Chemical Reaction Engineering 1 (Homogeneous Reactors)
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Lecture No 16
Basics of Mixed Flow Reactors

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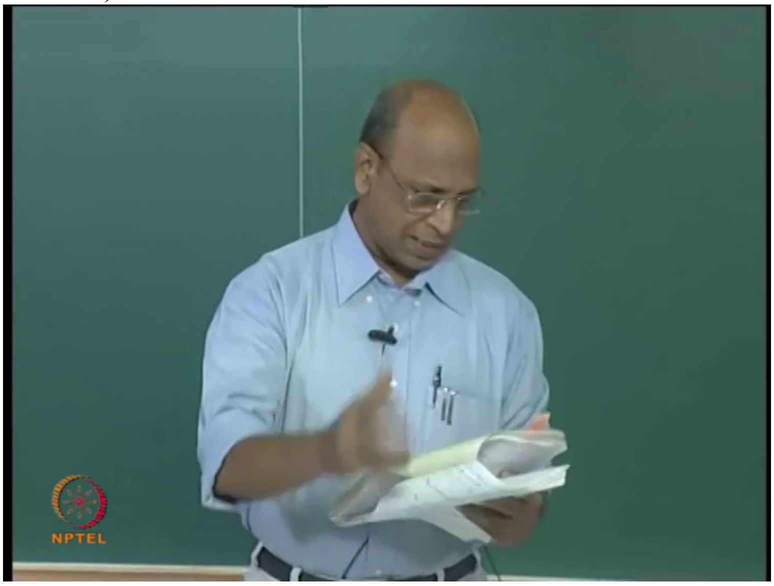

Please take this plug flow assumption. You write this plug flow assumption. This I have taken from Denbigh book, the original person in his own words, we will write that and then you know you can just, I think whatever we have discussed it is here. But nothing like you have a para on that so that anytime you can refer. Ok.

Plug flow assumptions. One, over any cross-section normal to the fluid motion, over any cross-section normal to the fluid motion the mass flow rate, the mass flow rate and the fluid properties in the bracket, fluid properties in the bracket pressure, temperature and composition, pressure, temperature and

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composition, close the bracket, are uniform, are uniform.

Two, there is negligible,

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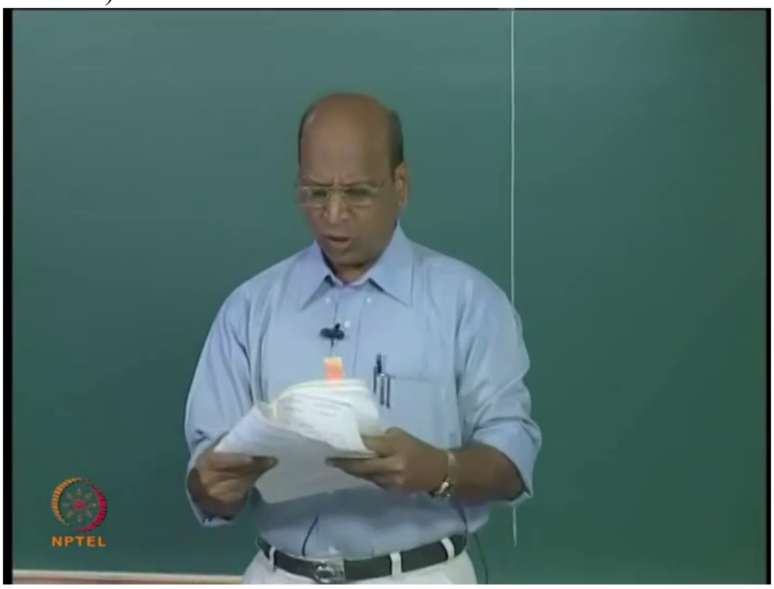

there is negligible

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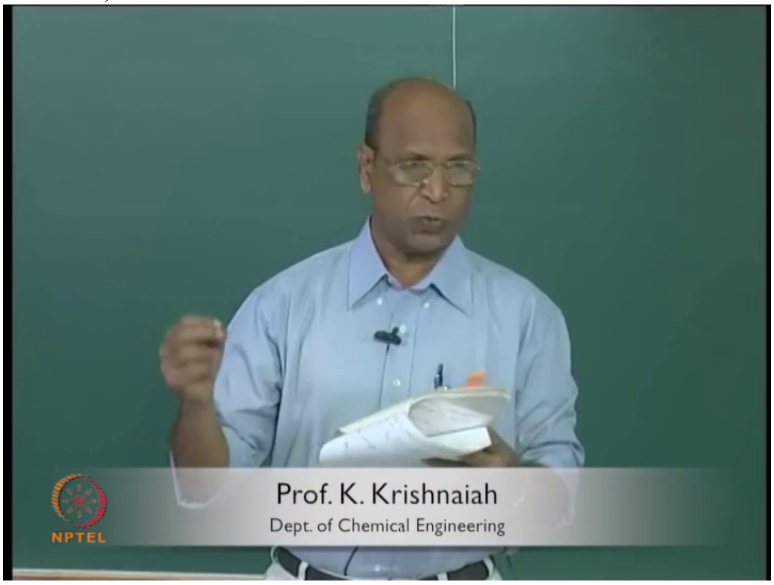

diffusion relative to the bulk flow. Good. Write next para. That is point 1 and point 2. Next para is, under assumption 1, the residence time of all the fluid elements in the reactor is same and all these fluid elements

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pass through the same sequence of pressure,

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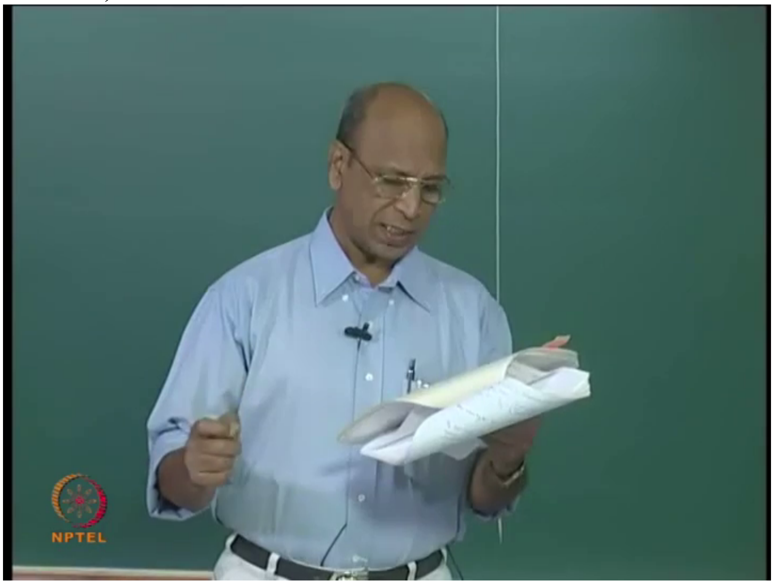

temperature and concentration changes.

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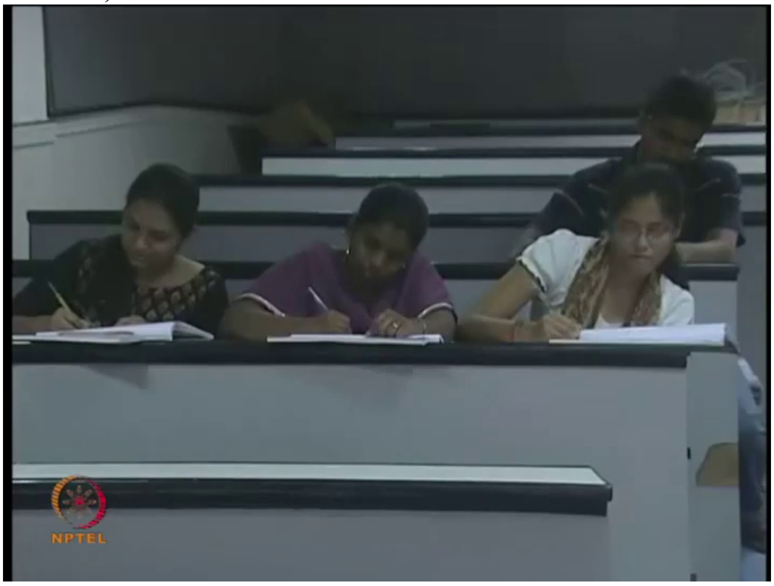

Ok write next

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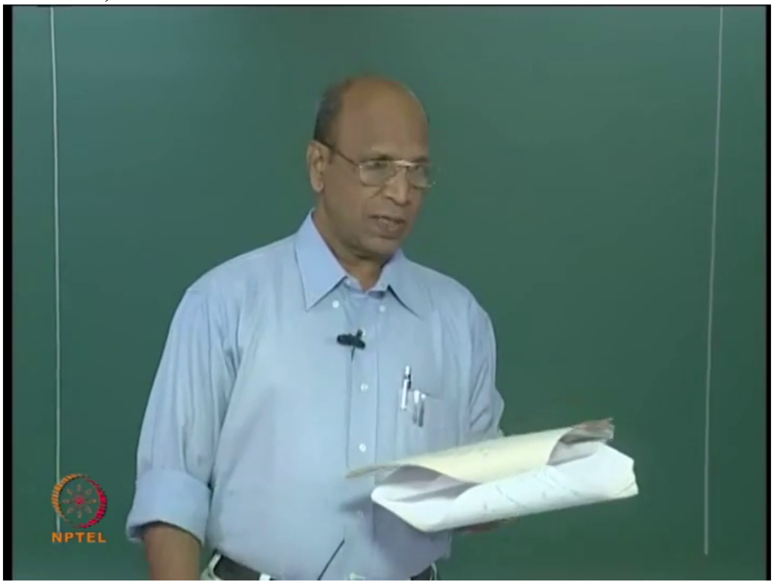

para. Under assumption 2, the molecules of reactants and products do not diffuse from one element to another element of weight. Ok, then write another para. The above two restrictions allow the conversion in each element same.

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What is

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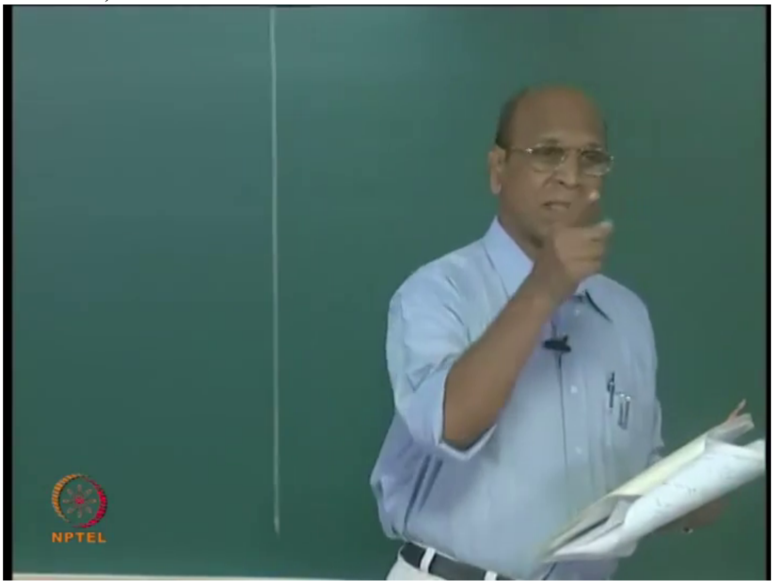

assumption 1? In your normal terminology, what is assumption 1?

(Professor – student conversation starts)

Student: Flat velocity profile

Professor: Is it flat velocity profile?

Student: Same...

Professor: Rajshree?

Student: Infinite mixing in the radial direction.

Professor: Yeah. Infinite mixing in the radial direction is assumption 1, straightaway because you are having pressure, temperature and composition same at any cross-section, no? So that means you have infinite mixing in the, that is what our assumption is, most of the time we tell that. What is second assumption? Janhavi?

Student: Axial mixing

Professor: Axial mixing equal to

Student: Zero

Professor: Ok.

(Professor – student conversation ends)

So under assumption 2 what I try to tell was first assume that all particles have uniform residence time, then the other two automatically come. He has given the other way. He first defined those two, then said that under assumption1 1, all residence times must be same, Ok and under assumption 2, there is no diffusion. That means there is no axial mixing, all that, axial mixing only.

Radial mixing must be there otherwise you do not get uniform concentration and temperature, very good? Yeah. So now I will just give you one exercise. Very simple exercise for you to do and then keep in your notebooks and when I ask surprise test, probably you have to derive this.

Show for unsteady state plug flow reactor

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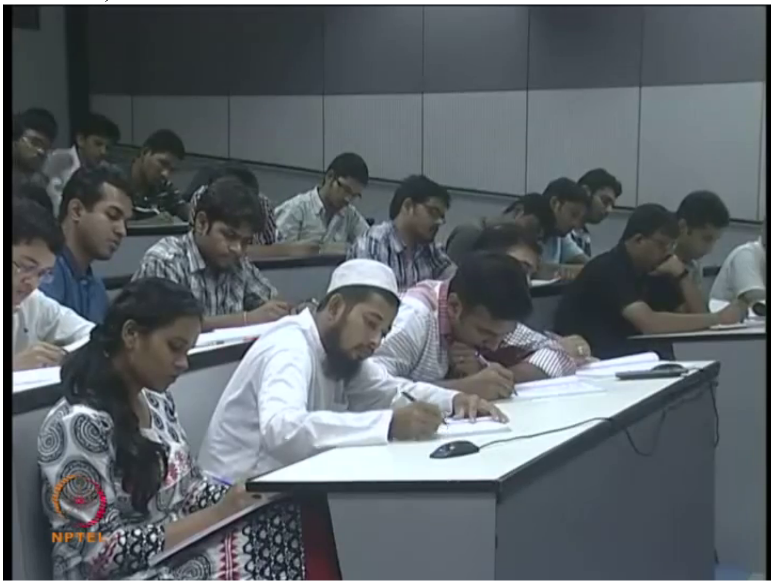

minus dau F by dau V equal to minus r A plus dau C A by dau t. That is the equation which you have to derive,

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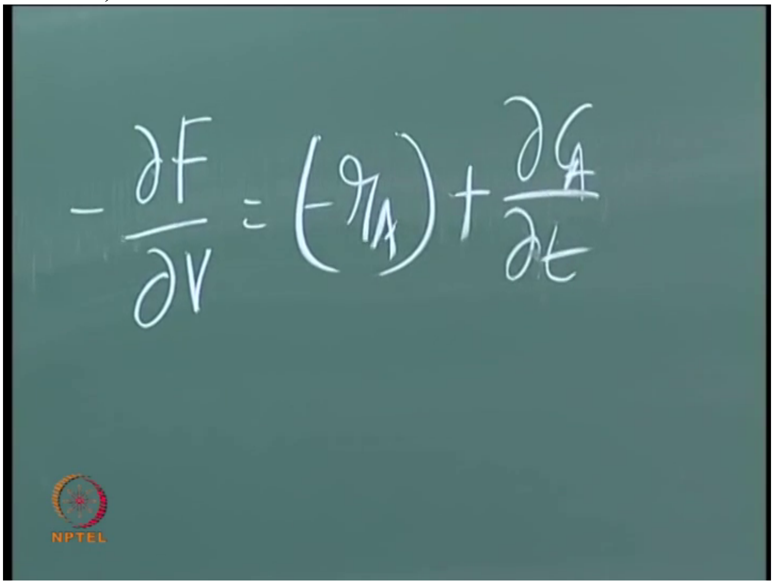

Ok. That means you have to write the material balance,

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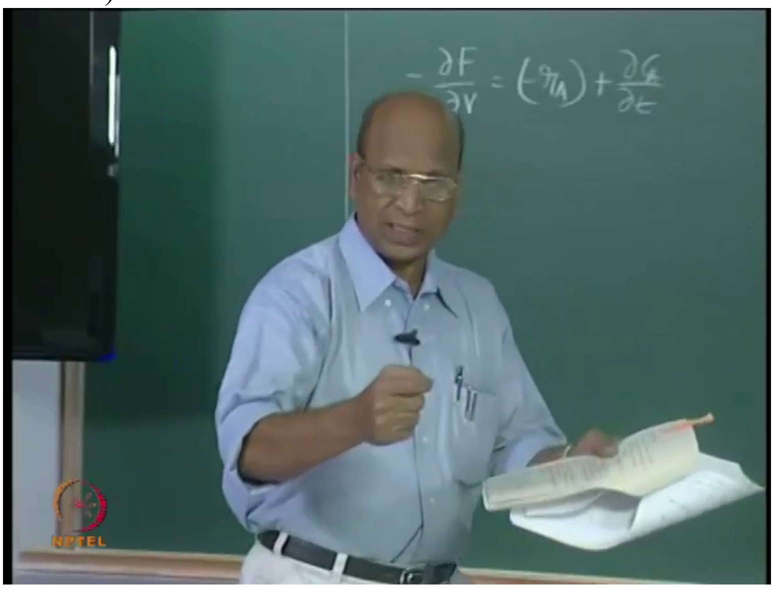

it is only isothermal condition, Ok, so what is entering, what is leaving, what is accumulation, what is reaction, all four terms, right?

Earlier we had taken only, yeah all three except accumulation. Now you have to also put accumulation and then you will get dau C A by dau t. But you have to write clearly what is the element that you have taken, what is entering in the element, leaving in the element, accumulating in the element, reacting in the element, put all 4. Cancel out whatever is there and arrange the equation in that format, Ok, good.

Now we will go for mixed flow reactor, Ok. So this name, mixed flow reactor, Levenspiel uses very widely. So that is why we also use that. But here there are also other names for this, Ok. Mixed flow reactor, you should have heard of C S T R?

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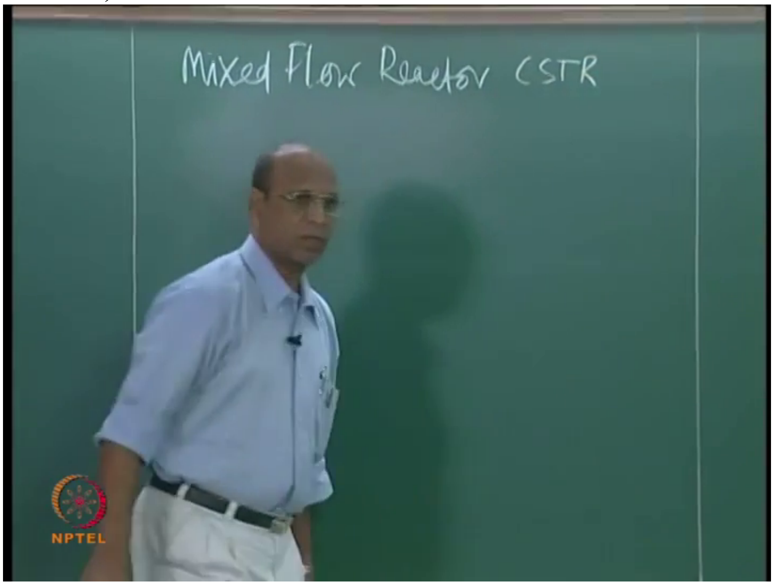

Yeah, back mix reactor,

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so this is C S T R.

