Chemical Reaction Engineering 1 (Homogenous Reactors)
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Lecture No 52
RTD for various reactors contd Part 1

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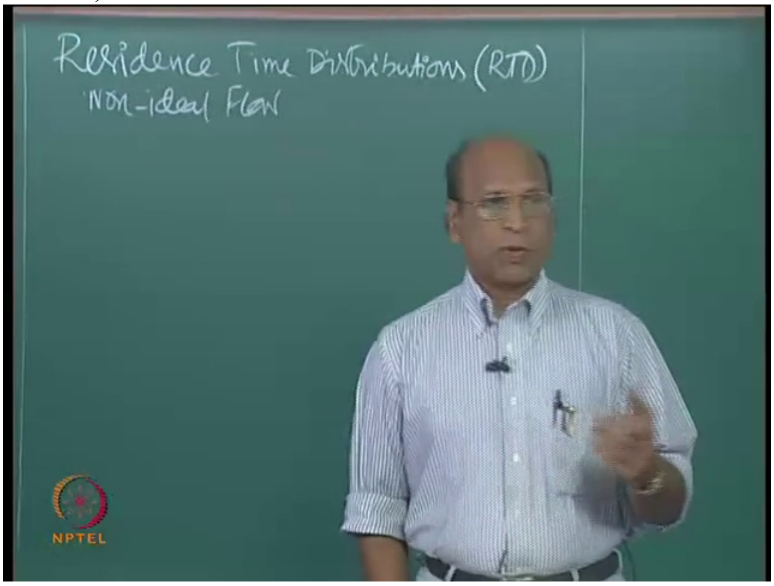

Yeah, whenever we have plug flow, we also discussed yesterday that we have few identified non-idealities. What are they? Yeah axial mixing

(Professor – student conversation starts)

Student: Radial non-uniformity

Professor: Yeah,

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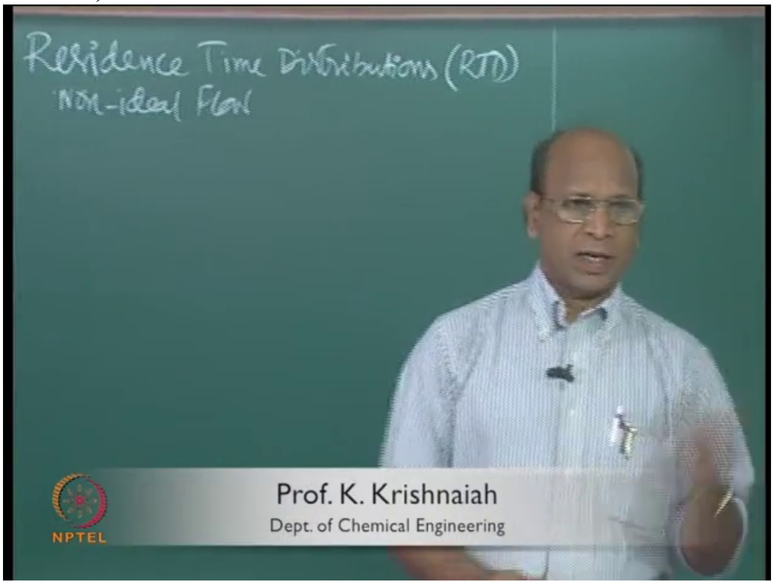

radial non-uniformity that means we expect radial perfect mixing but it is not there.

Then dead space, dead space is man-made or woman-made, (laugh), man-made you cannot say, yeah.

Student: Channeling

Professor: Channeling, channeling also is woman-made or man-made or both made. So

Student: (laugh)

So this is the problem now, I think, you know identifying that and I will ask you few questions very quickly and then go. Slurry reactor, if I take, there are how many phases?

Student: 3

Professor: So, solid we have, gas and liquid. Now slurry reactor, can you imagine in your brain or I have to again draw here?

Student: We can imagine.

Professor: You can imagine no? Good. So now tell me...

Student: (laugh)

Professor: I am very happy now. Now you came to know that you know we have brain. It has to be used. Ok, that is true. We may not know that we have brain, you know most of the time. So tell me Abdul, I think you are the first man to say, you know, imagination. Good. Gas flows in what extreme? Gas in a slurry reactor, you know how gas is introduced in a slurry reactor; I have drawn once or twice, right? So is it plug flow or is it perfect mixing? Gas, gas, first gas; perfect mixing, yeah why perfect mixing?

Student: 0:01:40.2

Professor: If you just imagine, you know slurry reactor and then bubbles are just going up. Ok, why do you say it is perfect mixing?

Student: Because we assume the...

Professor: How gas is flowing? You are not talking about diffusion of gas in the 0:02:01.6. How gas is...You see you know that it is entering at the bottom. You put some kind of sparger. And then bubble it...

Student: It will automatically

Professor: Yeah, and it is coming out. So what we are talking is what is the entry for the gas, and exit for the gas? Entry is the sparger at the bottom and entry/exit is on the top. So L by D here also may be 1 point 5 2, Ok in slurry reactor, Ok. So simply it is coming out. Right so, I am not saying whether you are right or wrong. Justify why do you say that it is mixed flow?

Student: We have stirrer so it will...

Professor: If there is no stirrer?

Student: Then it will go with just plug flow.

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Professor: Yeah, but when you say that it is stirrer...Normally slurry reactor will have stirrer?

Student: No

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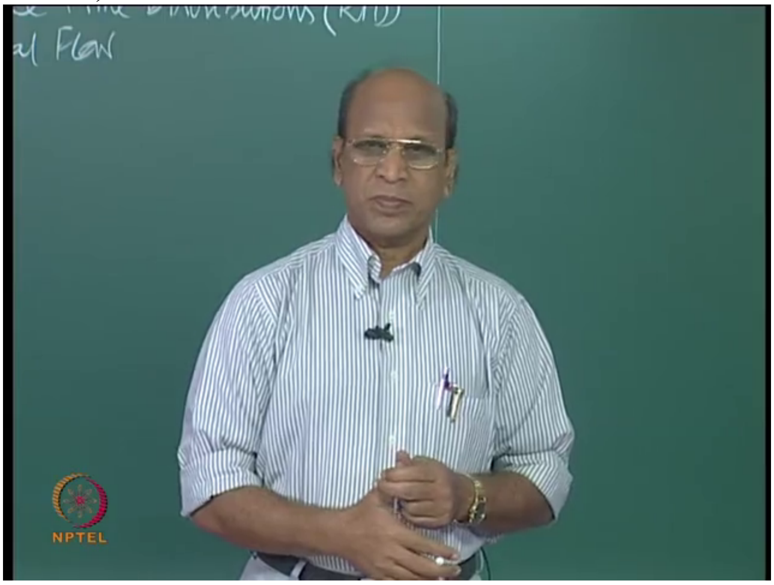

Professor: Very rarely you have. You cannot. But you will also have a stirrer there, if your catalyst is trying to settle.

(Professor – student conversation ends)

You know catalyst is a solid. It has got more density than gas and liquid, Ok, nickel at least. So if you are taking large particles of nickel size wise and then they are trying to settle, if it is very fine dust of nickel it will move happily with the liquid, right? Because gas is bubbling, so the solids also are brought to the top and again they may go back and again, you see.

And that is why you have solids also in perfect mixing but it is batch. Generally we do not take solids as continuous in a slurry reactor. You see now? So gas without stirrer will be plug flow. So the moment we say we have plug flow, then what are the non-idealities?

(Professor – student conversation starts)

Student: Mixing

Professor: Yeah channeling may be there and channeling will be there for gases

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when it is going. Because sometimes

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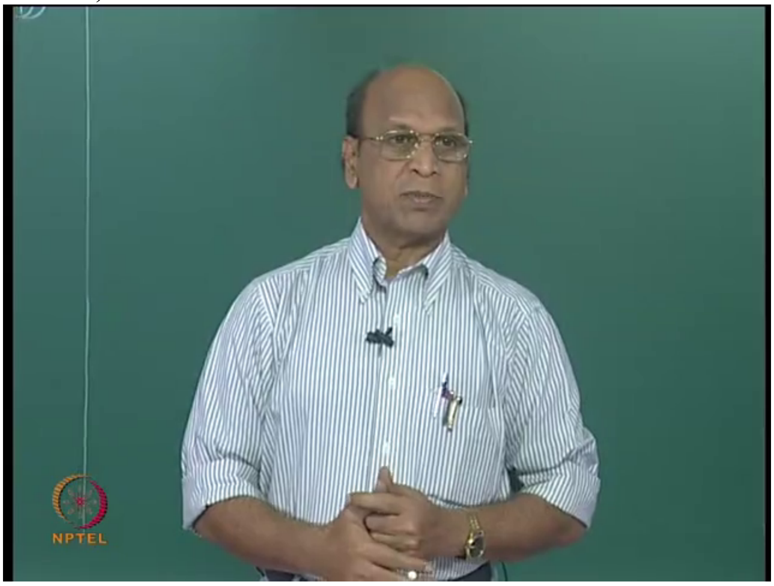

you know, gas will go in some other route very fast and some other route very slow. So depending on which side you have more and more liquid, because it is simply bubbling.

(Professor – student conversation ends)

And bubbling creates chaos, Ok. That chaos only creates good mixing in the liquid. So I do not have to even ask now. If you have a continuous liquid phase in slurry reactor we will happily take that one as

(Professor – student conversation starts)

Student: Mixed flow

Professor: Mixed flow. The reason is that we have perfect mixing, not by stirrer; by gas itself it is created.

(Professor – student conversation ends)

So like that every reactor you have to just imagine in the mind or draw and then try to find out, Ok, where are you closest to, which contacting pattern? Either plug flow, that is one mixing, and, sorry one extreme.

So we have, so we say that yes R T D equal to zero for plug flow and R T D equal to zero to infinity exponential decay is for mixed flow and what are the non-idealities when we say mixed flow? Mixed flow, liquid is in mixed flow in a slurry reactor. What are the non-idealities?

(Professor – student conversation starts)

Student: Bypassing

Professor: Bypassing may be there, yeah

Student: Dead zones

Professor: Dead zones,

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in fact,a lot in sparger.

Student: Sparger

Professor: If the sparger is not

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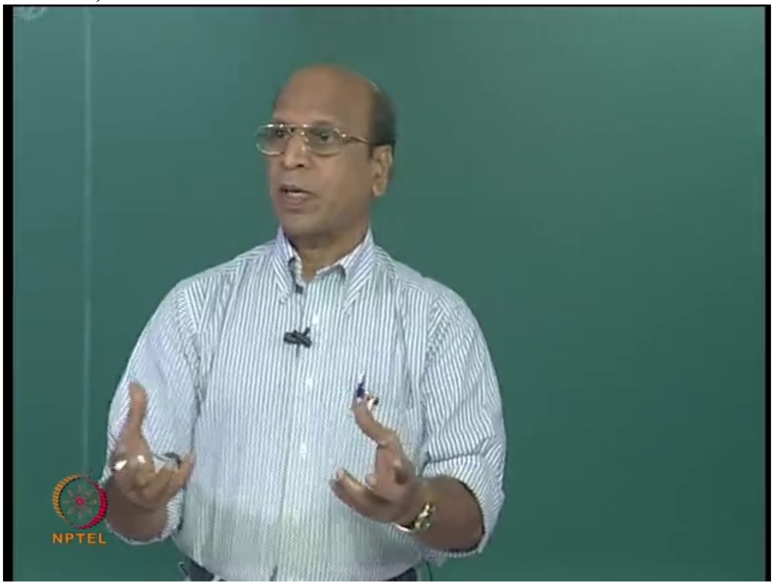

properly distributed.

(Professor – student conversation ends)

Same thing, yesterday we talked about fluidized bed. Fluidizing bed also has a bottom, at the bottom; you know gas has to be distributed, as a perforated plate. If that is not designed properly, again you will have dead spaces. That is why I said, you know it is man-made.

Because we are only creating that. If you are able to design those things very well, at least some of those things can be eliminated. That is the advantage with non-ideal flow. There are some parameters which you can eliminate. There are some which you can never eliminate.

For example, in plug flow, particularly gas phase reactions and all that, or liquid phase also, single phase, even single phase, you can never avoid axial mixing. But the only thing is, whether axial mixing is very serious or you can neglect when compared to the overall conversion, that is what only you have to decide as an engineer, that is all.

So any reactor, for example, rotary kiln, it will be moving like this. You feed at this point, Ok and the solids will be coming like this. And gas can be sent, you know, even in cement kilns and any other non-catalytic reaction where, even, sorry, even yesterday we have discussed about iron ore reduction, right. Iron ore reduction in fluidized bed. It is not only fluidized bed, iron ore can be also reduced in rotary kiln, right.

So H 2 may be sent either counter-currently or co-currently right, and then how the solids are moving, how the gas is moving. Normally the length of rotary kiln is 20 meters, 30 meters, 40 meters. That much is the rotary kiln length. Diameters in industry will be 1, 1 point 4 meters. Big pipe rotating slowly, right.

So how the solids are moving? Because for each phase you have to find out. How the solids are moving? First ideal. Plug flow or mixed flow?

(Professor – student conversation starts)

Student: Mixed

Professor: Mixed flow. Who told, Pooja? Who told mixed flow? I am not saying right or wrong, do not be afraid, do not hide. Yeah, who said mixed flow? Pooja only. Yeah. Why Pooja, mixed flow?

Student: Sir, because when rotary kiln is rotating, they all are mixing together.

Professor: Yeah,

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I mean how do you define mixing? Because I think you know,

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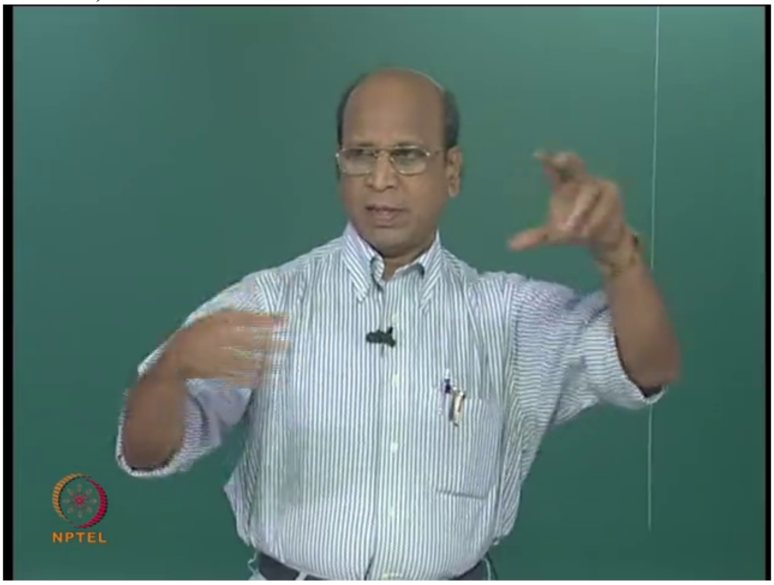

just only trying to get some more information from you, that is all. Ok, how do you define mixing?

A particle should be anywhere at any instant of time, can be anywhere at any instant of time. So when I have almost 30 meters or 20 meters or rotary kiln slightly inclined, slowly rotating, what is, you know r p m of a rotary kiln?

Student: 5 r p m

Professor: 5 r p m, will it create that kind of mixing?

Student: No

Professor: It will simply slide. See it is slowly moving like this, right. And also please remember that, you know I used this term holdup.

(Professor – student conversation ends)

Holdup means the amount of solids, not only solids, amount of gas, gas holdup we call, amount of solids, solids holdup we call, in slurry reactor if we take amount of liquid, liquid holdup we call, all three is in that volume and fractions wise we will call epsilon s, epsilon g, epsilon l. Epsilons are the holdups.

That is what; you know most of my research area concerns, this hydrodynamics and then holdups. Because unless you know how much is gas is there, how much solids are there, how much liquid is there, you cannot design the reactor at all; why?

If gas is only one bubble and liquid is, may be 10 meter cube, where the reaction? Almost zero. That means the gaseous reactant is not at all enough, right? So that is why that is very important information. So that is why in the rotary kiln how much you expect as a solids holdup? Anyone, anyone has idea?

Let us say 10 meter cube total volume I have. Out of 10 meter cube, how much do you expect solids to be?

(Professor – student conversation starts)
Student: 5 to 10 percent
Professor: 5 to
Student: 10 percent.
Professor: You agree with her? She may not be right,
Student: Less
Professor: Still less?
Student: 1 by 3
Student: 20
Professor: I thought you will say 90 percent.
Student: 20-30 percent
Student: 20-30 percent
Professor: She is around 5 to 10 percent. Why? Why you do not fill it up? You can fill up and rotate, no?
Student: 0:09:07.9 contact
Student: Sliding
Professor: Yeah, contact as well as that nice movement of the solids.
(Professor – student conversation ends)

That is why inside the rotary kiln they will also have some kind of baffles. The baffles lift the particles and then fall, lift the particles, fall. Lift, fall. There are many. And only solids are sliding. So every time it is going up and down, falling, up and down, that is where you have the good contact with the gas.

So it is only around 10 percent. And the rotational speed can be only 3 p m, 3 r p m or 5 r p m or 7 r p m like that. Very, very small. Angle?

(Professor – student conversation starts)

Student: 5 degrees

Professor: Again it is 2 to 3 degrees. May be 5 degrees also. Ok. But not 30 degrees, 40 degrees. 40 degrees means everything will come, very fast.

(Professor – student conversation ends)

Ok, so all these things are there. So, now tell me Pooja, solids will have what kind of contacting pattern? That means, you know distribution R T D wise, is it P F or mixed flow? Are you are convinced it is not mixed flow, or you are not convinced? So how do you imagine this, you tell me?

How do you imagine

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that the solids will move in mixed flow?

(Professor – student conversation starts)

Student: Sir, actually when some building is made, no

Professor: Some?

Student: Any building is made, they bring that rotary...

Professor: Oh. That is concrete mixing.

Student: Concrete mix

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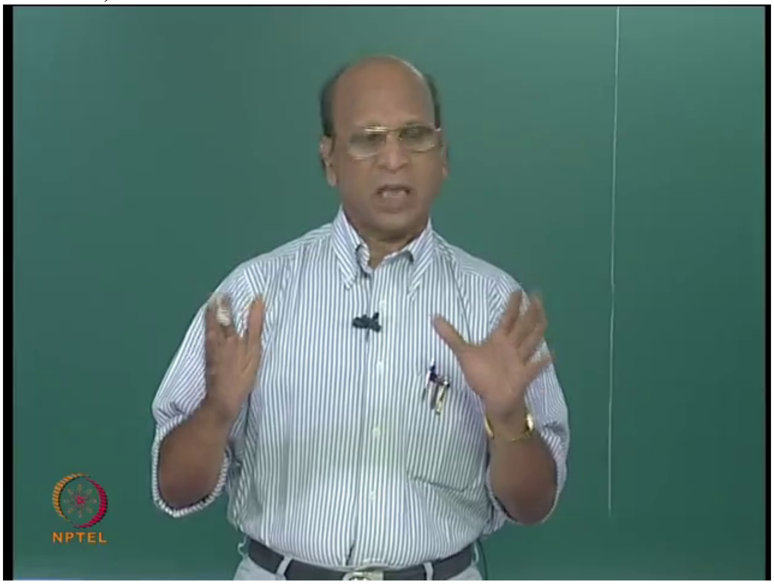

Professor: It is not rotary kiln, please. Yeah, that is why I said diameter is 1 meter and then length is

Student: 20 meters

Professor: 20-30 meters. Now you ask your building people to use this kind of thing as mixer. Nothing will mix there, Ok. Yeah. I think she is imagining that because on the road most of the time we see only those things. You know what is L by D of that?

Student: 1, 1 point 5

Professor: That is all, 1, 1 point 5 maximum.

(Professor – student conversation ends)

Now you are convinced or still you are not convinced? Still you are with building people? Arya? Solids will beautifully slide, like this, like this, like this, like this, like this. Overall, you have good plug flow but with axial mixing. Because when the solids are raised, falling, sometimes it may go back and forth, Ok. And again it may move further, fall, a little bit back and forth.

So if you look at the entire 0:11:26.7, a little bit of back and forth movement will be there, axial mixing. That is non-ideality, Ok, radial uniformity we do not take it there. Mainly it is taken as, you know, as axial mixing part. So that is what. For gas, Pooja? Gas is plug flow, right?

So you are sending one end, it is going and when it is going through the kiln, so naturally it will touch the solids, contact, then you will have the combustion, Ok. So like that, any equipment...

(Professor – student conversation starts)
Student: Sir, in this case, this non-ideality, this back mixing

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happens a little, it actually helps the performance, no, Sir?
Professor: No. Any back-mixing will not help the reaction.

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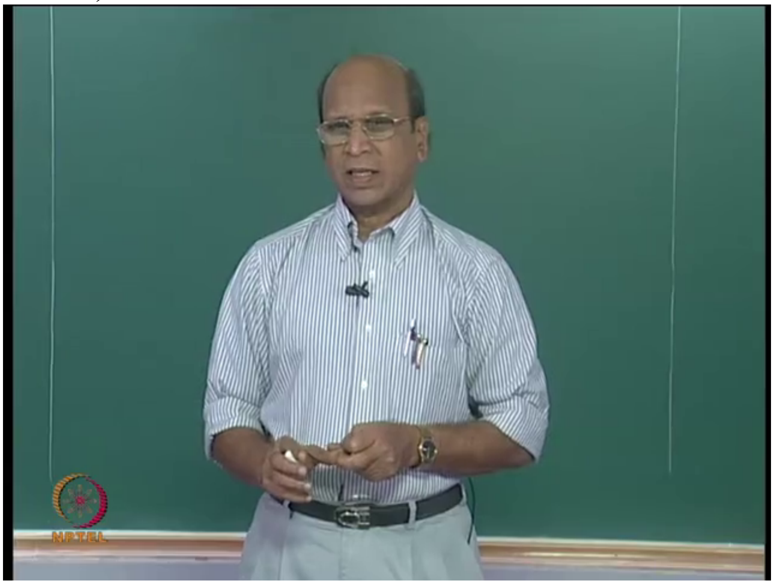

Student: But in rotary kiln,

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there will be only radial mixing.

Professor: Why you should have mixing at all? Mixing is bad

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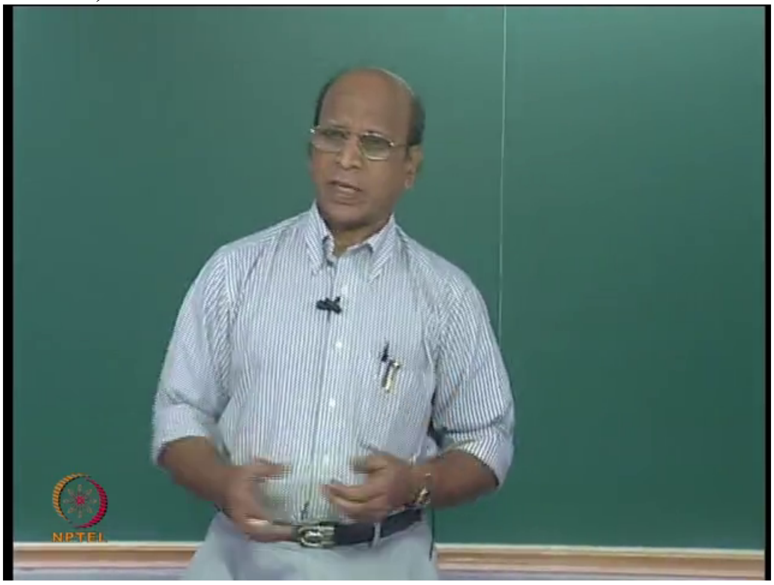

for reactions, we have been telling all the time. Because concentration will decrease.

(Professor – student conversation ends)

So rate of reaction will decrease. So even when the particles are moving this way, that way, the particle which has already converted a little bit more than the earlier particles again and coming and mixing with other particles. I mean it is not solid-solid reaction but even then it is unnecessarily going back and coming forward.

So what we design is, Ok, for 1 inch particle, just for easy imagination, or 1 centimeter particle, you need 1 hour residence time for getting converted to complete iron. So Ok, so anything less than that, more than, less than that will give you less conversion. More than that, there is no use for us, Ok.

So that is the reason why, you know axial mixing also is bad for, even in rotary kiln. Ok. Any non-ideality, Ok, the way we imagine our plug, plug flow. So like that, any reactor you bring. You give me one choice. One choice of the reactor apart from what we have discussed?

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What other reactors you have come across?

(Professor – student conversation starts)

Student: Fluidized bed

Professor: Fluidized bed we discussed, no?

Student: Moving bed

Professor: Ok, moving bed is the easiest one. That is why I did not say. Slightly complicated one?

(Professor – student conversation ends)

Ok, moving bed, what will be the patterns? Moving bed, you know

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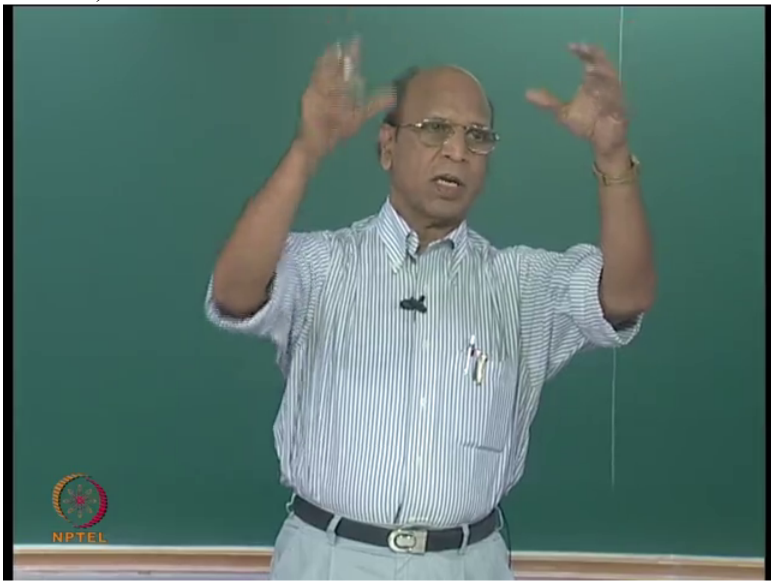

the solids, if you take counter current; solids will be coming from the top, slowly moving. Moving bed, I told you. Moving bed is nothing but packed bed moving, Ok. That entire thing will be simply sliding down. So wonderfully we can assume, imagine this one as plug flow.

Because those particles, you know we can never get exactly same size in reality, so that is why some particles will slide more, some particles will get stuck somewhere, so that is why, on the whole, it is plug flow but nearest non-ideality there also is axial mixing, Ok.

And radial uniformity may not be there sometimes depending on the size. So like that, any reactor, like for example, F C C, what kind of reactor they use? F C C, fluid catalytic cracker?

(Professor – student conversation starts)

Student: Fluidized bed

Professor: Yeah it is fluidized bed but it is not conventional fluidized bed where you have large diameter and height is small, L by D equal to 1 and all that. So it is fluidized bed, actually it is called fast fluidized bed.

(Professor – student conversation ends)

The solids will be moving with the gas and then they get separated in the cyclone and the, you know solids are nothing but you know catalysts. So that will get regenerated and again it comes back. So solids are moving in plug flow and also gas also is moving in plug flow.

Like that, that is why, the first statement which I made long time back, that any reactor you bring, you can beautifully classify only into these two categories.

(Professor – student conversation starts)

Student: 0:15:05.9

Professor: It means that all the reactors can be classified into two categories and ideally you can imagine what kind of flow and we know that in reality there is no ideal flow, right, but closest to ideal flow what you are imagining.

(Professor – student conversation ends)

The moment someone says that I have plug flow in this reactor, your mind has to go there. If you are very, very fussy about exact conversions, then Ok, let me also see what is the non-ideality, how much you are losing?

Because you are assuming ideal plug flow and calculating conversion. But in reality you may not have. When you do not have in reality, how much are you deviating from that plug flow? That comes through non-ideal parameters. Ok? Yeah.

So that means definitely if I want 90 percent conversion for a, in a tubular reactor, in a plug flow reactor and ideal plug flow gives me 1 meter and because of the axial mixing you get the same conversion, I may have to put 1 point 1 meters or 1 point 2 meters. That extra length. That any way we do not care as engineers because by factor of safety, that is given by God to us, Ok, factor of safety. Ok.

So that is why I calculate 1 meter cubed and then add, Ok, I am not very sure, I put 1 point 2 meter cubed. That is why, always you know, I think even digital cameras will have factor of safety.

Because you know, always when you say, I think, any photographer did you see taking only shot taking and going away? He will first say smile, and then you will smile, he will take photo. And you are about to leave, no, no, sit down, one more, smile please, again. Because second, because he is not confident that the original one would have come properly. So that is why there also, factor of safety.

But only in the examination, same examination you cannot write twice. Ok, same time. So that is only problem there. Ok, good. So like that we have factor of safety, we are taking care of it.

Now believing that these non-idealities are creating different distribution than ideal distribution. Ideal distribution we have. Exponential decay. It goes beautifully. But if I have channeling, sorry bypassing for example, bypassing it will not be exactly like exponential decay.

Or if I have, this one I have already told you, plug flow when I have, right, when I have plug flow, what kind of response have I shown you there in the outlet? If I have step, you know pulse input? So that means, imagine disk. Disk is pulse input. How the disk is moving?

(Professor – student conversation starts)
Student: 0:17:40.3
Professor: Exactly like that when it comes out. If I have the non-ideality, what kind of, what will happen to distribution? It goes like this. That is what is non-ideality. That is the effect of non-ideality.
(Professor – student conversation ends)

So your flat velocity, no not that, other that flat concentration curve which is simply one line, direct delta function, that is now distributed. That is because of non-ideality, in this case axial mixing. So if I have dead space for example. In same plug flow.

What it should come, how the, how the curve, axial mixing is there? And over axial mixing I also have dead space. Another disease like diabetes and heart attack.

(Professor – student conversation starts)
Student: Two peaks
Professor: Why two peaks?
Student: Delay
Student: Time lag

Student: Two peaks

Professor: Two peaks?

Student: No, one peak.

Professor: One peak for

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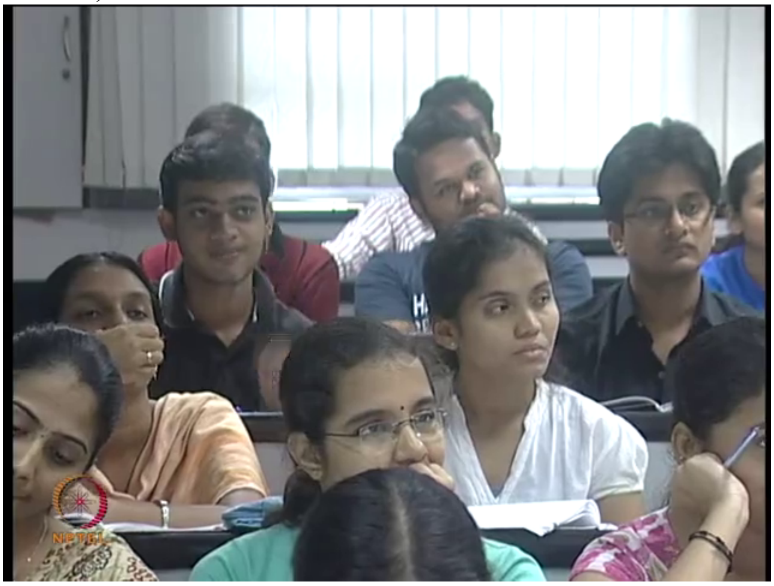

heart attack, another peak for diabetes?

