Chemical Reaction Engineering 1 (Homogeneous Reactors)
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Lecture 58
Direct use of RTD to predict conversion (Macro & Micro fluid as well as Macro & Micro mixing Concept) Part 1

(Conversation between Professor-student starts)

Professor: Incinerate, Now a days all incineration, no? So dead body you send it to incineration, that is all, yes. That is all 5 minutes, so I think volume, Volume…

Student: Laughs.

His rate of reaction is very slow, 45minutes you have to wait because I know it has to cool, okay. Yes that is correct, total batch time including, you know charging, reaction and cooling, discharging and finally giving only in terms of small ash, see finally all of us will become only that much ash, that is the philosophy of life, correct no? So why all these, why M.tech, B.tech, Phd?

Because with all this at the end only that much ash and okay, this much ash which you cannot keep in the house and there is a photo hanging on the wall, that is all no? All of us will become in the beginning at the entry of the world photo because I think people are very proud of us. As a small boy they take 100 photos and at the end also big photo on the wall, that is all.

In between entire thing is drama like me, you know that is all. Okay good, so these are the just general things which I want to give to you, how people think about various models, okay. So this is what the information I think nothing much to explain. Good, so now we are coming to the 3rd part of residence time distribution, what is the first (())(1:51) by the way? See entire RTD can be taught off into 3 parts.

The first part is, I know most of you will not remember, you see you have to appreciate my psychology, I know your psychology very well, I know where you forget, when you forget, what you forget, all that I know, okay even though I repeated many times. If you see these videos tomorrow you would see that how many times he is repeating, okay. And of course my happiness is that even after seeing the video next day you will forget very well.

So next day you here it is again new to you, so that way we are very happy, okay. Because I think you do not remember, you know very nice for us, yes the first part what I told is the definitions and also ideal reactors, definition and ideal reactors, right? So that is what, what you have done. How do you define ET, how do you define FT? First of all what are the 9 idealities for single phase, multi phase all that we have done it, okay.

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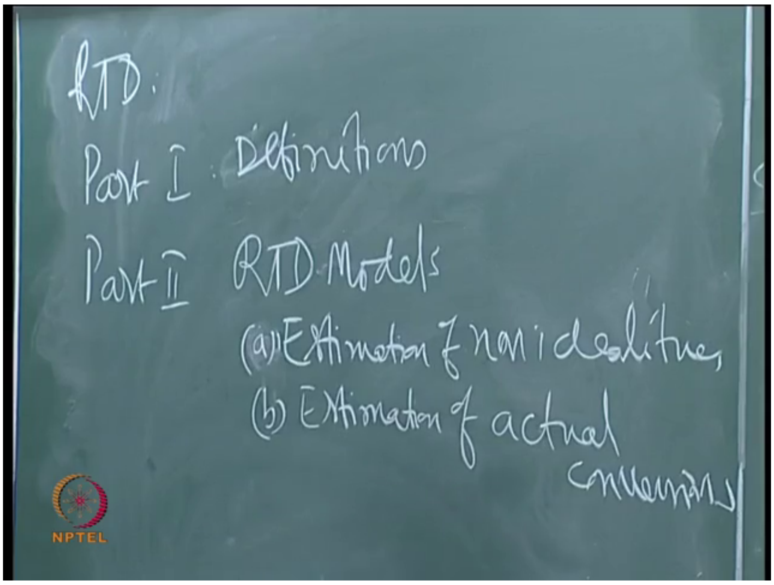

RTD:

Part I : Definitions

Part II RTD Models

(a) Estimation of non idealities

(b) Estimation of actual conversions

(Conversation between Professor-student starts)

Professor: That I think, let me record that first, okay. RTD part 1 is definition, okay and part 2 is, now at least can you tell?

Student: Laughs

Professor: I am also writing continuously the title in almost all the classes…

Student: RTD models.

Professor: RTD models, okay. Now what is the use of this RTD models? Yes to quantify first non-idealities and using them for conversion, right? That is what. So this one RTD models will give us estimation of non-idealities and, okay. This is A, B is estimation of the actual conversions, very good, that is what. Actually this is 2 steps, right? First is estimation of non-idealities, second step in that is estimation of conversion, okay.

(Conversation between Professor-student ends)

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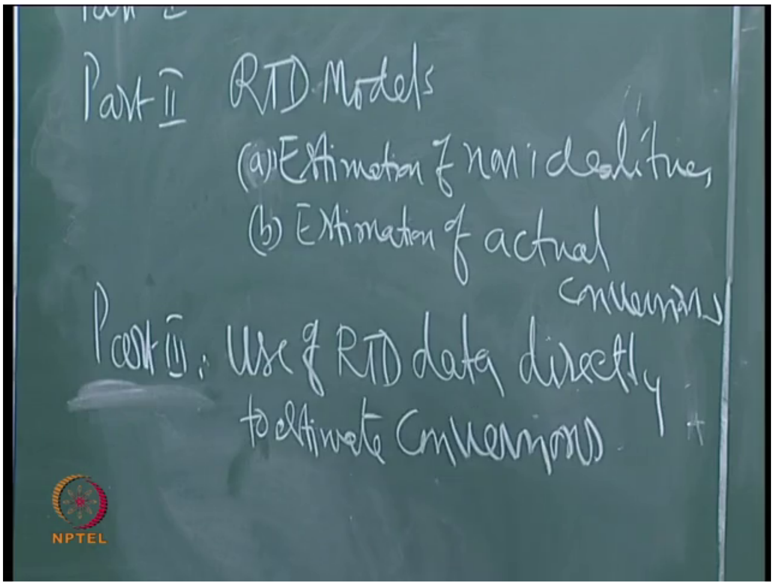

Part II RTD Models
(a) Estimation of non idealities,
(b) Estimation of actual conversions
Part III: Use of RTD data directly to estimate conversions.

Now part 3 is use of RTD data, RTD data will simply give me fraction of material coming between time t and t plus delta t, that information use of RTD data directly to estimate conversions, okay. What is the meaning of that? I do not want to use any model, I do not want to use any estimate any non-idealities, okay. I simply give you ET versus t data. Can you calculate conversions using that?

But I will give you Kinetics, I have a first odd reaction, I have second odd reaction plus I will give ET versus t data, right? So that means can you use directly the RTD data to calculate conversions without going to RTD models that is the third aspect. That is correct, no? Why should I do again, you know like estimation of non-idealities develop another new model in terms of non-idealities to calculate conversions.

So these are 2 steps unnecessarily but this is straight forward, RTD data directly to be used for calculating conversion that means there is no modelling required there that is why we call that one sometimes 0 parameter models because there is no parameter, there is no actual mixing, there is no dead space, right? Simply whatever data I get for the reactor it may have dead space, it may have bypass, right?

Or it may have channelling; simply what I give you is ET versus t data. Please do not remember that this ET versus t data is ideal reactor is ideal reactor. Any real reactors it may have all non-idealities but still that will give me some ET data whine I conduct the experiment. May be the shape if I draw that may be different when compared to ideal reactor, right? With long tail or suddenly 2 peaks, right?

That means channelling what you have, all that information will be there but we do not care about all that information. What you care is I have now ET versus t data and I will give whether I have first order reaction, second order reaction. Can we now use this first order, second order information that means kinetics and find out conversion using RTD data, okay? That means you do not have any reactor in your mind, correct no?

I am giving RTD data, right? So I am not saying whether it is ideal PFR, I am not saying whether it is ideal mixture flow, if you have ideal mixture flow, ideal PFR I do not have to even go to RTD data, I have second order, first order, I have the equations calculate but here any real reactor with RTD data can I use to calculate conversions that is the 3rd part that is quite interesting part, right?

Because it is straight forward no? But unfortunately that is not that interesting in the sense that you cannot use the data beyond one particular case, by the way who is the starter of RTD residence time distribution in chemical engineering? How did I miss this beautiful thing in the beginning itself?

(Conversation between Professor-student starts)

Student; Da...

Professor: Some doctor.

Student: Laughs.

Student: Danckwerts.

Professor: Who is Danckwerts anyway?

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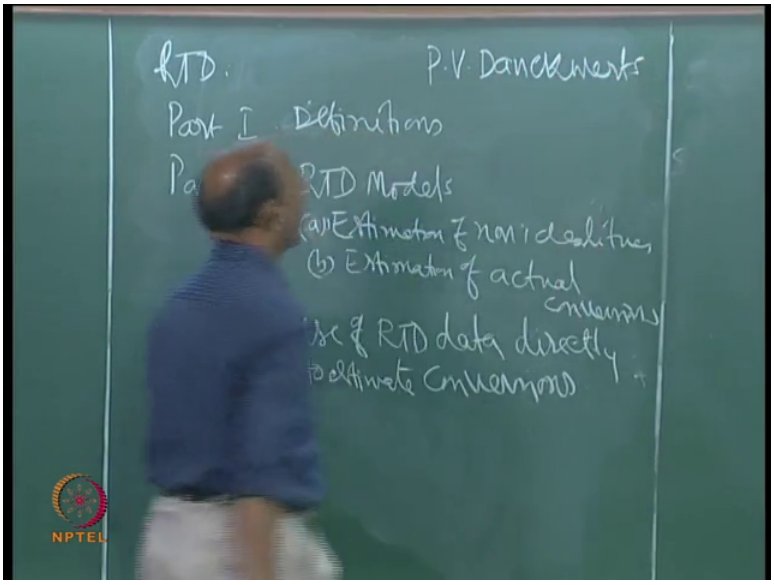

Professor: See, I think you know this adhesis is also very humorous, he wrote an article PVD on RTD.

Student: Laughs.

Professor: PVD, PV Danckwerts PVD on RTD, okay. So because I think Danckwerts he is the first person in fact that original paper, if you promise at least 5 people will read I will send the original paper, okay. You will read, okay I will send for the entire class 5 is enough for me. If 55 reads excellent, okay very good. So at least minimum 5 otherwise I am creating a pollution, correct no?

You very sincerely download store and forget, so unnecessarily it will be there on your computer for a long time on your hard disk without any use. Okay, I will send that original paper. Original paper definitions are slightly different, in time they are slowly modified but the seed came from there and you know how the seed he got. It seems when he became lecturer in Cambridge University he did not have a course to teach (())(9:10).

So then I think you know he used to go and sit in the canteen and then drinking Coffee, so when he was drinking coffee and you know thinking, thinking about what are the problems in reactors and all that and we know ideal reactors we have equations we can solve, what we do with no-ideal reactors?

Then he imagined all this in his mind, all this in his mind and then finally he defined what is ET, what is FT and how do you find out ET, how do you find out FT and how do you join ET and FT with IT, IT you know internal edge distribution, all these things he imagined and he wrote that first paper in 1953 chemical engineering science volume 1 page 1, okay.

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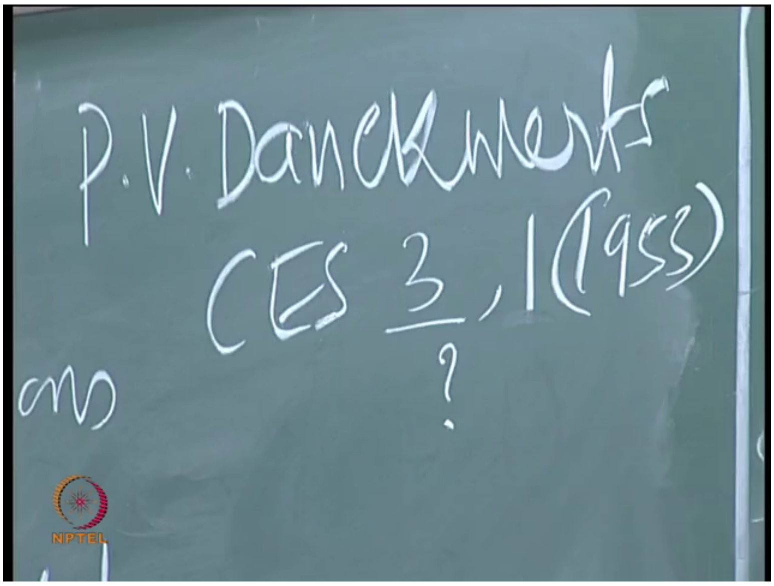

Now I think this is CES, chemical engineering science volume 3 1953 not volume 1 I think.

Student: Laughs.

Professor: Yes that is what I said but it is wrong, issue 1, oh! Anyway I think 3, volume 3, okay page 1 1953, okay. Yes, I am just putting a question mark here, volume 3, page 1, 1953 but question this, on this page, okay. That is the first page that I remember but my remembrance is not that good but I think it is volume 3 not volume 1, okay sorry for that.

Good, so he was the person and then how many beautiful things also he imagined where his original idea was the part 3, original idea was part 3, right? And yes 1953 only paper, in 1958 second paper has come he took 5 years to tell that RTD is not completely useful for finding out conversions, okay. And in that paper again he discussed many beautiful things about age of molecules, life expectations of molecules exactly like our age.

So when you come to this world at time t equal to 0 our birth time then onwards our age is calculated, right? But unfortunately we do not know the end, right? Except for plug flow, plug flow means if all of us are exactly living 100 years then we have plug flow then we know very well what is our age and what is our life expectancy, right? Yes, if I am 100years living, now 65 the remaining is 35 that is the life expectancy.

But unfortunately god is not so kind to us, he does not want us to know when we are... At least mother father know when we will come, right? But when we will leave even mother father also they do not know, correct no? Anytime it can happen, so that is life expectancy, right?

That is the same thing in Cstr you do not which molecule will come out so the life expectancy is not there, you cannot say but if it is plug flow you can beautifully tell, yes now he is 10, 90 years life expectancy, okay. That in fact is called what is you know beautiful name called micro mixing where you get the information on molecular lever, right? And when the life expectancies are together those are the molecules about to leave the system.

Like for example a boy maybe with 10years and his grandfather may be 75years he has got 25years life expectancy and this guy has got 90 if I know plug flow, if I know that it is plug flow because we do not know unfortunately imagine a situation where both of them are travelling by Skoda and accident happen both of them will die. So at the moment of dying that time accident time immediately if they die then the life expectancy equal to 0, both have the same life expectancy.

Or let us say that both of them travelled for 2 hours, 3 hours together and we do not know the end is going to come, right? When they started from the house and then moving let us say that 5 hours they have gone around Chennai, after 5years unfortunately this thing happened and if I am able to know that then what is the life expectancy for both of them? 5, so age does not count now.

So when they are leaving the reactor it is the life expectancy which is more important and thermodynamics come there, 2nd law of thermodynamics once they mix they cannot unmix, so that means once they mix means a molecule has entered now just 10 seconds back that joint with another molecule which has entered 15minutes back both of them have life expectancy 1 second.

Once they come together and then trying to leave and as per 2nd law of thermodynamics it cannot unmix on its own but it has to go together outside this kind of overlapping, perfect overlapping is only in mixing flow reactor because where life expectancy is and RTD, okay...

In a sense what is information you are getting from RTD?

