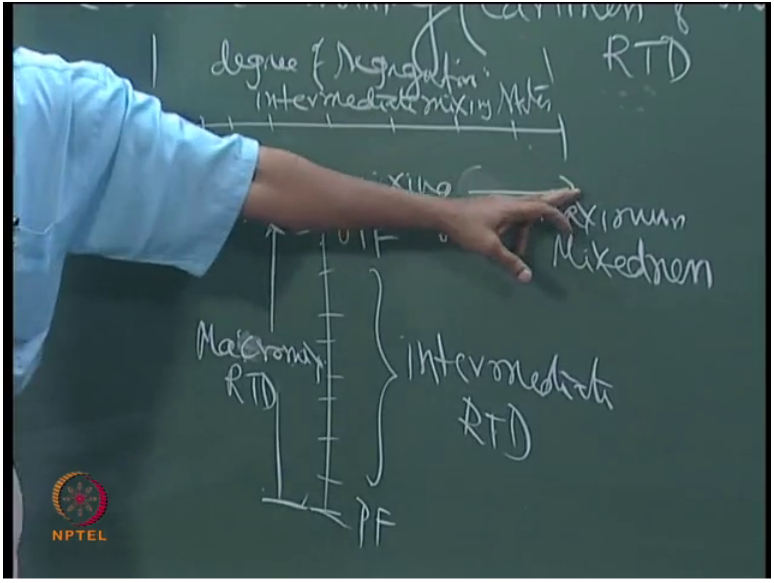

individual molecules. So here

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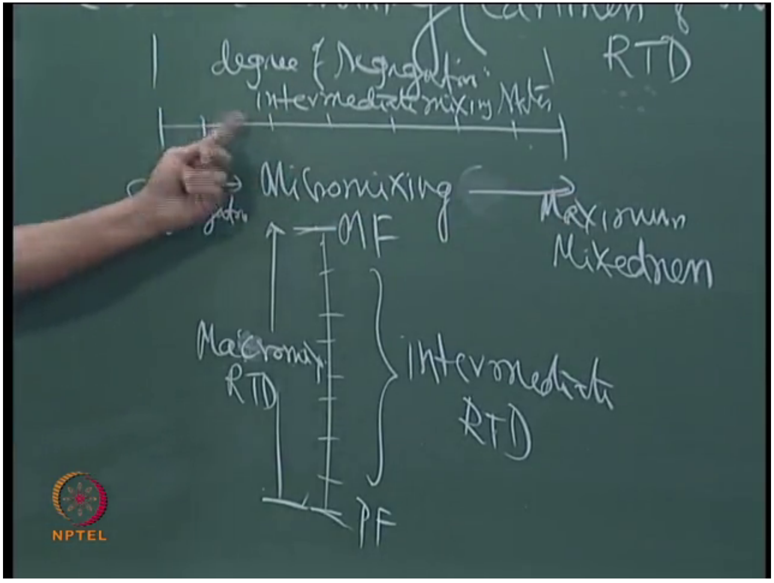

if I look at this point, I have more number of packets and few molecules. At this side if I look

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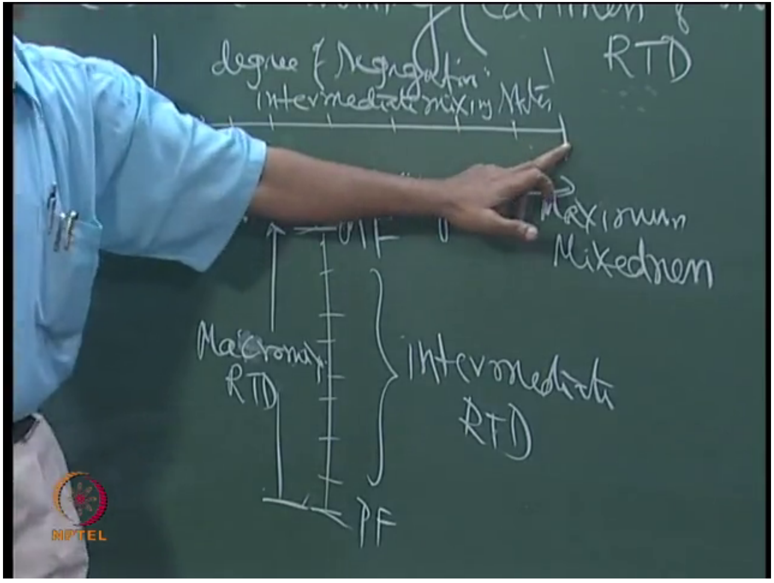

then I have more molecules and few, that is

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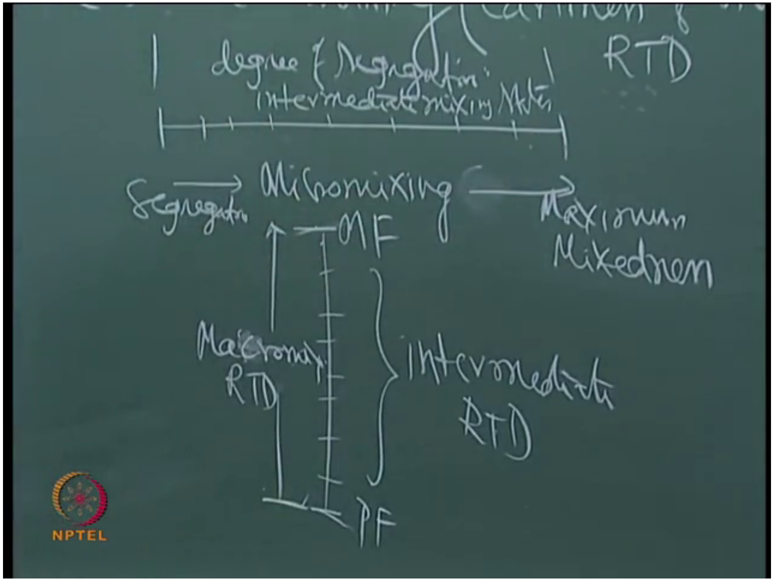

what is the degree of segregation.

And now we do not have any possibility of taking care of them under those conditions. When I have

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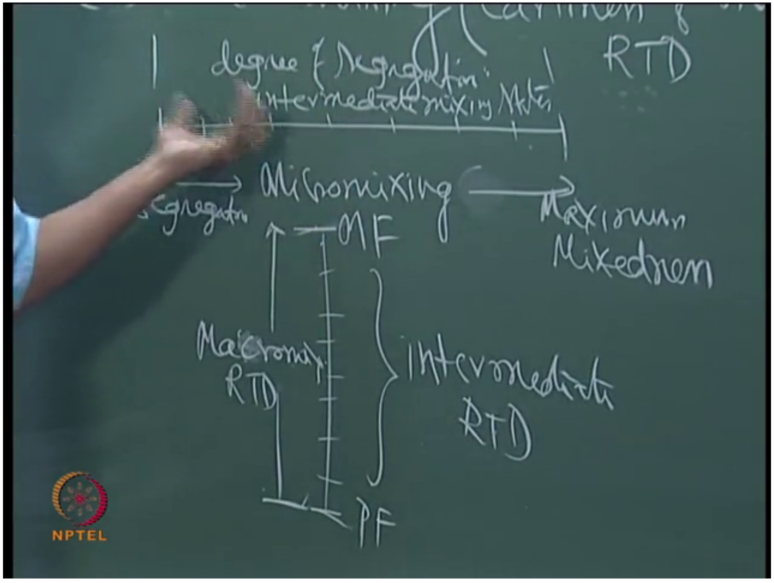

a packet separately and also

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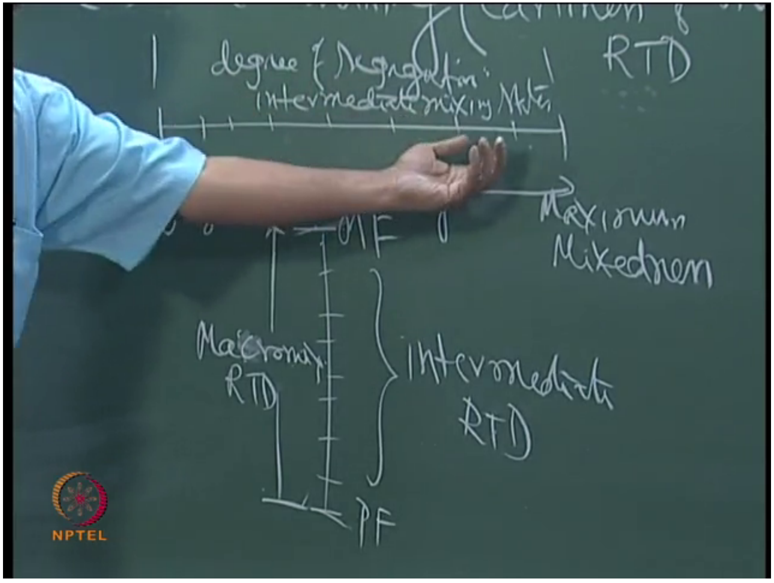

the individual molecules separately I can handle but few packets and few molecules information is impossible to get. How can you get this information from the fluid when you look at that?

