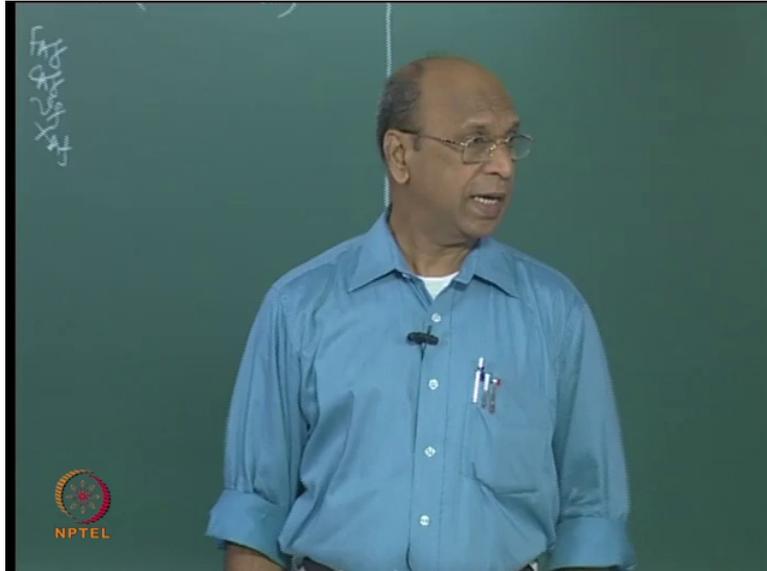


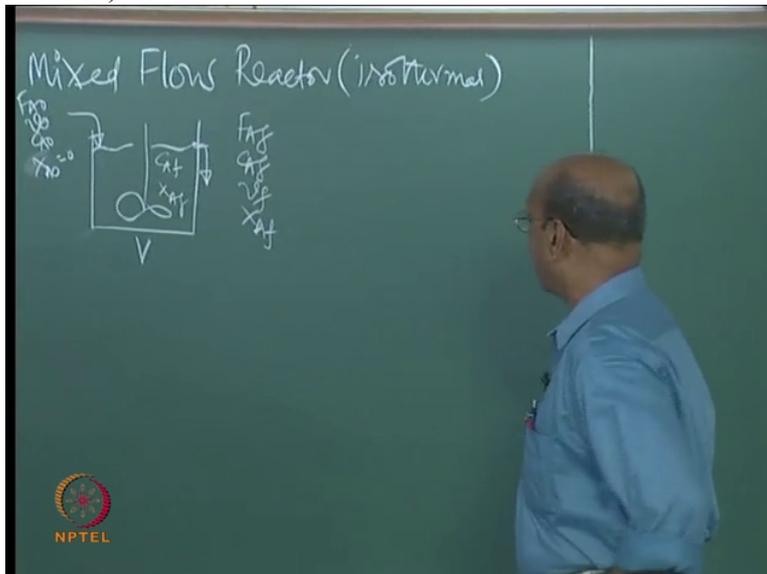
Chemical Reaction Engineering 1 (Homogeneous Reactors)
Professor R. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology Madras
Lecture No 17
Design of Mixed Flow Reactors

(Refer Slide Time: 00:10)



Ok, so we have been discussing about this mixed flow reactor

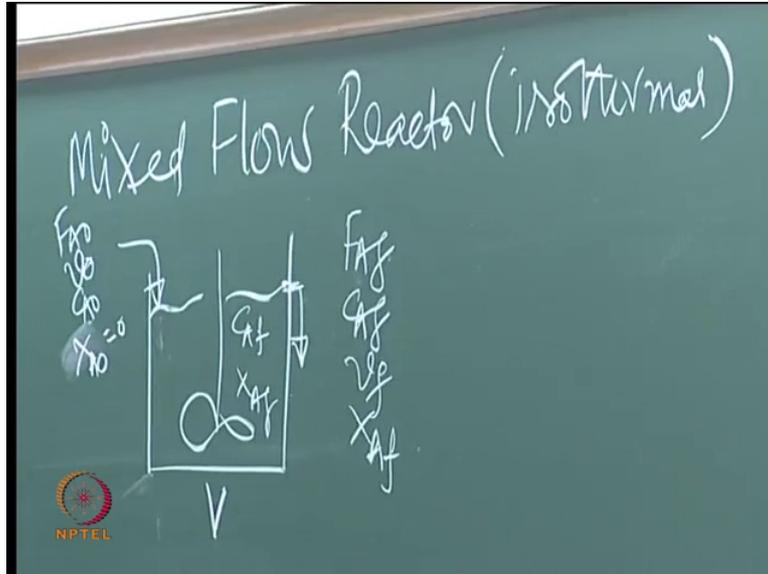
(Refer Slide Time: 00:14)



and of course this is the diagram which we have given and then we just want to know what is the context of mixed flow and if you do not want to use your brain like you have done in your B Tech you know, like simply saying that perfect mixing is one where everywhere inside you have same concentration and temperature, Ok.

So that will create some cobwebs. Some, you know, not properly understanding things like for example, so the moment we say perfect mixing most of us feel that you know it is instantaneous reaction. It is not.

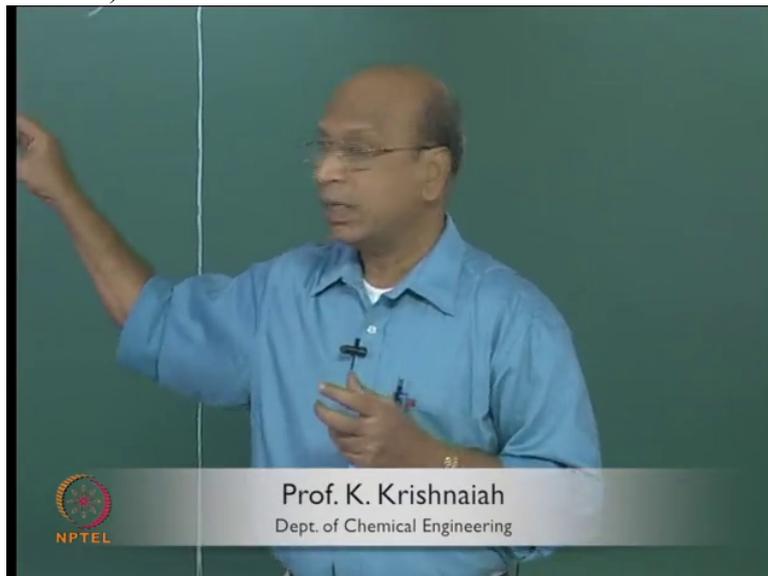
(Refer Slide Time: 00:45)



Right. Instantaneous mixing, that is correct. Instantaneous, the moment you have a concentration of C_A naught just entering, it should be instantaneously mixed to a concentration of $C_A f$ or conversion-wise $X_A f$.

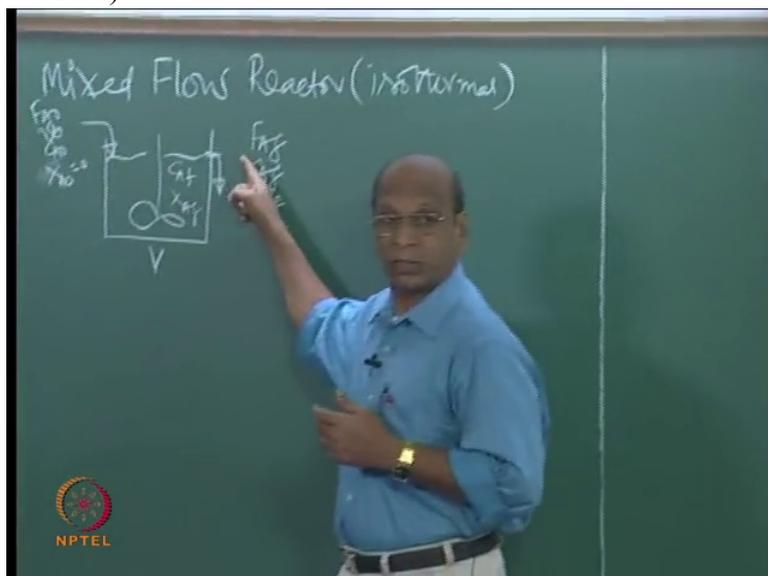
$C_A f$ is same because C_A naught is coming in; $C_A f$ is the concentration due to perfect mixing. But when I looked at, that concentration has come, that concentration in the reaction is prevailing, please listen this one carefully, that concentration $C_A f$ is prevailing due to elements of various residence times inside the

(Refer Slide Time: 01:25)



reactor and you know that because it is a perfect mixer. By definition of perfect mixing itself the outlet Residence Time Distribution,

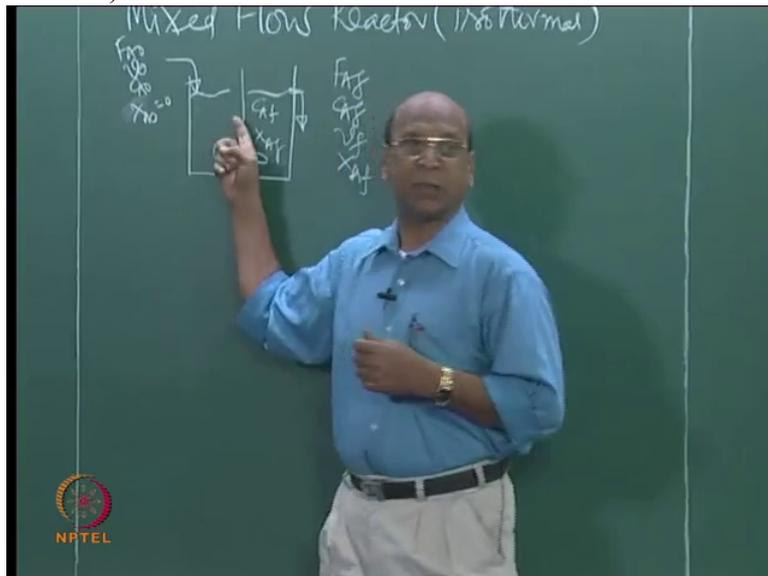
(Refer Slide Time: 01:36)



and also the inside Residence Time Distribution is exactly same.

Here also you will have zero to infinity

(Refer Slide Time: 01:43)

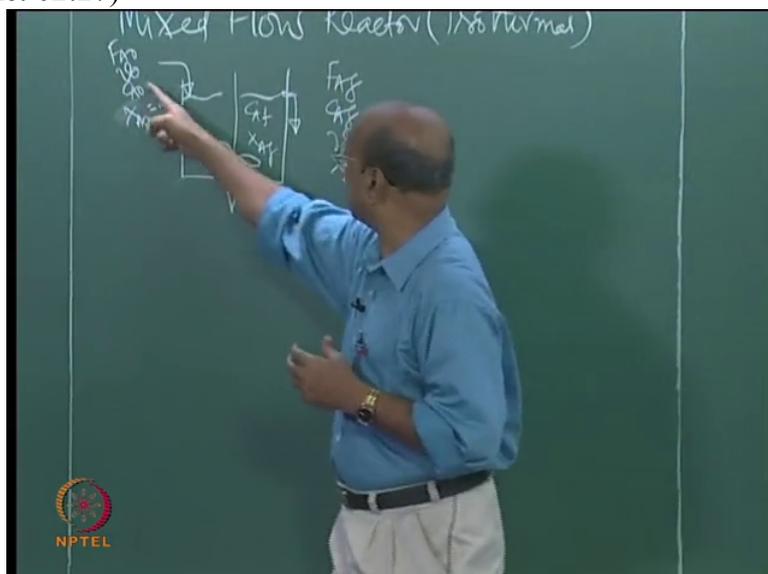


Residence Time Distribution that means the, Ok, I will take a small sample outside here and then I will look into what are the residence times. I may see there molecules or packets entered infinity time back, very long time back, infinity means not really infinity, Ok.

Then it also would have, average residence time is 10 minutes just for easy discussion. So all those molecules will not be exactly at 10 minutes. So you will have 100 minutes, even 1000 minutes, 1 or 2 molecules, right, 500, 100, 50, 10, 1, almost 1 second also. Why? All this is happening because of perfect mixing.

When you are continuously sending

(Refer Slide Time: 02:27)



the C_A naught, there may be one molecule which may be quickly coming out of the reactor and then joining this stream. So practically that molecule is not able to react. But on the average when I look because of the mixing, there are molecules now spent, you know, 10 minutes, 100 minutes, 20 minutes, 1 minute and 500 minutes, all that combination.

And that will give the average concentration inside the reactor which is also reflecting in the outside, you know, the outlet. So that is the concentration what we see here. $C_A f$ is the concentration because of mixing of various elements of various residence times. Just extend your imagination from here to plug flow.

So the moment you have plug flow, I think actually this is a tubular reactor like this, and we are only talking about exit here also. Exit concentration is $C_A f$. But

(Refer Slide Time: 03:22)



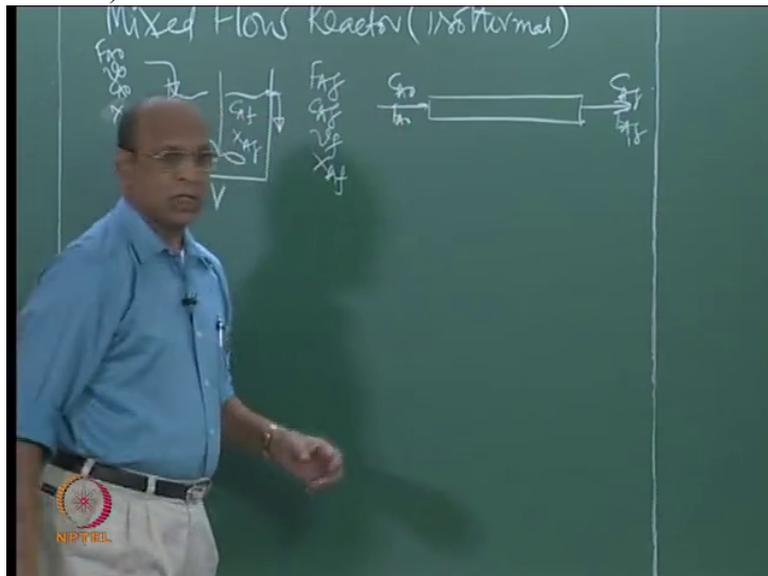
what about inside concentrations? May be I think...

(Professor – student conversation starts)

Student: Varies along the length

Professor: Yeah, so if I draw this, this may be C_A naught, this may be $C_A f$. And of course here I have F_A naught, F_A and all that,

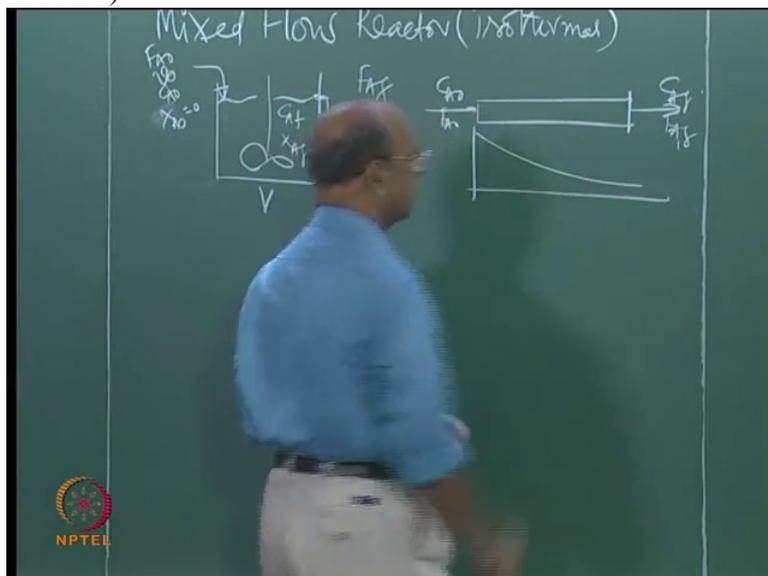
(Refer Slide Time: 03:40)



right? So we are talking about the, here the concentration C_A at the exit. But the moment I go inside, this C_A is different than, higher than the next one. Then you move somewhere inside, that will be higher. Like that if you come back here, then you will have C_A concentration.