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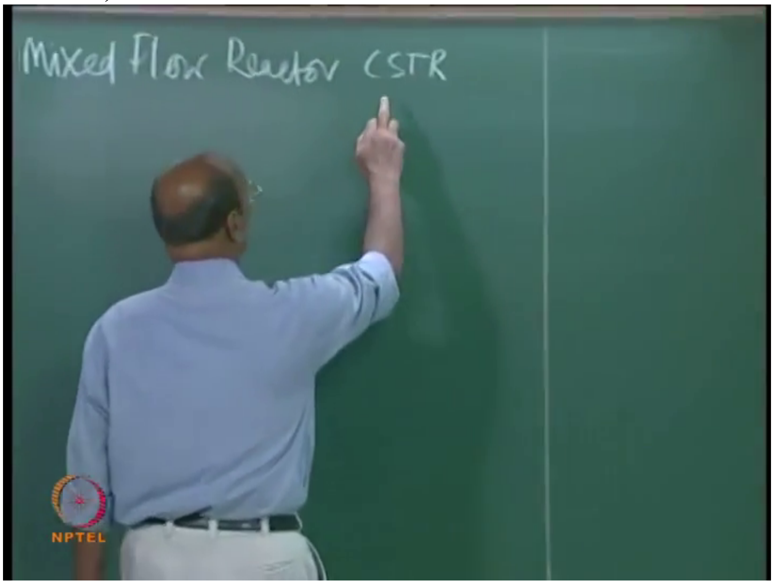

What is the meaning of C S T R?

(Professor – student conversation starts)

Student: Continuous stirred tank reactor.

Professor: Ok. So what is the difference between this and then batch reactor where you are, again continuously stirring, that is also a reactor? That is also a tank?

Student: 0:05:25.7

Professor: Yes?

Student: 0:05:28.5

Professor: Ok. So how do we know that, because batch reactor also it is same, continuous stirred tank reactor? There is continuous stirring, correct no? And it is a tank reactor; it is a tank and reactor. So...

Student: 0:05:43.7

Professor: Yeah, so what we have to remember here is continuous with respect to what? Flow.

Student: flow

Professor: flow

(Professor – student conversation ends)

So they write there continuous flow stirred tank reactor. They put F here,

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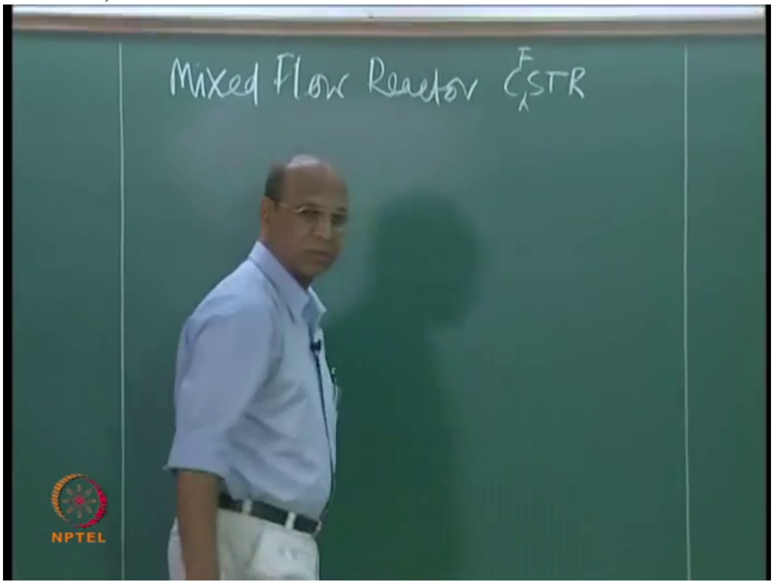

C F S T R, continuous flow stirred tank reactor to specify. But I think you know so many words we do not have patience to use, so that is why we say C S T R, that continuous is with respect to, yes good.

So I think other reactor also, B M R, back mixed reactor.

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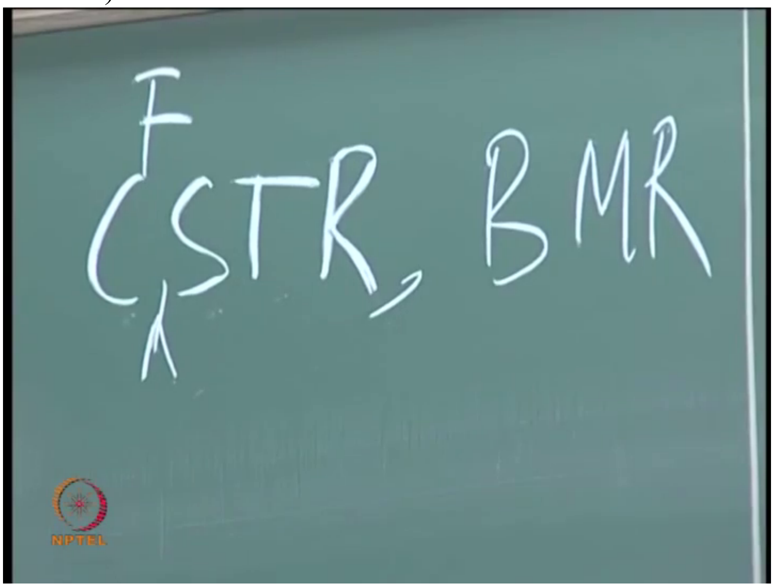

Continuous stirred tank is straight-forward. That is what is happening. Flow is continuous. There is stirring. It is a tank and it is a reactor. So continuous stirred tank reactor, good. So why do you call it as back mix reactor?

You see all these things you have to think, you should have asked 2 years, 4 years back. No, no. I think third year only it comes no? At B Tech third year only Reaction Engineering, you should have asked that teacher in that class, Sir why are you....

Yes, for example, the C, C refers to what? Is it a continuous stirring or continuous flow? Continuous stirring means it is equivalent to batch reactor. There also continuous stirring, here also continuous stirring. So B M R means, if he would have told B M R, then you could have asked, what is this B M R? Back mix, what do you mean by back mix?

So that means it is mixing back. Ok I think this name has also come from the two origins. Ok, one is that with respect to plug flow reactor itself, axial mixing is also called back mixing, correct no? It is going forward, again coming back, going forward, again coming back. So that means, you know that is what some kind of back mixing is happening but that is limited to only small, yes axial direction but small region, right?

But in C S T R when you say back mixing, yeah, the, yeah, let me also draw now the figure, normally what we draw for C S T R, Ok so this is the one, we will show that this is continuously entering, continuously leaving and if it is non-isothermal reactor, we will also put, Ok. So here may be, anywhere you can introduce, I will introduce here, coolant entering, coolant leaving.

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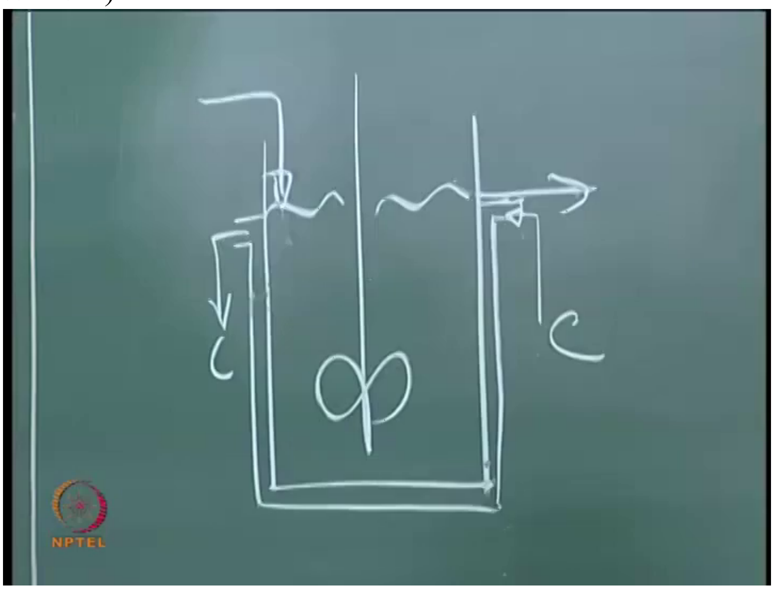

That is the coolant, Ok.

So here we will have same thing, F A naught, v naught, C A naught, X A naught. So here you have F A f, C A f, v f, X A f, Ok. So we are talking about back mixing. So the idea here is that you are continuously feeding these,

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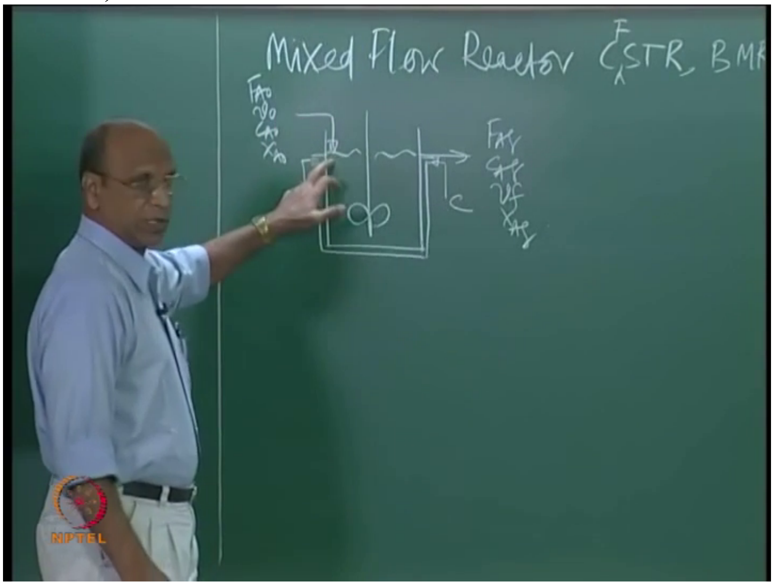

you know reactants. And then they come, they mix here, and then some of these molecules which have

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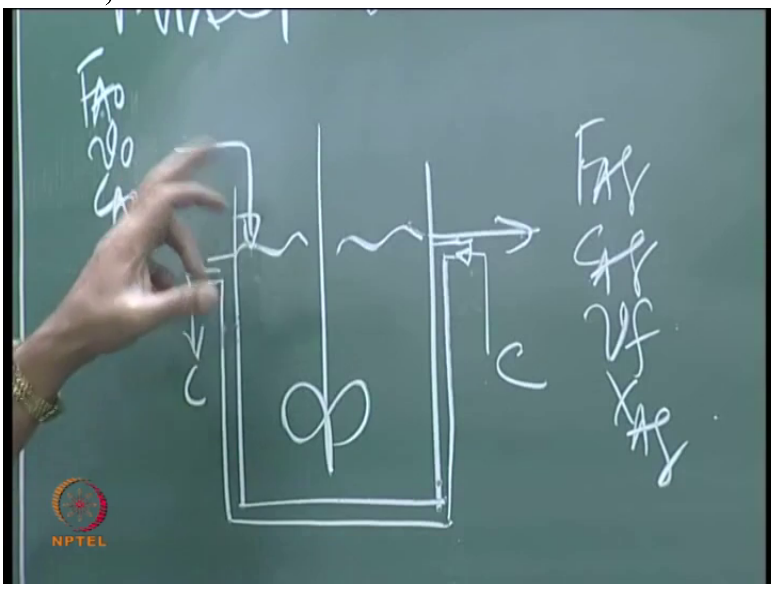

just entered because of mixing, some of them may about to leave,

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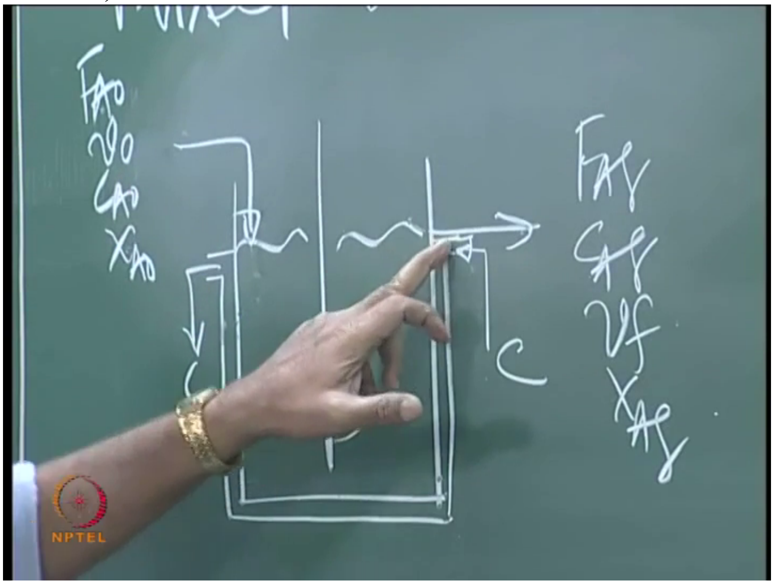

so this is outlet, about to leave.

But when they are about to leave, because of mixing, because mixing means chaos, Ok, the definition of mixing is that any particle, yeah, will stay in the reactor and the probability of, Ok, the probability of leaving a molecule, Ok the probability is same for all the molecules when they are about to leave. The probability, I think it is a confusing definition, mixing.

Ok, so you know, some of these things we do not have real meaning. Like I told you again, love. Ok. Mixing, we say mixing. We say perfect mixing. What do you mean by perfect mixing? When do you say that you have perfect mixing? Yeah, when do you say that you have complete mixing? She is saying when I have perfect mixing, complete mixing. Ok. So now tell me

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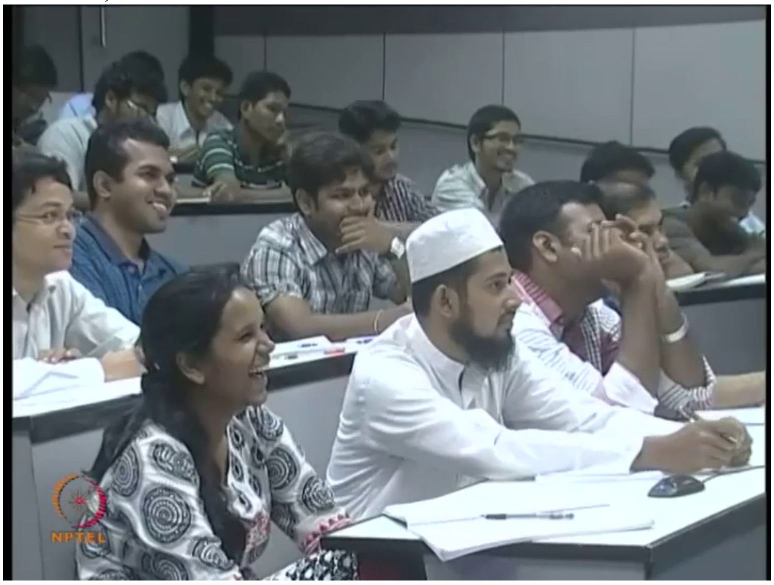

when do you say you have complete mixing?

(Professor – student conversation starts)

Student: Making the particles to pass through...

Professor: What level? See every concentration

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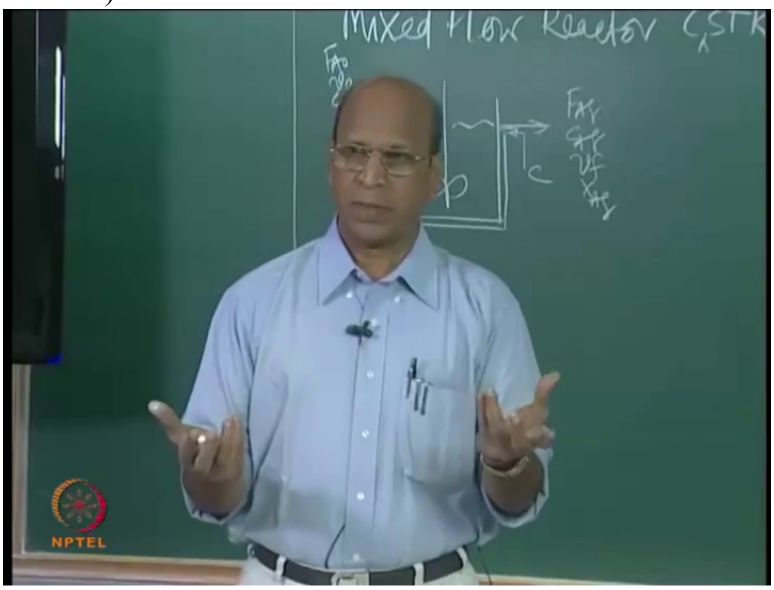

may be...at what level we are talking?

Student: The decide level of homogeneity.

Student: One molecule

Professor: Yeah, what is that level, homogeneity, how do you define again? Really. Because you should think all these, no. See, you know even if you do not have perfect mixing also, some molecules will collide with some molecules. Ok, so that is why?

Student: If one molecule, if it collides with all the molecules

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in the reactor, we can call it perfect mixing.

Professor: How can you expect one molecule collide all the molecules? My God, it is a Kabadi

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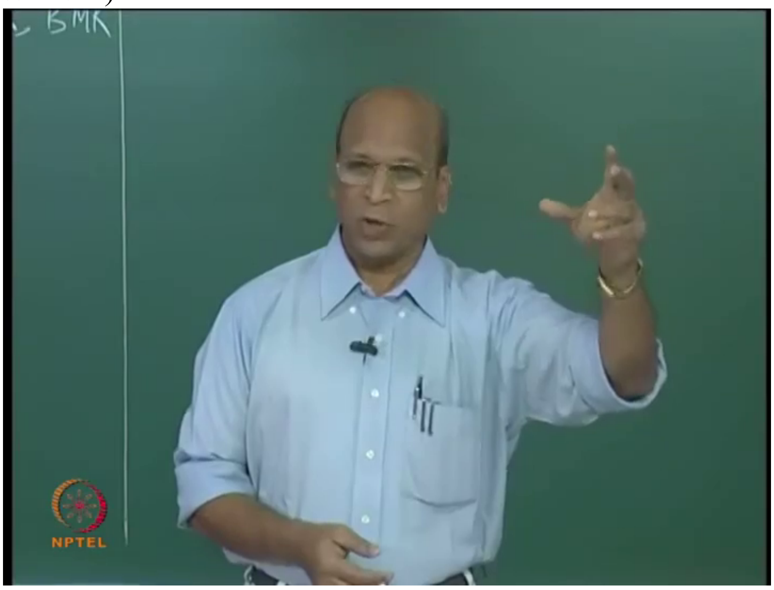

versus you know; it is 1000 people versus 1 guy.

Student: (laugh)

Professor: They will pull him out, I say.

Student: (laugh)

Professor: So one molecule, we cannot, no. Yeah.

(Professor – student conversation ends)

See the definition there is probability for this molecule is maximum when it is colliding with any other molecule. You know that is what. The probability of this molecule colliding with any other molecule, not all molecules. So any other molecule means what are you trying to say?

That molecule may be here, or here or here or here or here or here.

