Chemical Reaction Engineering 1 (Homogeneous Reactors)
Professor R. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology Madras
Lecture No 12
Basics of Plug Flow Reactor Part 1

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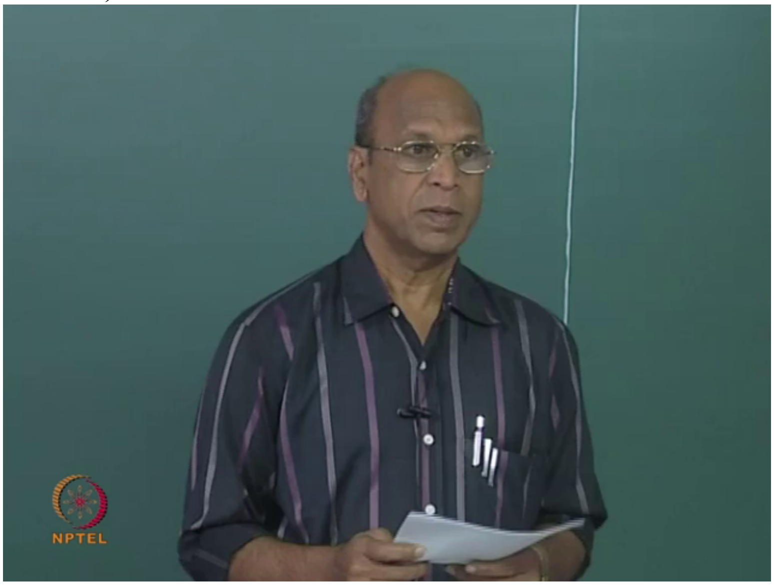

Design of the batch reactor which we have discussed yesterday, all the ingredients are there in this problem, Ok. What you have to find out is the reaction time, Ok yeah and after calculating

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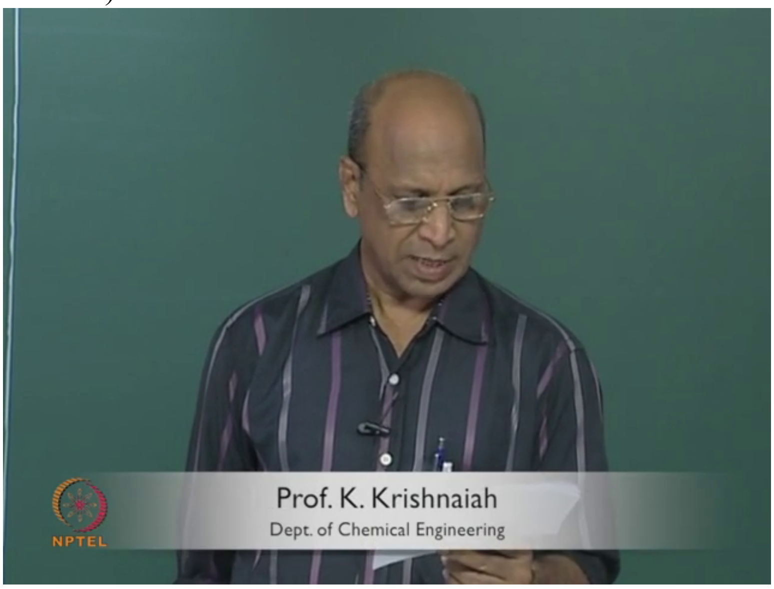

reaction time then you have to add 30 minutes, in the last line you have 30 minutes required for discharging, cleaning, recharging and all that.

Then you have to calculate how many batches and then you have to calculate what is the batch volume. Yeah it is a reversible reaction. And equations are already there, derived and all that in Levenspiel book also, right? So you can, if you derive then you will be more comfortable.

If you just copy from the text book, if I give the same thing in the examination, I do not give you text book, Ok.

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And then you have problem. And I also won't give you marks if you are putting from memory, Ok? Memory means only computer

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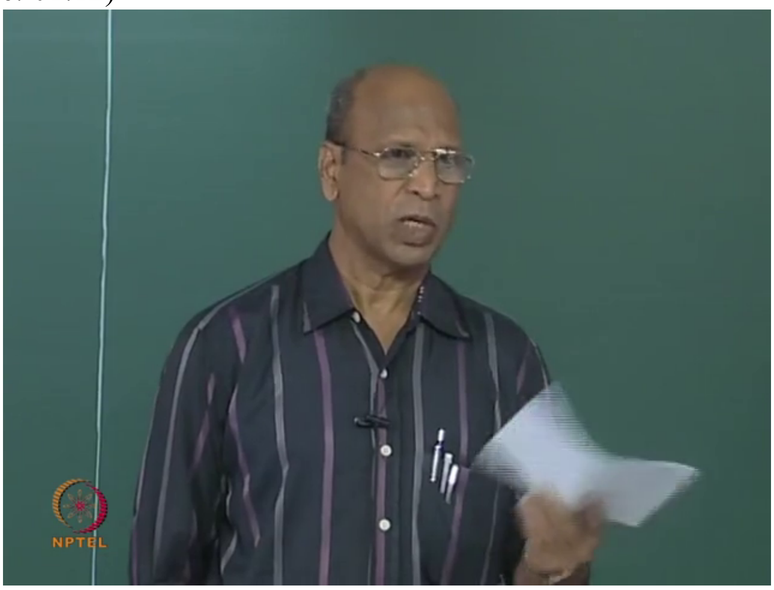

Ok. So that is why if you recall from memory and just write there, I do not give, you have to derive, good?

And the bracket A, B, R, S are the,

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like A plus B going to R plus S. All liquid phase reaction also, constant-density system, everything is there, good. Anything? Ok good.

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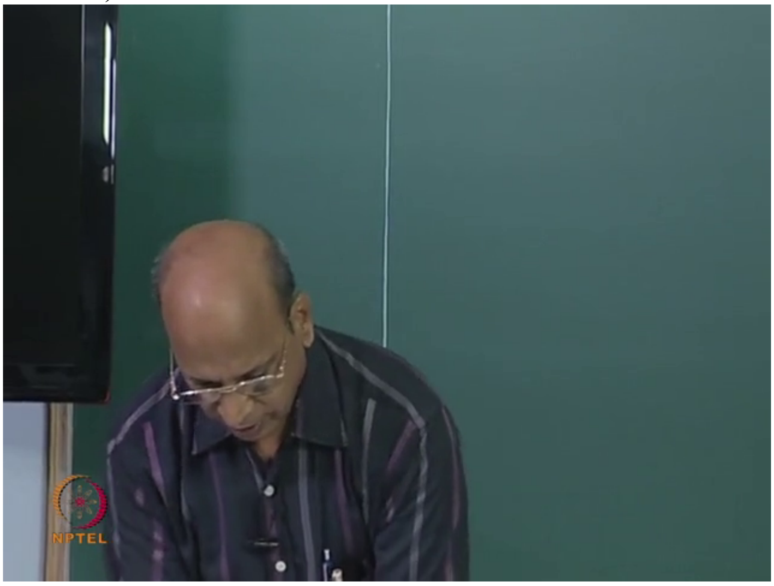

So that is the problem.

Now we will start logically plug flow reactor. Why logically plug flow reactor?

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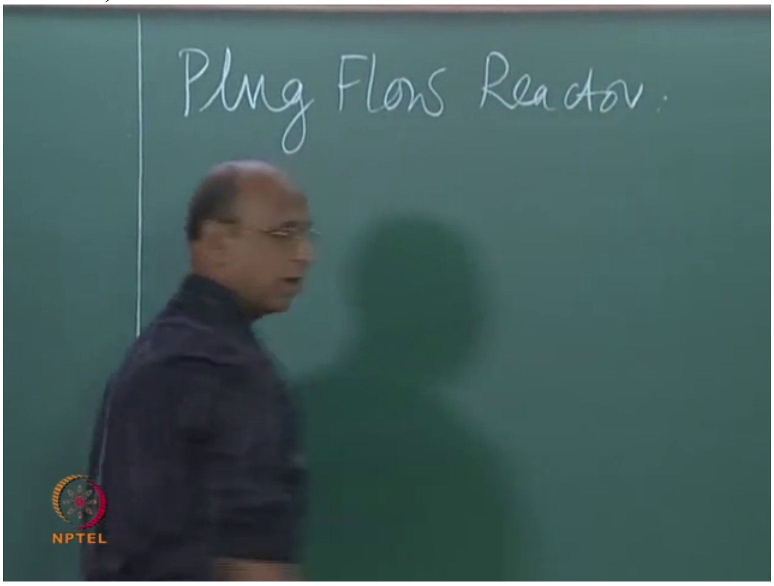

Why did I say logically plug flow reactor after batch? Plug flow and batch will be same under some conditions? Performance 0:02:05.3 Yeah, I mean both are same, and if they are same, why they are same?

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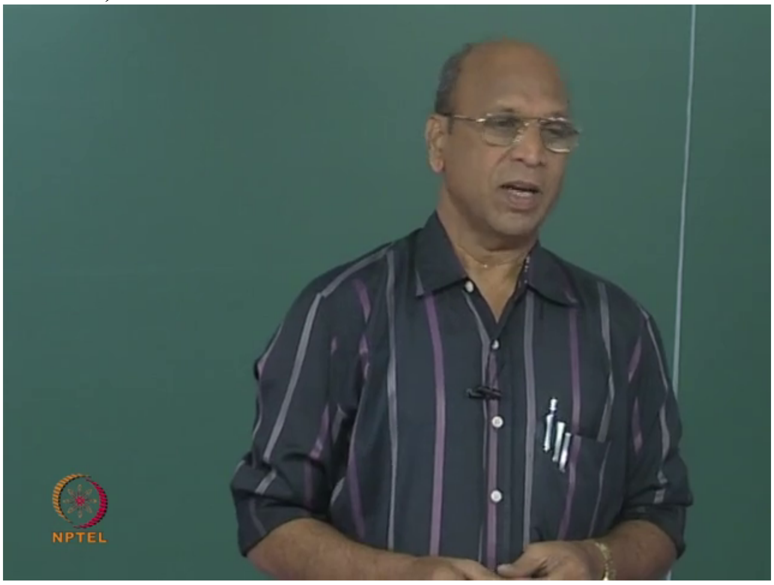

Logically I said because the same equation under certain conditions is exactly same as batch reactor equation for constant density systems. Why they are same and all that, now you have to get that knowledge. Ok, why?

And that with clarity, not simply you know like parrot. Because if everyone says they are same, or they may be different, then you are also repeating they are same, they are different. But if I ask you why they are same, why they are different, not able to tell. So in this course what you have to get is that clarity. All the cobwebs removed from the mind, clean house, correct no? So that is what.

I think you know definitely when you are going to choose continuous system, when you are going to choose batch system. That clarity has come. With examples and also with reasons and all that. So now in batch, sorry, in batch reactor again how do you calculate volume, even though volume is not directly present in the design expression, that also you know how to calculate.

So any batch reactor, the time is same. Even if you want to produce 5 kgs, 50 kgs or 5 tons, 500 tons, batch time is same. But depending on the production rate you will have different volumes. Ok sometimes you may use one metric cube, production may be less. Sometimes you use 5 meter cubed because production is more. So to calculate all that only this problem is given.

Ok, so plug flow reactor diagram what we normally draw is something like this. It is a tubular reactor, this is a tube right, and then something enters, something comes out and we also show, when we have plug flow reactor, that we have like this, correct no? Yeah, so like that.

What is the meaning of that?

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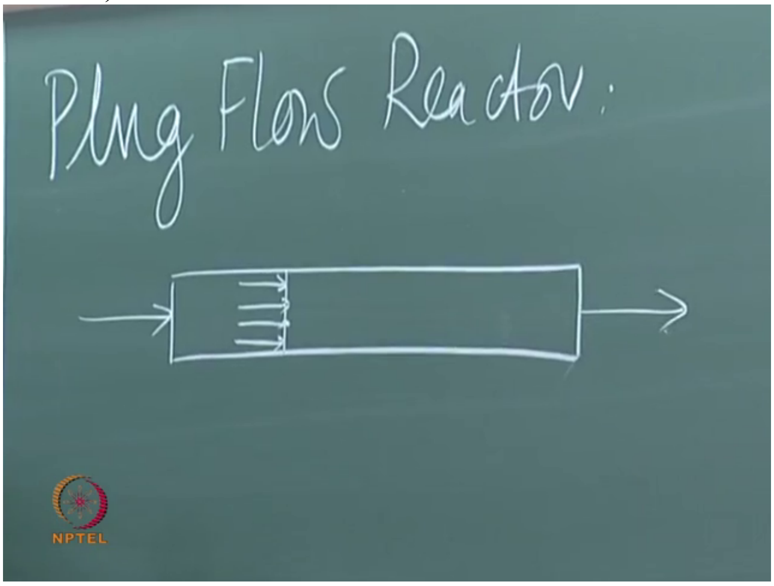

(Professor – student conversation starts)

Student: Constant velocity

Professor: Constant velocity and this constant velocity when do you get

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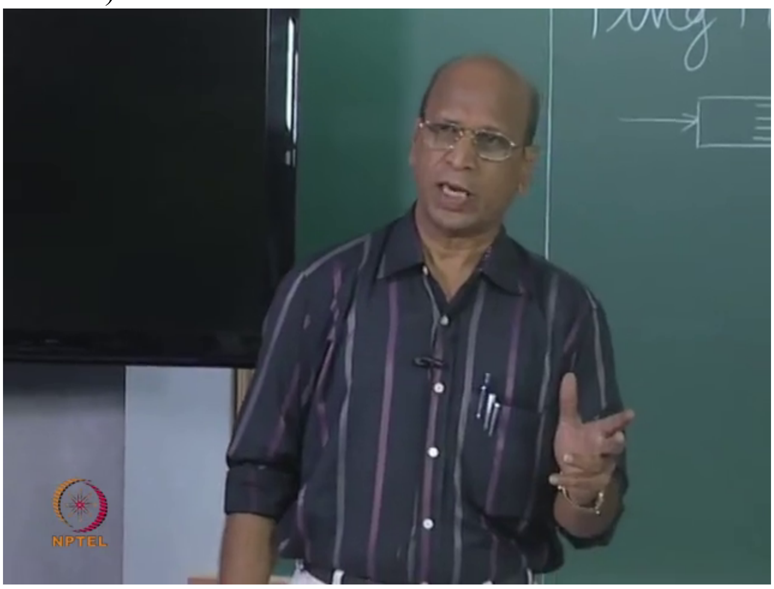

throughout the tube, fluid mechanics wise?

Student: 0:04:26.6 high.

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Professor: High, how high?

Student: Infinity.

Professor: Infinity .Because only at infinity velocity you will have velocity near the

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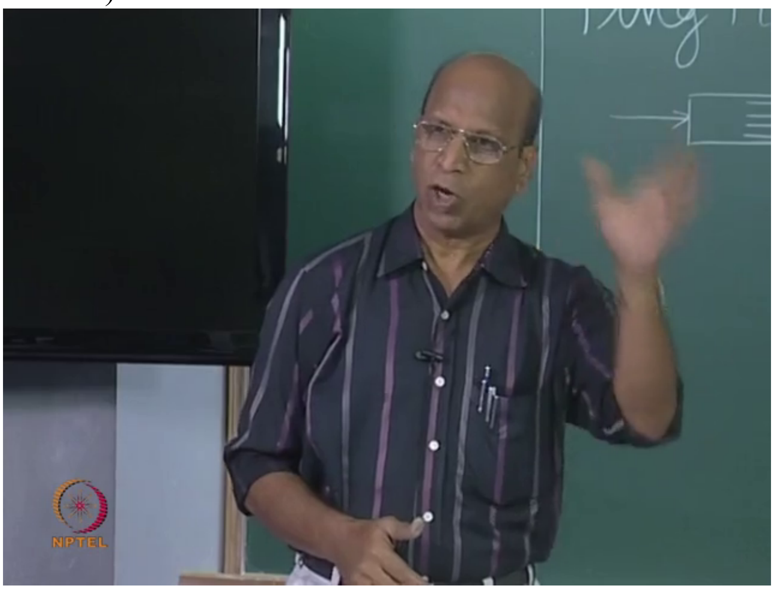

wall also, same. Otherwise as long as walls are there, there is no real plug flow reactor existing.

(Professor – student conversation ends)

Ok, without walls how do you conduct the reaction? You can conduct in some heterogeneous system, beautifully you can conduct. The true plug flow is there actually. You may not know that but I will tell you later that one also.