If you have water can you find out how many segregates are there and how many individual molecules are there? That itself is very, very difficult. That is why in reaction engineering what we do is, we only find out what is happening at this point, what is

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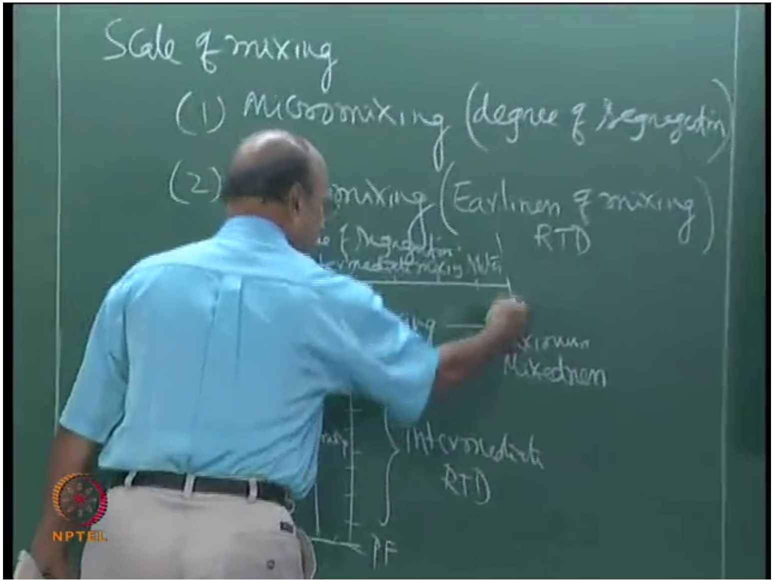

happening at this point and what is happening at this point,

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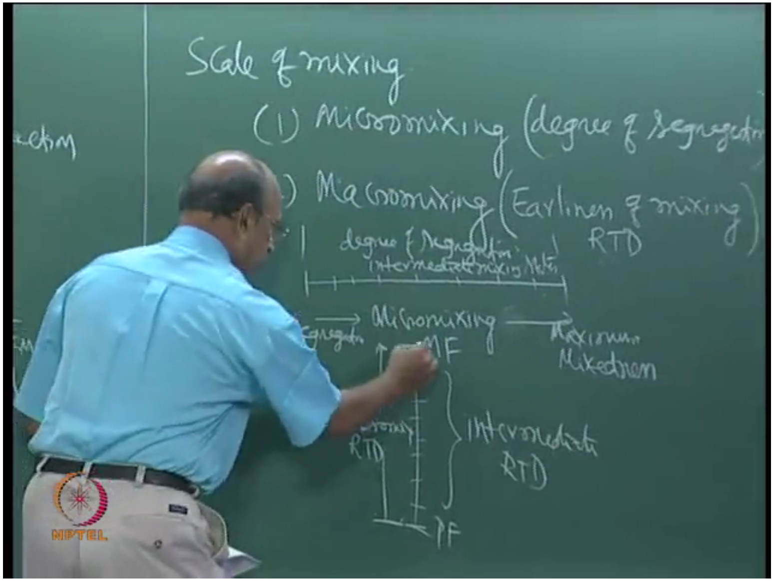

what is happening at this point. We have four cases.

Like I take M F and then find out what is happening with segregation, right? And also M F I will take to

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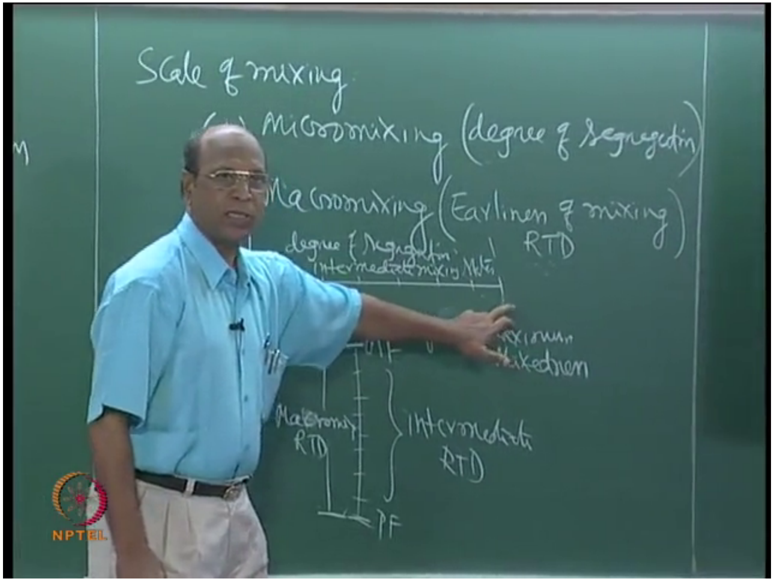

maximum mixedness, two covered.

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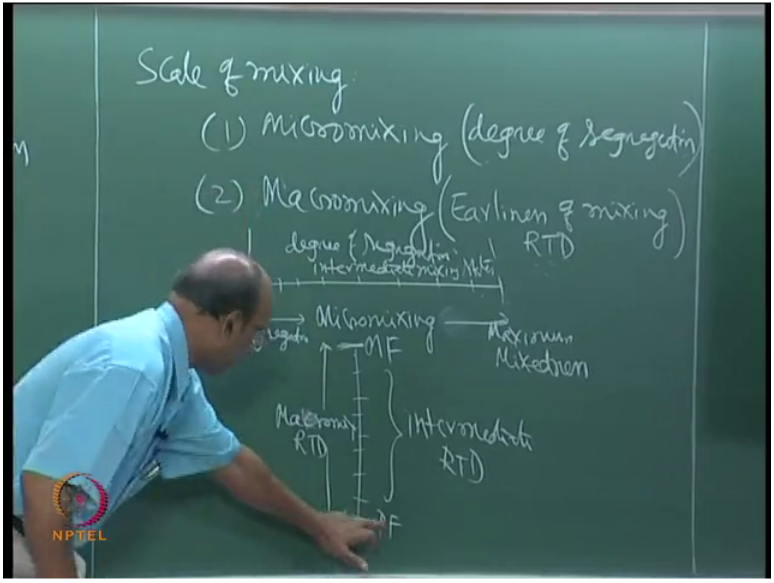

Same thing P F I put here

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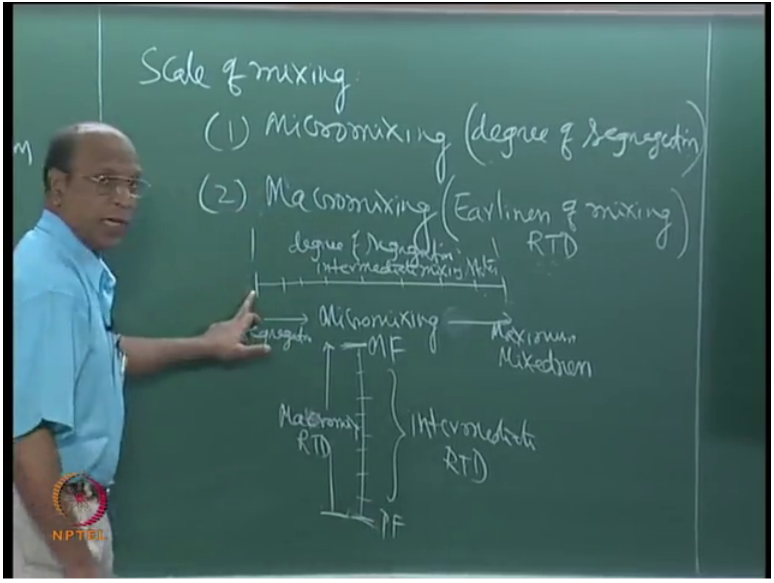

and also P F I put here, right? And maximum mixedness can be obtained by a, what kind of fluid, micro fluid, can be obtained, right? But the moment I put