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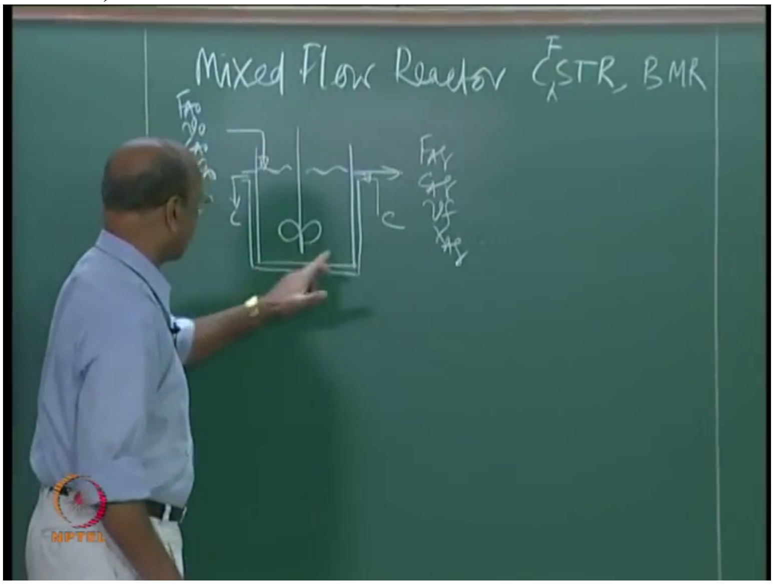

The colliding molecule may be coming here, Ok. So the probability of that molecule colliding any molecule is same. Like that for every molecule, the probability is same.

Any one molecule you take. So the probability of that molecule colliding with any molecule inside the system is same, right? And we are talking about the homogeneity, when you said homogeneity no? Homogeneity at molecular level. That is the real definition.

What is the size of molecules? You cannot even measure, no. I mean you cannot. Definitely you cannot see it and you need very, very sophisticated instrumentation to look at the particular molecule. Now we have, now we have beautiful instruments. Ok.

So that is what is the definition of perfect mixing and back mixing is

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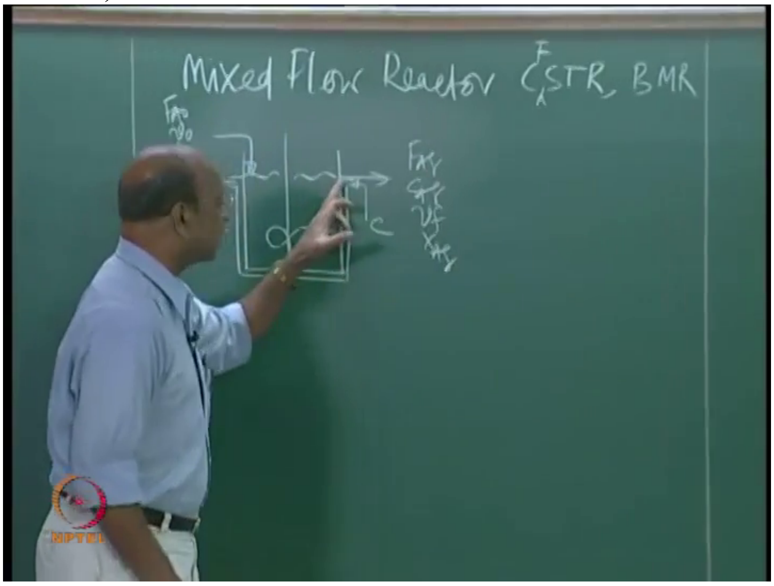

that molecule which is about to leave, because of that chaos, again it may be brought back even to the feed.

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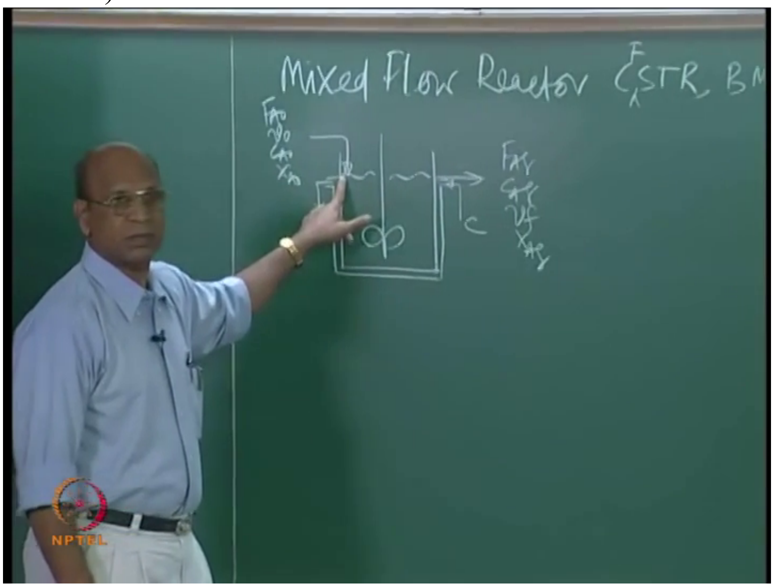

That is what is back mixing.

The fellow who is about to go out, Ok, you know like you joined 4 years back for B Tech and then you now about to leave, Ok, in the final year, you are now asked to again and join first year. First year, first semester, first class, Ok.

That can happen in perfect mixing. Ok. That is why in all academic system, that 4 years if every one of you pass, what is the system you describe? P F R, plug flow. All of you, really. All of you are spending exactly same time, 4 years. All of you join on one day; all of you leave on the convocation day, over. Exactly. In between what you do does not matter. (laugh). Does not matter.

(Professor – student conversation starts)
Student: (laugh)
Professor: But you know the leaving, entry and leaving is exactly same. That is what is exactly same. That is what is plug flow. But in reality what kind of flow you expect? Axial mixing. Why? Some people may take 6 years, some people may take
Student: 5
Professor: 4 years only because you do not have that system. But in I I T Madras, our system, credit system, theoretically one can go in 3 and half years also. Because it is electives, no.
(Professor – student conversation ends)

Core course are compulsory for everyone. And if you allow them, now I think we put a maximum of 6 courses here, right. If you allow them, if you are very good, you can take even 8 courses in a semester. So that means you are able to complete some more courses before others so you can go earlier.

I think in U S A, many universities, they have that credit system. There it is axial dispersion. The average time is 4, right? So some people may go in 3 and half years, Ok. 3 years may be too, I mean, ambitious. But I think 3 and half years they may go. Then some people may go, we do not know that time, infinity time also they take. That means they never got the degree. That is what it happens.

So that means it has got long tail we say, correct no? Time, infinity also still he is not coming out. So he is still in the B Tech classes. So that is why that back mixing is that example where you have completed almost everything and now you are brought back and then put again first year. So that is what happens in the mixing.

When the molecule is about

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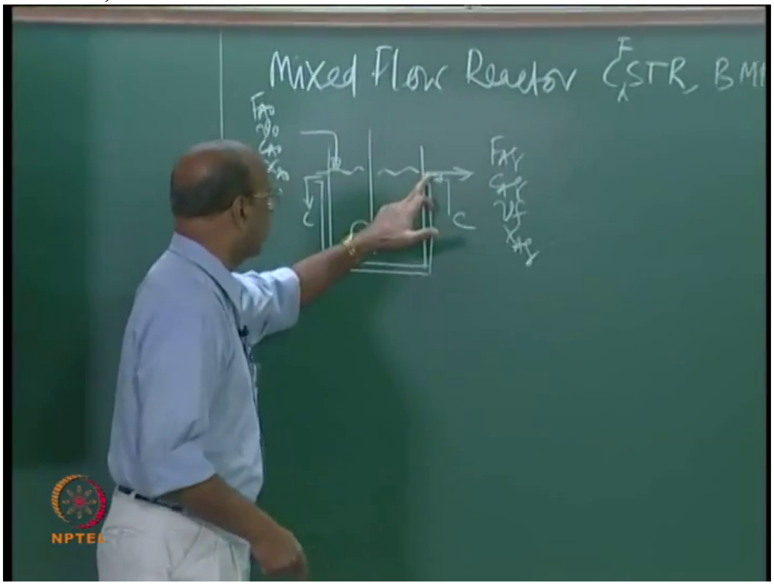

to leave it can back-mix with the molecules which are just entering. That is the meaning, no? When you are asked to sit down in again first year, you are now joining the molecules which have just now entered. Those students would have just then joined. You are also joining them. That is what is the meaning of back mixing.

You see how much meaning is there in each and every thing. I mean, as students you have to start questioning I say. Even now you can start questioning. You should make the teacher's life hell. Really. If all of you are asking questions, my God! We will become very sharp, I say. Really. We will become very sharp. I know, those I mean, those hands up, we cannot do anything with them.

You ask and I will say something and then we will go, we forget. But many people are not like that. When a student asks it is also a challenge to the faculty member to learn if he does not know immediately and to request others to explain. And also he will learn and come and teach you. So that he is also learning. That is why teachers are lifelong learners.

You will stop if you go for job. But we never stop learning. Really. So, but you can aid them to learn more with your questions. Any question. There is no stupid question, only there is stupid answer. Ok. Question is not at all stupid anytime I tell you. Because I told you no, simply Ok how many noses a person has, human being has. Ok. It is not a stupid question.

Because you have never seen a human being. So you do not know whether this is 1 nose or 10 noses. Ok. Or legs, how many legs human being has? You would have never seen a person. Like there is a horse in, you know that Avatar movie right, yeah that horse. What is the specialty of that horse?

(Professor – student conversation starts)

Student: 0:16:19.3

Professor: I do not think it breathes with nose. It breathes something here. I think there are two holes here I think, if I remember correctly.

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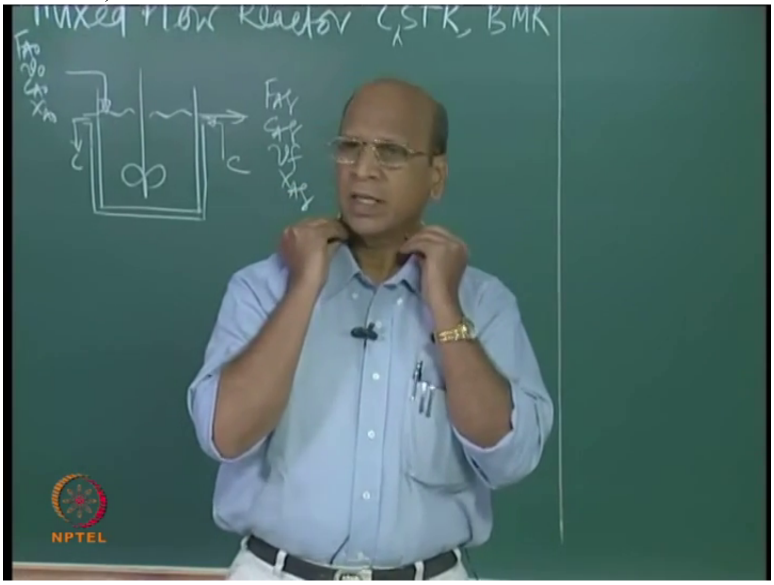

Yeah. So some change. Ok, so that kind of horse. Ok, where is the nose for that horse means you cannot tell. Because nose is here.

(Professor – student conversation ends)

Like that is what I remember vaguely. Now I do not remember whether it is, but here these flaps will move up and down. That is what I have seen. Here some flaps are there. So that is why I am just giving an example. That you know the question you should not be afraid in asking any question. At the maximum what will happen if you ask a wrong question?

There is no wrong question I am telling. But in the, in the, in the heads of your own classmates, Ok, you are afraid that you know, if I ask this question, my classmates will laugh at me. So when someone laughs what will happen? Nothing will happen. Only his teeth will be seen.

(Professor – student conversation starts)

Student: (laugh)

Professor: Correct no? You see. Pooja laughed and the teeth I can see. (laugh). It is very difficult to laugh without showing the teeth, no? How can you laugh, I say? Try

Student: (laugh)

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Professor: It is very difficult, no. Yeah, so what will happen maximum? Some white material

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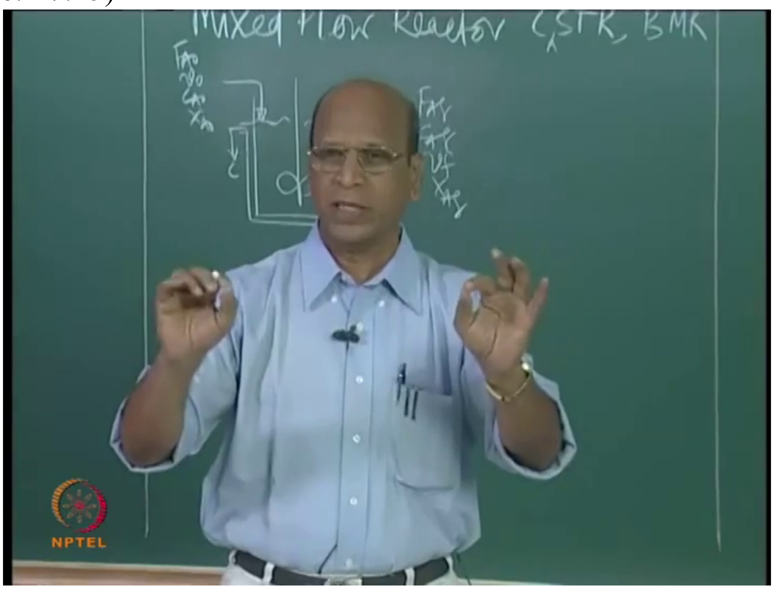

will come, more light is reflected. The room will become more bright, that is all. So nothing will happen to you. Ok. Nothing will really happen.
(Professor – student conversation ends)

So that is why I encourage you to ask any question the moment you have any doubt. Any doubt I tell you. But you are not doing that. I think every class I tell. But I think, because they are not asking, then I will ask the questions and I will also answer the questions. So that is what is happening in most of the classes. I think you should do that. Ok. good.

So in the perfect mixing you know that simplest assumption is that

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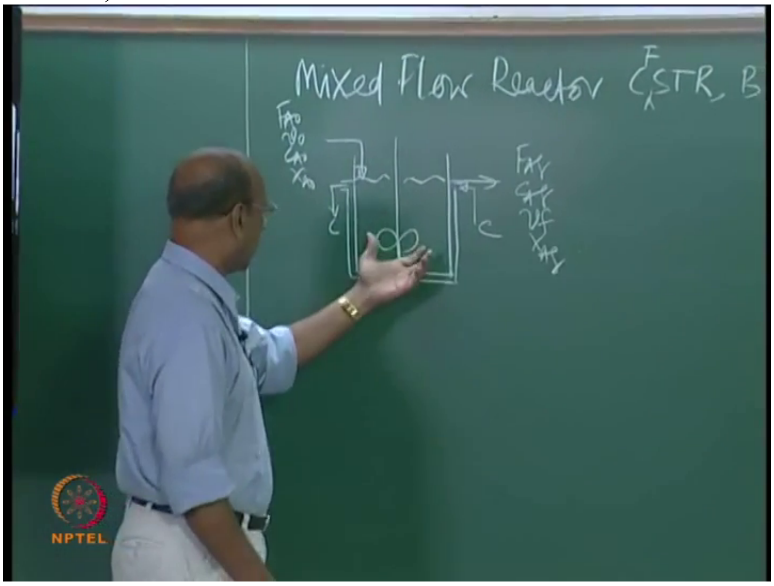

we have perfect mixing. Now the question is that how do you define perfect mixing. So we are trying to say that this mixing is at molecular level.

If at molecular level, if you can see the homogeneity, homogeneity means you take a small amount, and then see all the molecules are uniformly present there. And then you take in another corner, another small lump and then see again there, you will also get the same number, composition like any other place in the reactor.

Ok, it is very simple to just only keep in your mind that what is the meaning of perfect mixing, Ok, good. So now we can also tell something connected with this which is called

Residence Time Distribution. By the way what is Residence Time Distribution for a plug flow reactor?

(Professor – student conversation starts)
Student: Same
Professor: Residence Time Distribution, the moment we say distribution our minds 50 percent will be closed. Distribution? I am simply asking what is the Residence Time Distribution for a plug flow reactor. So then what you say?
Student: 0:19:00.6 Straight line
Professor: Straight line is not distribution. I am just asking what is Residence Time Distribution, in words you can tell. Ok. So then what we say? Residence Time Distribution is zero.
Student: Zero
Professor: Same you cannot say. Distribution is not same. Distribution means there is a distribution. 10 seconds means exactly everything is 10 seconds.
(Professor – student conversation ends)

What is the distribution? Distribution means you should have 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15. That is the distribution. Like you have here, distribution of ages. All of you are not exactly 21, correct no? If all of you have exact 21, in this world also, this group has plug flow. That means 21 years back exactly you were born. If the date of birth also is same for all the people. But in this room we have distribution from almost 21 to 65.

(Professor – student conversation starts)
Student: (laugh)
Professor: (laugh) because I am also in this room, I say. (laugh). Yeah, I cannot eliminate myself, Ok. You see that is the distribution.
(Professor – student conversation ends)

One guy with 65 years and many people with 20, there are some people with 30 years, there are some people you know, may be external registration people would have been around 32, 33 and I do not expect 50, 40 like that generally. So I think, you know it goes peak around 30, 35, not 35, around 30 or may be 28 and then long tail, this fellow here 65. Ok, that is the distribution, Ok.

So that kind of distribution is zero for P F R. So that is why sometimes we also ask, tell me a reaction where R T D equal to zero. P F R, Ok. Now we see this. Because of this thing what is happening to R T D

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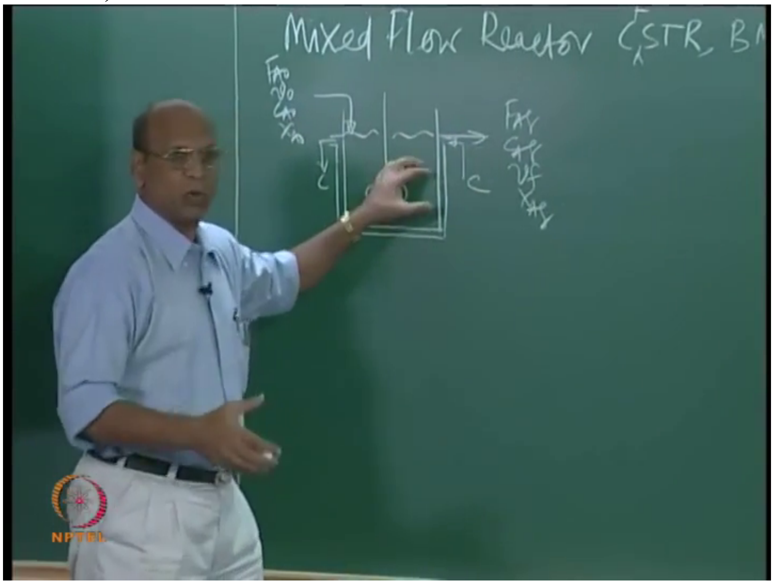

here? Residence Time Distribution. Oh R T D means I think, yeah, this is R T D we use, Residence Time Distribution.