Student: Residence time.

Professor: It is the residence time or in other words loosely taking it is edges, okay, yes that is what RTD and this life expectancy gives how many remaining life is there in the reactor, how many seconds more or how many minutes more will stay there? So that is why in life expectancy and RTD if they are perfectly machine that is what ET equal to IT in a mixture flow reactor.

Now you anytime thought about ET is perfectly same as (())(14:43) internal edge distribution that is what is the assumption I said. We say that inside conditions whatever is there, you know the concentration temperature exactly same as outlet, outlet describes ET and inside it describes IT. So IT equal to ET in a mixture flow reactor, no other reactor you will (()) (15:04).

So when you have this IT exactly there, IT tells me... IT is the internal edge distribution, so once I know the internal edge distribution that is also equivalent to life expectancy for me because that is happening inside they have not come out but ET is exactly only edge, right? So it is not ET that is important for me, it is IT which s important for me because that gives me the life expectancy.

Or if you do not want to get confused just imagine our life expectancy and our life expectancy if 2 people life expectancy is same they are about to leave the world, right? In some accidents or some Tsunami and all that there are how many people dying with different ages that means imagine that you know end of the world there is a outlet which they are going through that after death, right?

So what is happening now is all these people because their life expectancy is same they went out together not because their ages are same, okay.

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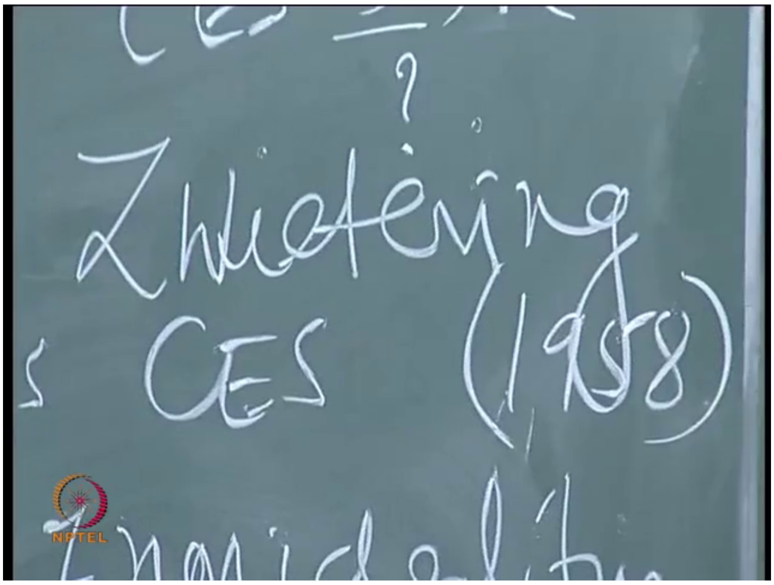

So those are the fundas he has discussed so many in that paper in 1958 paper and this paper there is another person called Zwietering he is from Netherlands I think he has also published a paper on CES I think it is also in 1958 if I remember correctly. You know this Zwietering has published only few papers may be 5, 6, 7 like that not like present faculty member just to go and tell that I have infinite number of pages.

Then another person will go and tell I have infinite plus 1, okay for promotion, so that kind of papers we have so many, okay I do not know this joke you know or not in Calcutta university Debayan one noble laureate to physics department I do not know whether it is truth some people say and the noble laureate was introduced to the department faculty and then they said I think, okay Professor Mukherjee 550 papers and Debayan Chatterjee, okay 350papers then we have some Samuel also from (())(17:22)?

Yes Samuel professor, oh! I see physics department, no I am just...

In physics department I am telling various name Mukherjee, Chatterjee, Banerjee, okay all JE, okay so all these people then they said I have 200 papers like that and noble laureate got a (())(17:46) told it seems, oh! My God I am very sorry I am really afraid to stand before you I have only 2 stages, okay and whereas you have 100s of papers, right? So that is why number does it really mean now your quality does that mean, okay.

Student: lesser or (())(18:10)

Professor: (())(18:12) quality will improve, of (())(18:15) is there quality will improve? Okay, I am just telling the number game, you know nowadays, why I am telling is, this Zwietering also has, in fact conceptually Zwietering paper is much better than Danckwerts papers and all that came from his mind that is what I want to tell you because of our mind I will also send that paper, that Zwietering paper also, okay.

If you are not able to read for this course at least you read some time in your life later, okay. Even after completing M. Tech, okay. So that is worth reading, how beautifully they thought about and what is the starting point for that they do not need any equipment, they do not need anything accept may be some amount of food because brain cells have to be active and then thinking and after thinking to write a paper and paper, pencil also is (())(19:02), okay.

So but what we have? We have bags for every student behind, okay and in that bag you have laptop, okay and also calculator and what else? Scales, pens, pencils, books that is all they are there all the time, what is that? Lunch box, biscuit packets...

Student: Laughs.

Professor: Biscuit packets all this we have, okay good.

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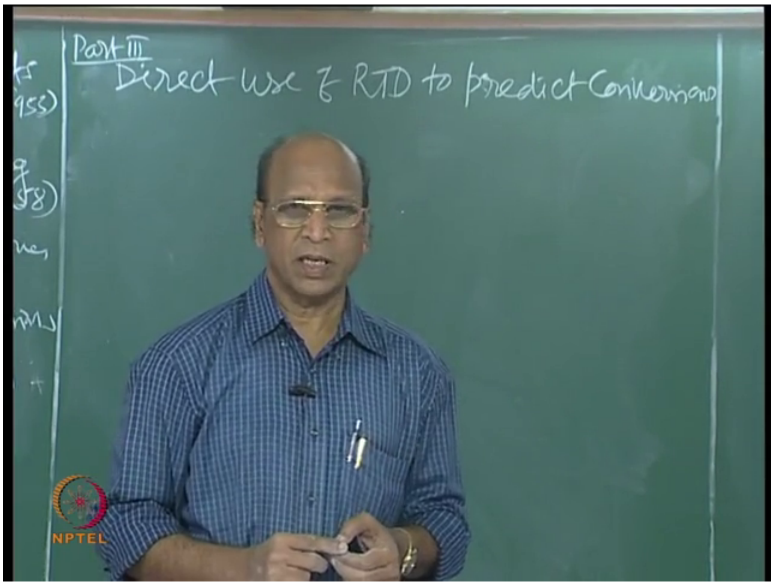

Okay now let us discuss about this one, this use of RTD, okay. Part 3, direct use of RTD to predict conversions that is part 3. So now you know the problem, no? I think you know actually the issues you have to remember I have been telling you all the time this, please remember the issues what is the problem?

Okay, now the 3rd question what we are asking is of course definition and all that over and can I use RTD information directly to calculate conversions instead of going to model estimate non-idealities use that non-idealities to calculate conversions using another molecule, right? Yes and this direct use of RTD is only possible if you have first order reactions (())(20:33) , right?

What is the reason? Because tracer information is linear or non-linear, I am going to ask you how you define linear. Process control linear process and nonlinear process, okay. I will ask the question in a slightly different way. Let us say that I have conducted an experiment, next time I am going to give you all this also in the lab, right? You have the tracer and you added the 10 grams of tracer and then you recorded concentration outside and then you have plotted.

You have plotted ET, right? That is experiment 1 then what I did was again, now do not use 10grams, in the next experiment use 50grams, right? Use 50 grams, so what will happen to the ET, is it same? Is it different or totally chaotic?

Student: One of the same trends?

Professor: Trend is different, same is different.

Student: It is not same.

Professor: It is not same, it is same, it is shame, okay. That is what they say, that is what they may say, okay. Debayan says, okay it is shame not to know, okay. Yes, why do you say it is not same?

Student: (())(21:52)

Professor: Why you should take longer time?

Student: (())(21:57)

Professor: Yes I remember.

Student: (())(22:01)

Professor: Why? Because you know instead of 10grams I added 50 grams. Why should it take more time? And 10 grams is also mixing perfectly it is not disturbing the system because that is the idea of connecting RTD test, no? I mean when you are doing RTD test it should not disturb the study flow, right? Only thing is concentration you are increasing 5 times that too initial concentration.

Same thing let us do step input, so earlier you use concentration equal to may be 5 grams per cc, right? So now I ask you, okay use 50 grams per cc, what will happen? Nothing will happen exactly same thing particularly when you are normalising you can, right? But when you are simply calculating recording concentrations, what kind of concentrations? 10 grams, 50 grams just the concentration you are measuring.

Excellent, 5 times just increasing that is the linear process, okay. That is the linear process, okay. So that is the reason why that is the linear process and first order is it linear process or non linear process? Very calm and sense question? Okay, answer it is linear process, so because both are linear then I can use only RTD information to calculate conversion for, for other orders you cannot, why?

There what happens is that something else will come into picture, here in first order when you have first order reaction I also told you sometimes back first order reactions only depending on time of reaction you will get conversion, okay. Second order again depend on concentration that comes in Damkohler number directly, right? In Damkohler number there is no CA not, there is no concentration term for only first order, right?

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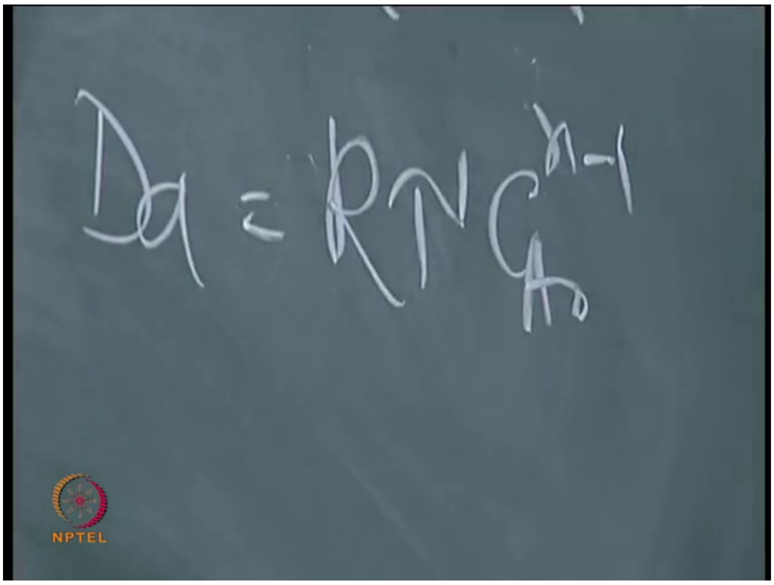

$$Da = k\tau C_{A0}^{n-1}$$

And Damkohler number is, yes. So Damkohler number Da equal to k tau n minus 1, right? So other than first order reactions you need something else which i also required for calculation conversions using RTD that is why I can only merge concentration of 2 linear processes and now try to find out for the conversion using RTD that is what I also told you, definitely you will not remember that.

What I told you in the beginning of RTD was that, the original idea is RTD definition is the fraction of material coming a time between t and t plus delta t, 10 percent of material is coming between 0 to 1 minutes. Another 10 percent may be from 1 to 2minutes, now what I do is, in this 0 to 1 minute what is the conversion? And 1 to 2 minutes what is the conversion?

Like that entire spectrum I take and then take all the conversions in each individual packet because I treat that fraction of material coming between 0 and 1 minute is 1 fraction or that is equal into 1 batch reactor, 1 packet that packet is spending only 1 minute, what is the conversion? So then I will take the second packet that is spent time between 2 to 3 minutes, right?

Okay that means total time of course may be 3 minutes when I am telling, okay. But between 2 to 3 minutes when I am saying, okay 2.5 minutes it has spent inside the reactor, so what is the conversion? So like that various fractions and average them I will get average conversion that was the original thinking and what they found was that the original thinking was correct only for first order because that is a linear process and tracer is a linear process.

And for other processes it is not possible, I will tell you why it is not possible and this is a wonderful explanation given by this Netherland people and I think Van Krevelen is the person who has done that first, what he has given as simple model very nice beautiful model.

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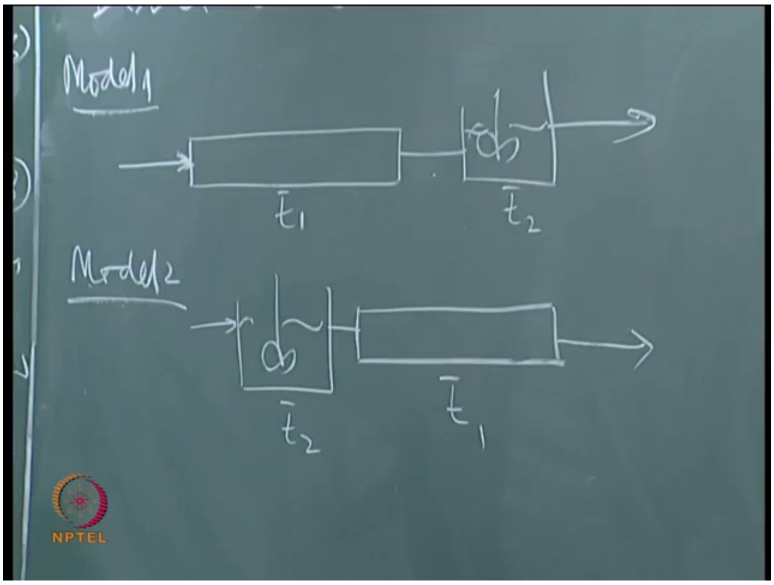

He says that I have a system where, I have ideal PFR followed by ideal Cstr this is model 1 and in model 2 I have just reverse this, yes, so this one is t bar 1, t bar 2 (())(26:41) or 1 also we can write and just this is reversal only t bar 2, t bar 1, this is an outlet then if I have, okay. What is the residence time distribution for these 2? For the first one what is the residence time distribution, how do I draw that? Both are ideal, okay it is exactly like, in process control if you remember that is exactly like you have time delay and mixture, right?

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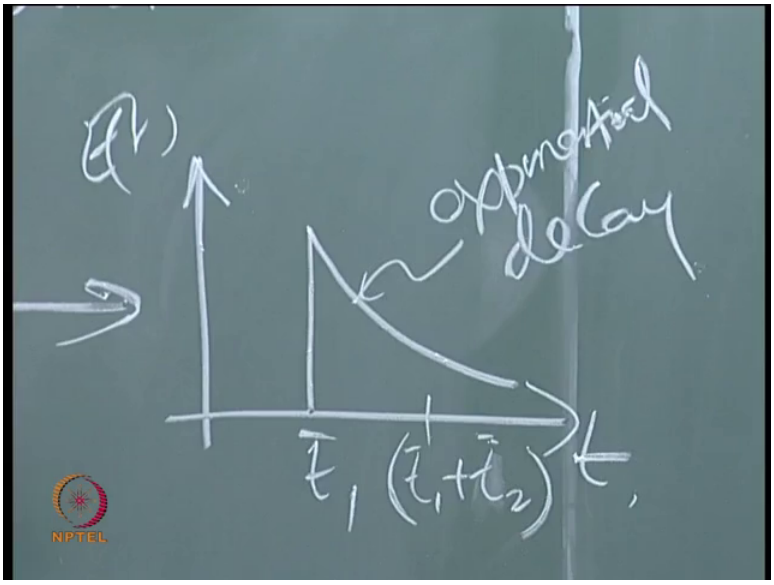

Yes, so then how do I plot them this is of course ET versus t when I plot, yes after t1 bar, you will have this kind of exponential decay, where is my t bar 2? I do not have t bar 2 but somewhere here you will have t bar 1 plus t bar 2 together some where afterwards, okay good anyway that is not important. Okay, now tell me for this starting...