Student: (laugh)

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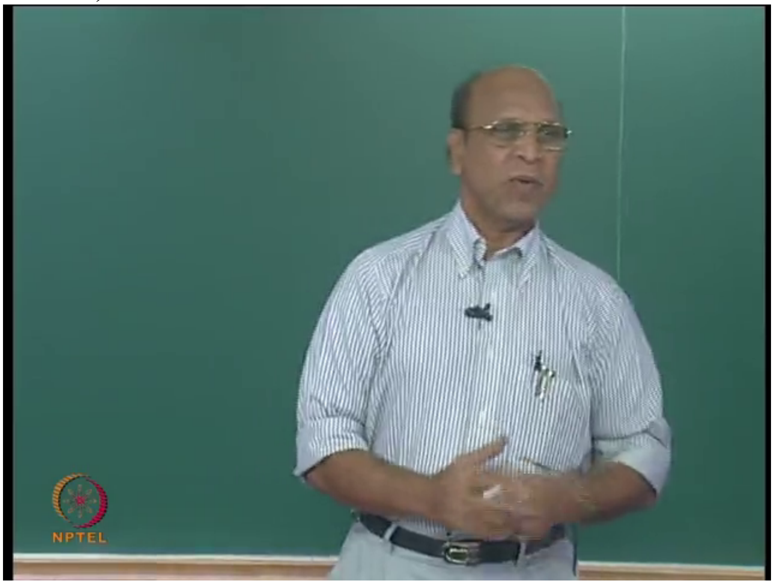

Professor: Why two peaks, Rahul?

Student: Sir the material

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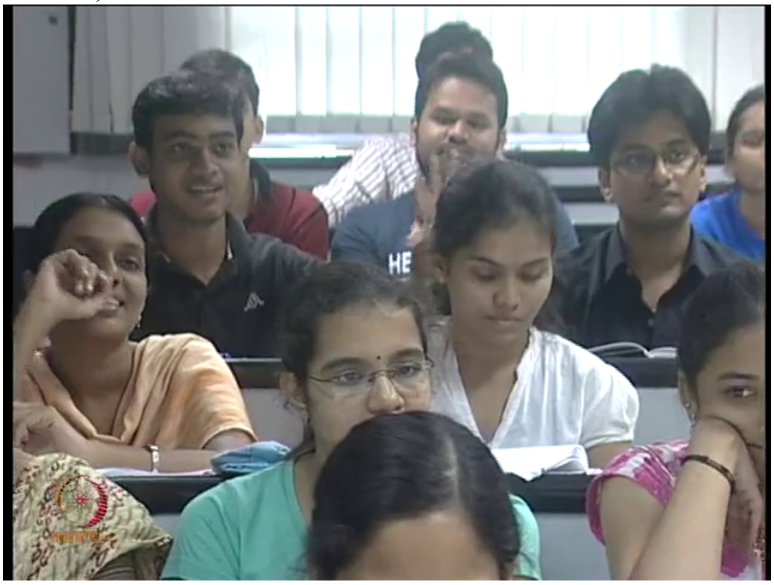

in the dead space will start coming after some time. It may not come but, if it comes...

Professor: It is dead space. Ideally dead space is not really dead. It is slowly coming.

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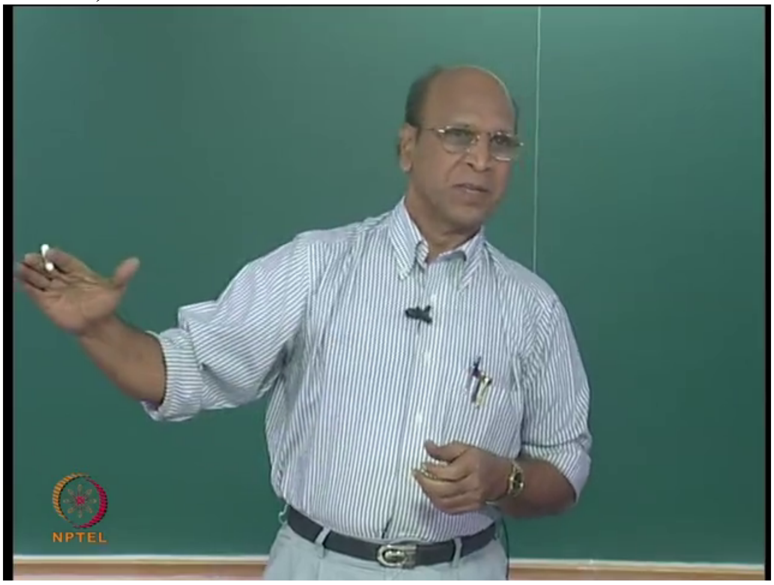

That is what what we say dead space, Ok. Slowly, somehow you know there will be mixing a little bit and it starts coming, it will have a long tail as Savita said.

(Professor – student conversation ends)

So you will have like this, that is spread and then it goes long tail. See that means now your ideal distribution has been totally spoiled by these non-idealities. Ideal distribution. Ideal distribution is simple direct delta function. You can imagine direct delta function, no? Arrow. Ok.

So that one has been spoiled by, like this by axial mixing and now by tail, another one, that is dead space, right. If you have channeling?

(Professor – student conversation starts)
Student: There will be another peak
Professor: Then what Rahul said is right.
Student: There will be...
Professor: Then what Rahul said is right, one peak for the channel, another peak for the main
(Professor – student conversation ends)

So the channel one will come first, with axial mixing it will take, because axial mixing you cannot avoid in plug flow, right and another peak? You see, how simple it is. Just you imagine, Ok in the brain and once

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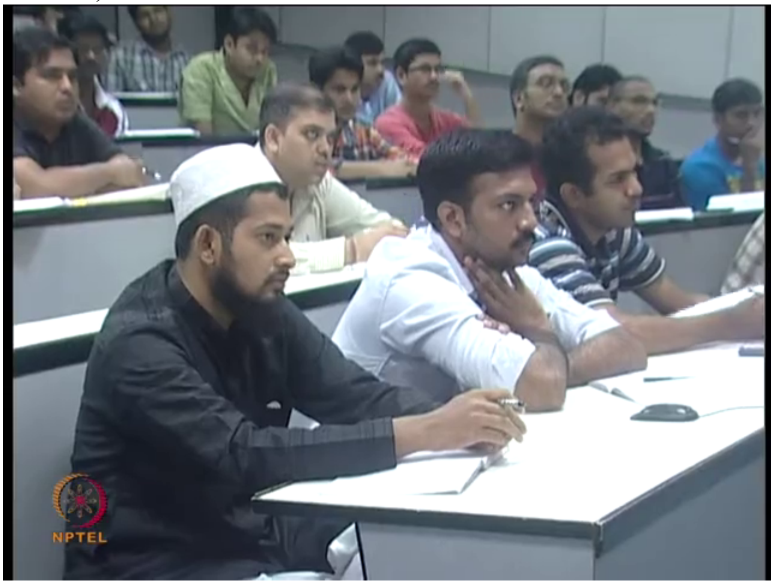

you imagined all this in the brain now you have to go

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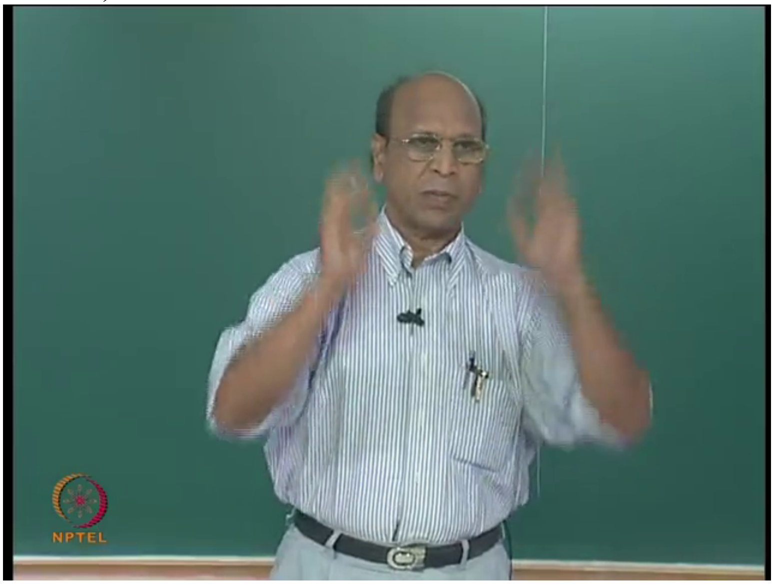

for actual mathematical representation, Ok, good.

So now we believe that residence time distribution is really

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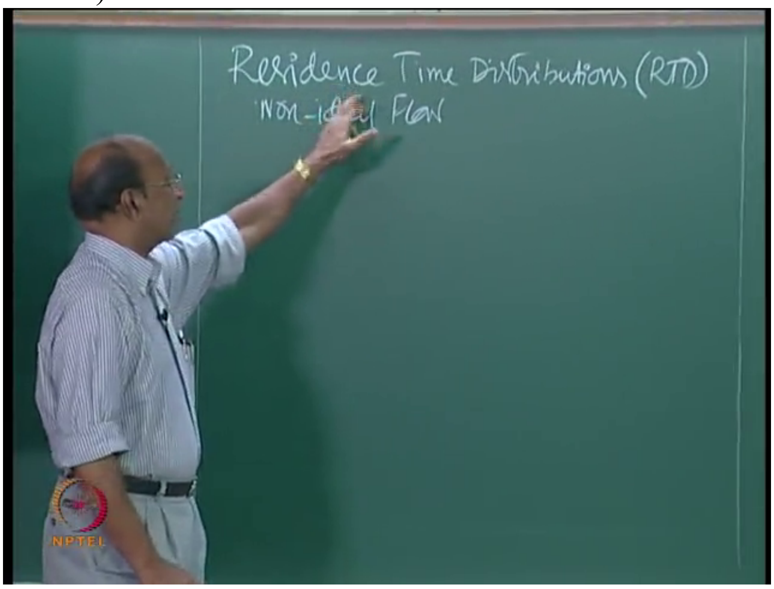

spoiling the ideal, ideal distribution so that is why we have to find out R T D. How do you, how do you estimate R T D for any curve?

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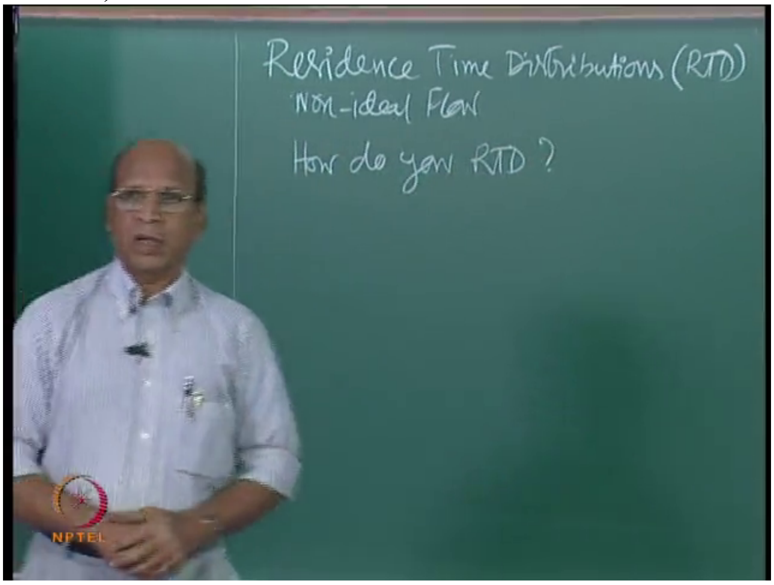

Ok, so how do you estimate R T D, how do you, Oh, estimate gone, or determine, that is the question. What is the technique used?

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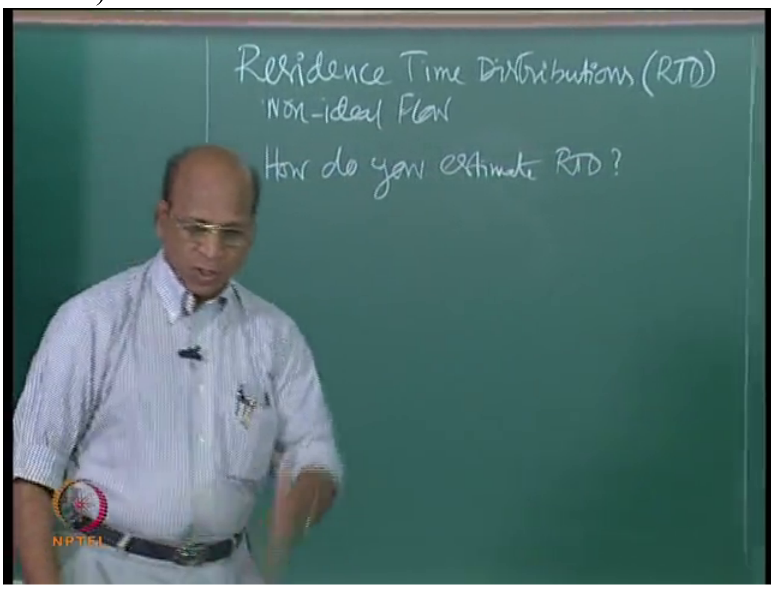

Ok.

So the ideal one is Ok, if I know, if I can reach each and every particle, or like that you know earlier also I told that each and every molecule is attached with a timer and collect all these timings at the outlet and then plot those timings, that means number of molecules and the corresponding timings.

So I mean I am sending 1000 molecules, out of that may be 10 would have come in the first second. So may another, may be 20 would have come in the next second. So all that number, Ok, if I plot, then we will get normally this kind of distribution for a general vessel. We are not talking about ideal plug flow or ideal mixed flow. This is what what we get.

So but actually that is not possible. You cannot even put timers and also reaching molecules is import/important, impossible. So that is why what we try to do is we will try to find out the behavior through some tracer techniques. So that technique generally is called stimulus response technique. Stimulus response technique. What is the stimulus response technique?

I will give you one simple example so that you will not forget about what is stimulus response technique, Ok,

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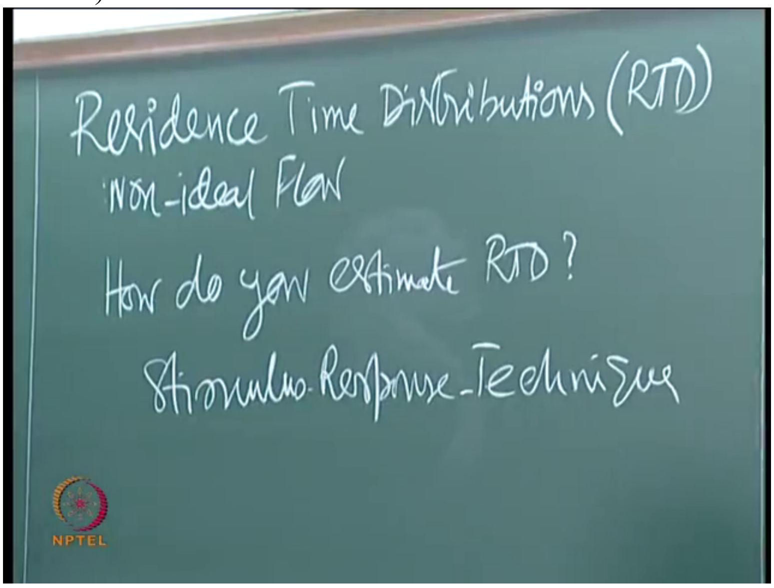

same example which normally I give, Ok. So that is what is the one which you have to find out, you know, response technique, Ok now please take this. Because you will forget anyway, right that is why so let me record.

This you have written no, how do you estimate R T D and it is through stimulus response technique, Ok good. I will just, to estimate R T D the ideal situation is to measure or obtain information on each and every molecule, in the bracket

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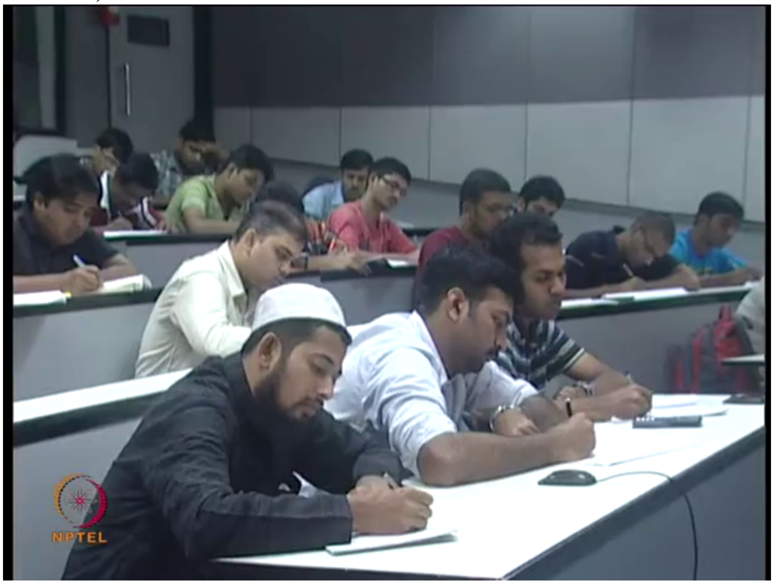

you write, information like concentration, temperature, velocity, c, capital T and u, so that one can calculate the conversions in the reactor.

Once you know concentration profile at every point, so then automatically

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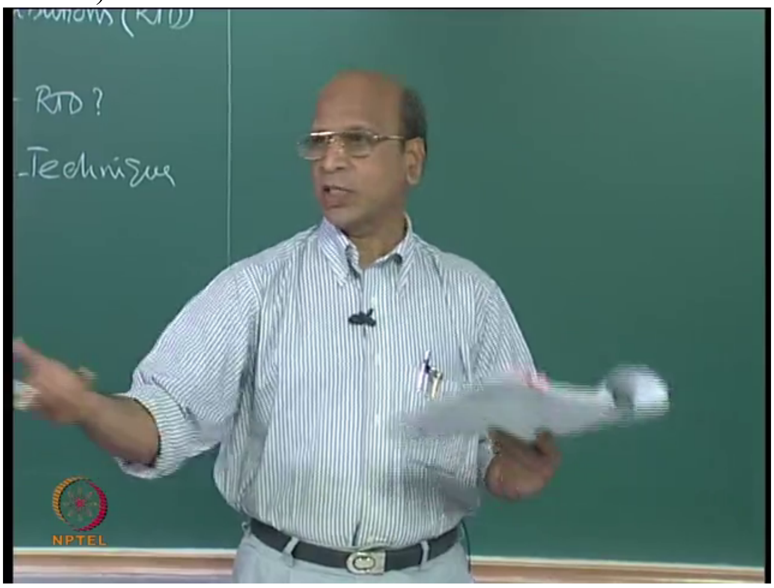

you know what is the conversion, Ok, full stop. This is impossible at molecular level full stop. Hence we should to resort to at least getting information on a group of molecules or a packet of molecules using tracer techniques or more precisely stimulus response technique, Ok. Good.

So what we do normally is that I have a general reactor, maybe I think I will just draw like this. Ok. I will just draw like this only. Otherwise you may be thinking that only that kind of reactors you have to design.

Ok, this is real vessel. We are not saying

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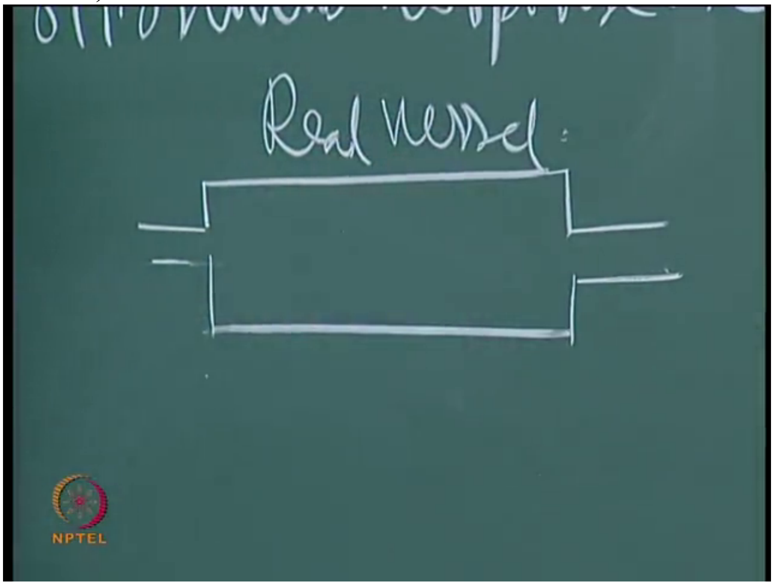

whether it is plug flow or mixed flow, Ok. So then here, under steady state, under steady state conditions you have the flow, volumetric flow rate, volumetric flow rate.

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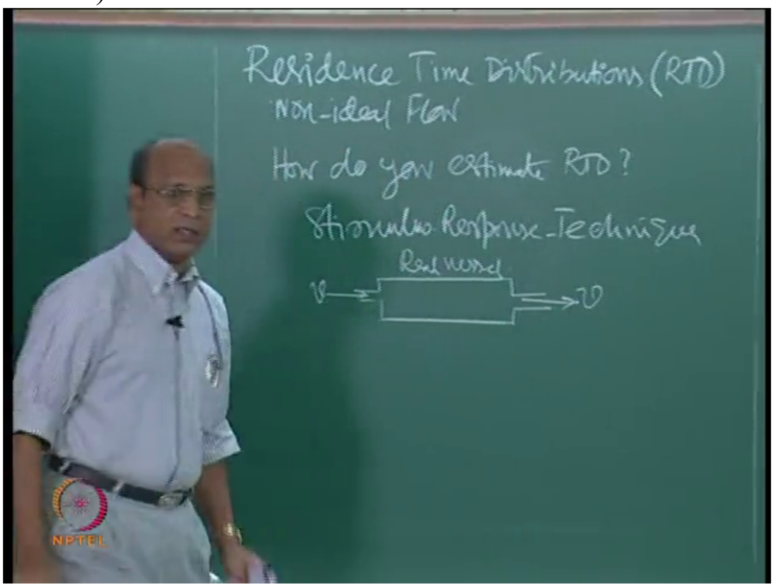

There is no reaction, Ok and most of the time we do R T D without reaction just to find out hydrodynamic information and R T D is one of the hydrodynamic, even afterwards we will see how do we couple this information with the reactions, Ok, good.

So this is at time t equal to zero; the pulse input means suddenly I will add some amount of tracer, at t equal to zero.

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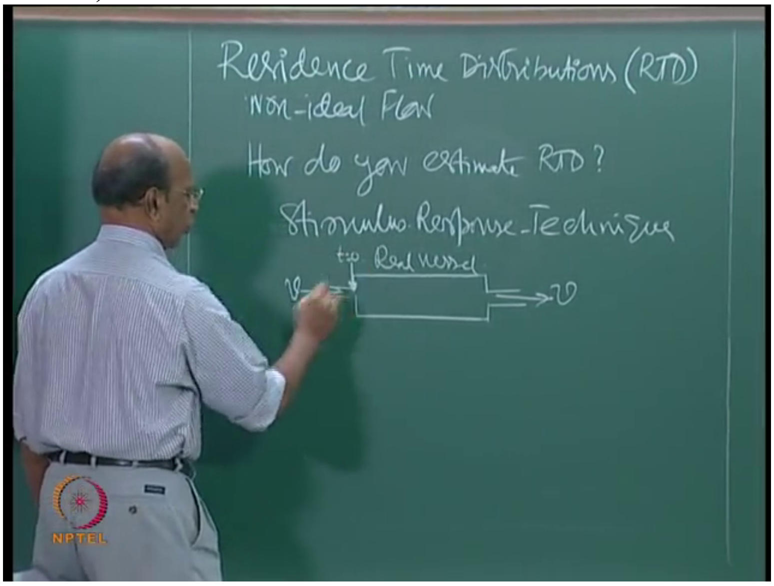

And then here I will put a probe, or otherwise you will have to collect samples and then get, this is probe. Of course this probe should be

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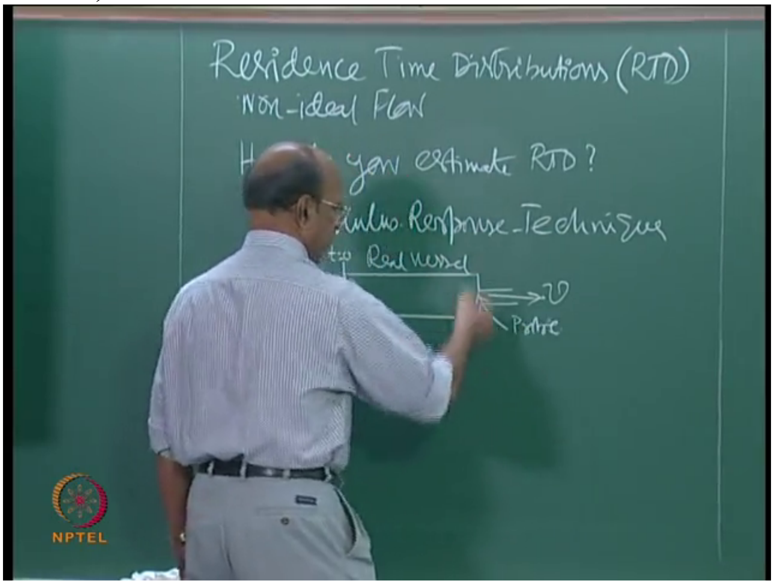

taking concentrations along the cross-section uniformly, Ok, good.

Now we have to record, yeah, we have to measure with respect to time what is the concentration of this tracer. For example if I put the color, may be red color, this is normal water and I suddenly introduce

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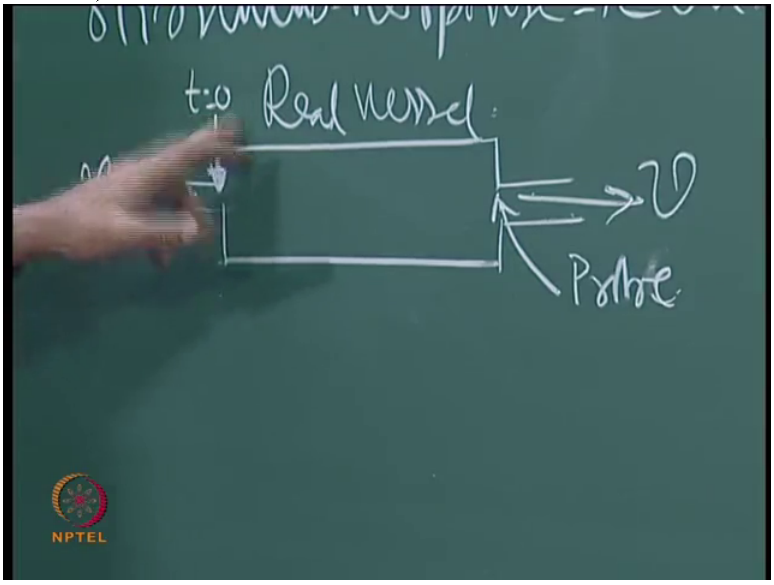

some kind of red color, may be 10 m l of the tracer and then that 10 m l depending, depending on the kind of flow that is inside, you will see at the end.

For example all this 10 m l, if it is ideal plug flow, I will see only after, this is V, and t bar and also tau, because we are talking about only no reaction and all that, so volume by volumetric flow rate,

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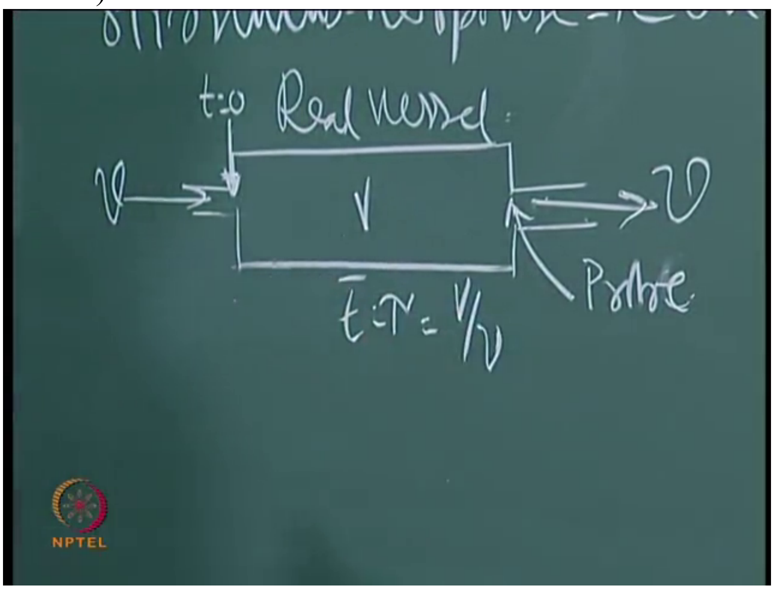

so if this 10 m l is only ideal, I mean if it is, if this is plug flow, that 10 m l will come exactly after this t bar or tau, right? If it is mixed flow?

(Professor – student conversation starts)

Student: Zero

Professor: It starts from zero onwards, right? But in general what you record here is this kind of concentration versus time,

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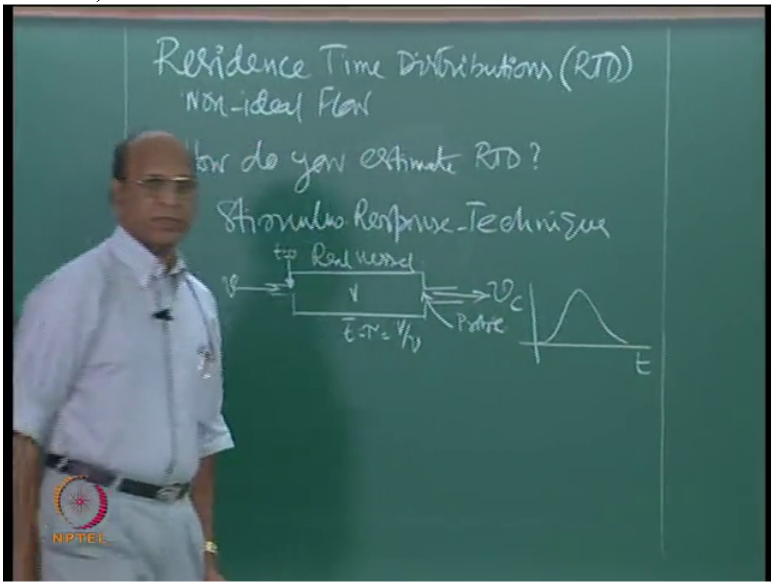

Ok. Because normally what we expect is, you know the meaning of this curve is most of the time we expect that… this is t bar

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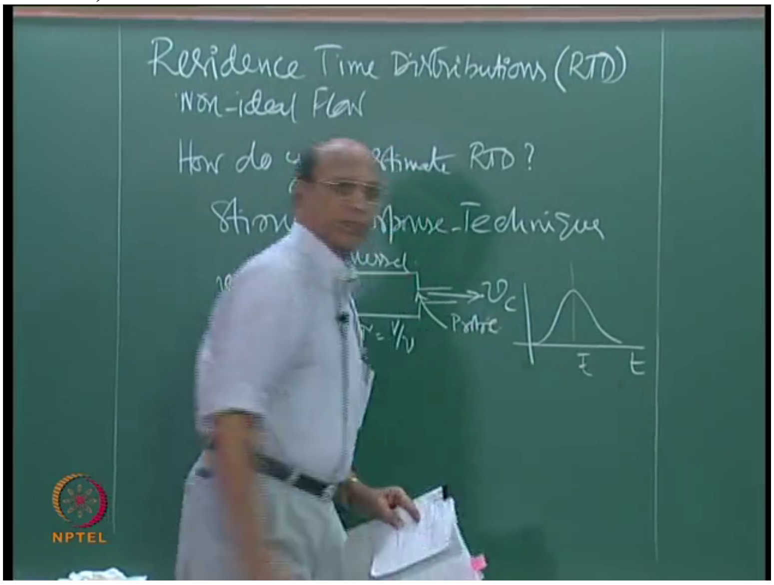

or tau.