Yeah so this is how we have to show, we will show the plug flow reactor. Then normally we will say that we have F A naught entering and this one is final F A f, and here also you may have C A naught, v naught and isothermal we are talking now, isothermal, isothermal plug flow reactor and

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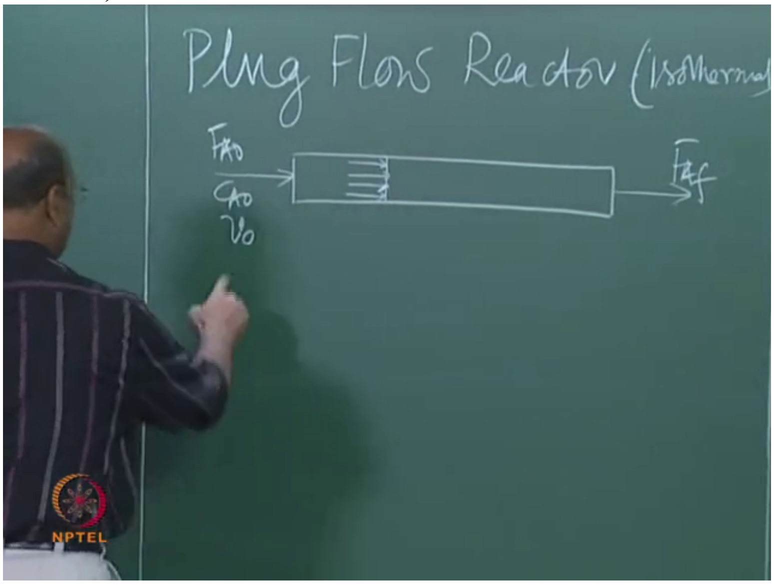

temperature is same, that I do not have to write throughout because isothermal and then what else is missing here?

Of course X A we can write which is zero there. Ok X A equal to zero, then correspondingly here I have C A f, V f which may be final and also X A f which has some value. If it is also zero then beautiful design, no reactor. (laugh)

Because where is the reaction there? Because X A entering zero

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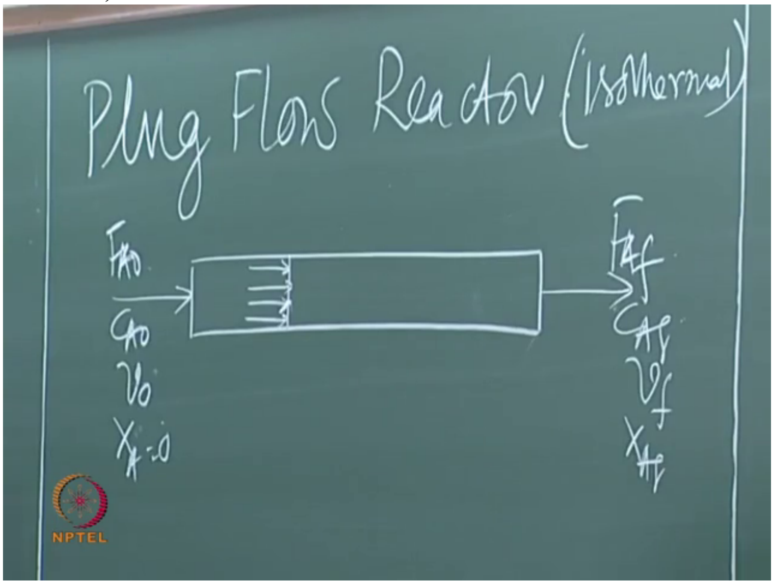

and leaving also zero, that is a wonderful design, nothing will happen there. Sometimes you know not doing anything is safe. Good, so this is what.

And I do not know if you remember any other names than plug flow?

(Professor – student conversation starts)
Student: Piston flow
Professor: Yeah we call piston flow. Any other name?
Student: Tubular flow.
Professor: Tubular flow but, yes?
Student: Annular flow
Professor: Yes, rod flow
Student: Annular flow
Student: Slug flow
Professor: Annular means you have two.
Student: One more
Professor: Slug flow means it is only 2-phase system.

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You are talking about homogenous. Ok, we have sufficient names. Don't invent slug flow and all that (laugh).

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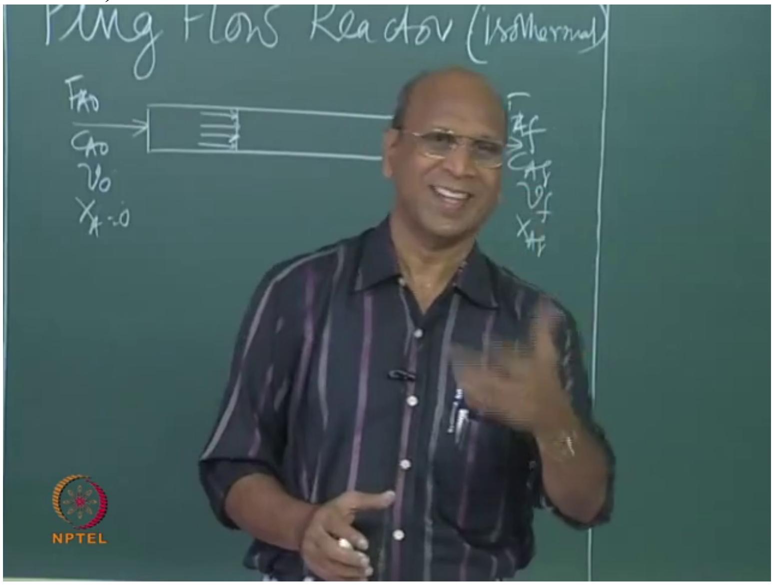

That will not come. Slug flow will never be plug flow. Ok.

(Professor – student conversation ends)

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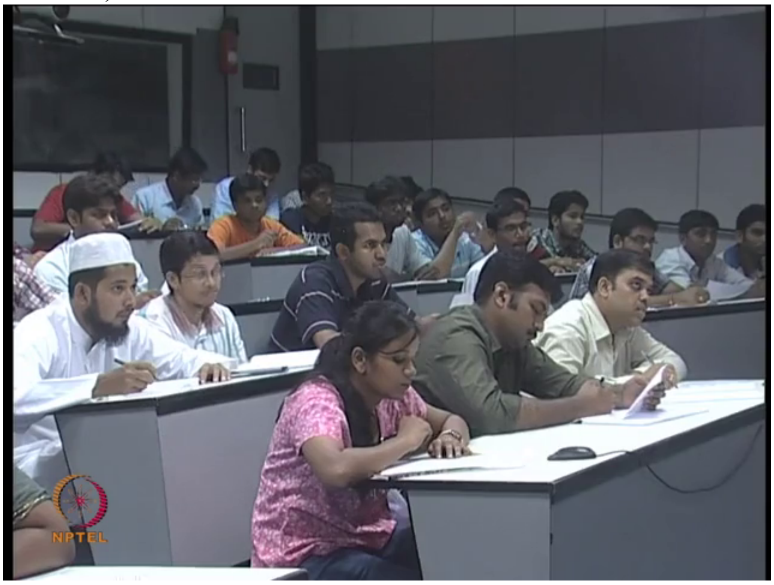

So slug flow we will discuss later when we come to heterogeneous systems.

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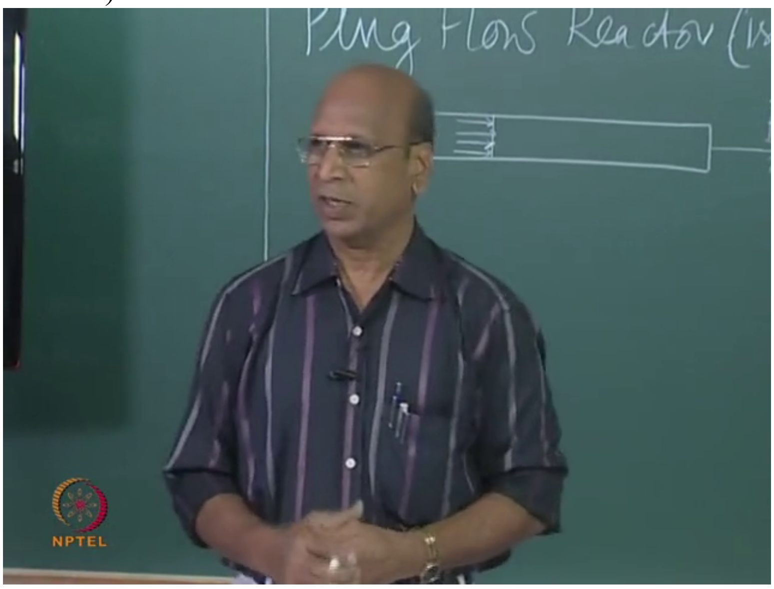

We are talking about homogenous. Normally the names what you have already told, you may call it as piston flow, Ok, and other

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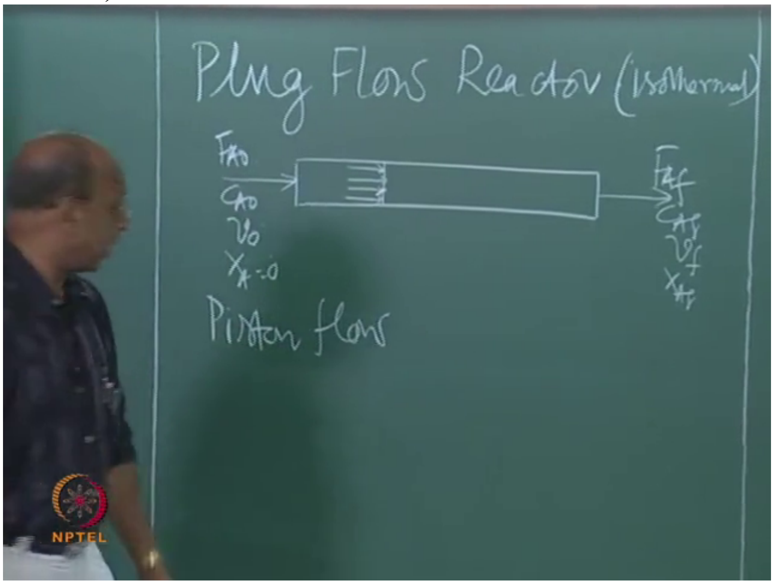

name you said tubular flow.

But when you say tubular flow, normally tubular flow, tube associates with flow where definitely at the walls you will have velocity equal to zero. So that is why when you say tubular reactor, it does not mean it is ideal plug flow reactor. If you want to specifically say ideal tubular reactor, Ok, that means it is plug flow.

What is ideality in tube? Our assumption is that you have flat velocity profile, Ok. That only gives me that plug flow condition. So piston flow, then ideal tubular flow reactor and rod flow is also rarely used, it is right, what he said is right, rod flow, rod flow also very rarely used. It is, that means it is like a piston. Piston is a rod, correct no?

See if you look at the piston when it is moving through a cylinder, how it moves? Exactly you have the cut there, Ok, the piston,

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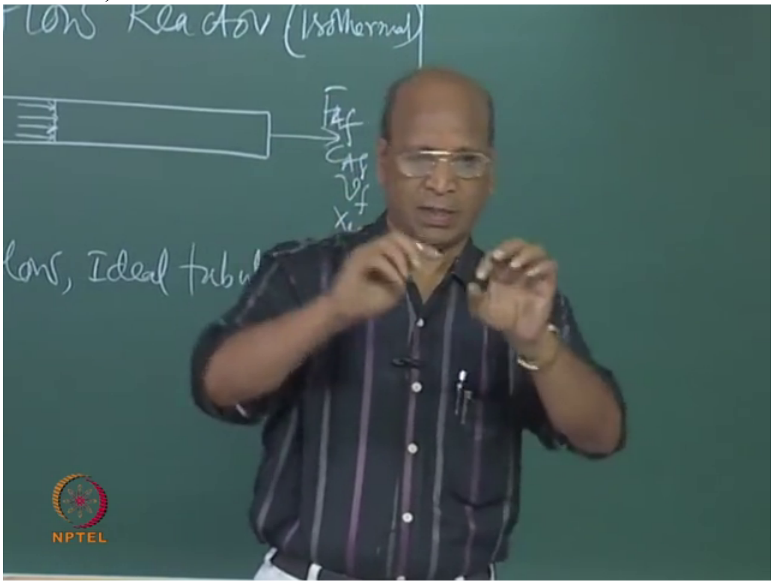

the piston diameter is cut like this exactly, so then this moves like this. Ok so that is why we say it is a piston flow because we expect in our tubular flow, that kind of flow, like a piston flow. Ok. So why should we assume that we have that kind of piston?

So the ideal definition for this is that all particles must spend exactly same time inside the tube, Ok inside the reactor. Each and every particle, Ok how do I imagine that? Ok. I will simply give you very simple example. Most of you would have seen that.

Ok, yeah, before that I will also write, time, times Ok time spent by each and every molecule is same in a P F, in a plug flow reactor. Yeah, plug flow is always ideal. We do not have to say that again

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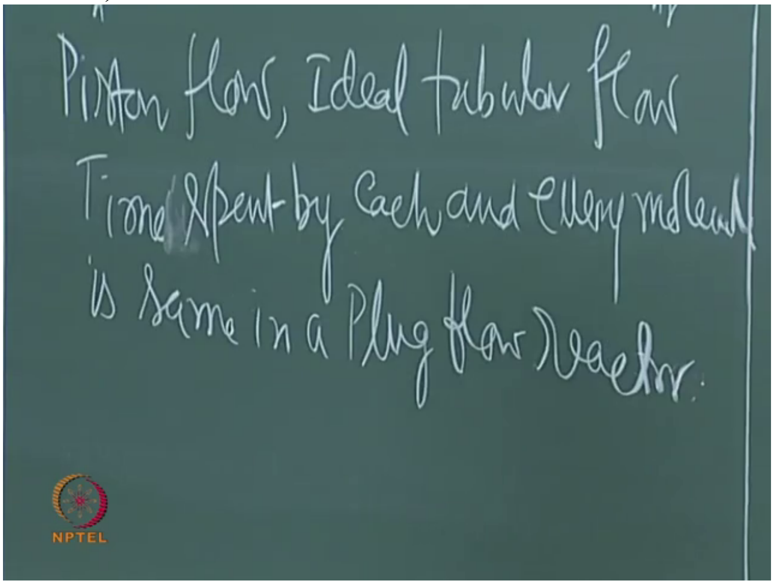

say that ideal plug flow. Ok, plug flow itself is ideal. Ok, so then why we should have this name, you know, plug flow?

The reason is that when you assume this time spent by each and every molecule, yeah time spent by each and every molecule is exactly same means that will be possible only when you have flat velocity profile or axial mixing equal to zero, axial mixing means this is the axial direction, this is radial direction or lateral direction, Ok.

So in this direction, there is no mixing. What do you mean by mixing? A molecule coming here and then again coming back, back and forth, Ok. So that kind of thing is not allowed, why? If a molecule comes here, there is a flow, continuous flow.

You are sending continuously volumetric flow rate wise V naught, if you divide by cross-sectional area then it will be velocity, so volumetric flow rate wise it is going with constant velocity, for example, first time we discuss constant velocity. Afterwards you can extend that to what will happen if you have variable velocity also, Ok?

So constant velocity and then the molecule comes here.

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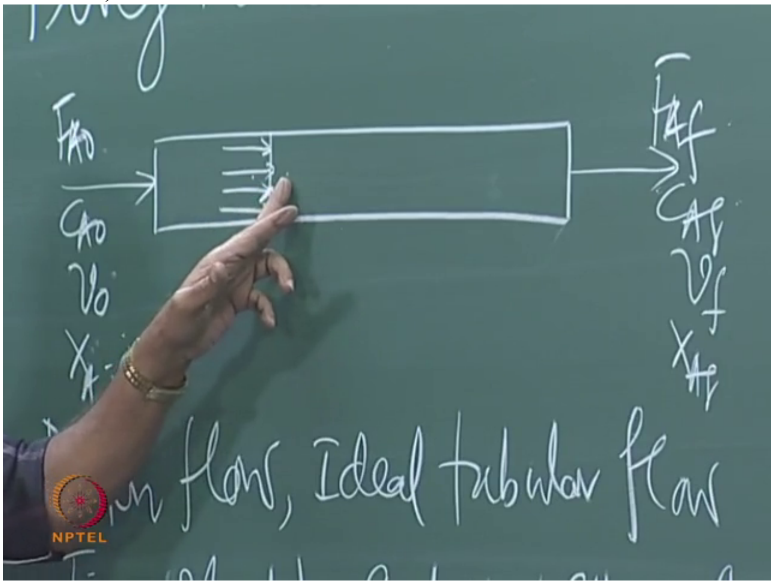

And by some reason, that will also, may come back, a little bit backwards. So that means this molecule which has been moving with some other molecules forward now coming back and joining the molecules which have come later than this molecule.

Ok, I think Ok, may be explanation is not, probably you are not understanding. So this molecule entered 5 seconds back at this point, Ok. At this point if I take its time, it is 5 seconds. Now there is another molecule which enters 3 seconds back. Right? When you say axial mixing equal to zero means this molecule, this molecule will never mix.