Student: I expect between them there will be direct...

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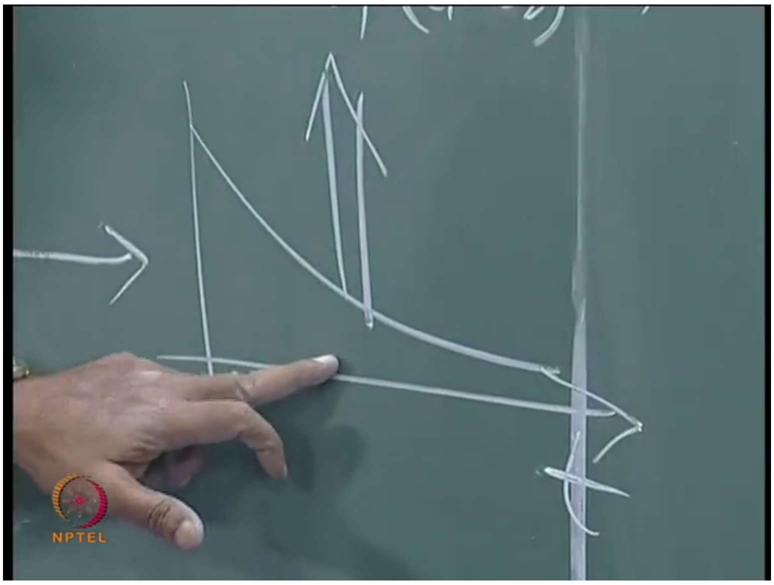

Professor: How do I plot that? You will have like this and then...

Student: Laughs

Professor: Like that, no, I am not saying whether you are right or wrong, what do you mean by same? Same as Pooja, same as merit, first, why first? Why not second? Because why is important, no? We have to explain you may feel but still you should be able to explain.

Student: t1 bar will be final.

Student: (())(28:31)

Professor: Okay everyone is convinced. You convinced Debayan, Janvi. IF Debayan is accepting your explanation then fine fantastic. Pooja is in between she will understand automatically because they have to pass waves through that. Yes, why?

Student: It fits all...

Professor: It is exactly same as earlier one. Okay, Pooja why this is not correct is that when I am seeing a particle here it is entering here in perfect mixing but what is happening later t bar one time later only I will see that there, right? This is t curve, this is t co-ordinate, this is 0 what you are telling, right?

So because you have this but this is logical explanation what she has given any student 95 percent of the students will only think this is the correct, okay. That is a logical one because our brain cannot see you know beyond certain things, right? Yes, so that is why that is a logical explanation but little bit deeper if you think what is really happening here is that I have here a molecule.

Okay, a particle is entering it has come out, right? But that particle I will see at this point...

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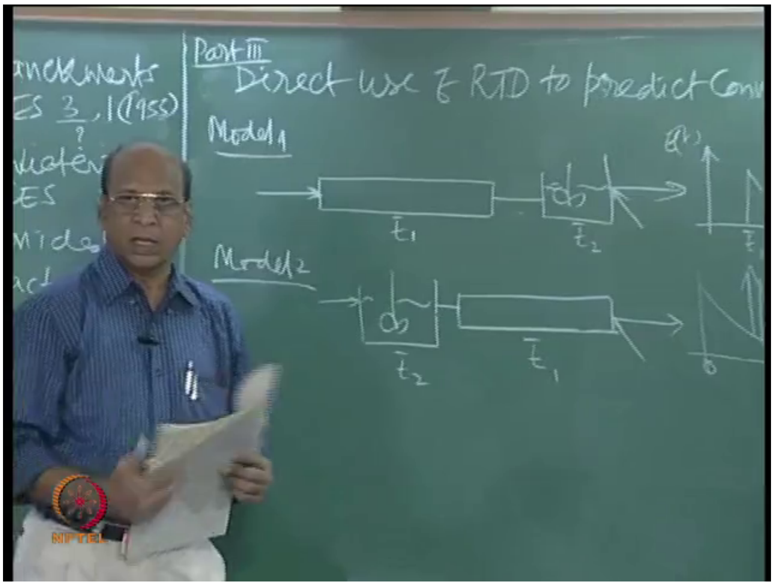

Because my collection point is only here, collection point is only here, so this much time I have to wait still to find out that particle to measure that particle. So that is why exactly this also is like that. I think Abhishek told it very nicely.

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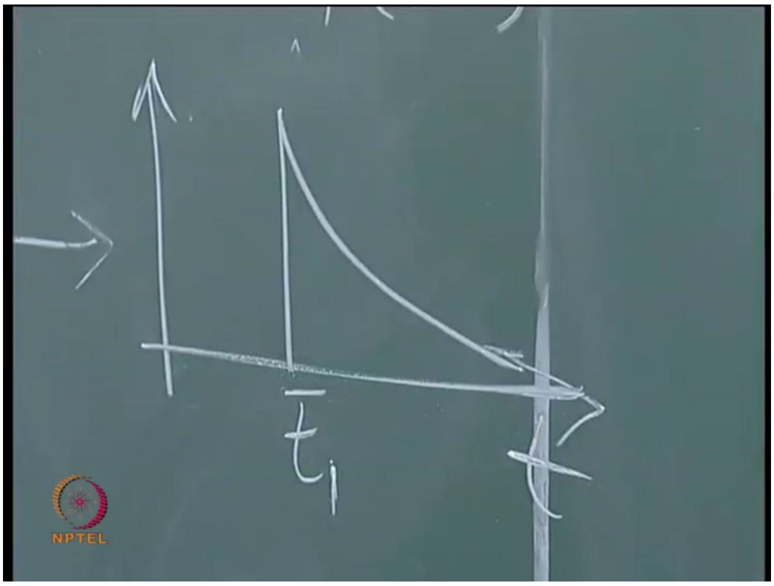

The plug flow will have only that time delay this is t bar 1 only. After t bar 1 only I can see that, so that means what is, okay...

Now the beautiful question, if I have a first order reaction which one will give me more conversion. See before question itself he is answering, yes why? Actually this is the 5th chapter or 6th chapter problem we also gave them. For first order reaction if we have a PFR and Cstr how do you join them?

Student: (())(30:58)

Professor: Why?

Student: It depends on time.

Professor: Yes it depends on time, now you answer the question, now you answer the question. Now you get the point, right? It only depends on time, so what is the information we are getting from RTD? Only time information, it is the fraction of material which is spending time between t and t plus delta t and first order requires only that information, only time information.

So that is the reason why first order reactions RTD can be used directly to calculate conversions and now here if I go to second order which one will give you more conversion?

Student: PFR followed by....

Professor: Debayan?

Student: PFR followed by...

Professor: Following no? Okay, why?

Student: (())(31:49)

Professor: Yes that we have discussed because for second order concentration should be kept as high as possible, okay good. That means this will give for second order low conversion, this will give for second order high conversion, okay. So that means I will now ask another question because I think you know this third part is most of the time discussion only.

The derivations are very very simple but discussion that is why it is very important for us, yes and the question which I want to ask is that I will say that in this model 1 the mixing is happening late or early? Late and in this model?

Student: Early.

Professor: Early, so I will write here this is late mixing and this is early mixing, okay good. So now that means other than first order reactions, okay and the other question is that if I have half order which one will give me more conversion? That means if I use early mixing I may get more conversion but I think physically I could not explain that one but late mixing second order I can definitely explain.

Because you have to keep the concentration(())(33:09) as possible that will happen only without mixing that is why please remove from your mind that mixing is good for reaction that is very bad concept. Mixing is not good for normal reactions and greater than 0 but there is one reaction mixing which is very good, what reaction?

Student: Negative order.

Professor: Apart from negative order because negative orders you do not get many.

Student: Auto catalytic.

Professor: Auto catalytic reaction, I am trying to bring out all that I am telling you know, grinding, grinding, grinding, okay. Regrinding so many times, okay. Yes, so that is why again I brought I do not have ask that question I asked you so that you will remember once, you will answer your interviews well, you will get the jobs, so that is the reason why I am asking you that.

So for that one definitely you have to maintain some kind of nice mixing. Of course for multiple reactions again different kinds of mixing all possible for multiple reactions, we are not talking about multiple reactions, so that means late mixing and early mixing is the concept that is coming in. So conclusion is, for other than first order reactions something more information you need.

What is the more information whether is early mixing or whether it is late mixing? You see now, you see here for second order you say that we want late mixing, right? And for (())

(34:36) order we say we need early mixing, so that is another parameter, no? Unless we say that we have early mixing or late mixing and you cannot really say that you know you cannot calculate conversions.

No, meaning if I do not give this model how can you calculate conversions for half order or first order, so that is why this will tell me that I have late mixing or early mixing, this model is late mixing, this model is early mixing.

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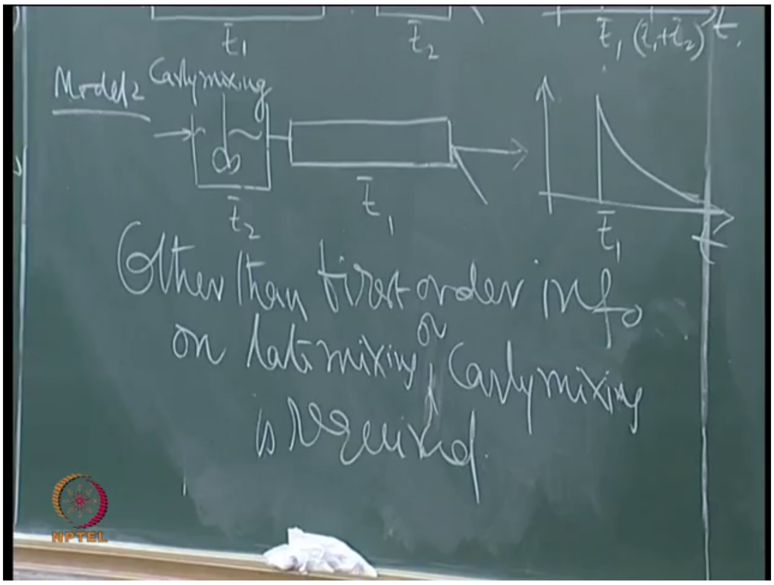

Other than first order info on late mixing or early mixing is required.

So other than first order information or info on late mixing or early mixing is required, okay. Now another question you have to be very smart in this now, okay. Everything what you are discussing is very important for understanding, right?

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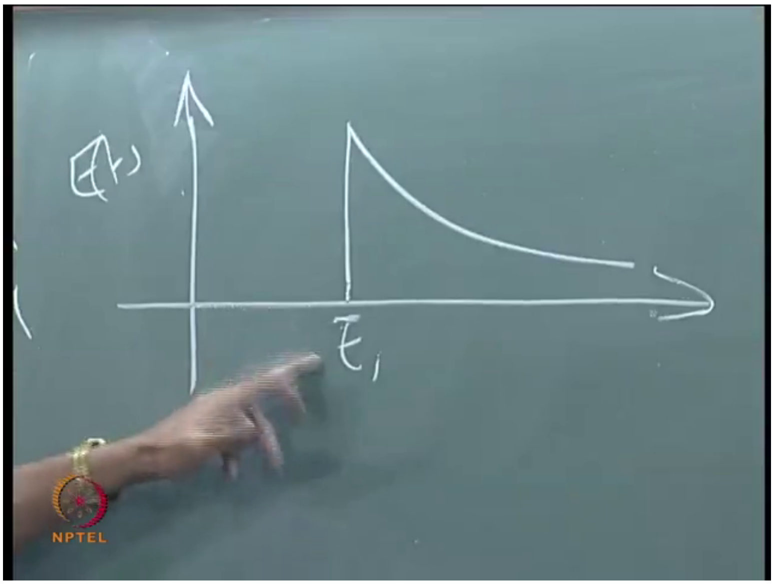

Okay, I do not give you these models, these 2 not there, I will simply give only this response ET, this is RTD I am giving you I have here t bar 1, okay I do not tell what is happening later, okay. So you do not know I am blocking these 2 now, okay. Now tell me this RTD curve tells what information. What do you mean by late mixing? Even early mixing you got the same thing, correct no?

I think even early mixing...

Student: PFR...

Professor: But this PFR is late.

Student: There is a PFR...

Professor: There is a PFR in this system but that is not the one because by looking at the RTD curve can you tell whether you have late mixing or early mixing? You cannot tell that is the drawback with RTD and I will tell you some more things where I think you know the exponential decay and all that there are infinite possibilities of getting same RTD but different types of (())(37:06).

So that means one RTD curve if I give you we can (())(37:11) 6 or 7 or 8 depending on your intuition your mind, so that means for a given RTD system is not specified flow pattern is not specified but whereas for a given system RTD is definitely specified, what is a given system?

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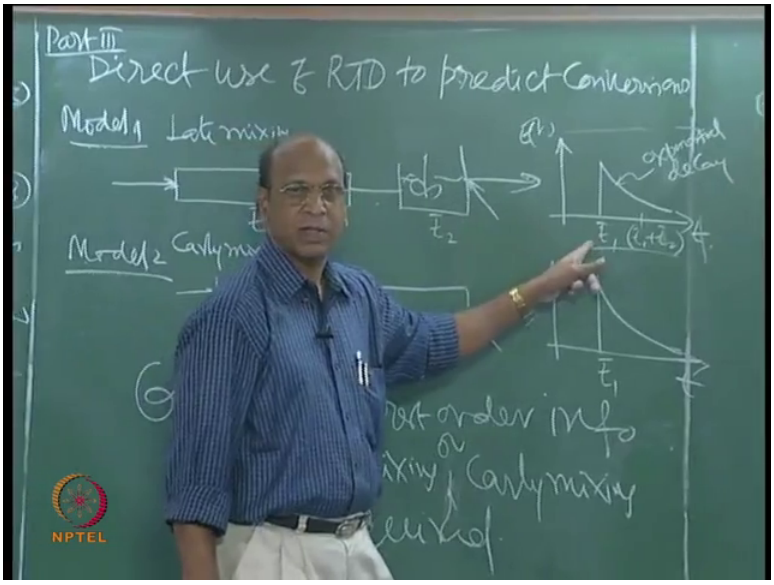

This is the one, this is specified the reverse is not true.