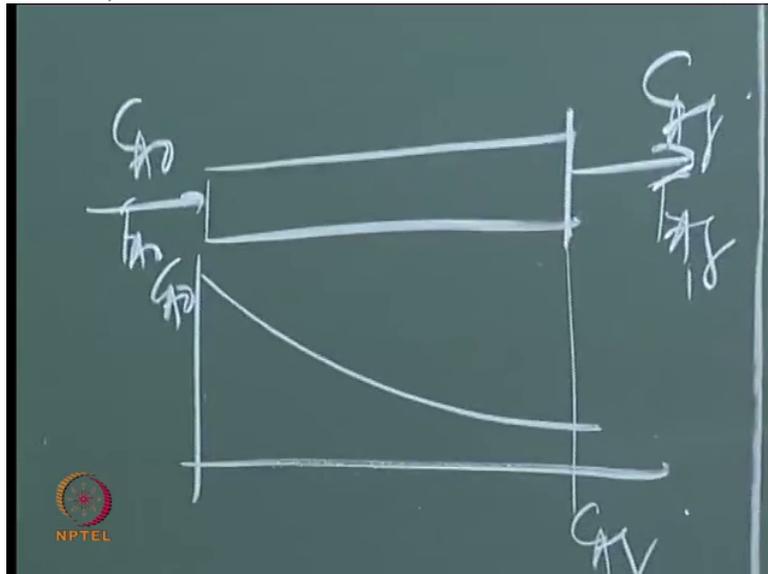
That means here what do I have? I have the concentration decreasing

(Refer Slide Time: 04:03)



slowly, right? And this is C_A , this is C_A , Ok. Now the same thing if I plot here? C_A , yeah how do I plot this? This is C_A , Ok, this is C_A .

(Refer Slide Time: 04:11)



This is C_A naught

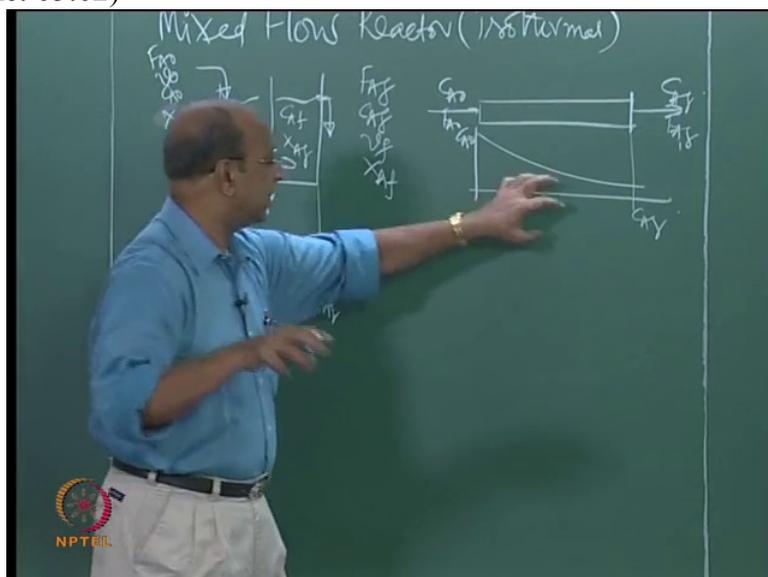
Student: How ...

Professor: Because it is instantaneous mixing, concentration will decrease to $C_A f$, which is this. There is no slow decrease here. This is $C_A f$, Ok, sorry. This is only spatial, Ok, no problem. This is C_A naught, this is $C_A f$.

(Professor – student conversation ends)

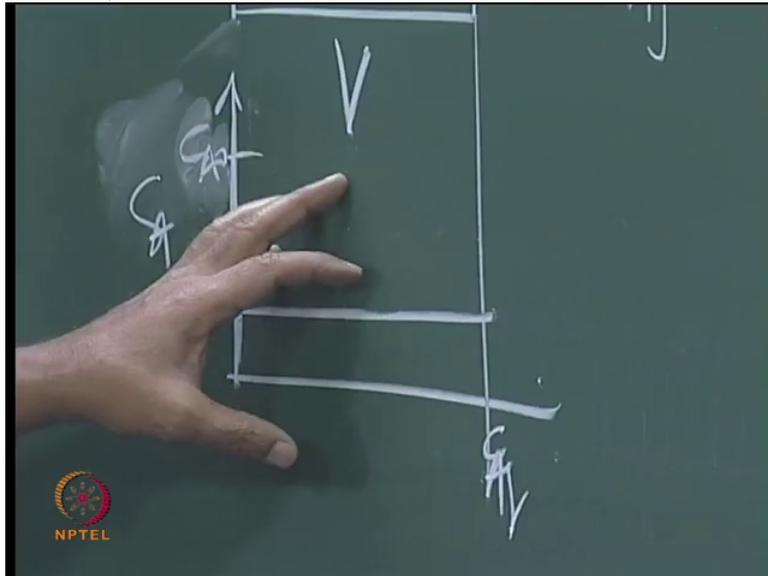
But now the difference, why even writing without, without writing equation, why a plug flow reactor should give you more conversion for a given volume, for a given volume. In this,

(Refer Slide Time: 05:02)



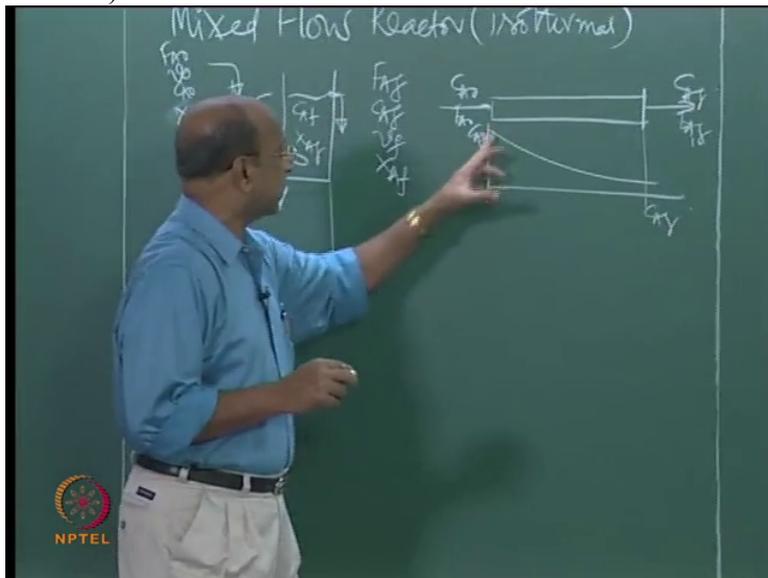
and here you will get less conversion for a given volume

(Refer Slide Time: 05:06)



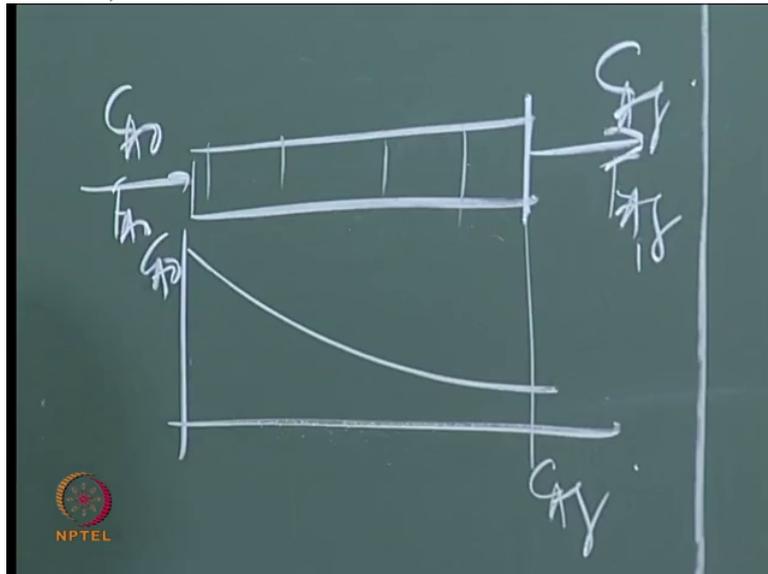
is here,

(Refer Slide Time: 05:08)



the concentration is changing slowly, and then what about rate here, here, here, here? Do you have

(Refer Slide Time: 05:15)



different rates? Why I have different rates?

(Professor – student conversation starts)

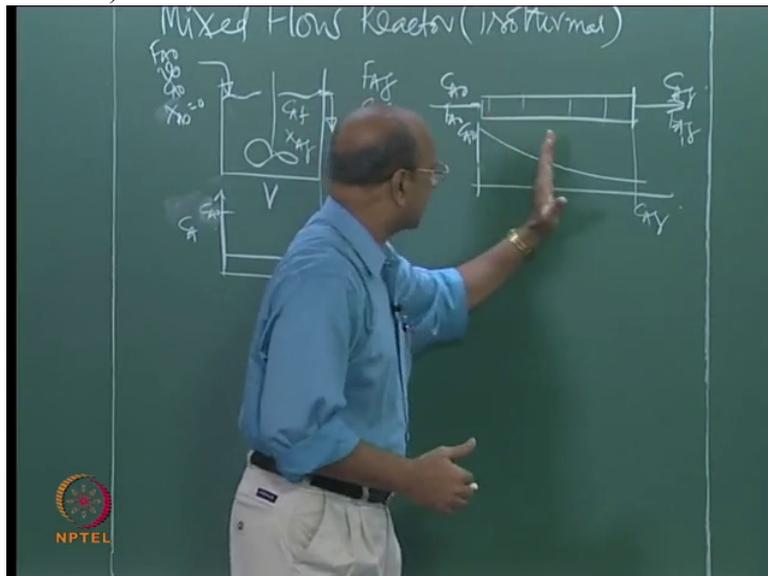
Student: Concentration is...

Professor: Concentrations are different. We know that at any point you have k into $C A$ if it is first order reaction or correspondingly whatever reaction we have.

(Professor – student conversation ends)

So that means what I see at the outlet is the accumulation of all that, no I do not say, not accumulation, not material accumulation we are talking, the changes in reaction and the concentration slowly,

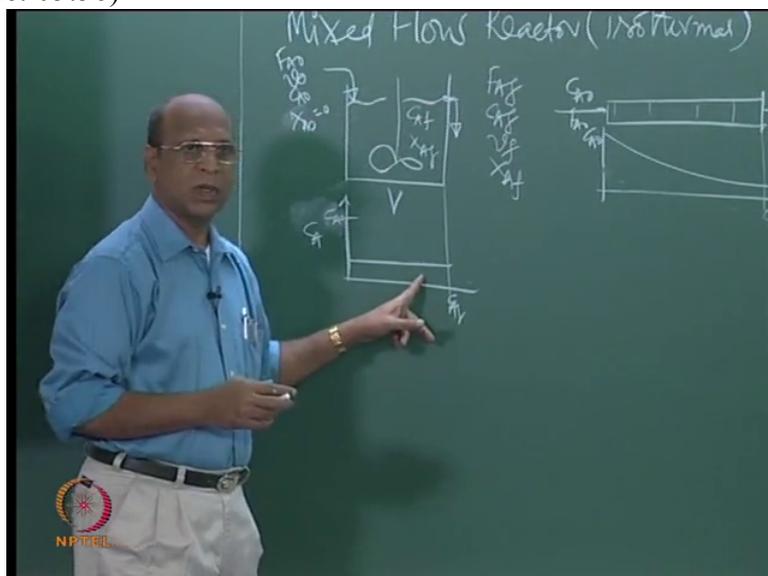
(Refer Slide Time: 05:41)



that means number of rates I have inside the thing, and what I see here at the outlet is some kind of average of all those rates.

Whereas here how many rates I have?

(Refer Slide Time: 05:56)



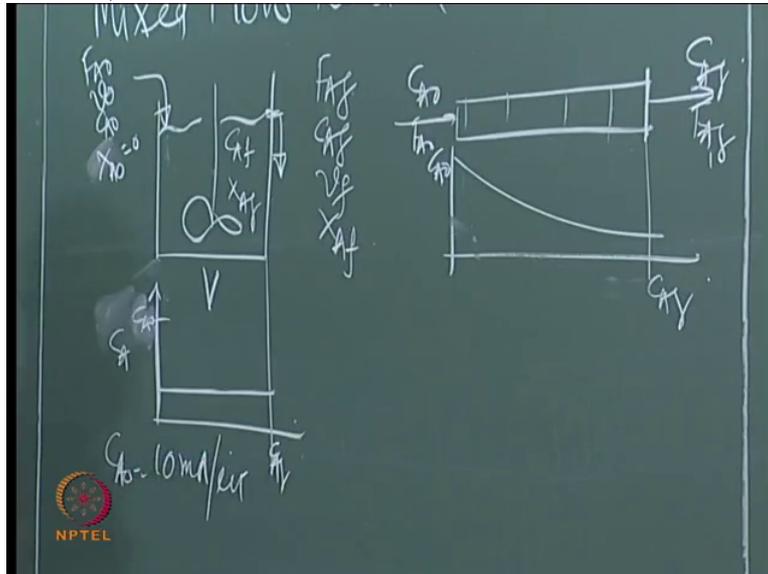
Only one. Because throughout the system I have only one concentration. So that is, and that rate corresponding to C_A , outlet concentration. So is it more than or less than inlet concentration?

(Professor – student conversation starts)

Student: Less than

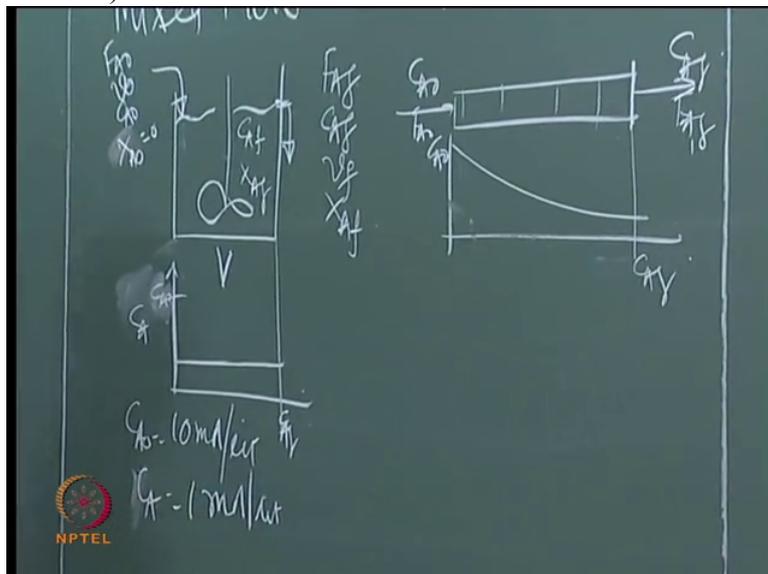
Professor: Definitely much less. Right. So if I, example if I say that C_{A0} equal to 10 moles entering, 10 moles per liter,

(Refer Slide Time: 06:26)



and outlet is 1 mole, C_A is 1 mole per liter,

(Refer Slide Time: 06:33)



Ok, what is the conversion now? We are talking about constant density. Conversion equal to

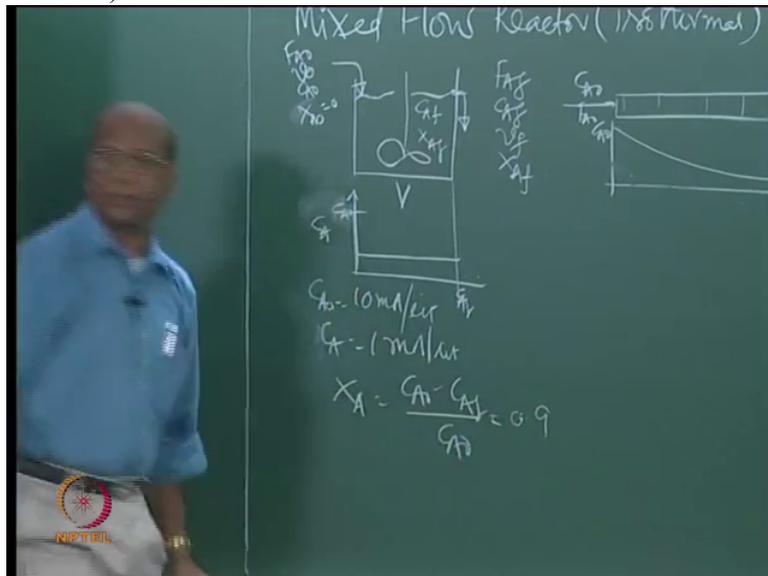
Student: 90 percent

Professor: 90 percent. You know the definition, $C_{A0} - C_A$ by C_{A0} . So I think I would also better write.