That means

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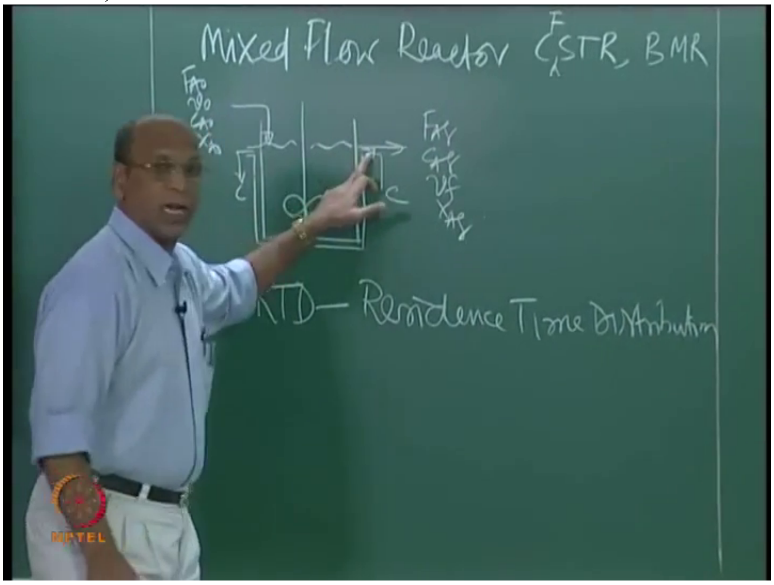

when you look at the outlet how the particles are coming. Whether some particles are coming slightly earlier if the mean Residence Time is 10 minutes in this case,

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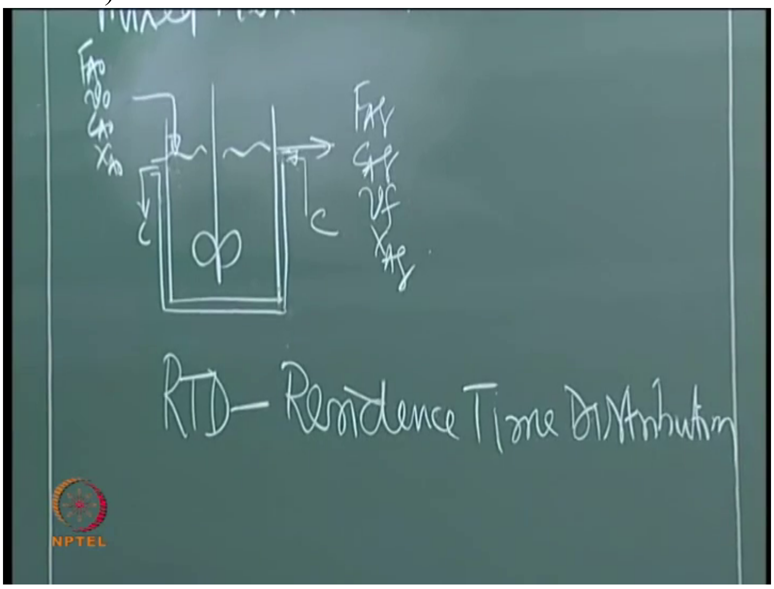

or some particles are coming 20 minutes, 30 minutes or all the particles are coming at 10 minutes only? Ok.

If you say that all the particles are coming only in, exactly at tenth minute then I have the plug flow. That all that over. Four classes we have taken. Now we are talking about mixed flow. In this case how the molecules come out. Because molecules are very easy, very difficult to imagine.

So now let us imagine that these molecules are, you know grouped together, some packets of molecules and now it are a continuous reactor. And I am now imagining that I have these packets continuously entering and also these packets are continuously leaving. Just for the sake now Ok, just imagine that these packets are continuously entering, continuously leaving. Ok good.

Then we can also imagine afterwards molecules.

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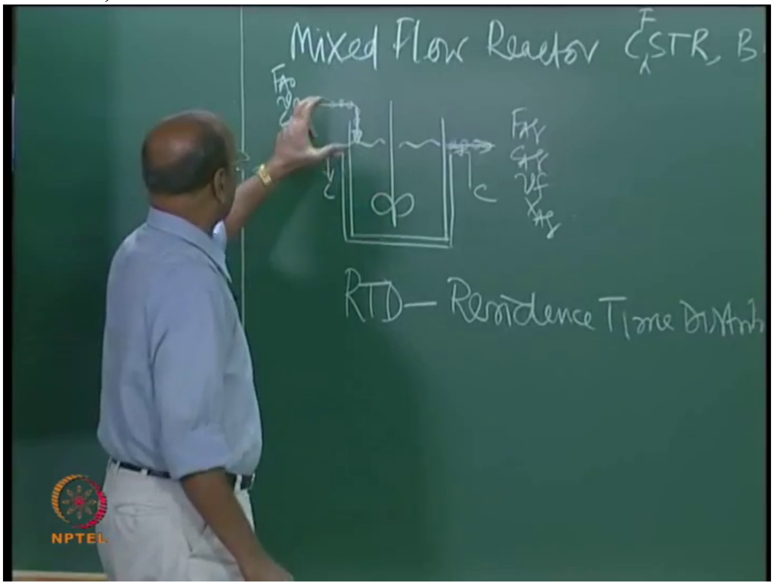

Then when the, let us focus on some 100 molecules. Or 100 packets. And at time t equal to zero, it is continuously feeding, continuously coming out, right? So at one time,

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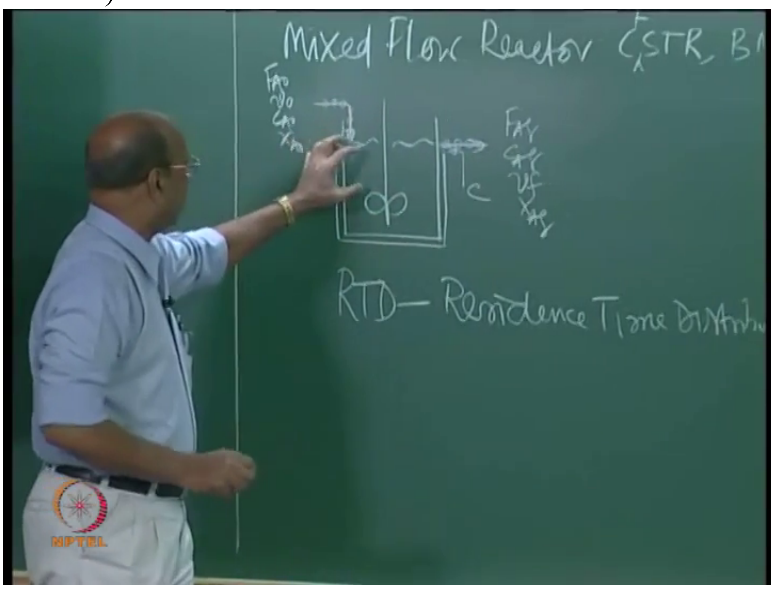

I would like to find out what is happening to these 100 packets.

Now I just imagine, you know jadoo, you know magic, so through magic I will say that let these 100 particles will be red color. So all of them will be suddenly red, right. Now I will try to follow that red color here.

According to perfect mixing definition, all these 100, there are others also,

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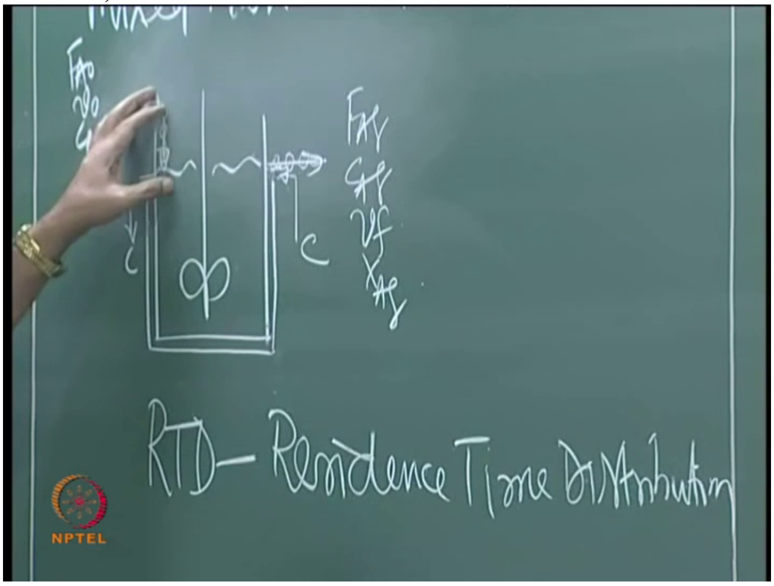

many other packets. These 100 packets only I am concentrating, these 100 packets will be uniformly distributed throughout. Instantaneously. Because that is meaning of perfect mixing. Ok.

So then when you have that immediately, uniformly distributed

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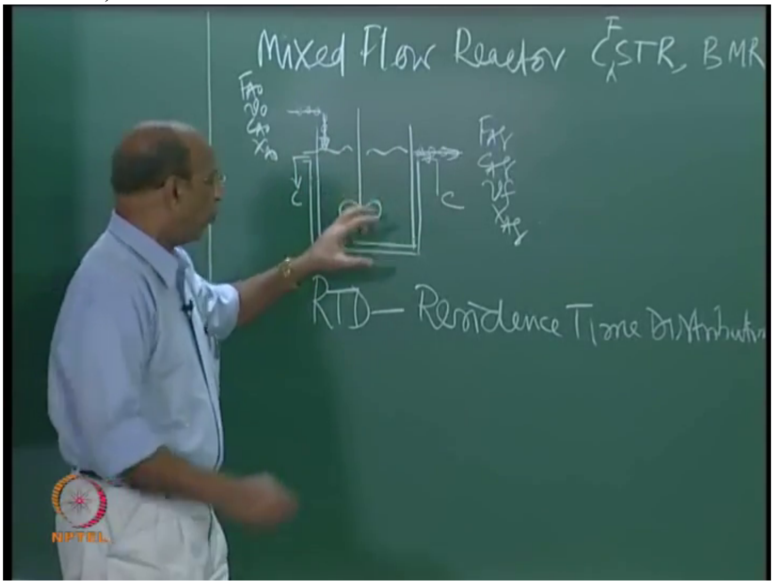

when they are distributing, because of mixing only they are distributing. One packet may come here and that may suddenly come out, right? There may be another packet which may go to this corner but still it is mixing well. But it is not able to come. It is moving here, moving here, moving here, moving here there. That can happen because of again mixing, yeah mixing, right.

So that is why you have the molecules moving inside

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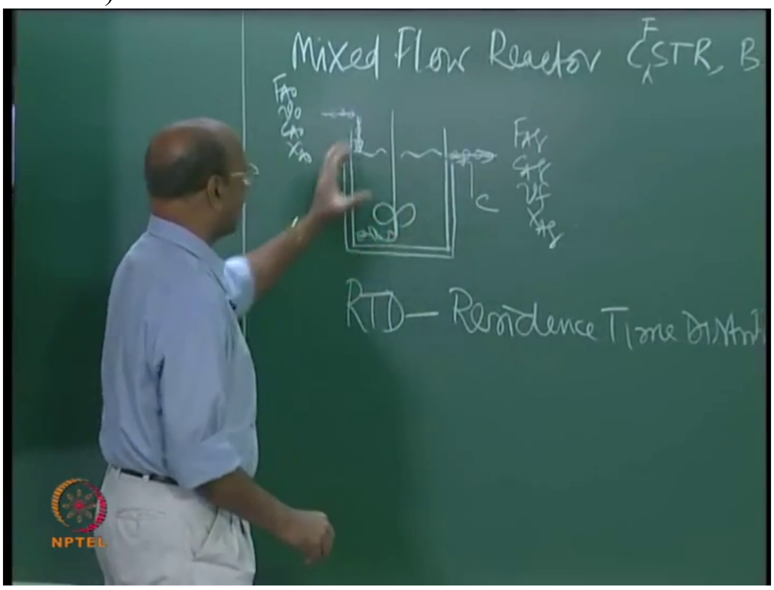

but some of them will very quickly come out, and some of them may not come out for long time. That means you have the Residence Time Distribution. If I choose that 100 molec/molecules, 100 packets, one packet will come in 1 second.

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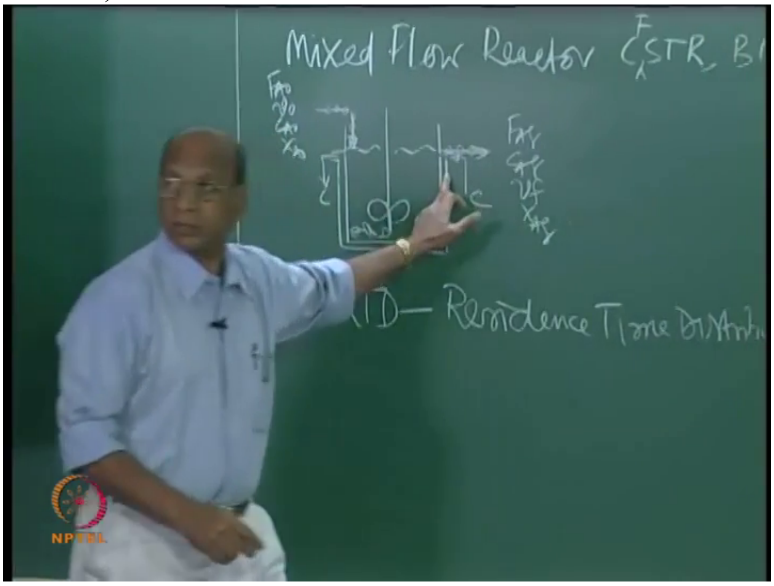

Another packet may come in 5 seconds. Another packet may come in 50 seconds. Ok. The mean residence time may be let us say 100 seconds for easy imagination, right.

And some other packets may come 1000 seconds, after 1000 seconds, so that means if I plot that

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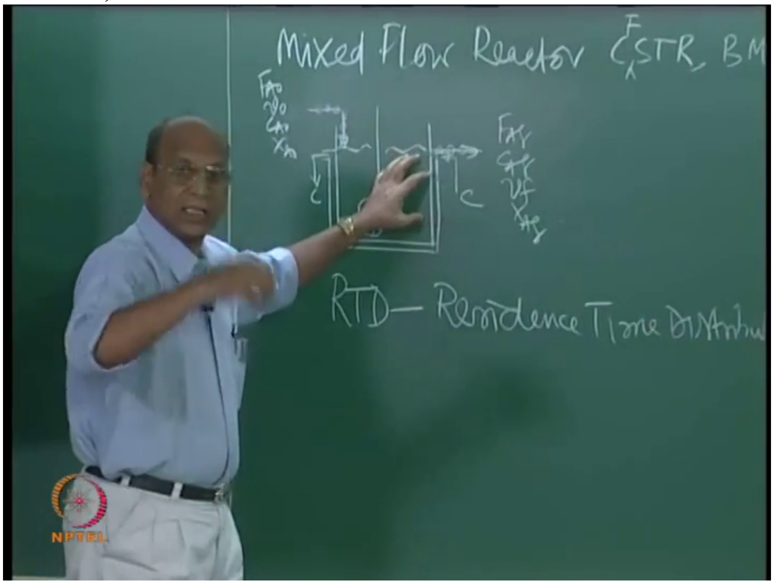

concentration of particles, because you know, concentration means that moles per unit volume, Ok. If I am able to plot that, then what kind of graph you get? Good. Ok.

So now, before that, this is the packet with red color and all that. Now imagine that I have water so that I can ask you how to plot that graph, concentration versus time, Ok. So I have water and continuously water is entering, water is going out. Then what I did here is

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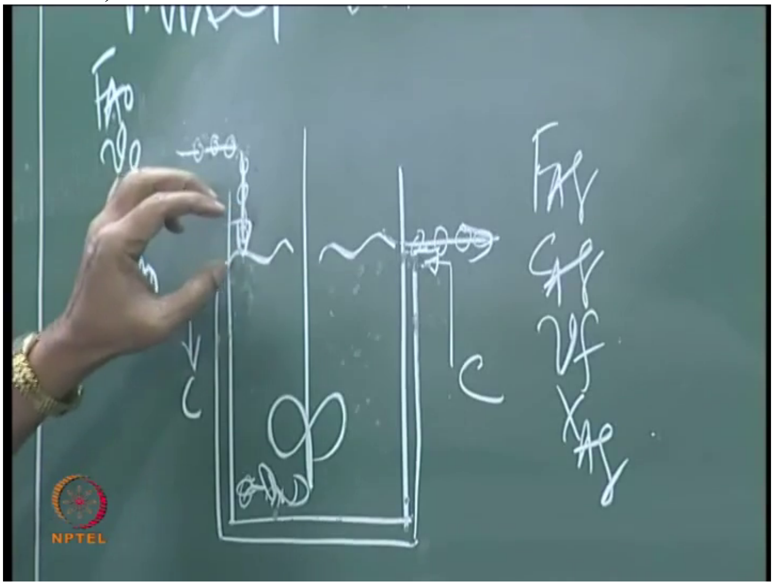

I took my pen, that is red color I have, Ok, so that red color may be 10 drops or 1 drop suddenly I added.

I have a small reactor, you know may be a 50 ml, yeah, jar. Ok. the beaker. So continuously I am putting water, continuously water is coming out. So in this there is stirring, good stirring. Then at one point of time I just put my ink, red ink one drop.

What will happen, it is a perfect mixing. What will happen to this ink, instantaneously, completely mixed, Ok. So then, then onwards how the color changes inside the reactor or at the outlet?

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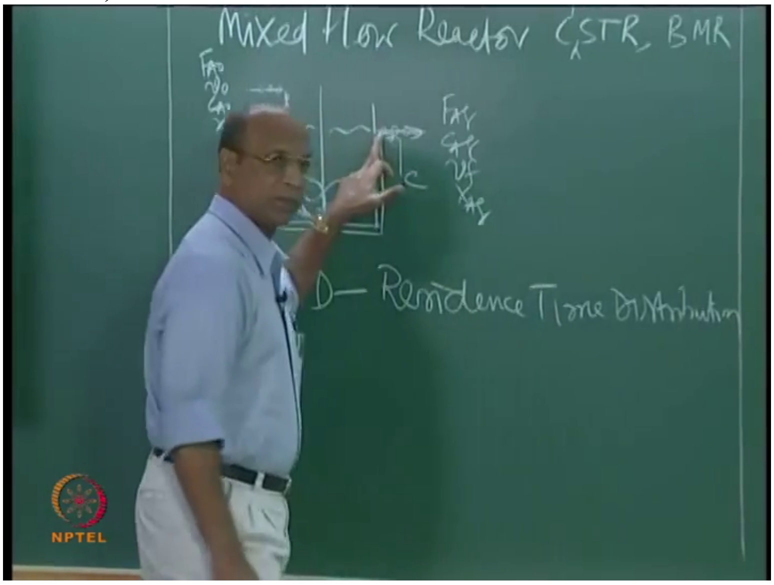

Just before adding what is the color? Colorless. Ok.