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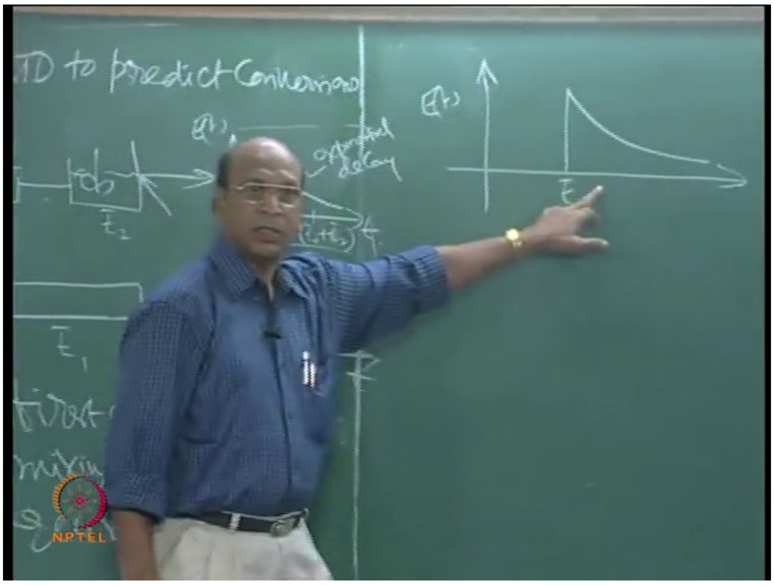

Given this alone you can have this or you can have this, right? Again comparing you know Janvi and Debayan. So if I give that RTD in examination, okay and then ask you to calculate conversions for first order or second order even if Debayan assumes this he is right and if Janvi assumes this she is right but both of them will get different conversions it is second order reaction.

Which one you will get? Here Janvi will get more conversion Debayan will get less conversion then both of them I have to fight, correct no? My answer is right, my answer is right I will come there and tell both of you are right, okay. Because you do not know I think you know you can either assume that or assume this that is why RTD drawback is that given an RTD curve you cannot exactly tell whether you have late mixing or early mixing unless we know whether it is early mixing or late mixing you cannot find out conversions, okay that is the drawback.

Now you understood this special issue in RTD why we cannot use direct information, okay. Yes that is the one and I think let us first find out for, yes okay. I think let me do this I think finding out an equation for first order using RTD that is simple that I will do later but let me tell this story first, okay.

Now the story goes like this, we say now late mixing and early mixing cannot identify whether you have late and early, right? Lat and early are really big words, correct no? You can ask me how late? Right? I think for you also someone coming in 1minute for himself it is very late, someone coming in 59th minute it is very early to come to the class, okay. That

1minute also why I should be there, so that is why this late coming or early coming or late mixing or early mixing are that late and early are really big words.

And in science and engineering you cannot be (())(39:34) you have to be perfect. That is why you will be caught many a times Debayan in the interviews. By chance if you are using wrong words unfortunately that interviewer will only catch that word without knowing you say late mixing you tell me now, what is late mixing? Okay and to cover them you can say something's are segregation.

Now what is segregation? Okay, so like that only they ask, so that is why particularly when interviews not only particular in our life whenever we speak if you are able to speak correctly with the specific exact words the world would have been totally different and one day you try from morning to evening till you sleep just record everything what you spoke, okay. I can tell you 99 percent is waste.

99 percent there is no meaning, only 1 percent efficiency, right? That is why I think animals are very good they do not speak, okay. So it is just a waste of time only that is why this early and late is really (())(40:40) where we cannot answer because my late is not your late. I will say that 1 second is late for me; you will say that no sir 110minutes is late for me, okay.

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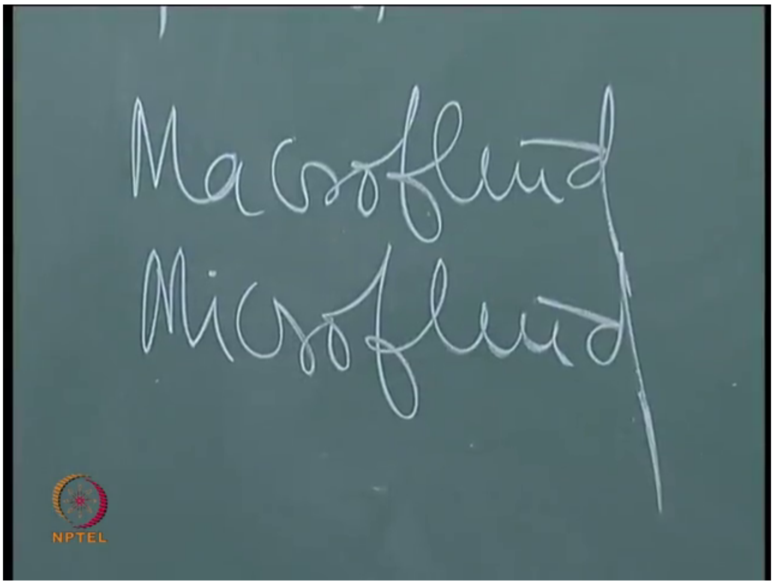

So that is why in engineering we have to specify then that is the reason why we have defined 2 fluids that are called macro fluid and micro fluid these are the words you see now, you have learnt 2 words late mixing early mixing. Now we are defining another 2 words macro fluid, micro fluid. Yes that we can define, okay. This macro fluid is available in the form of packets, right?

And each pocket size approximately with the molecules we have some number because that macro fluid is available in the form of packets and assumption is that these packets cannot be allowed to break, are allowed to coalesce, coalesce is also possible, breaking also is possible. You see how theoretical after some time in fact CRE tells you do not know how to calculate conversions.

Really unless otherwise you assume ideal plug flow, ideal mixture that is all really. That is the beauty at the end this is what happens in our life. Most of the people at the time of death bed they will know that how useless fellow I am. What are the wrong things I have done? Okay, may people are there, many people really good person will think like that how many wrong thing I have done in my life that is the philosophy and then closes his eyes, okay.

Student: Einstein.

Professor: Einstein also thought like that, yes. Einstein with respect to our mind Einstein is respect but with respect to Einstein's own mind he also told that I have committed biggest blunder of my life because in fact the universe expansion he was the first person to notice when he solved his equation for E equal to Mc square you know that theory of relativity in the equations he found that when the solution comes universe is expanding.

He said that it is a stupid idea, so he put one constant called there is a very special name for that, yes something like that only, right? So I think I am not able to recall that constant he had introduced to stop the expansion. So that means his actual equation showed that universe was expanding and then he has introduced a constant where that constant will take care of whenever this expansion that constant will become bigger and suppresses, okay.

So I mean later he found that I think who is the person? Hubble is the person who found that universe is expanding, so when he said that many people told that, yes Einstein's equation already indicated that but he killed his equations by putting this constant that is the fudging factor they call because why, at that time in his mind he was thinking that universe is constant, volume is constant, it is stationary it is not expanding.

Later they found that it is expanding even now, okay. Yes, so after expansion and expansion it seems the average temperature in the universe will become 0 then you know, the other what is that attract to force, now it is expansion forces which are broken up and then that pressure is still pushing all the planets, planets are very small there, solar system it is pushing away and now after sometime gravity will take over and attraction will come and again come together and then become one small point where it was there before according to the theory.

If you are able to prove that you will get the (())(44:46) either experimentally or theoretically, okay. So many noble prizes I say, okay. Yes, so that is why this macro fluid is defined in certain sense that these are packets, why I am telling? All these I am telling you only to use your brain, please your brain thinking and thinking and unfortunately we are not doing that thinking and we are also responsible because we are not allowing you to think, okay.

Where is thinking time for you? Everyone is getting hundreds of assignments, okay. You see, yes. Okay, yes but even when you are doing you can think, do not do it mechanically that si what you are trying to tell, okay. Do not copy, you do problems but thinking not copying from someone or otherwise mental solving, mental solving all of you are experts, right? Mental solving, you know what is mental solving?

Read the problem, oh! Concentration is given, time is given and reactor is given oh! We can calculate conversion because that is the only thing missing but when you out on the paper everything is missing, you do not know how to calculate conversion first of all, you forget about design equation and you forget Epsilon is there, that is one fellow, okay. All these things you forget.

But when you solve it using your brain once or twice then you do not forget and why us give more number of problems is that at least you do few problems, okay. If you do all the problems you will become expert in this subject, okay. If you do not do at least few problems I think you do, okay you understand that is the reason, okay anyway coming back here. So Macro fluid is available in the packets which are not allowed again why I think all the discussion went because of the brain.

So in the brain we have to imagine that these are the packets which are not allowed to coalesce which are not allowed to break, okay good. Now what is the definition of micro fluid? Micro fluid is the fluid where individual elements are capable of moving very very freely, right? It is very very freely, good. So now when I have that means when I have this Micro fluid entering in a reactor.

Let us say mixture flow reactor, micro fluid entering perfect mixture flow reactor what will happen to each and every molecule? They are perfectly mixed once molecule can communicate with any other molecule, okay. And once molecule at the end when it is just coming out will join with your molecule whose life expectancy is same as its own, we are only focusing on one molecule.

Molecules are continuously entering, so one molecule I looked into now, so that molecule I am following, so this fellow can move here and there and all that but when it joins a molecule whose life expectancy and this molecule life expectancy is same after that life expectancy it comes out, it would have entered 5 seconds back but at the end when it is about to come out it joins a molecule which has been therein the system for may be 15minute or 5minutes then it comes out, okay.

That is one thing that means these molecules are capable of moving anywhere in the reactor communicating with any other molecule and capable of moving anywhere, capable of leaving also at any point of time. At that point of time it will join the molecules whose life expectancy is same all of them will have the same otherwise they cannot come out, right? So that is what is the definition.

Now same this mixture flow reactor I now put macro fluid what will happen? Packets are not allowed to break, packets are not allowed to coalesce they are having their molecules together and those molecules inside this pocket not allowed to communicate with any other molecule, okay. Yes any other molecule in other packet, right? So that is why this pocket and that pocket will have I mean no communication at all and these packets also will come out, these packets also like molecules those are the packets it is a perfectly mixed one.

Now earlier we are mixing molecules, now we are mixing packets so there may be 2 packets whose life expectancy is exactly same. See I am saying packets like this but in fact the size will be very very same you cannot see, right?

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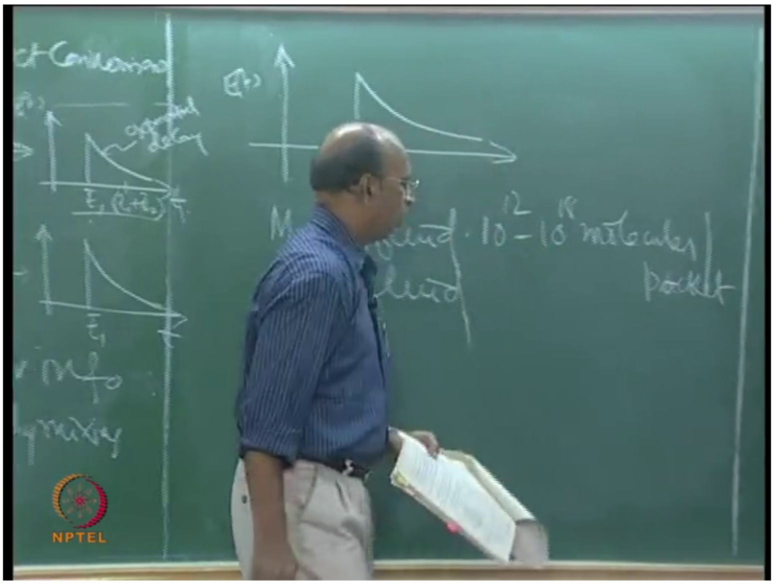

And if I tell you the molecule’s size, so each pocket will have 10 to the power of 12 to 10 to the power of 18 molecules. So that is the one and you know how many molecule (())(50:18) number has one more, yes. So you can see these are very very small things even though we say bigger ones. So that means the communication between the packets is not there and the conversion depends on the time of that packet which is spending inside the reactor, right?

And then when I take that pockets and then break all of them and then find out average conversion that will be different, right? If it is a second order reaction then the conversion (()) (50:44) you have individual molecules together and then coming out and I am finding out average conversion, in this which is late mixing, which is early mixing?

Student: Macro is late mixing.

Professor: Macro is late mixing, micro is early mixing, right? Yes, so now that is for mixture flow. Now imagine that I have now Macro fluid in plug flow reactor, right? Macro fluid, all packets I am sending and each packet, by definition of plug flow each packet will spend exactly same times.

What is the conversion in each packet? I know same, average is same, good over is simple. I will now send micro file, micro fluid by definition of plug flow each and every molecule also will spend exactly same time what is the conversion in each and every molecule if you can imagine that same and average is also same, so that means what either micro fluid or macro fluid in a plug flow, okay same conversion.

Now what can you say about mixing? Is it late mixing or early mixing in plug flow?

Student: Early mixing.

Professor: Yes, what do you call that? In these 2 terms whether you call this late mixing or early mixing. Latest mixing (())(52:01), when they are mixing they are only mixing outside the reactor because we are breaking all the packets and then seeing that, right? So the latest mixing possible that means you see how many beautiful things are coming now.

Why they are beautiful? Because we are now thinking that individual molecules because we said that we have late mixing and early mixing, right? And we said that here for micro fluid we may have earliest mixing possible if I use in mixture flow but if I use in plug flow either macro fluid or micro fluid I will get exactly same condition as latest mixing possible. So that means macro fluid is by definition latest mixing, correct no, they never mix also.

Mixing we are talking about at molecular level, right? Yes and macro fluid depending on which reactor you use it behaves as if it is a latest mixing or earliest mixing. So that is why the RTD comes into picture because when I say mixed flow and plug flow they are associated with RTD. Mixed flow and plug flow they are associated with some RTD, right? Definitely, So now depending on what kind of RTD you have, what kind of fluid you have, your late mixing and early mixing can be defined.

Okay I think I am trying to tell as simple as possible, right? But I think please do not loose I think you are understanding everything but only thing is connections. Because when I ask you are not I mean most of you are replying also because now there are so many terms that is coming into picture.

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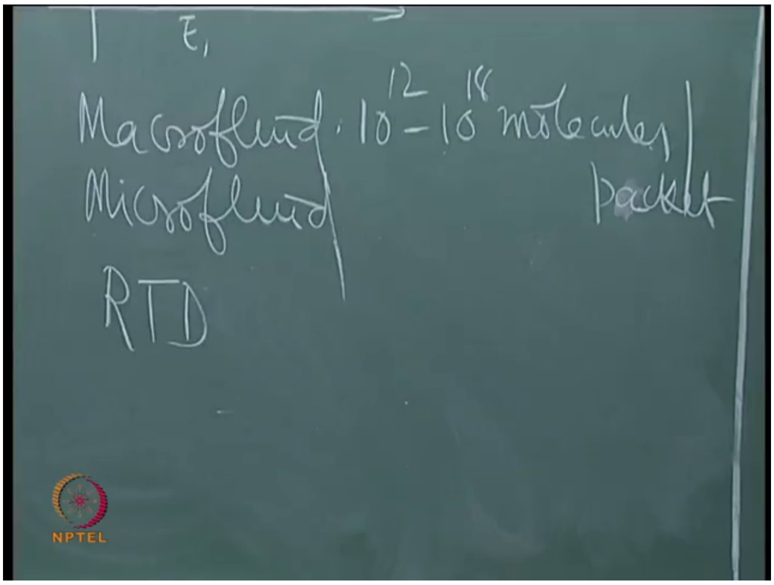

Late mixing, early mixing, micro fluid, macro fluid, now I brought another thing called RTD, okay.