In reality what will happen, this molecule because of some disturbance will come back

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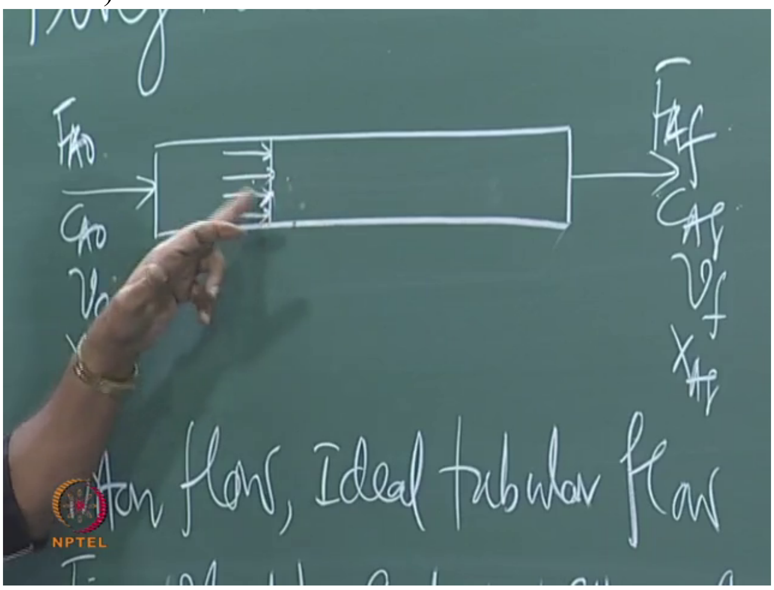

and then mix with this molecule. That is not allowed in plug flow. Simple example is conveyor belt.

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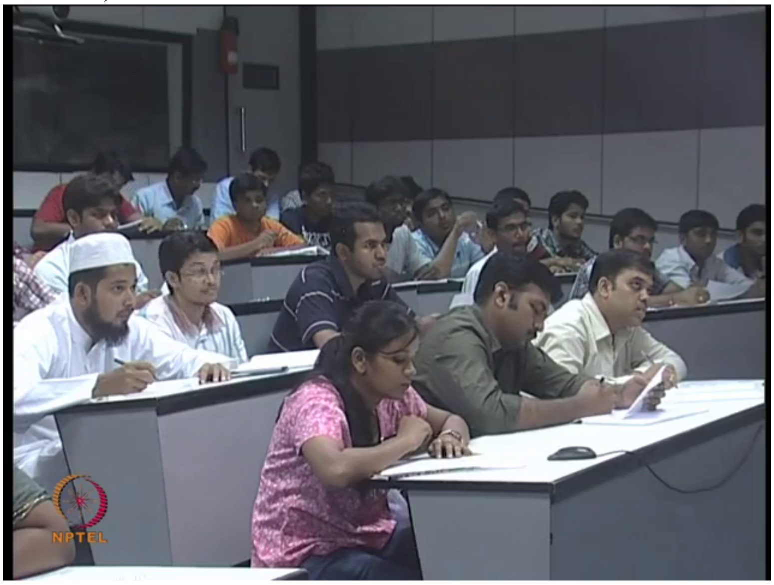

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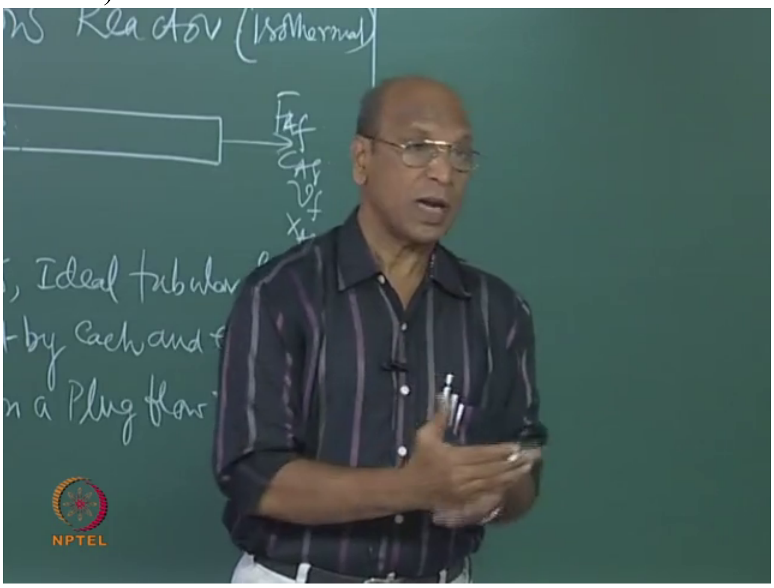

But that velocity is with respect with what? Velocity of the conveyor belt is with respect to what? There must be some reference no? Ground.

With respect to ground may be the velocity of this conveyor belt is 5 kilometers per hour. Ok. The other is normal walking speed that is why. And yeah, and all of you are standing there, just and behind you also there is another row, three people, behind you also there is another row, I am talking, I am imagining you as molecules, so 3 molecules, 3 molecules, 3 molecules, in reality there will be millions of molecules but only just for imagination we are telling only these 3 molecules just standing there and then just you are pushed on, pushed by the conveyor belt where that is equivalent to for us here convection, the flow.

So this flow is simply pushing the molecules without any disturbance simply like that. Ok. So then in first minute your color changes to green.

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Your normal color, this color, Ok (laugh). So then after, another minute,

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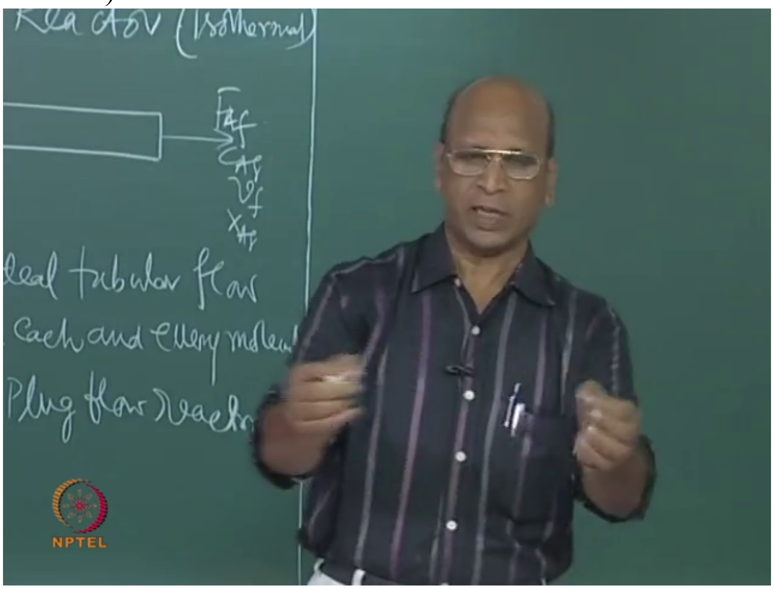

then it becomes red. After another minute it becomes green, sorry orange.

So like that by the time, end if you go, you may get purple color or something which is equal to 100 percent convection, right? Easy imagination no? Now at any time when I look into this and I look into this, people standing here will have red color. All of them are uniformingly have red color,

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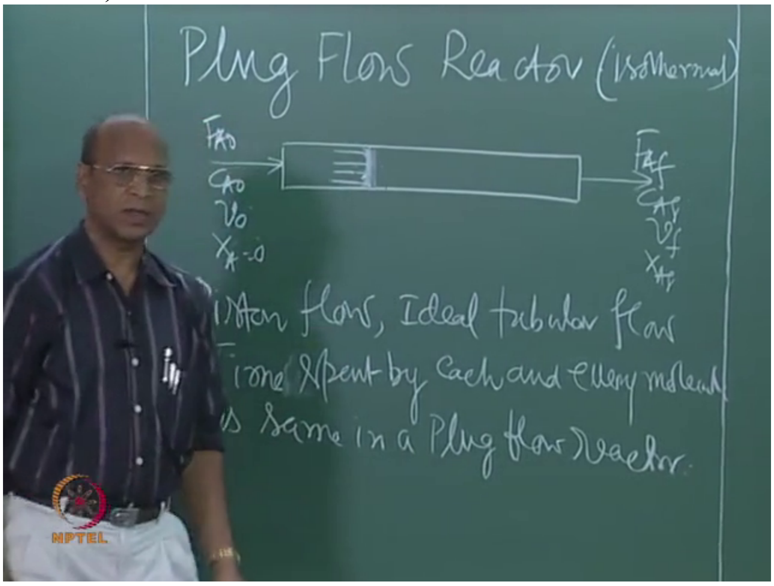

Ok. What is the meaning of that?

That means the concentration, if you, if I imagine that color as concentration, all that color is same for each and every person and the concentration is same, yeah at that point, at this point so that means what is the assumption we are giving without

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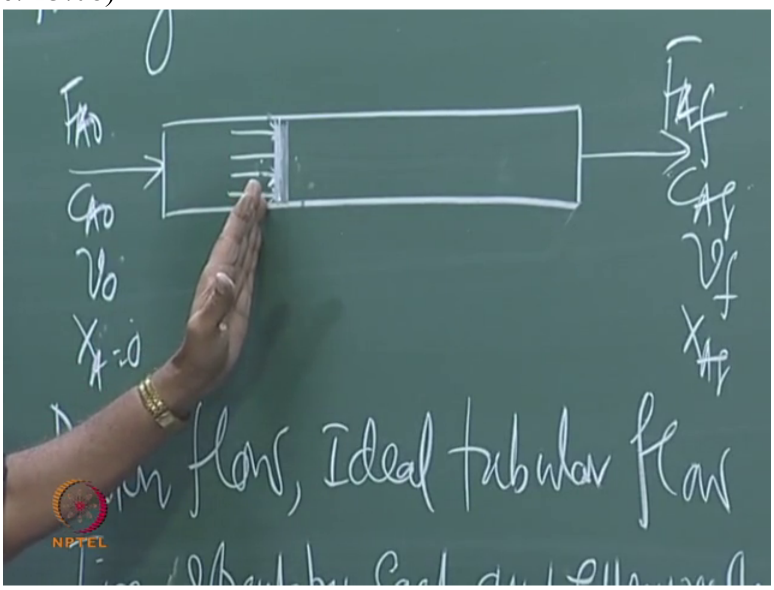

knowing also? That the radial mixing must be infinity we say, yeah 100 percent or infinity we say. What is the meaning of that?

Yeah there is no change in the concentration and that is happening because all the molecules entering in that row just moving are uniformly converted, not for 100 percent.100 percent conversion is not occurring. At this point it may be 30 percent but uniform. At this point it may be 60 percent still uniform. At this point it may be 90 percent still uniform. This is 100 percent, if you get 100 percent conversion.

So that means whenever I look at the reactor across the cross-section, lateral direction we say that we have uniform concentration. When do you get uniform concentration in a mixture?

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Yeah, yeah exactly. When you have perfect mixing, then you

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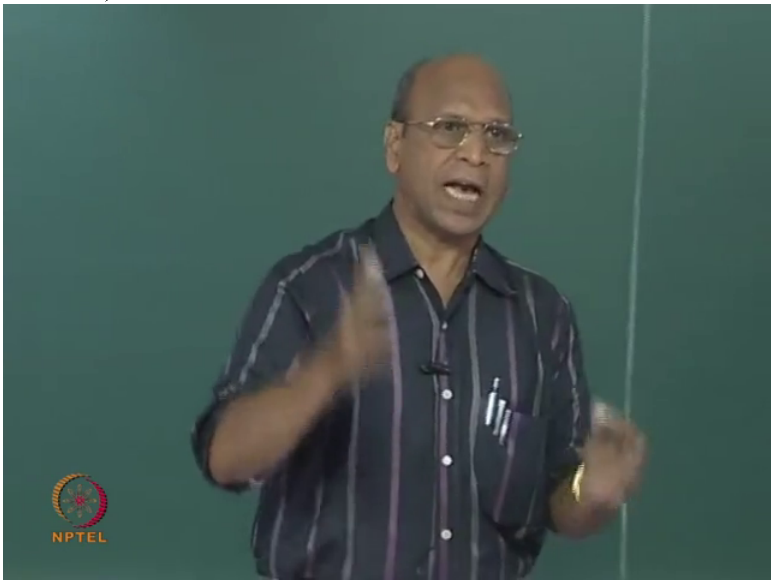

say I have mixing throughout the reactor same. So that is the reason why even here at any cross-section we say that we have perfect mixing.

And in other words we will also say, because we are saying zero there, the axial mixing, this direction, Ok, the axial mixing is something like this,

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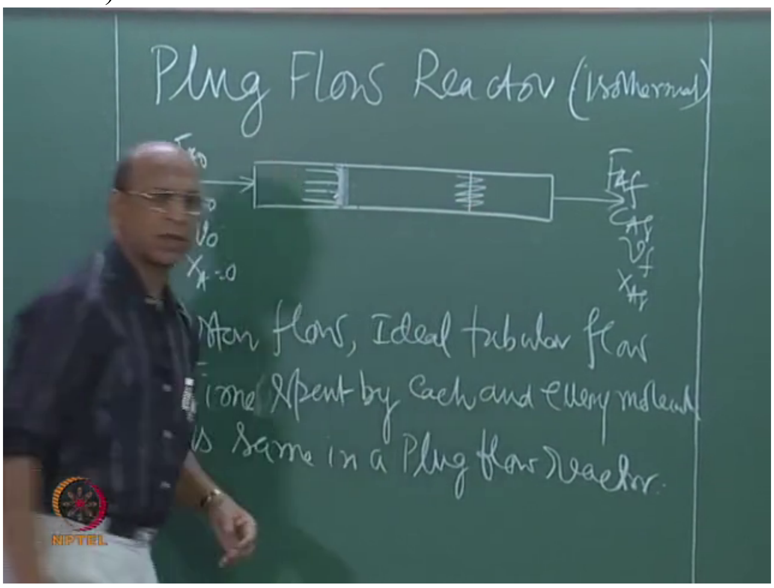

right. Some molecule is here, again it will come back. Some molecule is here, another, again it may come back; molecule here, again it may come back. Same molecule

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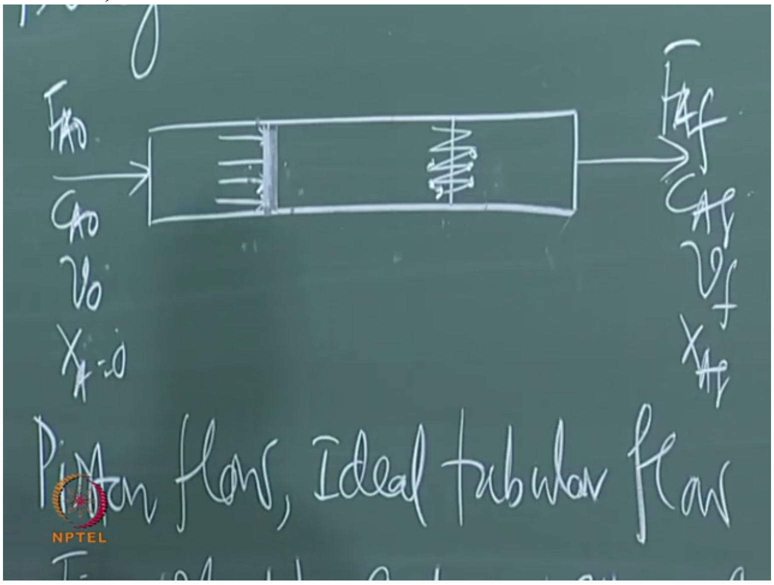

may be coming backward and forward.

So that means this is mixing with molecule which has entered a little bit late and again going forward, and again coming and mixing with some other molecules which have just entered there. So all that mixing is called axial mixing, axial mixing

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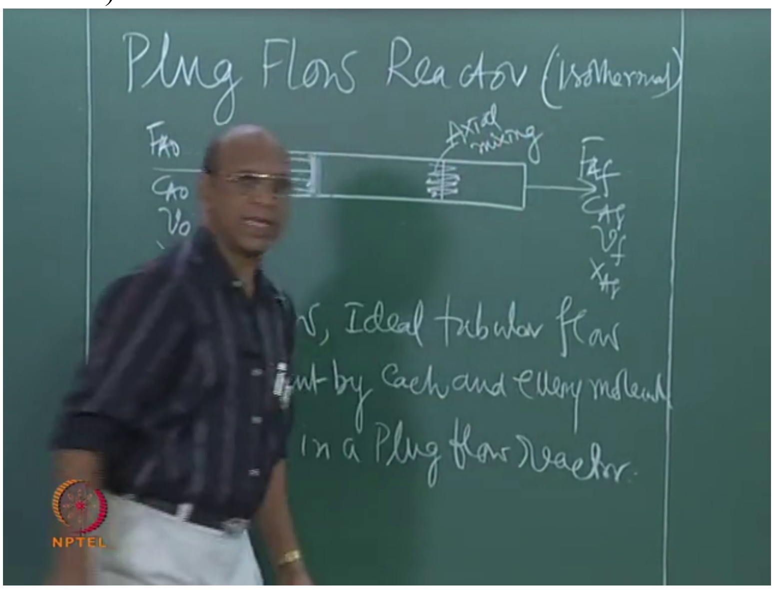

but in plug flow we say that it is not allowed. Ideal condition.

So now what we say is we have this axial mixing equal to zero, in fact which means that radial must, radial mixing must be infinity. We do not have to say again. But we say axial mixing is zero, radial mixing equal to zero and then what are the other things you said?

A flat velocity profile. Unless you have the flat velocity profile all three conditions will not be satisfied. But three times we reiterate. Ok, axial mixing equal to zero, same thing as radial mixing equal to infinity. These two can happen only when you have flat velocity profile. All three can happen only when you have time for each and every particle exactly same.