At time t equal to zero I have added that color. So my time t equal to zero will start here. This is concentration Ok,

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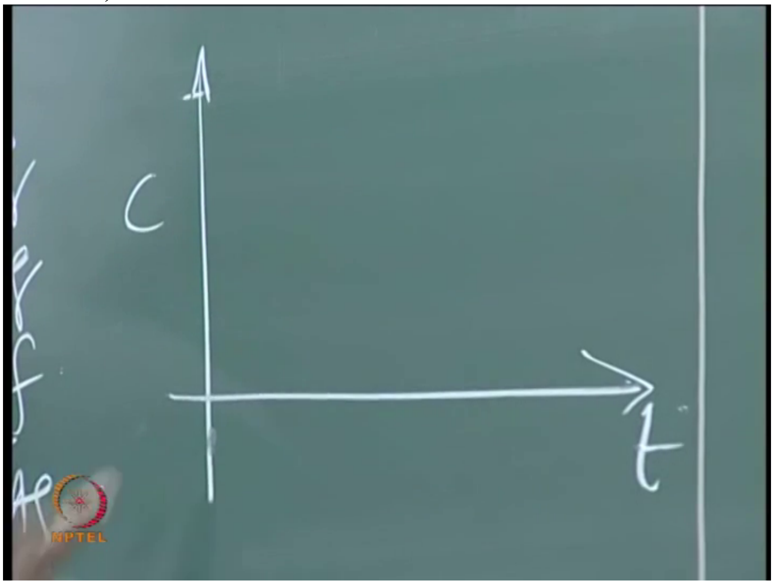

right, at time t, this is zero. At time t equal to zero, I added. Previously it is only white. Instantaneously it is distributed, mixed very well. So then what is the definition of perfect mixing? Other extension of perfect mixing also is when you have this assumption, the contents inside and also the contents in the outlet both are

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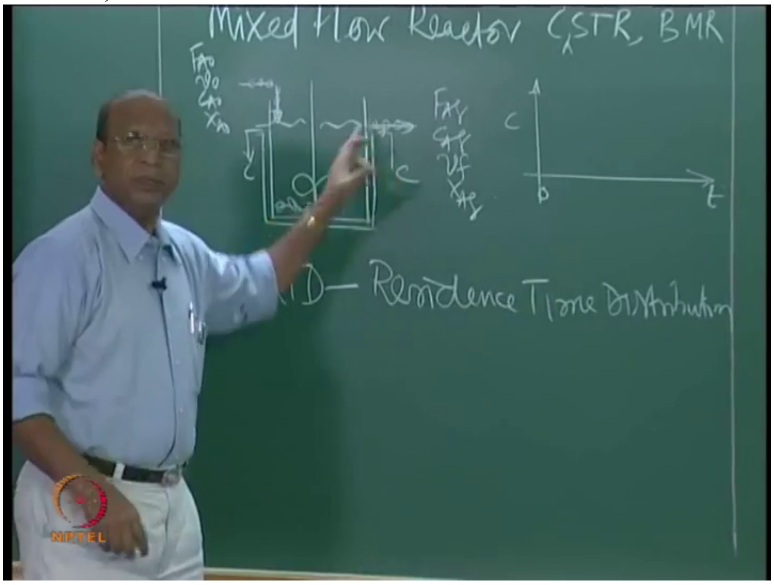

(Professor – student conversation starts)

Student: Same

Professor: Must be same. Right. The moment you mix it, this color also will immediately reflect in the outlet, Ok, yeah. This is where I am measuring now, that concentration in the outlet, not somewhere inside, in the outlet. So now tell me how the concentration, whether the concentration increases or decreases, first of all?

Student: Concentration decreases

Professor: Concentration, why it should decrease?

Student: Increase

Professor: Yeah

Student: Concentration

Professor: Abdul has another idea. Concentration decreases

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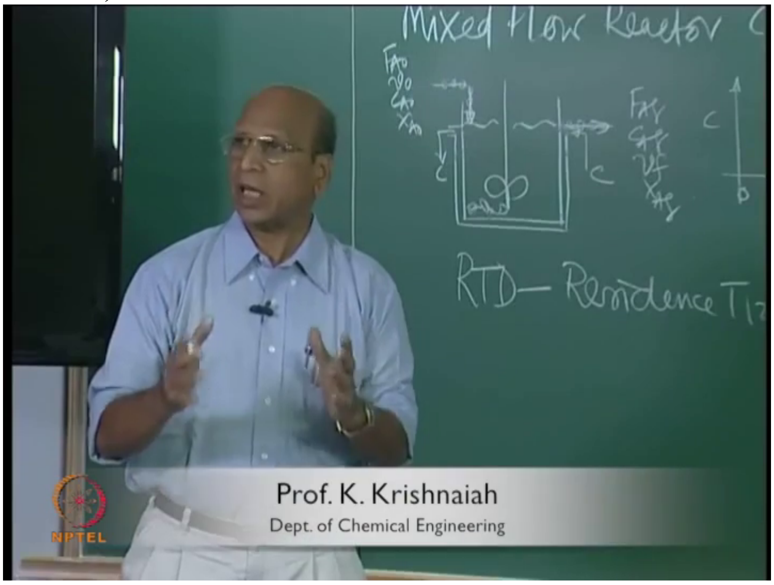

or increases? There are only two options.

Student: Concentration decreases

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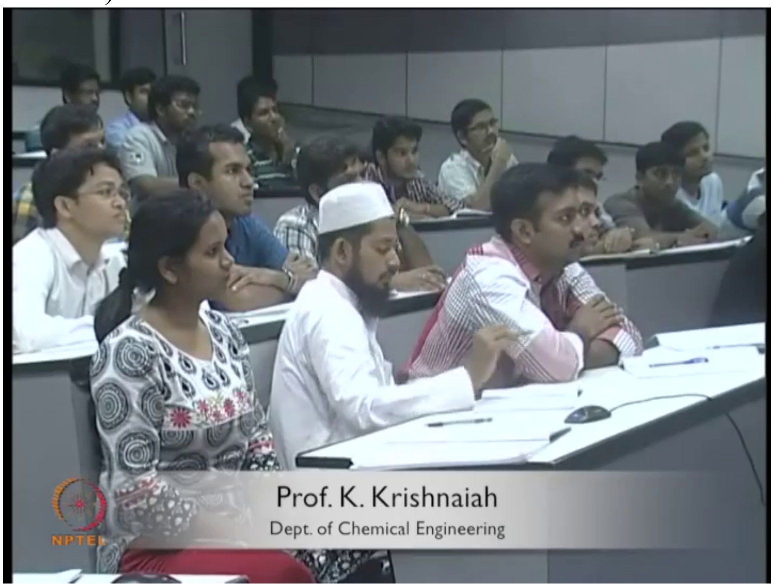

Professor: But Abdul says it is increasing.

Student: It increases then decreases.

Professor: Yeah, why it is increasing and decreasing?

Student: Water will be added. Then the...

Professor: Yeah, more and more water is added, more and more

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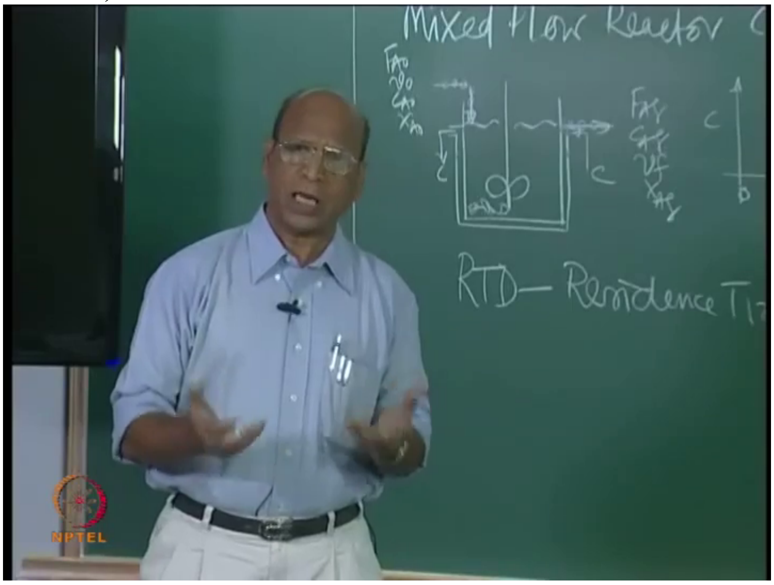

it is diluted.

Student: Initially concentration will be high.

Professor: Why? I mean, at time, when it will be high?

Student: After 1 second

Professor: Why 1 second. I think Sushmita will say 2 seconds. Can you contradict her?

Student: At least...

Professor: 0:26:51.5 will say 5 seconds. Why do you choose 1 second?

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Student: We can choose even zero, because instantaneous mixing so

Professor: Yeah, it is only at the zeroth time you have the

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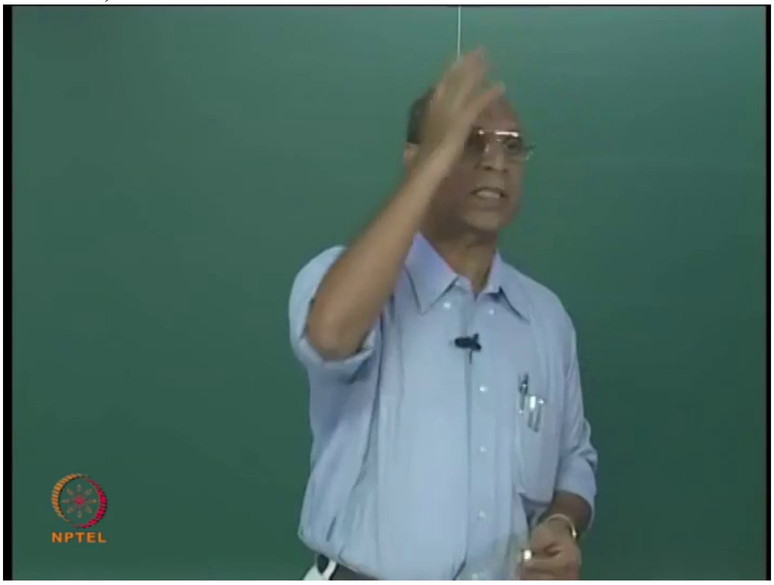

maximum concentration because you are not adding concentration later.

You are adding the concentration only at t equal to zero. Afterwards you are stopping. One drop I have added, that is all. Water is continuously flowing. At that time it is uniformly mixed. So instead of drop if I say I added 10 grams of color, 10 grams weight wise, what is the concentration if I have 1 liter, 1 liter reactor I have.

Student: 10 grams

Professor: 10 grams per liter, that is the maximum, Ok. Then continuously water is entering and this fellow also going out.

Student: Continuously decreases

Professor: Yeah it continuously decreases. Ok. Continuously decreasing means you can draw that lines in infinite number of ways, correct no?

(Professor – student conversation ends)

There is no unique way of decreasing, no. I can draw like this, like this, like this, like this. I can draw like this, like this, like this, no, no, no, increasing. So like this, anyway. No, no increase. So that is why all that is not valid for mixed flow.

In mixed flow, it is only valid, mathematically also we can show that, if it is exponentially decreasing. So this one and then exponentially decreasing. Exponential, Ok I simply write exponential, exponential, Ok right.

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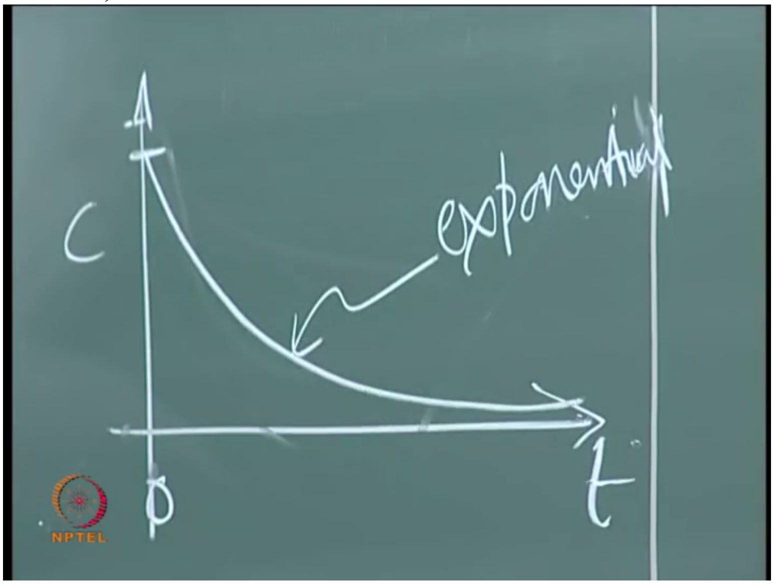

Ok good.

Now I know at time t equal to zero I have the maximum concentration, in our example it may be 10 grams per liter, Ok, at that instant. Afterwards it may be 9, 8, 6, 7 like that, go on, not 6, 7; 6, 5, 4, 2, 3 till what time it will come?

(Professor – student conversation starts)

Student: Infinity

Professor: Why infinity?

Student: Because of curve

Student: Until all the particles come out.

Professor: Yeah, until all the particles come out, that is a logical answer. But what is the time taken for all the particles to come out?

Student: We cannot tell exactly

Professor: (laugh). Why do not know?

Student: It is possible that one molecule may stay for entire lifetime.

Professor: Yeah, it depends on actually what is the system you are using for measurement of that concentration.

(Professor – student conversation ends)

If the color, if you are not able to see beyond certain concentration, eyesight, Ok, that means, does not mean that everything has come. Still there may be 1 or 2 molecules where you cannot see the color. But still it comes out.

(Refer Slide Time: 29:30)

So that is why we say theoretically it is...

(Professor – student conversation starts)

Student: Infinity

Professor: Infinity.

(Professor – student conversation ends)

So that means now what is the Residence Time Distribution? Zero to, yeah that is what. Zero to, mathematically we can prove now, with perfect mixing you will get a differential equation where you have exponential, e power minus 1 by E t, Ok. So e power t by t bar it will come, right? That we can prove. I mean when R T D comes, it comes.

But I think why I am telling this at this point of time is that we have a system where Residence Time Distribution equal to zero. You have another system where Residence Time Distribution equal to zero to infinity. As far as reaction is concerned, which system you think more efficient for a given volume? More efficient means more conversion.

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Example I gave,

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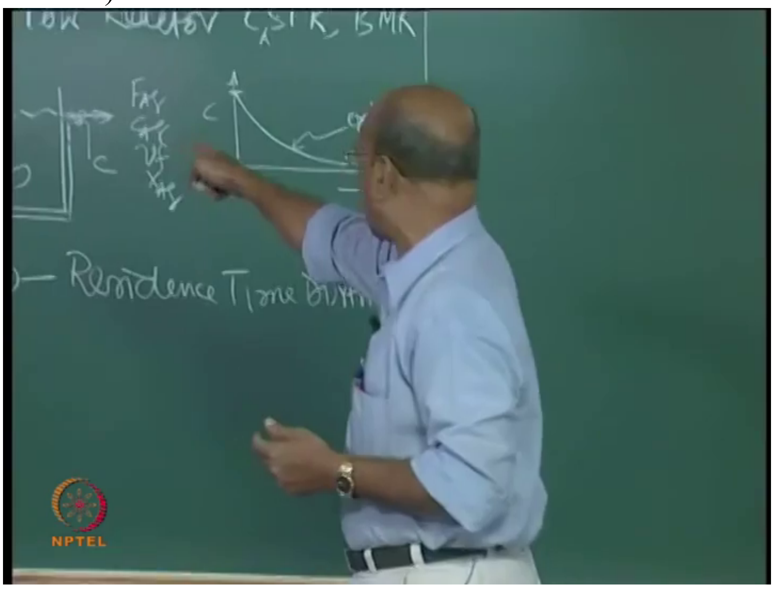

adding this color and all that, which we said tracer and all that, so that example I gave to show that there is Residence Time Distribution in mixed flow where as there is no Residence Time Distribution in plug flow.

How did we prove that there is no Residence Time Distribution there? You added one disk in the pipe, correct no? Colored disk. Without any dsp/disturbance disturbance to this disk, exactly it comes out at the end after yeah, whatever time you provide, 10 seconds or whatever. So that means if there is distribution, disk should have spread like this.

Same thing. Sir, why do you say one drop? Can I put this,

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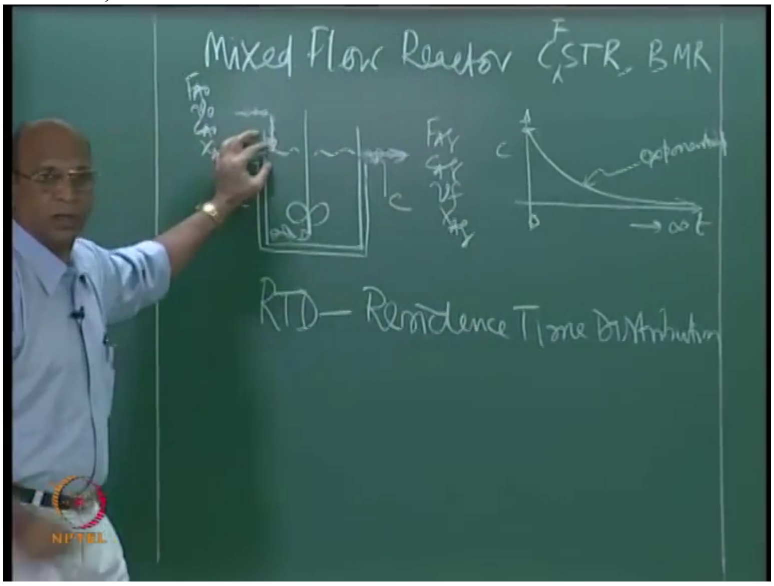

you know disk here? You can also put that disk there. I show just arrow here but actually if I have only one arrow,

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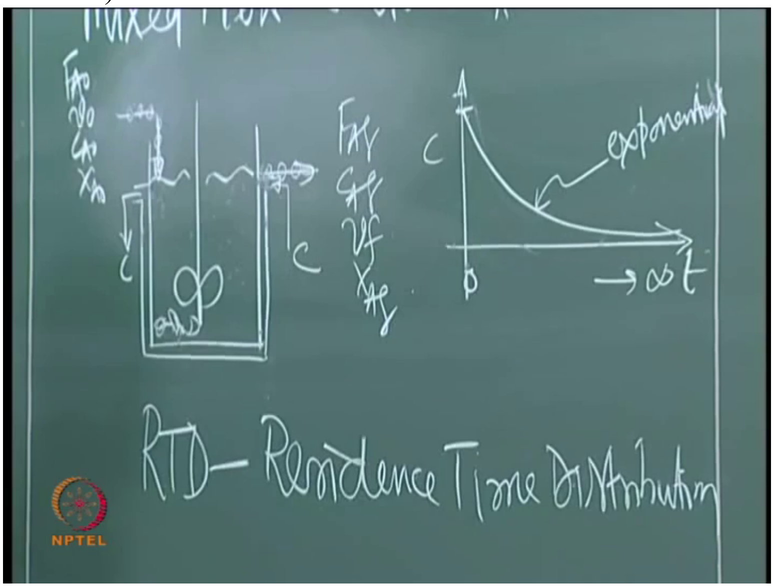

no fluid can enter, correct no? It should be a pipe. So that pipe is something like

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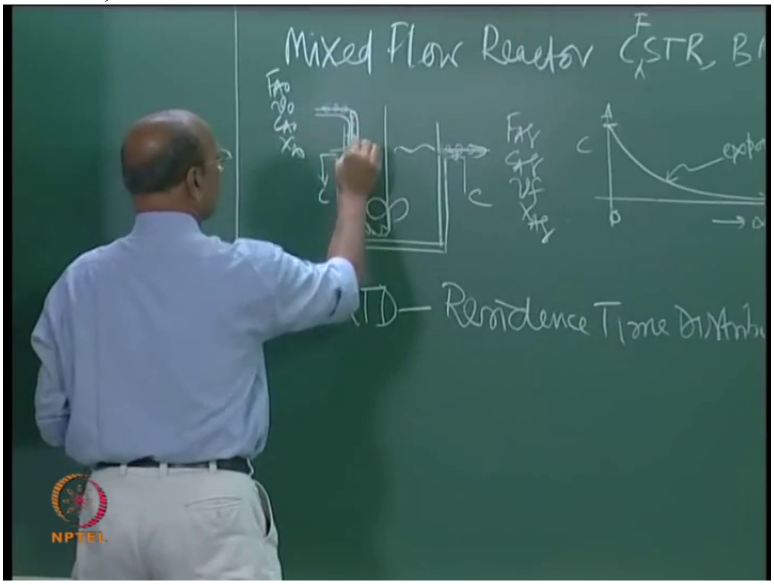

this, right?