(Professor – student conversation ends)

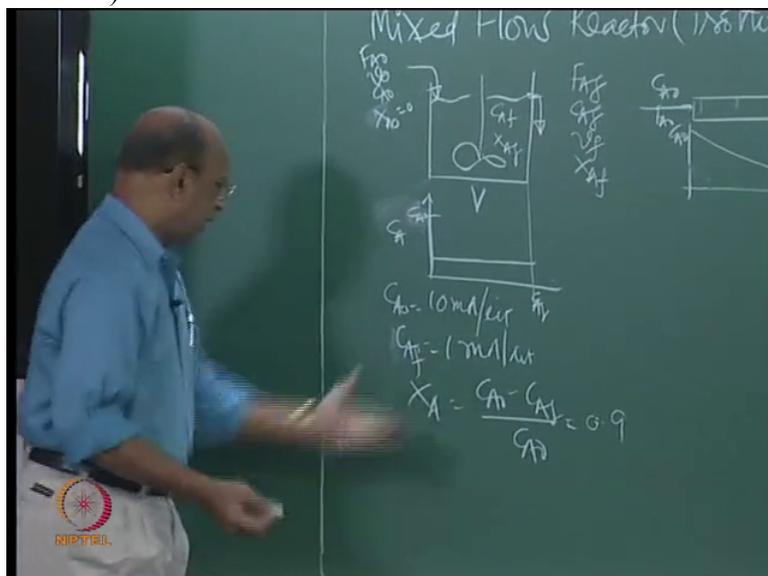
$C_A \text{ naught} - C_A \text{ f}$ by $C_A \text{ naught}$ this will be point 9.

(Refer Slide Time: 06:56)



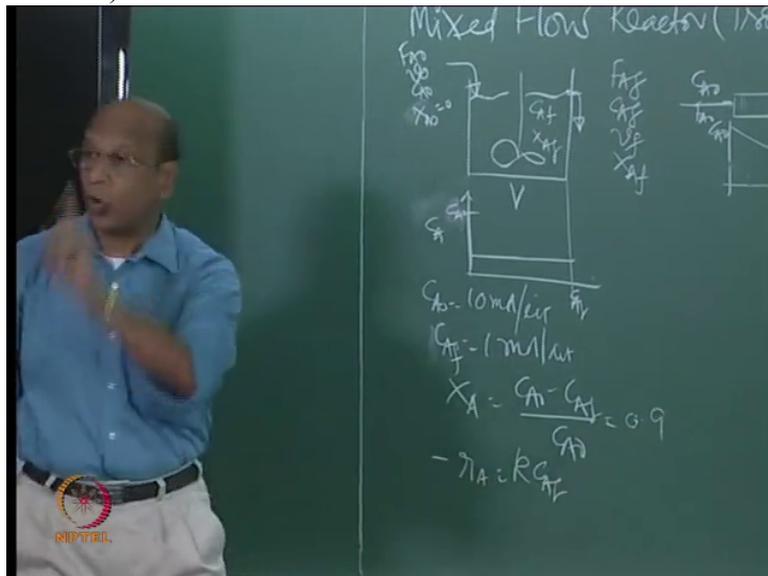
That will be the concentration, Ok that is the conversion which I get here in the outlet and which is same throughout, right? So corresponding to this $C_A \text{ f}$,

(Refer Slide Time: 07:09)



the rate if I calculate, minus r_A equal to k into $C_A \text{ f}$, only

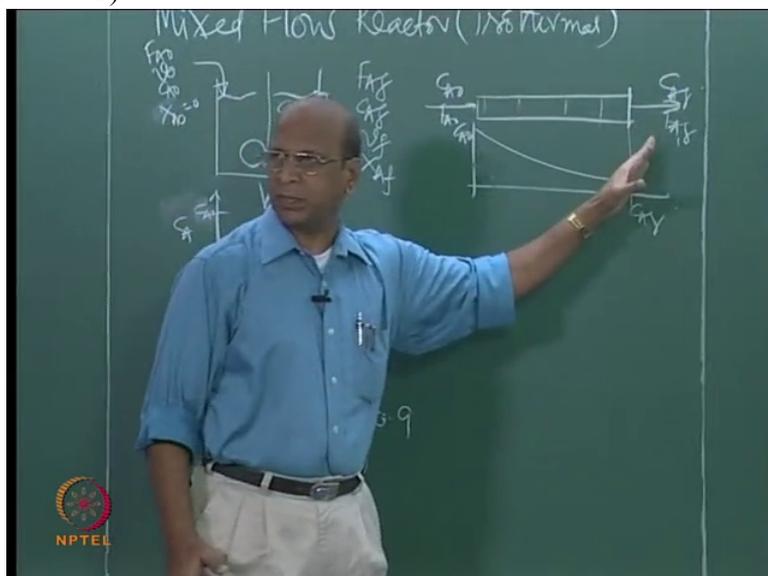
(Refer Slide Time: 07:14)



one rate which is very low, that means that is almost exit rate, right?

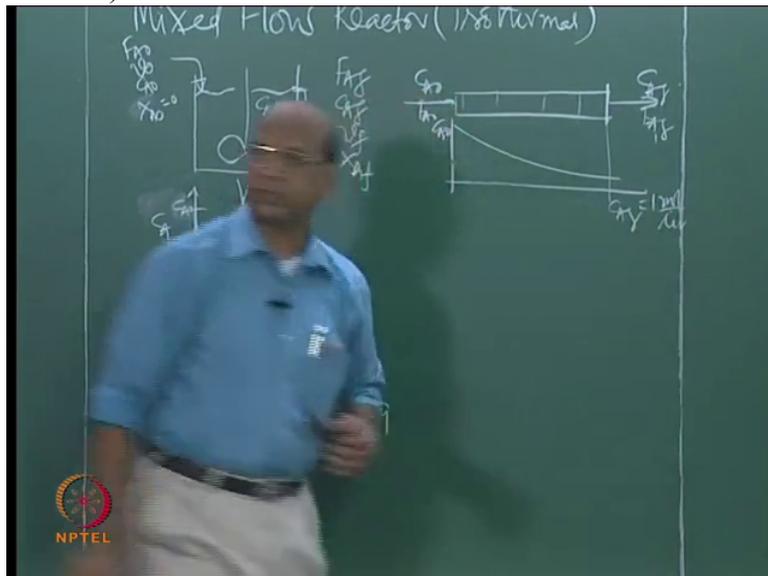
So now in our design expression we will have always this rate in the denominator, by r_A , Ok, by, something by r_A it will come. Now here I have only one rate. And the rate is very less, Ok. I mean very less means it is not. I mean it is corresponding to exactly this rate only.

(Refer Slide Time: 07:41)



Ok, here also if I have 90 percent conversion, here also I will have 1 mole, 1 mole per liter

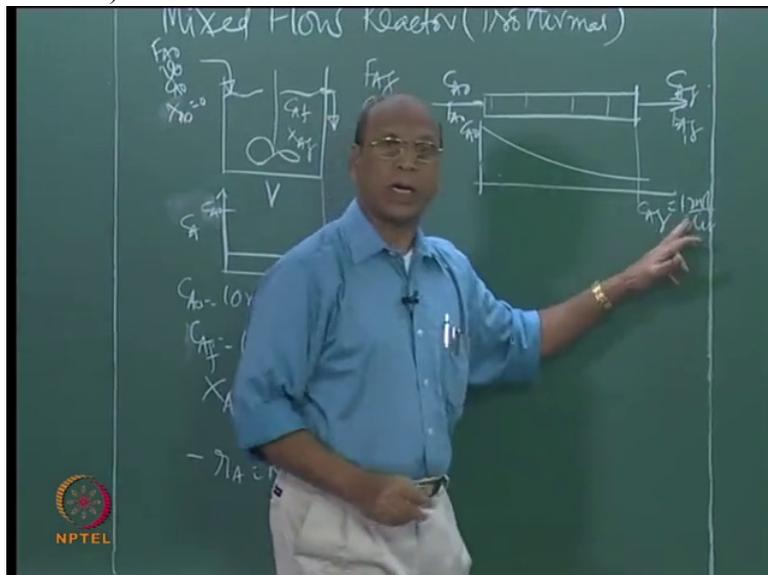
(Refer Slide Time: 07:49)



only, right? I mean for comparison sake, please remember that.

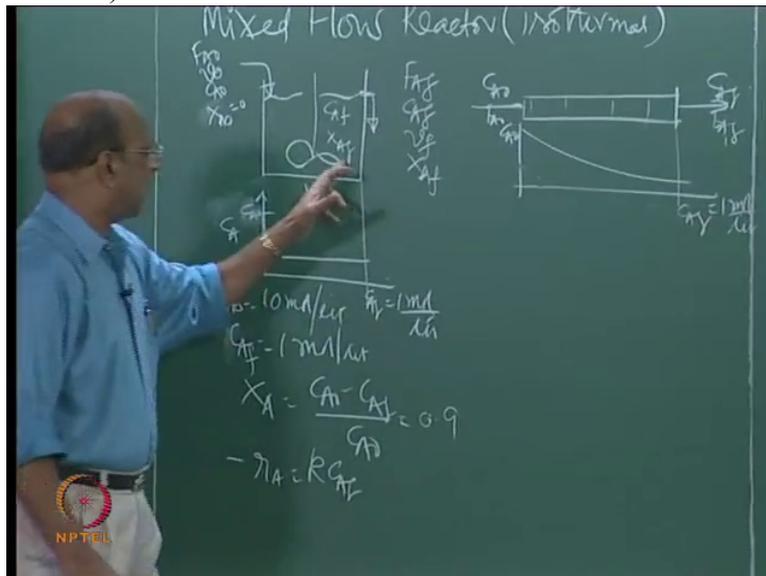
So here also I have 1 mole coming out, Ok. Here also we have 1 mole per liter and here also I have 1 mole per liter only.

(Refer Slide Time: 08:03)



But before coming here as 1 mole per liter it would have gone through so many rates. Rate means already some conversion would have occurred. Whereas here there is only one

(Refer Slide Time: 08:16)



rate and one conversion and one concentration.

So this rate is, because the average of that is only one. Only one rate, whereas here there are so many rates and then all of them giving me more conversion when compared to this because I have only one rate here and I have here, theoretically how many rates you can put inside, imagine. Infinite because that is the reason why at every cross-section again we are thinking that we have infinite mixing.

That means each cross-section now depends on one, I mean sorry, is equivalent to one tank. So infinite number of tanks you can put there. So that is why you have here more conversion for given volume and here you have less conversion for given volume. Because the rate is only one. r_A is small now, only one rate. And that is the reason why you have, you know, larger volume for a given conversion, larger volume for a given conversion, or for given volume, higher conversion, right?

So that is what what you have to remember. I think you know, this should go out, now I think after this course, definitely at least the basic definitions must be very clear in the mind. Right? Why plug flow is efficient? What is the definition of plug flow? What is definition of mixing?

I could have completed this long time back if I do not discuss much about, you know simply saying that assume complete mixing. But still you will have many, many doubts in your mind

that what is this perfect mixing and instantaneous reaction you feel. There is no instantaneous reaction.

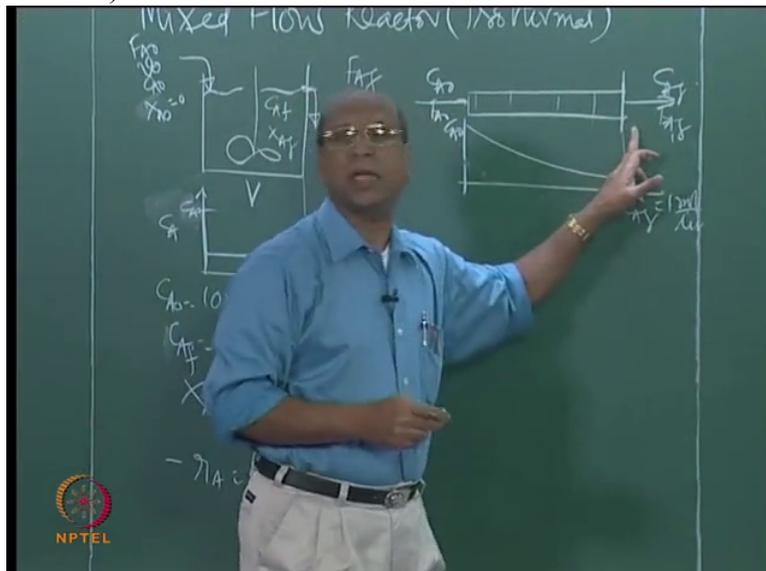
(Refer Slide Time: 09:49)



There is still an average rate, right?

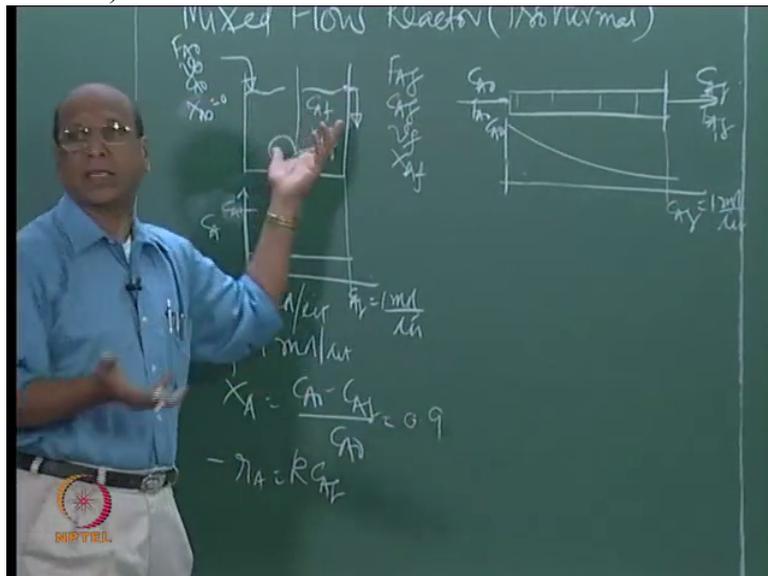
Average rate due to various residence times inside the reactor, whereas here I have all the residence times of all the molecules are exactly

(Refer Slide Time: 10:03)



same here. We are talking about outlet. Here also outlet only, but outlet and inlet exactly same here.

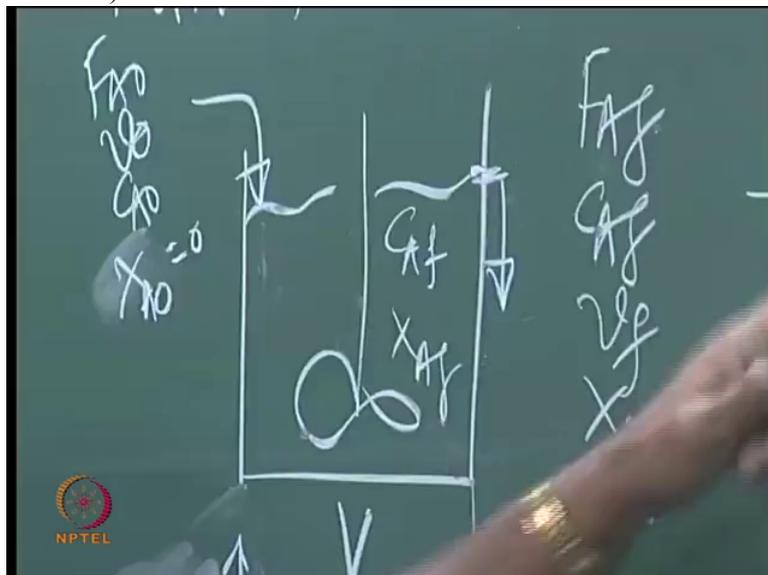
(Refer Slide Time: 10:08)



Right, whatever is happening also reflects in this one. If you have doubts you have to raise and ask, right? Ok.