(Professor – student conversation ends)

We expect that most of it will come around that. But with that variations and all that, you may have this kind of thing or you may have sometimes, you know long tail or you may have two peaks, all kinds of things may come. But in general this is what we show.

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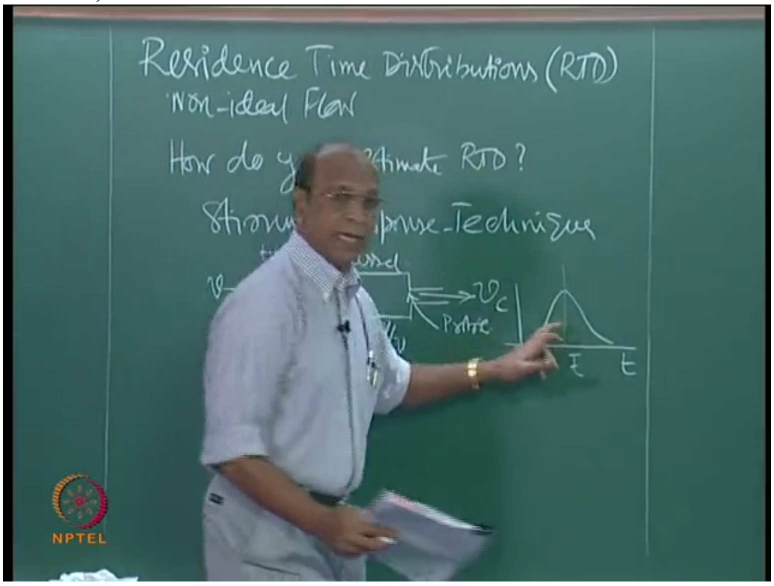

That is why even in the first examination when I gave, you started only this one. When I asked what are the, what is the E t, E t only I asked I think, E t for ideal reactors, most of you people have drawn this. For ideal reactors we have two, right?

So you should have drawn exponential decay. That is for mixed flow, or direct delta function, one of them. But many people have not written that. I think almost nil have written that. Ok, good. So this is the kind of thing.

So you have to take some

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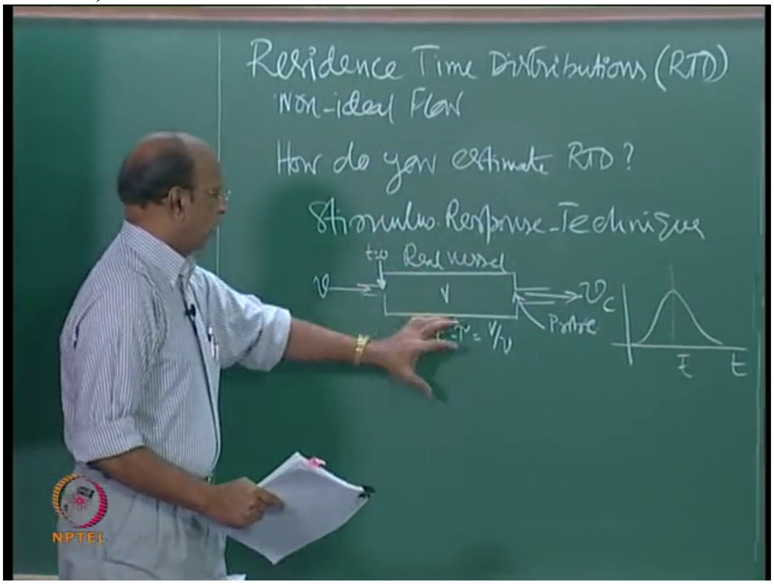

kind of, you know proper care when you are doing this experiment because this flow should be steady first of all. Otherwise your tracer will be different. Ok, I mean because unsteady flow, unsteady flow also can be done but we do not do normally plus, Ok and afterwards

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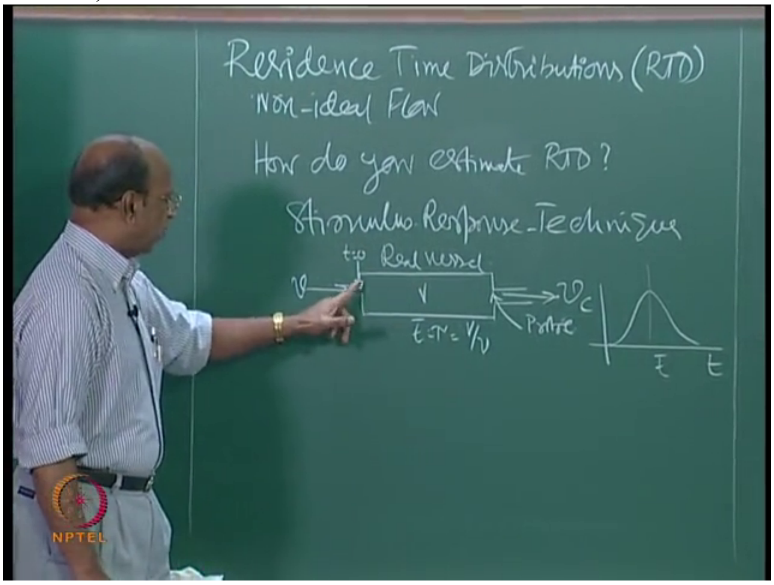

you have to very carefully add this, right and also we know that this tracer should be identified

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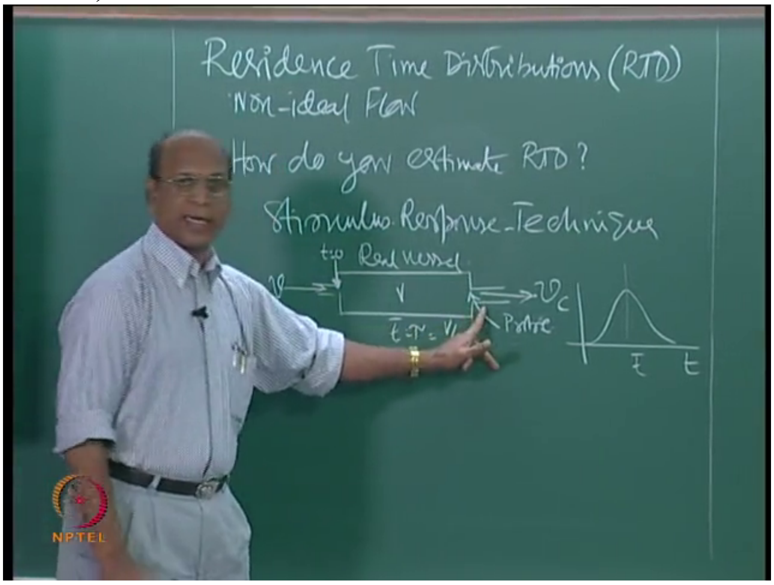

at this point.

How do I identify? You can measure color. You can measure conductivity. You can measure p H. So some property which you can very accurately measure. And then that property is converted into concentration. Concentration of tracer, Ok.

So I mean, in reality it is not required but still, we have to only use this concentration versus time diagram.

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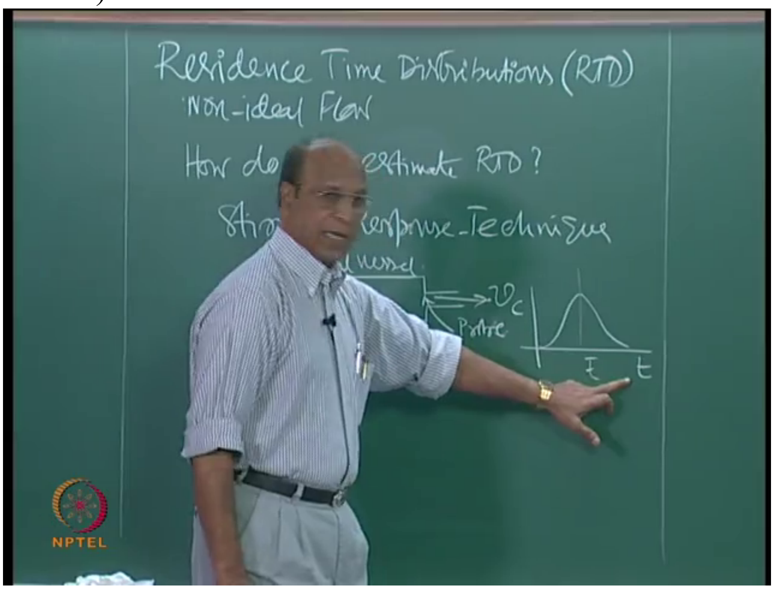

Otherwise if you become expert you do not have to. I think the same property whatever you are measuring, that also can be used because in the actual utilization of this curve,

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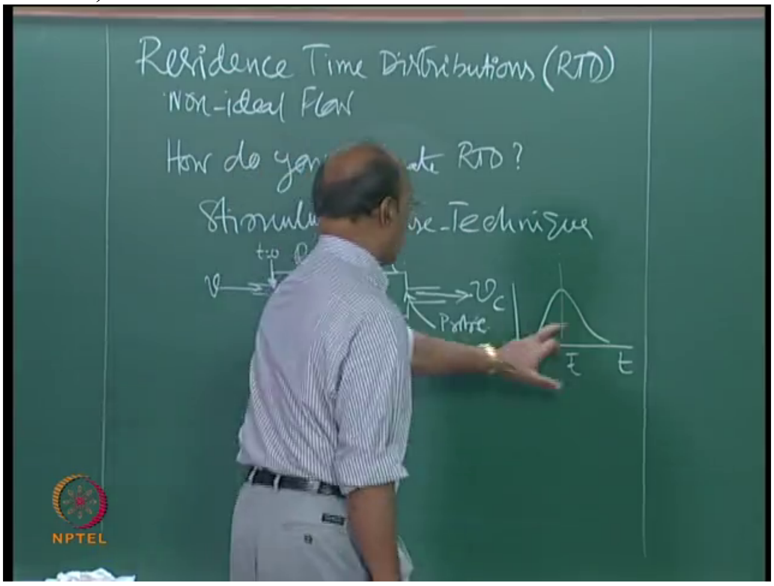

you are normalizing this curve for the area under, under that curve to be 1, Ok.

And why do we do that and all that, I will tell you now. Good. So this is what is the experimental technique to find out. And it is very easy for me

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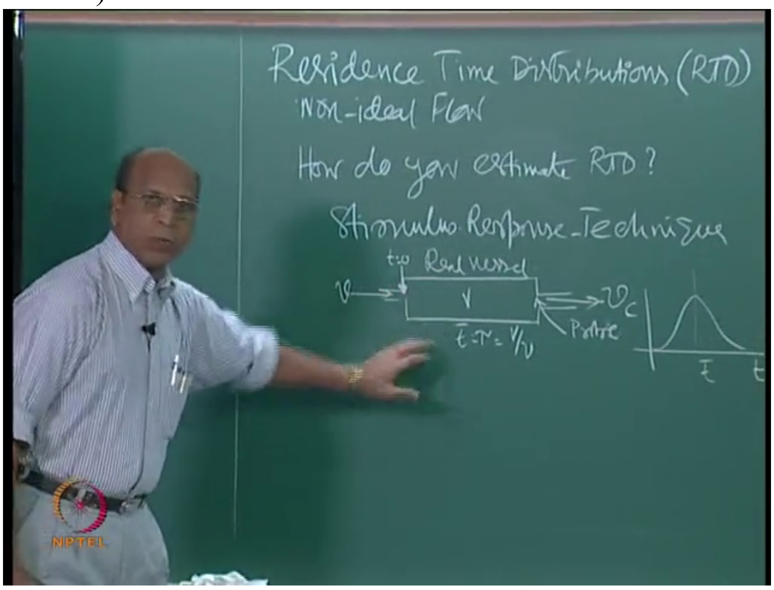

to tell on the board but when you do the experiment, it seems next semester they are asking me to take your lab. Ok.

So I will also give open ended labs. You design everything and then you conduct the experiments. Then definitely you learn a lot, right. So this kind of experiment also I am planning one, where you can...You have done this kind of experiment probably in your B

Tech, right. At least 1 or few people. Right. So in your B Tech you had no, C R E Lab? R T D lab also was there?

(Professor – student conversation starts)

Student: Yes Sir

Professor: Yeah so but on your own I think if you are able to do, how much you have to add and all that, then I will observe you how you are doing, right? Ok.

(Professor – student conversation ends)

So that is why doing is very, very

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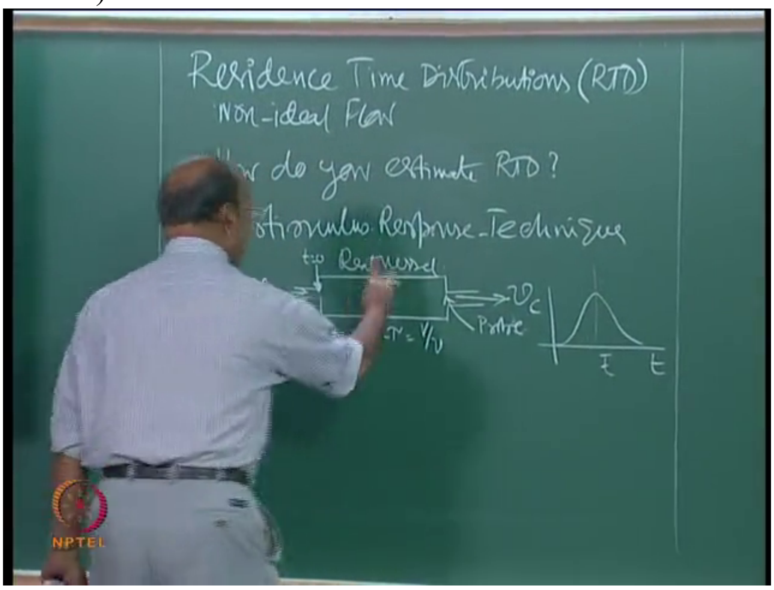

difficult, you know. That means you can make lot of errors. First of all, you do not know when to collect the samples. What time you have to collect samples? That question is also will come. Anyway next semester you will see all this, right?

If mean residence time is 10 minutes, how much time you take the samples? And what is the sample frequency? Right. And particularly all this will come when you do not have instrumentation. Automatic recording means without understanding you are recording it, Ok.

But I do not give automatic recorder. You have to do with your own hands first. Learning is, you know, doing is learning, right? Yeah, Ok. So that is how you know there will be lot of difficulty

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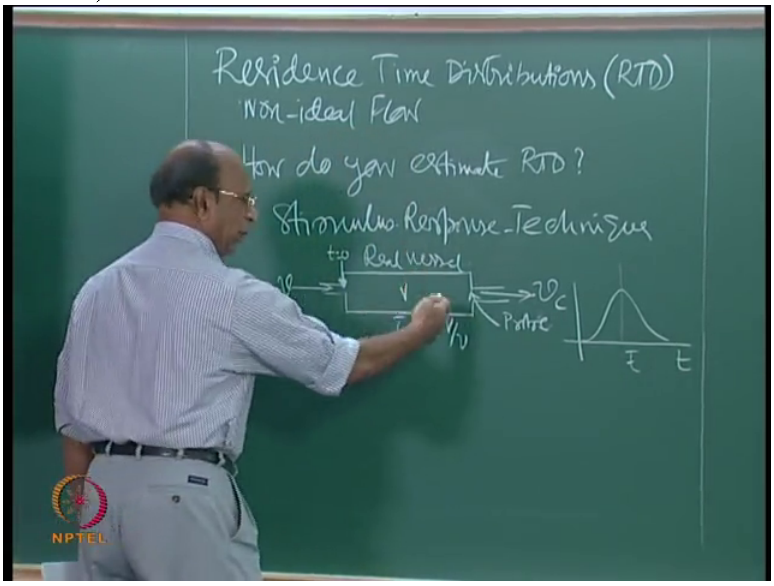

in doing this accurately and inaccurately there will be thousands ways of doing. Not doing also, Ok. Good. Anyway.

So this is the one what we have. And with this information how do you define now this E t, F t and all that now? Ok. So now if you have come to the definitions, definitions, what we do after getting this one is that we first try to find out area under this curve as Q, area. Ok.

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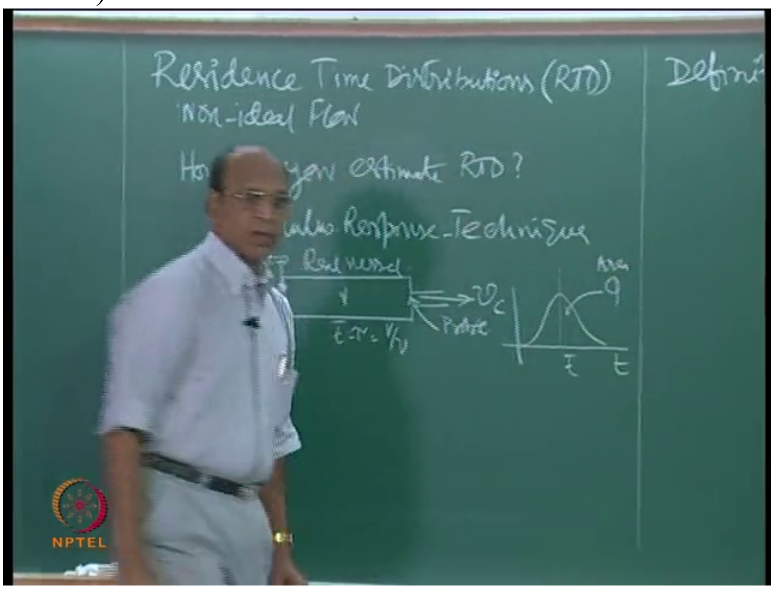

Right. How do I find out area under this curve? This Q equal to, simple calculus

(Professor – student conversation starts)

Student: Zero to infinity

Professor: Yes. Q equal to integral zero to, zero to?

Student: t

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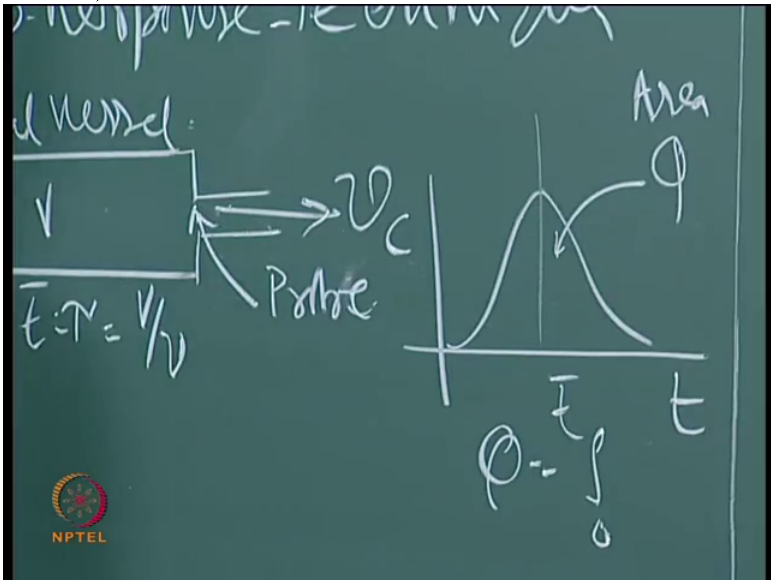

Professor: Which t?

Student: Zero to infinity

Professor: Zero to infinity because I do not know the boundary. And you never go to infinity, anyway. Ok. C into, C into d t, d t.

(Professor – student conversation ends)

So then we get the

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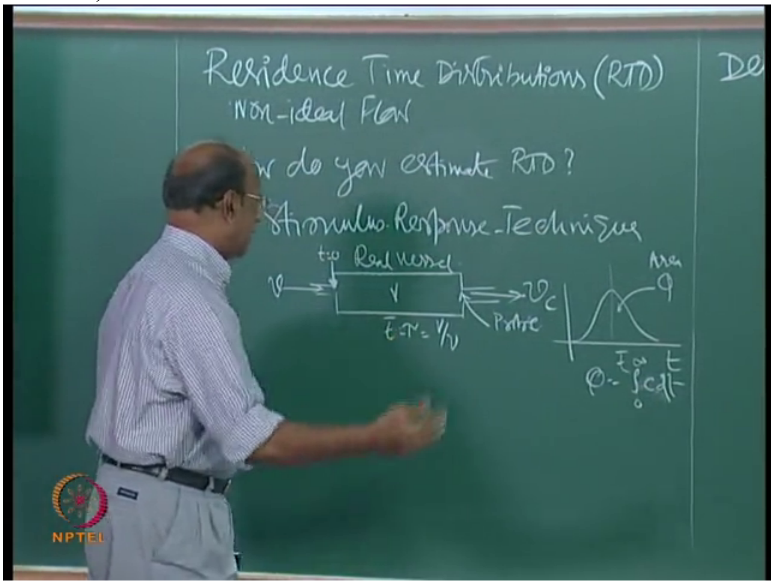

exit age distribution E t as C by Q where

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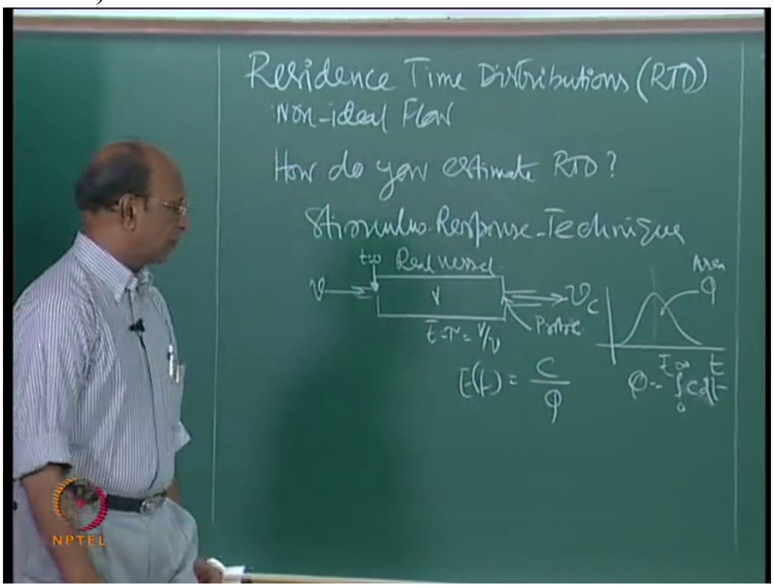

Q is that. But why we should draw like this, I will explain. I think, you know we will also derive that. Why should we draw, I mean why should we calculate in this and then say it is E t. By the way what is E t? Exit age distribution.

What is exit age distribution? I think I have not, I told you no what exit age distribution, Ok, good. Yeah. So that is the one. And now we, why, Ok, we will just stop here because this is what is experimentally done. This procedure, adding, running this at steady state and also measuring any one can do.

Because I mean, with slight training, anyone can do without much brain thinking, right. So now this will stop it. And afterwards we now try to find out what is that we have to do here, information that is required in terms of definitions.

We define our curve, this residence time distribution curve as, Ok, Ok, now it is E t. And this is t. Normally we may expect a general curve, something like this, I mean any shape I can draw. Ok, any shape I can draw and now if I take, this is zero, this time also zero, and this is E t, the units of this is

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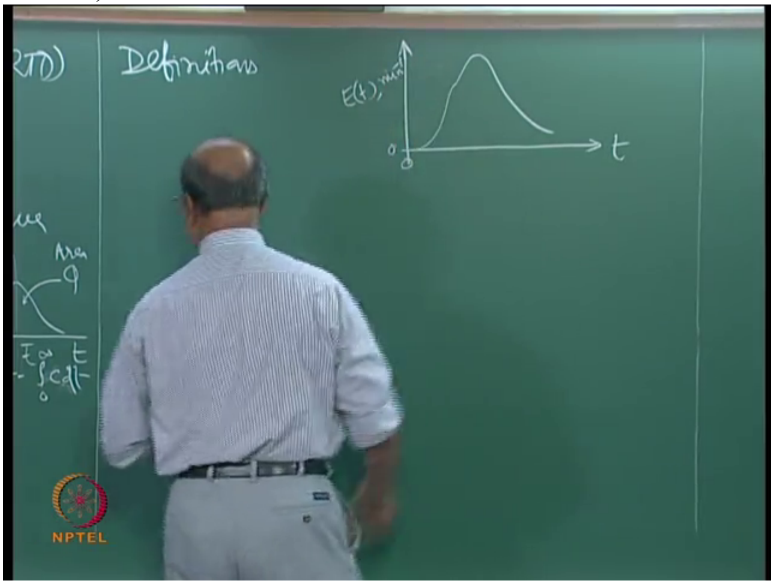

minutes inverse. Is it correct? Minutes inverse?

Yeah this is C, this is

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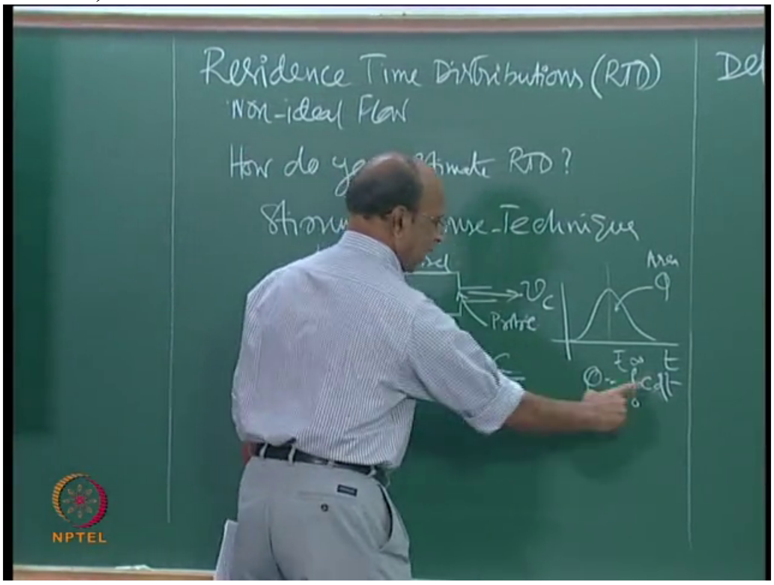

integral zero to infinity C d t, C, C units will get cancelled. Only time units will be there, inverse time units. So this is the one. So if I have to take, yeah, so this area,

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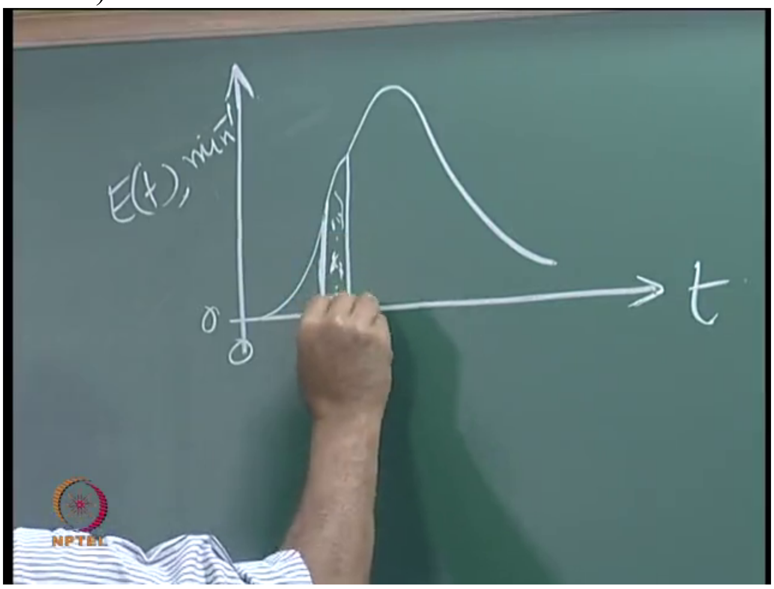

let us say this is time, this is fourth minute, so this is sixth minute.

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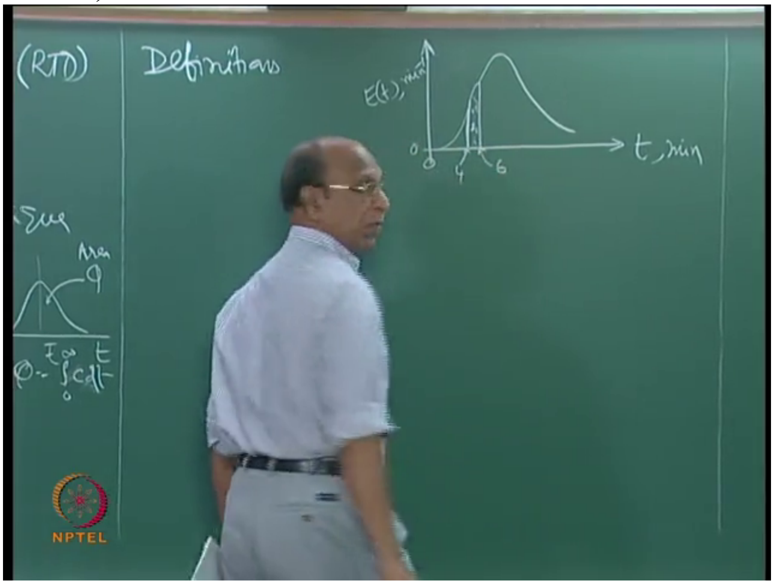

So this value, this is point 1. That is point 1. Now what is the area of that particular strip?