So that is why the basic definition what we would like to remember is the time of each and every particle, Ok, yeah, why they are same means without any disturbance in the sense that all these molecules...

Ok now we will expand our imagination slightly more. Now I will say that I am now feeding the molecules continuously but these molecules I am sending in the form of packets. Each packet may have some molecules where there is some concentration and all that.

So that means at time t equal to zero I imagine these are the molecules

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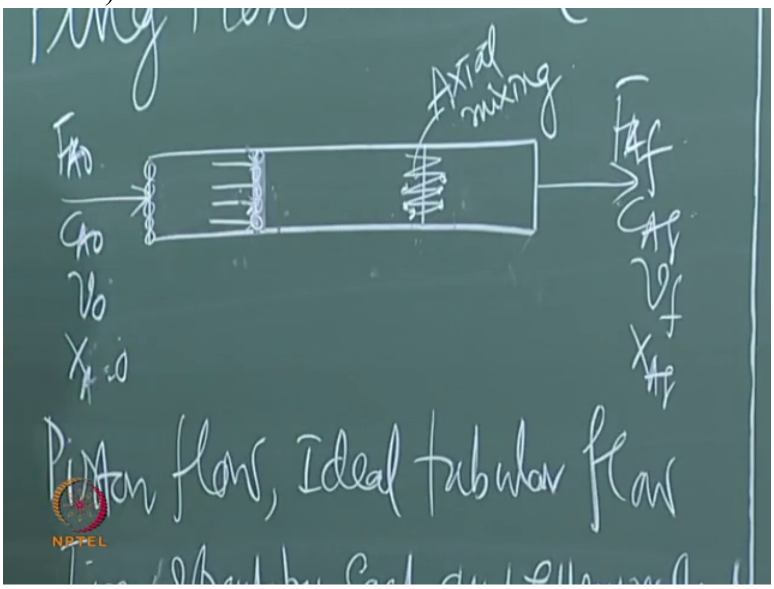

just entered, Ok. These are the molecules just entered. So now if we accept this definition, like axial mixing equal to zero, and radial mixing equal to infinity, and of course the other one what is that, flat velocity profile, all that if I assume, then the same packets will move from here to here.

Each packet now we can imagine as a very small batch reactor. Inside that batch I may have good mixing and all that, Ok. So our imagination we are making smaller and smaller and smaller and smaller till individual molecule.

But first let us...I started with molecules but let us imagine that we have small packets and in that packets the reaction is going on and this, we are not allowing them to move forward and backward, and, that means axial mixing equal to zero which also means that radial mixing equal to infinity. Then at this point, what is the conversion in each and every reactor, that small batch reactor?

Conversion. It is same. And that conversion depends on how much time it has spent inside the reactor. If it is one minute, some conversion, 5 minutes some conversion. Let us say total time is 10 minutes required. For 10 minutes you may get 99 percent conversion. So at the end, if I see, oh they have not become bigger, same, yeah they may become bigger under some conditions also, Ok, same size, yeah, at this point if I look, each and every

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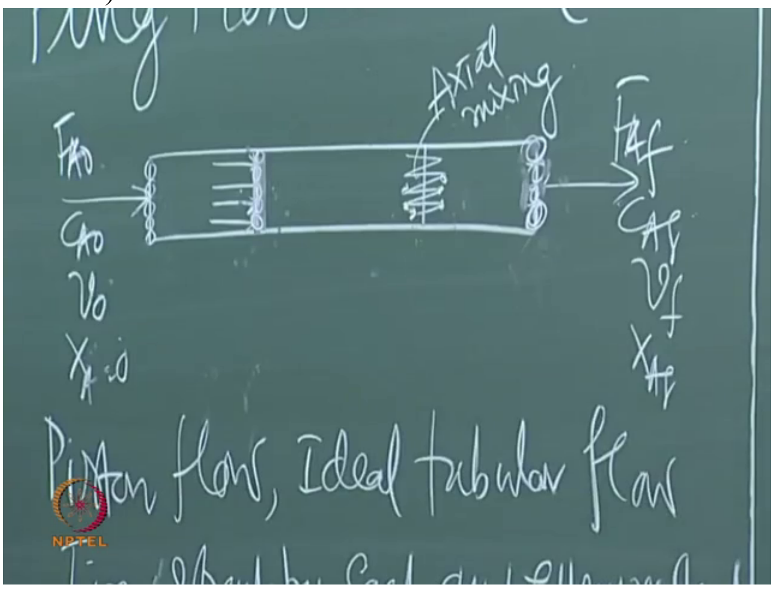

packet also will have exactly, Ok.

So slightly relax our, I think this is clear now? Yeah the turbulence and all that when we say, when you know you may have that very high Reynolds number you have turbulence. What do you mean by turbulence there? It is not the turbulence we are talking when a molecule here can suddenly jump here. A molecule here can suddenly jump here.

That will happen if I have a tank reactor. If I have tank, like batch reactor we have studied. So batch reactor you take and then you put all the reactants and then start stirring. Can you identify its location? You cannot because one molecule may be momentarily at the bottom of the reactor, because of mixing suddenly it may

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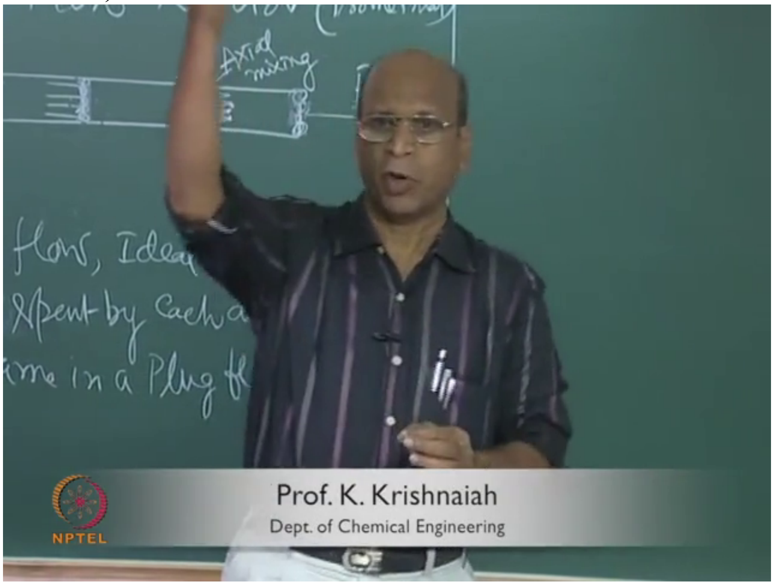

come out.

Or again because of mixing it may go to one corner. And again you know another corner. Like that, at any time, any point of, yeah at any time inside the reactor, at any point it may be there. In fact that is the definition of mixing. You cannot say that... yeah I will come...you cannot say that I have mixing but molecules are not moving. Ok.

So then when we say that we have perfect mixing the possibility for the molecules to move from anywhere to anywhere is possible because of the mixing. Yeah Abdul?

(Professor – student conversation starts)

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Student: We know that reaction happens by collision of molecules. And in plug flow it is highly limited. There is lesser conversion; there is lesser collision of molecules.

Professor: Why do you say that there is lesser collision of molecules?

Student: Let it deviate from plug flow and let it come, let there be actual, actual mixing

Professor: But why do you say lesser collision? I think you say that

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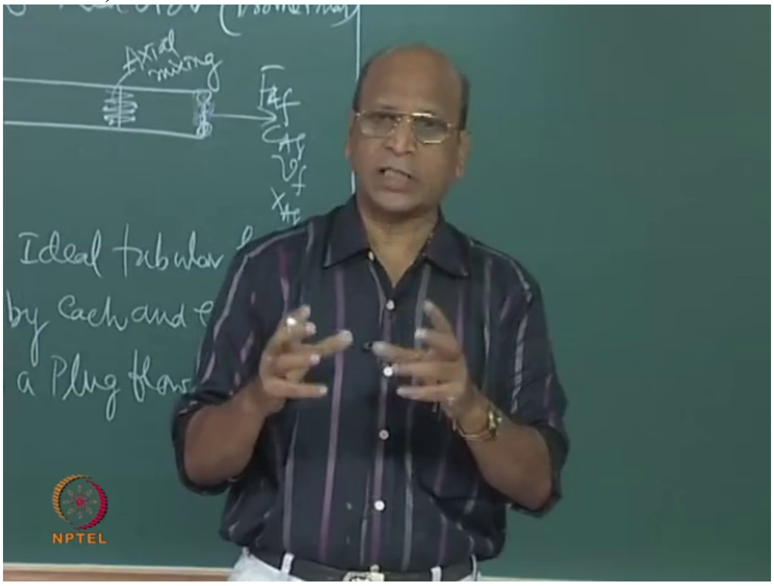

the collisions are there only when you have tank reactor?

Student: They will be some lateral mixing, Sir but...

Professor: Yeah but even here, at the molecule level, what is the size of the molecule? How many molecules you can put in one inch pipe diameter? So there, yeah, so there is again you know those collisions and all that is there definitely. But that is not this way but only this way. Why only this way, only why this way? Because the flow is so good that it is not allowing anything to come back. Any molecule is not allowed in this direction because of the convection, velocity, push.

Student: Then if possible we can allow it to even have axial mixing? That is better conversion.

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Professor: That is bad actually. Because if I have a, yeah I think that is a good question also because so that others also will learn that. If I am allowing a molecule

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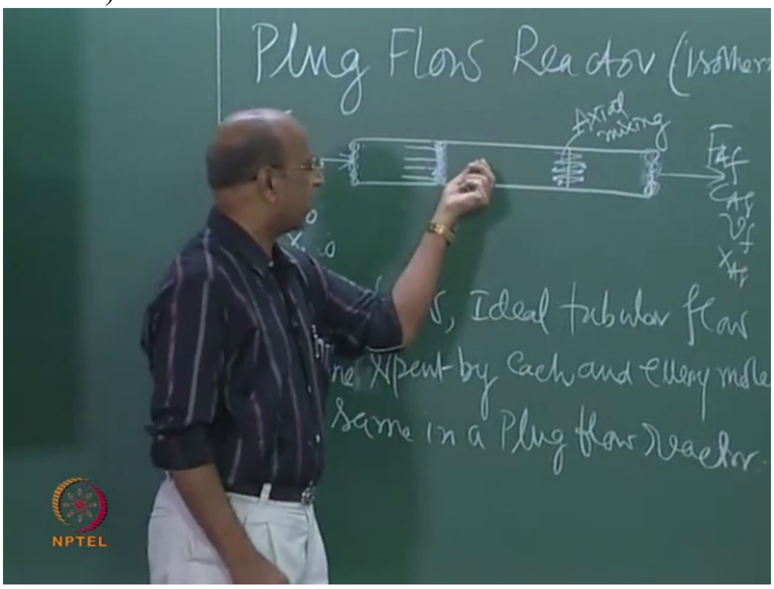

which is already converted with the molecule which is not converted, what is the concentration now?

(Professor – student conversation ends)

We cannot say one molecule, but few molecules here, they are converted 50 percent, suddenly they come and join here, mix, right so then they are coming and mixing with these molecules. These are 25 percent or 30 percent converted. What will happen to the concentration now? It will go down.

And what will happen to rate of reaction? It will be down because I think rate is a function of concentration, C A, first order if you take, very simple imagination, directly proportional. So that is why the concentration falls. This is the reason why the mixed flow reactor is inefficient, correct no?

We know that if I take 1 meter cubed mixed flow reactor, 1 meter cubed plug flow reactor, 1 meter cubed mixed flow reactor will give me low conversion, because volume is fixed. And 1 meter cubed plug flow reactor will give me high conversion, you know why? Now at least the reason?

The reason is because of that mixing. That is why here that same collisions are taking place but that is only in that restricted region.

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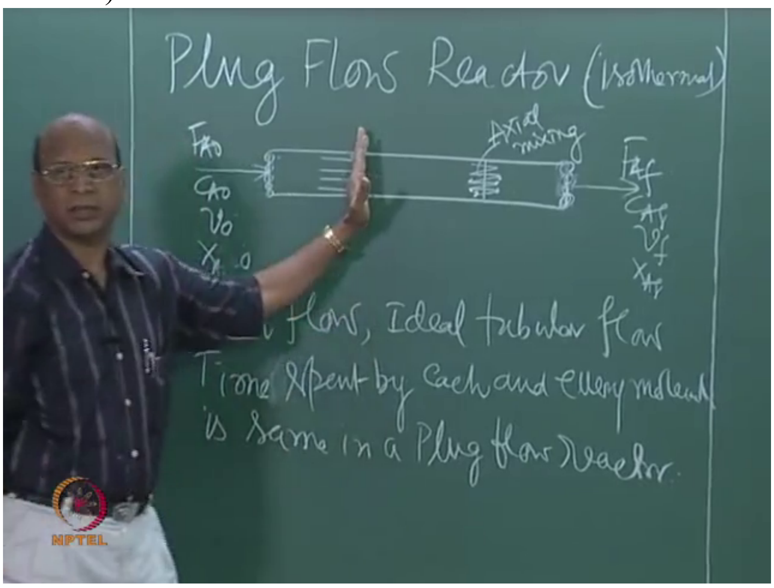

Theoretically speaking it is very, very thin infinitely small region, not at molecule level we are talking. Molecule levels are very, very small.

Ok, so that is the reason why we say that, yeah, the plug flow reactor is more efficient than mixed flow reactor because mixing always, you know this is what, many students will have this imagination that mixing is better for reaction. No, mixing is bad for reaction.

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Ok. Perfect mixing is bad for reaction. But you are allowing the, you know....

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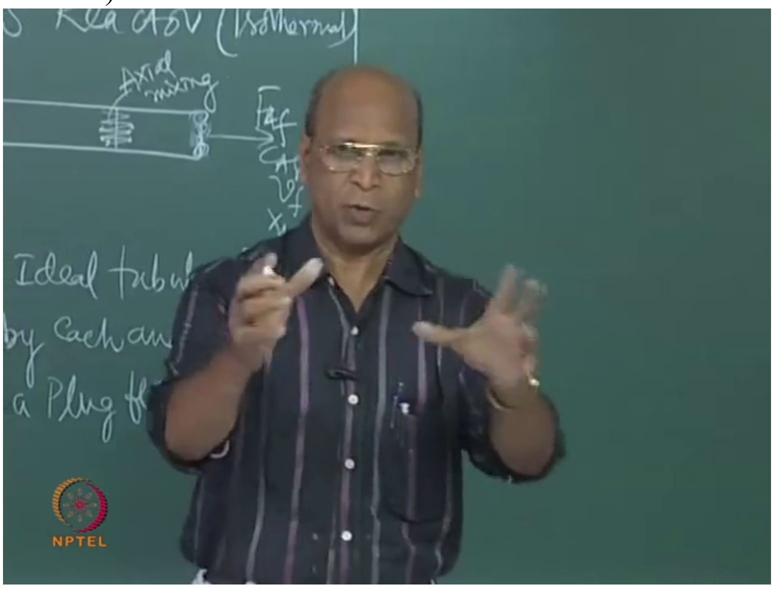

again do not get confused.

So even here, in this cross-section I have perfect mixing. So that means at this cross-section I have the same concentration for each and every packet, because molecules we cannot say and then say concentration. Molecules are so many moles per unit volume only; that is what is the concentration. That is why

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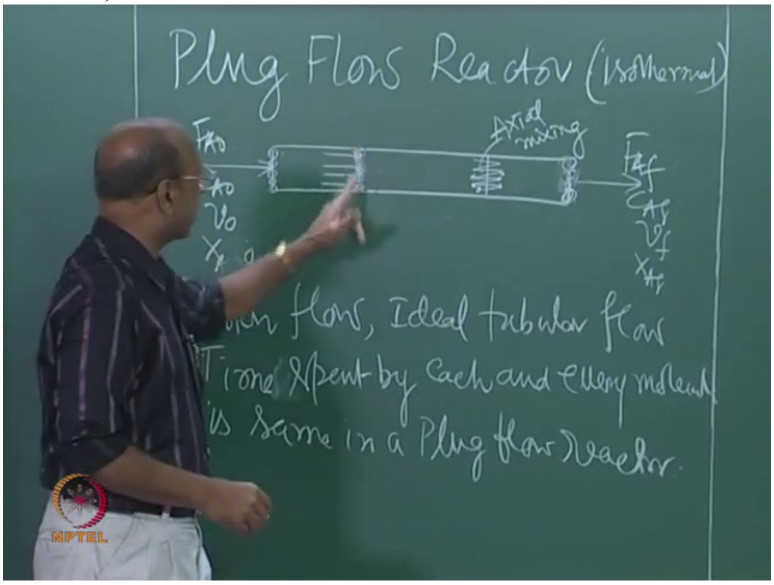

this concentration is not diluted here in a plug flow.

You already told me, no Sir the concentration slowly changes, Ok. Very good. That is the definition of also plug flow. Slowly means how slowly? At only each and every cross-section only that concentration is changing slowly. Not across, Ok. But definitely, at this point, means I have a different concentration. At this point I have a different concentration.