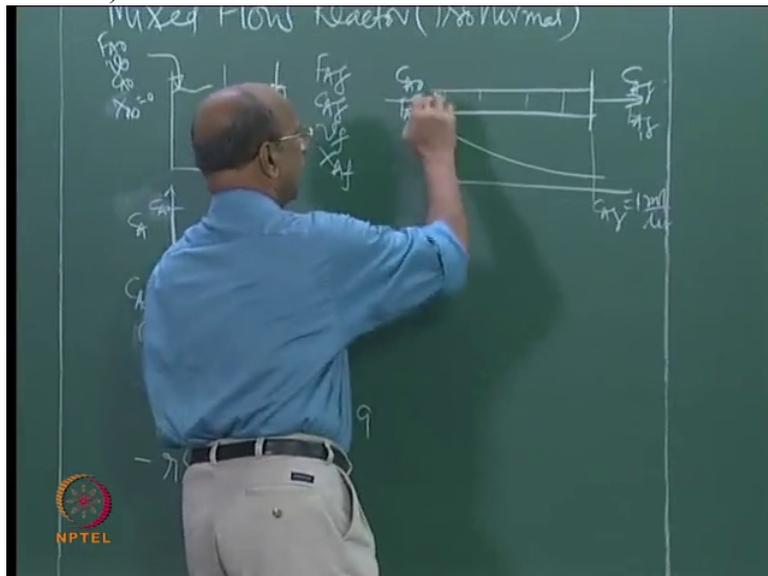
So that is how

(Refer Slide Time: 10:17)



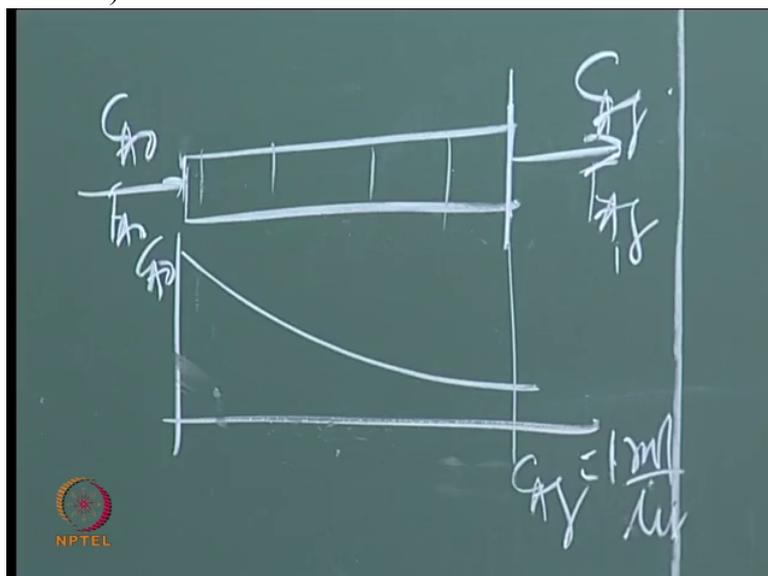
it happens

(Refer Slide Time: 10:19)



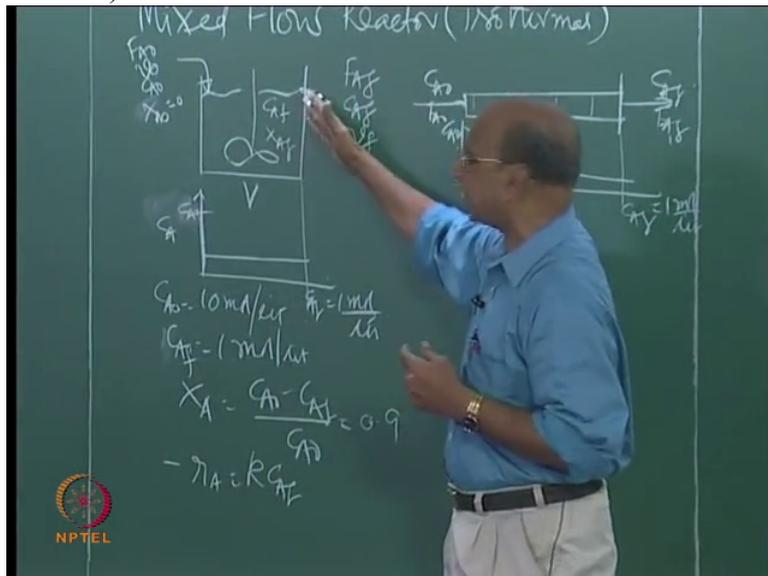
that PFR is definitely, no, having more conversion for a given volume. If someone is asking you in the interviews or examination this question, probably, you have to definitely

(Refer Slide Time: 10:34)



imagine that this Residence Time Distribution that is coming into picture, that is why by definition of plug flow, we say that each and every molecule should spend exactly same time and there we can prove that, that is not so in a mixed

(Refer Slide Time: 10:46)

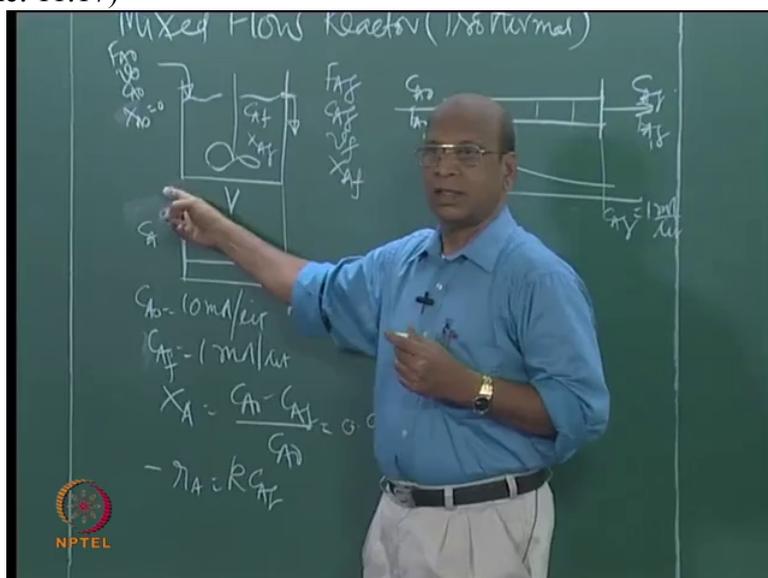


system where the residence times are varying from zero to infinity, right.

That means molecules are packets which are spending 1 minute, less conversion, 2 minutes slightly more conversion, 1000 minutes 100 percent conversion but there is no use of that being inside because it is like, it is already converted. There is nothing will happen. But still that is occupying some volume, right?

So that is why, to compensate that volume if you want to get the same conversion as plug flow, what you do here?

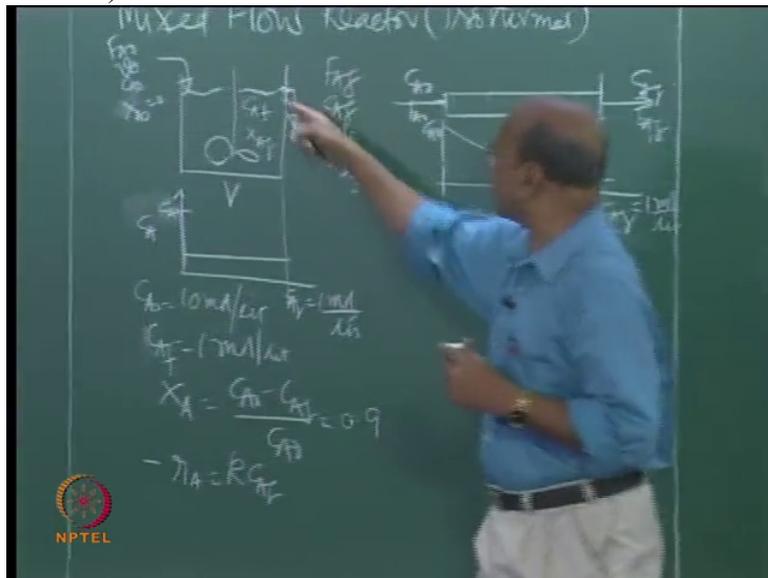
(Refer Slide Time: 11:17)



You increase the total volume. That is why for given conversion, the volume of plug flow will be smaller and the volume of mixed flow will be larger because you want to compensate the rate lost due to residence times.

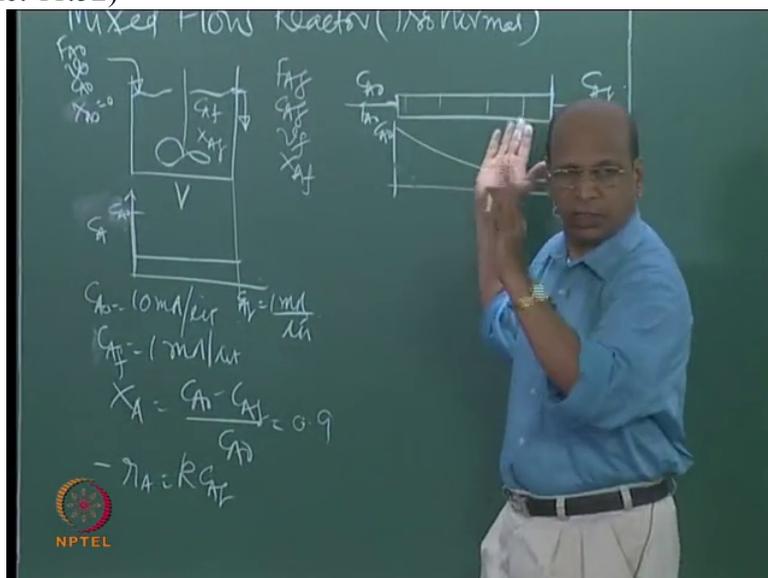
So see here every particle is spending exactly same means the concentration is, or the conversion is same in each and every packet, right? So even if I take the average of that, definitely I will have same conversion. Whereas here, I have 100 packets,

(Refer Slide Time: 11:50)



I mean here also 100 packets

(Refer Slide Time: 11:52)



but equal concentration, here also 100 packets but starting from C_{A0} to C_{Af} , that time again averaged, right?

So that will definitely give me, yeah, less conversion but what I am trying to do is, I am now trying to provide more volume so that some more time all these packets will be on the average, Ok, all these packets are again going to spend time. So that is why that will compensate this conversion, yeah, higher conversion here by increasing the volume.

Anyway, even if you derive the equations and then able to calculate you will definitely see. There are many graphs. I think Levenspiel book has given that you know, for given conversion what is the volume for first order reaction, second order reaction, third order reaction, you will just go, take 90 percent line and then read this side and then you will know what is the ratio of C S T R, single C S T R and volume of P F R, that ratios are given, right?

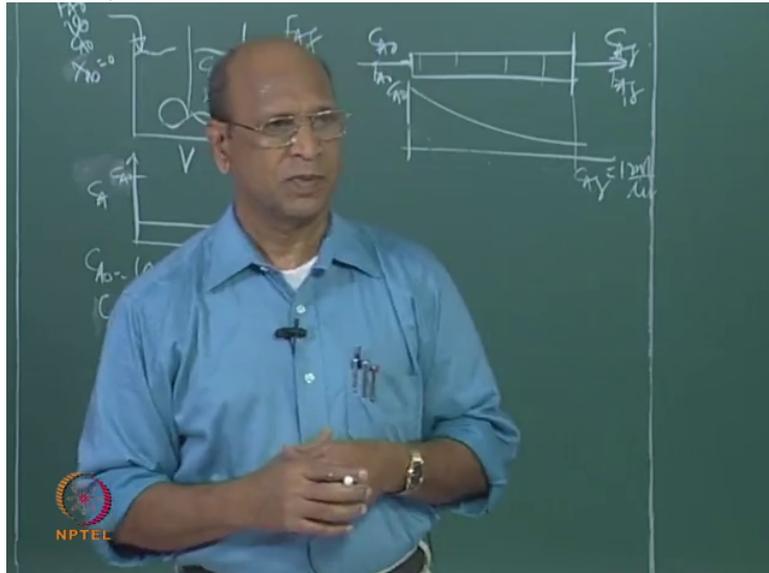
So directly some people may give, you know always in chemical engineering, we use lot of dimensionless numbers. The volume of mixed flow by volume of plug flow also is a kind of a dimensionless number, Ok? Yeah. And conversion is anyway a dimensionless number. But it will be depending on again what is the order of reaction, so you have one line for one order of reaction.

Then you just read and then Ok, for first order so much difference, for second order so much difference, Ok, that is why one can also easily prove it. So if you have still further any doubts about mixed flow and plug flow, now I think we are going to stop that now, right so please tell me, please ask me, please do not keep those cobwebs again.

(Refer Slide Time: 13:30)



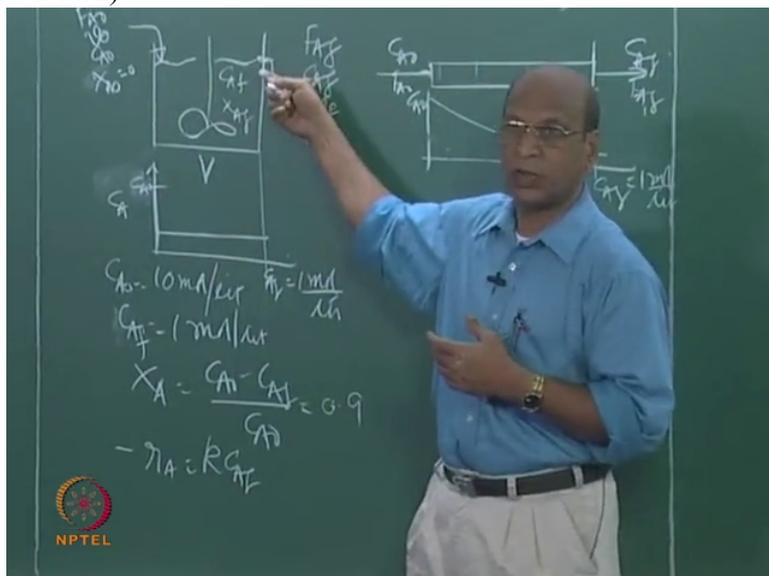
(Refer Slide Time: 13:32)



Ok, how do you operate C S T R? Ok to; see we are talking of only steady state system now. But how do you come to that level where you have zero to infinite residence time under steady state condition? That means you can slowly fill up the entire empty, take empty and then slowly fill up so level rises and then after that it comes out, Ok.

So then what is the concentration when it is about to come out? Because our steady states are only at time t equal to

(Refer Slide Time: 14:02)



zero.

(Refer Slide Time: 14:03)

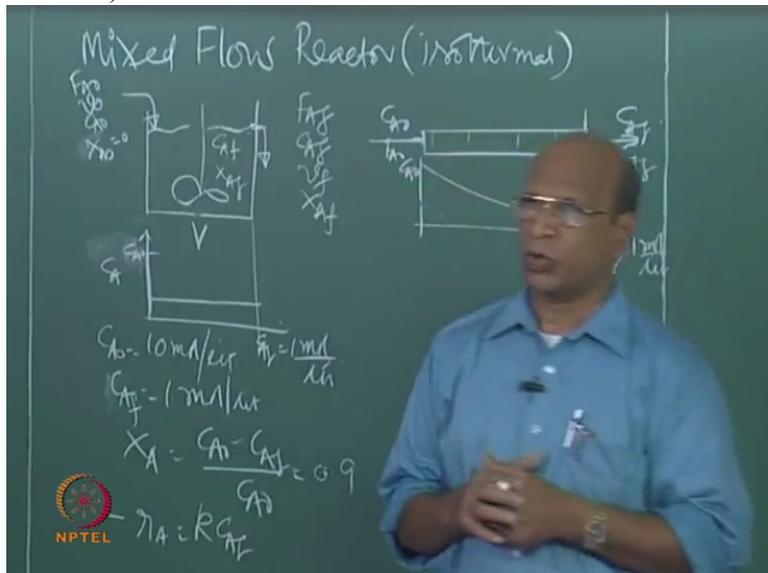


(Professor – student conversation starts)

Student: Inside 0:14:02.6

Professor: Yeah, but I think you know you have to be specific here. Slow means how slow

(Refer Slide Time: 14:07)



you are talking.