(Professor – student conversation starts)

Student: Point 2

Professor: Point 2, right? So this area equal to, by the by what is the formula? It is E t

Student: Integral

Professor: Delta t where

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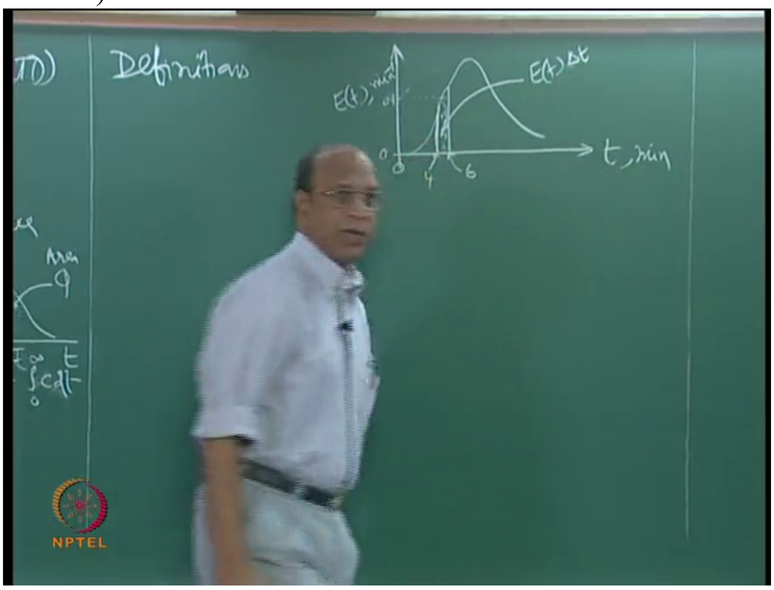

delta equal to 2, Ok. That is why this is equal to point 2.What are the units?

Student: No units.

Student: No units.

Professor: No units Ok.

(Professor – student conversation ends)

This is how you want to define this distribution; anyway finally it has to go to zero. That means all the materials should come.

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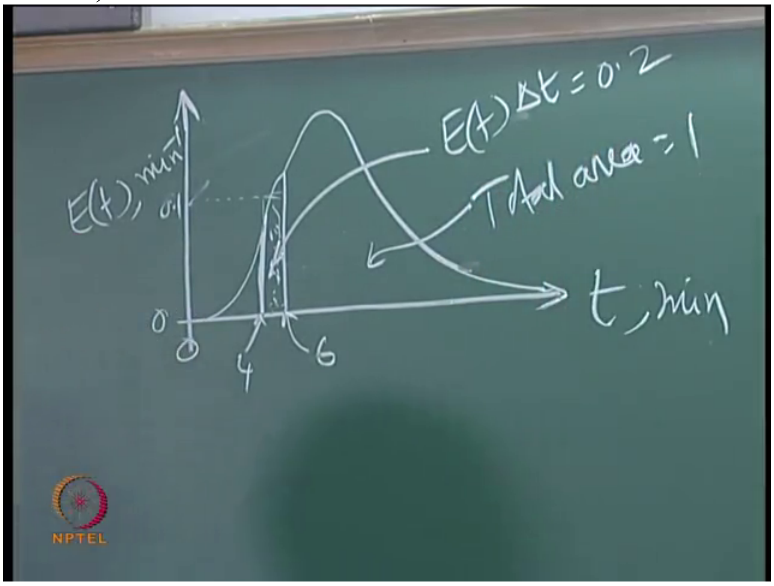

All the materials should come out, definitely, right? So that is why. Good. So this area under this strip, it is 20 percent. Now why we are defining in this way, and what is the total area?

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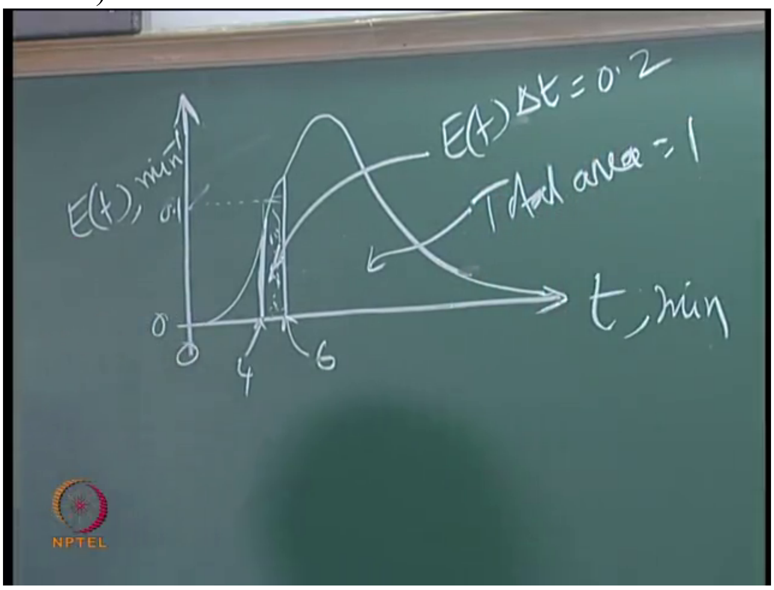

This is what actually you do in your particle size analysis also. You know, particle size analysis also, exactly you do the same thing, right? Yeah, now this gives me an idea,

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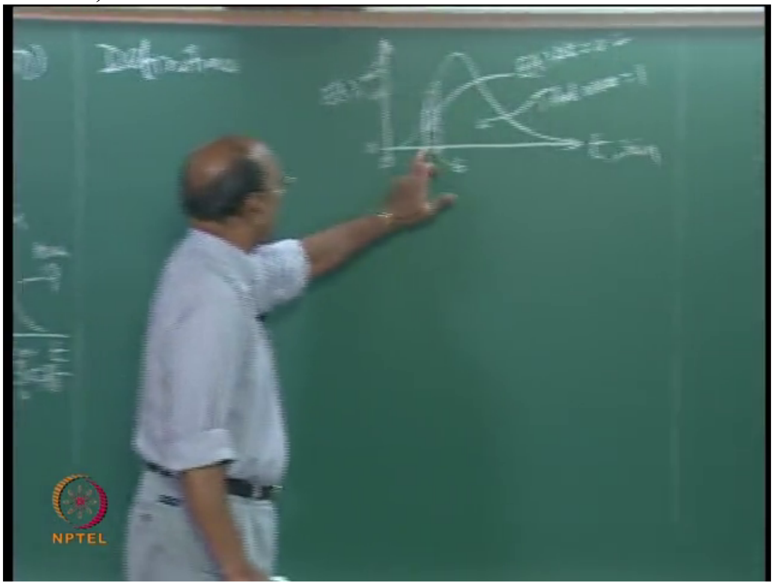

now that 20 percent of material is spending a time between 4 to 6, on the average 5. What is the use of this information for me? What is the use of this information for me?

(Professor – student conversation starts)

Student: Calculate conversion

Professor: Yeah, to calculate the conversions.

(Professor – student conversation ends)

So that means now in a non-ideal reactor where I do not know what kind of pattern it has, the ideal plug flow means I have equation. Ideal mixed flow means I have equation. But somewhere in between. I do not have.

That is why I conduct this R T D test and find out, and then draw the information in this format and now I know that

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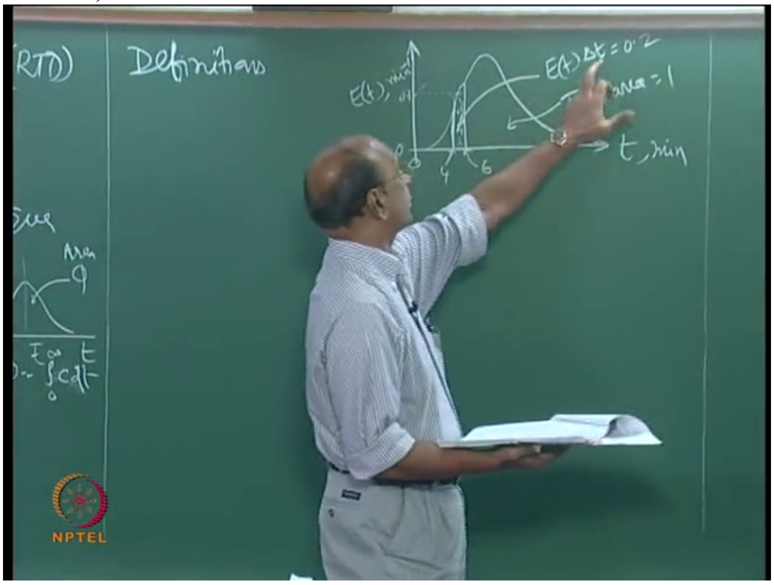

20 percent of the material is spending a time between yeah 4 and 5, I mean 4 and 6 that means on the average 5 and I imagine that that group moving as a batch reactor which has spent a time, average time 5 minutes.

Now if I have a first order equation, I mean first order reaction,

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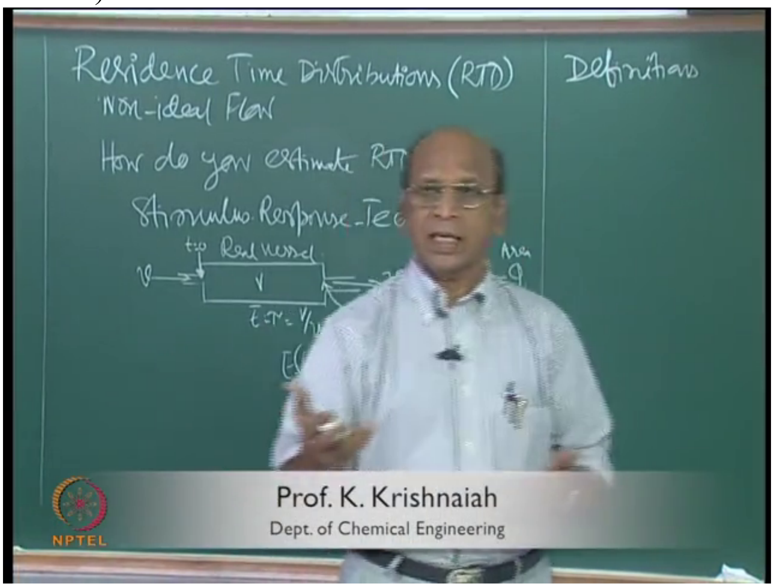

then I will have conversion from there. That is what is the original idea of Residence Time Distribution. How do we calculate the conversions for a non-ideal reactor where I do not have to have a design expression but conduct this R T D test and then try to find out what will be the conversion?

That was the original but it was not successful. Because that was only successful for first order reactions. Other than first order, it... It is only for linear processes. And for non-linear processes it was not possible and why it was not possible, I will tell you, you know, after some classes, right? But right now this was the idea. And once they had this idea and then did it

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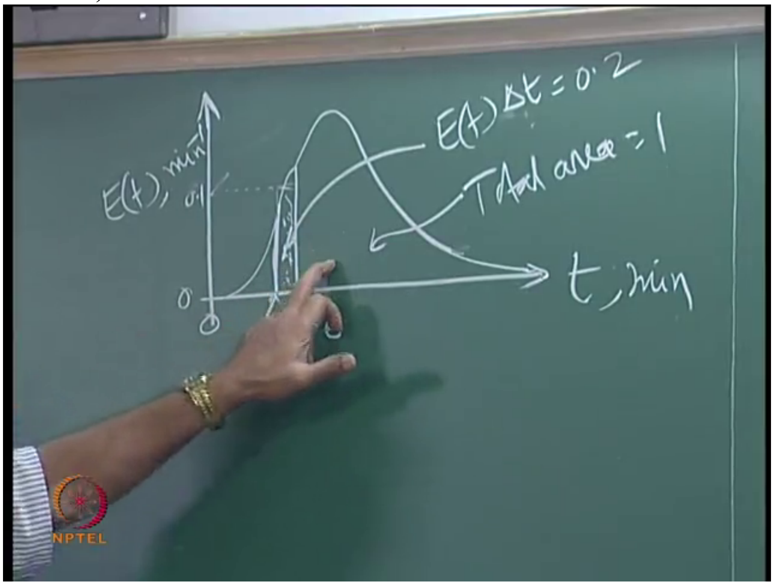

and then tried to calculate what is happening thinking that for all reactions we can do this. They found that, except for first order reactions, other reactions we cannot do. So for second order reaction some more information is required. For half order reaction, some other reaction is required. Ok. So we call what is called micro mixing, macro mixing, so this kind of information is required, right, that is what is micro mixing, macro mixing I have to tell you later. So that is why. This is how it is defined.

So now what is, and E t is called the exit age distribution.

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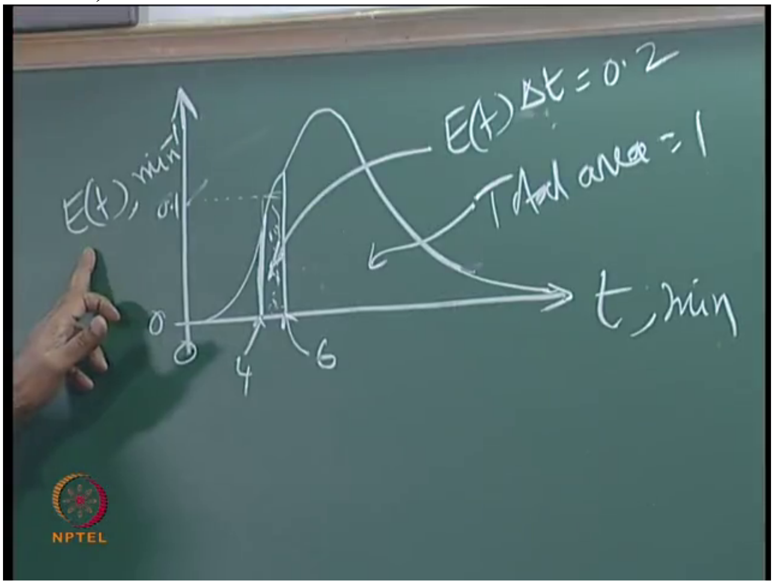

Now we have a definition

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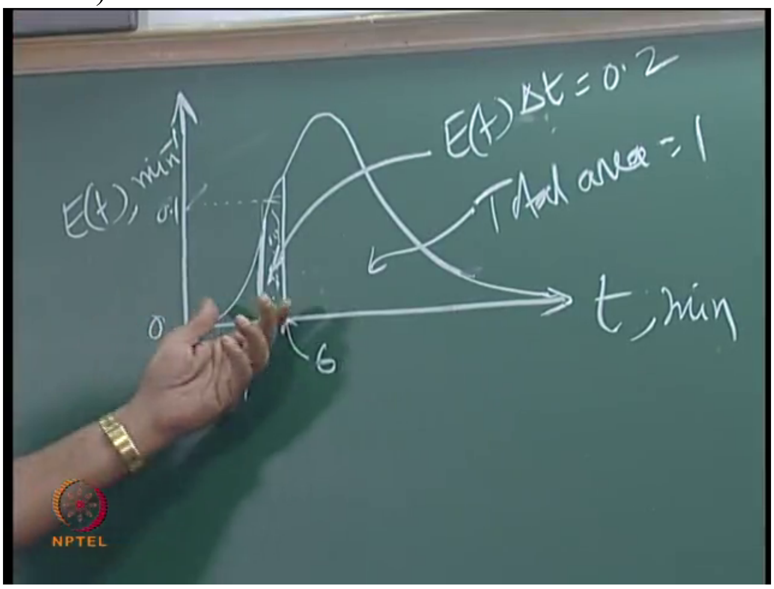

from this figure itself what is the exit age distribution function, because E t is a function, E t is not a fraction. Fraction is only E t delta t. E t delta t is the fraction. That is why please remember, that is where normally students make the error, right?

E t itself they think is that, E t has an equation, that E t also what we will derive, for all systems we can derive equations for E t so that I can predict the, you know, the material coming out between any time t and t plus delta t, right? Ok, please take these definitions now.

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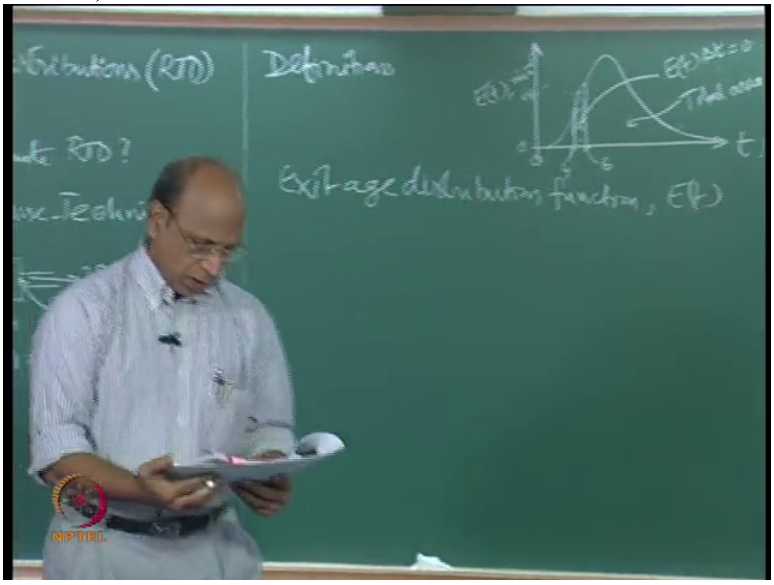

Yeah

So E t, exit age distribution E t, definitions we are writing, exit age distribution, E T, distribution function I think. E t. Yeah. So this is defined as the fraction of material, because we are measuring at the outlet. The fraction of material which spent a time between t and t plus delta t is E t delta t.

Next sentence is E t is called the exit age distribution function. Then next one is you have cumulative age distribution function. Very widely used, these two distri/distribution.

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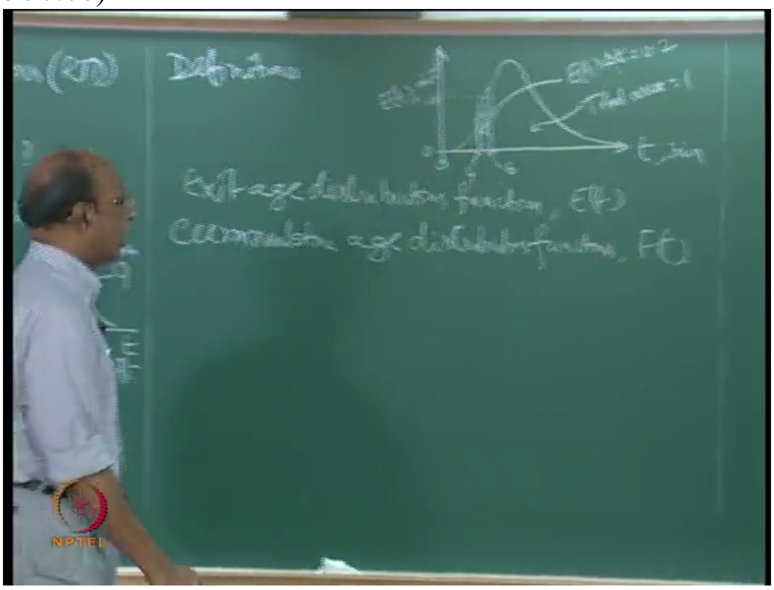

That is called F t. So why we are telling E t and F t, is E t is

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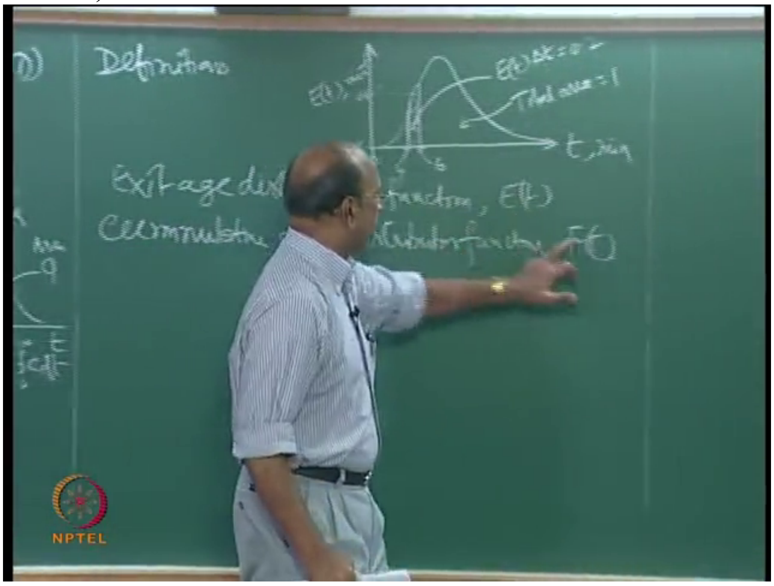

a function of time. And F t also is a function of time.

So once you understand this,

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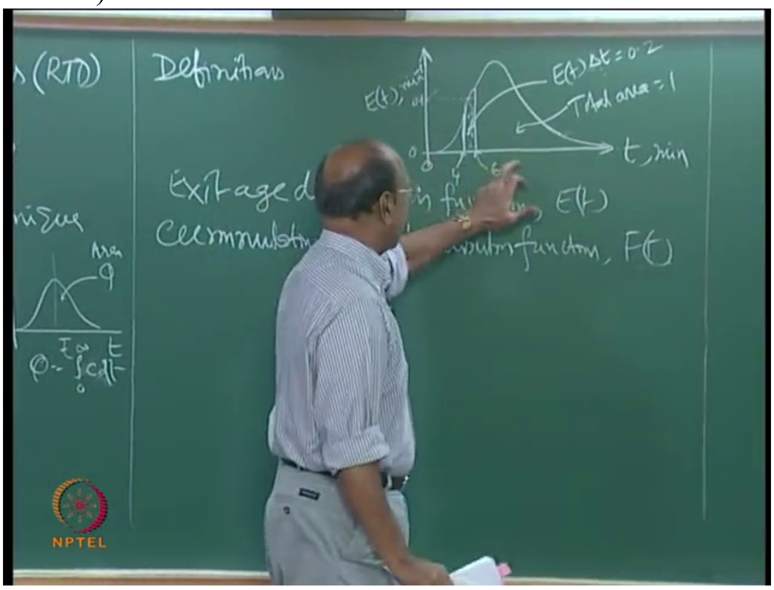

F t is very easy to understand. What is that? It is cumulative. That means I am not talking about between 4 and 6.

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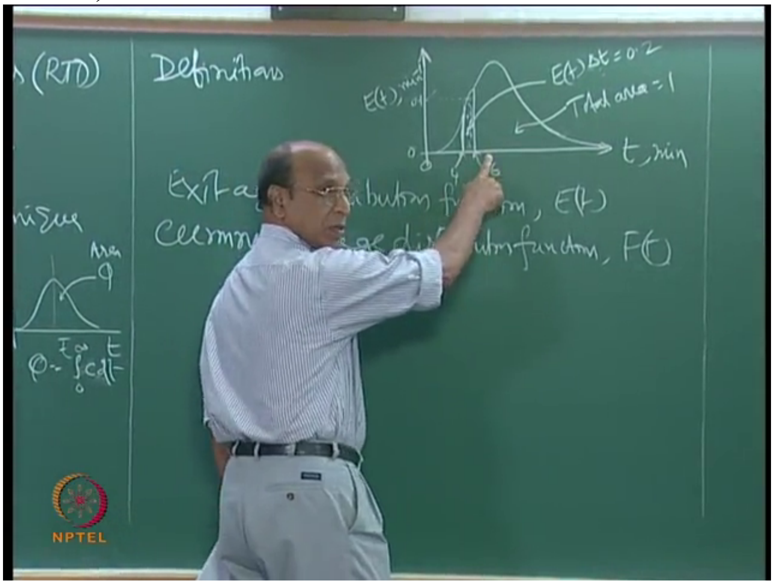

Yeah, from zero to 6. So that means what? This area under the curve, correct no? Yeah, till this area, Ok all this area.

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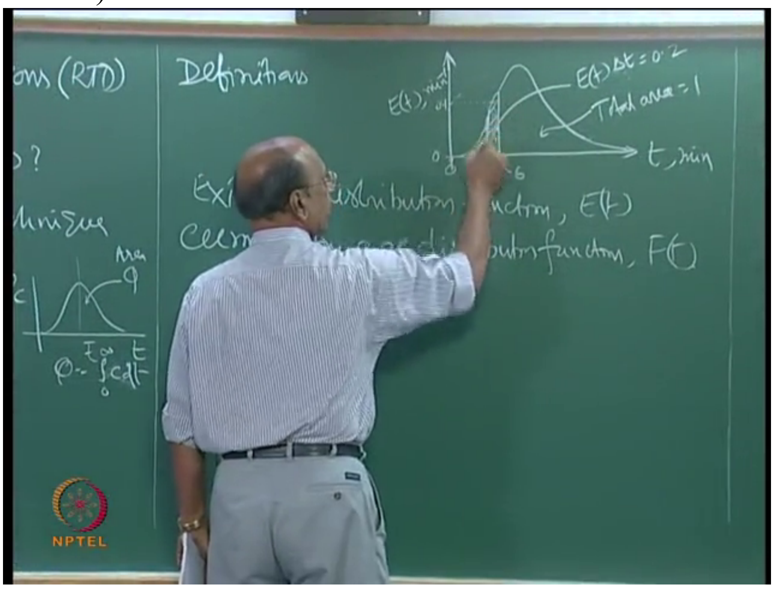

So this will be F t.

So we know, zero to t E t d t, that is the one.

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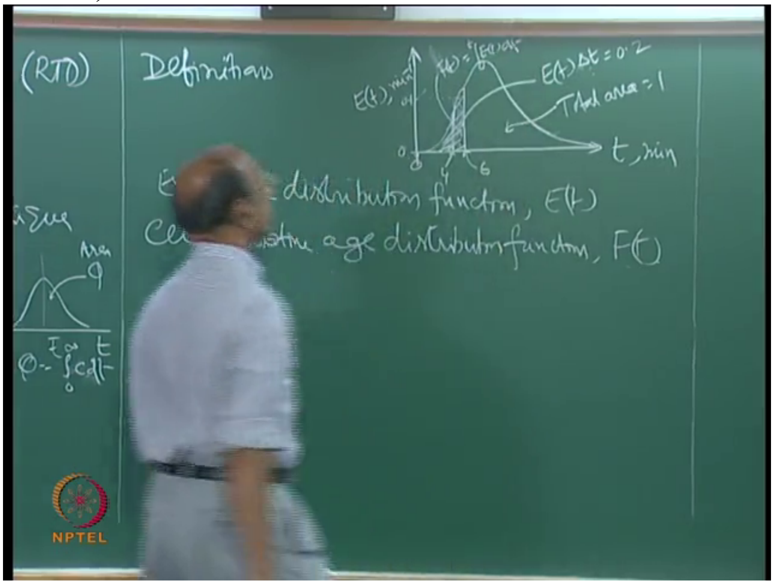

And there F t is called cumulative distribution function. So that also please take, for cumulative distributive function, below that, yeah. The fraction of material in the exit stream which has been in the system for a time less than t is F t. What are units of F t? It is dimensionless. It is a fraction

(Professor – student conversation starts)

Student: Which has been in the system

Professor: Yeah, Which has been in the system for time less than t is F t. Less than t means you know till 6 minutes. That is less than t, no? Yeah till 6 minutes what is the fraction, in this example if I say. So we can also write the same thing as 1 minus F t is what?

Student: t to infinity

Professor: Yeah, right. I think 1 minus F t will be the fraction that is spent inside.

Student: 0:39:50.0

Professor: E t has come out. Yeah, more than 6, from 6 to infinite time. Ok.

(Professor – student conversation ends)

So these are the definitions what we have. And we also have another definition called internal age distribution. Internal age distribution, this is not very widely used, internal age distribution function. Normally represented as I t. This one is the fraction of material which has a time t and t plus delta t inside the reactor.

The other two are exit,

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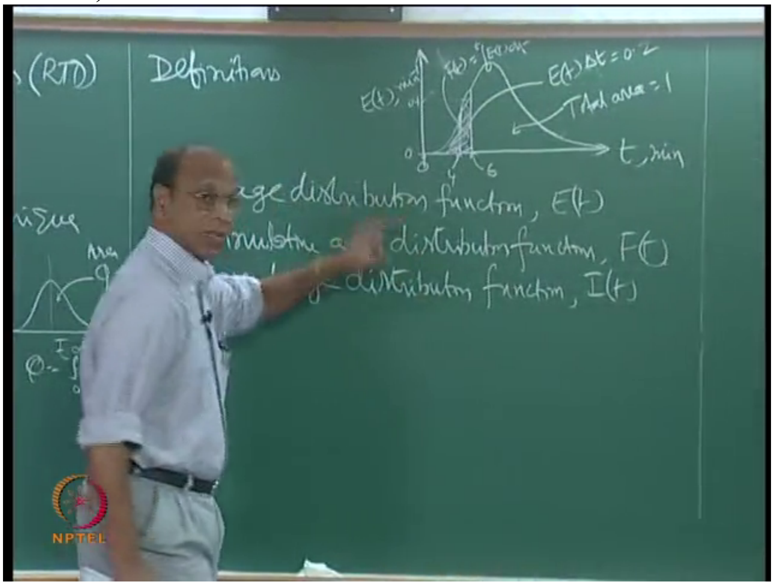

please remember that, exit. This is internal, right. So I mean, Ok, please write that, the fraction of material which has a residence time between t and t plus delta t inside the reactor, t and t plus delta t, already told, yeah inside the reactor is I t delta t. Again that fraction is only I t delta t. Ok. Now then full stop. You have to write I t is called internal age distribution function, internal age distribution.

So, yeah the internal age distribution function

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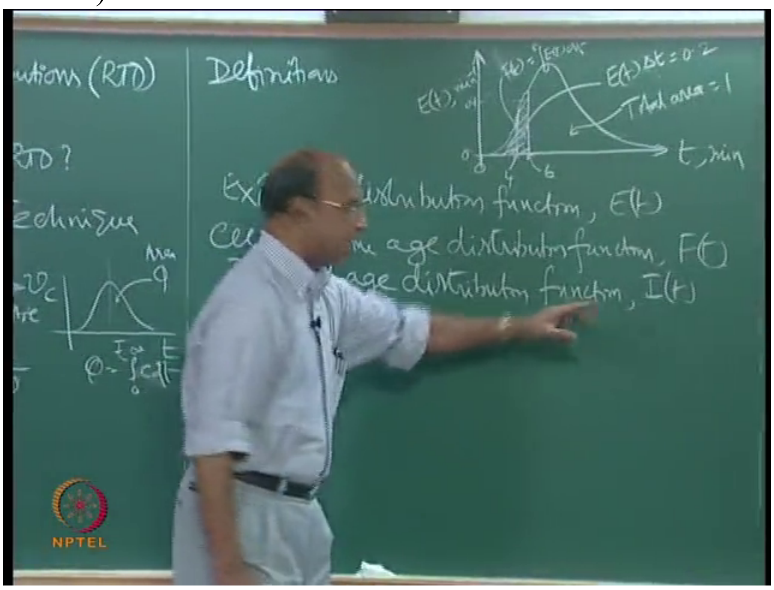


I t is similar to you know in our, I I T, if you assume that may be 1000 people every year entering, 1000 people every year going out in the Convocation, right. So then all the programs we know, I think, you know, how many are people total holdup, that is total?