So that is why when I plot this graph, concentration versus length, this is the length,

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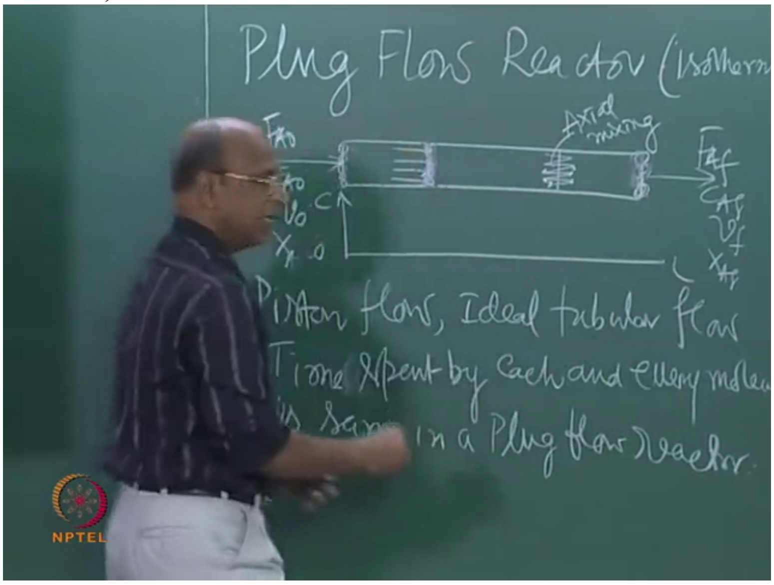

then we will have, this is C A naught.

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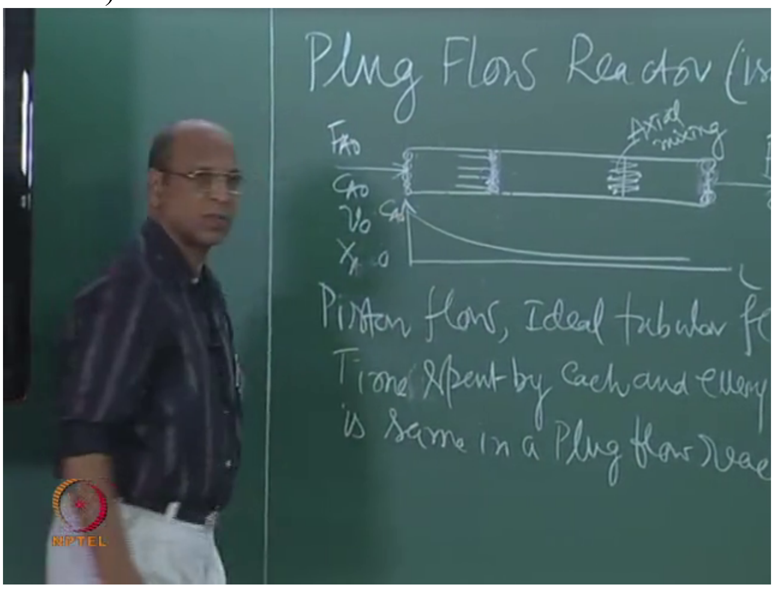

It slowly decreases. And you also know that, I mean as we already discussed, that mixed flow reactor is better than, sorry mixed flow reactor is less efficient than plug flow reactor. We discussed that.

The reason is this concentration; it is slowly decreasing depending on

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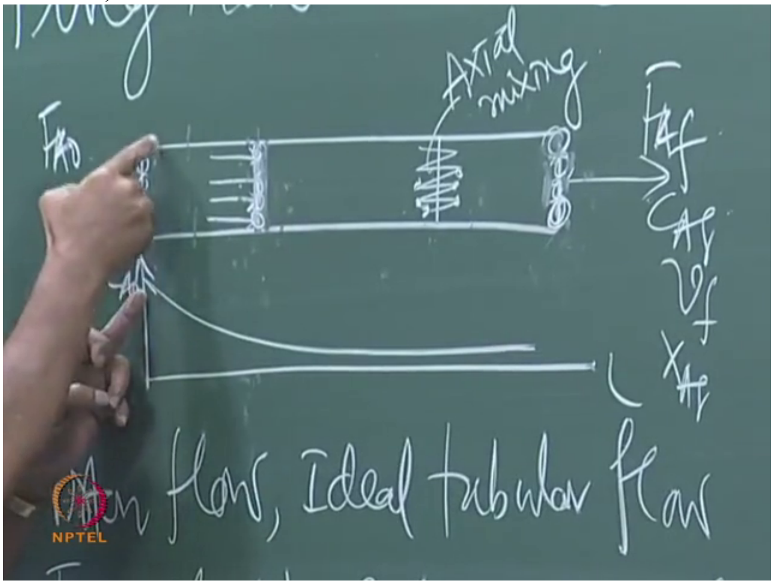

its time here but across one cross-section. So now next you have another cross-section. Ok, another concentration, next another concentration. That means at every point this rate, rate is maximum here because assuming ideal, I mean, non, isothermal reactor I have first order reaction, k into C A naught is the rate. Or C A is the rate.

At time t equal to zero, just when it entered, what is C A naught? Highest. So that rate is more. Ok. I am talking of simply A going to R, first order reaction. Then slightly inside now, it is k into C A but

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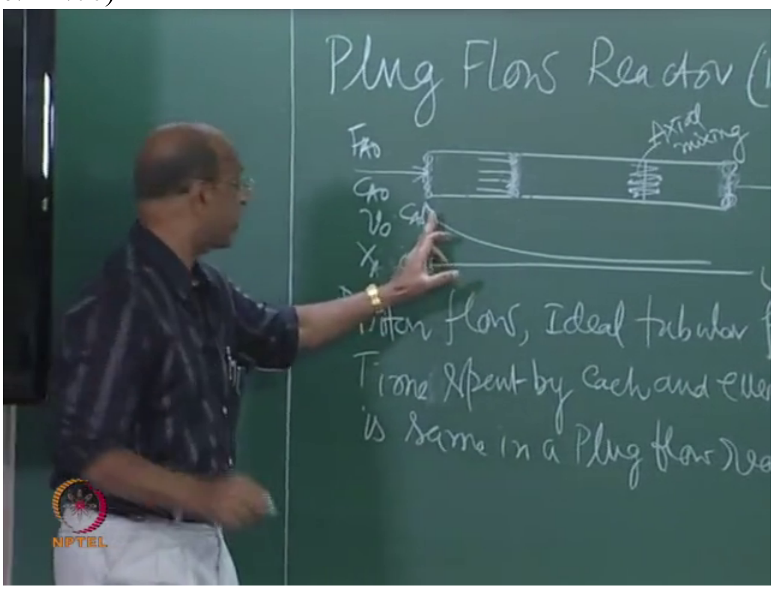

this C A is highest, Ok. Highest means it is not highest, not more than C A naught but next, to next one it is highest. So like that slowly, it is, the concentration is decreasing.

When you have slowly, the concentration is decreasing, the rate of reaction, you know then that means I have one rate here, one rate here, one rate here, one rate here, one rate, one rate, one rate so many rates, right? So all those rates when you average them; that only gives you the overall conversion.

Ok but that is why the concentration of each and every, I mean at each and every point very

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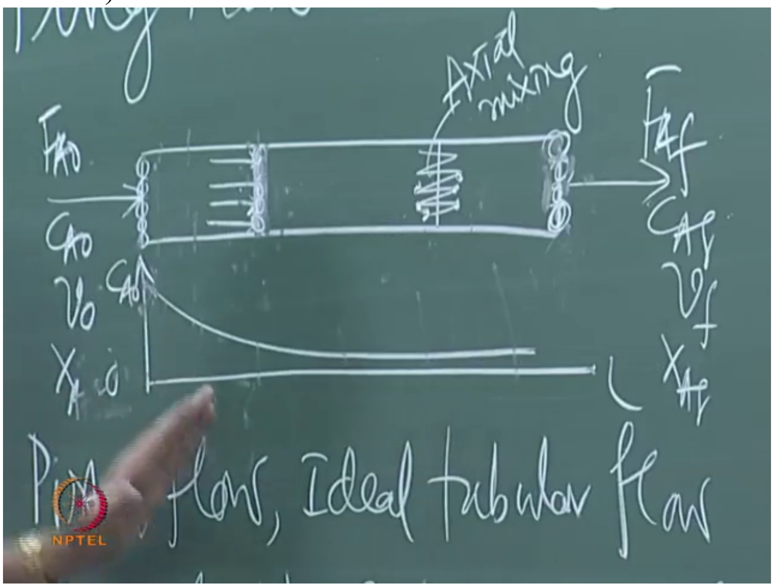

optimally used in a plug flow reactor. Whereas mixed flow reactor, you are taking a, one tank and then continuously putting water, I mean reactants, continuously you are taking out. Stirring is there, perfect mixture.

So the moment you put C A naught, then yeah, then it is suddenly mixing, instantaneous mixing, because you have perfect mixing. What is the meaning? Everything is instantaneously mixed. Now when you see the instantaneous mixing, do you see C A naught at all? Then you see slightly less than C A naught? Yes Sir? Yeah, how much slightly?

(Refer Slide Time: 25:25)

What concentration you see in the reactor?

(Professor – student conversation starts)

Student: outlet concentration

Professor: Yeah, it is the outlet concentration, and outlet concentration is how much? 90 percent.

(Professor – student conversation ends)

So your C A naught

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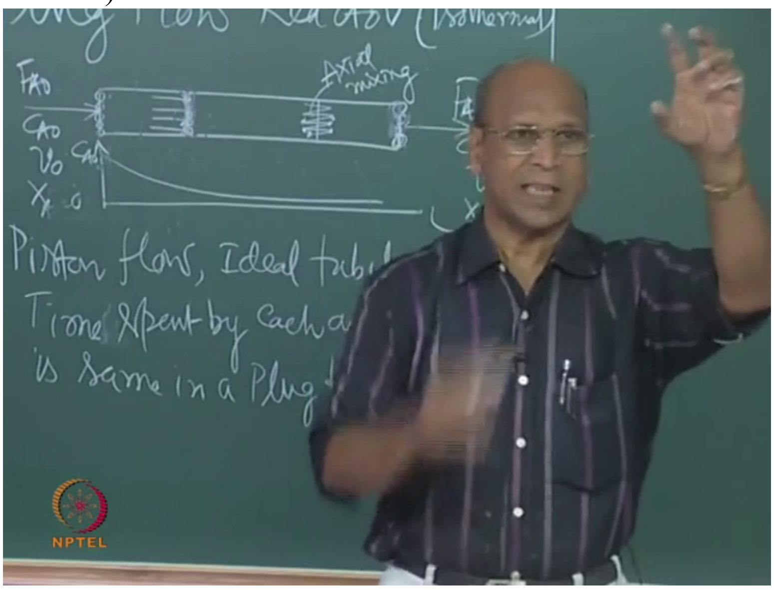

is suddenly decreased to 90 percent concentration which is equivalent to your outlet concentration, right? So that means all that concentration history gone. Like here. I have concentration history. At this point, say, Ok, if this is 10 moles per liter, 10 moles per liter, this will be 9, Ok. This will be 8, 7. So at this end I will have 1 mole per liter.

What is the conversion? 10 moles to 9, conversion equal to 90 percent, right? So now yeah, but that 90 percent occurring here through so many rates, correct no, because concentration here different, concentration here different so that will have a rate, that will have a rate, what you see is the overall effect of that concentration at the end.

Whereas if you go to mixed flow reactor where you take the tank and then just put, let me also, because for discussion I think I have to give this, yeah, continuously this is entering, continuously you are taking here. So now here I have C A naught, here I have C A f and by perfect mixing assumption which is simple assumption, this also

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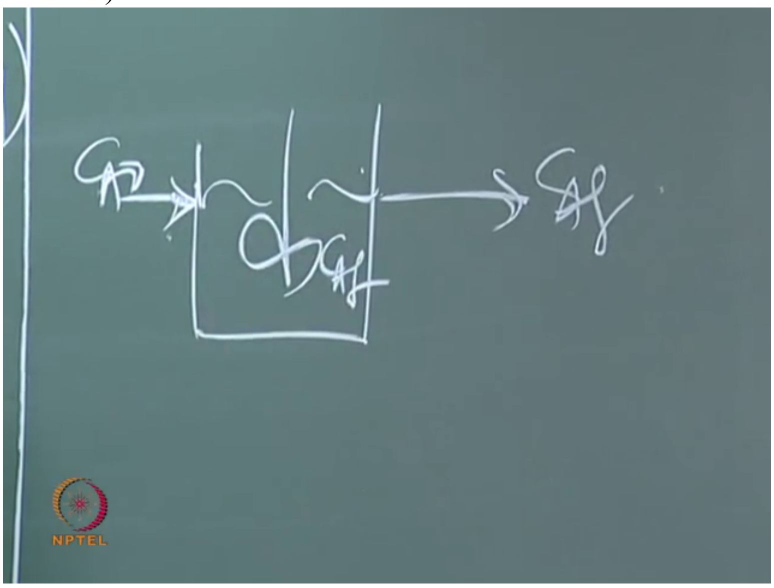

C A f.

And now you see there is no temperature history at all. Yeah, what is the plot here? Concentration versus, C A naught versus, Ok, length?

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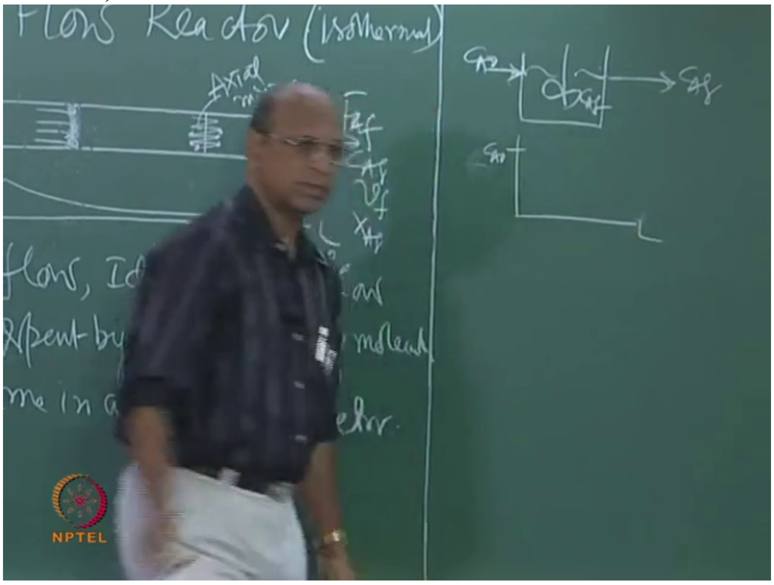

There is no length actually but I think you know space coordinate, so what is that much now? Like this and then you have

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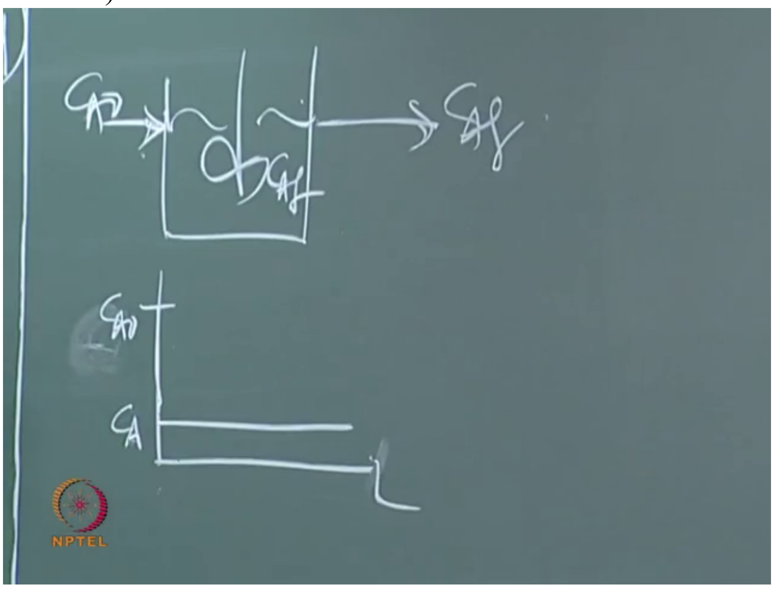

C A f.

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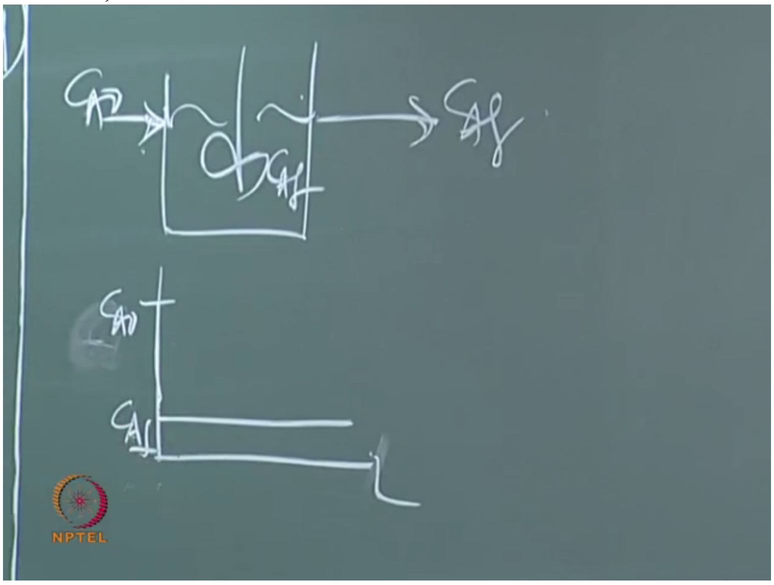

So all temperature history totally gone there. That is why to maintain these conversions, because given a volume, given volume this conversion will be less. This will be more, right. But to compensate, let us say that you want to also get the same conversion like this, where concentration maintained, concentration maintained, every rate, all rates are averaged and you are not averaging. System averages and gives you finally so much conversion there. If you want to compensate what you have to do?