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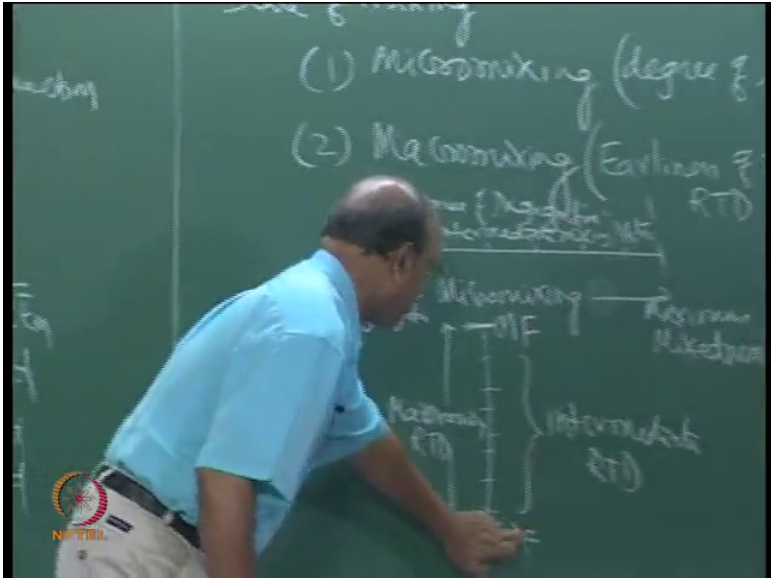

this P F extreme here,

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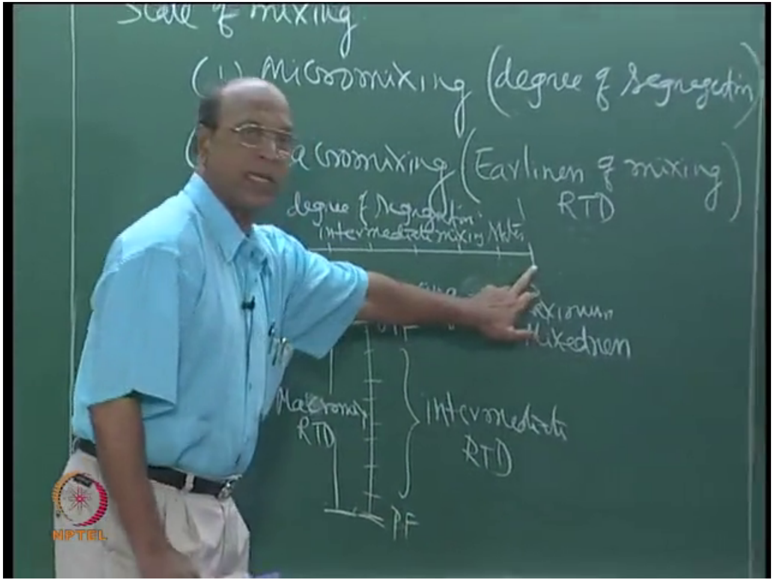

then it won't exhibit any mixedness right?

So that is why please do not confuse with maximum mixedness and earliness of mixing. This is the word he has used for

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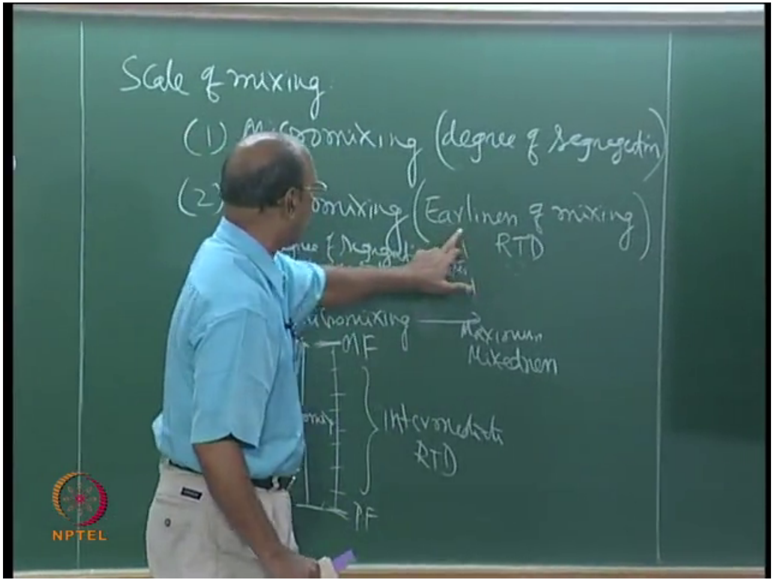

R T D representation which we are calling as macro mixing. That is why macro mixing other people call, and Levenspiel calls this one as earliness of mixing.

And the other one, micro mixing which gives me degree of segregation, Ok micro mixing is called

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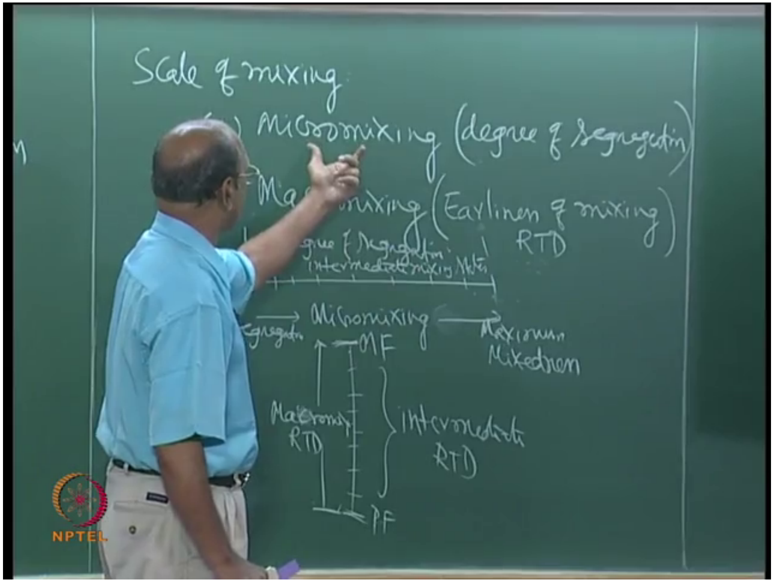

by some other people and Levenspiel calls that as degree of segregation, Ok, good.

So I think this is clear now, the connections are clear. All these diagrams and then scales we have had, the reason is only to answer how late, how early. And that is why this figure is very, very important figure for us. Really very, very important figure for us.

So now what we have to do is let us take this first, one degree of segregation

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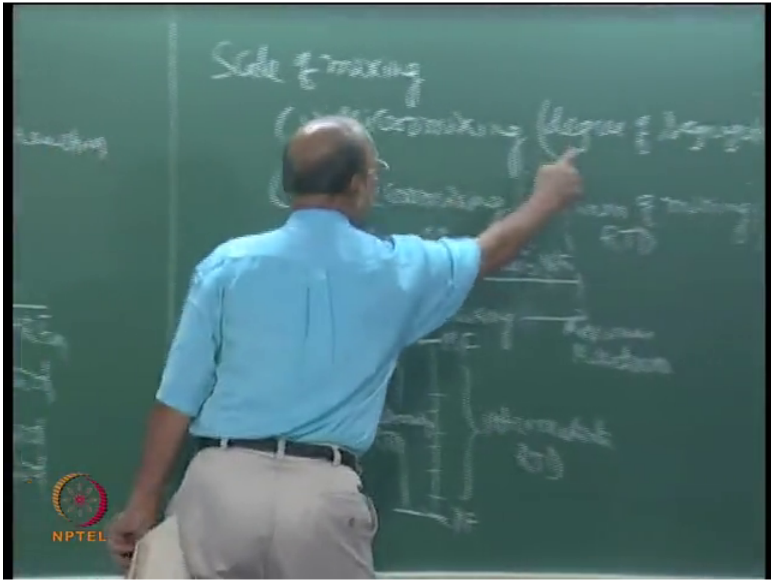

and then discuss quickly. Ok. First take degree of segregation. That means we are now talking of the state of the fluid, right. Degree of segregation, yeah this is segregation here,

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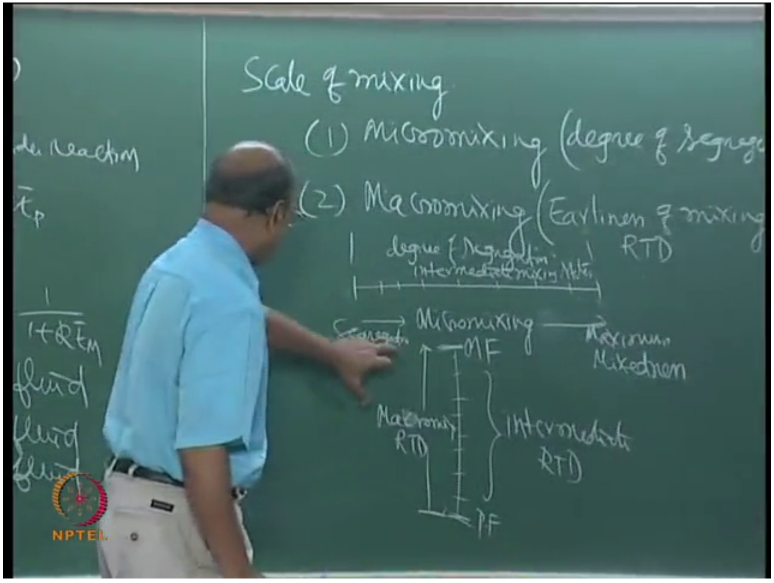

complete segregation is macro fluid. If you want you can also write, macro fluid. Do not write macro mixing.