So inside how many people have spent a time 1 to 2 years. Or may be 1 to 1 and half years. All programs together. And less than 1 year you cannot go. Maximum, minimum time to go out of I I T is, minimum 2 years. And maximum is

(Professor – student conversation starts)

Student: 4 years

Professor: Infinity. No really infinity. We have also given a degree for person who was 17 point 5 years. Yeah and I think some of the B Techs are taking, I think may be 8 years, 9 years, 12 years, something like that, Ok. Anyway there are special cases. You know one or two molecules you know will be there always like that. We should not worry.

If I take, you know the M Tech program, Ok, how the people are moving, is it plug flow or is it mixed flow?

Student: Plug flow

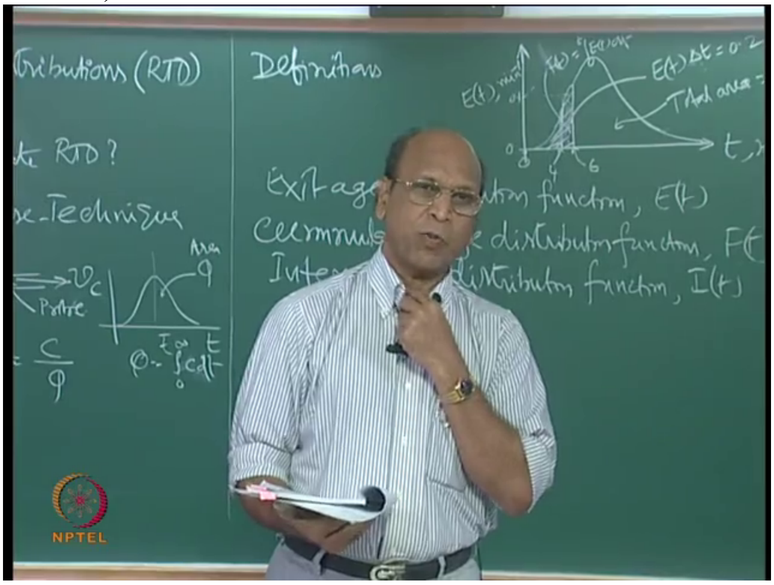
Professor: Why?

Student: They spend...

(Refer Slide Time 42:14)

Professor: Pooja, why plug flow for M Tech?

(Refer Slide Time 42:16)



Student: Yeah, after 2 years...

Student: Same residence time

Professor: Yeah they join in July, and after 2 years in July, they will, all of them will go. Again there may be one particle by some reason that we are not talking. But many people, many people will get...

Student: That is non-ideal...

(Refer Slide Time 42:33)

Professor: That is non-ideal which you can ignore, 1 person, Ok. If there are many, then you have to worry,

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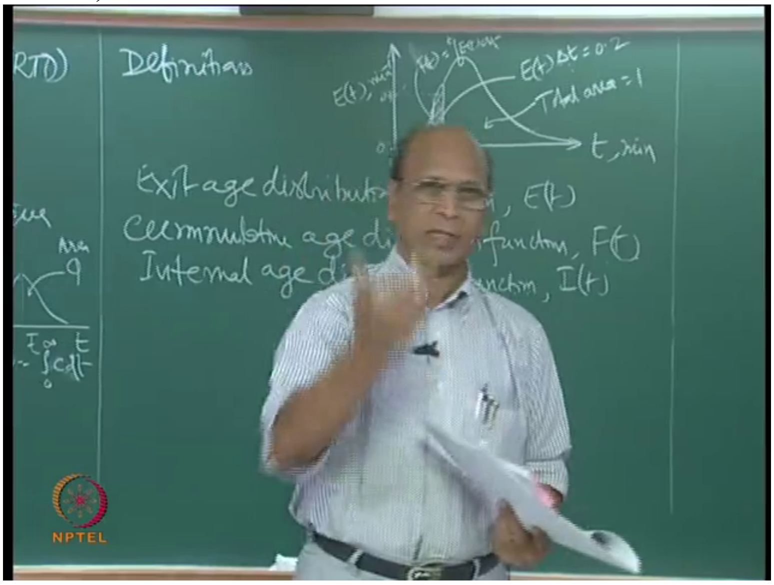

as you said why this dead space? Ok, yeah. Good. So then if you take M S P h D program?

Student: (laugh)

Student: It cannot be told

Professor: You know, then only you remember, I say. Otherwise concepts you will forget, right?

Student: Maximum Distribution

Professor: Yeah, sometimes very large distribution. Ok.

(Professor – student conversation ends)

In fact when I plot this information, every time we plot for Senate after Convocation is over, now, zero time, you know when they enter, it is zero time and the maximum may be 7 years, theoretically speaking, Ok, the time given by Senate. But occasionally we are also allowing in cases where they go beyond 8 years, 9 years and all that.

Now peak is going like this. Not able to follow? Ok. This is zero time. This is 10 years, let us say. So number, this is number. Yeah it goes like this, zero, zero; the average is 5 point 5.

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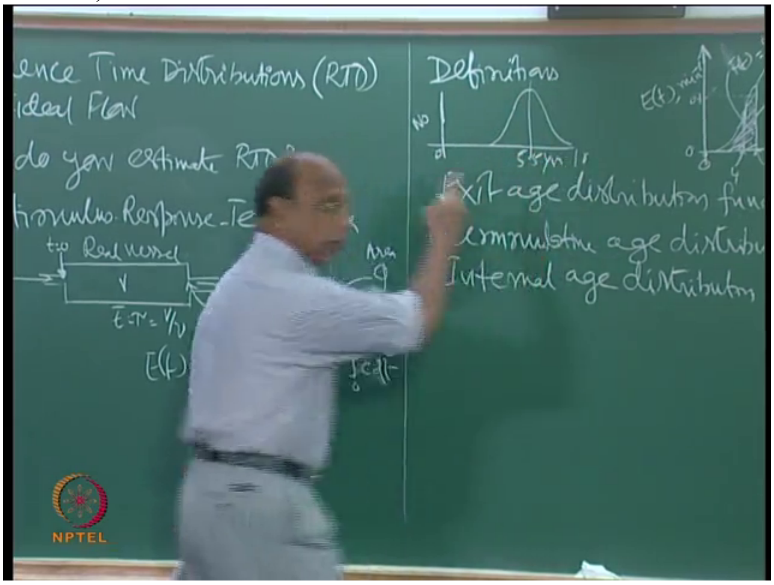

This is for P h D, right?

No, that is what is happening. That is true. You can go and check our websites and all that. We will have this data, may be you are not allowed to Senate minutes. But I think you know Senate minutes we can show them. So that is the distribution. This is exit age distribution. Because after convocation only we are plotting this. It is not inside. Please remember that. It is not inside, it is…

So that means, you know all this time till here, what you call?

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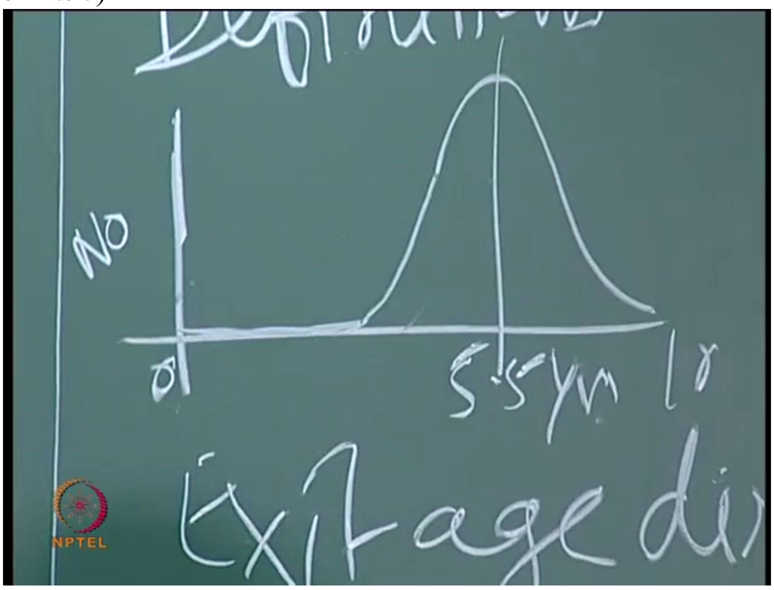

(Professor – student conversation starts)

Student: Time lag

Professor: What?

Student: Time lag

Professor: Time lag. And the real time lag which is given by Senate is only 2 years for P h D and 1 and half years for, 2 years only, no within 2 years you can complete, just after 2 years you can complete P h D. And within 18, just after 18 months, or one and half years you can submit for M S. Beyond that it is not allowed.

(Professor – student conversation ends)

Even though I allowed 1 or 2 people because as Dean, because they have done extraordinary work, I think 3 months before or 2 months before also we allowed them. That means even in 16 months, or 15 months, but there was also a reason.

Because that guy was a project leader. He has done lot of work. So special permission given by Senate and then we allowed that. Right, so this is what is happening. So this is the average,

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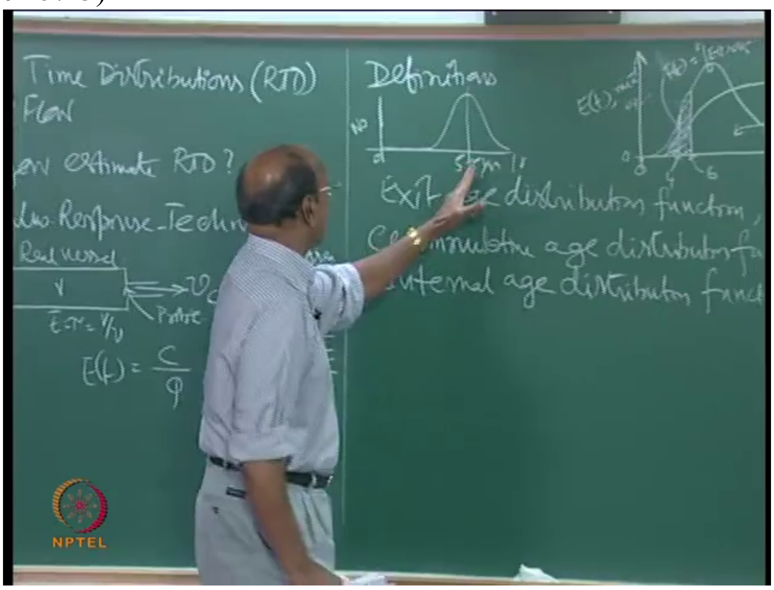

5 point 5 years. Now, and you know this is not for the people who are doing external registration and all that. External registration, they work outside, so it may be difficult, you know for them to do, but this is only our brother and sisters who are on the campus full time. Full time. Full time always.

(Professor – student conversation starts)

Student: (laugh)

Professor: (laugh), Oh yeah. Yeah. So they are there full time, 0:45:49.4 not doing the work. So that is what is happening unfortunately. That is why you know we are trying to call them to, Director, Dean we used to call them and then talk to them why you are taking time and all that.

(Professor – student conversation ends)

So because most of M S P h D scholars should know. Because M S P h D scholars we know only entry time, exit time is not known. Whereas M Tech they cannot stay. Beyond 24 months, they will be thrown out. That is plug flow; this is axial dispersion with tail. 10 years, 16 years I told no, that is tail.

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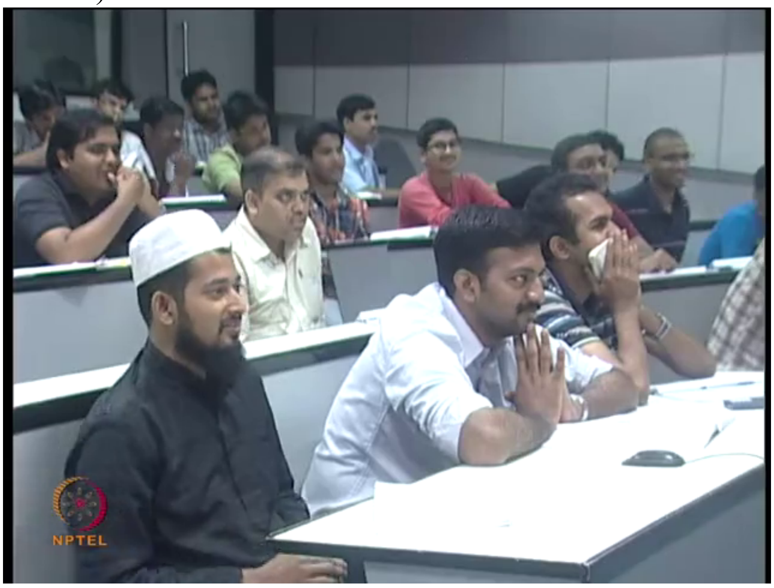

No, bypass is not there.

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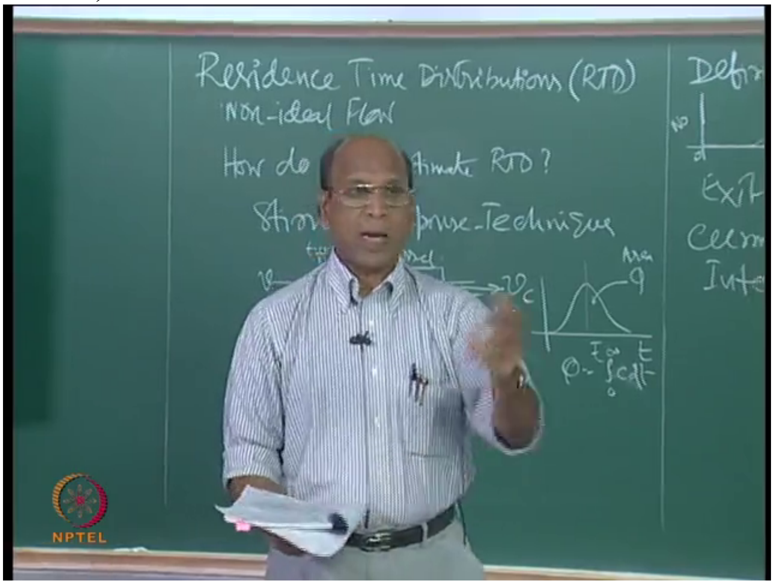

Bypass means that person, I told you...what is that, within minimum time, that should be at least 1 and half years, so that fellow has submitted even within 15 months. That is bypass, Ok. You see, everything is there within us. All R T D can also be explained nicely. So that is the definitions of all these, right?

So

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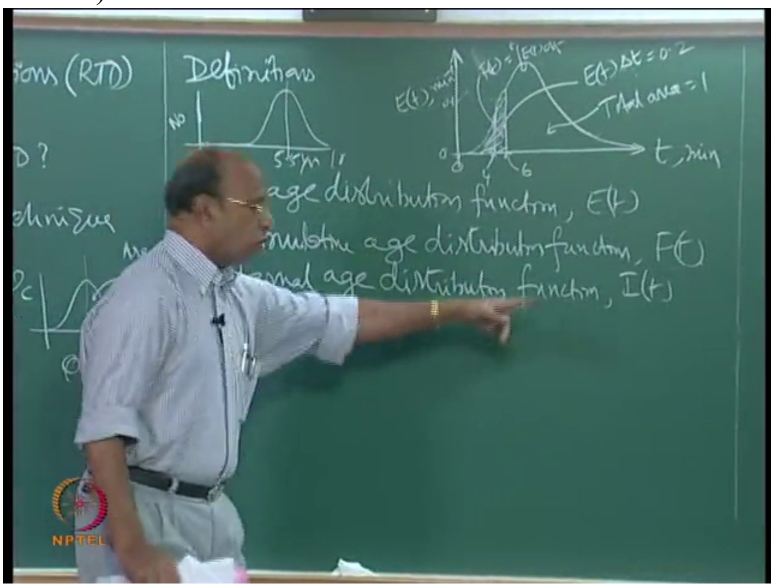

I t we do not use usually except for material balance. There is one equation where we have to use that. This is t bar equal I t to 1 minus F t. Ok. I mean you do not have to worry about how that equation has come. Can anyone tell what is the meaning of that equation?

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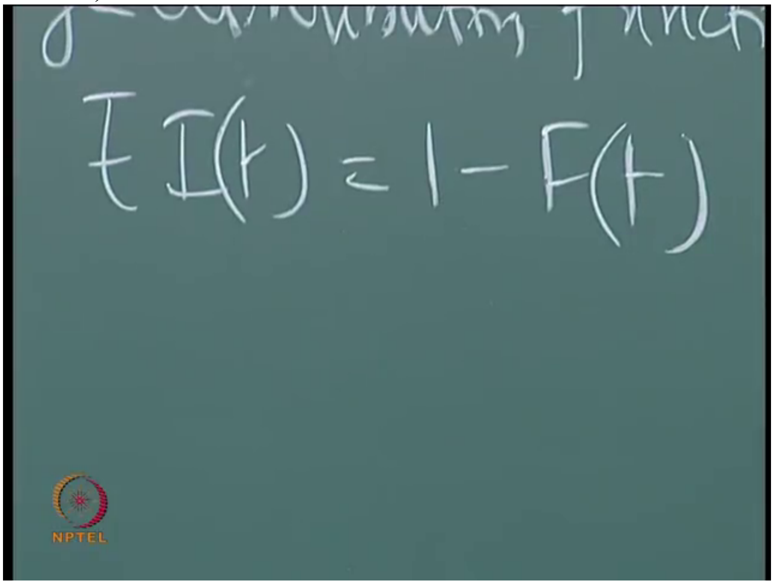

(Professor – student conversation starts)

Student: 0:47:16.3

Professor: First thing, what is F t?

Student: F t is

Professor: What does 1 minus F t?

Student: 0:47:26.0

Professor: Yeah, Pooja?

Student: It will stay inside.

Professor: Yeah, very simple. F t is the fraction which has come out, Ok, at least spent this much time and we are exit. So 1 minus F t of that must be internal. So that is why t bar I t.

(Professor – student conversation ends)

Because we are taking the overall balance, there will not be delta t, there will be t bar. That is all. See the physics of the meaning, no of the equation, meaning of the equation is also simple provided you start thinking, you know. Thinking and trying to understand. Very good, beautiful.

So this one;

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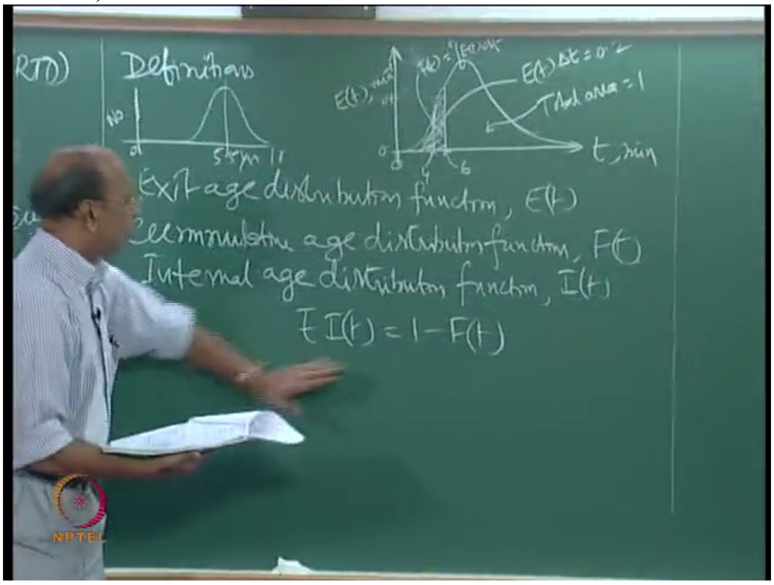

and here

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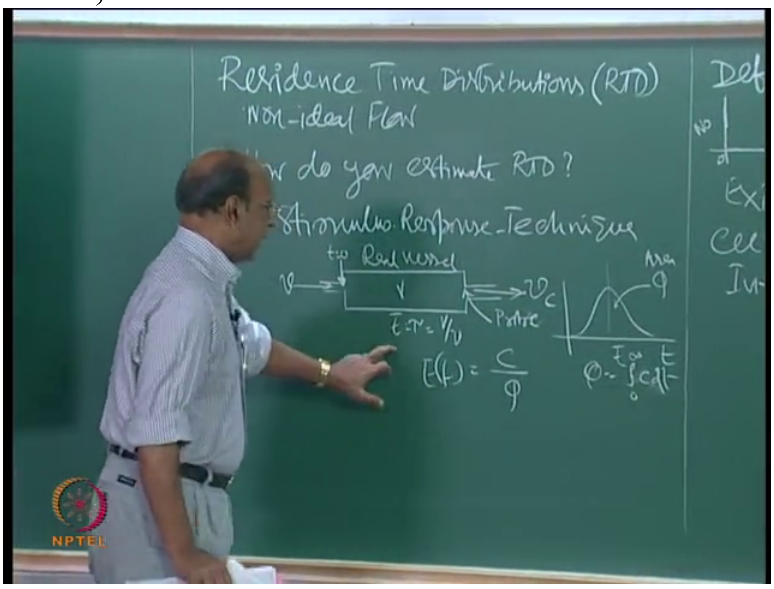

the tracer when we were talking about, so there are also some properties for the tracer, Ok, properties for the tracer. That also, let me write that, properties of tracer here. Yeah what are the, do you know any...

(Professor – student conversation starts)

Student: 0:48:22.4

Professor: Very good, first one will be non-reactive. But I think I will write here. If you are, this itself is enough for everything. Same physical properties, properties as original fluid. Or flowing fluid. Ok that is 1.

(Professor – student conversation ends)

And next one is it should be

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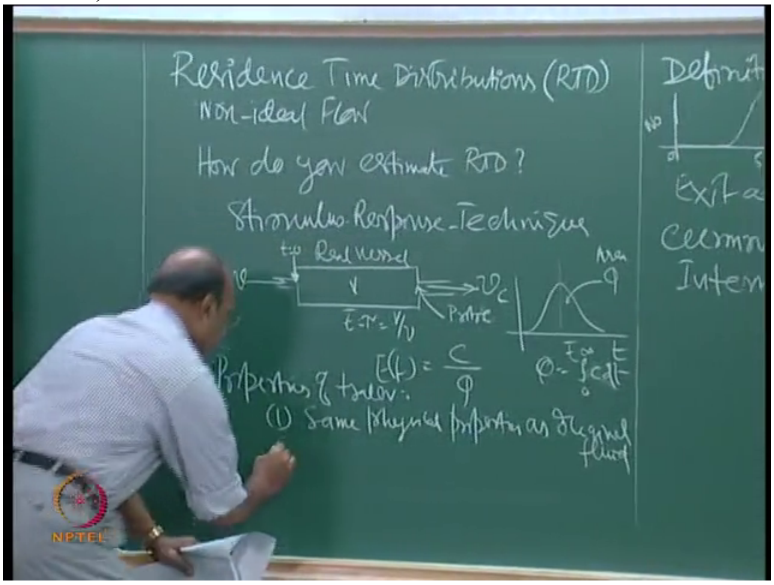

miscible. Sometimes you know it may have the same physical properties, it may not be miscible. Ok. The tracer should be miscible.

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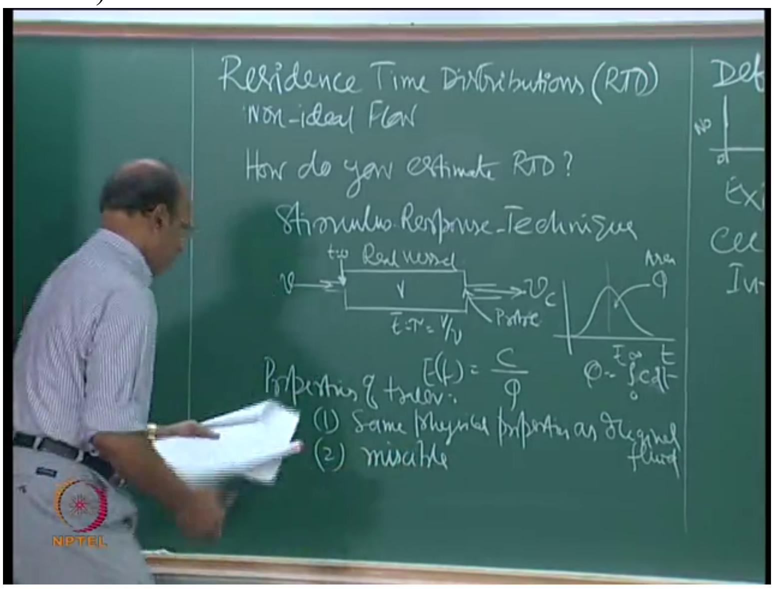

Oh my God! Many things I have to do, I say.

Number 3, yeah, not reactive, should not be reactive.

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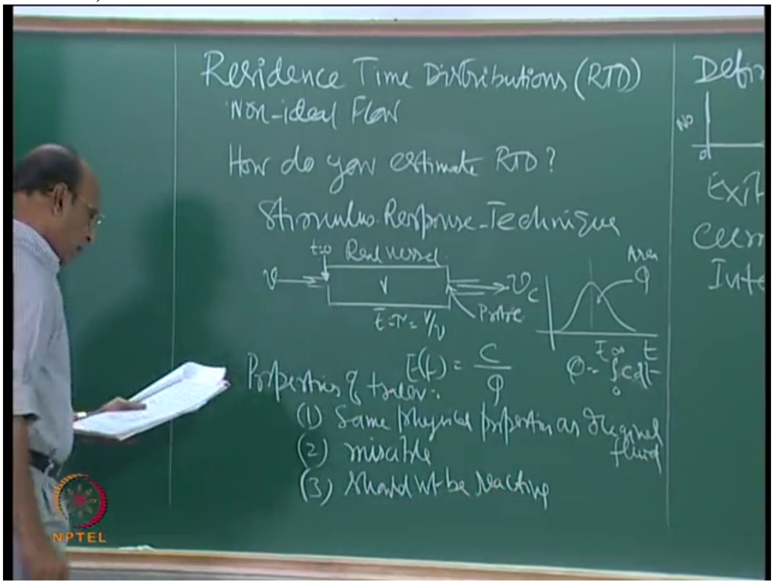

Number 4, should be easily analyzable, should be identified by some technique, yeah, Ok. These are the properties.

But there is another thing,

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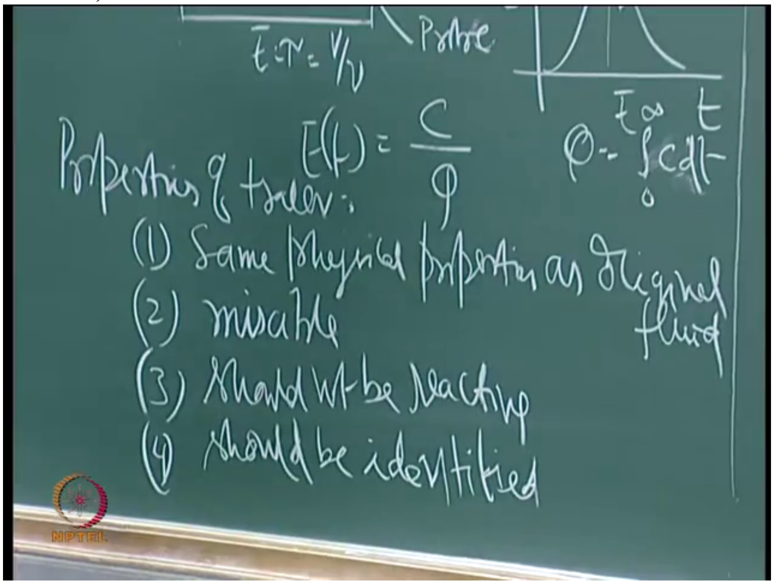

it is not a property but again it is man-made. Ok. So how much quantity you have to add? How much quantity? I have, let us say 5 liter vessel. Yeah, it should be measurable, that is all.

But you should not add, because it is 5 liters, means the tracer volume should not be 10 liters Ok (laugh). That is like, like this World Boxing Champion trying to find out who is good, who is bad on the road. Correct, no? If we use our pulse input, one slap, he is heavyweight boxer…

(Professor – student conversation starts)

Student: (laugh)

Professor: Correct, no? Even if he touches, we will fall, that is all, over. So there the system destroyed. System destroyed, there is no response there. Only one response, dead (laugh).

(Professor – student conversation ends)

So that is why we should not add so much where it disturbs the system, Ok. So the best thing is as what he said, it should be as, with less quantity, recognizable. As less as possible but recognizable, right? That is the kind of tracer amount what we have to add.

And you know this,

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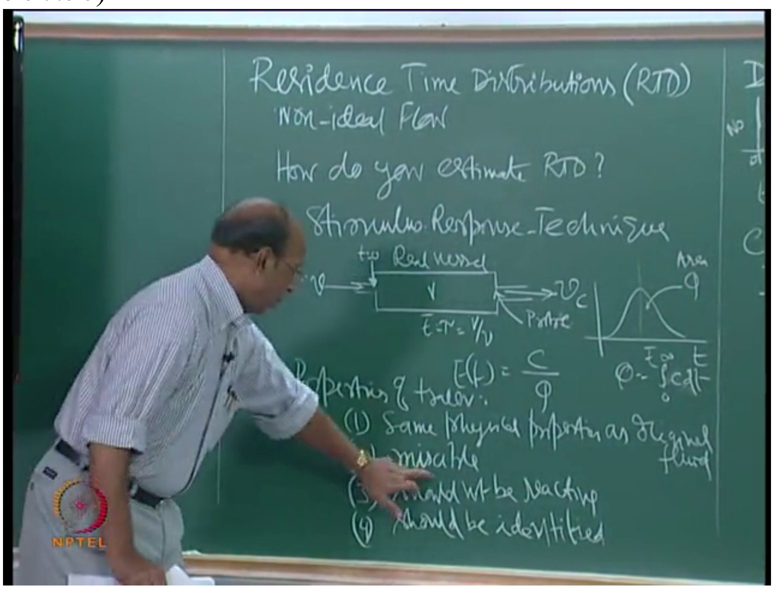

miscibility like I can easily tell you, imagine that it is a simply water flowing and then you added without knowing, mercury as tracer, what will happen? Water is flowing and you do not know. Ok, how to come and 0:51:13.0. You took, mercury was there in the laboratory and....

Yeah it will happily go and sit there. Permanently dead space and you will be waiting, waiting, waiting. Nothing will come. Ok. So that is why that miscibility and all that should be perfect. They should be instantaneously miscible, Ok, good. So these are the properties.

And now why should we plot in this way?

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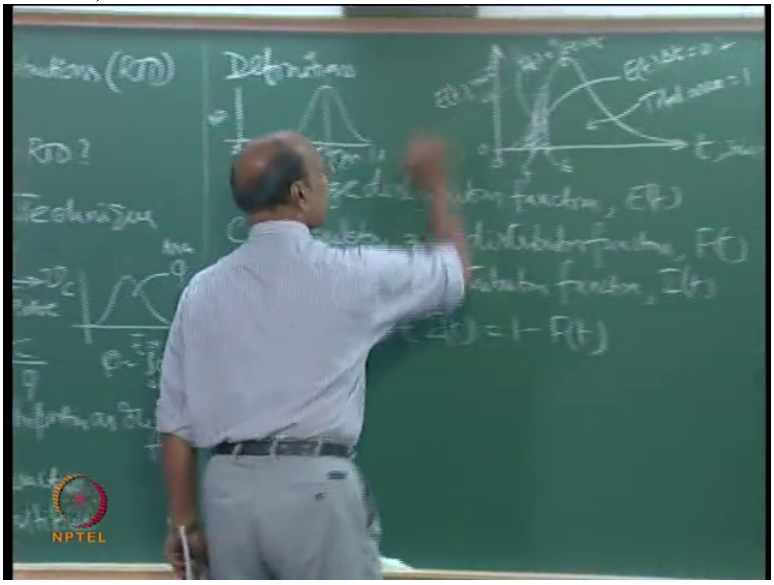

Let us discuss. Ok. That is mathematical description of E t and F t. First let us take F t.