Student: At steady state it is taking 0:14:08.1

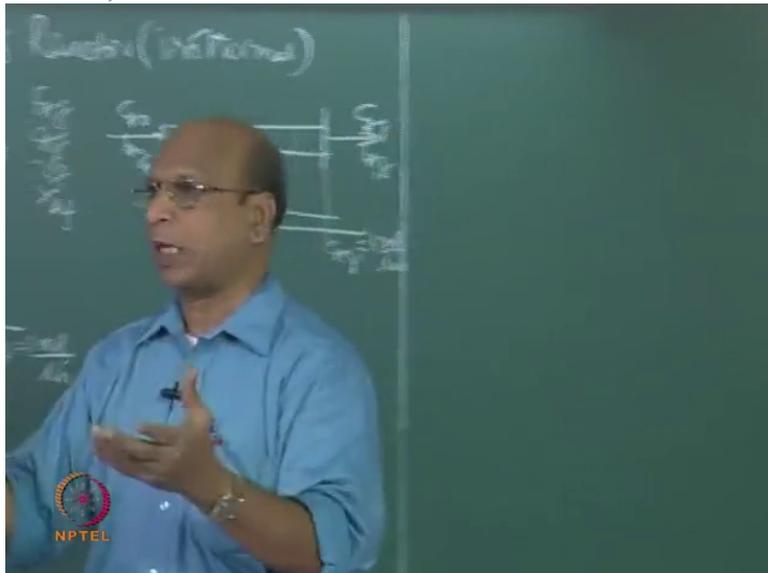
Professor: Even 20 hours also we can run here. 20 hours but we are talking about average residence time,

(Refer Slide Time: 14:16)



right? Yeah. See very slow reaction means it may take

(Refer Slide Time: 14:21)



more time for the reaction to happen and may be much more time you want to go to 99 percent conversion.

Student: Reflex in the reactor

Professor: How does it reflex?

Student: Inside reactor this 0:14:36 is required

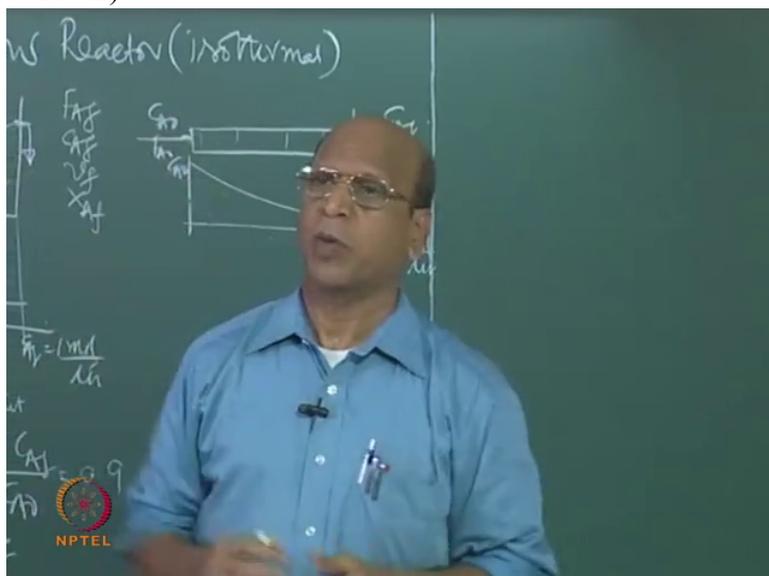
Professor: Yeah, tell me why?

(Refer Slide Time: 14:38)



Professor: Yeah, tell me why? See these are all vague things in our mind. That is what exactly I am asking no,

(Refer Slide Time: 14:42)



that cobwebs. So why should I use a reflex in this reactor?

(Refer Slide Time: 14:47)



Student: That is boiling no, the reactant...

Professor: Why should I do? Under what conditions, yeah, there is perfect mixing in this system you are talking. Why should I boil and why should I reflux? 14:59.5?

Student: There are some reactions that does not take place in normal temperature.

Professor: Like what? We should also be clear, right? Like what?

Student: It has to be taken up to the boiling point of the mixture.

Professor: Ok

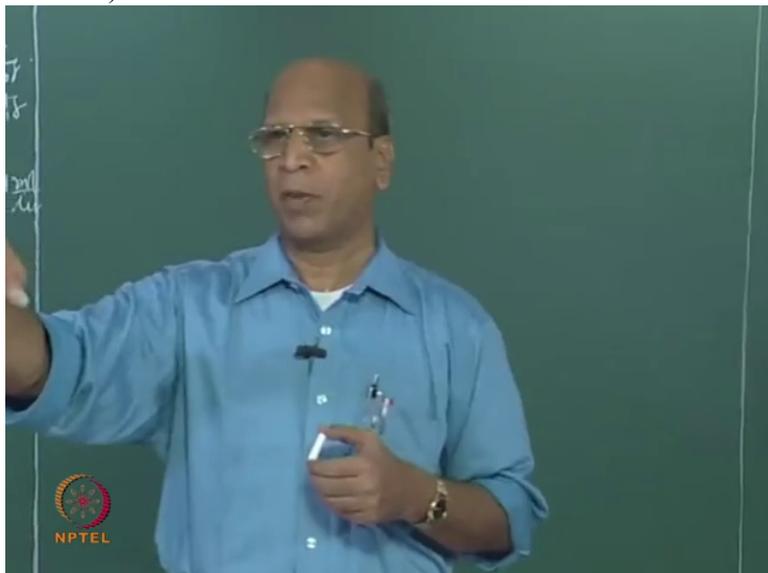
Student: Then reflux will come back. We have to put a

Professor: What for you are doing that?

Student: Suppose some

Professor: I mean his question is that I have a liquid where

(Refer Slide Time: 15:24)



the boiling point is only 60, example. But the reaction is taking place, may be 100 degrees centigrade, Ok.

It will not happen normally but you know

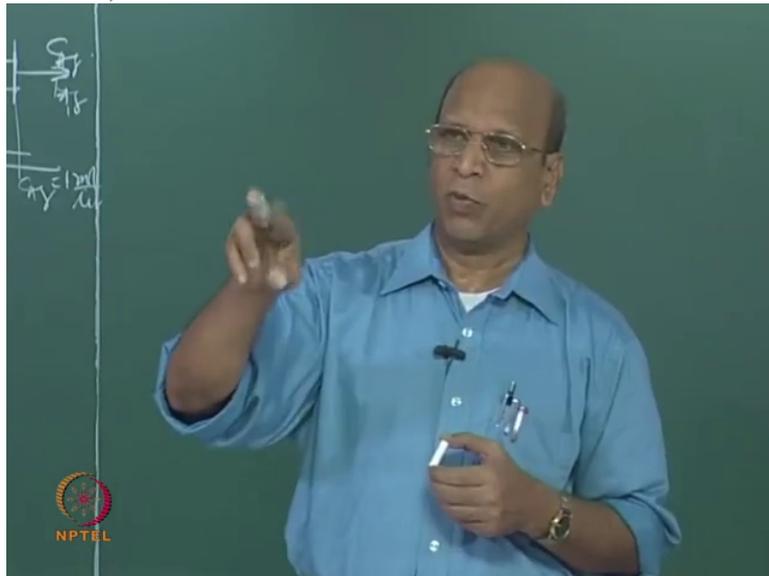
Student: Material in the

(Refer Slide Time: 15:37)



Professor: You can conduct in gas phase. The problem comes when you have 2 reactants,

(Refer Slide Time: 15:42)



where one boiling point is higher, another boiling point is, you know lower and if the reaction is somewhere above or in-between then the low boiling point one will be boiling. You have to keep the number of moles same. That is why what you do is either you, yeah, either you put a condenser so that it evaporates immediately, gets cool and then falls there

Student: Then take the another 0:16:03.6

Professor: But that is not the reaction problem. Ok.

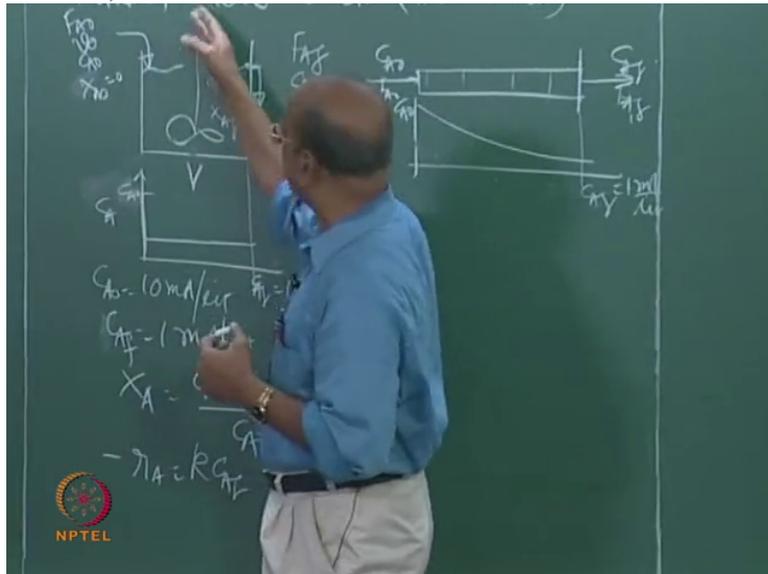
Student: Then how to take that material outside?

(Refer Slide Time: 16:10)



Professor: Which material? It is only a just

(Refer Slide Time: 16:13)



distilling there and then falling there. So then no question of taking out. Ok, that is the easiest one. Otherwise you can also put an outside condenser and then again feed back.

(Professor – student conversation ends)

Under steady state conditions, the number of moles will be kept same. Ok. So that is only, you are only trying to see that the concentrations are not changing due to evaporation. That is all, you know, that is only the physical thing. It is not the actual reaction.

Because if I allow that to go out, then you will have one reaction, yeah, you use one reactor, right? That is why just close it perfectly. Otherwise you know I told you in our villages when they are cooking rice, I told you no, they put water just above and then they cook. Because that is also same thing. Water should not get evaporated.

(Professor – student conversation starts)

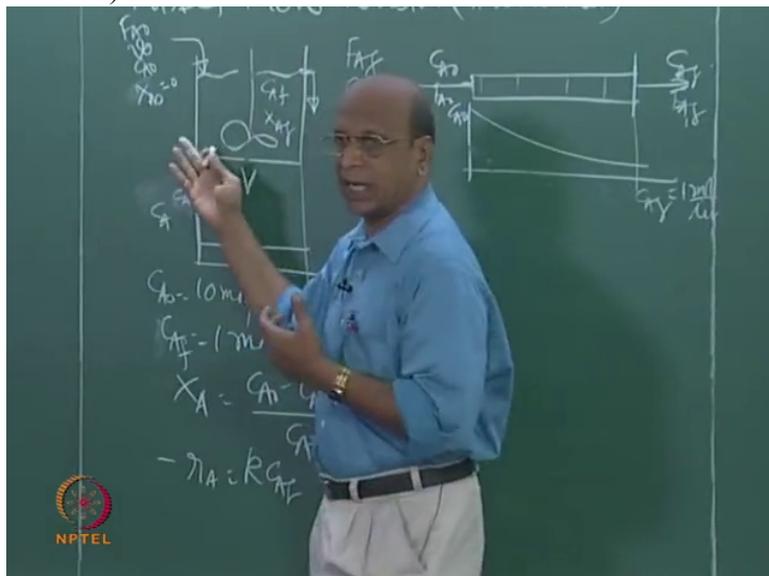
Student: In that case how do we 0:17:05

(Refer Slide Time: 17:05)



Professor: 0:17:06.0 here will not change no. I think you have perfect

(Refer Slide Time: 17:08)



mixing there and I close this, Ok here I have and then you have the outlets somewhere here, right? So put a condenser and again send it back.

(Professor – student conversation ends)

That is only the engineering problem, as a mechanical engineering problem as how do you put that hole where the vapor is escaping, where it has to condense and it has to come, that is all, Ok. And for that condenser again, you should have some coolant entering, coolant coming out and all that. That is just only engineering problem. It is not really C R E problem.

There C R E problem is that you should maintain number of moles, yeah, not uniformly, the way it has to be in normal reactor, so that is all. But you know, other than that there is nothing special in that kind of thing. You know not only that, there I think this question is good. Now because he is asking only reflex but I can extend this question to heat transfer.

If the reaction is highly exothermic, right, simply putting an external jacket may not give me that kind of area where I can control the temperature, highly exothermic. I want to control around may be 75 degrees. But providing only that jacket and also whatever is available, you know, coolant right, still I may be getting around 90, what do I do?

So people take out a stream there, put an external heat exchanger, again send it back. That is one way. Other way is directly put the coils inside. There are many ways. Or again inside also, you have all the time instead of wall, you have only coils. These are again mechanical engineering problems. How do you remove the heat, I mean heat if the area is not sufficient.

Even for batch it is same. It is not only for C S T R. Even in batch reactor, if only jacket is not providing sufficient area for removal then you have to go to various means. Various means of putting internal coils, because sometimes internal coils you cannot put because they may be highly corrosive liquids, Ok.

So then you have to take out and then you know, effective volume will, good, effective volume will also decrease. And mixing may not be proper. Because inside coils if you put, near the coils again, these are all general engineering problems. That is what exactly the difference between science and engineering.

A scientist will not bother about all these things. You somehow remove the heat, Ok. So that is what I have been telling you, the difference between science, engineering and technology. Technology is the one where it is ultimate, telling you that use this temperature. Use these flow rates, use this volume. You will get this much product.

And this technology does not need any brain at all. If you want to just copy, one technology, that is all. That is why I do not know. You may not, anyone has worked in pharmaceuticals? Oh you worked now. Which pharmaceutical is that?

(Professor – student conversation starts)

Student: Orchid, Orchid Chemicals and Pharmaceuticals

Professor: Oh here?

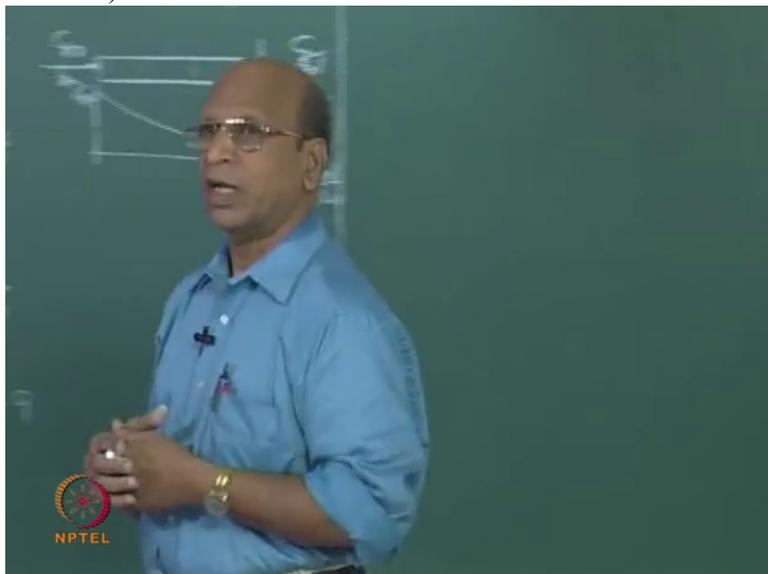
Student: No, in Aurangabad.

(Refer Slide Time: 20:10)



Professor: Oh, Aurangabad also they have unit, I know. Yeah, yeah,

(Refer Slide Time: 20:12)



good. So earlier when we were also doing our B Tech and M Tech, have you heard of a company I D P L?

Student: Hyderabad.

Professor: Yes, Hyderabad. They had various units but Hyderabad was mainly pharmaceutical unit. They have surgical unit.

(Professor – student conversation ends)

I D P L means Indian Drugs and Pharmaceuticals Limited, Ok. Totally that was destroyed by the people who were working there inside, you know the employers, sorry, the employees. What they did was they just, you know duplicated the technology; there was some sulpha drug, this drug. I also took training at that time.