This is

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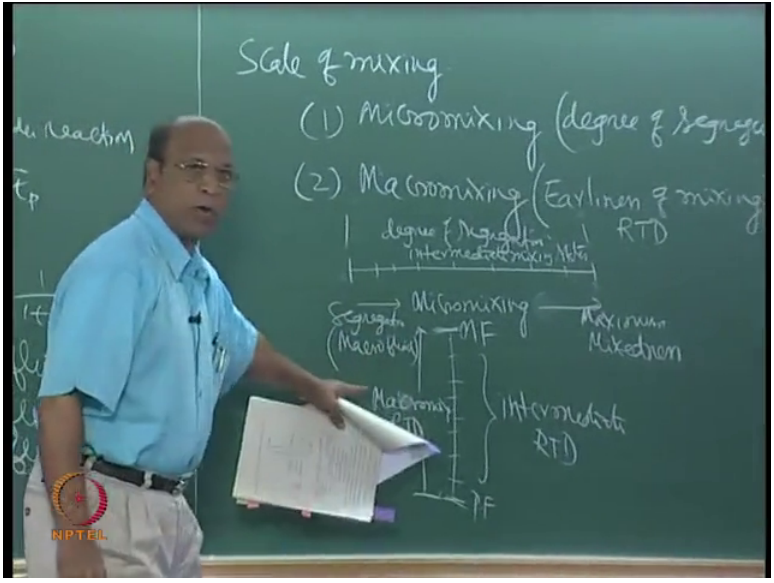

macro fluid and this one is micro fluid, right. In degree of segregation, let us quickly discuss for batch reactor what we have and also P F R and we have M F R, all three, right. Ok good. So now let us take batch reactor first

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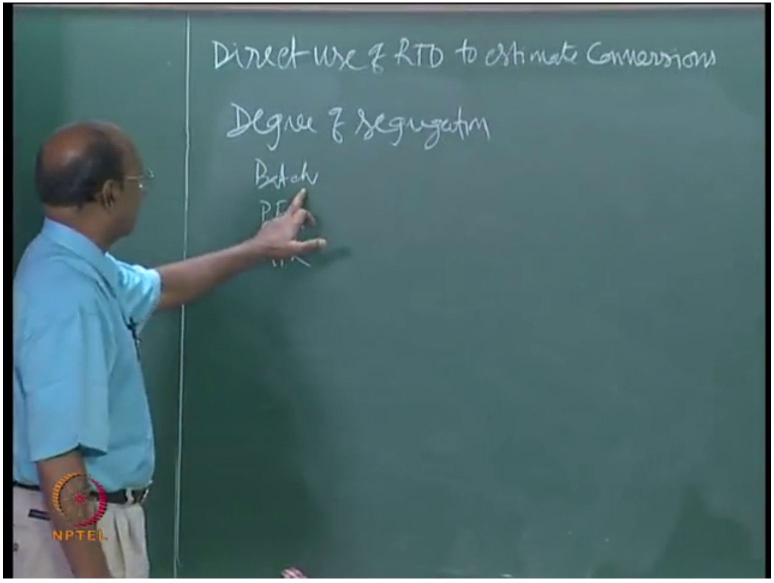

and one extreme is let us first talk about micro fluid, micro fluid means maximum mixedness that is possible, right?

That means I am now putting this point here, right. This extreme P F I am just coinciding with that. That means I have

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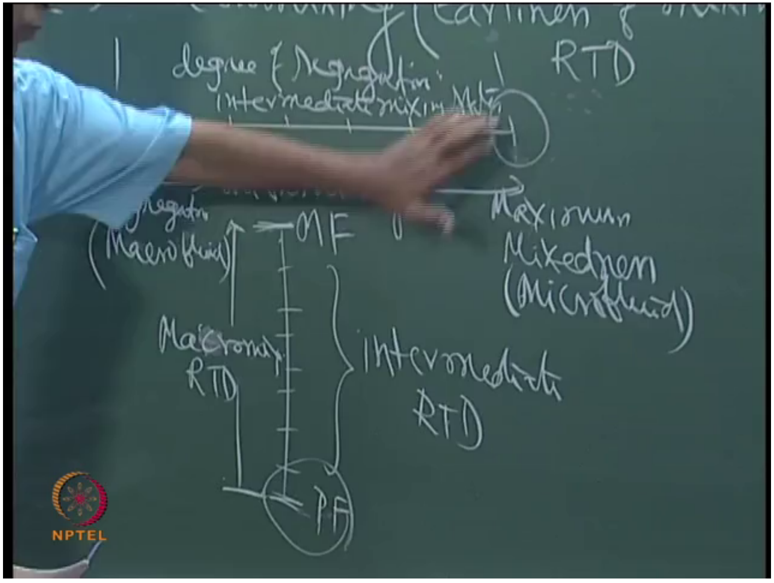

P F and maximum mixedness. Maximum mixedness possible only for

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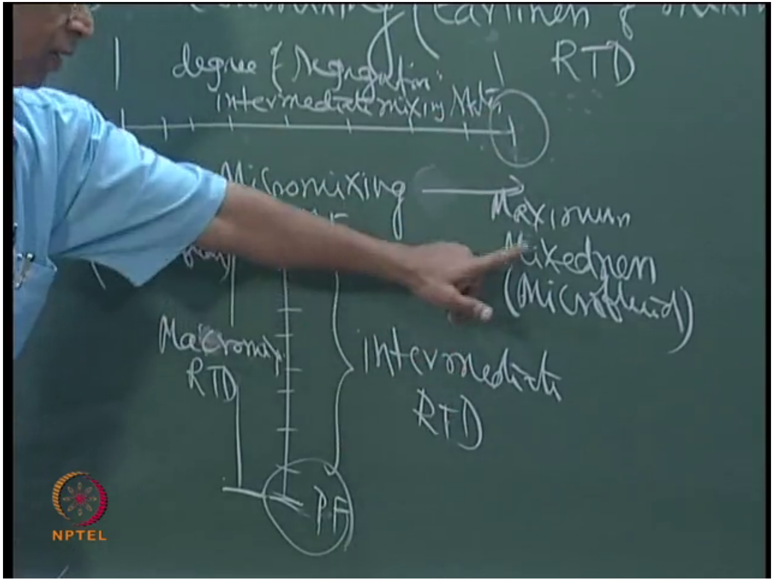

micro fluid. So that means what I am trying to say is we are now talking about if I treat micro fluid in batch reactor what will happen, Ok.

Micro fluid also here, individual molecules,

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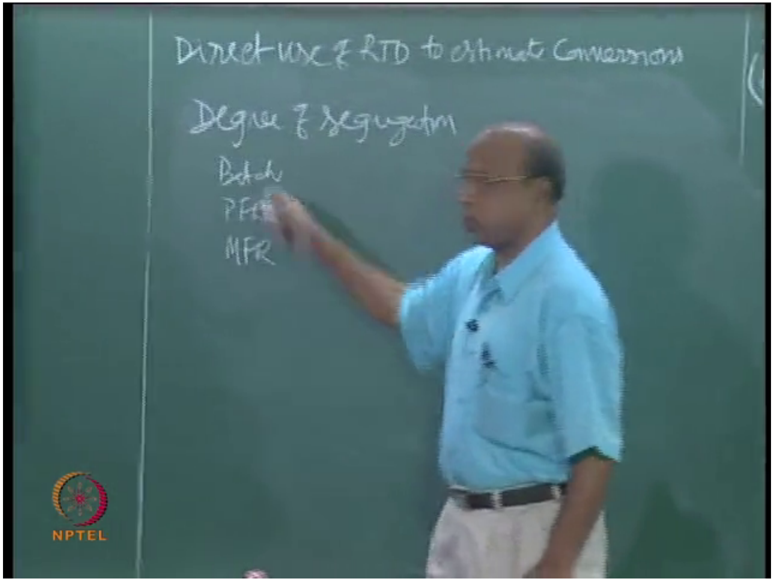

all molecules must spend exactly same time, right, so there is no, already we have the equations for this, for micro fluid, right, micro fluid. And you already know how to calculate concentrations for first order reaction, second order reaction whatever reactions, Ok good.

Now the same thing I also put in P F R

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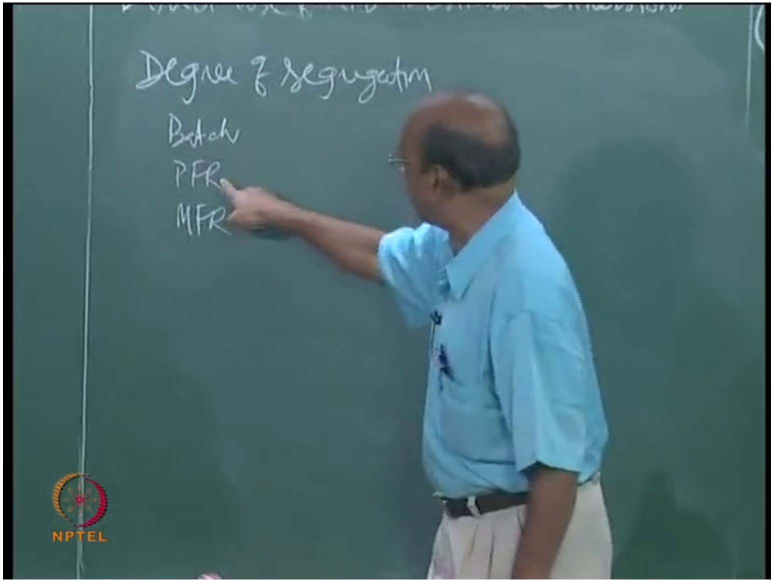

because batch and P F R both are same, right. So here also the molecules individually enter and then exactly spend same time like batch reactor and you also know under those conditions how to calculate conversions for micro fluid.