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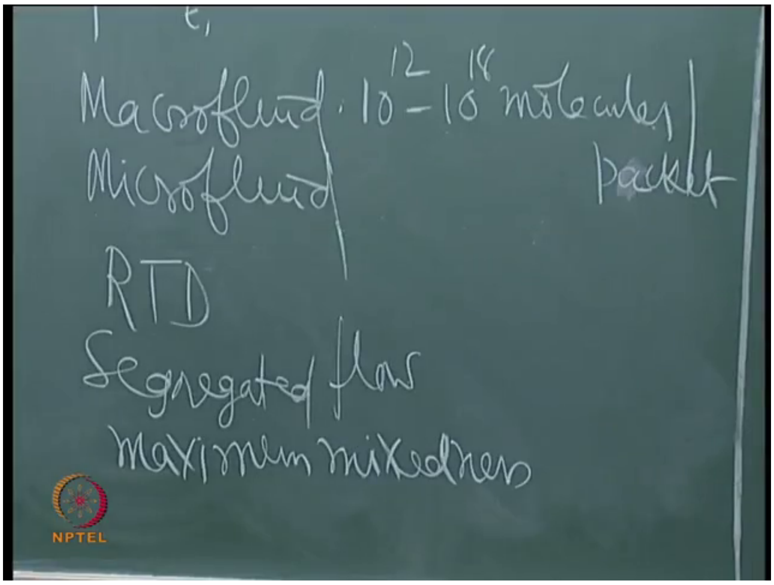

Macrofluid · $10^{12} - 10^{18}$ molecules packet

Microfluid

RTD

Segregated flow

Maximum mixedness

Now we have another 2 terms called segregated flow and maximum mixidness, okay. Yes, now I think Sushmita is seriously looking, okay. Yes, now can you assess it, this segregated flow and maximum mixidness to macro fluid and micro fluid.

Student: (())(54:40)

Professor: Correct, okay but is there any other condition that means RTD, okay. So that means maximum mixidness is possible only in micro fluid in (())(54:55), right? But even this micro fluid will become segregated fluid if it is (())(55:04), right? So that is why we are now trying to define these scales. These scales if you understand I think that afterwards it is easy to discuss.

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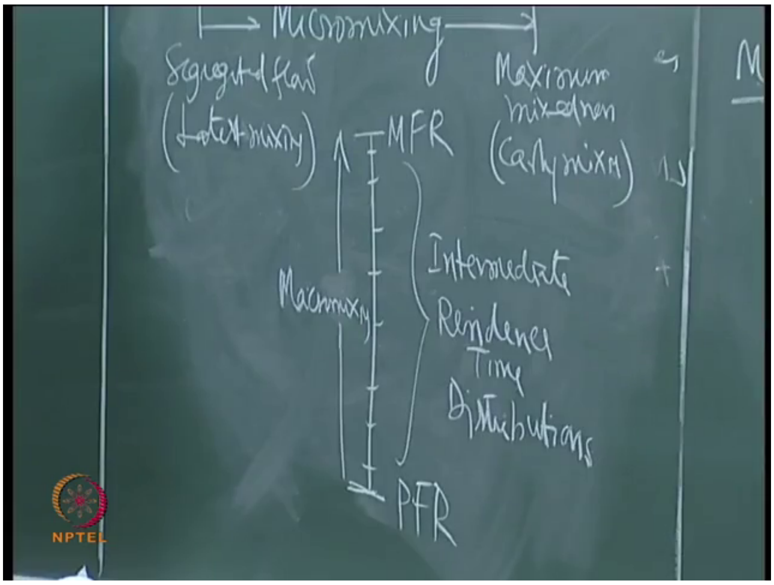

Define the scales as, we have a scale called micro mixing, it is increasing in this direction, so here this corner you have segregated flow or in other words this is latest mixing and this corner we have maximum mixidness or in other words you have early mixing and this is also called degree of segregation, okay. Okay, so that is one scale the other scale is, in this direction we write.

We have MFR here, we have PFR here and we call this one as macro mixing scale, macro mixing increasing in this direction and here we have intermediate RTD, intermediate residence time distributions, okay.

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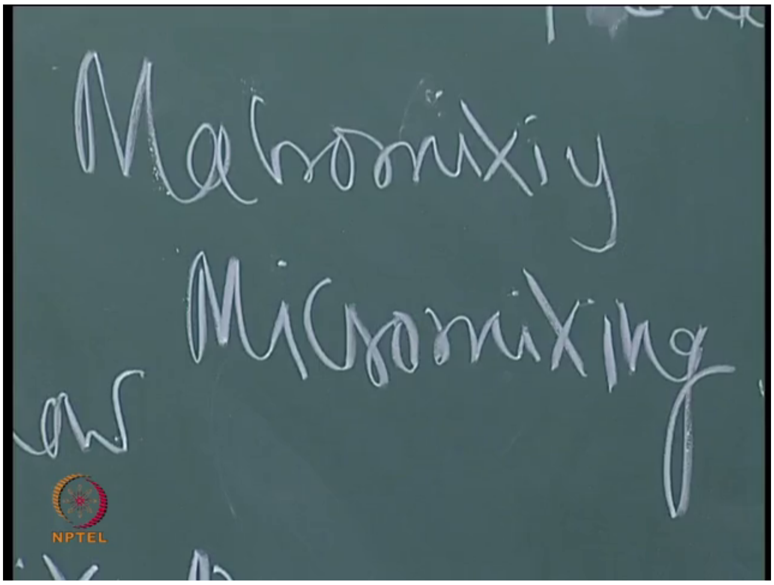

Yes, so these are the other 2 terms, now I have introduced that is macro mixing and micro mixing, okay. Now of course I will give the notes to you, right? Now what is required? All our problem came now, how this problem has come now for us? What is the issue now? The first thing is what we have asked is that what was the question we had asked? Part 3.

Student: (())(58:14)

Professor: Whether RTD information is directly useful or not? Then we found that it is only useful for...

Student: First order.

Professor: First order because it is a linear process other than first order you have to define whether the, yes system is mixing that or you know the fluid is late mixing or early mixing. Unless that information is known to us we cannot calculate conversions. To define that all these things are required.

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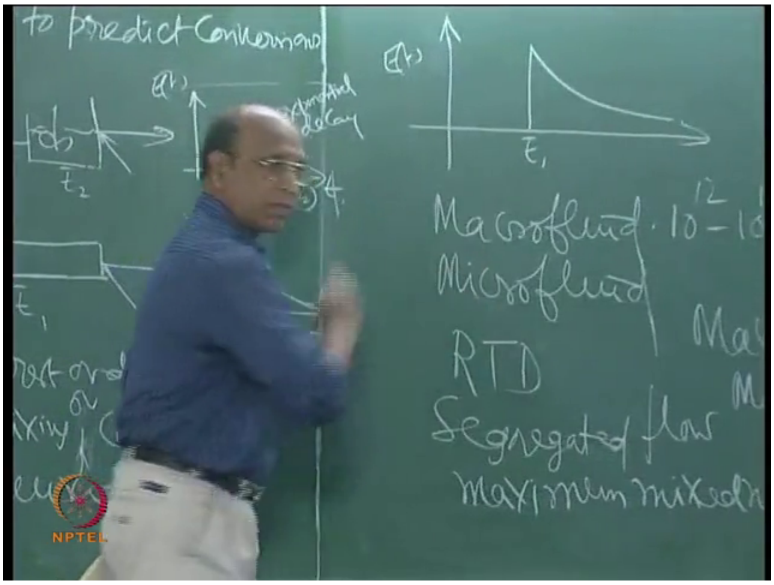

What is that required? First we have to define the fluid, right? And also next we have to define macro mixing and micro mixing, okay yes good. So now this macro mixing, micro mixing we are writing like this because macro mixing tells us about RTDs, right? Macro mixing will tell us of RTD that means the age distribution or in other words life expectancy also, right?

So that is what is here and the 2 extremes what hear is PFR and MFR that we know already and all kind of other intermediate RTD distributions can be there in that macro mixing, right? And the other one what we you are defining is micro mixing which is telling the state of mixing whether it is early mixing or late mixing, right? Where is early mixing here when I have maximum mixidness we have early mixing and when I have segregated flow that macro fluid we have latest mixing but there is some kind of over lapping now please remember that.

What is that overlapping? Even though I am using micro fluid if it is PFR then that behaves as if it is a, yes it is a late mixing that is why RTD automatically comes into picture. So now you see macro mixing and micro mixing both are coming into picture whether it is PFR or MFR is also required to discuss whether macro fluid is behaving as latest mixing or micro fluid is behaving as latest mixing, correct no?

So that is why in the beginning itself I told, Krishna last? Is it difficult now? Yes, what is difficult you tell me? Where you have not understood?

Student: Laughs.

Professor: Unless you tell me I cannot clear, no? I feel that I am explaining very clearly but you are lost somewhere where?

Student: What is the need to define late mixing or...

Professor: What do you mean? The basic question otherwise how do I calculate here. See my basic question is I think you are at square number 1.

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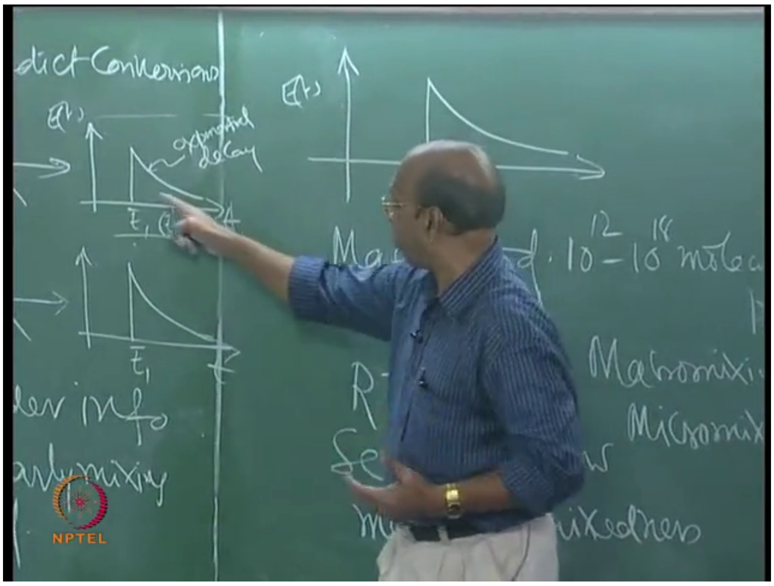

Square number 1 what is this is that I gave you only this, right? Yes that you understood, right? But now I also gave another example Debayan and Janvi. By giving this they may choose either 1 may choose and early mixing another person may choose, okay. Now it is wake, you cannot choose for the same RTD 2 things.

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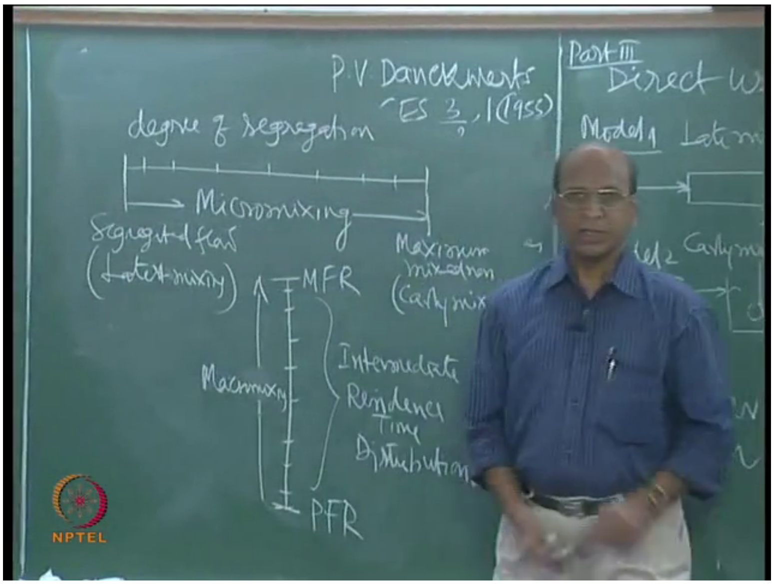

So that is why now we have to tell another parameter whether the fluid is available in segregated manner or in maximum mixidness manner that is why these 2 terms have come. See we talked about late mixing or early mixing. Now to define late mixing or early mixing we defining the boundaries one is the segregated flow, what is the mixing here latest or earliest? Latest and other corner what we are defining is maximum mixidness which is the earliest possible mixing, right?

But that scale tells me that whether I have latest possible mixing or earliest possible mixing but this will not tell me whether I have micro fluid or macro fluid, why? Even micro fluid if you know it can behave as a latest mixing provided this and this matches that is why this scale I have to take it and then draw here that is why now it you know both are required now.

Again confused? Yes, so that is why you see the connections as far as I am concerned I think it is very simple connections which I am trying to give question number 1 that figure remember, right? So by giving that figure you can never calculate correct conversion unless we say whether you have late mixing or early mixing but late and early mixing both are wake terms. So that is why now we are defining mixing, how are you defining mixing? That scale is called micro mixing scale.

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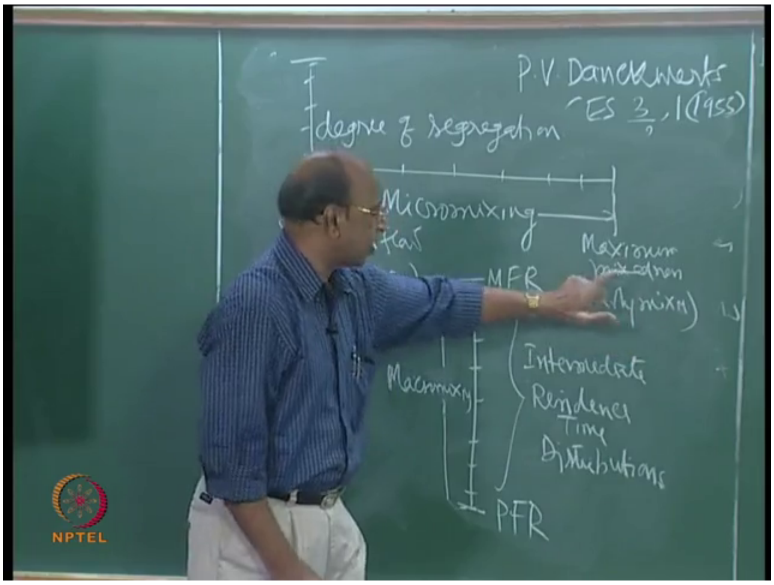

One corner I have latest mixing possible which is also called segregated flow and other side I have earliest mixing possible which is called maximum mixidness.