In R E C Warrangal was one place where we had chemical plant engineering even in B Tech. So one semester, we had to go for industrial training. One semester. It is not in-between the semesters where you have 3 weeks, 4 weeks like that. So one week, I mean one semester we were there in Hyderabad, some people went to FACT, Kerala, F A C T. F A C T and some people went to Bombay NOCIL.

And because at that time of course our strength was only 30, now also may be 30, 45 they have increased, Ok, in R E C Warangal I am telling, now N I T Warangal. So when we went there, at that time it was running Ok. But after 10 years later when we saw, in the news and all that, that entire company was totally destroyed.

What happened was the people who are working there; they simply copied the technology because we know only temperature, pressure what is the size of the vessel, simply duplicate it outside. Take to I D P L 0:21:49.2, you know that Balanagar area, you are familiar with thing, there.

There were many, many pharmaceutical companies that have come there. All of them, you know normally we have a partner called wife, so wife's name for that company. Because this fellow cannot start on his name. He is working still there. He is getting salary here but he is producing same thing in some other unit.

And then he was trying to send it to some other, not export but other companies where most of the pharmaceutical companies, if they are producing headache tablet, they collect material here and there and only mix and then tablet and then give it to you, putting Novalgin name.

Or Dispirin name. Ok. Now I do not know. Now Chinese have dumping I think lot of those things here. Right.

So but unfortunately what has happened, or fortunately we do not know, what has happened there was that if there is some problem there, they were not able to solve. Because they know only that temperature, that pressure, that volume of the vessel and, that is all, that kind of stirring. And many units have been closed may be after 5, 6, 7, 8 years because the product was not coming the way they expected.

Most of the time the color is changing. Because you do not know how to control that. There are no fundamentals. That is what you know, technology stayed but even then few companies have survived because now they started using their brains, that means they went to technology to engineering how to solve; that color removal for example. And then from there to science if it is required, right? That is one way. So technology, engineering and science.

In the beginning itself you understand all the science in the lab with the help of chemists, right and then try to find out under what conditions you will get very purest form of product, when you do not get the colors, all that you understand. And then start. And you know engineering principles are heat transfer and heat removal for example, or heat addition or stirring or you know, collecting the filtration, tableting all these are engineering applications, I mean engineering principles.

So then finally Novalgin tablet will have this condition, this condition, this condition, this condition if you want to produce Novalgin. That is what is technology. Because again you know I am just giving you, many people lifelong we may not remember what is the difference between, we may not know what is the difference between science, engineering and technology.

This Saturday I was there in Guntur, one college, R V R J C college also, and because my friend is Vice-Chancellor now in Vignan. We both did P h D here in I I T Madras, one V G Rao, Professor V G Rao. So he was also there in Vignan University. He also just asked me, just why do not you come there? Because I had morning off, afternoon there was a lecture.

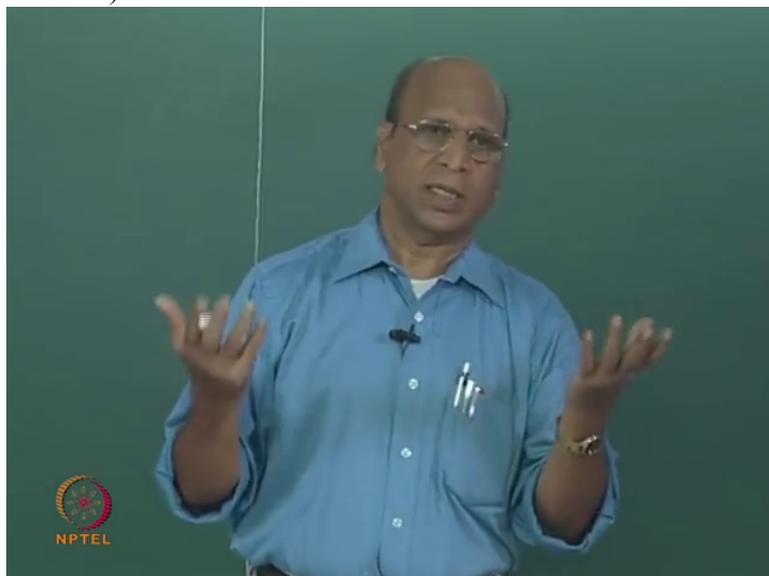
Lecture is not for students, for faculty only, their faculty, not chemical engineering, all faculty about research. That is why I went there. What is research, because they have many, they have

(Refer Slide Time: 24:46)



240 faculty members out of that may be I think around 30 or 35, or may be around 30 have the P h Ds, Ok. You may think that

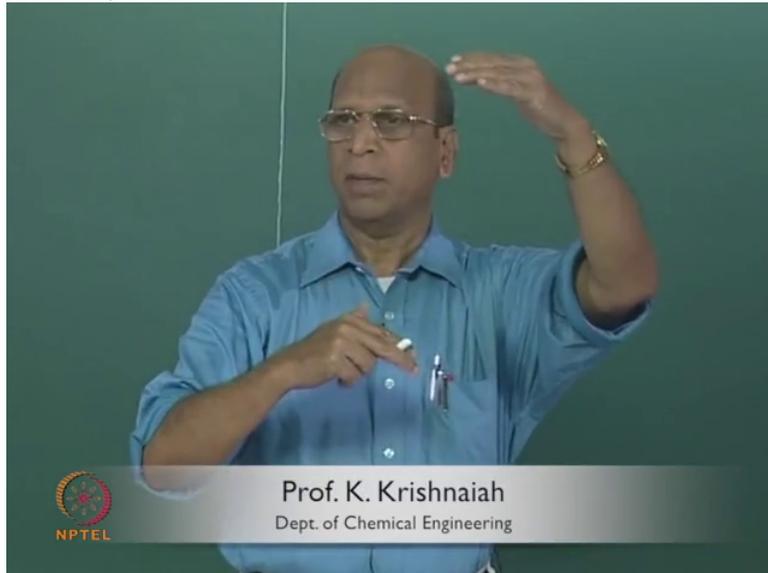
(Refer Slide Time: 24:57)



so what? I think there are many people with P h Ds who do not know anything still, Ok. But I think in academic institution that gradient must be as much as possible.

Gradient means

(Refer Slide Time: 25:07)



P h D to B Tech teaching. Now if you go to many private engineering colleges, B tech teaching to B Tech, Ok. He would have just finished now final year and would have got the result and immediately he is asked to teach, again B Tech people, maybe third year, second year whatever. So where is that gradient, that ΔC , concentration gradient?

Because this fellow may be in equilibrium, that fellow may be, how much time, may be 1 year before or 6 months before. So that accumulation of knowledge is not that easy to do. So that is why I just went and told them that you know, at least for your self-confidence, even if you do not teach well, that confidence you will have there at least, I can teach if you do P h D.

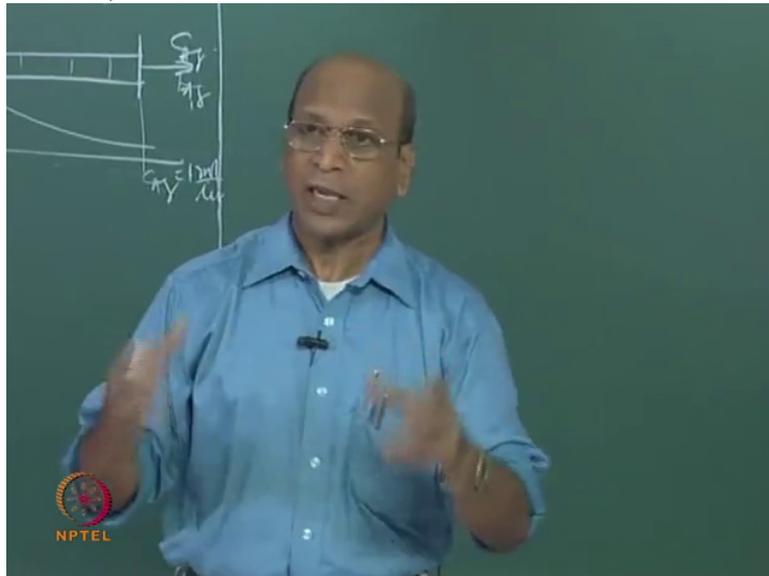
(Refer Slide Time: 25:46)



And when when you are doing P h D, a good P h D makes you think, that is all.

So wonderful quotations are there. Aurobindo told that no one can teach anyone. Really no one can be taught. When you are listening to me; that means your mind is already thinking about that. That is why you are listening. So but only thing is, as a teacher I can only make you think. That is what all my classes last 15-20 years. Before that I do not even know what I have done. Ok. First 5 years or so, right?

(Refer Slide Time: 26:20)



So that is why so many questions I raise even if you do not raise. Because those questions are supposed to make you think. That is all. Why I was telling was that I asked the same question. In Vignan College I asked the same question, what is the difference between science, engineering and you know technology and I also asked them, I do not know whether I told you this particular thing, Ok, in the last class, I mean, the beginning.

I asked them, I think there were chemical engineering students when I met in Vignan. And I told them that you know, you have, you have written your examination, that M-CET examination in Andhra. They call MCET. still they call MCET or? Yeah that examination and so your subjects were Maths, Physics, Chemistry. Correct no? Only Maths, Physics, Chemistry. Then you joined R V R J C College in chemical engineering.

And do you know what is the degree you are getting? That is what I asked them. Some people kept quiet, they do not even know. Poor fellows you know, (laugh) nice guys, they do

not want to know what is the degree also. Some people said we get technology. Yeah, that is what precisely I wanted to ask you.

You started with basic science courses and then you passed that. Then suddenly you came to R V R J C and then depending on your rank and all that then you are given chemical engineering. Chemical engineering Ok, it is not chemical technology what they got. And at the end of 4 years you are going to get chemical technology.

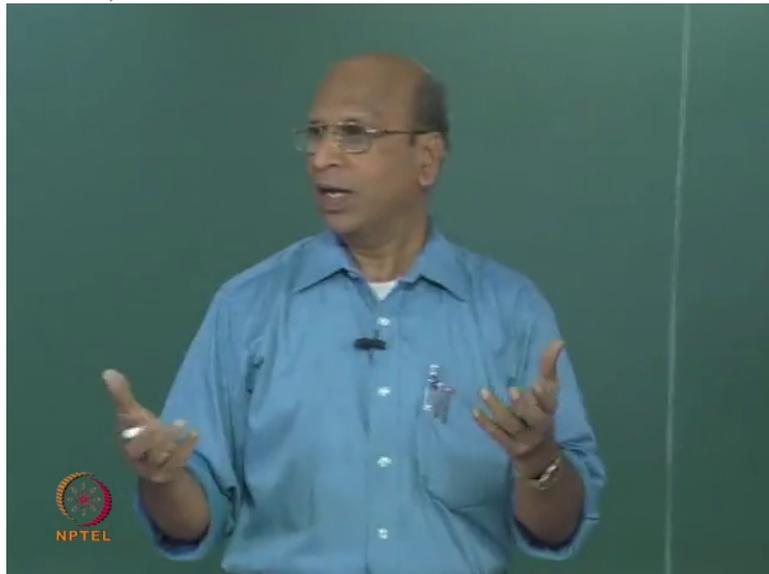
Have you any time thought

(Refer Slide Time: 27:49)



what is the connection between these three? I tell the same thing everywhere (laugh). Did I ask this question? Ok, I also told you,

(Refer Slide Time: 27:59)



yeah, yeah. So not even one, could not. And I saw there were 6-7 faculties and the faculty members; at least I observed some three, that their face also has shrunk a little bit. That means they also do not know. That is not their fault. I am not finding any blame, Ok.

Because I was interested in that so I first questioned myself, I also do not know when first I joined here, what is the difference between science, engineering and technology? Later I had to see many things because no book you find this, I tell you. And some journal papers are you know about technology. You have to go to Humanities journals and all that finding out what is the definition of technology.

So when I am doing that only finally I thought that this is the logical explanation for, and now I think, so many people say this is the same thing what we are discussing. So that is why the technology is totally different but always you can start from technology to science, or science to, that is only left to you.

But there are some things where you cannot start with trial and error. For example aeroplane design, Ok. Or rocket design. These are all highly sophisticated, Ok. They have to solve all the fluid mechanics equations. There are only 2, 3 forces, right? Buoyancy, lift and drag that is all. You can make, I think, even a 100 tons object to fly using only these forces. But you should have the feel for that 3 forces. Ok then only you can solve that problem. Otherwise you cannot.

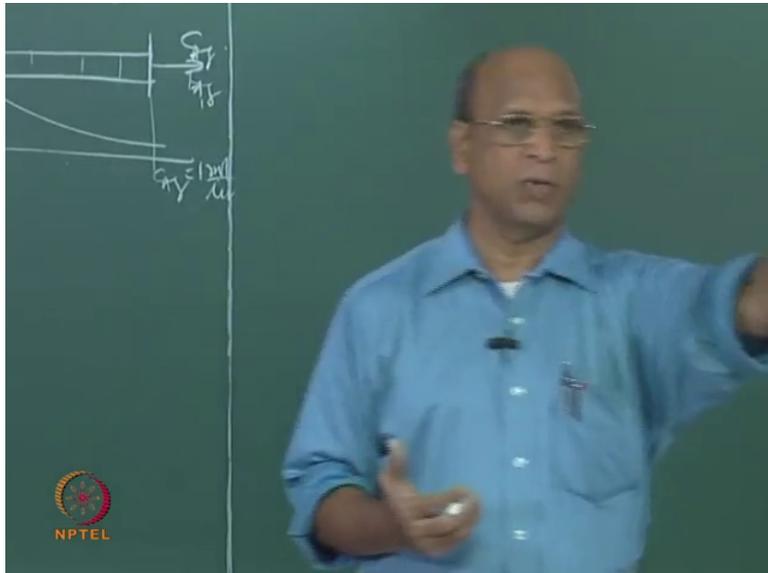
And you do not have to worry drag, lift and what is the other one, buoyancy when you are designing a bullock cart, correct no? In villages who is using computers to

(Refer Slide Time: 29:37)



design bullock carts? No one, no? Very happily they will do it. I think this is by experience, family, family-wise it will come.

(Refer Slide Time: 29:46)



One family in the village will be experts only in making bullock carts. So they know what is the size of the wheel.

But if you go to science again there is tremendous science. And this science through technology those people have perfected and you know by wrongly designing the lengthwise

and where you keep those, I am talking about bullock cart, where you keep those big wheels, why should they be first of all, so big. There is beautiful theory in that.

And where in between you put, is it in-between or slightly behind or slightly front? If you change wrongly the bull will die and you have to pull it. (laugh) Ok, because you know, its neck will be strained. That design is also there in that. But by experience they got it. Ok, that is what is technology.

For example brick I told you another example, brick technology. Try to make scientific bricks. Then you have to go to materials, you know what is that, material science course what you have taken and you have to find out strength of these each grain. And strength of multi-grain. How do you put them? What should be the amount of mud? What should be the amount of the solids, what is the particle size, how the orientation, what is the temperature to sinter?

All that things, that is science. How many people are using that? Still many houses are safe, no? I think many, many houses are safe. So that is why I think all these things are important but you have to think about this. You have to discuss in your mind, you know.

Finally there also I told all faculties, most important thing for all of us is that, this, brain. Ok, unless you have that good brain, you can never deliver either in teaching or even in research. And 3 hours I have taken, continuously. Ok, they have not slept. I can see that (laugh), Ok. They have not slept there. I think in between jokes and all that were there, so I thought they have enjoyed.