That is what you have done in your B Tech. That is what you have done in the first few classes here. It is only micro fluid, without knowing we assume. So you have equations for batch reactor and also plug flow reactor and even for mixed flow reactor, right, so all these three.

But I think I am now talking only batch and P F R because this extreme we put here

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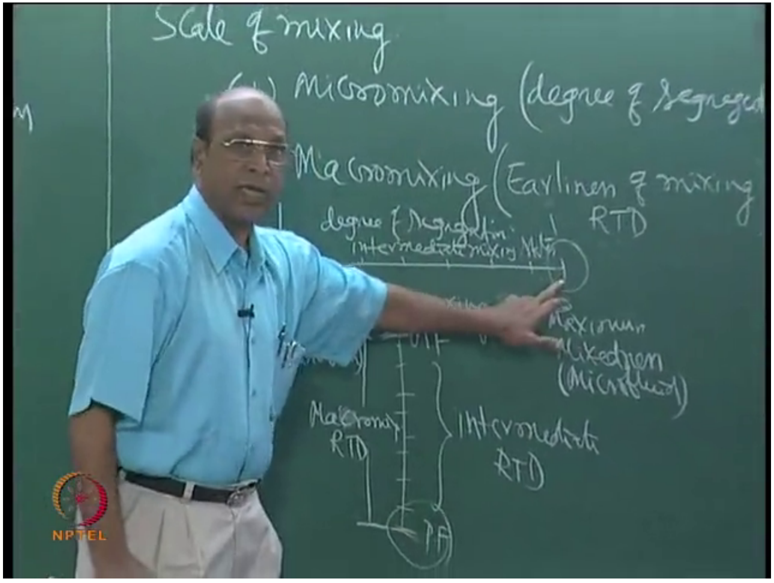

where you have micro fluid because this extreme cannot be satisfied by this macro fluid.

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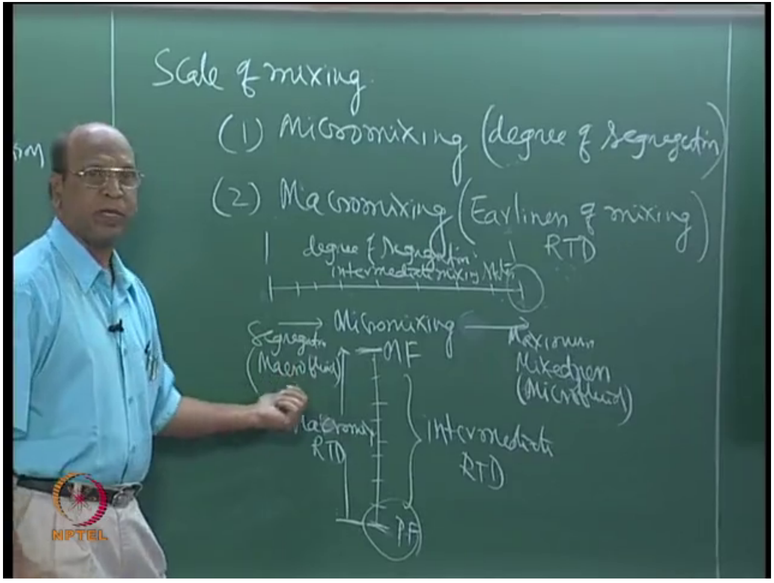

Because here you have segregation. Whereas here, this is capable of mixing, right so at individual molecular levels. So that is why this one.

And now if I take this extreme and then put it here,

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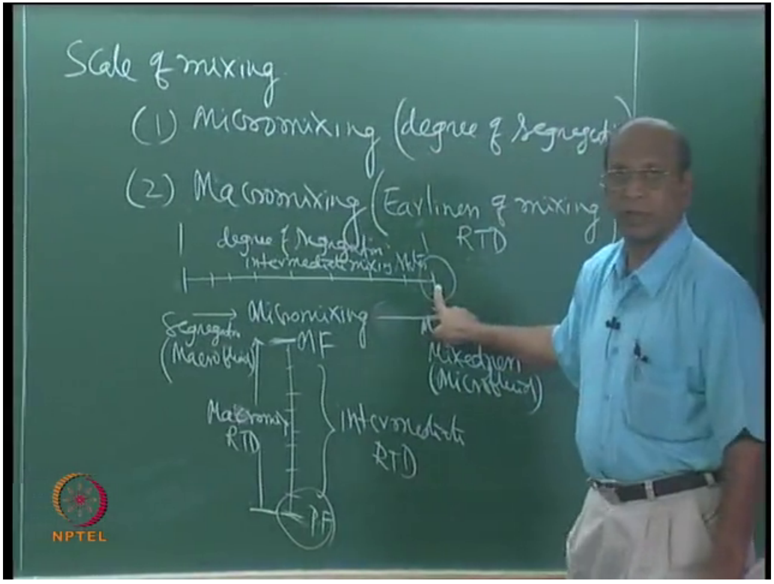

right, P F R, M F R extreme,

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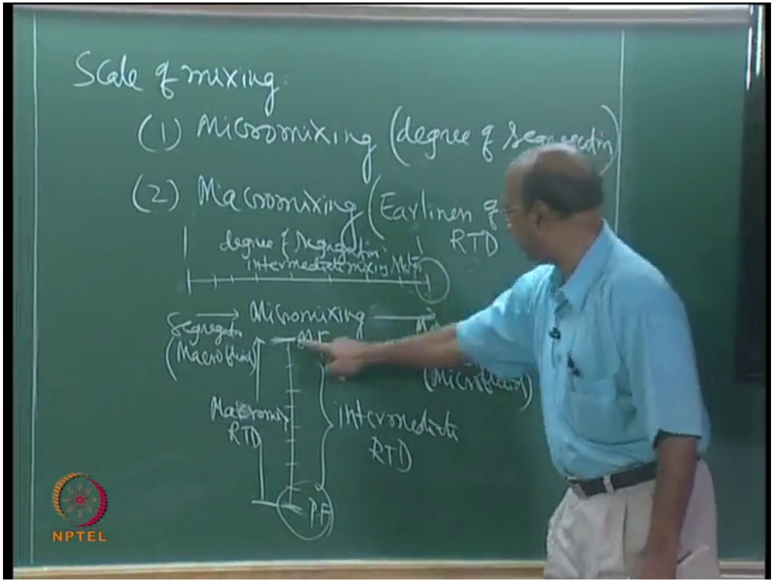

even then you have the equations because individual molecules would be moving and you know how to write the equations, entering, leaving and all that. You have the equations.

So for micro fluid, we have all the equations in the degree of segregation point at this, at this side, where you have micro fluid which is capable of giving maximum mixedness, Ok. Now we have to talk about only segregation.

Now same thing, Ok so that means P F R I will put here and also batch reactor is P F R again and this one, mixed flow also we will put it there. First let us take batch and P F R, which are, both are same, right because Residence Time Distribution equal to zero. Now when I use batch or P F R,

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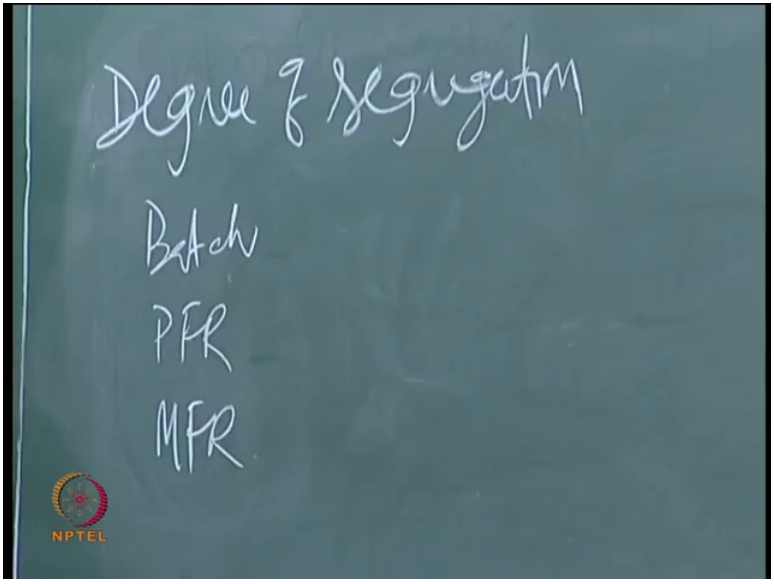

Degree of Segregation

Batch

PFR

MFR

like individual molecule here also, each and every particle, Ok each and every packet should spend exactly same time, so.