(Professor – student conversation starts)

Student: 0:27:53.7

Professor: No, no that is different. The same one reactor, you should go for larger one, bigger one.

(Professor – student conversation ends)

So that is why, you see, you do not need any mathematics. Simple logic we know that the volume of the mixed flow reactor will be definitely larger than the volume of plug flow reactor for a given conversion, that you have to always say, for a given conversion.

For a given volume, the conversion in plug flow reactor will be more than C S T R, Ok, good. So that is what is the plug flow and that will happen only when each and every particle exactly moves like that. And now I will give you another example, as I told you that you have, you know, heterogeneous system I told you.

You know the coal is burnt using moving grates. I do not know whether you have heard or not,

(Refer Slide Time: 28:46)

coal, coal for combustion. So that will be something like this. You have a wheel here, which will be rotating, another wheel here which will be rotating; over this you have the conveyor belt. So this moves like this, comes out and then moving. So here I will feed coal.

Continuously I am feeding.

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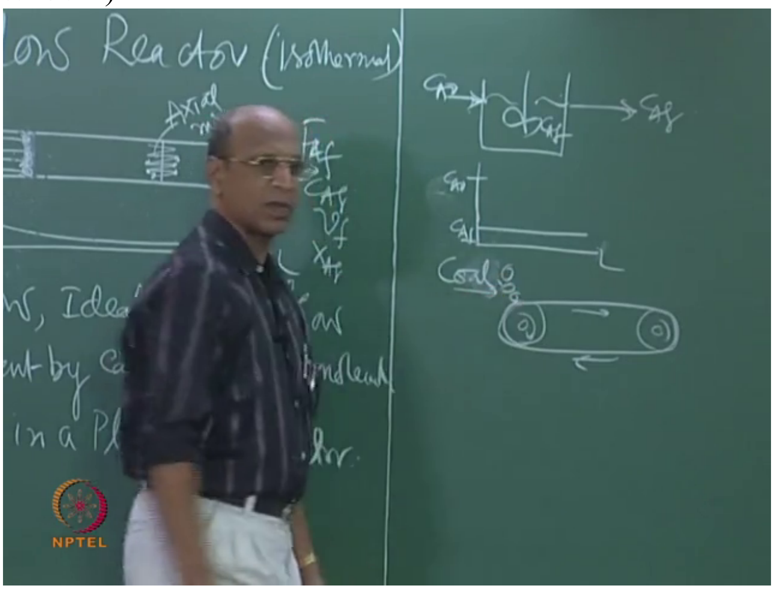

And I will now calculate what is the time required for each and every, let us imagine that every particle is 1 centimeter, easy to imagine, Ok, 1 centimeter uniform size, right? So all the particles are coming there and then by this time this comes here,

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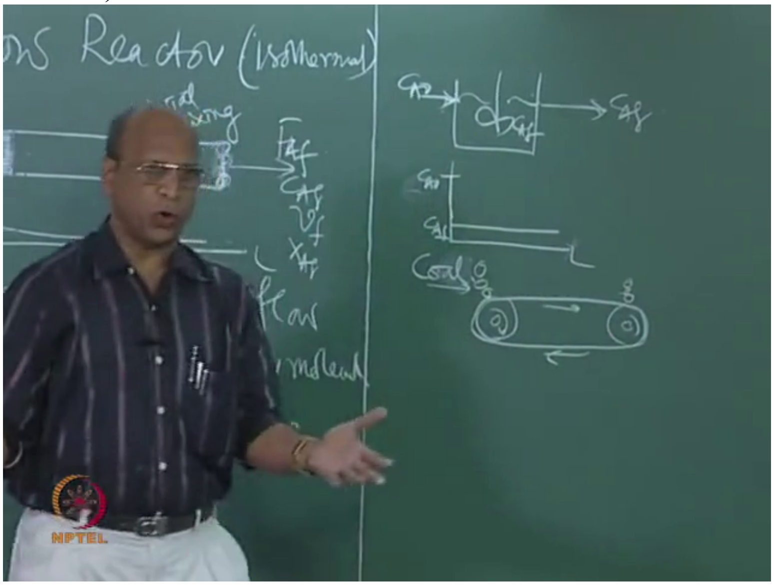

if it is pure coal, you do not have anything, you do not have even ash.0:29:36.6

Ok, ash you will have you know whenever you have some silica, or minerals and all that. Then only you will get ash, otherwise no. So that means each and every particle is entering, coming here, by this time at this point the particle completely disappears. Right?

Because you have now fixed the space, the, not space, the speed of the conveyor belt Ok, at 50 percent of the time,

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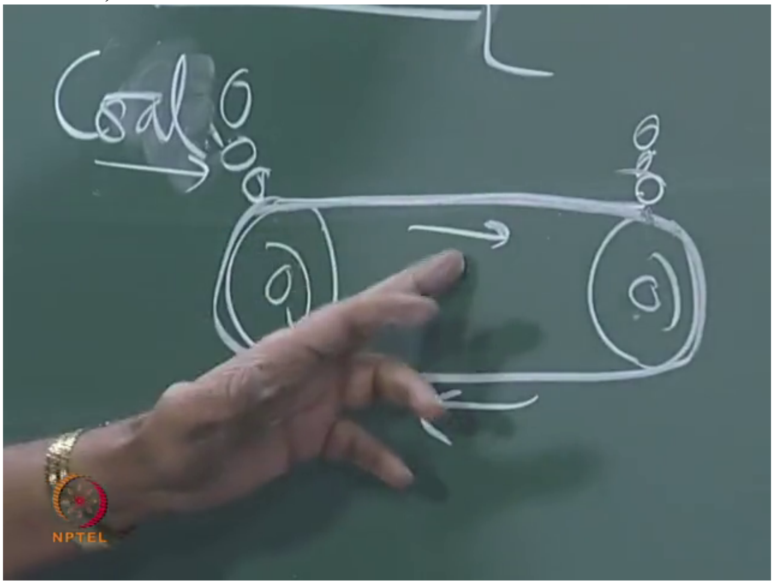

that means you know if the total is let us say 5 minutes, at 2 point 5 minutes at this point each and every

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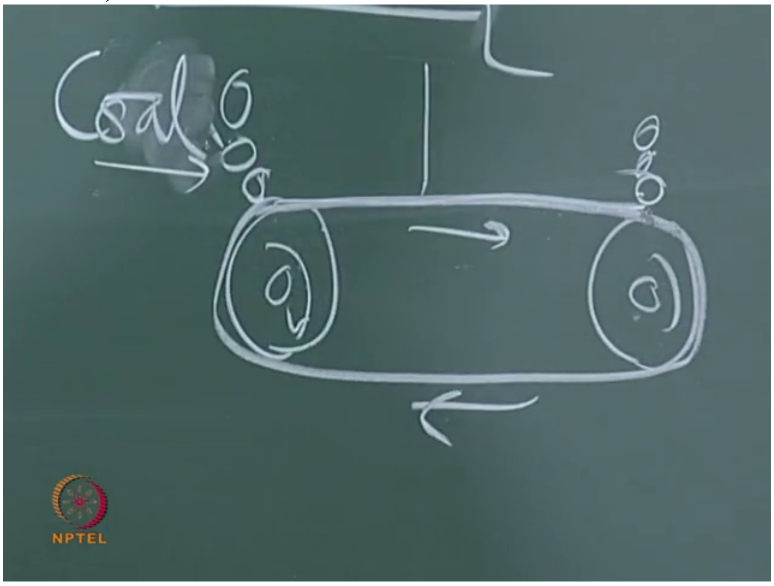

molecu/molecule, each and every particle would be uniformly converted, right? Uniformly converted.

Then when I look into this direction that means the, yeah, so this third dimension, this flat rate no, this is moving like this, Ok. This is moving like this. This is what the distance I told.

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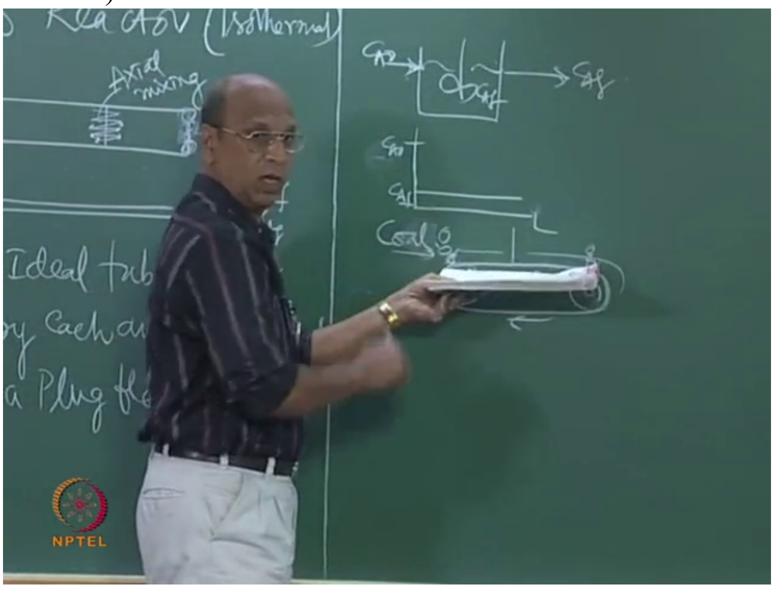

So now at the middle if I just see here, I will have the conversion of the carbon particles uniform throughout.

So at this point if I draw a line and see the concentration what do you say about that concentration? Same that means radially you have same concentration, uniform concentration. That happens because of infinite mixing. See that is what is the meaning of infinite mixing there. Because you know, it is only uniform concentration.

Normally when do you imagine that we have uniform concentration? When you have mixing. So what we say for axial direction is, the mixing equal to zero, right? And then in the radial direction, mixing equal to infinity. Because you said zero there, you are putting here infinity, right? But in words, it is, the uniform mixing means infinite mixing, uniform concentration means that will only happen if you have infinite mixing.

Infinite mixing means good mixing. How can you provide infinite mixing? There are many words which we do not mean anything, including love. When you say I love you, you do not mean anything. But as I told you, no, love explain to me, what do you mean by I love you? You cannot tell, that is a feeling.

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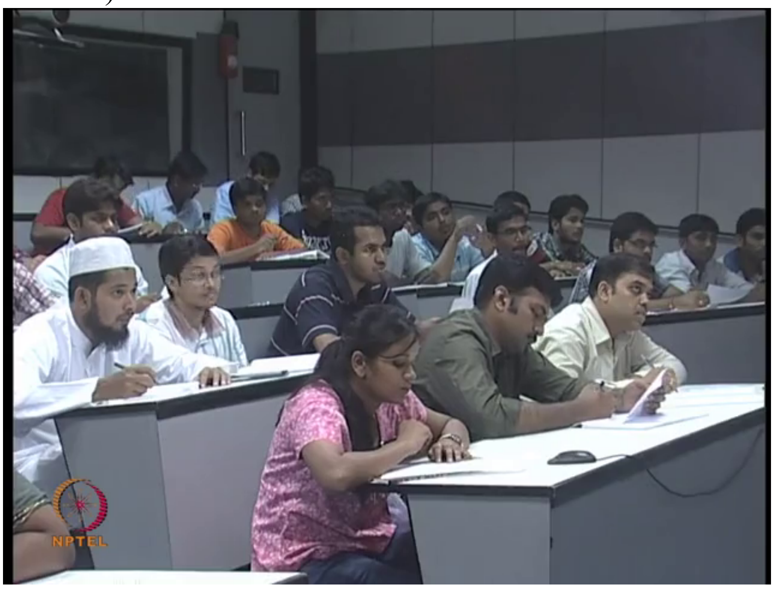

Infinite mixing

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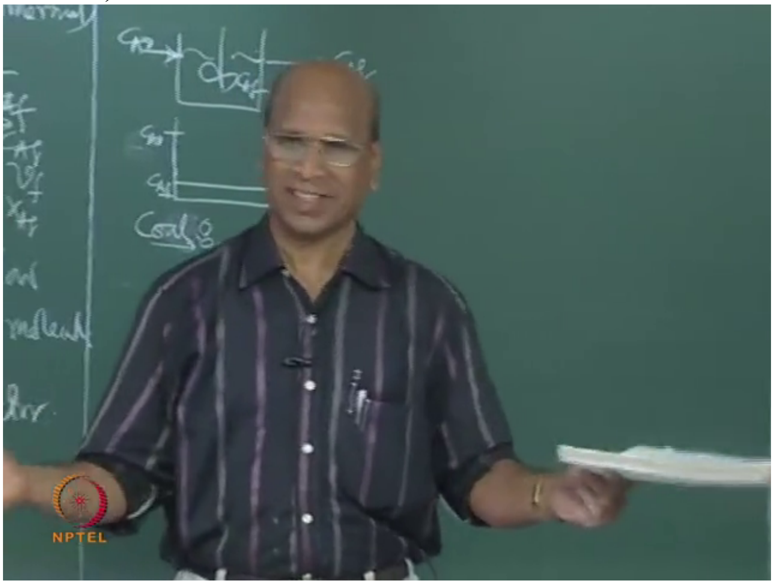

means that is good mixing, that is all, where you have uniform concentration. That is why those words infinite mixing and axial mixing equal to zero, axial mixing equal to zero I will explain. That may be true. But infinity we can never see. The moment you see infinity you cannot come back again. Gone. You have gone to infinity.

So that is

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the problem you know, with these words. But still we use very frequently

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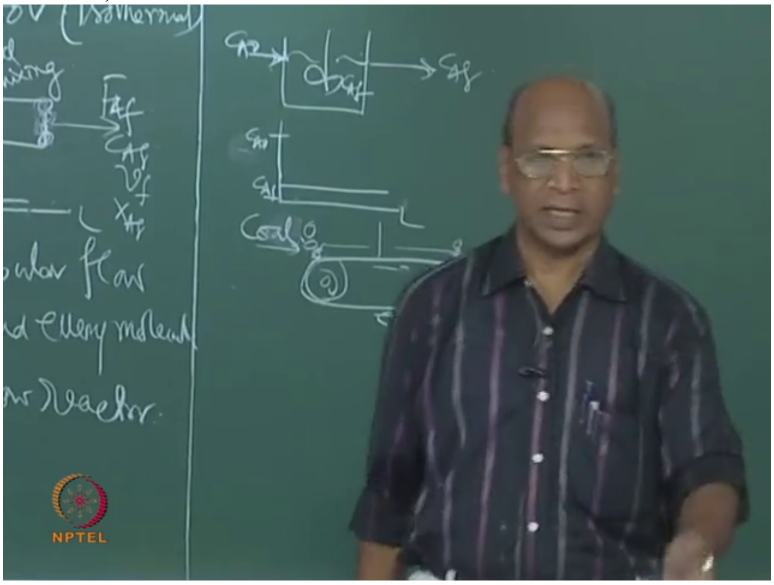

infinity mixing for radial direction, zero mixing in axial direction. Zero mixing in axial direction is explained by this, you know

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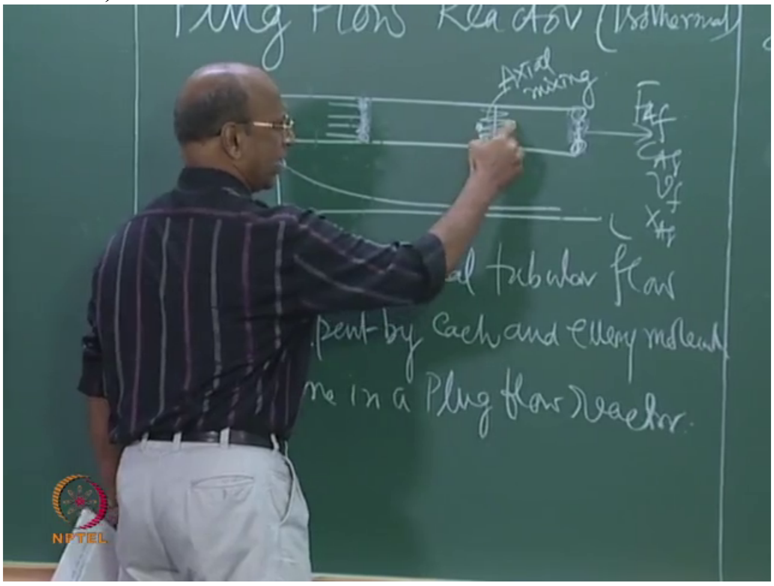

very clearly that this molecule, this packet is not allowed to mix with this molecule, Ok, and this kind of mixing when you have,

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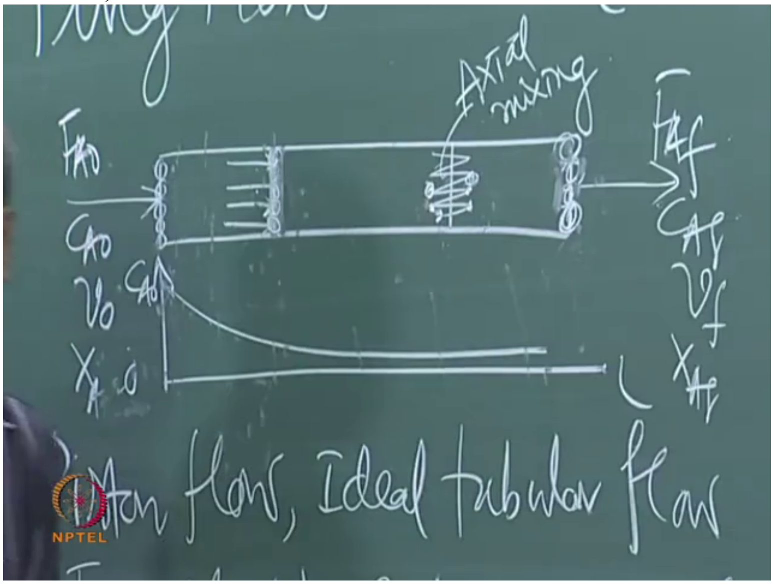

you will not have this condition.