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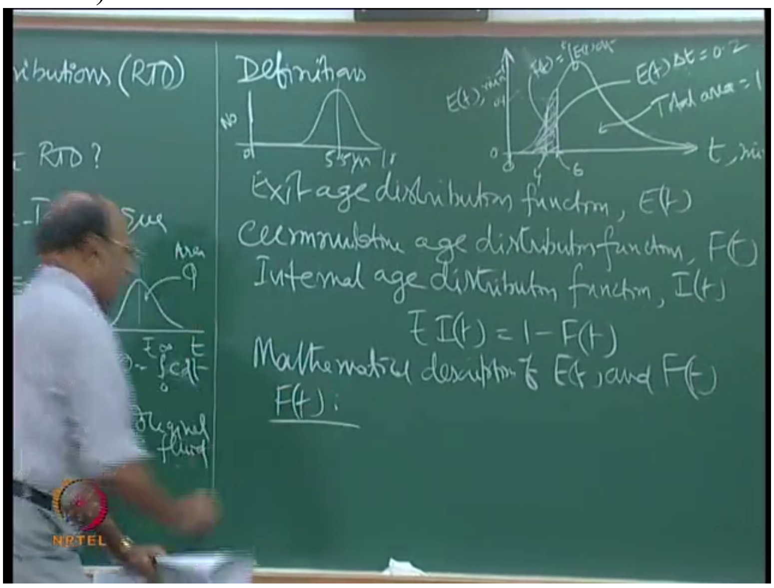

So, and you know that F t, Ok, pulse input will give you always E t and step input will always give you F t. And I think here I have told you about

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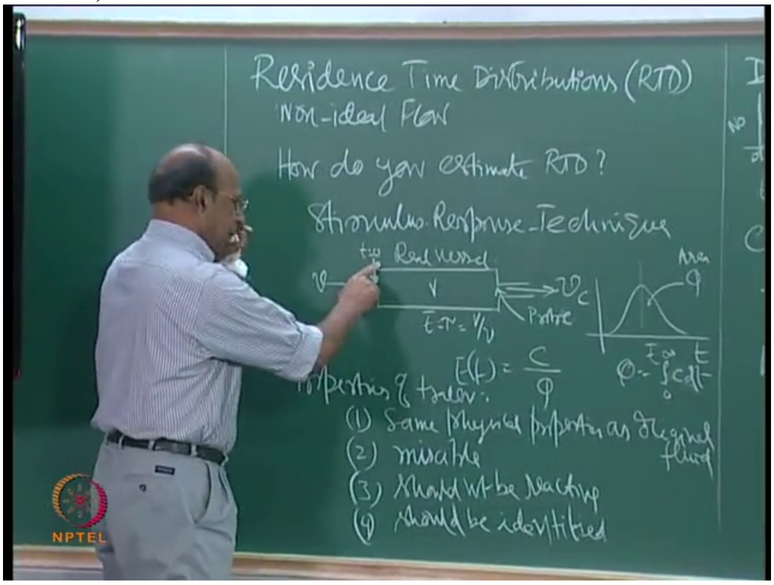

pulse input, but step input, how do you conduct experiments with step input?

Yeah. Go on adding means you cannot go on adding. But what we do is we have here, a normal parallel line, this is tracer,

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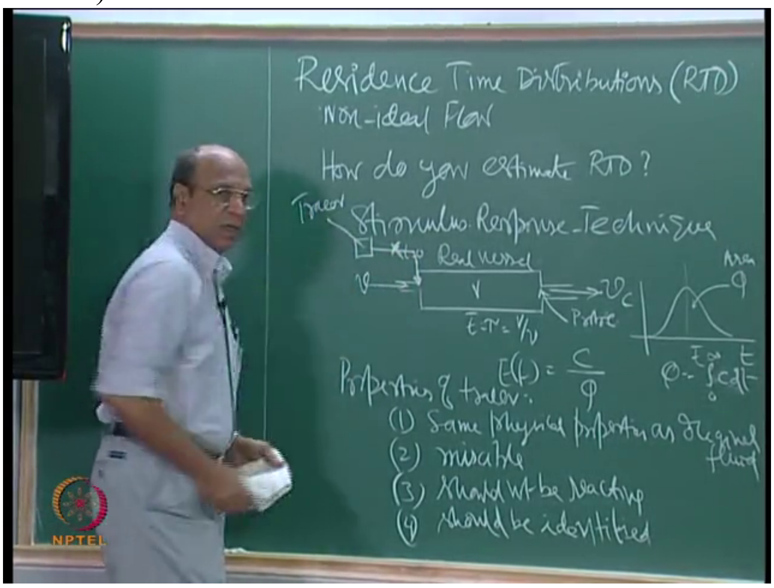

Ok and time t equal to zero, you switch off this and then start this. Ok. And then start that. So now what will happen? If you are imagining that you have a red color, red color now is continuously entering,

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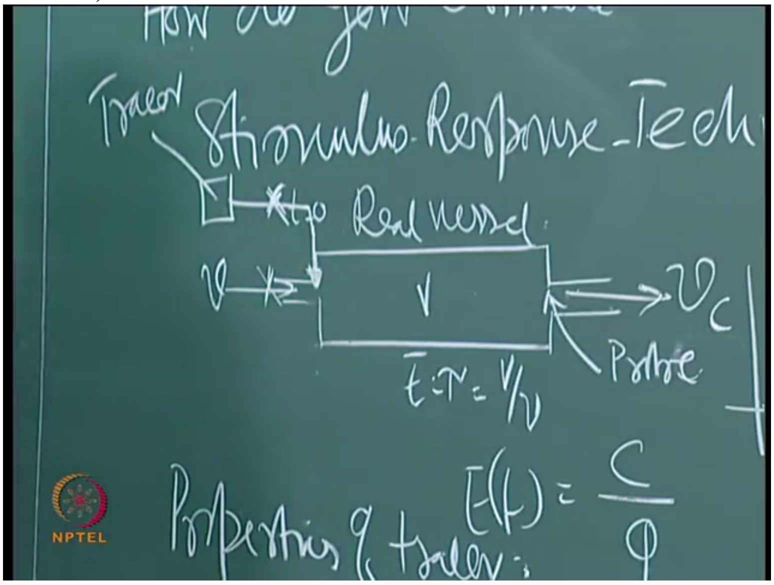

right? And till what time you have to conduct the, conduct the experiment?

(Professor – student conversation starts)

Student: Till all the...

Professor: Yeah till almost all white will come out. That is why it reaches here, concentration will be like this. This is finally the concentration what you have

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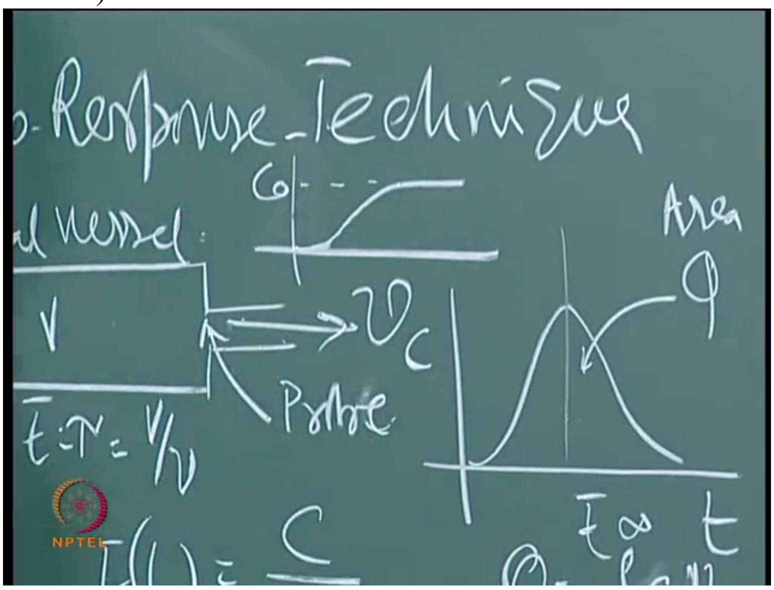

added here, C naught, that is C naught, Ok.

(Professor – student conversation ends)

So this is step input and this is

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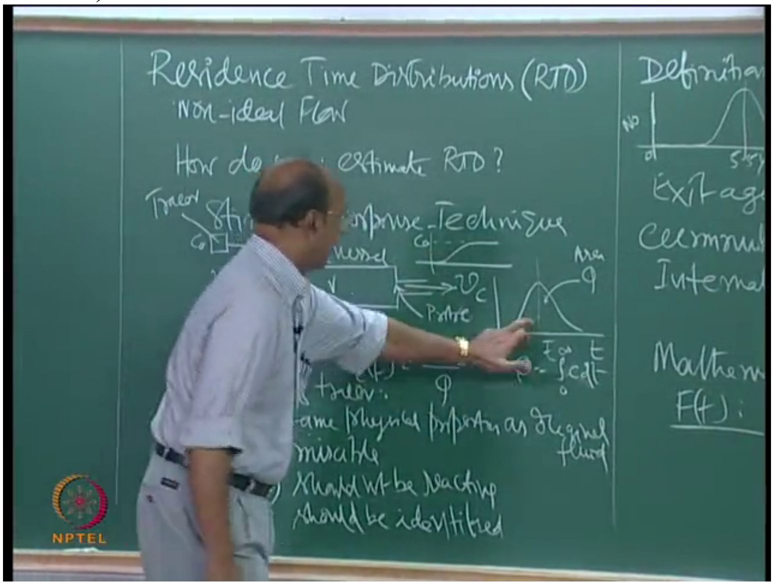

pulse input. So by looking at the curve or

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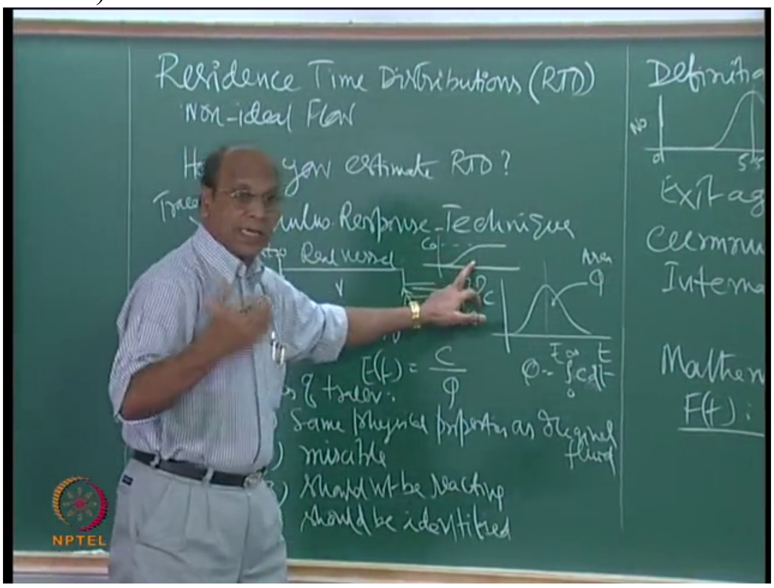

data, if data given to you shows that initially it is increasing, increasing, increasing and then staying some 2-3 values constant. So that means I do not have to tell you which input is that. That is step input.

On the other hand

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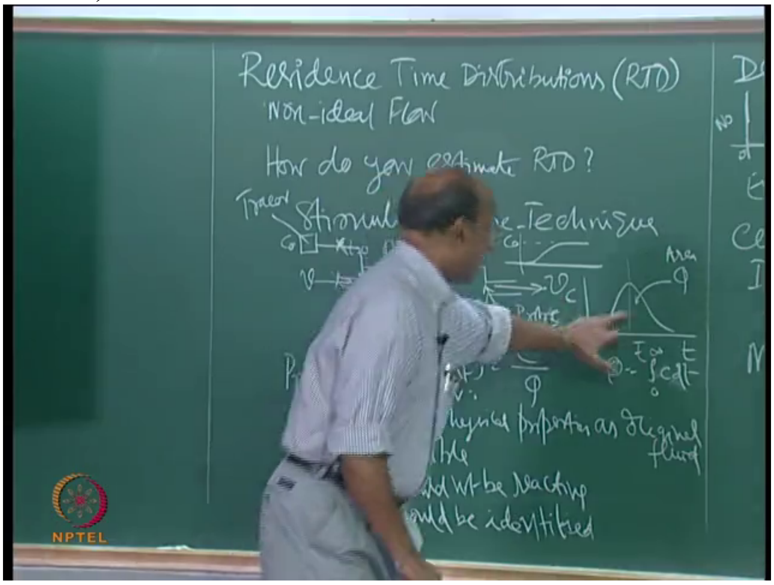

this pulse input data is, first may be zero or very small value, goes up and then comes down and then finally goes to almost zero. It should go to zero, that means otherwise it is not going to zero, meaning is that still there is some tracer inside. So material balance wise it is not correct. It is not correct. That is why you have to conduct the test till all the concentration comes out. Right. Ok.

So this F t will give the step input, F t step input, let me draw here that Ok. This is the one. Ok, yeah here I have C naught, this is coming out. v, v and at time t equal to zero, C equal to C naught, that is my tracer and this is cut off. Ok, both are connected like this.

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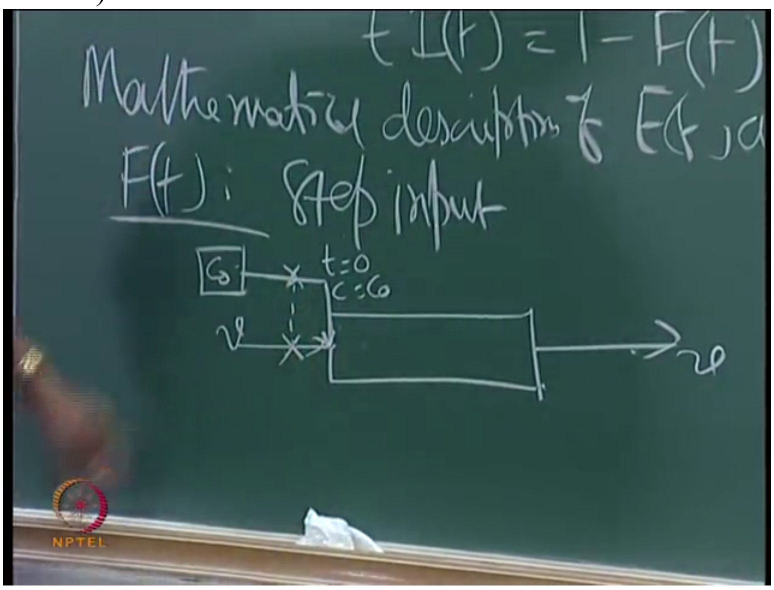

So when this is closed this is open or this is

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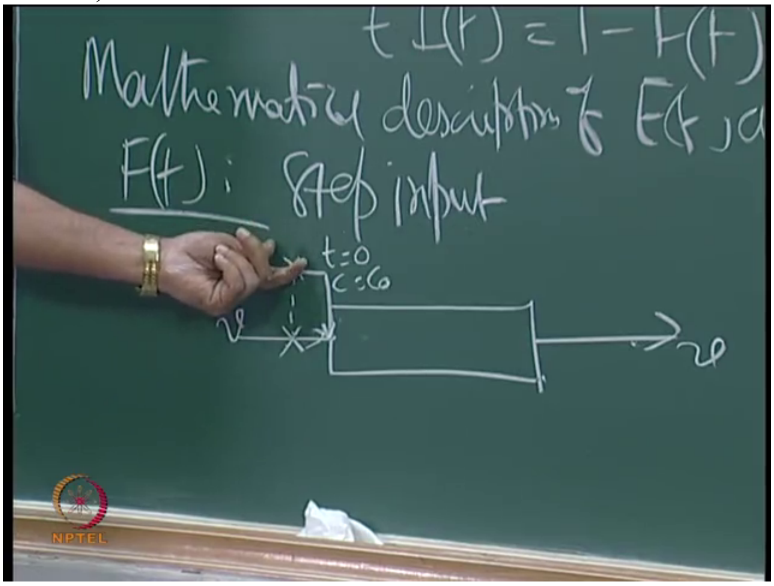

open this is closed. Ok, so what kind of valves you use?

One opening, one closing? Remember, 0:54:52.6 people, many people are happy with 0:54:55.0

(Professor – student conversation starts)
Student: Two-way valve
Professor: Two
Student: Three-way valve.
Professor: Heard of solenoid valves?
Student: Solenoid valves.
Professor: Solenoid valves. When you press that, one will open, the signal goes that the other one should be closed, Ok. Yeah.
(Professor – student conversation ends)

So that is the kind of valves you will have here.

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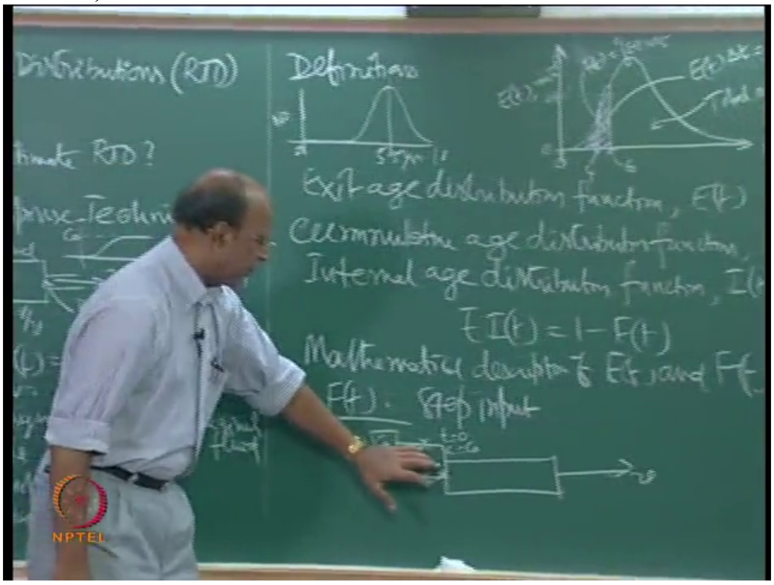

Then you have to conduct here, then this goes like this. This is C naught finally, this is time. Good. So now what we do now here is,

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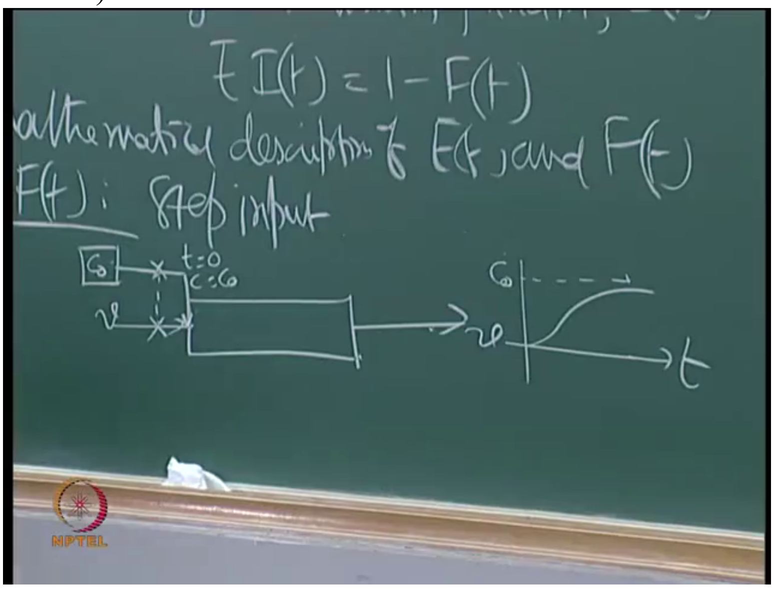

to write the balance, we focus at any particular time here at the outlet, at the outlet we focus. And outlet is only here.

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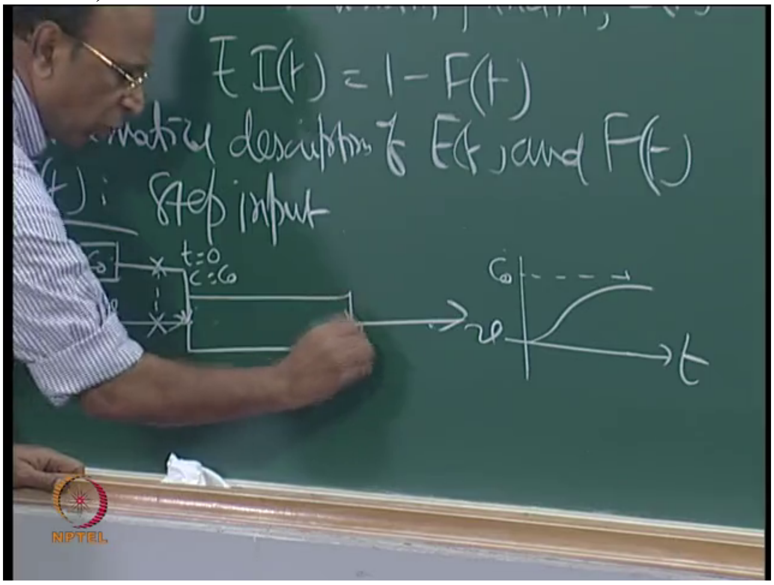

Even though I have shown so much, does not mean you are measuring here. You are only measuring here.

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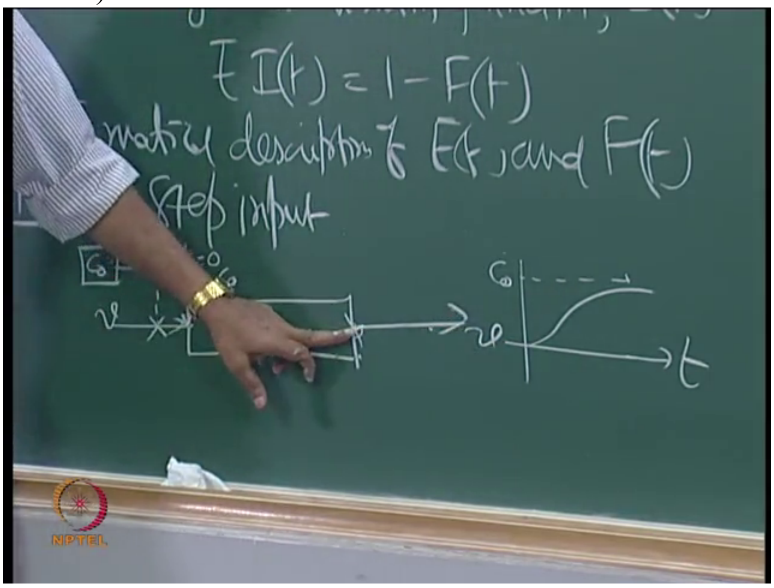

Ok. You are only measuring here, that is.

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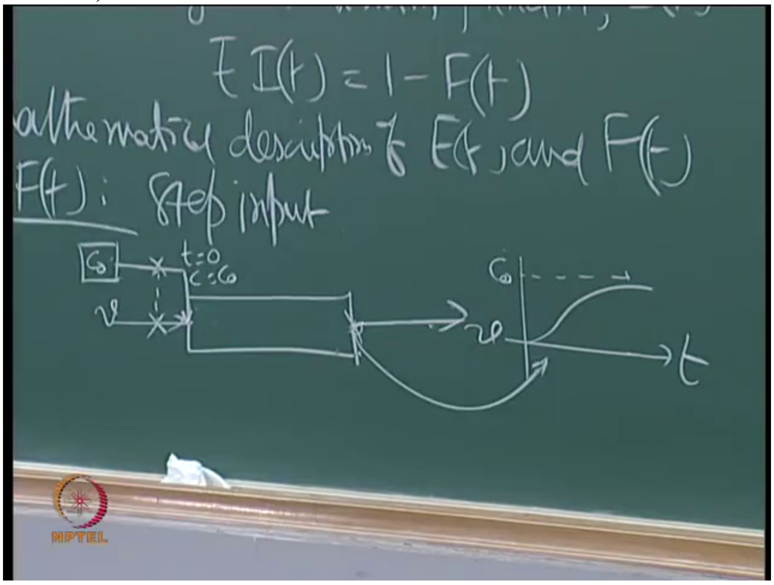

At time, after some time t, after I switched over from normal fluid to my tracer

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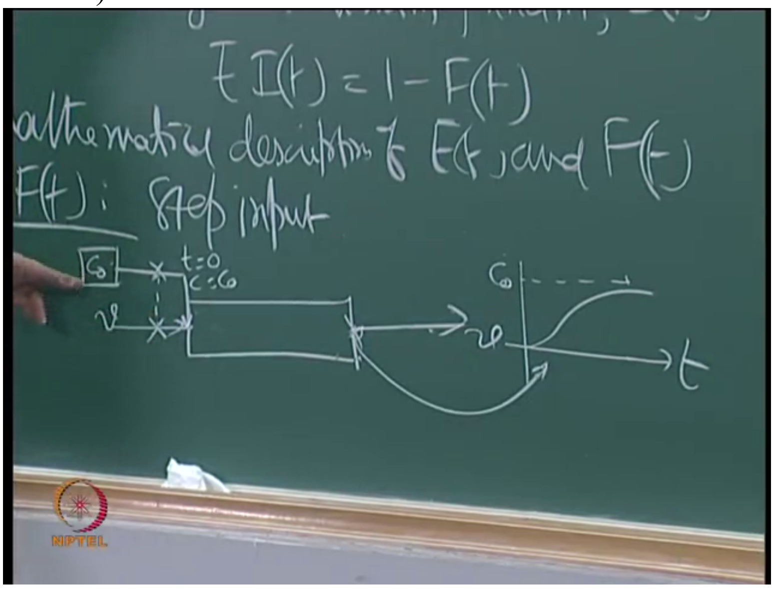

C naught, after some time t I will just imagine here, at the outlet,

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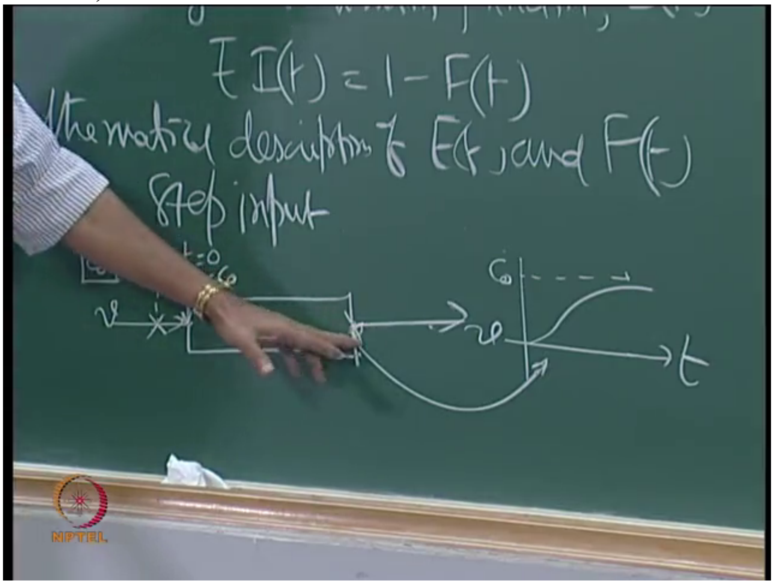

Ok.

What is that imagination? What kind of fluids I have? I have old fluid that means at time t

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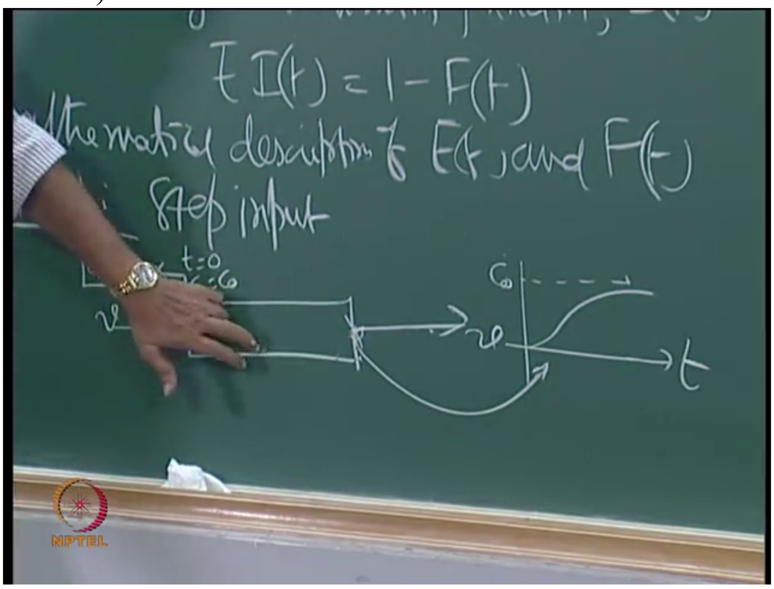

equal to zero that was there inside. We are switching off, no? White fluid switched off. Red fluid started. So now at this point

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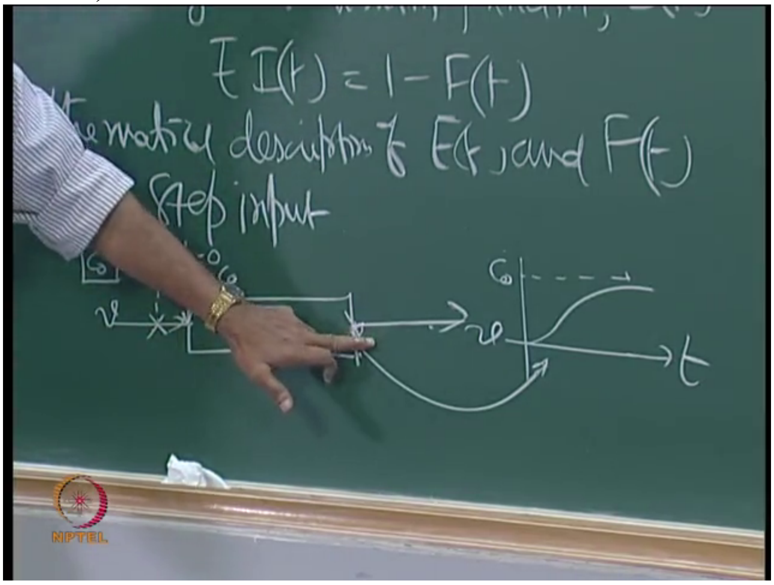

after some time t you cannot, I mean analyze that after infinite time. After infinite time, there will be only red, nothing will be there. Right? Yeah.