So in this pipe, now we have suddenly introduced my disk, correct no? I can do that. Then that comes here. I will count my time t equal to zero when it comes here. And assumption is this fellow is not

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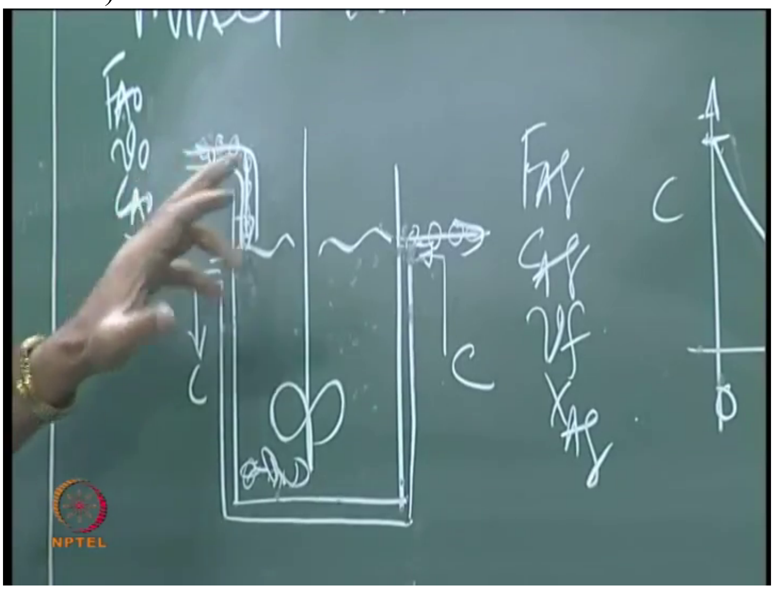

dispersed in the, in that pipe. It is still maintaining as exactly disk only when it comes here. So here I have the disk, the moment it touches, it enters there what will happen to this disk? Pieces into pieces. What is the piece size?

(Professor – student conversation starts)

Student: Molecule

Professor: Molecule. Molecule, because it is perfect mixing we are assuming, right?

(Professor – student conversation ends)

So that way it is now made into pieces into pieces and now one piece it will throw out very quickly out of the reactor. So that may be somewhere here.

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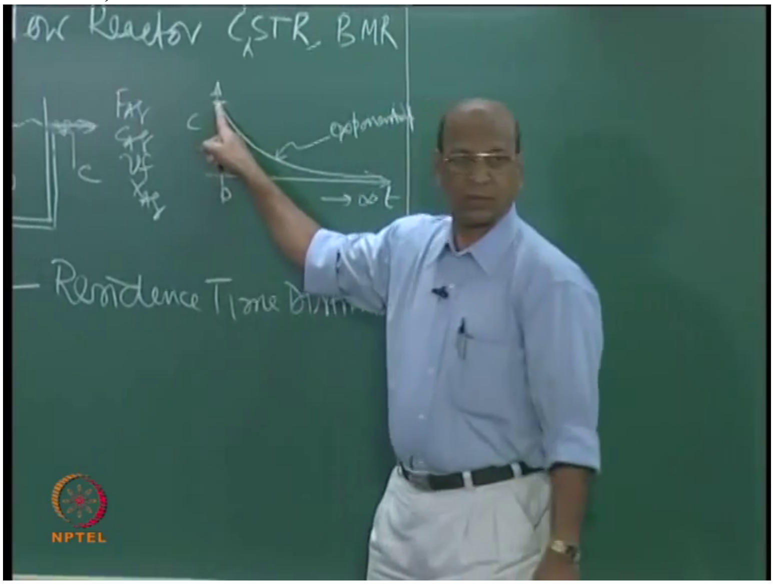

Ok, because concentration you are calling. That piece weight divided by volume of the reactor, so may be 1 gram would have come, no not 1 gram, all that in ideal mixing that will be maximum 10, 8, 9 you know, that will slowly decrease but in exponential way.

You know if I say 10, 8, 9 and all that, sorry, 10, 9, 8, 7, it is not linear again, time I am not telling. At what time it is coming. So that is why, yeah so these timings are, all of them will fall on this exponentially and Ok, that, that disk is into, I mean destroyed into pieces and pieces and then that will also come exponential way.

Whereas the same disk there in a plug flow, without any disturbance it will come exactly same time, I think without any, same time means yeah, exactly same time entire disk will come. So that will be t equal to may be 10 seconds or t bar if you take at the end of 10 seconds, right.

Here I told you, for comparison sake, volume of the plug flow reactor, volume of back mix reactor both are same, 1 liter, 1 liter so volumetric flow rate is same. What is t bar in these two? t bar is defined as, t bar or tau, the constant density system we are talking, volume by volumetric flow rate, Ok. I think, Arya, this is, I do not know

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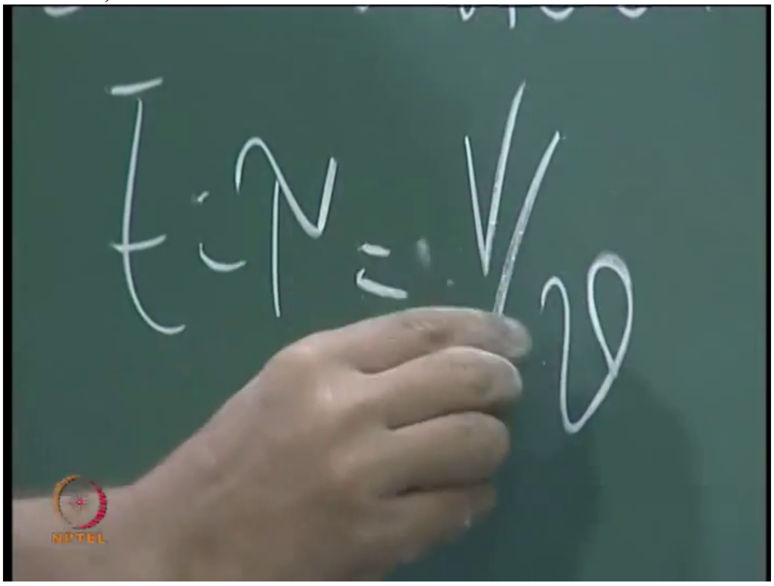

whether you could get this.

This is meter cubed divided by meter cubed per second,

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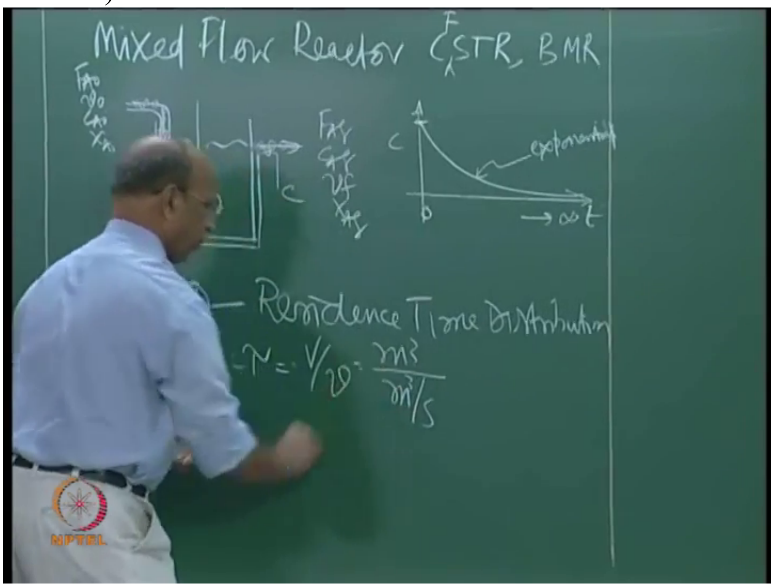

Ok. So meter cubed, meter cubed will get cancelled. Then you will get seconds. That is why this time is taken as

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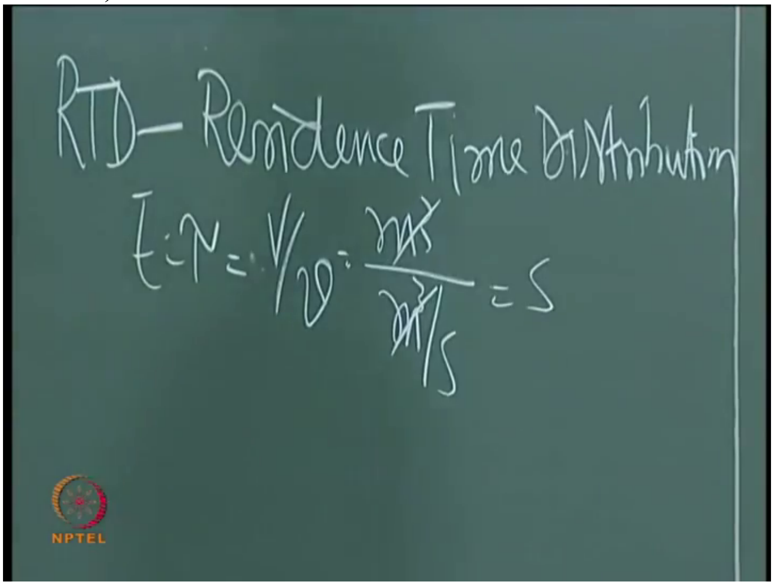

volume by volumetric flow, even though there is a derivation actually for that also. T here is a derivation. In R T D I think I can show you that, Ok.

That is why we call this t bar as volume by volumetric flow rate, right. Yeah, based on volumetric flow rate. What do you mean by ideal residence time?

(Professor – student conversation starts)

Student: Mean residence time that actually depends.

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It may not be this.

Professor: Constant density system I say. I said constant density system,

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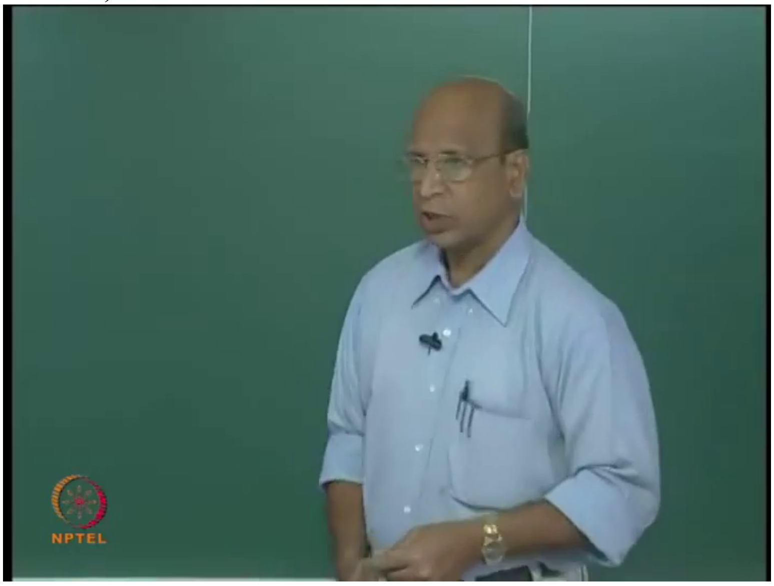

Ok. So t bar. So even, even in volume expansion, how do you define that tau?

(Professor – student conversation ends)

Even if it is mixed flow, even if it is plug flow, even if there is change in the moles, right, still we define tau based on initial volume. There both are entering same, at the same temperature, same pressure. That is why tau will not change. t bar will change, actual flow, Ok. That will come when you are talking about later.

Ok good, so this is what is t bar. See t bar is same in both, here right. So here t bar is, this is going from zero to infinity, right. Infinity I cannot show. That is why I think I just only draw something there. So my t bar will be somewhere here.

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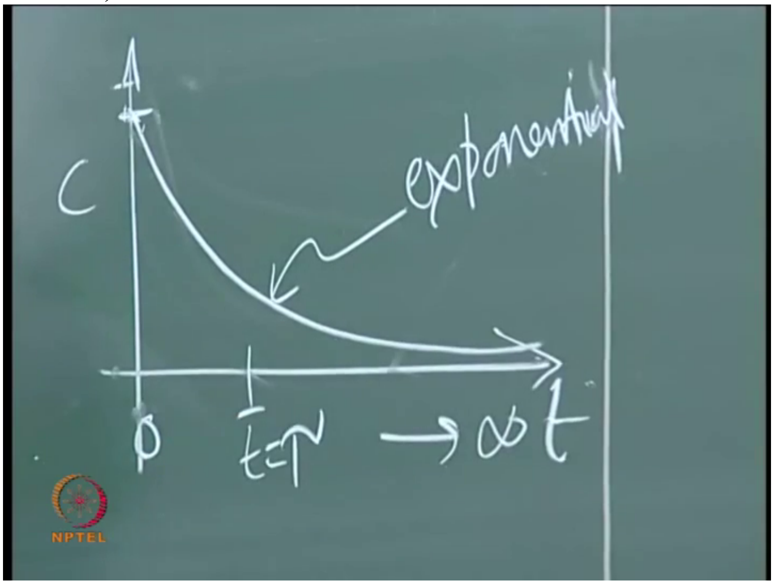

t bar equal to tau.

So that means you see now, if I take this is the average residence time, so now beyond average residence time also, there is, there are molecules coming till infinity, right. Now I asked you the question that what will happen during reaction, you know, I asked you a question, no, that given the same volume, Ok, so where do you get more conversion? I said efficiency, more conversion. Plug flow you said, why?

Because in terms of Residence Time Distribution you can beautifully explain that. That is why I am asking this question. Residence Time Distribution.

(Professor – student conversation starts)

Student: Molecules,

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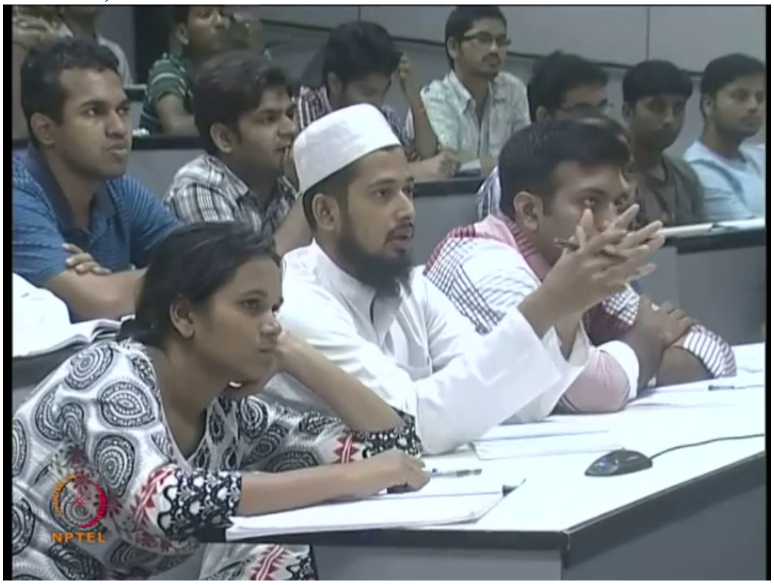

the conversion is very high initially.

Student: Concentration is very high.

Professor: Initially where is conversion very high?

(Professor – student conversation ends)

You see, all these cobwebs you have to remove

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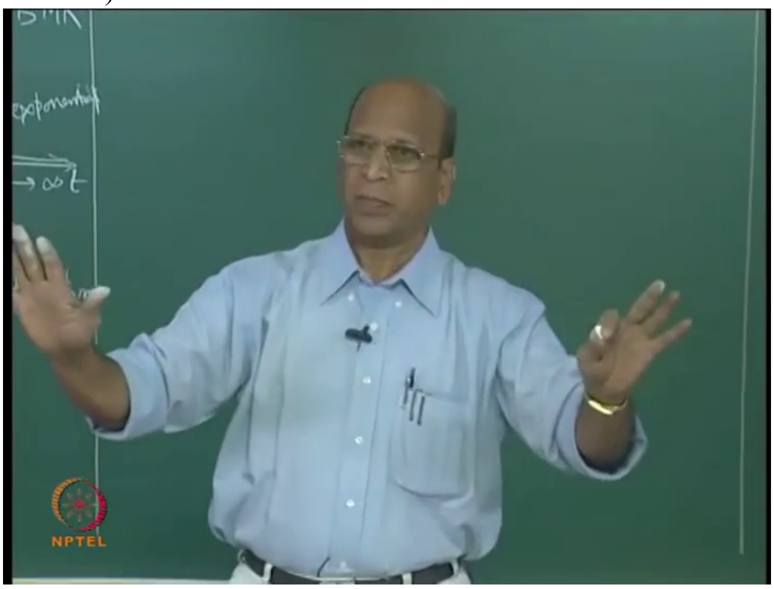

totally, right? Because I tell you, see here we have written X A f, right? What is X A f inside the reactor? Same thing. And is it same thing throughout

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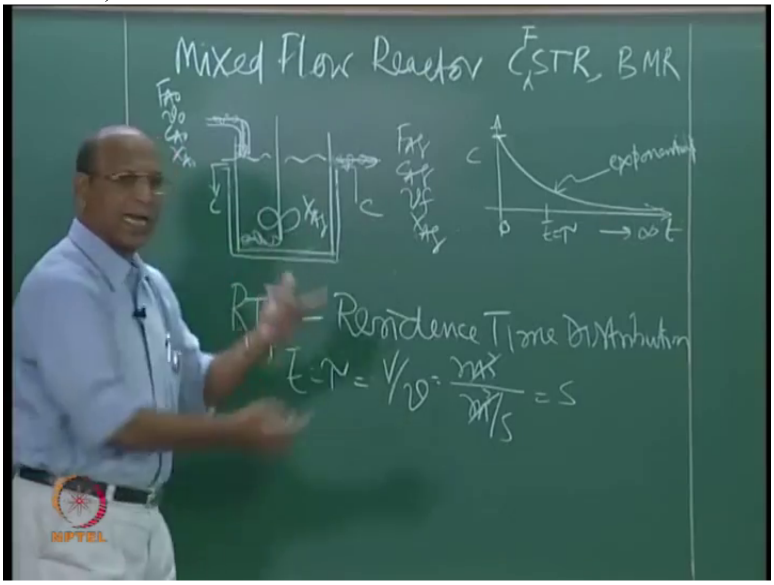

the reactor? Yes, because it is mixed flow. Then where is the more conversion or less conversion here?