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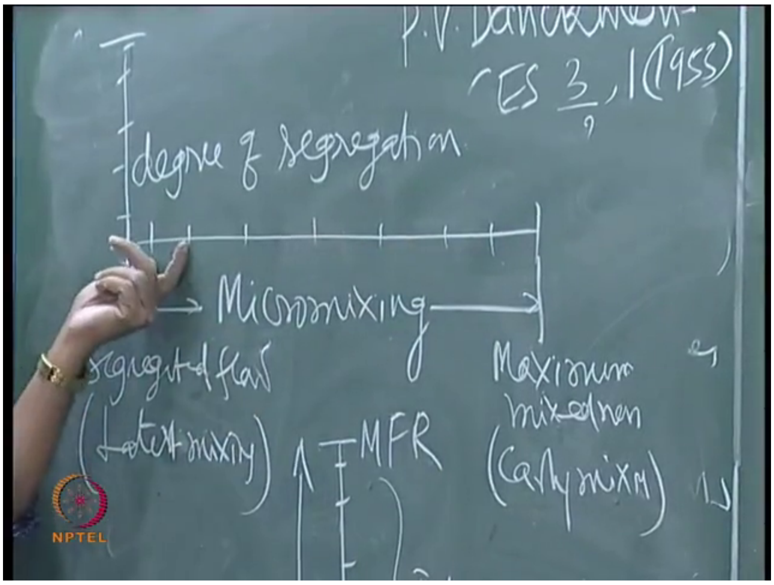

This intermediate I can have any number, you know all between these 2 that means some amount of segregation, some amount of you know maximum mixidness, right? In between 50 percent this 50 percent that all possible combinations and at this point if I say small amount of segregation and maximum amount of maximum mixidness, okay. So that is why we are now but I think you know you cannot calculate, in between is very very complicated and particularly micro fluid.

By the way what is micro fluid? I mean have you come across this micro fluid earlier in your B.tech or in your M.tech or your whichever honour you are done.

Student: Molecules.

Professor: Yes, exactly Swami till now what you have assumed is micro fluid without knowing yourself in fact you never assumed macro fluid, all the equations we have derived for reaction engineering till now, kinetics till now they are only micro fluid, so that means you have been with that but fortunately without knowing yourself, you assumed ideal plug flow and ideal mixed flow.

Unless you assumed you can never calculate that, okay because anywhere in between RTD it is impossible to calculate for you know the conversions in the reactor unless I assume ideal mixture flow ideal plug flow that is what Zwietering tried to do he has take this scale maximum mixidness scale, okay. And then this scale now he has moved along all this or other words this scale will go and then moved from MFR to PFR he has derived equation for maximum mixidness in Zwietering problem but it is very difficult to use that is why it is not popular and no one is using except for discussion, right?

And what is that maximum mixidness is nothing but your micro fluid, right? So unless you have the 2 extreme RTDs, one is plug flow another one is mixed flow, right? You cannot calculate conversion s exactly those are the simplest cases but Zwietering has done in between cases also intermediate RTDs also he has done it. He has taken for example (()) (65:29) because that is intermediate mixing, correct no?

At one corner you have N equal to infinity, in other corner you have N equal to 1 and he tried to solve that problem for maximum mixidness scale. Maximum mixidness scale is nothing but earliest mixing, right? Earliest mixing is possible only with micro fluid, possible I tell but even micro fluid will behave as macro fluid the moment you go to PFR, so it is not that even though you define micro fluid as molecular you know molecules can freely move RTD also comes into picture.

That means macro mixing also comes into picture, macro mixing define RTD, micro mixing define state of the fluid whether it is aggregates this side or whether it is individual molecules, right? But the overlapping comes because when I have micro fluid and when I put in PFR that fellow behaves as if it only latest mixing macro fluid, okay or segregated fluid, right? So that is the overall picture.

And what are possible things? What we have done I think there is another paper also Weinstein and Adler they try to do something else in between, okay. So I think all those things are very complicated and that is why it has not even come to the text books where you can use those equations for example if you see Fogler, Fogler has written recently another book Essential of chemical reaction engineering I do not know whether anyone of you have seen may be recently 2012 or so.

In this book there are many things are repeated but may be probably he thought that RTD is not essential for reaction engineering he removed I think RTD chapters from that but if you see the earlier one the previous edition to this in that book he has derived also Zwietering equation I am not including that in the examination but definitely I will give the equation, so that you will remember for your future thing because we are not definitely using them to calculate conversions but to appreciate the complicated things in the reaction engineering to calculate conversions I am going to give you that, right?

So this is the over I am at least did you understand the problems now, what are the problems associated with RTD? The first thing is RTD cannot give you complete information to calculate conversions except for first order and why? RTD is linear and also first orders require only that kind of time information and that time information is given in RTD and it cannot solve second order or other orders the reason is there is another parameter coming late mixing or early mixing or segregated flow or maximum mixidness.

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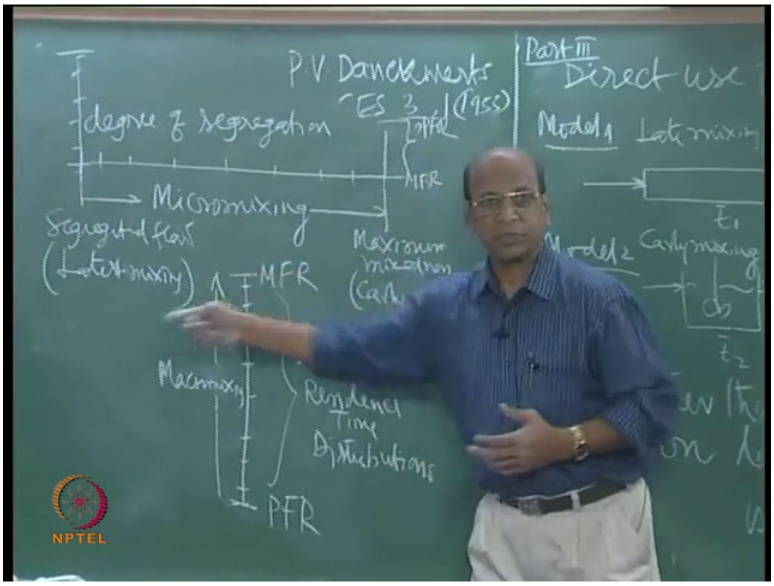

Another name for late mixing and early mixing is maximum mixidness and segregated flow that is why I have written in the bracket, okay. So for other than first order reactions unless you know these 2 parameters whether you are this end or that end you cannot calculate conversions and what you can calculate conversions is segregated flow. Segregated flow is easy to calculate, you know why?

Again as a (())(68:57) I can just explain segregated fluid whether I have first order or second order each pocket is behaving as if it is a, yes individual batch reactor each packet is a batch reactor.

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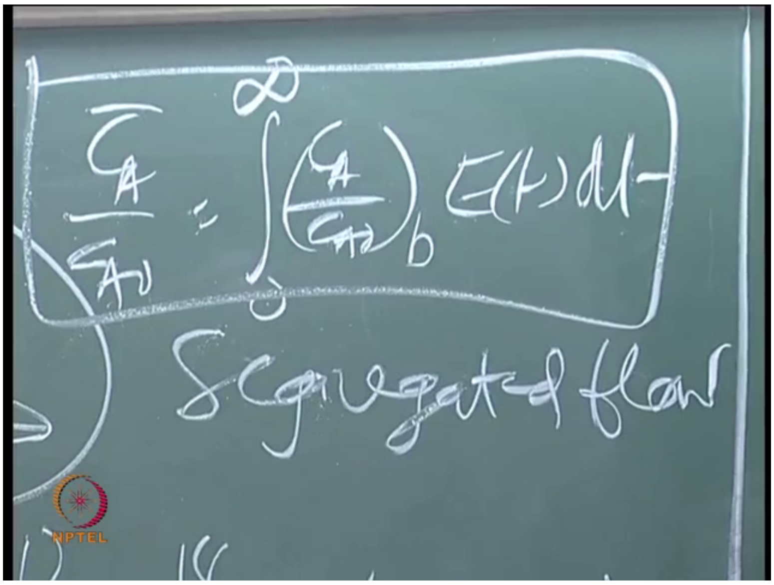

Now I can calculate this batch reactor conversion and then average all of them and you know the equation what you get it is the simplest one where CA bar by CA not equal to 0 to infinity CA by CA not batch Et dt this is what is for segregated flow. For first order also it is exactly same because for first order what is CA by CA not batch? CA by CA not batch for first order that is for segregate flow.

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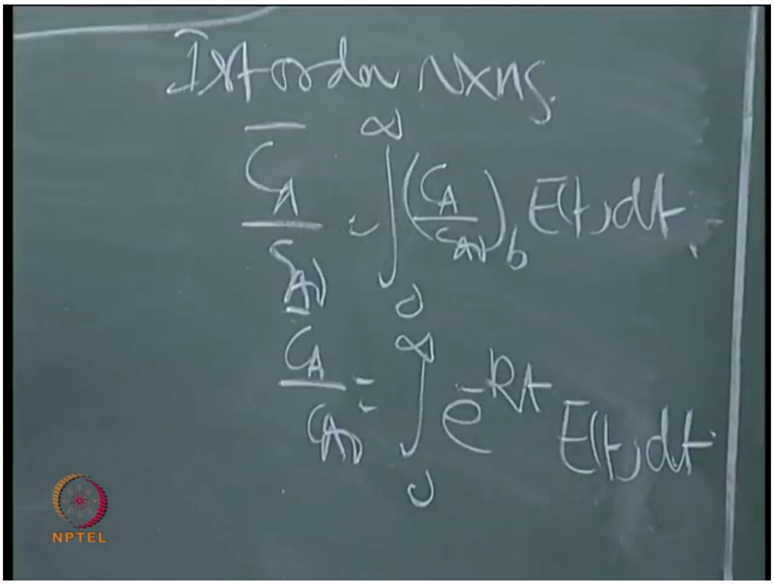

Ist order rxns.

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

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

For first order reactions CA bar by CA not is again 0 to infinity CA by CA not batch Etdt and that is also equal to 0 to infity e power minus kt Etdt, So that is CA by because average CA bar by CA not, okay. That is specifically for first order reactions, how did I get that equation? This equation I got thinking that, okay. The material coming between time t and t plus delta t is Etdt.

The material that is the definition of Etdt the fraction of material which is coming between time t and t plus delta t is Etdt, right? So in that fraction what is the conversion if it is first order? Right? Like that how many particles I am getting? 0 to infinity and then dt will take care of that small small intervals that is all the equation that you have and for segregated flow exactly it is same.

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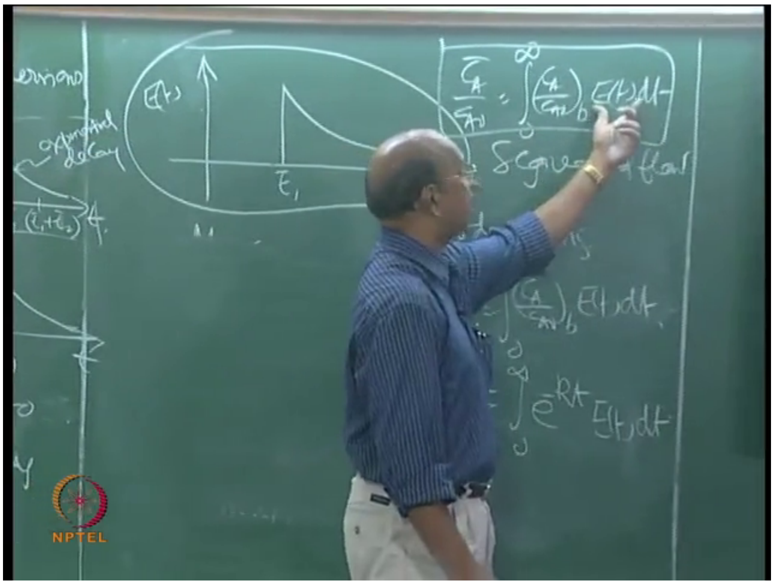

Segregated flow beauty is that these particles are not interacting with any other particle but there also how many pockets are coming between time Et and dt. There are 100 packets coming between 10th minute and 12th minute, how do I find out that fraction Et? Et delta t but now delta t is between 10th and 11th minute, so in that packets what is the conversion? Right?

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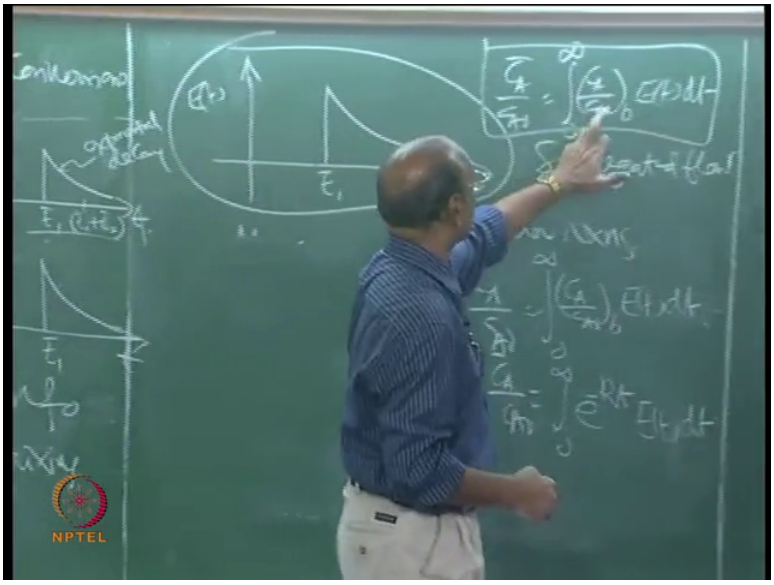

And now here I do not have to specify the order because here any order is okay for me because in that reactor because these packets are there inside the reactor without any mixing with any other molecules. So it is returning as if it is a batch reactor, so all the conversion are taking place in that packet, so whether it is first order or second order or third order it does not matter, right?

But if the packets are breaking and then mixing with other molecules then I do not know how to take it out because that becomes now micro fluid at molecular level that information is not known to me but for segregated flow it is easier to calculate, are you able to follow me? Why segregated flow is easy? Because, yes segregated flow is behaving as if each pocket is a batch reactor.

And now depending on my Etdt information how many of those batch reactors are coming between 0 to 1 minutes, 1 to 2 minutes, 2 to 3 minutes how do I get to that information? It is only through RTD, correct no?