What is that condition? Time spent by, you cannot, you know, have that condition. The reason I will tell you. The same thing, the same mixing is happening everywhere, axial mixing, there is axial mixing so by the time you come here you will also see

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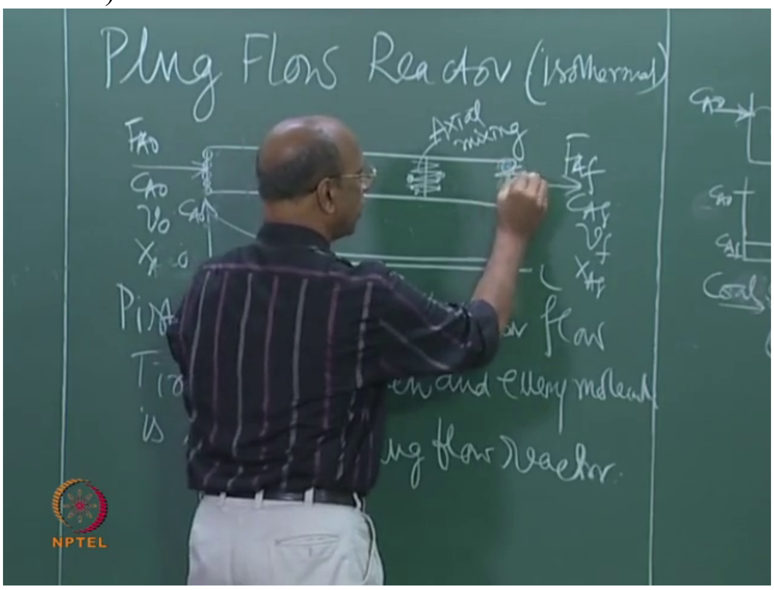

same thing, same thing I am just pushing it there.

So a molecule comes here and a molecule coming here, so each and every molecule

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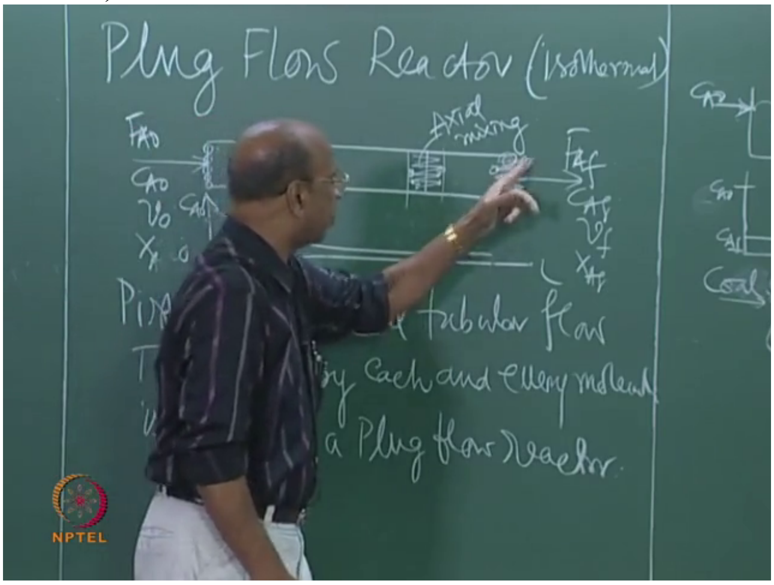

is not gong and mixing with that. Ok. So one molecule which is coming here may come out. Other molecule which is about to leave may come back. So now what is the residence time of this molecule which has gone out and what is the residence time of this molecule which has come in?

And the average of that is 10 minutes. The average of

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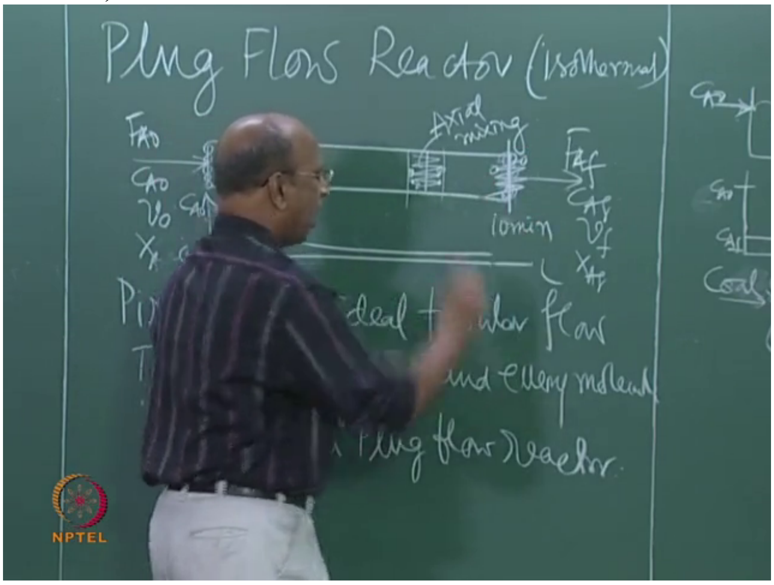

all those times if I take that will be 10 minutes. Correct no? You know, you have seen recently Olympics. 10 people are running. So few people will come faster, some people will come, you know just behind and you add all those things and just take average. So then we know that average run time for that event.

We are not, yeah, that is what is the mean residence time here. Ok.

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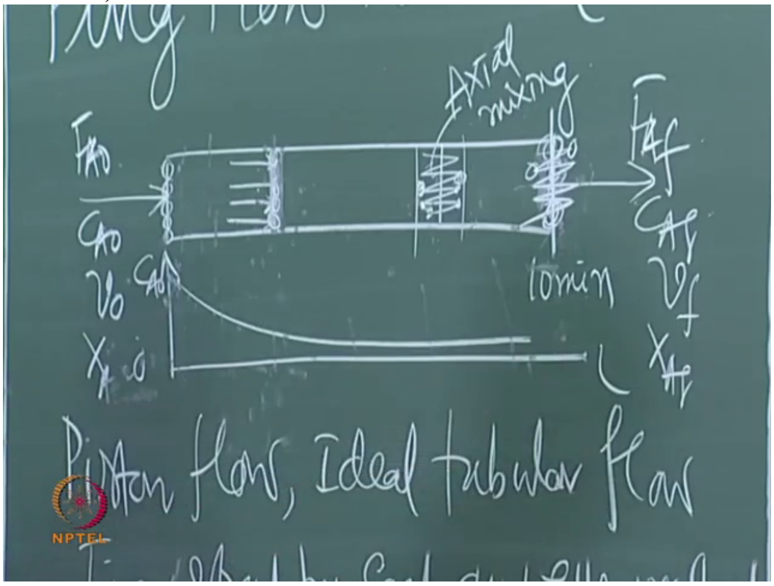

But some people would have come early. Some people would have come late. But now when I have 10 minutes there may be a molecule which has come in the ninth minute itself. And there may be one molecule which has come at twelfth minute

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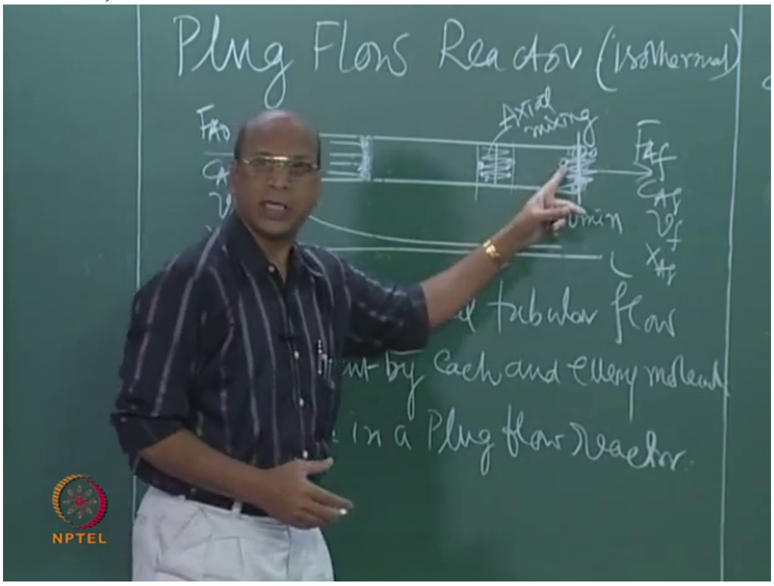

itself here, right? So that is not plug flow.

Why? Every molecule or every particle should come exactly at tenth minute. That is what is plug flow. If you have plug flow in Olympics, you have to give medals to everyone.

(Professor – student conversation starts)

Student: Correct

Professor: Correct, no? All of them are coming exactly at same time.

(Professor – student conversation ends)

But in chemical engineering no, we do not allow that. All of you should exactly come out of the run with the same time. That is what what we tell there. And if you want to have a feeling for this, I will tell, same example. When you are walking, when you are walking, some people may be more enthusiastic people. They may move faster. They will push you aside and then cross you, correct no? So that is why maybe, going another 5 minutes may be 2 minutes before than you.

And there may be very slow fellow who is having diabetes, heart attack and everything.

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So those people cannot move. So he is going behind only, not going forward. So those molecules may spend more time. So

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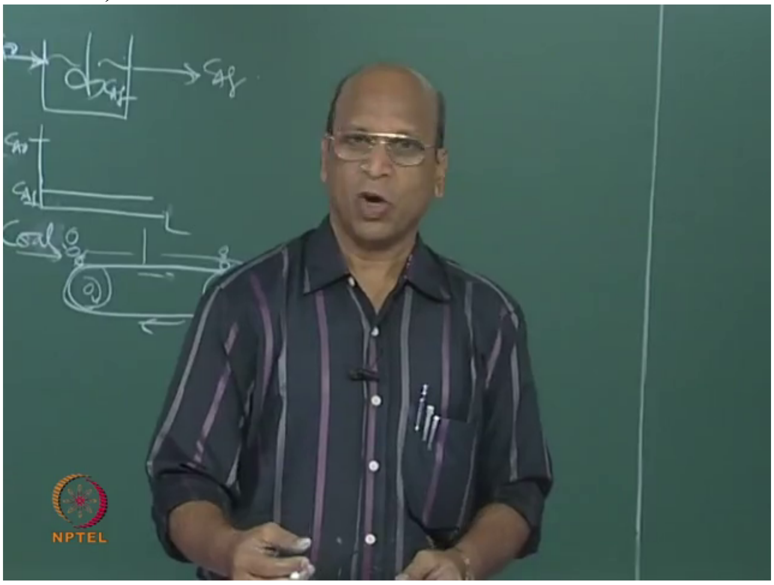

that is not allowed in plug flow. That is what is axial dispersion model.

When you really allow that, because we can allow. We have to allow that. Because in reality you will never have plug flow. Plug flow is only in our minds, as a definition. But plug flow for heterogeneous system this is the excellent example,

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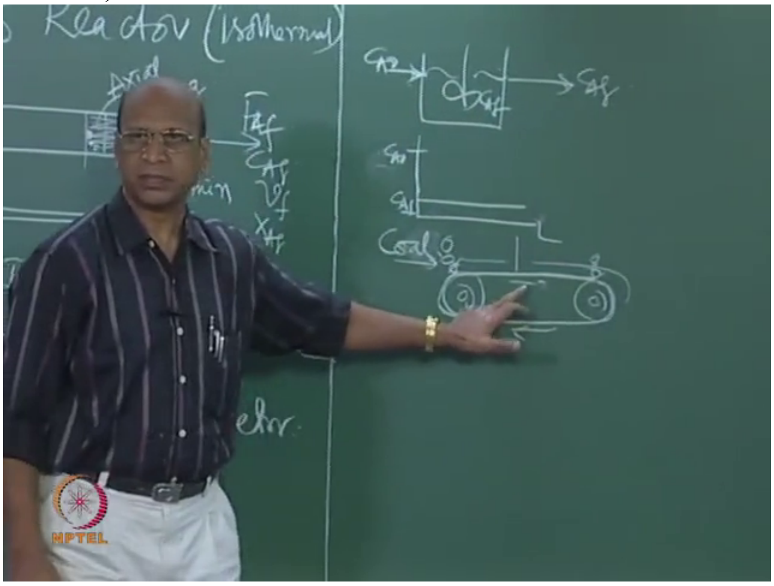

you know, this conveyor belt, coal conveyor belt. Perfect

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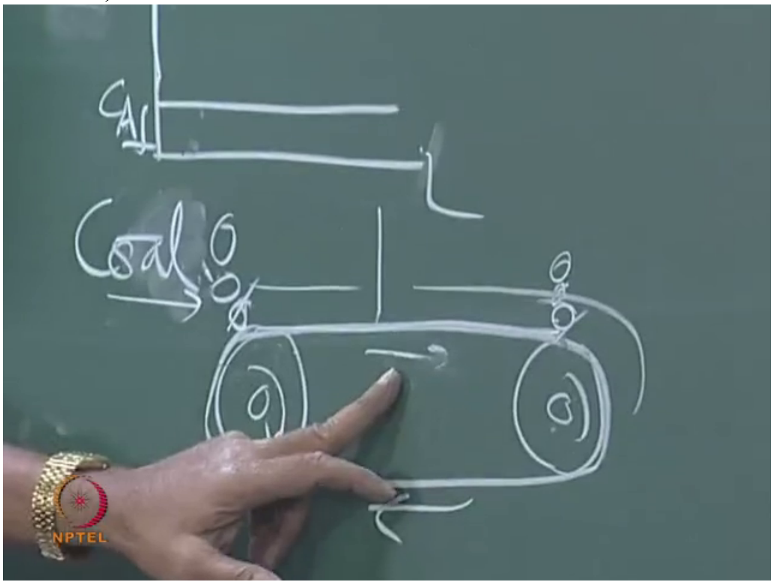

example is only this.

That means you are designing this. And also you know, perfect means I cannot really say perfect because when you are designing this, you should design that without any vibrations, right and without any sagging. You know when you have this side one wheel, this side another wheel, when you put a belt it will definitely sag a little bit, right?

So without that slaggng also you should, sagging also you should design. No vibration. So what will happen if I, vibrations allow this a little bit?

(Professor – student conversation starts)

Student: 0:36:04.1

Professor: Yeah, particles will be coming forward and backward, Ok. So that is what is axial mixing, right. So that is why and that kind of perfect design even for conveyor belts I doubt, whether there is any. That is why I told, plug flow is only in our mind.

(Professor – student conversation ends)

But still that will help us in design, you know very beautifully so that our volumes will be, not exact, but I think it will give one extreme, that Ok if it is ideal condition this is the volume. If it is a real condition like I have, axial mixing. You need definitively more volume, right? Because, because of axial mixing the concentration is decreasing. So instead of 1 meter cube, you may have to use 1 point 2 meter cube.