You know how to calculate, that means now even this, the packets also behave like individual molecules because individual molecules also spending exactly same time. So that is why if you have batch or P F R and you have micro fluid or macro fluid, does not matter, you have the same equations valid. Because it depends on the residence time.

Residence Time Distribution equal to zero even if it is individual molecules and also Residence Time Distribution equal to zero even in the molecules inside that packet, correct no? Each packet is spending exactly same time. So both are same.

So that is why batch and plug flow gives same conversions for macro and micro, what? fluid dash dash. So we do not have to worry about that. Now we have to worry about

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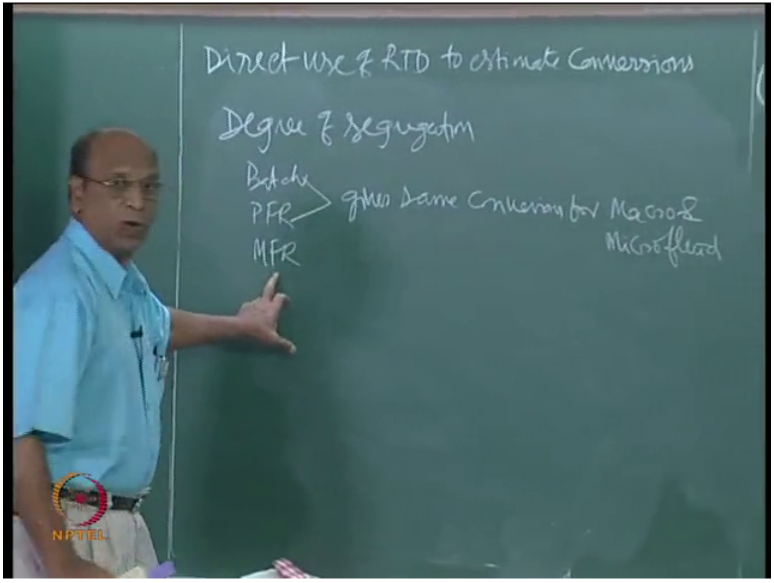

Direct use of RTD to estimate Conversions

Degree of Segregation

Batch
PFR > gives same conversion for Macro & Microfluid
MFR

only this fellow, M F R. M F R also as far as micro fluid is concerned, we have the equations. Micro fluid, equations available, available B Tech. Ok good, I mean you have done that definitely, yeah.

So now for

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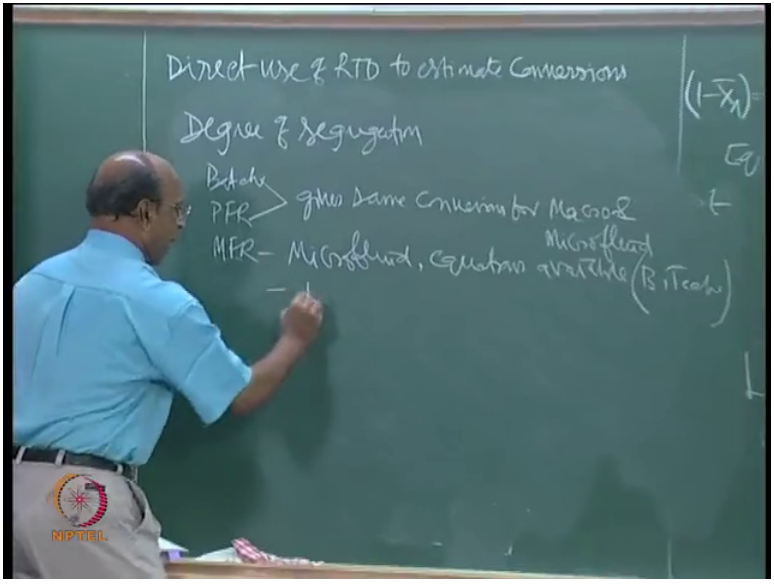

Direct use of RTD to estimate Conversions

Degree of Segregation

Batch
PFR > gives same conversion for Macro & Microfluid
MFR – Microfluid, equation available (B.Tech)

$(1-\bar{X}_A)=$

macro fluid, we are discussing now. Macro fluid is nothing but segregated fluid and when you have this mixed flow and now what you have to imagine is, so these are the packets coming. They are supposed to be equal size, Ok. We have stirrer and also packets are coming out, Ok. Mixing is taking place,

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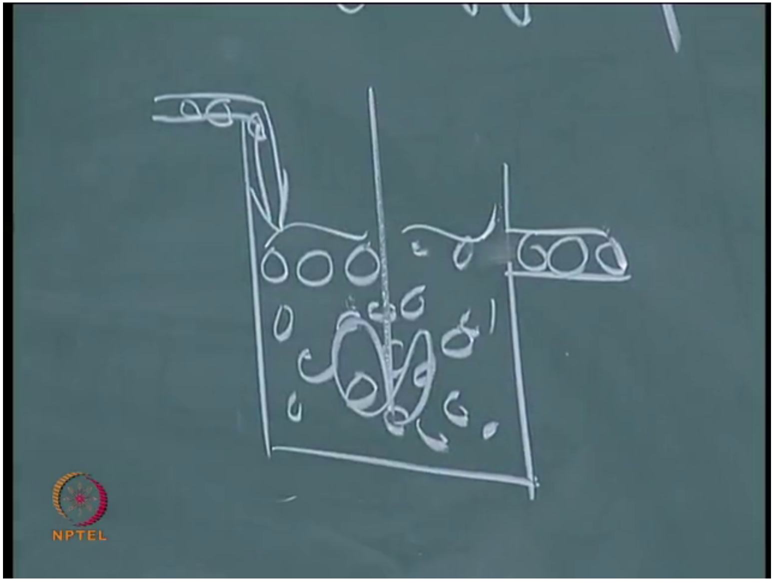

good.

So now when I look into the macro fluid, this is macro fluid, so continuously the, the packets are coming inside, right and then continuously the packets also coming outside but if I look at the packets here, if I take 100 packets, just as an example, in that 100 packets what I see is packets which have just now entered or packets which have stayed overtime because distribution is possible from zero to infinity.

So what I do, I break all that because, and each, the beauty here is that each

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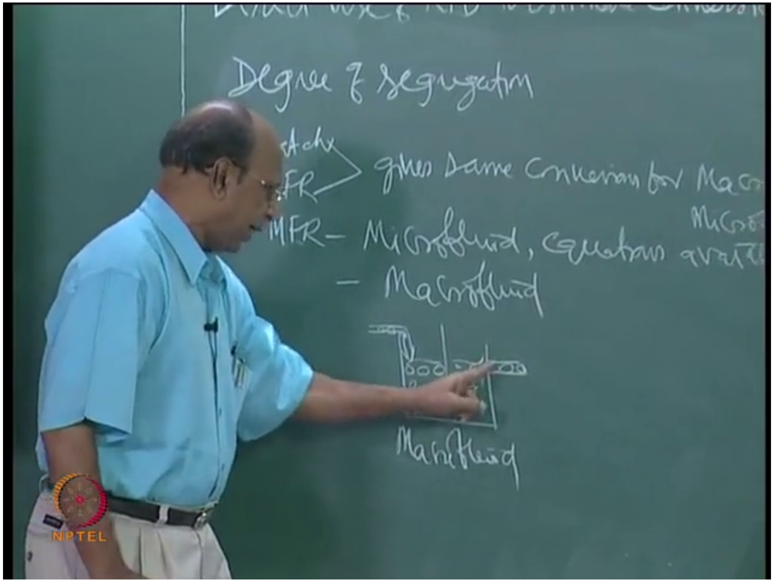

element, each element here, each packet here will have the same conversion because depending on its own residence time inside whether I have first order, second order, third order because whether late mixing or early mixing will not come into picture for the, at molecular level.

Late mixing, early mixing will not come into picture here because the only that packet inside that we have the sufficient mixing to, for the reaction to take place because all the molecules are communicating within that.

But if I compare two packets, one would have spent 1 minute, another would have spent 15 minutes. So conversion in this is different and conversion in the other one is different. So what we have to do there also is, exactly the same equation what we have written for batch, Ok, batch that means now I have to, yeah, in effect what I have to tell is I assume segregated fluid now the conversion depends only on the amount of time that is spending inside the reactor.

And how do I get that information? From R T D and from kinetics inside that packet, right. So that is why the equation that we have to use here is for segregated flow, same balance we can write, C A bar by C A naught equal to zero to infinity C A bar by C A naught batch E t d t.