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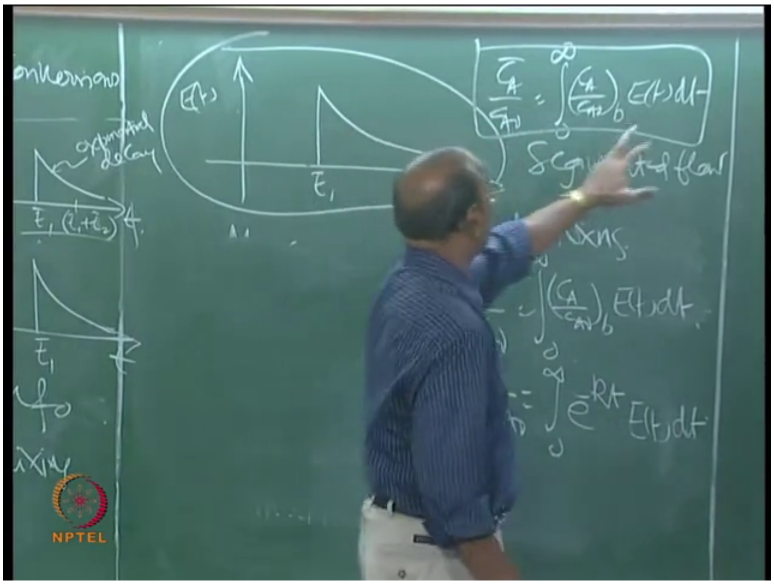

It is only through RTD, so that is why this ETdt is the fraction and so many packets and this will give me the conversion in that. Now here whether I have 0 order, first order or second order that does not matter, okay. That is why very clearly for first order and segregated flow RTD information is directly closing, right?

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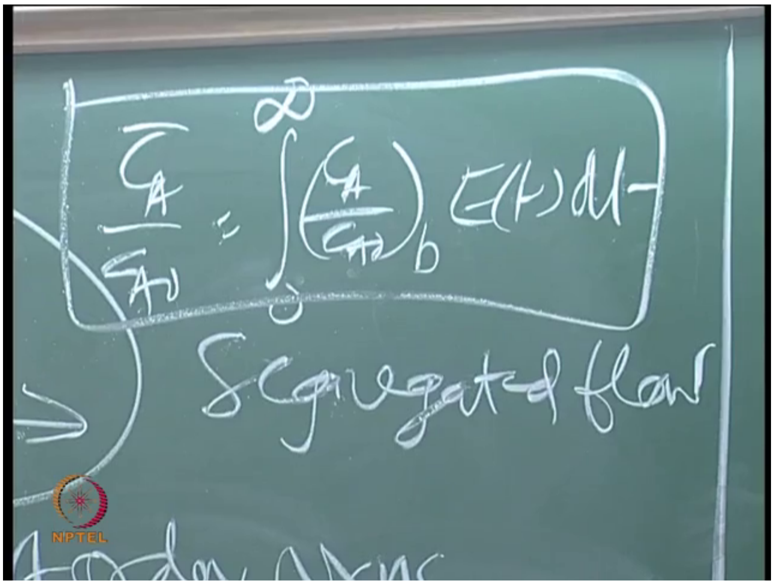

And the derivations are so simple it is not what we write there is the same thing what we write is the conversion in that pockets multiplied by what are the number of packet that are coming in this time between Etdt that means t and t plus delta t that is the fraction of material that is coming, in that fraction I may have 1000 packets, right? Okay good, so this is the, I mean the equations for first order and also for the segregated flow and now we can also prove that for first order...

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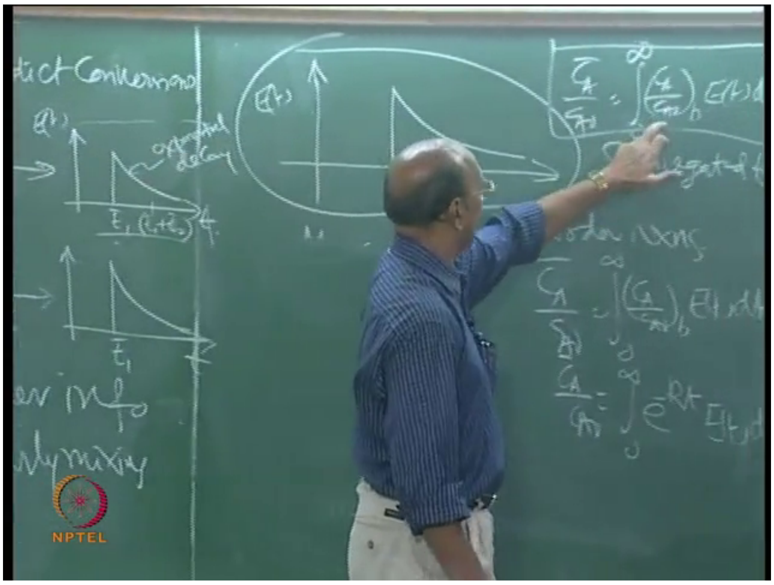

Yes this equation for first order even if I use this equation or this equation for first order, both are same in fact I simply wrote e power minus kt, right?

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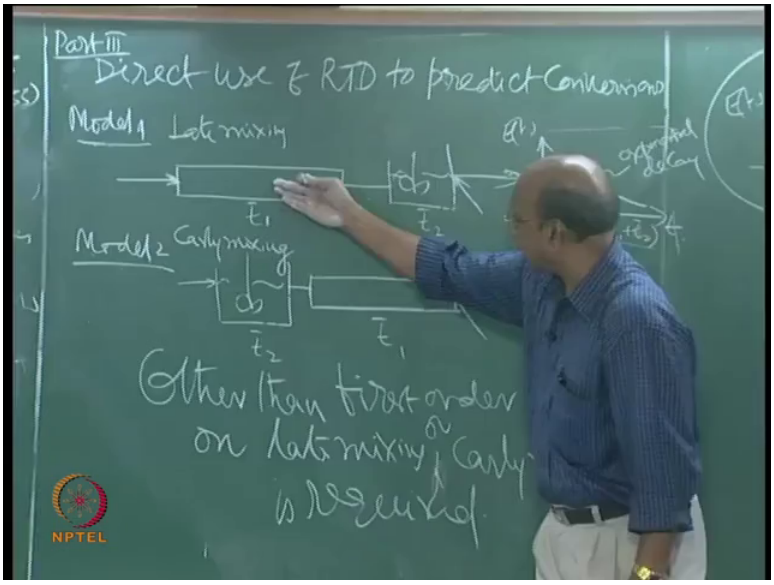

Like here whether I have late mixing or early mixing we are going to get exactly same thing for first order. You know what is equation for first order, for these 2 systems conversion equations? You know the answers can I quickly derive and tell or you cannot derive, you do not have to derive you can tell me the answer finally.

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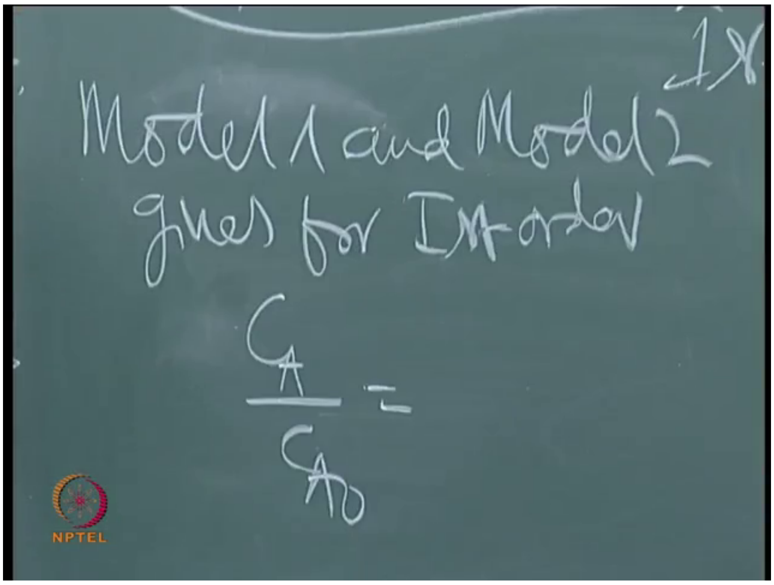

18

Model 1 and Model 2
gives for Ist order

$$\frac{C_A}{C_{A0}} =$$

CA by CA not equal to, if I have this RTD in fact for first order either this model or this model, model 1 and model 2 gives for first order, yes CA by CA not equal to e power minus kt bar 1, excellent Swami 1 plus k t bar 2, you can derive in fact using this you can derive, using this you can derive you will get that, okay. So message here is that this equation when you are getting it does not matter whether you have early mixing first or late mixing first both will give you same conversion if it is first order, why?

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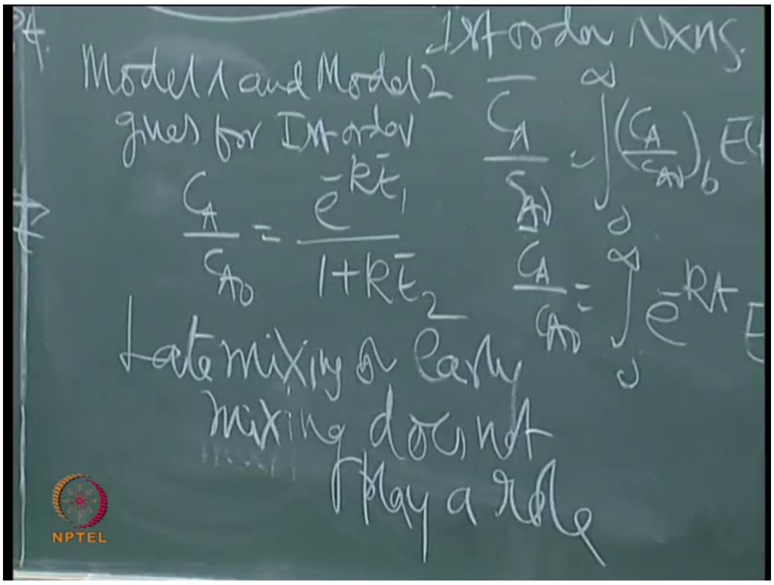

Model 1 and Model 2 gives for Ist order

$$\frac{C_A}{C_{A0}} = \frac{e^{-k\bar{t}_1}}{1+k\bar{t}_2}$$

Late mixing or early mixing does not play a role

Ist order Rxns.

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

$$\frac{C_A}{C_{A0}} = \int_0^\infty e^{-kt} E$$

Because there late mixing or early mixing does not play a role that is what is the conclusion. Late mixing or early mixing does not play a role that is what is the conclusion, that is what is given and now I will also give you quickly for second order I think where?

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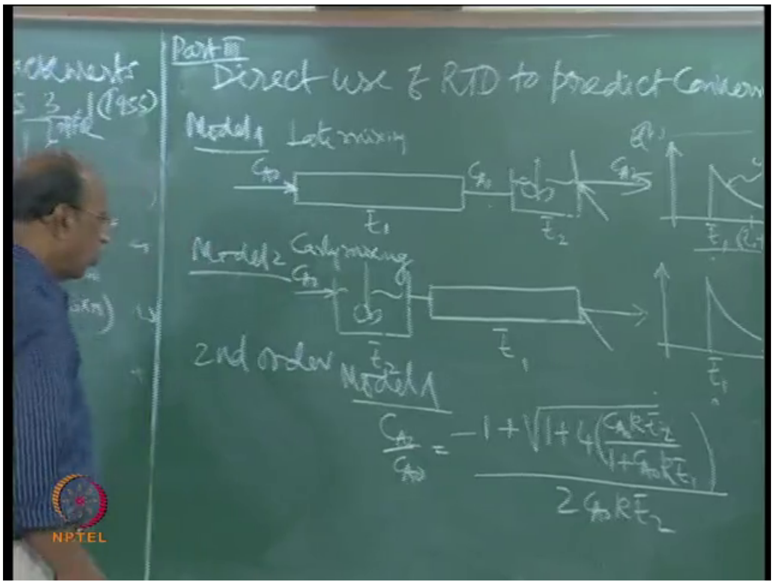

Second order model 1 I am giving the equations, okay. You can derive that later this will be CA by CA not equal to, this is second order no, so I have minus 1plus square root of 1 plus 4 CA not k t bar 2 divided by 1 plus CA not CA not kt bar 1 good, so whole thing divided by 2 CA not kt bar 2 that is the one for model 2, so you know how do you get this?

Okay I think if I say this is CA not and this is also CA not both are same but this will be CA1, this will be CA2, so then let me write here CA2 and here this is CA1, this is CA1 dash and this is CA2 dash that I have not yet written, you have noted down this, you have marked this no? Okay shall I?

Student: (())(78:18)

Professor: Where? This one, you are asking me to write here or... This is here 2 by CA...

Student: modelling 2?

Professor: Oh! This also you mean, okay. So here both are same CA2 and CA2 dash both are same, okay. Yes, so now and I tell you as far as this mathematics are concerned you are not learning anything new because you would have done this even before RTD when I have Cstr followed by I mean plug flow or plug flow followed by mixture flow you would get the same equation.

Okay, I do not know whether... Did I give that one in assignment? PFR followed by Cstr for second order, no? Okay I could have given that.

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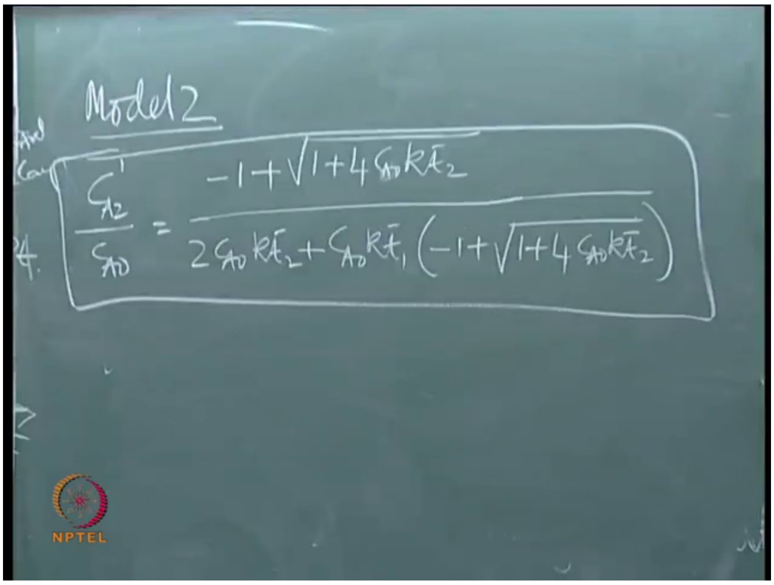

Model 2

$$\frac{C'_{A2}}{C_{A0}} = \frac{-1+\sqrt{1+4C_{A0}k\bar{t}_2}}{2C_{A0}k\bar{t}_2 + C_{A0}k\bar{t}_1\left(-1+\sqrt{1+4C_{A0}k\bar{t}_2}\right)}$$

Okay, so model 2 CA2 dash by CA not, so that is why I am deriving I think you know because those equations are already... There is nothing new in that except Algebra that you have to do. Yes, second order model 2 will give me minus 1 plus square root of 1 plus 4 C not CA not kt bar 2 whole thing divided by this is complicated 2 CA not plus CA not kt bar 1 minus 1 plus square root of 1 plus 4, yes so this is the equation.