It is only one conversion, steady state conversion. Even C A f is same. This we are talking about

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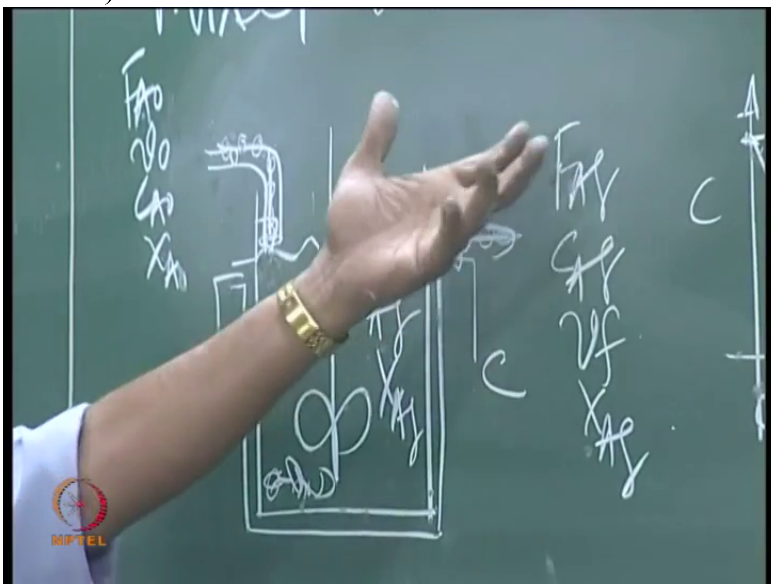

isothermal. Yeah, I have to write here,

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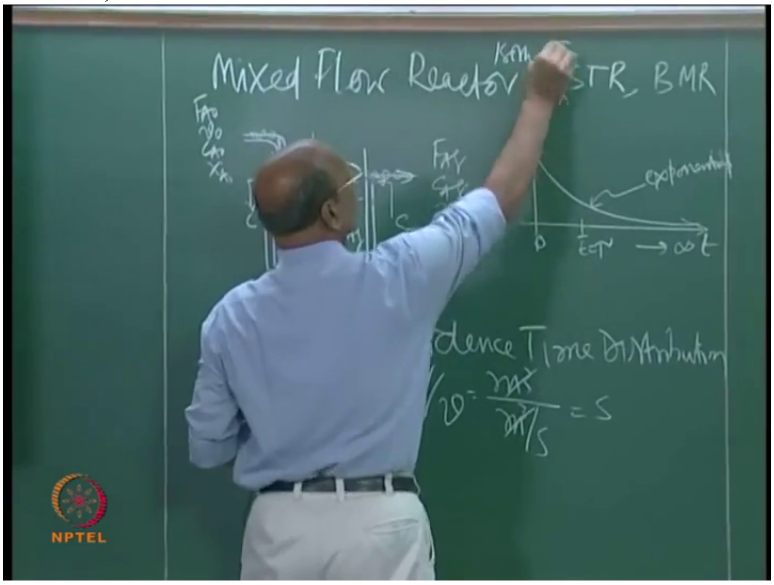

isothermal. Yeah, isothermal, right. So that is why temperature is same throughout anyway. Good. Yeah

So that is why, why do you say that in a mixed flow you will have, you said less conversion? Or you are not of the opinion to have less conversion? Because many students will think that mixing is good for reaction. It is not good for reaction. Why?

Mixing always dilutes the concentrations. When you have dilution of concentration except negative order reactions and we do not find them many in the nature. So negative order means, Ok, first order if I take, negative order minus 1, minus r A equal to k by C A.

(Professor – student conversation starts)

Student: C A

Professor: C A, you put zero concentration, you get infinite rate, excellent. How do you maintain zero concentration?

(Professor – student conversation ends)

Yeah, I mean theoretically it is very good, no? But negative order reactions you do not see in nature. Ok this is greater than zero only, zero plus. Ok. So that is why, I mean most of the things. But in, under some conditions, you get also negative order but that negative order comes only when you have the, you know I asked also question, Hougen Watson model, right?

Hougen Watson model, I also asked a question. What is the information you get from Hougen and Watson models? Hougen and Watson models will give you only rate expression for heterogeneous catalytic reaction.

So under certain conditions of that complicated equation, when you are simplifying terms, when you are removing terms, some terms, how are you removing some terms? When I have 100 may be partial pressure of A, and 1 partial pressure of B and the denominator again you may have another 20 partial pressure of C, so like that when you have, this 1 we can remove. Some people may remove even 10. It is Ok, it is not…I mean when I put 90, that 10 also I can remove.

So when you are simplifying under some conditions you will get some constant divided by, yeah, partial pressure or concentration of some component. That becomes negative, we do not have many. So that is why we only have positive orders greater than zero, then under those conditions you will have definitely

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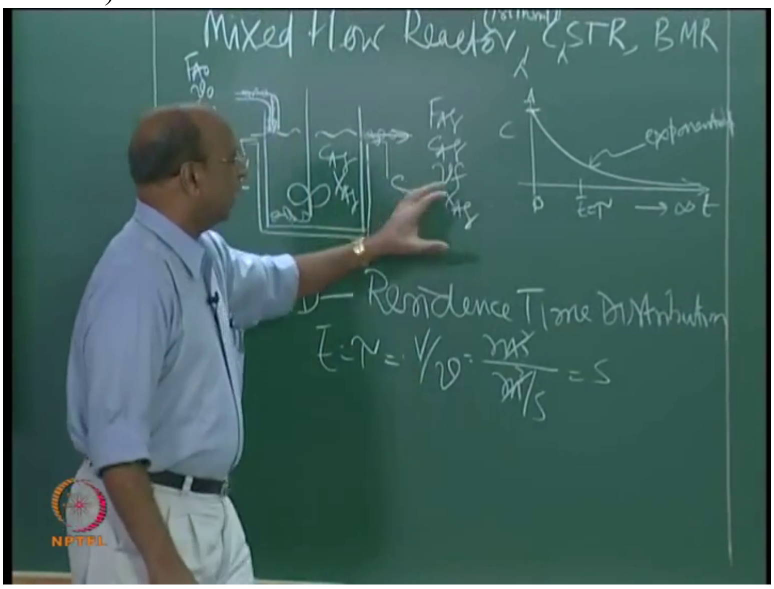

a mixed flow reactor giving low conversions because...

Now you come to packets. One packet has come here. Immediately you added that 100 packets, continuously

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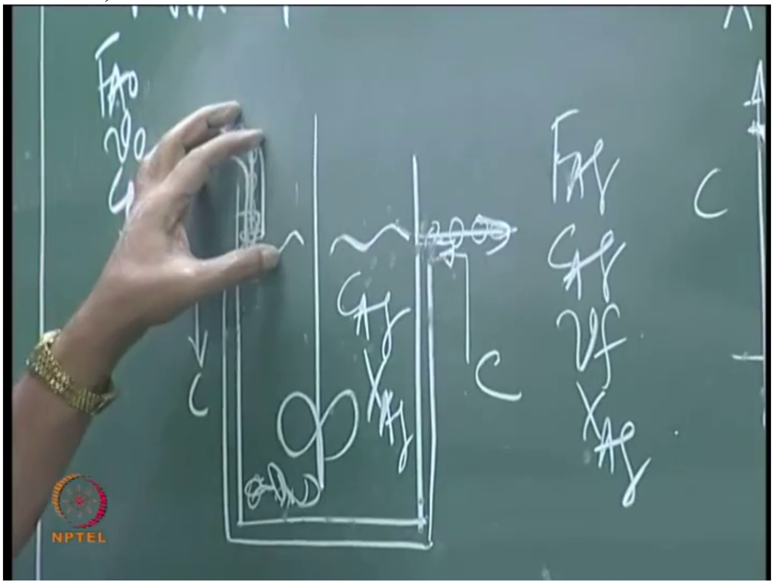

you are adding. So one packet has come here very quickly. What is the conversion in that packet? Very quickly, instantaneously it came out.

(Professor – student conversation starts)

Student: Very less

Professor: Very less. So that means are we using that concentration?

(Professor – student conversation ends)

Are we using that concentration? We are not able to, right? So quickly it comes out. So that means in that, there is no conversion. And I may have another particle coming, the mean residence time is only 10 minutes, let us say. And the particle is coming, the packet is coming after 100 minutes. What will be the conversion there? Ok 100 percent.

But after 100 percent is converted, what is this fellow doing inside? You know it is waste no? See it is a dead space in fact there. That fellow has to come out and fresh fellow has to come for the reaction to take place. What you see here is instantaneous mixing and when I look at this reactor

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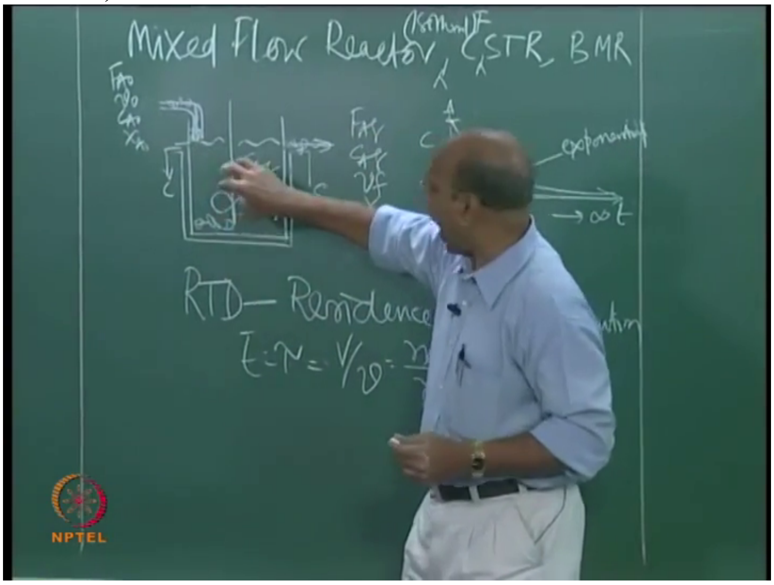

I will see the concentration, you know the packets which have stayed 1 second, 2 seconds, 5 seconds, 100 seconds, 200 seconds. Imagine packets. Ok.

So now that means in, in the packet where one minute back it entered, conversion may be only 1 percent. The packet which has entered 100 minutes back, because it may be there still, because still infinity it has to come, the conversion is 100 percent. The average of that, now remove the packets and then just imagine molecules. So what you see is the average composition of all these packets.

And these packets are there because of mixing with various times, different times. What you see at the outlet is, which you cannot see with naked eye is a composition, average of all these packets with different times. You look at the reactor, you will have again zero to infinity distribution. Why?

That is the definition of perfect mixing. I measured here, zero to infinity.

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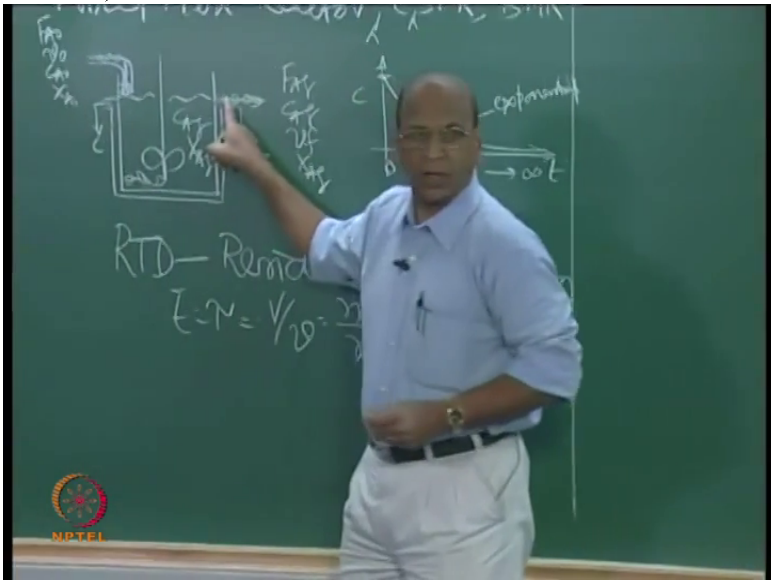

But even if I look at inside, because this is true reflection of inside. Inside also I will find out packets with zero to infinite Residence Time Distribution.

So then the particle which has entered just one minute back, conversion will be 10 percent. In another one, 50 percent. Another one 40 percent. Another one 60 percent. Average of all that is coming here.

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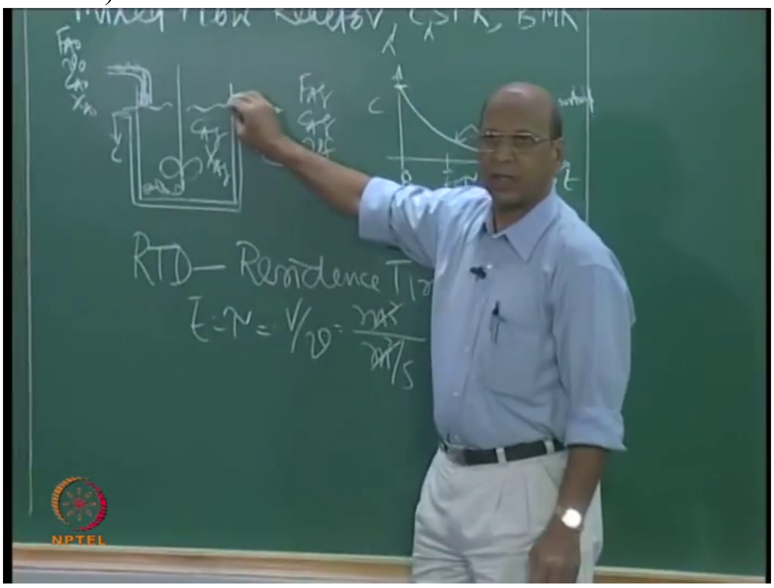

That is what what you see.

On the other hand, one second, that I will come, you have the plug flow. In plug flow, Ok, all these, yeah, all these packets, again 100 I just introduced, all these packets are coming.

Absolutely we are not allowing any axial mixing or any, you know disturbance. All of them will be coming here. What is the conversion

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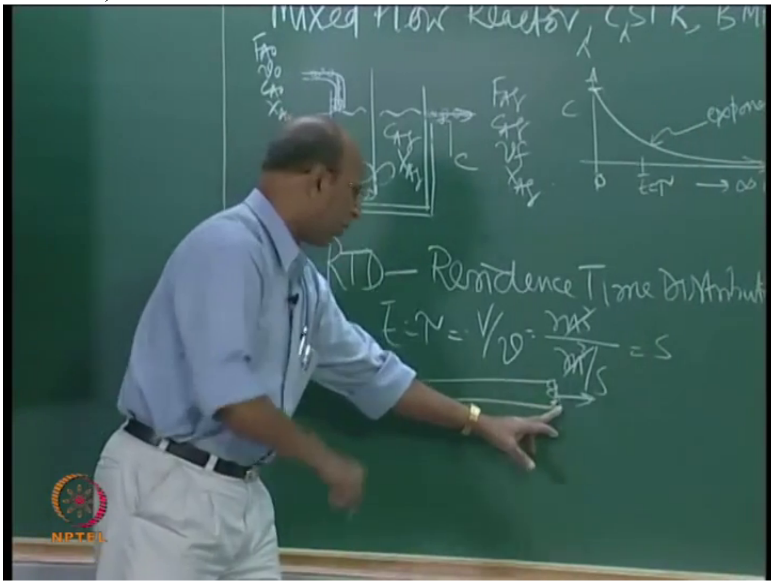

of all the packets here?

If you define 100 percent, that is 100 percent conversion. Or if it is 90 percent, I mean it is 90 percent conversion each and every packet. So now I break all the packets and then mix there. It is same. Whereas here, if I break them and then see, I have 20 percent, 30 percent, 50 percent, 40 percent, 100 percent, average of that is definitely smaller than this. Now, doubt...

(Professor – student conversation starts)

Student: Ideal Residence Time Distribution

Professor: This itself is ideal Residence Time Distribution. Because we are mixing ideal, perfect mixing,

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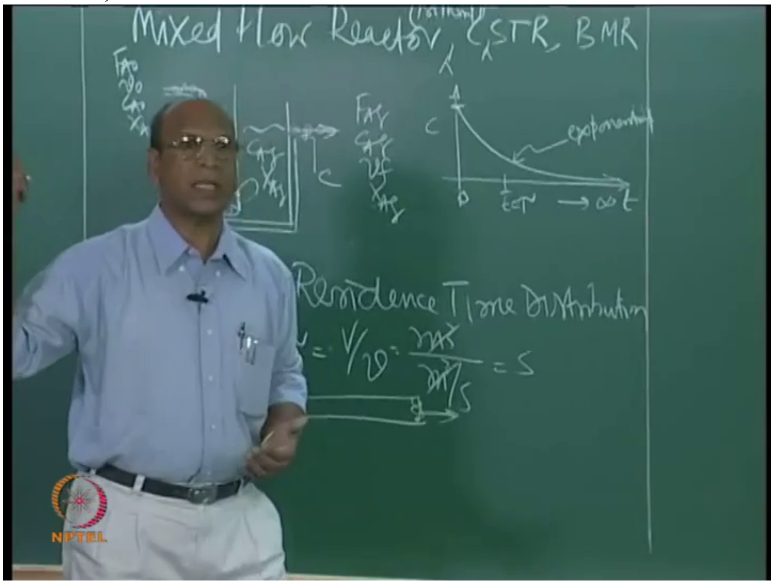

perfect mixing and ideal reactor.

Student: But assuming that it will come in this way

Professor: Not assuming, we can mathematically prove. We are not assuming here. Mathematically we can prove, precise. It is exponential decay.

Student: I say, for example we have 100 particles coming in,

(Refer Slide Time: 42:54)

say 100 molecules. Molecule number 1, 2, 3 we number them. And like, it is not practically possible but let us assume for a moment that...

Professor: That is why we said packets. Because one molecule we cannot say conversion. So there should be group of molecules.

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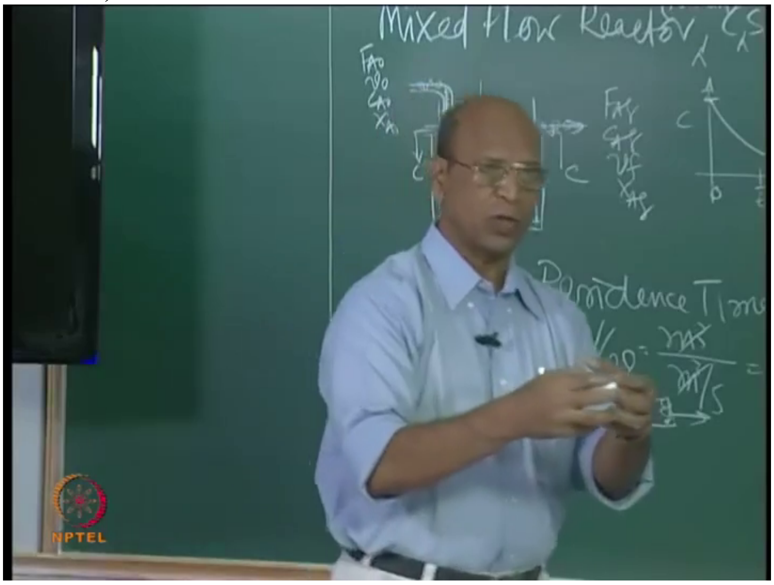

That is why we are saying it is conversion, right? Yeah

Student: 0:43:12.2 Packets we number them as 1 to 100. And when we, let us after some time, let us check the outlet. Packet number 1 conversion, 2 conversion, 3 conversion,

(Refer Slide Time: 43:21)

4 conversion, it is not possible...