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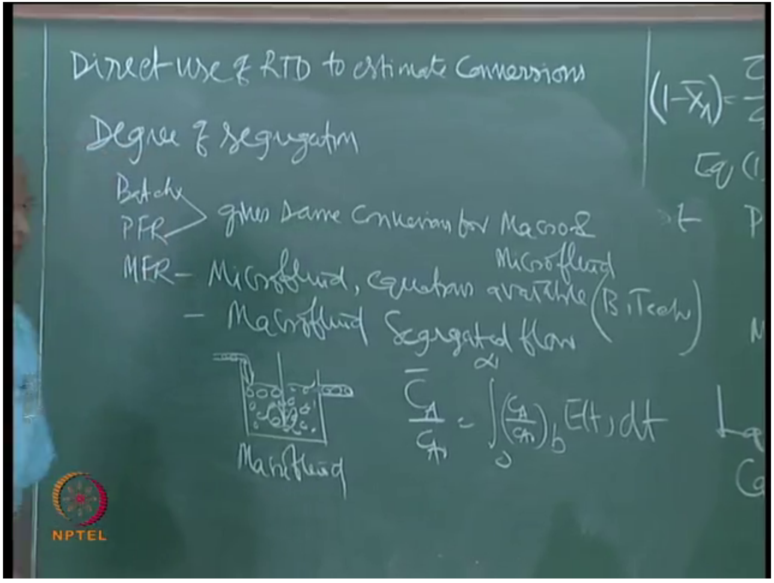

Direct use of RTD to estimate Conversions

Degree of segregation

Batch
PFR > gives same conversion for Macro & Microfluid

MFR – Microfluid, equations available (B. Tech)
– Macrofluid Segregated flow

$$\frac{\bar{C}_A}{C_{A0}} = \int_0^{\infty} \left(\frac{C_A}{C_{A0}}\right)_b E(t)\,dt$$

This is for segregated flow. Please remember that.

And

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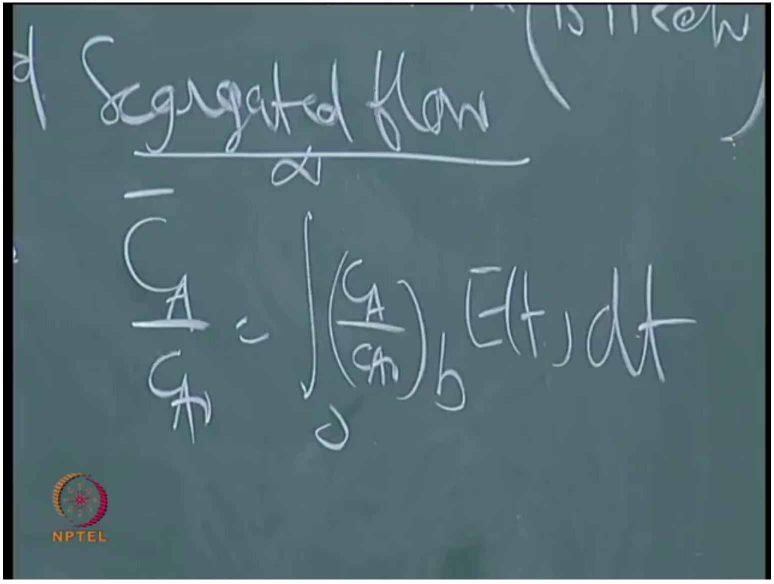

Segregated flow

$$\frac{\bar{C}_A}{C_{A0}} = \int_0^\infty \left(\frac{C_A}{C_{A0}}\right)_b E(t)\,dt$$

only thing here is that the other one for first order reactions only,

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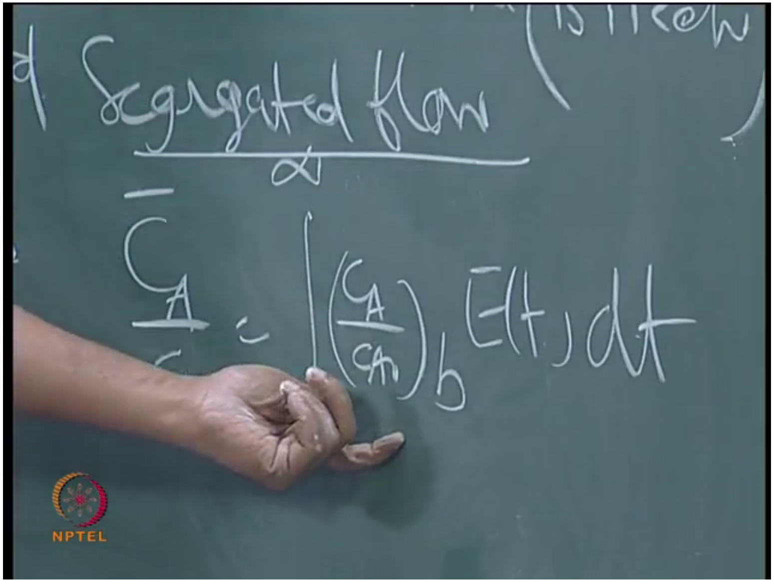

Segregated flow

$$\frac{\bar{C}_A}{C_{A0}} = \int_0^\infty \left(\frac{C_A}{C_{A0}}\right)_b E(t)\,dt$$

but in this when I assume segregated flow absolutely no problem. Like I can tell you an example.

Coal combustion, right. So coal particles have, you know almost same size we assume and continuously I am feeding coal particles, 1 m m, and they are coming out, but depending on their time inside the reactor, some particle would have completely burnt, some people/particle would have only partially burnt, some particles may not, significantly burn at all, because that would have spent only one second.

But what I see, the total energy that released from this combustion is a total of average of all these particles where some partially converted or some not at all converted because some time you know quickly it may come back or some over, only ash structure you will see and ash alone will come out. So that is what is overall.

So same thing. Even someone was telling droplets. I think 0:41:09.4. So the droplets also when I look, each droplet is exposed to the other material also, Ok. We are not talking of mass transfer effects. Reaction is going on in these particles, in these droplets and when I take different partic/particles droplets, then I can see what is the conversion.

But in the reactor they are not mixing. But after coming out of the reactor, I may break all that and then see what is the average conversion. That is what is the latest mixing I am telling. So inside the reactor, latest mixing means they are not mixing, you know, at all.

So that is why this equation what you have to use. Now if I substitute here

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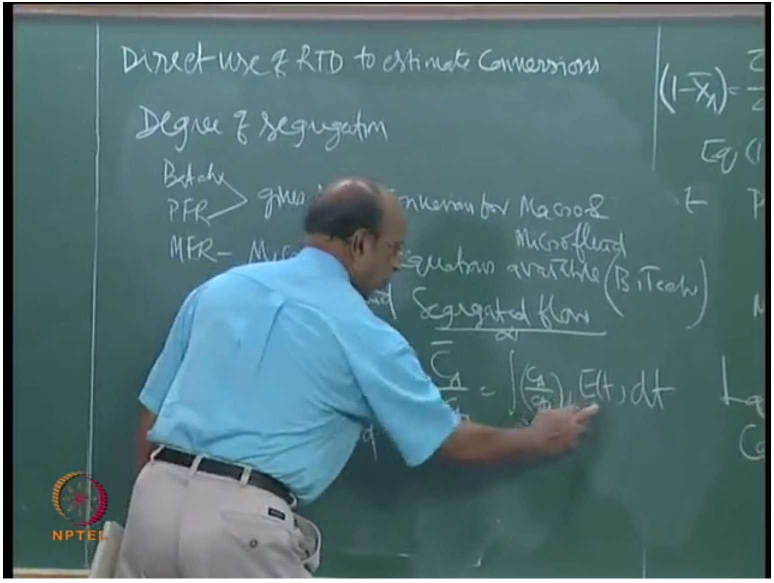

for mixed flow, I know E t d t, right. For n greater than 1, second order reaction, second order reaction I know what is C A by C A naught batch. What is C A by C A naught batch

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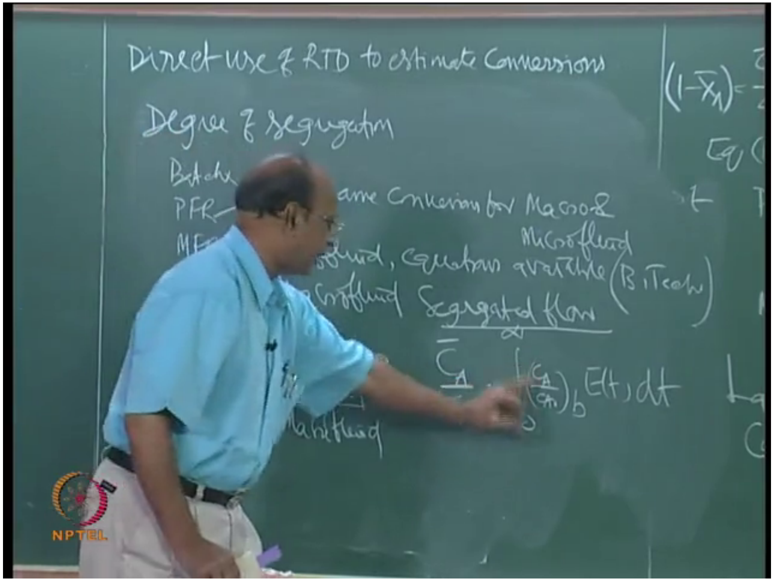

for second order reaction? Quickly expansion of the brain. For n equal to 2, C A by C A naught batch

(Professor – student conversation starts)

Student: 1 by 1 plus k 2

Professor: 1 by 1 plus k 2?