One thing you have to notice there what is CA not kt bar 2? So you can call that one as DA1 DA2, okay. He is so angry, okay. So now you have calculators, no? No one? Now what you would have if I could have given surprise test, you know that I do not give.

Student: Sir we thought if you give a surprise test you would give numerical problems.

Student: Laughs.

Professor: Human mind can explain anything, okay good now take CA not kt bar is also equal to CA not kt bar 2 and kt bar1 both are same equal to 1. Can you calculate CA2 dash and CA2 by CA not.

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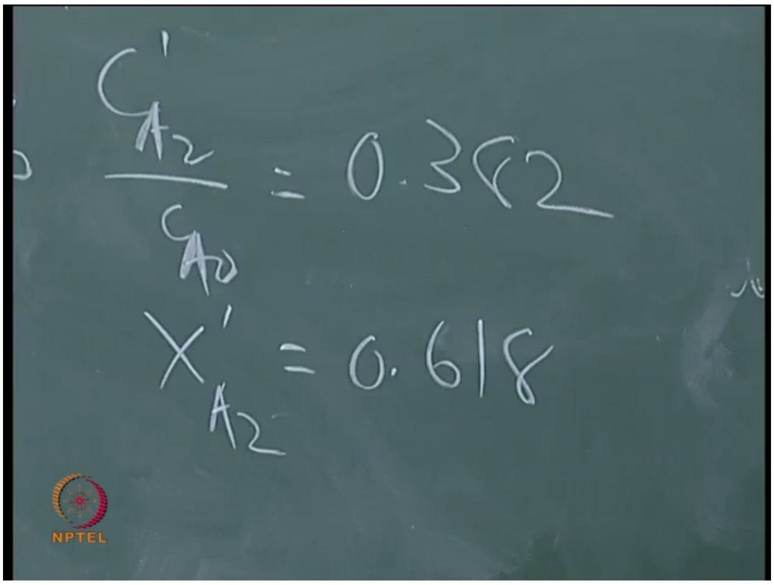

$$\frac{C'_{A_2}}{C_{A_0}} = 0.382$$

$$X'_{A_2} = 0.618$$

CA not kt bar 1 also equal to CA not kt bar 2 equal to 1 by the way those 2 are Damkohler numbers, so Damkohler number 1 and 1 for both the reactors, what is CA2 dash and what is CA2? CA2 by CA not and CA2 dash by CA whoever does correctly they get 5marks...

Student: (())(82:00)

Professor: I do not understand you have to give me the final expression, final value?

Student: (())(82:08)

Professor: Excellent, this is 0.366, so conversion XA2 equal to 0.634, correct no? Yes for the other one 0.382, so X2 dash equal to 0.618, no? Yes what is the conclusion Debayan? As if we do not have any other work we have calculated.

Student: Laughs

Professor: That is true you may think that you do not have any work. Yes Venkat?

Venkat: More conversion.

Professor: Why?

Venkat: That is not...

Student: Order is greater than...

Professor: Yes because it is second order and because it is late mixing, so you are able to calculate that but life is not so easy because here we specified ideal PFR and ideal you will not have this kind of equation and this kind of equation if I say that they are not ideal reactors both the reactors.

If we have some other intermediate RTD, okay then you will not have this kind of clear picture.

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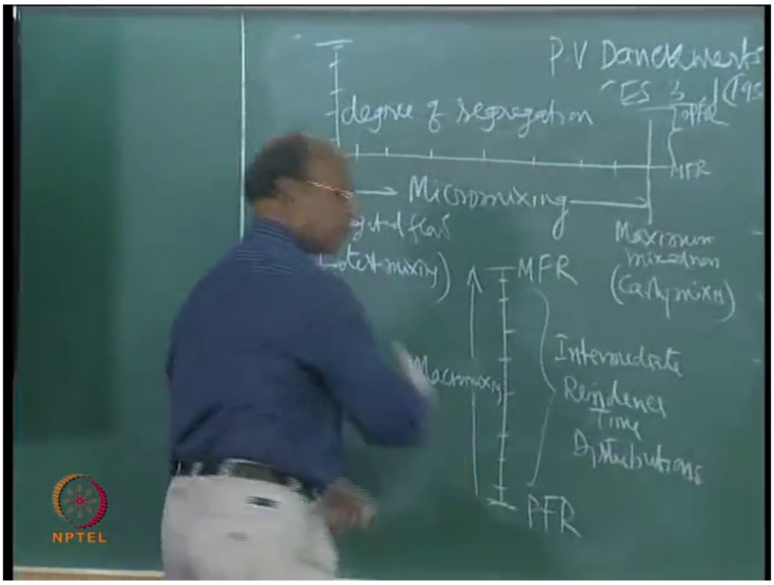

So that is the reason why we have drawn this, right? And now we are saying that how do we understand the 4 corners, this corner, this corner, this corner, this corner, okay. My next thing is comparing this corner here I take MFR and segregate it from here. That is what I already explained I know in words. We have MFR we have taken segregate flow, what will happen now?

So packets are continuously coming out, what is the RTD of these packets? Same thing exponential decay, right? So I will know what are the fraction and all that, so I can now calculate what is the conversion in that? Because segregated flow I know, why? Because in segregated flow each and every packet is not breaking and that packet is coming out after sometime which is dictated by RTD, correct no?

If I know RTD the fraction coming between time t and t plus delta t is Etdt and in that fractions let us say 10 and 11, so 10.5minutes, 10.5 minutes if it is second order also I can calculate conversion because it is batch reactor, right? These packets, so that is the reason why I know I can calculate but only thing what is happening in this mixture flow reactor is that molecules are not communicating, only molecules within that packet only are communicating and getting reacted.

So the concentrations are kept as high as possible, so that is why for second order reactions you get more conversion and on the other hand if I use mixid flow this curve maxim mixidness individual molecules freely moving earliest possible mixing what is now happening? Now happening is that the moment molecules enter the reactor they are free to communicate with anything.

They are not keeping the concentration high but they are diluted now because it is mixing with each and everything whereas in the pockets they are not mixing packets keep the concentration high because they are not mixing with the entire reactor the other things, the other packets. So that is why the concentration is maintained as low as possible because of mixing, right?

And then you will get some conversion that conversion you can calculate using our normal Cstr second order because when you are talking about second order reaction, so that means MFR corner this side and this side we have matched, correct no? MFR we have taken segregated flow what is happening I will derive tomorrow MFR segregated flow equations, okay.

Again it is not great derivation but we will give for second order, right and then now, yes so mixid flow already, you know you have already done it. Mixid flow and maximum mixidness where you have earliest possible mixing with individual molecules that is what you have learnt in B.Tech now also learnt M.Tech now, okay and now those who have completed M.tech they also learnt in PHD now, okay.

So that will not change second order mixed flow and normal fluid micro fluid you have the equation, good. Yes, yes we are going, okay.

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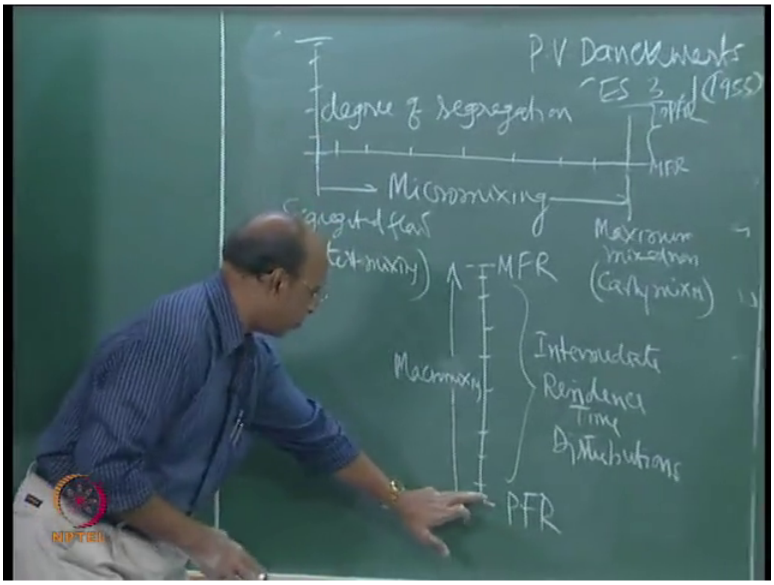

Then the other one is PFR here

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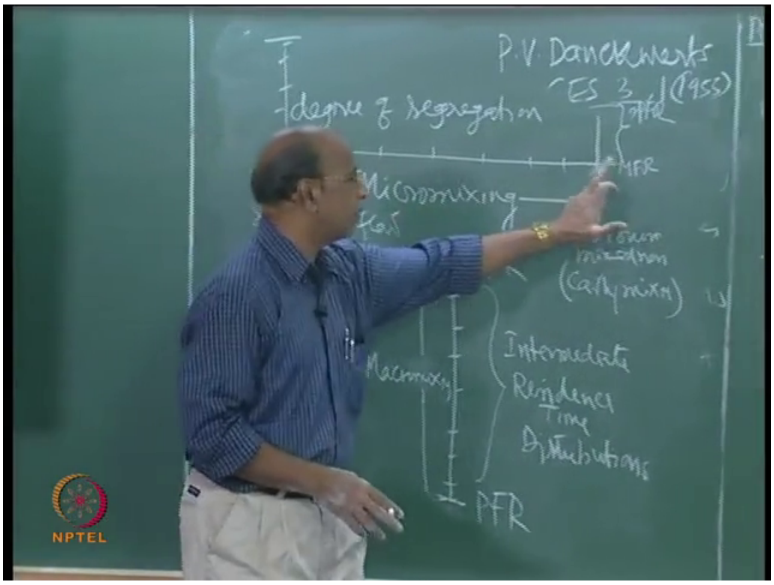

And PFR here, right? PFR segregated flow, how do they behave? So when I put segregated flow in PFR each and every molecule exactly for each and every packet spends exactly same time

Student: Ideal plug flow.

Professor: Ideal plug flow even if I have segregated flow I get the same conversion and even if I have PFR here this corner again you have same, so when you have PFR does not matter whether you have maximum mixidness or(())(87:34). So in other words do not care whether you have micro fluid or macro fluid if it is PFR that is one of the important conclusions important conversions, yes that is true.

For you it is conversion, right? You have to convert not the one, so that is why important thing is do not care if you have micro fluid or macro fluid, if you have PFR or RTD close to PFR, right? That means if the deviation of RTD also not very far from plug flow (())(88:15) that is what is the thing. So the moment you have plug flow you do not have to think about, okay late mixing early mixing, why?

Because it is always late mixing, correct no? Why late mixing by definition of plug flow there is no mixing, okay. And Savita wanted to tell it is 0 mixing, okay. 0 mixing is late mixing inside the reactor or latest mixing because inside the reactor it is not at all mixing if at all we break it and then mix together and then check average conversion packets and all that, so that we call the mixing is only outside the reactor but not within the reactor, right?

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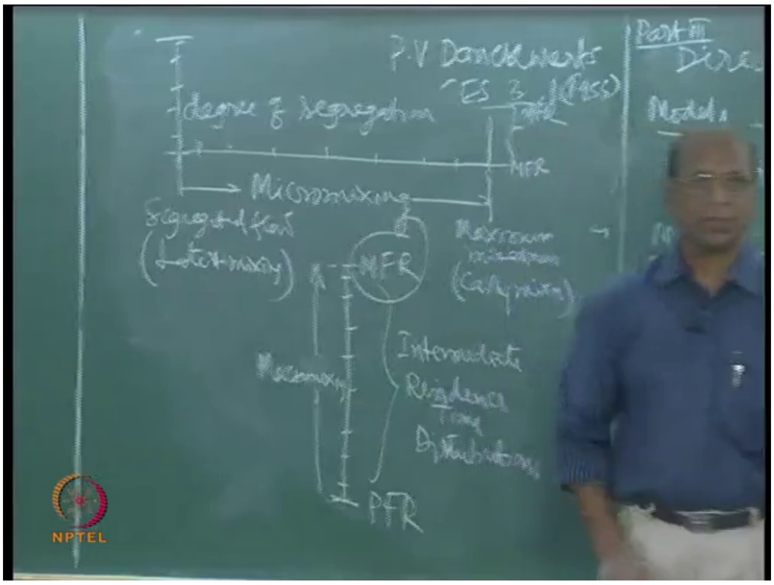

So now what is the problem? Problem is with this fellow, MFR; also what you have to learn new is what? Segregated flow not this, this already you have equations, right? So now if I take this scale that means only this corner, this corner here we have done it, right? So now somewhere in between if I put we do not know how to calculate, Zwietering did it, right? And then those equations are complicated, so we are not I mean I just gave you the Zwietering equation we just leave it there and in between I can also you know we corner this side and this side, now the same scale I can take here and then move up and down, okay.

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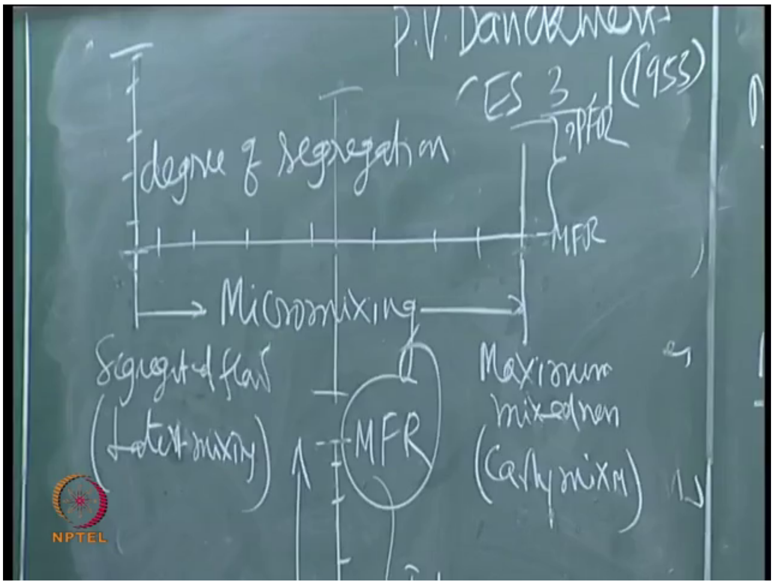

So that means PFR here somewhere intermediate degree of segregation that means some amount of segregated flow late mixing, some amount of early mixing, right? How do you take it off? But note wonderful information is there but it is not possible to use that information to calculate conversions it is complicated, right? But how people thought about that and very quickly tomorrow I will try to give that thing, right?

So what we do tomorrow is in the class is that I will take this segregated flow alone, yes okay. Segregated flow alone and then we will try to discuss whether how the (())(90:20) had changed what we have done, the little bit now again I will repeat and then derive only for segregated flow MFR because PFR absolutely no problem, right? PFR you can forget.....

(Conversation between Professor-student ends)