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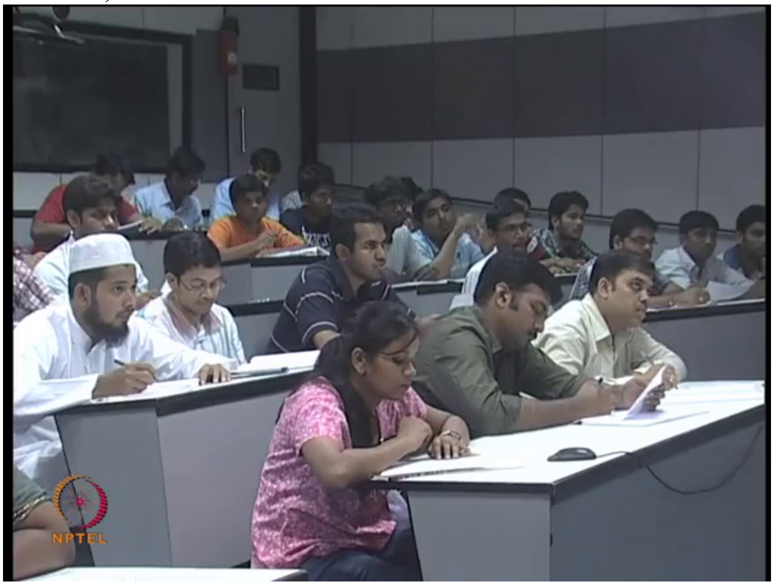

Anyway, so when you are moving in that queue

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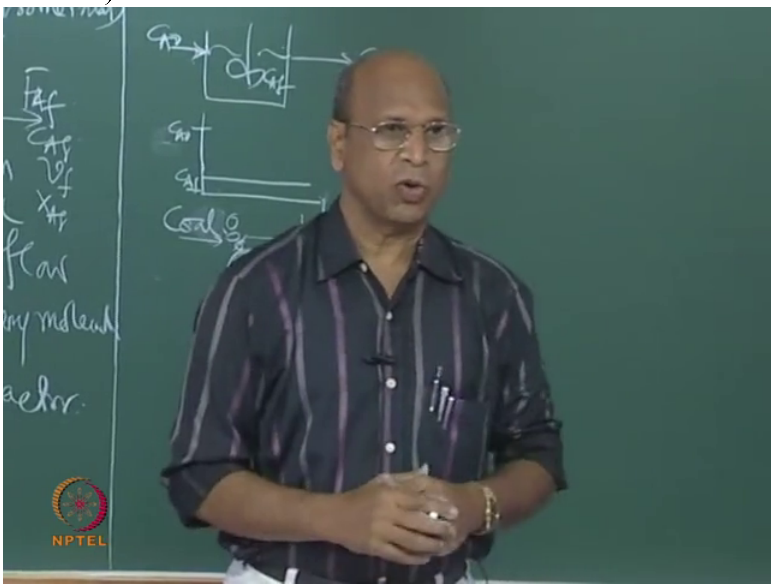

if everyone is exactly moving with a same speed without pushing, without pulling, Ok (laugh), correct no, that cannot happen anywhere. Those who entered there, that cannot happen. Without pushing, without pulling then that is ideal plug flow.

Everyone will see the God exactly after half an hour if it is continuously allowed. Ok. But most of the time it is not continuously allowed. They will put you in a place called cell, Ok (laugh), cell and then lock you. Yeah, that is a batch reactor (laugh).

(Professor – student conversation starts)

Student: (laugh)

Professor: That is what what you are doing you know, in batch reactor you are not allowing any flow. So intermittently they do that. But I think after locked cell, you are allowed to move. So when you are moving that, when you are moving in that queue, sorry? Ok, (laugh) that, batch would be of 3 or 4. Ok, so we are talking about only plug flow section when they are moving.

(Professor – student conversation ends)

So when each and every one is exactly moving with the same speed, no push, no pull, by the time you lose patience. Ok because last cell will really kill your patience. By the time you should have spent 10 hours or 15 hours, you know, the entered, the entering time.

So that is why, and that is why you start pulling and pushing. Ok. When you start pulling the particle will go forward, correct no? You push them. So, (laugh), in that queue there may be 5-6 people or 10 people you know, so if you are so strong you will push them, all 10 move. Or maybe 1 person will move forward. So that fellow will be very angry. He will say, like this! (laugh)

(Professor – student conversation starts)

Student: (laugh)

Professor: So he is pushing them back. That is why I said push and pull, you know. Yeah. So when this fellow is pushing them backward, then that molecule will come here,

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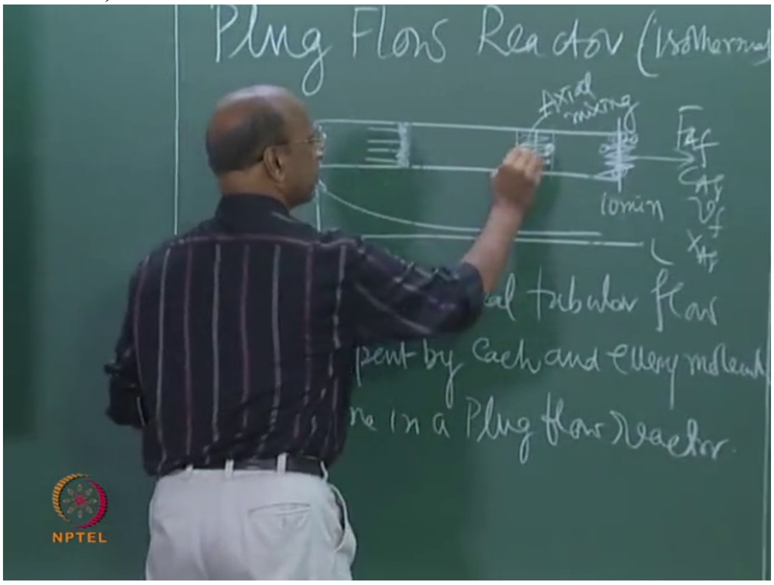

Ok. So now a weak person may be moving always from here to here, here to here, here to here, here to here (laugh).

(Professor – student conversation ends)

That is what is the example of axial mixing. So next time when we enter the queue remember plug flow and axial mixing. Ok. Yeah, that is what. In ideal plug flow that is not allowed.

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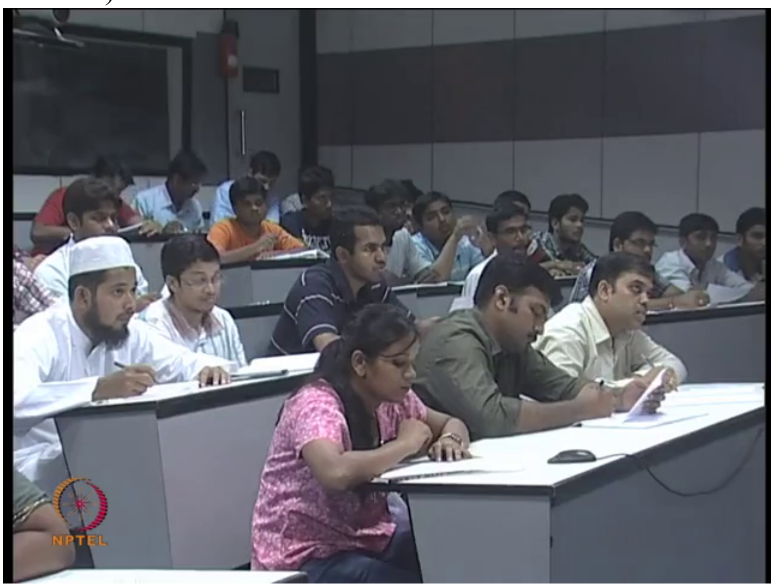

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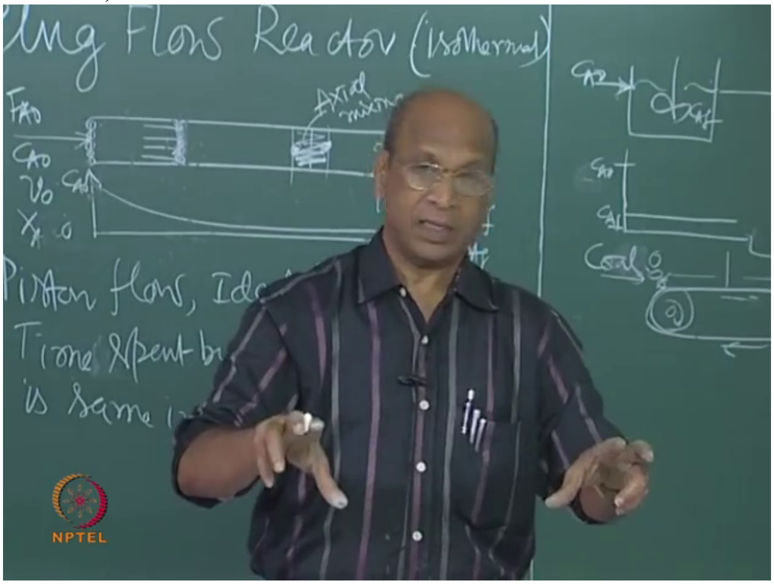

And of course even with conveyor belt we are so impatient; we will be pushing and pulling there also. Ok.

So conveyor belt is to make them uniform time but I think proposal was not successful because there is not much space, all that I think, so that is why. May be one day it may come, right? So that is another example for this axial mixing but in reality you will have that kind of pushing and pulling. That is the same thing that is happening when you have ideal, I mean tubular reactor, not ideal, tubular reactor.

In tubular reactor, now I am coming to your question, you asked me no, why there is turbulence in the packed bed? Yes,

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there is turbulence but that turbulence in packed bed, sorry in

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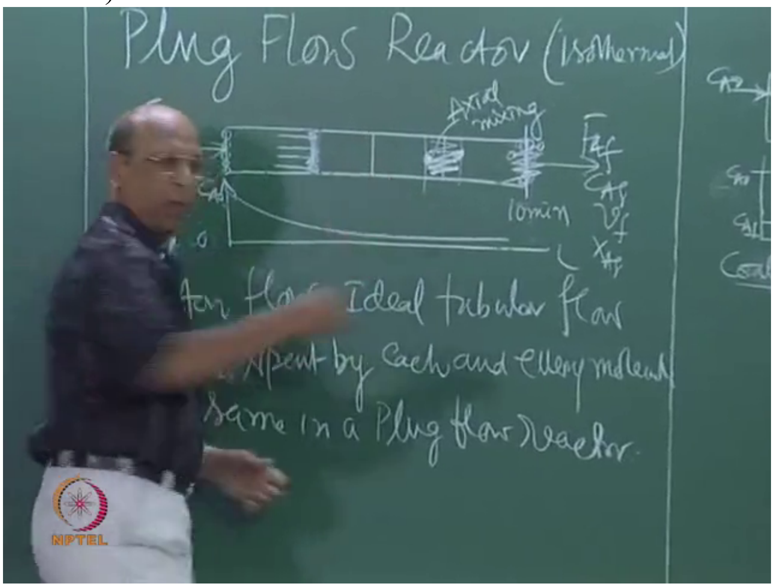

plug flow is only limited like this. You can show that, no. You are showing. How are you showing turbulence in, in, Ok in turbulent flow? How are you showing pictorially? Yeah, but what do you call that?

(Professor – student conversation starts)

Student: Eddy

Professor: Eddies

Student: Eddy current

Professor: And all those things are velocity fluctuations.

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We call them as velocity fluctuations.

(Professor – student conversation ends)

In ideal plug flow what you are mixing is, I mean what

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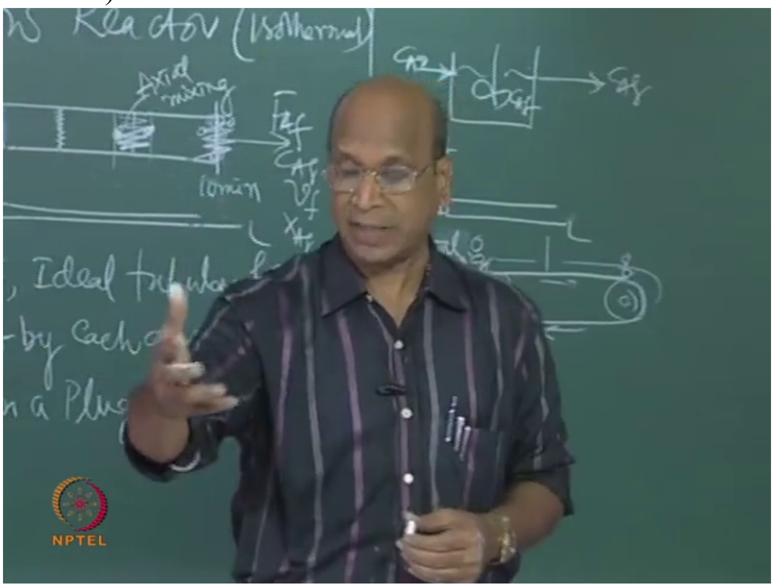

you are imagining is that fluctuations are not allowed. Sorry? yeah they should have, when we imagine plug flow ideally, then they should have that kind of, no velocity fluctuations are allowed in plug flow, Ok.

So that is why the turbulence is happening because of the velocity fluctuations. Because of the velocity fluctuations, why the velocity fluctuations are there? Molecules are coming backward and forward. And when they are coming backward and forward they are losing concentration because they are converted to slightly higher conversion but they are coming back and again mixing with lower conversion, I mean higher conversion making that entire region is lower conversion, average conversion, right?

And average conversion is between these two conversions. This fellow gone here, low conversion if you take reactant and again you are bringing him back,

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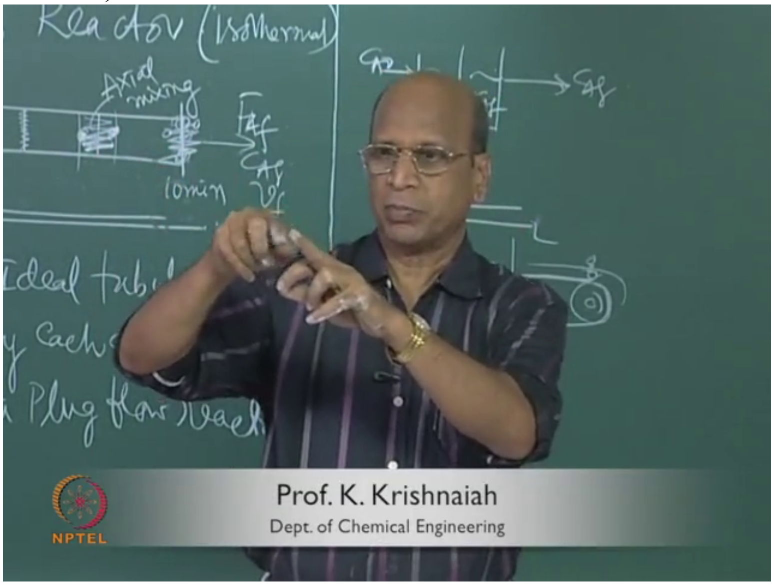

and you are spoiling this fellow. This fellow has higher concentration, right, back, somewhere here. Ok.

This is higher concentration, this is lower concentration. We are talking about only

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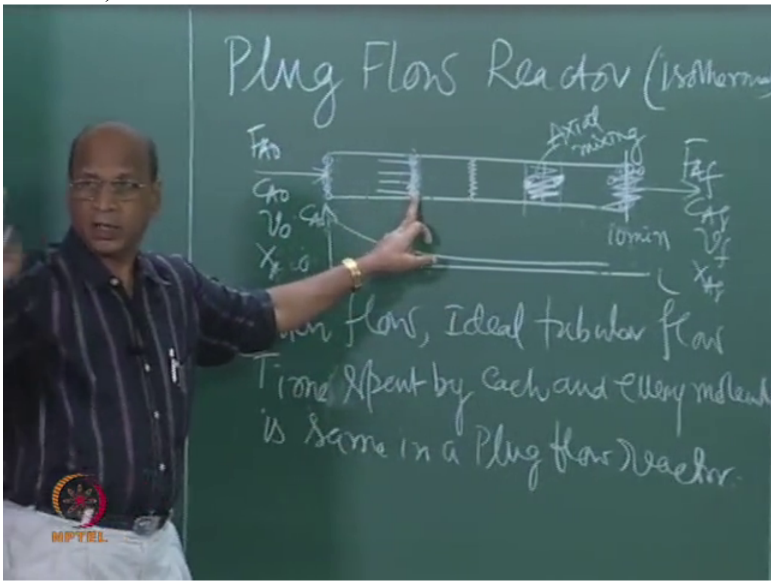

reactants. So then you are, in this region we are diluting the concentration. So when you are diluting the concentrations the rate of reaction will be lower. When you have rate of reaction lower, then naturally your reactor volume should be higher. Why?

In all reactor designs, I mean, how many, we have only 3 reactor, batch reactor, plug flow reactor and mixed flow, not so many, yeah in all these reactor expressions if you remember, if you recall your memory, in the denominator you have rate, Ok. So when, when denominator is smaller then volume will be high, Ok.

I think you know the derivation of this equation is very, very simple if you understand this. Ok. Ideal plug flow is the, sorry plug flow itself is ideal, yeah the plug flow what we are imagining in our mind, to be in our reactors is like conveyor belt where no one is moving. Like coal particles, perfect conveyor belt, without any vibrations, without any sagging and all that. So that is what.

So each and every particle will spend exactly same time. So when I calculate, I mean when I, yeah, when I measure the concentration any point across then I will have uniform concentration. That means I have, I will say now that I have infinite mixing radially.

No molecule is going forward, no molecule is coming backward. So I will say axial mixing equal to zero. Right. And then the other one, this one. Time spent by each and every molecule is exactly same. So all these things mean only one definition that is time for each and every particle is same. Ok.