Student: discussing

Student: 1 by 1 plus k t Sir

Professor: 1 by? Batch reactor I say.

Student: k t

Professor: 1 by 1 plus k t, C A naught is not coming there?

(Refer Slide Time 42:38)

Student: C A is C A naught, second order k C A naught

Student: k C A naught C

Professor: Yeah, C A by C A naught batch equal to

Student: 1 by 1 plus k C A naught

Professor: 1 by 1 plus k t C A naught, or otherwise

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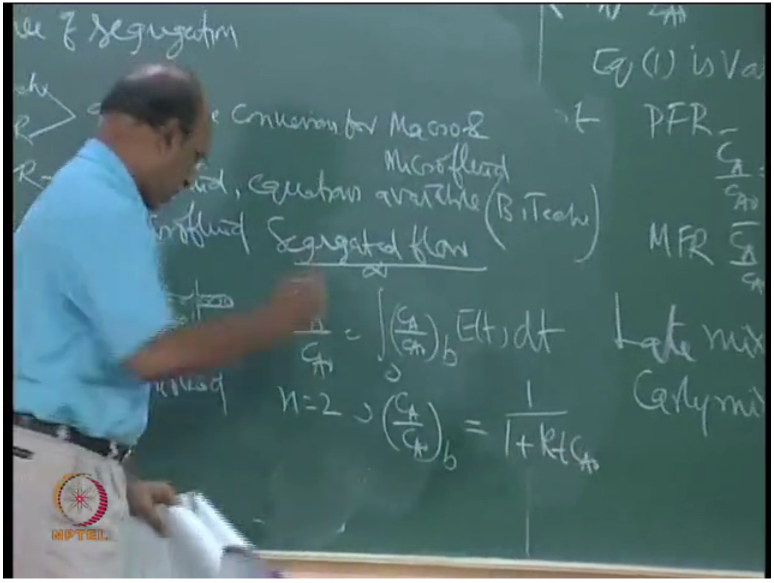

k C A naught t, because those two are, k C A naught t, that is what what you have to substitute here. And what is E t

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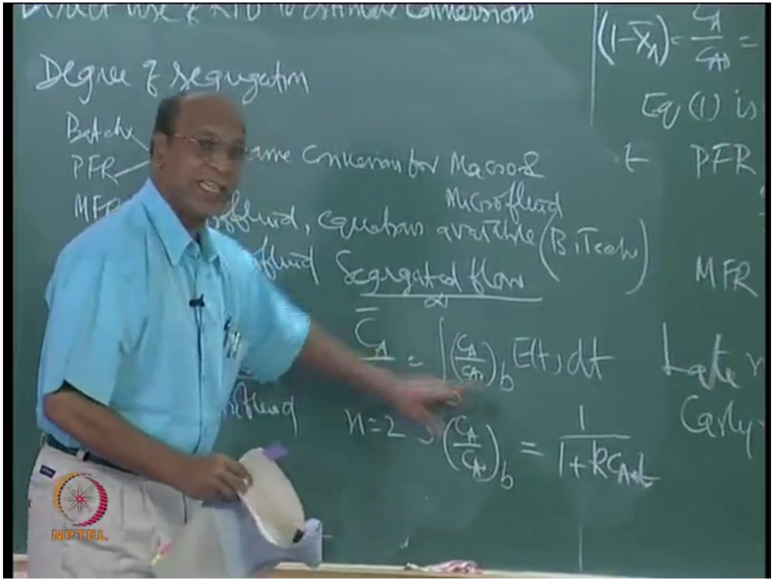

for M F R, we are talking about only M F R. e power minus t by t bar by t bar, M if I want to put, yeah.

(Professor – student conversation ends)

So now these two

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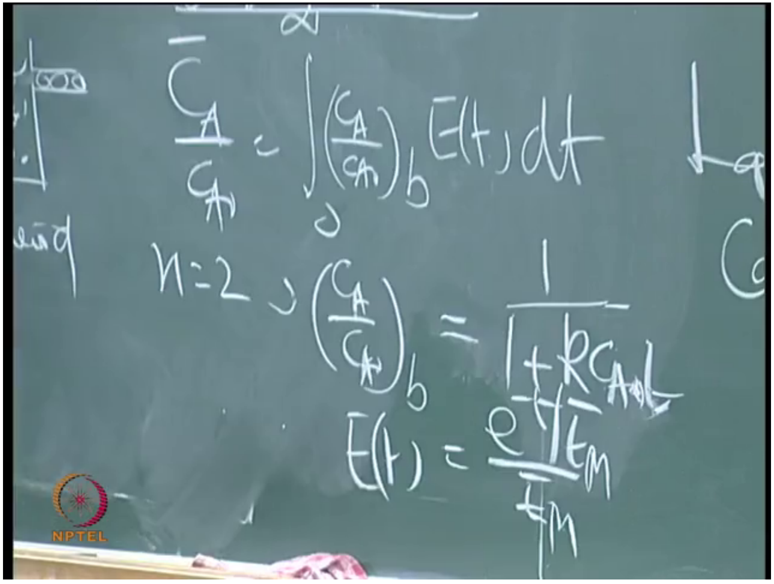

we have to substitute there and then try to, Ok anyway. So C A bar, substituting those two equations, C A bar by C A naught equal to 1 by t bar zero to infinity e power minus, e power minus t by t bar M divided by 1 plus, yeah k C A naught t, this into d t. So this is what

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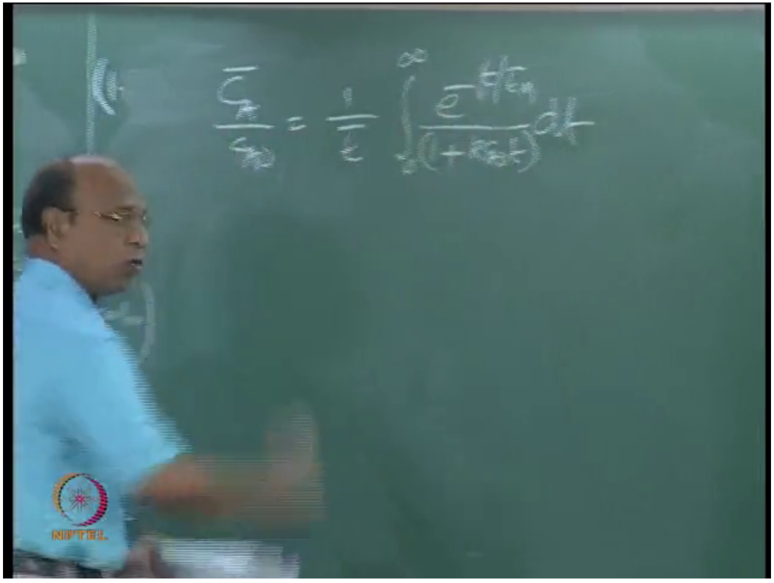

you have to integrate.

It is not easy to integrate. You cannot integrate, Ok. Do not try. Do not try and then just give some answer. Ok, so you cannot, so that is why the exponential integrals will come here, so that exponent integrals will come.

That means exponential integral you have to put this one, alpha to sometime t, some other variable, I think tomorrow morning again I have to finish this, and then

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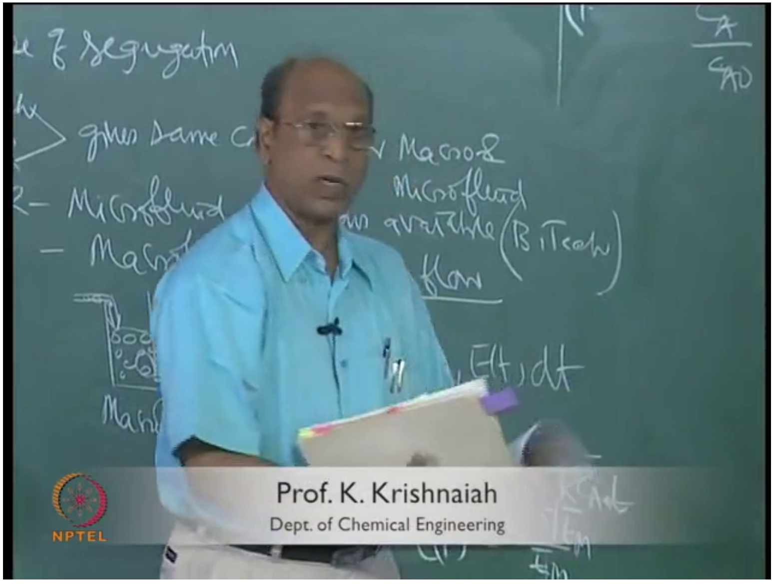

we can chit chat. I think you know the other thing also, even this earliness of mixture also I have to give some idea.