So after some time, logical time,

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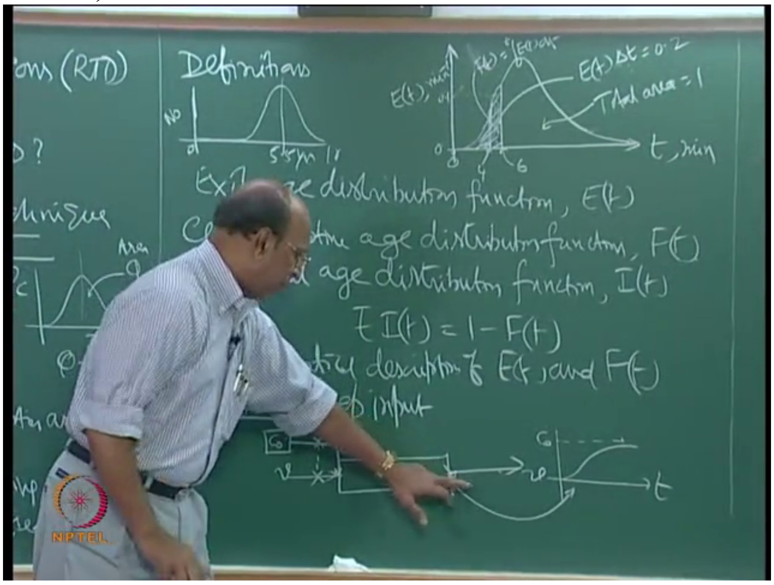

you look at this and then look at the streams, Ok, or stream and then imagine that in your mind you have separated both. What is that separated both? White fluid separately, red fluid separately, Ok.

Now as far as our definition of F t the red fluid is the fraction of material which has spent a time less than t because that t is I have decided. That is F t. What is the concentration in that?

What is the concentration of red material? C naught. Correct no? C naught only. What is the concentration of red material in the white fluid, in the other stream?

(Professor – student conversation starts)

Student: Zero

Professor: Zero. That is the balance only we are just making. Right and here, yeah, Ok that balance is, you understand no, v plus, sorry, v into F t C naught plus v into, in fact the other one is 1 minus F t. You remember this?

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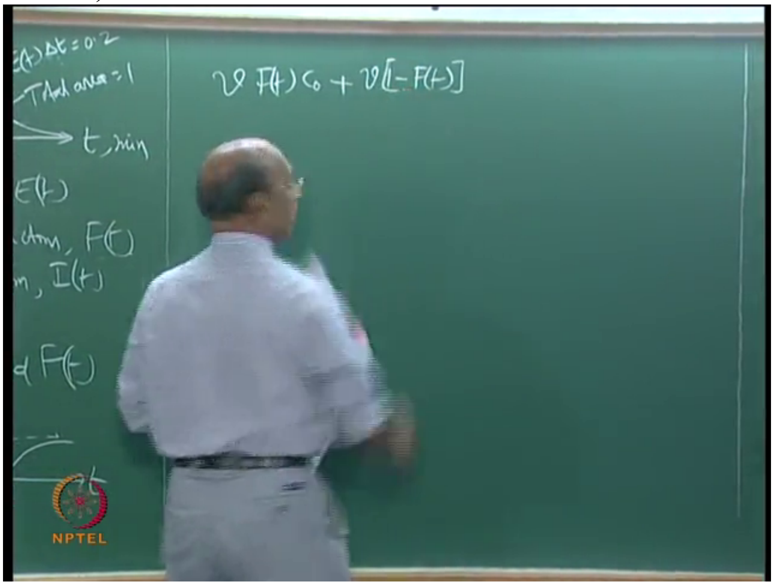

(Professor – student conversation ends)

See at this point of time,

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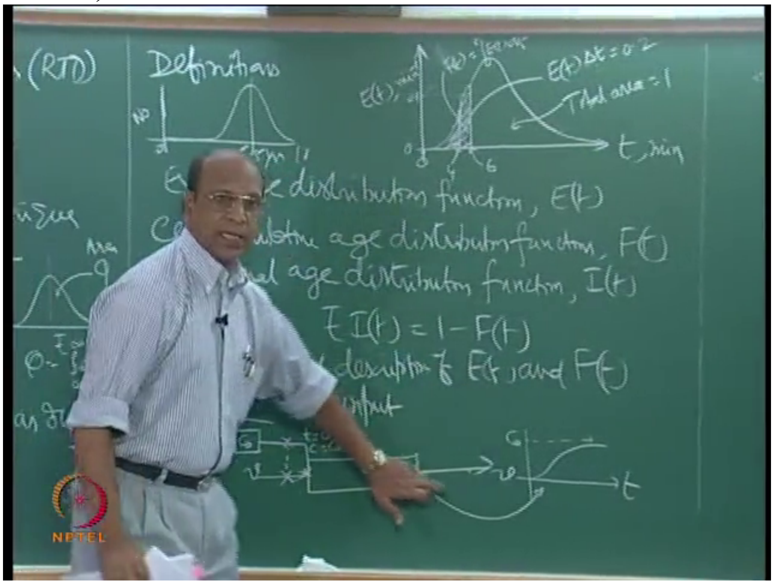

I think, do not get confused. 0:57:27.5. You already confused. Looks like that. Correct, no? Yeah. So what is that you have not understood here?

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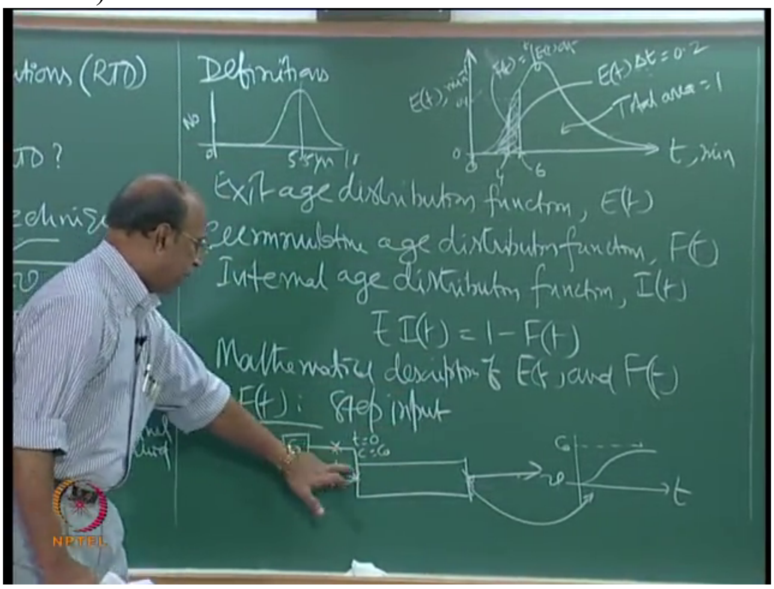

At time t equal to zero I am sending red fluid. Right. And white fluid is stopped. So that means the entire

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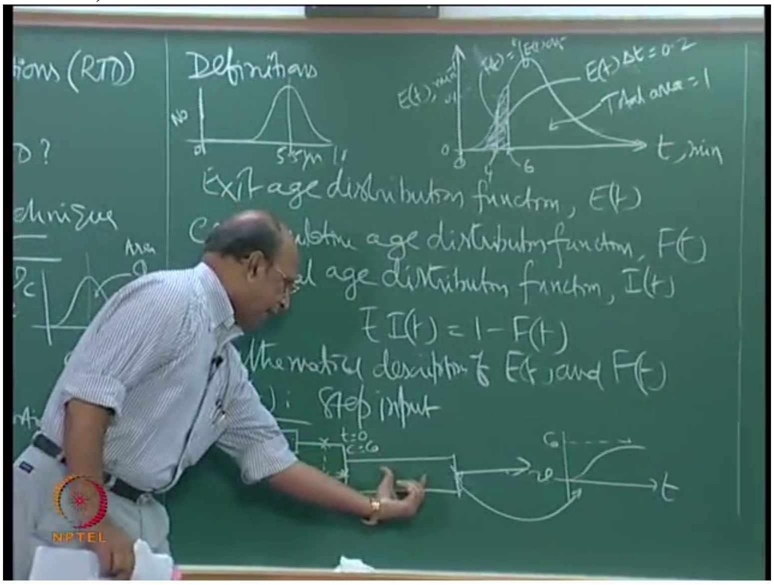

thing at time t equal to zero, at that instant, is only red fluid, sorry white fluid. Red fluid just entered.

Then depending on the kind of mixing, and whatever, we do not know what is happening inside, depending on conditions there, you will get mixture of red fluid and

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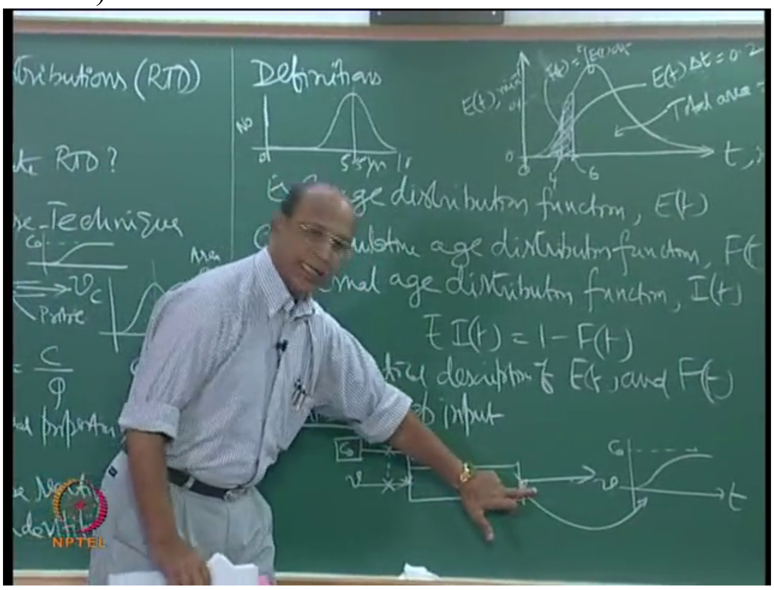

white fluid at this point, various times. I am talking about, Ok, after 5 minutes what has happened.

At fifth minute I have taken some sample and then looked at that, right? So that contains white and red. Now I separated those two, mentally, right. So the separated one, red one is the material which has spent a time less than t, that for 5 minutes. Because red fluid started coming only 5 minutes back, correct no, till then only white fluid was coming, right? Yeah. So then that is F t.

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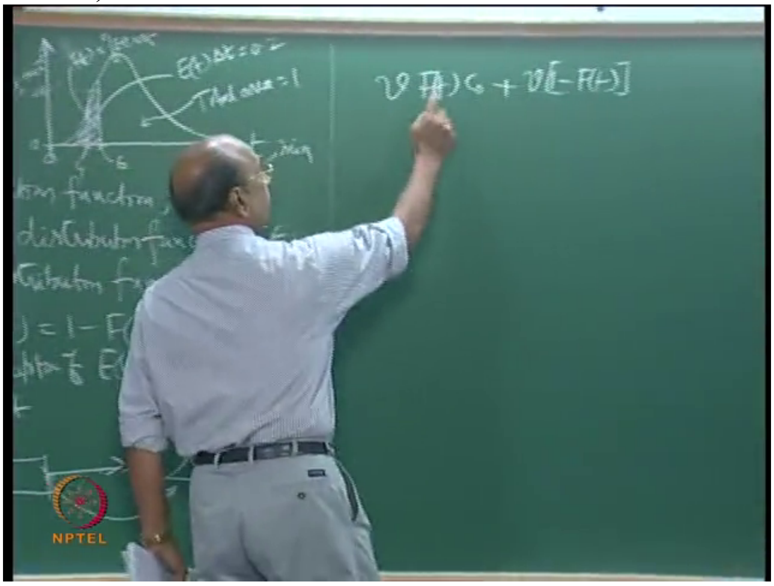

What is the concentration in that? C naught. And total flow will be, yeah, I think you can calculate and tell me, I mean sorry you can put the dimensions and tell me what is concentration units? Yeah, moles or grams, you know in tracer we will say grams, Ok grams per?

(Professor – student conversation starts)

Student: Moles per unit volume

Student: Seconds

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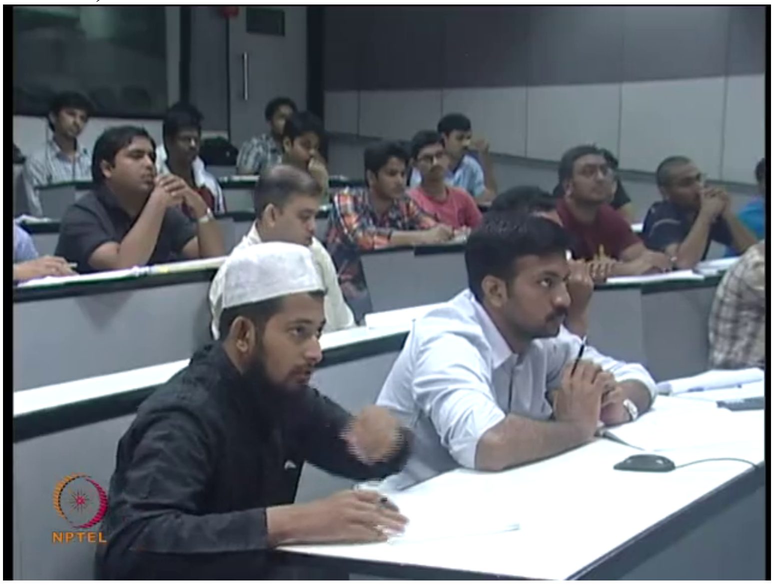

Professor: Concentration I say?

Student: Grams per liter.

Professor: Yeah grams per liter and volumetric flow rate?

Student: Liter per second.

Professor: So what is the overall flow rate? Yeah, it is only grams per...Mass balance that is tracer mass balance, tracer M B. That is what

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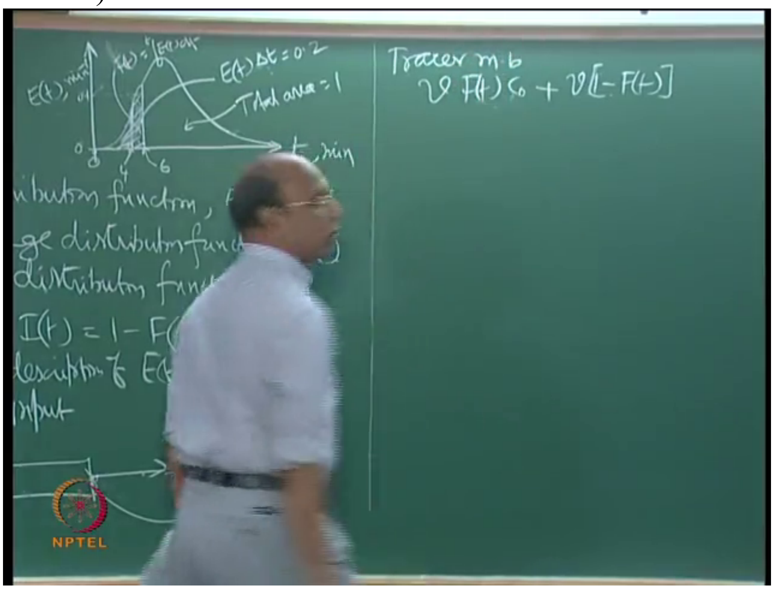

what we are writing. Right, that is one.

(Professor – student conversation ends)

And the other fraction, 0:59:15.9,

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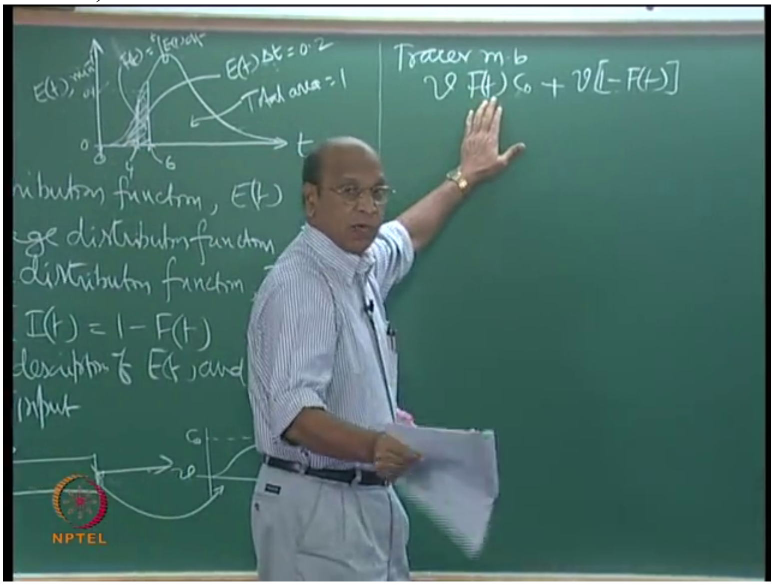

what is the other fraction? This is for red. What is the other fraction?

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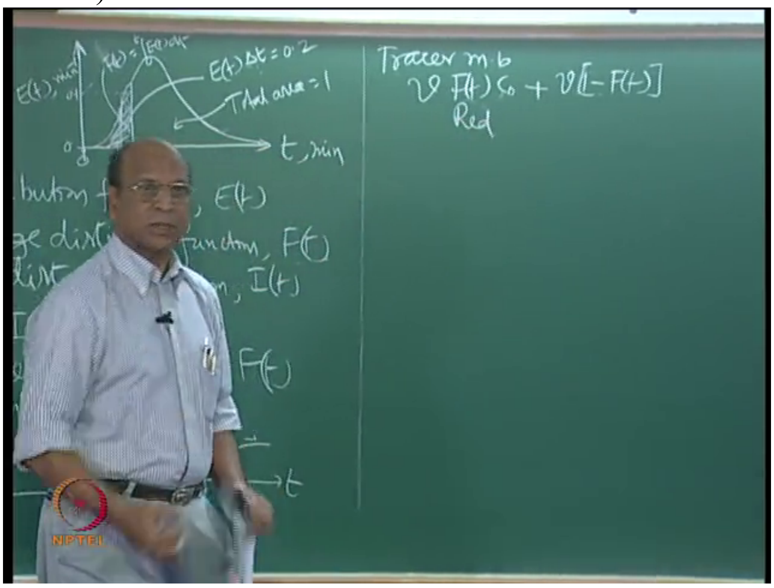

White. So that means this white would have entered t minutes before, correct no? Because at times t equal to zero or 5 minutes before, there was no red fluid, only white fluid.

What is the concentration of red fluid in that, in that particular 1 minus F t? Zero. So this will be zero.

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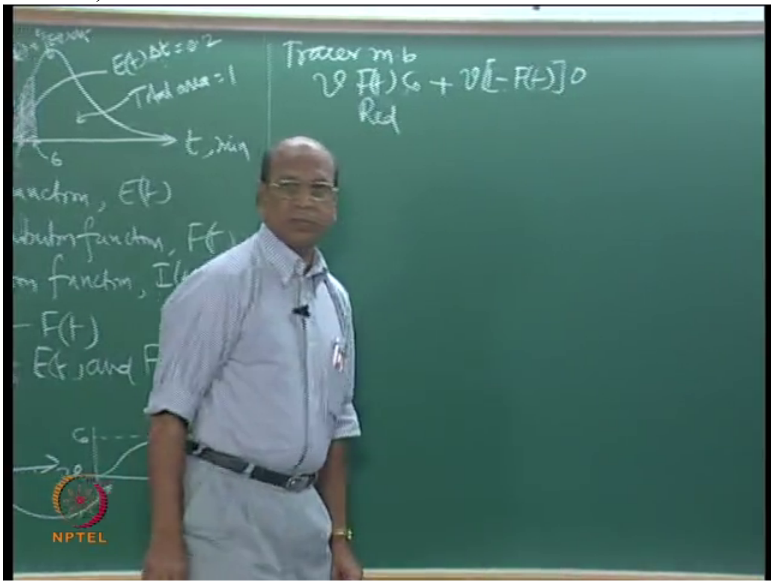

Concentration equal to zero. Because we are writing only balance for tracer. Tracer is red, right, Ok. So now this entire thing equal to what we see here, v into C.

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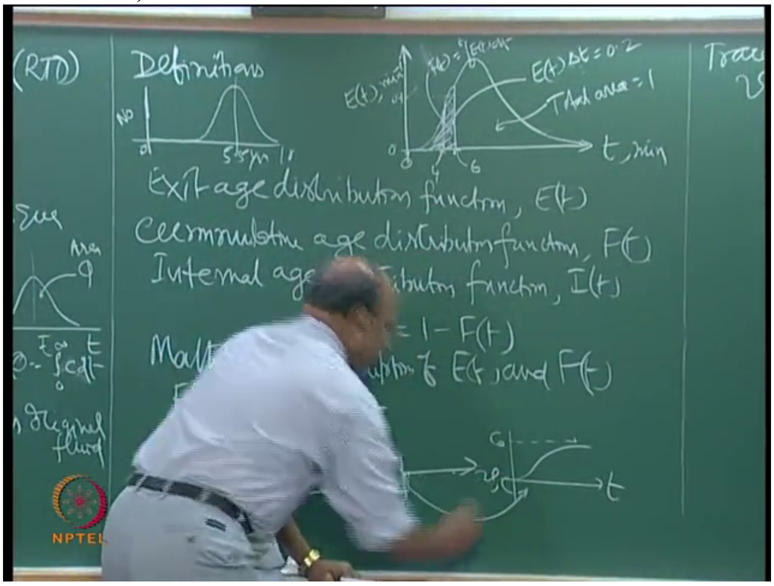

Correct no?

(Professor – student conversation starts)

Student: But how can it be C naught? Outside 1:00:13.7 say for example, the tracer comes out; it may not be the initial concentration.

Professor: I separated. The whole picture is that, that stream I have separated, red fluid separately and white fluid separately.

(Professor – student conversation ends)

Because red fluid entered only exactly 5 minutes before. And that means when you are measuring at the outlet, 5 minutes, I mean at the time of fifth minute, all that fraction that you collected till 5 minutes would have entered only 5 minutes before or would have spent only 5 minutes. That is the definition of F t.

(Refer Slide Time 01:00:46)

That is the definition of F t.

So that is why, yeah this balance, this is white fluid, yeah, so this total equal to v into C.

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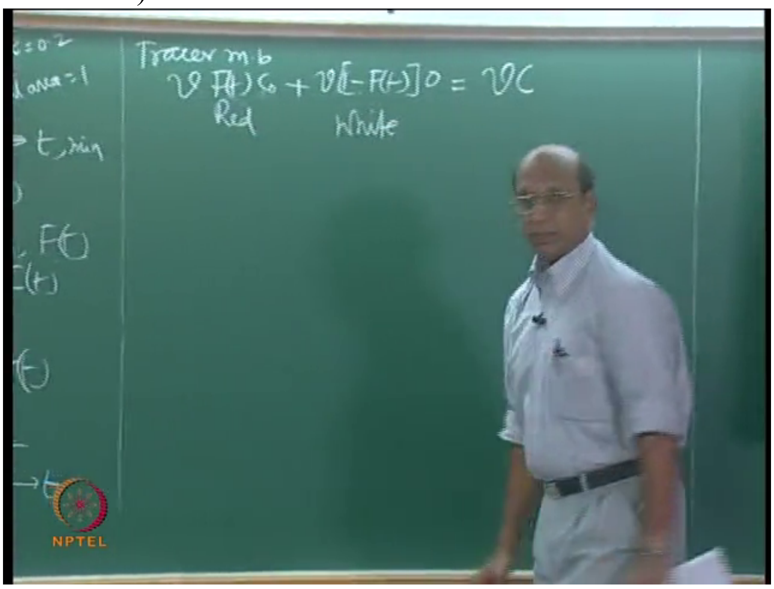

What are units of v into C? v is again moles per second and concentration is , sorry...v is liters per second and concentration is

(Professor – student conversation starts)

Student: Moles per liter

Professor: So again you will get mass balance, right? Arya, Ok? Yeah. So this is the one. This entire thing is zero. So v, v will get cancelled. Then what is F t?

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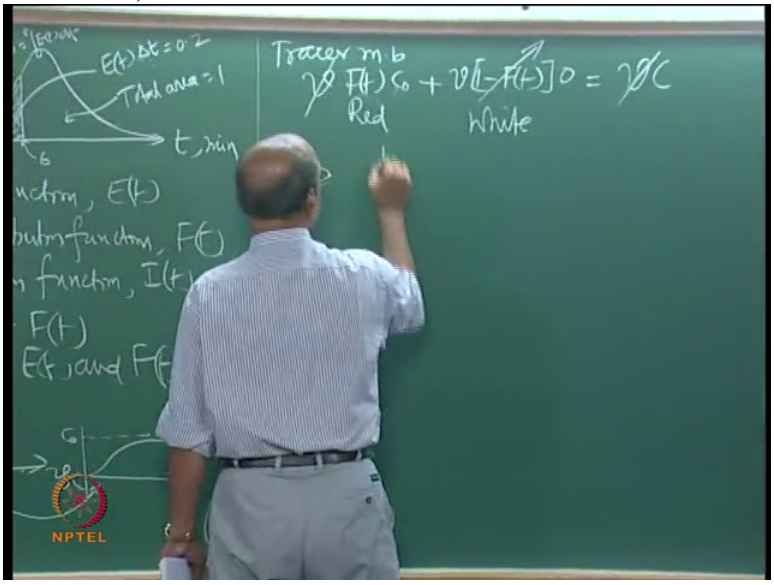

C by C naught.

(Professor – student conversation ends)

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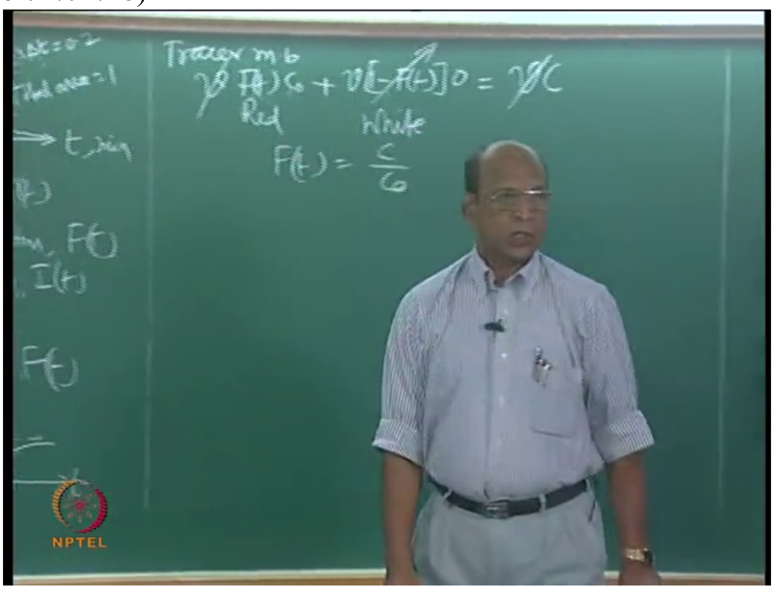

So you conduct step input experiment and then plot C by C naught because you are measuring every time C

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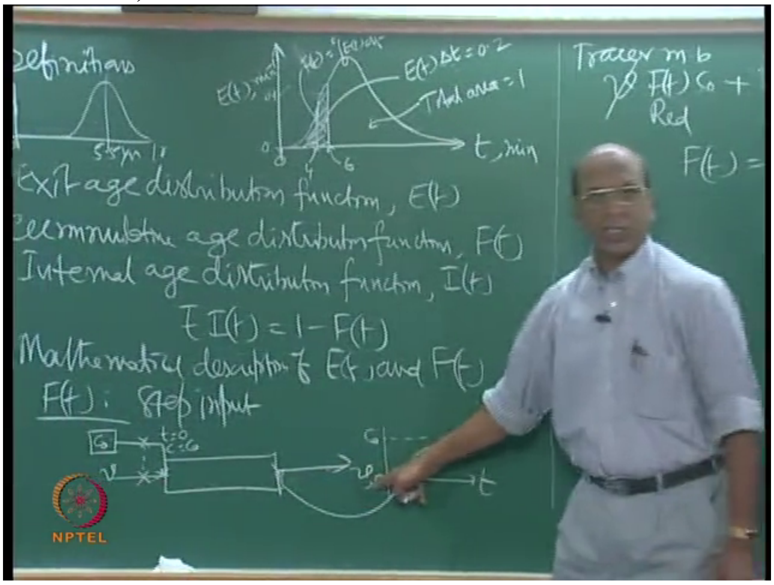

continuously. If it is a probe, continuously it gives you C. Otherwise you have to take samples and then measure. C you know, right, C naught you know,

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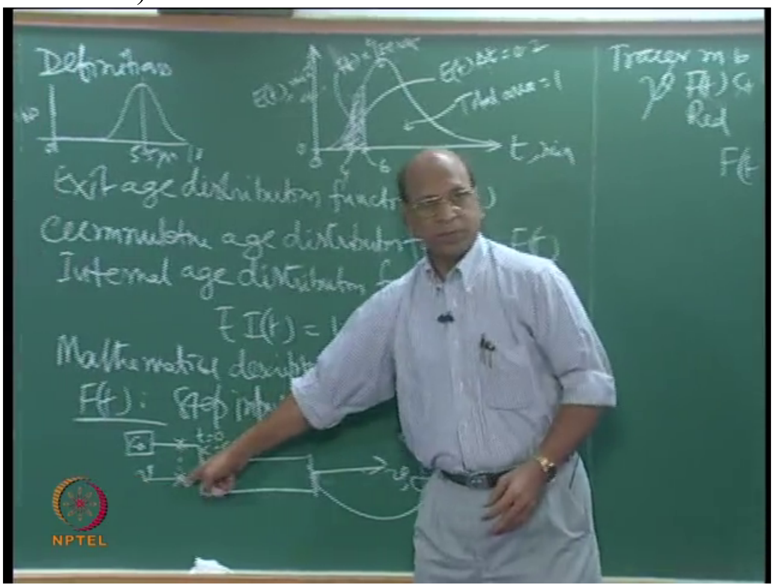

and if you do that one, you will get a curve something like this. Sorry.

What is this value? Very good.