Professor: No, no, no, no

Student: It is not possible 0:43:27.1

Professor: See when it is not possible we do not have to discuss that, no?

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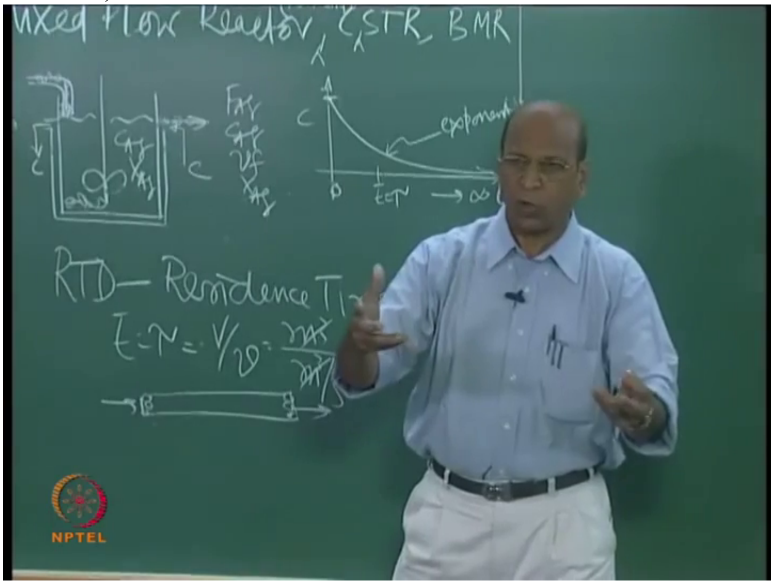

When it is not possible, because you know here, I collect let us say, small amount of liquid, right? So when I look into that, if my packets are able to identify, when I am identifying I will see packet with 1 minute mean residence time, 2 minutes, 5 minutes, 6 minutes, 100 minutes all that.

Now 100 minutes one, 100 percent conversion. 5 minutes one, 40 percent conversion, another 60 percent conversion. All that average only I am seeing at the outlet.

Student: If I take the packets

(Refer Slide Time: 44:04)

like 1,2, 3, if they came out in the order in which they came...

Professor: No, no, you are imagining, this packet 1 is coming first, afterwards another one is coming. No!

Student: It could be an ideal...

Professor: When I take a sample of, you know some amount

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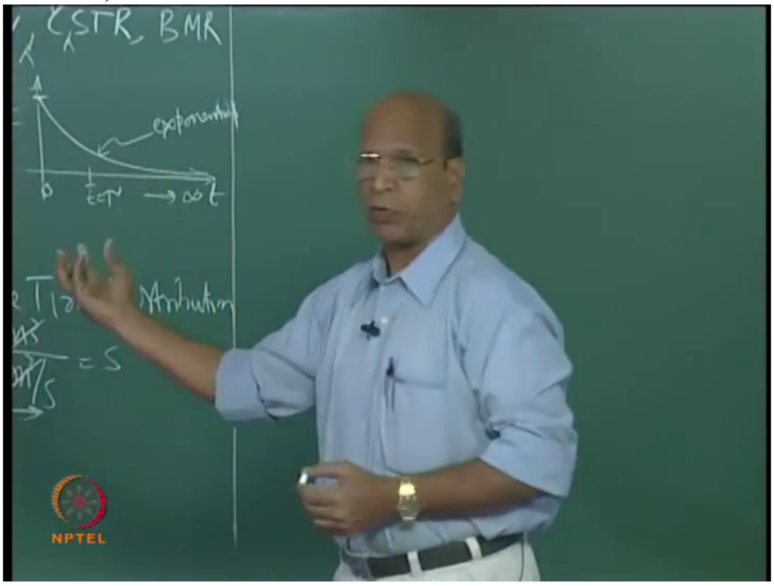

of liquid, in that liquid itself I will see all my packets with different ages. And average of that, you know and now different ages means different conversions. All those conversions I then mix them. And then see that. That is what you are seeing when you are measuring it at molecular level. Ok.

(Professor – student conversation ends)

So then what you see here is a low conversion because now you are mixing the packets with 100 percent conversion, that means zero concentration, zero concentration of reactant, Ok with 1 minute packet where the concentration is, you know if I have 10 moles per liter that may be 9 moles per liter. That means 1 percent conversion, sorry 10 percent conversion, right? So these things I am mixing. Right.

Abdul what I see at any time here is mosaic of all residence times, theoretically speaking zero to infinite residential time. And when I have these packets with zero to infinite residence time, the conversions or concentrations of each packet is different. I am now putting all of them together and then trying to get an average concentration.

That concentration will be definitely, yeah I mean if we are talking about product it is more than the concentration of, concentration of product. Conversion let us take. That conversion is definitely less than the conversion in plug flow. That is the reason why without even equations we can say that why the concentration, the conversion in a plug flow reactor is higher than conversion in a mixed flow.

What you have to remember that it is not instantaneous reaction. When continuously, when you are putting

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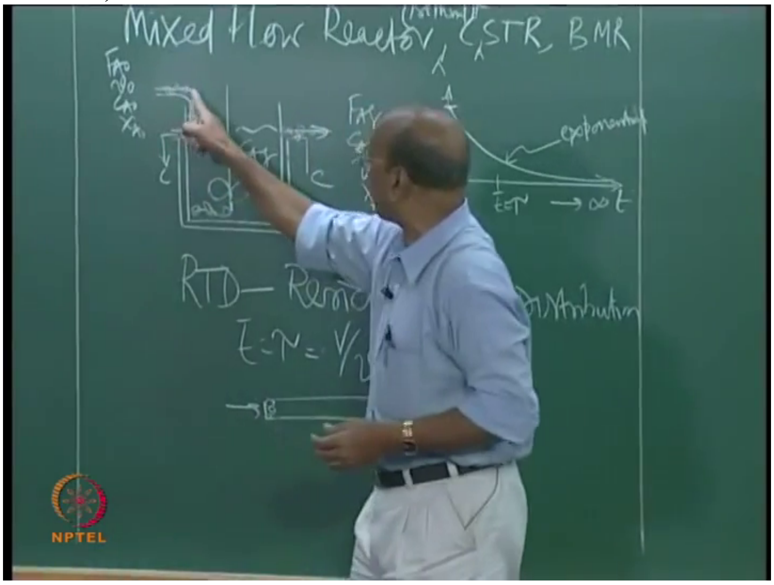

some fresh reactant that goes here. It is already having some concentration C A f outside, because of perfect mixing and C A f is also coming because of average of all those packets. You are talking about steady state. That means steady state has reached somewhere already earlier. We are talking about steady state only.

If it is unsteady state then we have to also see how concentration, one can find out. That is not a problem. We are talking about steady state where C A f is already established here by the combination of packets with different concentrations. Right?

So when this is continuously entering, when and that distribution of packets, because you know no accumulation there. 1 liter is entering let us say in 1 second. In that 1 second this 1 liter is coming out. In this 1 liter if I see I have zero to infinite Residence Time Distribution.

So in that various conversions, various concentrations. So the average concentrations will be less.

Same thing, here plug flow.

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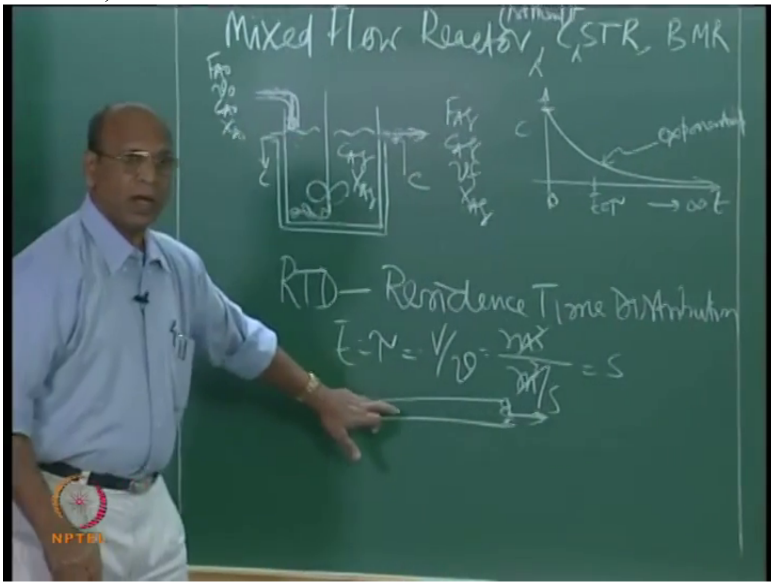

I have here 1 liter entering, 1 liter coming out. So when I take 1 liter here, when I see it, and then because of our ideal definition, that 1 liter only exactly comes here. So

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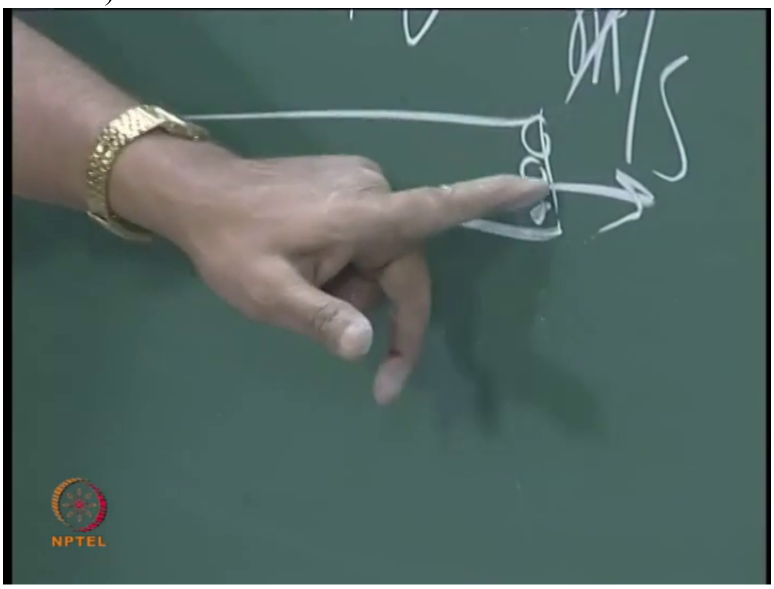

what is the conversion in that 1 liter? 1 liter contains 100 packets. Exactly same. Now I am mixing them. I destroyed them and mixing in terms of molecules. What is the concentration there or conversion there? Exactly same.

So you are not diluting. Whereas in that case, it is diluting. Please remember, I think 0:47:29.1 was also asking me, Sir it is instantaneous reaction in mixed flow? No! Ok that average you are perfectly mixing, but that perfect mixing creates zero to infinite Residence Time Distribution which comes at the outlet and by

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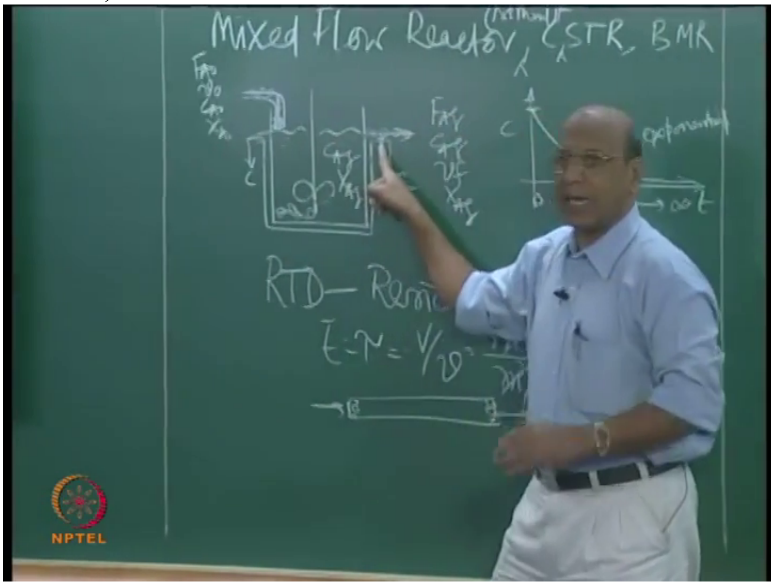

definition outlet equal to, outlet conditions must reflect inside the reactor, the distribution here also exactly zero to 100 percent, I am sorry, zero to infinite distribution so then the conversion here and conversion here is exactly same. Pooja, you were asking some doubt? yes

(Professor – student conversation starts)

Student: Got this point, P F R is having more conversion

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then C S T R

Professor: Very good

Student: But the point is the outlet C A f, how can it be equal to inside C A f? Because one packet is coming out, so if you have a distribution like 10...

Professor: Ok

Student: 10 percent, 20 percent, 30 percent and one molecule, one packet is residing in that container for more time period, so that 30 percent, 40 percent so there is difference in C A f in outside and inside.

Professor: No, what is the definition?

(Professor – student conversation ends)

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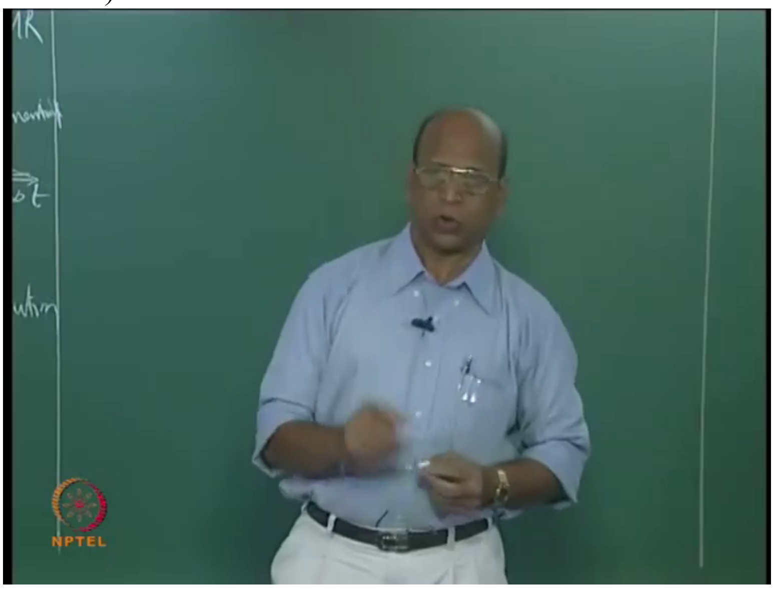

I think you have to do this experiment in your room. You have taps there inside? No. May be I think you have bathroom taps no? Take a glass, Ok. Allow the water to flow into that,

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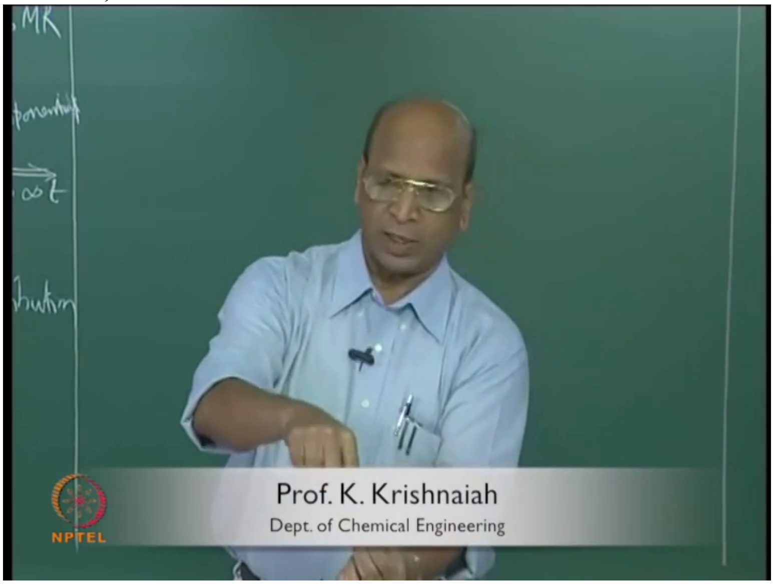

you know tap water into that. And then you know, let it overflow. You call Dhania or someone and then ask, take a pencil, stirring, Ok. Then add one drop of ink. Right. Just see whether you are getting same color inside and same color outside when it is overflowing.

Yeah, then why do you say that C A f is different here, C A f is different here? It is exactly, that is what is perfect mixing definition.

(Professor – student conversation starts)

Student: Because that particle inside having more...

Professor: No, no the combination of all that,

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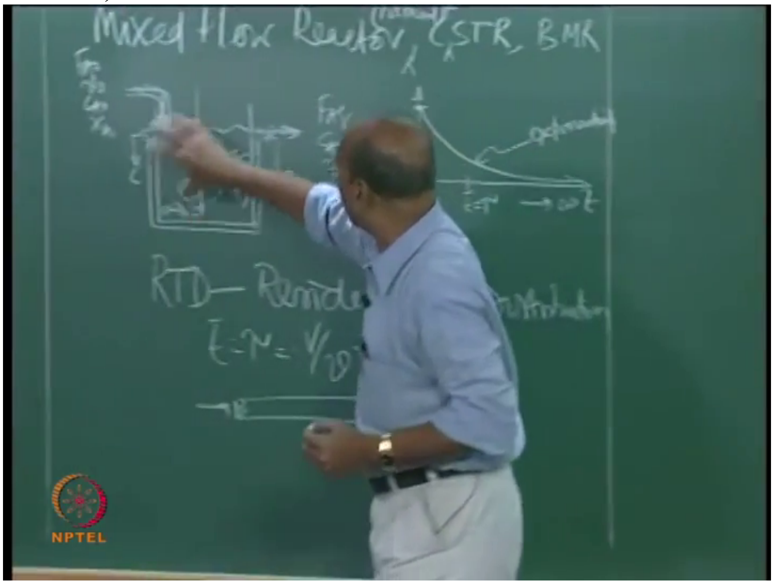

because of mixing that zero to infinite Residence Time Distribution which gives you some average concentration, that is reflecting here. Because this is a continuous reactor where whatever is coming here, it has to overflow. It has come out, right?

(Professor – student conversation ends)

So whatever is happening, you will have immediately coming out. Because of perfect mixing. You just imagine. You have the tank and then you know glass tank where you have a very high stirring.

I think if you go to our lab, I think may be Nagrajan or Rahul will show you we have a stir tank there you know in that R T D experiment. You put one drop of ink. And then show them. I think you know, beautifully you can understand that. the moment you put that one drop of ink, if you allow good mixing there, the same concentration is reflected in the overflow pipe, outlet. Ok.

Then onwards, the color is decreasing in the tank. Also the color is decreasing in the outlet. That is why this concentration decreasing continuously. Ok, so beautifully we can imagine. It is not a problem at all for us.