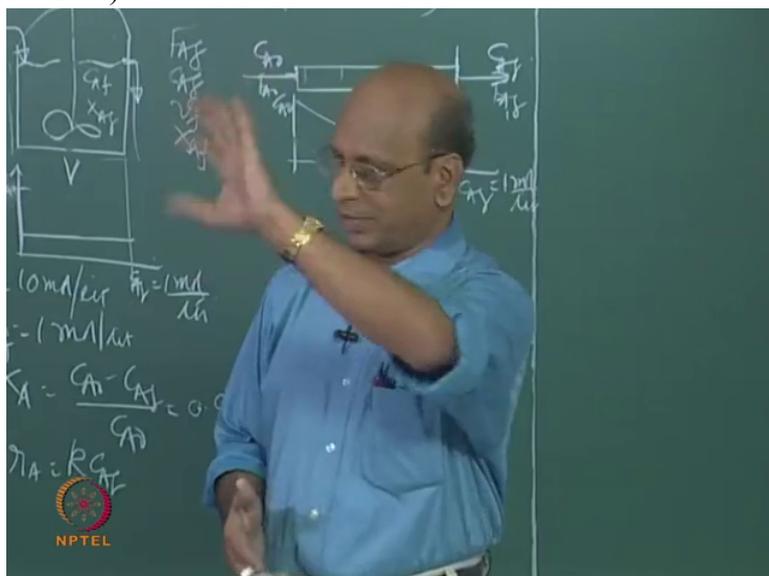
That too when? Saturday evening, 3 to, 2 to 5. Very difficult to, I told them. Very difficult to keep you here

(Refer Slide Time: 31:57)



but still try, that is all. I think except some 4-5 where they have to go and all; I think there were almost around 150 people. The only 4-5 people went

(Refer Slide Time: 32:06)

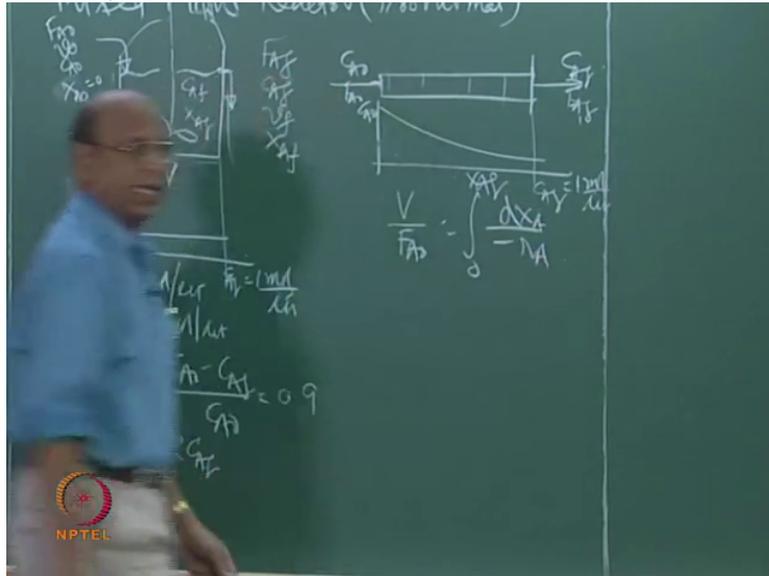


after last half an hour that is all. May be they had some work.

Anyway this is the one. So I was trying to encourage you to take, you know, to think and then ask me questions. If you do not get any doubt now, when you are preparing for the exams you will get definitely doubts. At that time you can ask, Ok? Yeah, good. So this is the one.

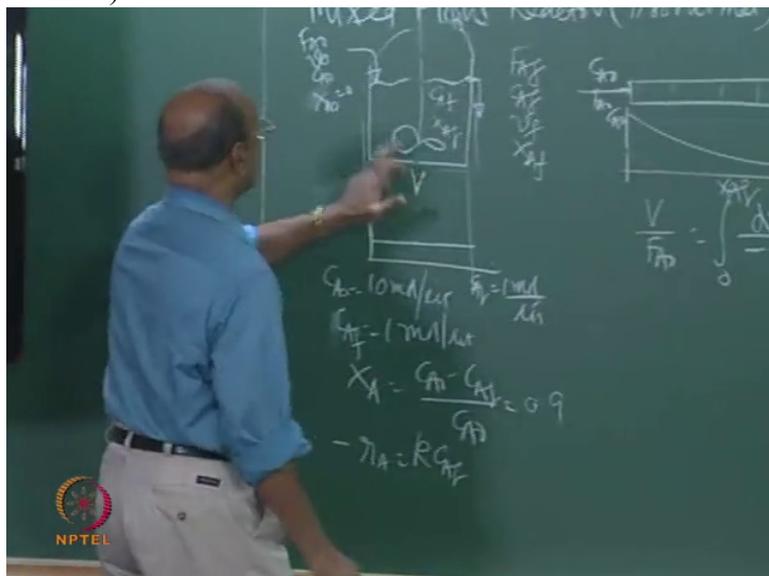
Now once we understand this, here we have developed an equation, right? So that equation was V by $F A$ naught equal to...these things you have to remember, whoever it is, $d X A$ by

(Refer Slide Time: 32:38)



minus r_A . Now let us also derive the equation for this which is very, very, very simple, Ok. So for this,

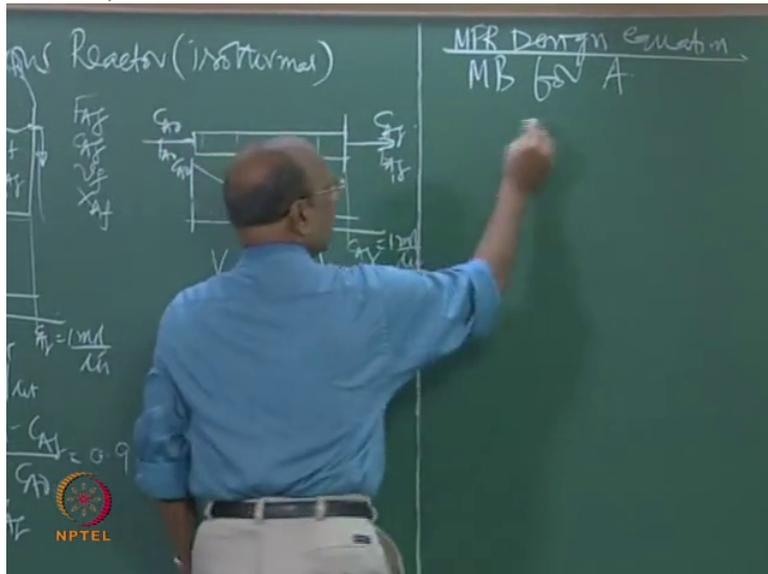
(Refer Slide Time: 32:45)



mixed flow reactor also when you are writing an equation, it is isothermal, so we have to write only mass balance equation.

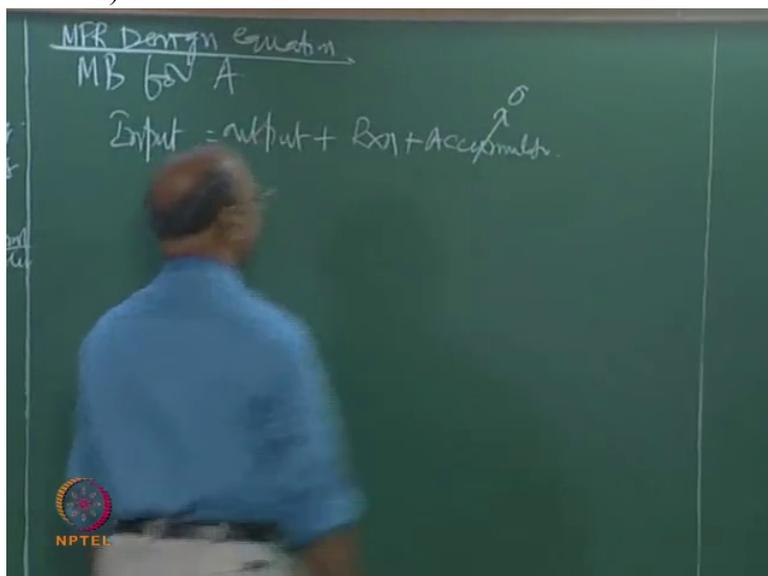
And mass balance equation M B for A, this is M F R design equation, yeah. M B for A will be

(Refer Slide Time: 33:11)



universal equation tells me it is input of A equal to output plus, yeah plus reaction plus accumulation, Ok and as I told you we are steady state people so

(Refer Slide Time: 33:31)



that will be zero and the, this mass balance, you can write mass means mass only, no k g, right, I have to write k g entered, k g leaving and all that, right.

But we can also convert that into moles. But why do you do that in chemical engineering? Particularly reaction engineering. See the moment you go for distillation column, do you use moles, how many entering, moles coming? What do you use there? Bala? You are Bala no? Yes.

(Refer Slide Time: 34:08)



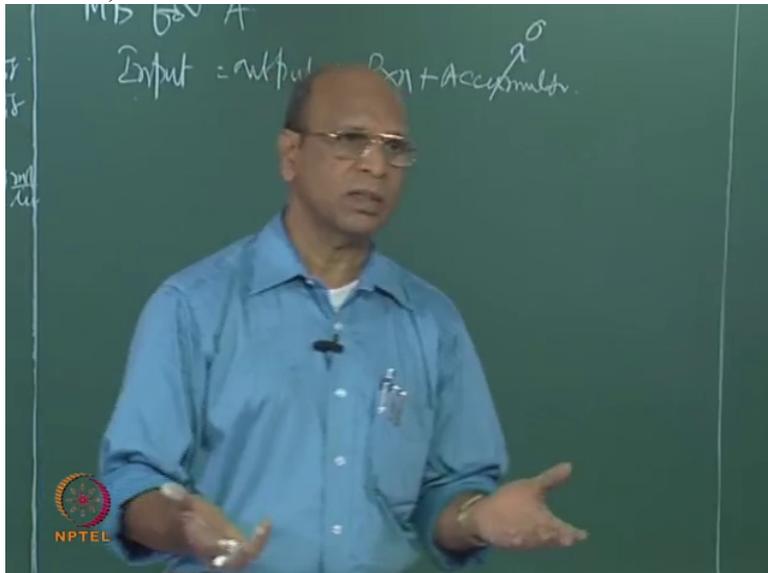
(Professor – student conversation starts)

Student: Input

Professor: Input and output to distillation column.

Student: Large scale

(Refer Slide Time: 34:12)



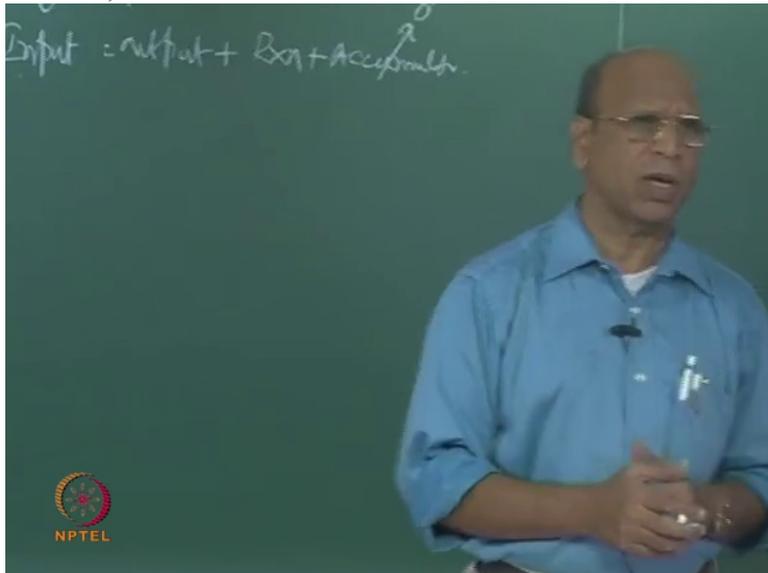
Professor: Normally standard question is 100 k g per hour.

(Refer Slide Time: 34:16)



right, Ok. Yeah like that only we do not use

(Refer Slide Time: 34:20)



right, Ok. Yeah like that only we do not use 0:34:20.4, and for example heat transfer?

(Professor – student conversation ends)

You know these are simple things where you would not have thought, I say. That is what I am trying to do those connections. Right? And I also found in some interviews when I asked Ok, why are you using moles in the reaction engineering? And heat transfer and mass transfer you are using only, the mass yeah, actually mass in terms of k gs, I do not get answers easily.

And the same problem even in mechanical engineering even for chemical reactions they use mass. They use combustion, no, for combustion reaction, simply write you know 12 k gs of carbon reacting with, easy to relate. Easiest is only 1 mole, 1 mole, 1 mole. Depending on the stoichiometry.

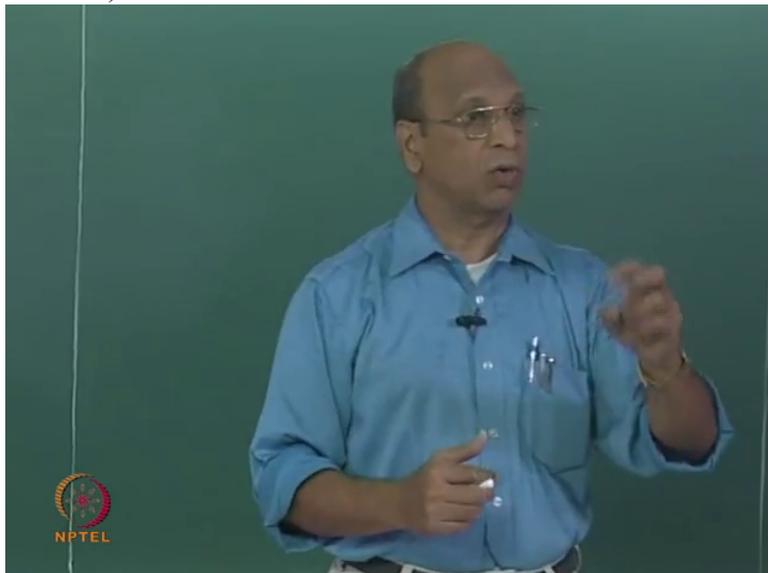
Otherwise 1 mole needs 2 moles

(Refer Slide Time: 35:07)



to give 5 moles. Otherwise you just now see,

(Refer Slide Time: 35:10)



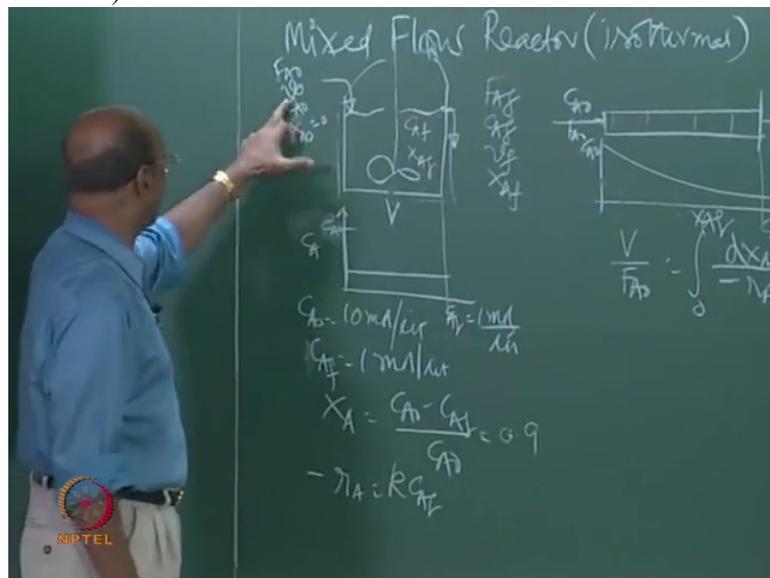
that you know 100 grams here, Ok, 100 k gs here another 500 k gs here giving me 600 k gs. Mass cannot be produced 0:35:20.8, so that balance so this is why, this is what exactly what you have also done in your batch reactor design problem.

If you convert everything into moles that is easy. What you calculated you know that 769, divided by number of batches are known, no, no, 10 tons divided by number of batches is only mass, but if you convert that into moles, then so many moles have been produced, acetic acid no, yes ethyl acetate, ethyl acetate. To produce that how many moles of acetic acid is required?

I think acetic acid is the key component. So many moles. But if you can calculate, may be 6 moles, 6 moles, but this 6 moles equivalent to only 30 percent because your conversion is only 30 percent. That is why you have to now compensate that. You have to take that, divided by point 3 will give you more number of moles that should be in the reactor.