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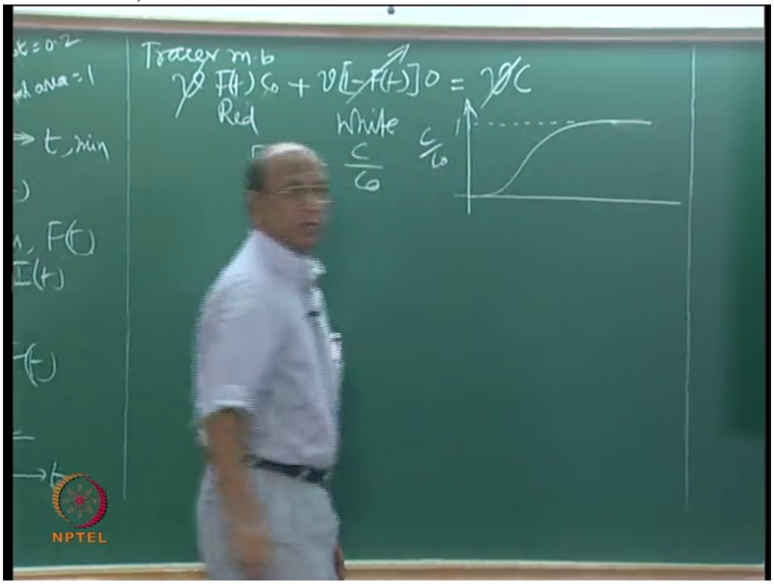

That value will be 1. And what I have shown here is only,

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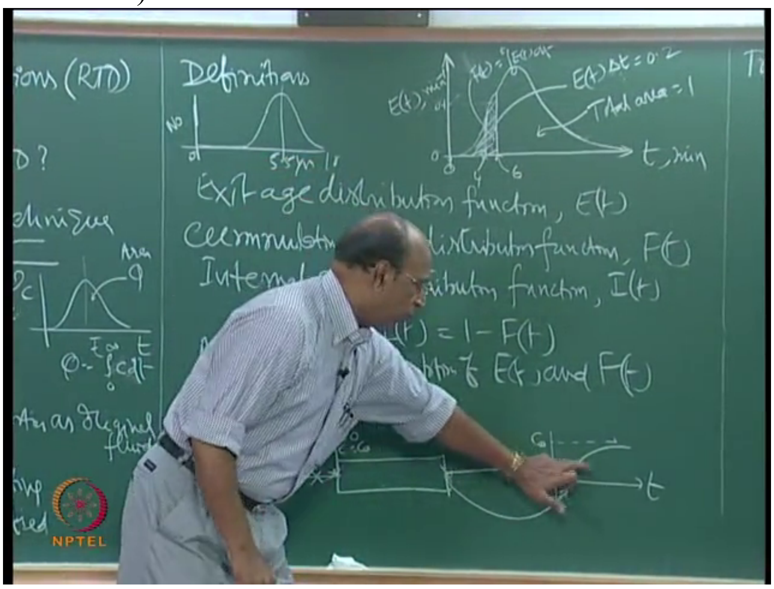

only C, C. This is C and that maximum value will be

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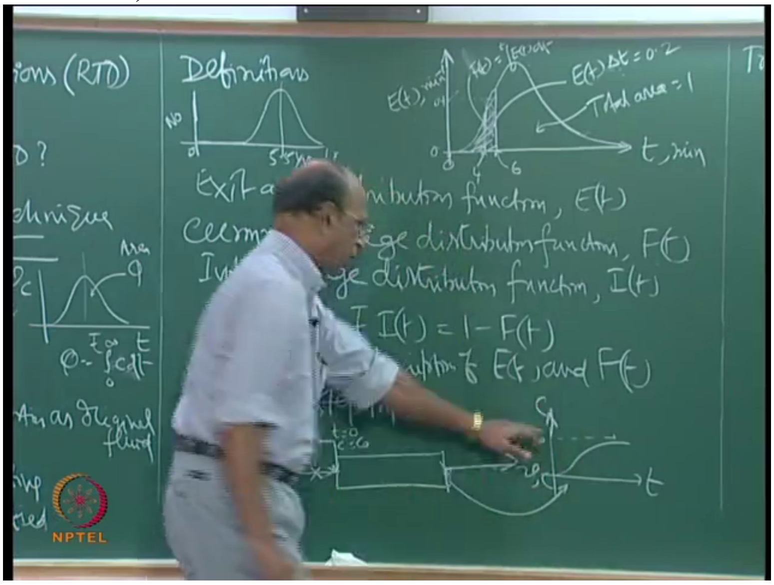

only C naught. So C by C naught will be 1. So you see how simple it is, F t. So that is why when you conduct step input, automatically you will get F t. Very simple balance but only thing is in your mind that clarity should come. Right.

So red fluid, white fluid. White fluid was flowing originally. I switched over to red fluid at time t equal to zero. After switching over at time t equal to zero, 5 minutes later, I collected the samples, Ok, sample. Then I imagined that, you know that sample separately, what is the white fluid and what is the red fluid?

White fluid would have, sorry red fluid would have entered only 5 minutes back and our definition of F t is that. The fraction of material which has total fraction, which has entered at time less than, Ok which has spent a time less than t. That 5 minutes is the t. What is the concentration in that? C naught. Because only red fluid. Only red fluid I have taken.

And other white fluid is 1 minus F t, that fellow would have entered earlier. Right. What is the concentration of red fluid in that? Zero. So that is why this entire thing will get cancelled. And this is the mass balance. Finally you will have grams per second, correct no? Or gram moles per second. I think that is Ok. Right, molecular weight will give you that. So this is what is for F t.

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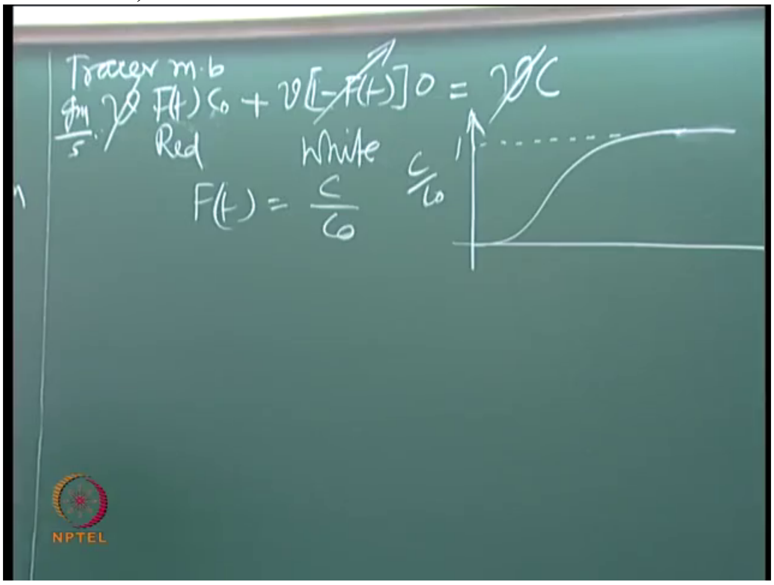

Now let us see for E t. E t pulse input Ok. Here also we do the similar experiment. Oh this is 1:03:57.3. Similar experiment. Ok, volumetric flow rate, volumetric flow rate, and concentration and here we introduce, this is direct delta function, delta function, this is at time t equal to zero.

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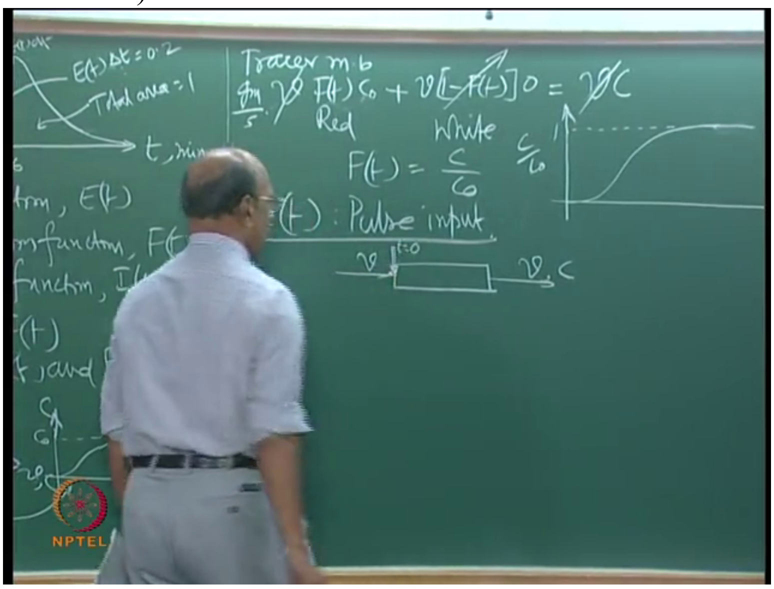

So saying that, you know direct delta function is always, I told you no, we should not take k gs and k gs of material. Volume if I know, density if I know, I can calculate what is mass also. So let us say 10 grams of tracer I am using which can be identifiable without disturbing, that is very important.

When you are adding it should not disturb the flow. When it disturbs the flow, your steady state will disturb. Under steady state conditions only. So that is why what we do is we take injection in the laboratory, I am telling, next semester you have to imagine yourself, next semester you have to somehow inject without any disturbance, Ok, good.

So you will somehow introduce this material into the reactor or into the vessel and then, that is all, stop. And also direct delta function definition you know, no? The width of the pulse will be

(Professor – student conversation starts)
Student: Zero
Professor: Height equal to
Student: Infinity
Professor: Area equal to
Student: 1
Professor: Most lousiest description where we never get any idea. What do you mean by width zero, height infinity, area 1?
Student: (laugh)
Professor: Ok, yeah but that is mathematical description. Great mathematicians said it is possible. We also say yes. Ok, Yeah. But you know that is impulse. Very quickly that means that pulse is very, very small, right. That is the meaning there.
(Professor – student conversation ends)

So that is the kind of input I give. So why I am telling

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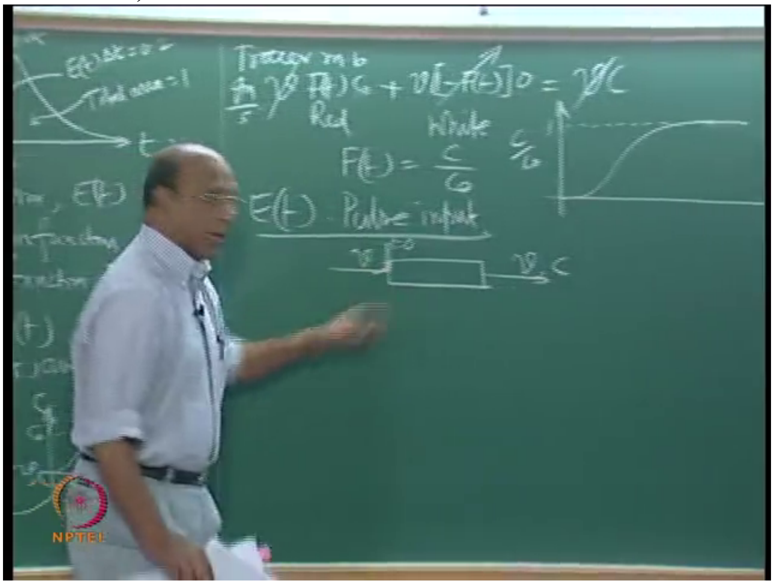

is you take the syringe and then half an hour if you inject, that is not pulse. (laugh). Because the entire experiment time may be 1 hour and half an hour you are injecting that. So that you cannot treat as pulse input. Ok, so that is the reason why I am telling that. Ok, good. So this is the one.

Now here, we would like to find out E t. I will write the material balance again. Here. Ok. So the amount of, the amount of tracer coming out, amount of tracer coming out of the reactor, out of the reactor between t and t plus delta t, I am not asking fraction. I am only talking about amount of tracer that is coming.

That means

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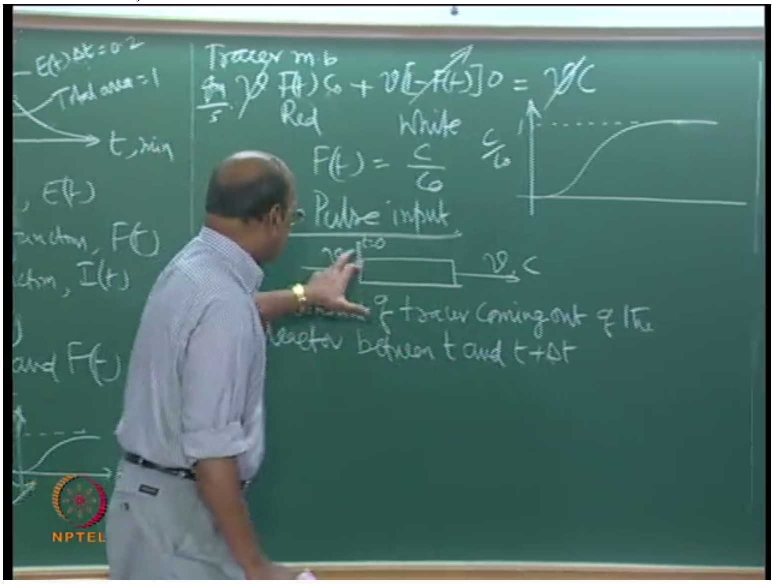

after introducing what I collect here is between, like that you know fourth minute and fifth minute what is the tracer I am getting, right? Yeah. What is the tracer, the amount, total amount? How do I calculate this?

Let me call this one as delta M, Ok. So this delta M, yeah equal to, and what is this one, how much is coming

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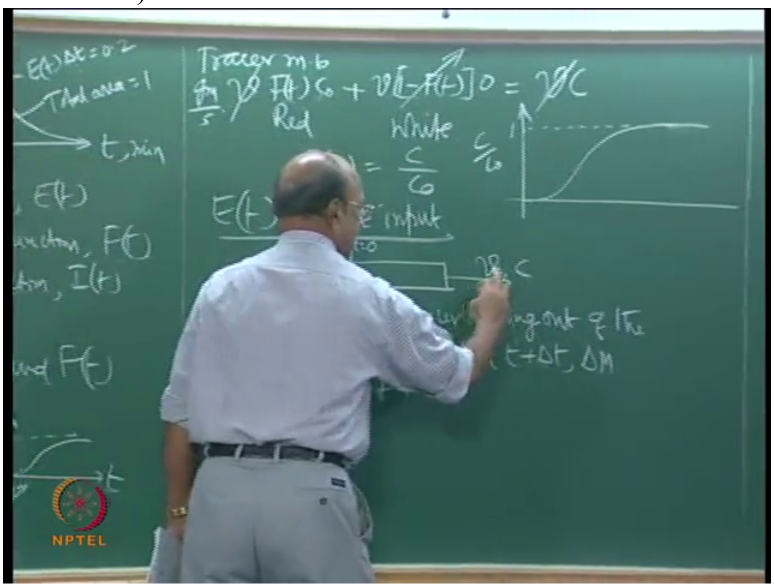

here, v into C. Ok, and I am asking for what is the amount of tracer, that means amount, grams. Amount means grams, no, or moles, Ok grams. How do I calculate that? At this point? v C into delta t, that is all. That is grams.

So that means between fifth minute and sixth minute, that 1 minute that is delta t, how much mass has come, right. So that is the volumetric flow rate multiplied by concentration, that gives me grams per time multiplied by that interval time, delta t. Ok, that will give me the total amount, Ok.

So what is the

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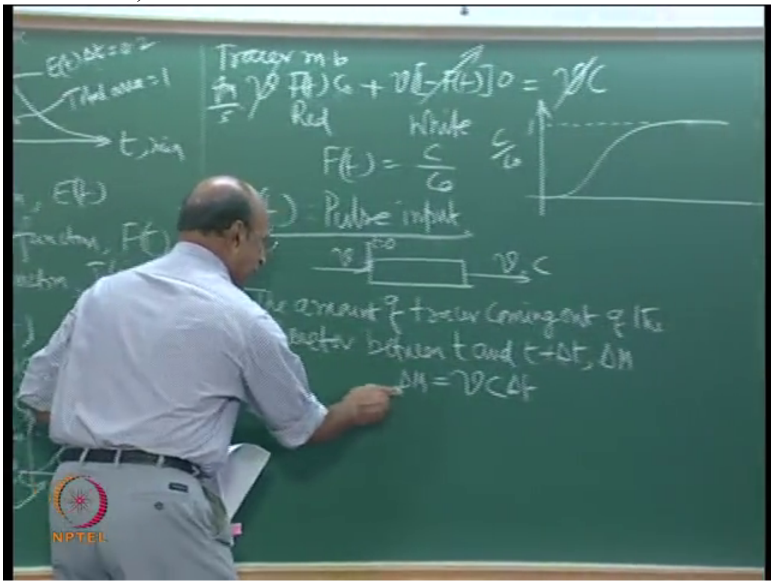

total amount, you know, completely all the tracer? If M is the mass, M is the mass which is added there, Ok, sigma of all this, or otherwise total, total mass equal to M which is nothing but zero to infinity v C,

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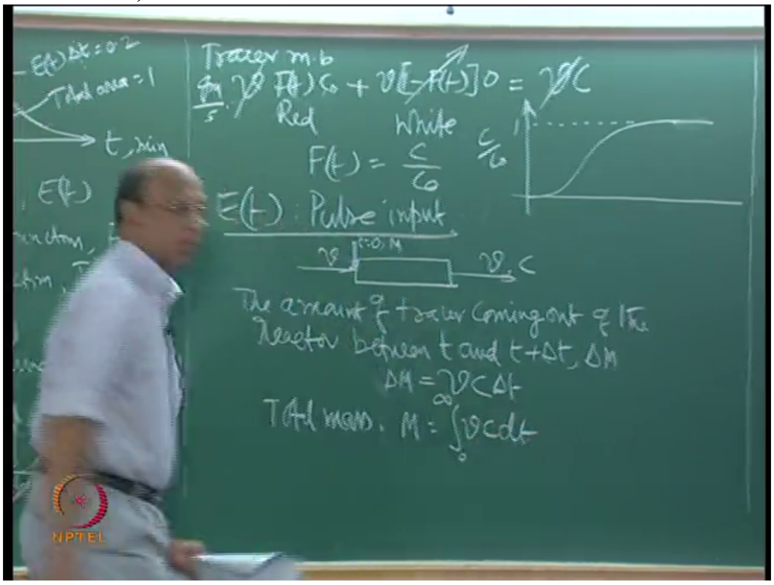

correct no, I mean, as in, Sushmita said I can put 1:08:26.8 sigma, sigma is again for discrete but I think continuously when you want to write, this one.

Now the definition, Ok this is the total mass. That is the amount of mass coming between t and t plus delta t. What is the definition of E t?

(Professor – student conversation starts)

Student: Fraction...

Professor: What is the definition of E t? Fraction of material which has spent a time between t and t plus delta t. Can you get from these two equations?

Student: Yes

Professor: E t equal to

Student: Delta M by

Professor: Yeah

Student: Delta M by

Professor: Delta M by, excellent, delta M by M which is nothing but v C delta t divided by zero to infinity v C d t. v is constant.

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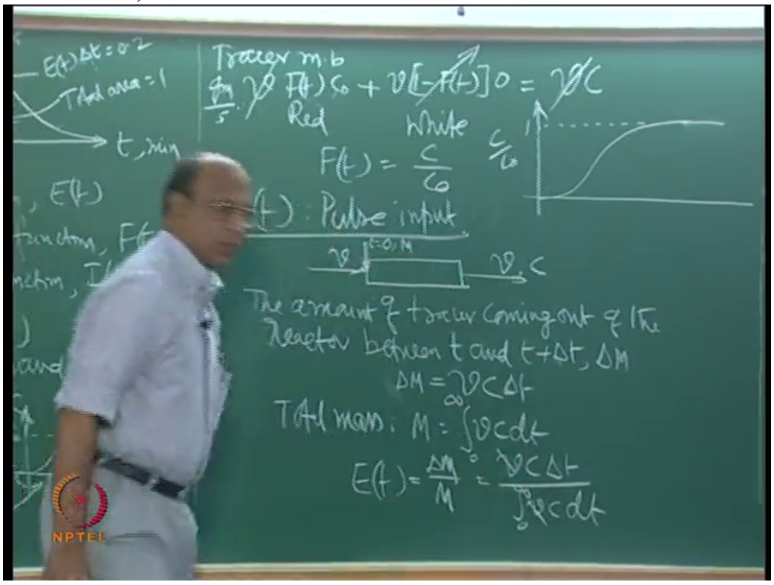

Volumetric flow rate, I told you not, it is constant density system, Ok. Yeah. And also no reaction there.

(Professor – student conversation ends)

So now what is equation now? C, Oh no, no. That is right only but here it is not, this is only fraction of material with r t, residence time t and t plus delta t. I have swallowed some words here.

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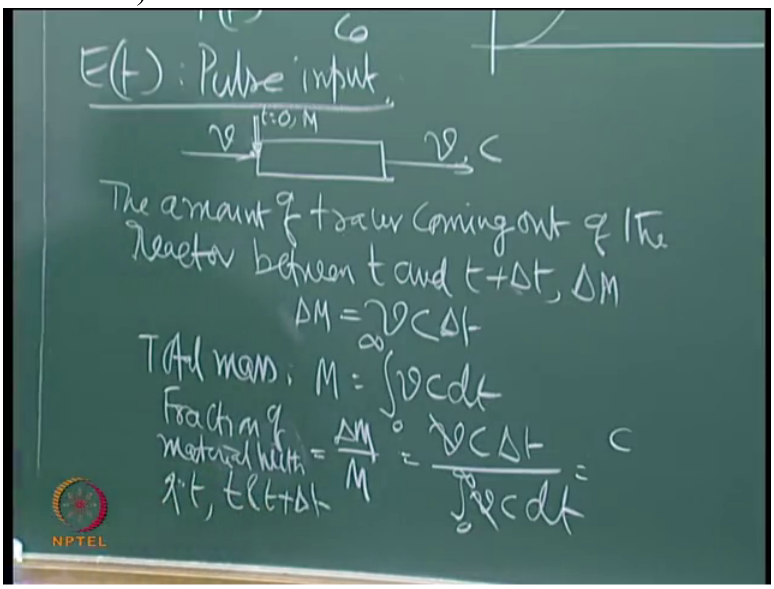

r t, r is the residence time, this is the fraction no, it is not E t. Please remember that. Correct, no? It is not E t. Ok. So here I have C delta t, C delta t divided by integral zero to infinity C d t and what is this one?

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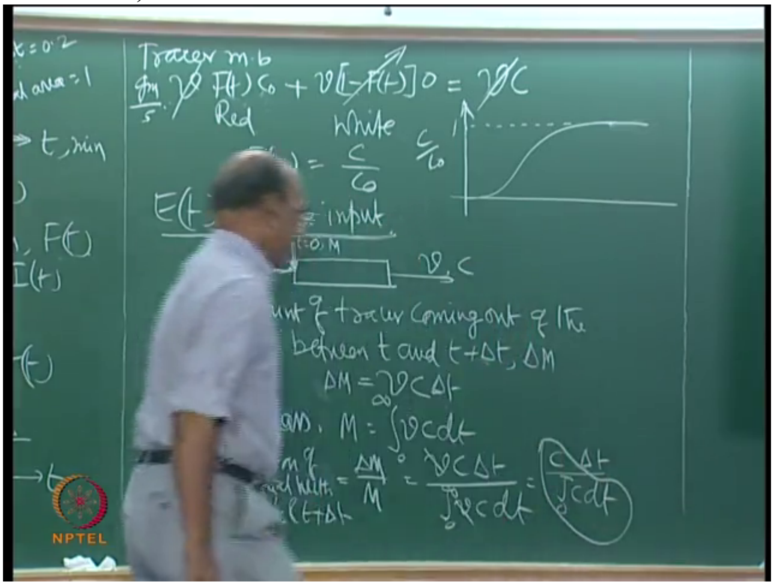

(Professor – student conversation starts)

Student: (laugh)

Professor: Doctor Krishnaiah will solve. Krishnaiah only, no?

Student: (laugh)

Professor: Ok, so this is C by, zero to infinity

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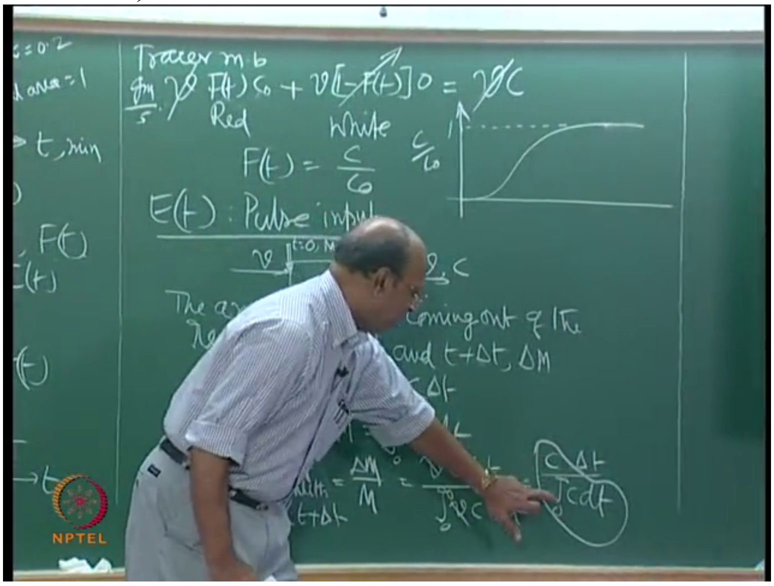

C d t. That is what is plotted here. Somewhere I plotted ?

Student: E t

Professor: That is E t but… This is nothing but E t?

Student: E t

Professor: That is what is the definition.

(Professor – student conversation ends)

Very simple definitions, and original Levenspiel book you know, not original means second edition, all these derivations

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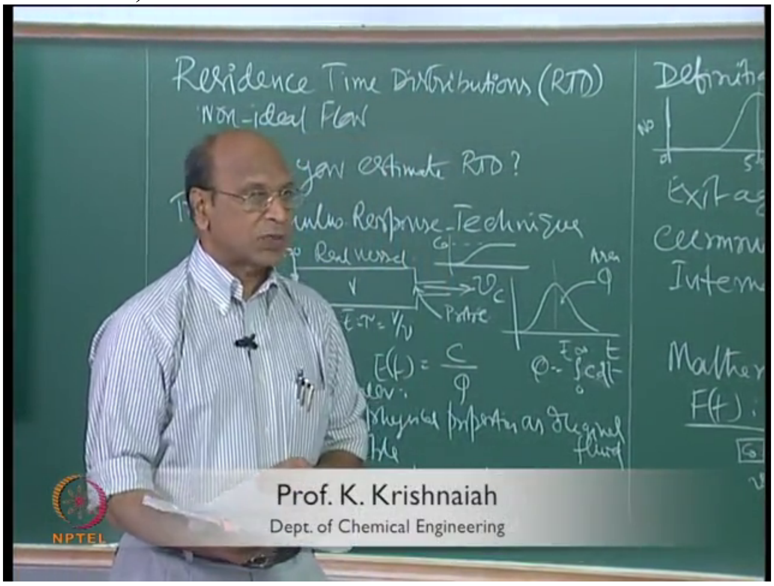

are not there but in the last one he has added. But I have been teaching this earlier also because I think Carberry and some other people have given this one.

Because it gives a feeling. Otherwise

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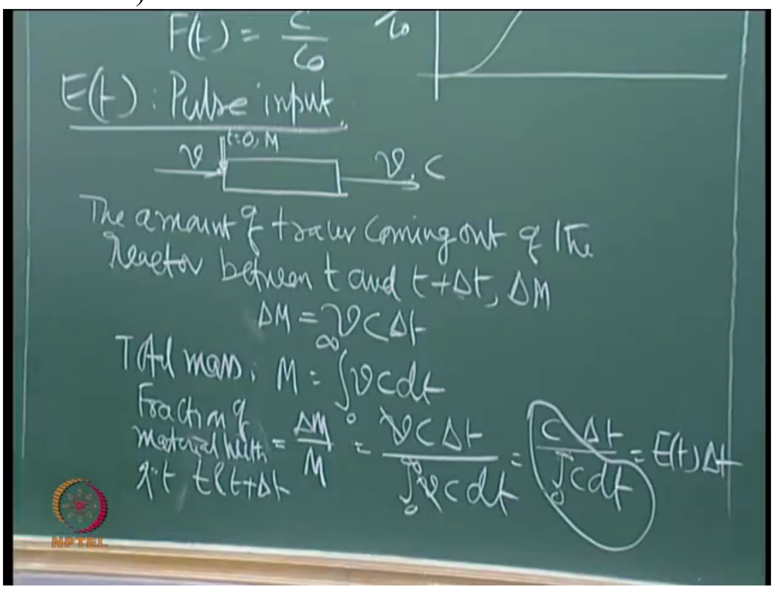

blindly we are asking them to plot, I removed that? I plotted no, integral zero to, Q, Q, here,

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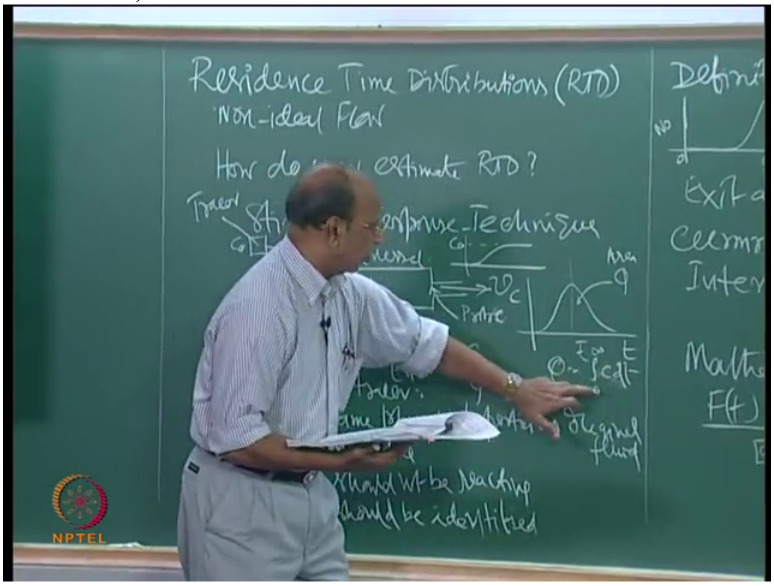

this is Q, Q equal to zero to infinity C d t. That is the area under the curve. And E t equal to C by Q, that is nothing, that is E t only.

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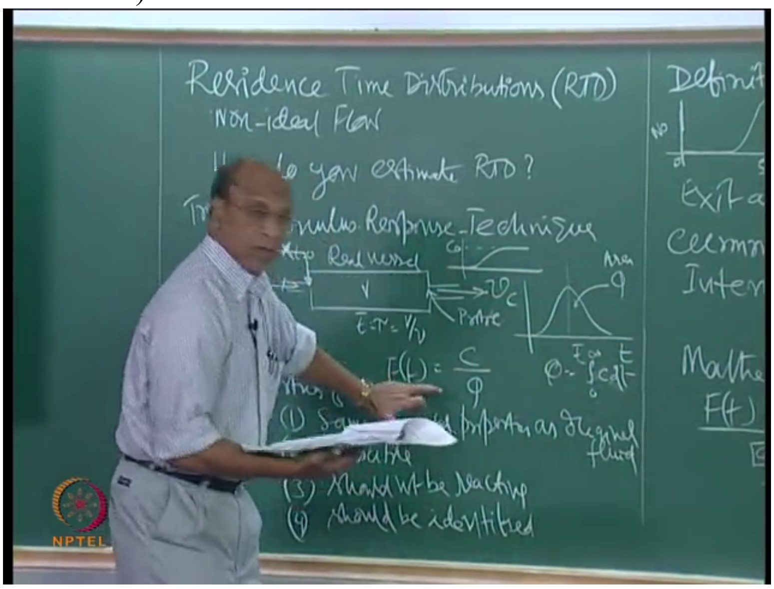

So if I add delta t, delta t both sides that will be fraction. Very good. Very bad?

(Professor – student conversation starts)

Student: Break

Professor: Break? This program is without any breaks, I say. No advertisements in between. Ok, so Ok I think break.

(Professor – student conversation ends)