What you have assumed is 100 percent conversion. The first time you made that mistake. So that is why very simple balance only, that is the reason why all the time you will go for moles. That is why here also you will have moles per second because it is flow reactor so and I know here, our units F_A naught is moles, volume is volumetric flow rate,

(Refer Slide Time: 36:41)

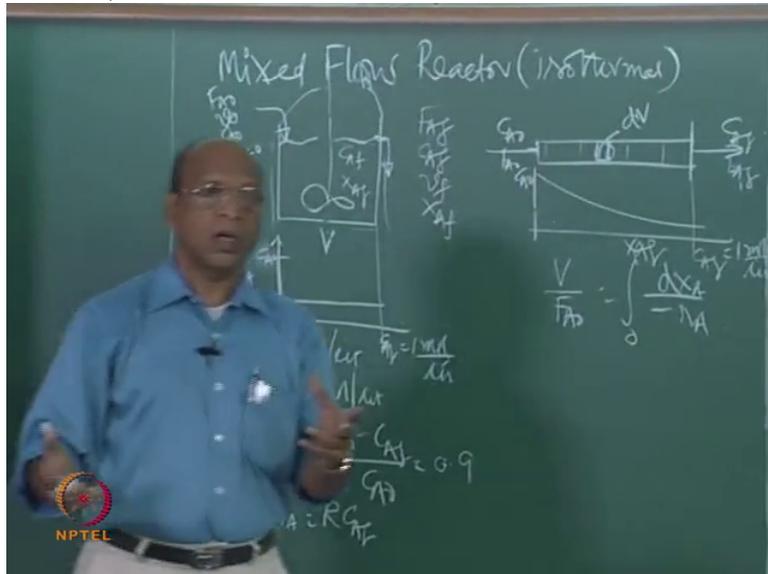


meter cube per second. C_A naught here you can use kg moles or gram moles per liter. And X_A naught is zero. Anyway that does not have any units.

So here I will simply write F_A zero, number of moles that are entering per unit time and output is F_A f very simple, here, then reaction is minus r_A into V , V is the total volume.

Earlier we had taken only , yeah , only differential elements, that is all, what the volumetric, this is dV why, again I am telling.

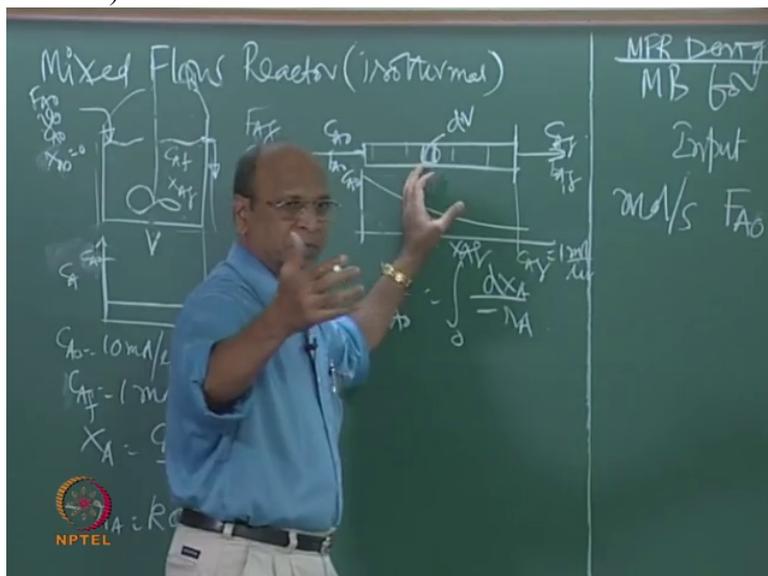
(Refer Slide Time: 37:20)



Yeah, so this is the distributed parametric system. That means there is distribution of concentration along the length. it is not one concentration. It is not one concentration. It is not lumped, lumped means everything together, right.

So that is the reason why, whenever you have changes within the system,

(Refer Slide Time: 37:39)

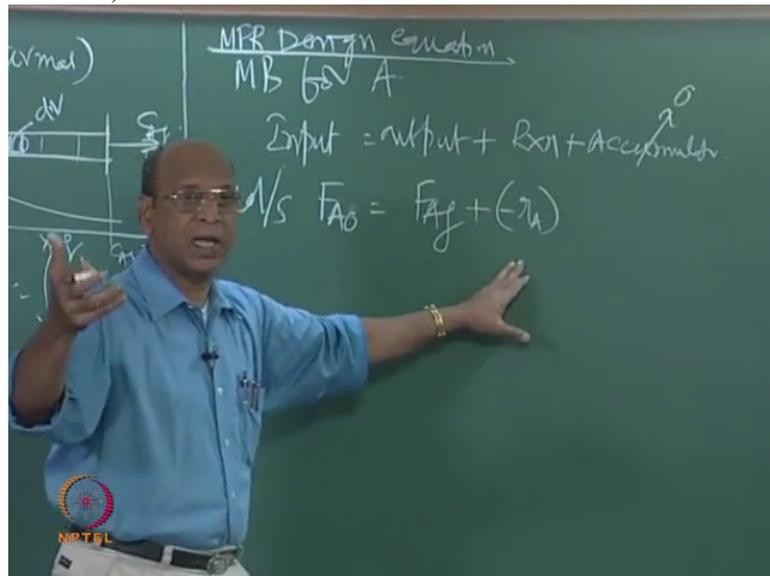


either temperature or concentration, because you know, we are either talking about energy balance or mass balance or momentum balance, these three, right? So there you have to

assume a small element and finally when we write input output and then expand that with boundary conditions you will get a differential equation.

Whereas in lumped parameters, that means everything together, there is no change at all here, You do not get a differential equation. You simply get a

(Refer Slide Time: 38:05)

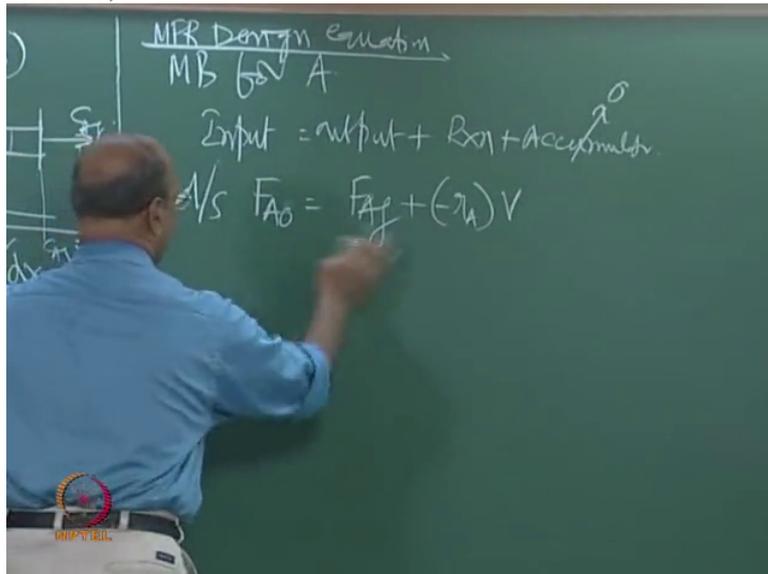


algebraic equation. So that is why here minus $r A$, change is only in this V , total V . There is no change here. If I take a small element here, what do you write? I cannot write anything. Because concentration is same.

Yeah the concentration is same throughout the element, $r A$ is also same throughout that element. Not only that element, entire system $r A$ is same. So I cannot write anything, no changes. So that is the reason you take the whole volume $r V$, anyway that is equal to zero, right?

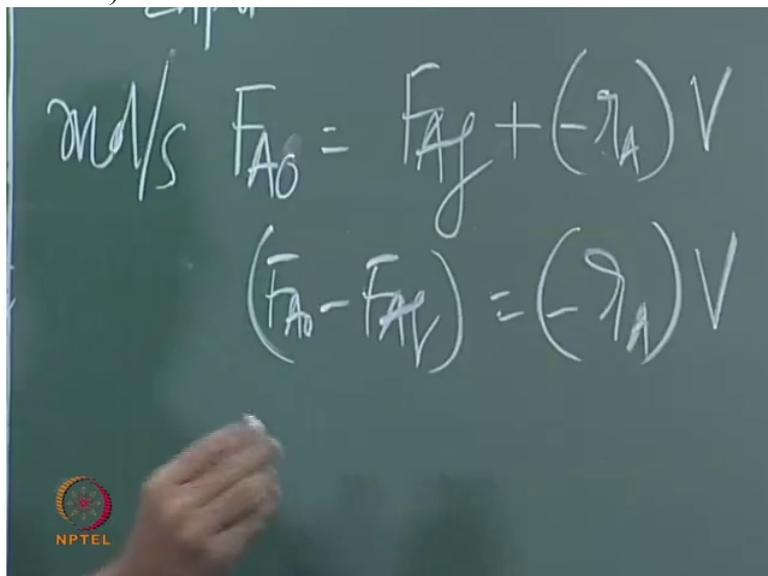
So

(Refer Slide Time: 38:37)



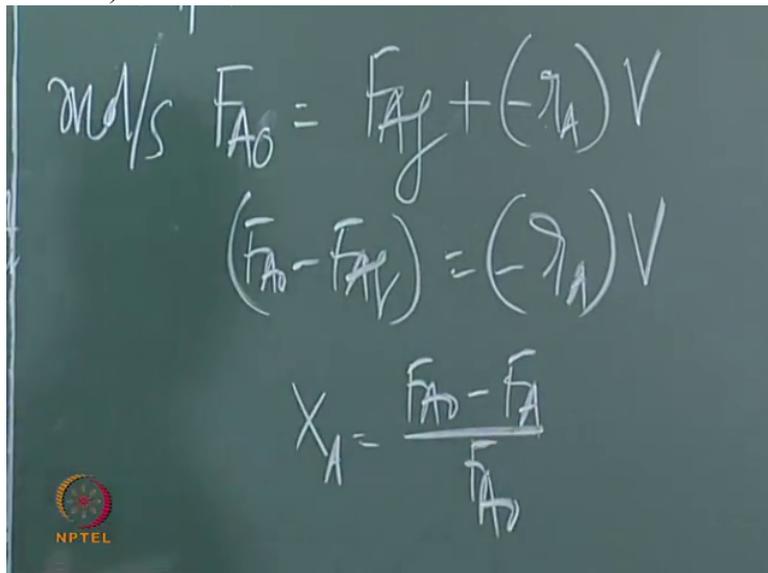
if this I write, this will be F_{A0} minus F_{Af} equal to $-r_A V$ so in our normal term, you know in conversions if you are able to express this, what is the conversion equation we have given for

(Refer Slide Time: 38:53)



flow system? F_{A0} minus F_{Af} by F_{A0} .

(Refer Slide Time: 39:02)



Handwritten equations on a chalkboard:

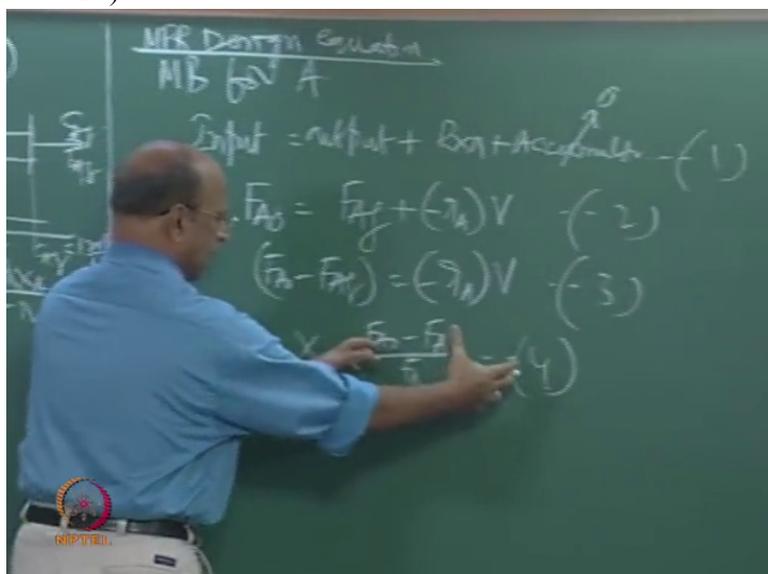
$$\text{mol/s } F_{A0} = F_{Af} + (-r_A)V$$
$$(F_{A0} - F_{Af}) = (-r_A)V$$
$$X_A = \frac{F_{A0} - F_{Af}}{F_{A0}}$$

NPTEL logo is visible in the bottom left corner.

F A f here is you know, otherwise I have to put X A f here. Ok good.

Anyway we will put that one here. So now, yeah this F A naught and F A f, if I convert this two to F A f, this is general definition of F A f, right, so then what I get here? This is equation 1, equation 2, equation 3, equation 4 then replacing

(Refer Slide Time: 39:26)



A person in a blue shirt is pointing at a chalkboard. The chalkboard contains the following text and equations:

MPR Design equation
MB for A

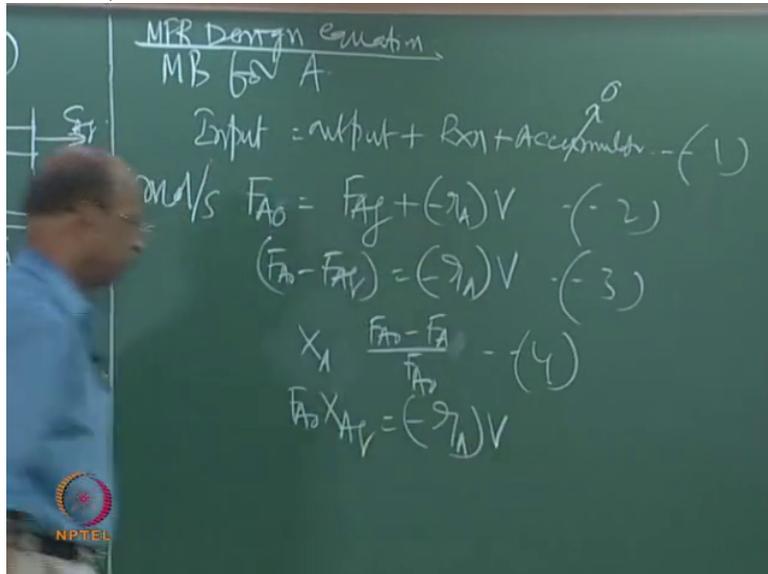
$$\text{Input} = \text{output} + B_{\text{out}} + A_{\text{consumption}} \quad (1)$$
$$F_{A0} = F_{Af} + (-r_A)V \quad (2)$$
$$(F_{A0} - F_{Af}) = (-r_A)V \quad (3)$$
$$X_A = \frac{F_{A0} - F_{Af}}{F_{A0}} \quad (4)$$

NPTEL logo is visible in the bottom left corner.

equation 4 in 3, please write there replacing equation 4 in 3, that will be F A naught X A f because we are talking about, this is general expression, Ok or if you are getting confused but I think no, not required, I say.

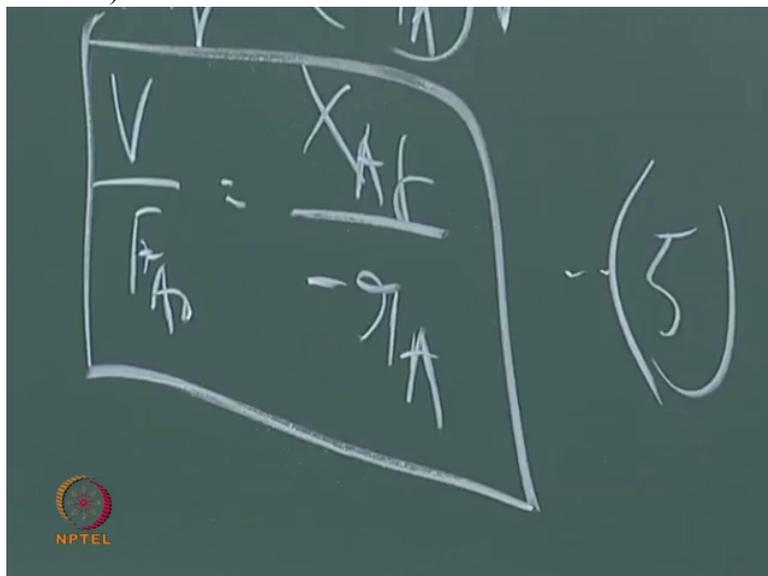
That should be general expression and you should be able to extend that, Ok. Yeah, so $X_A f$ equal to minus r_A into V ,

(Refer Slide Time: 39:54)



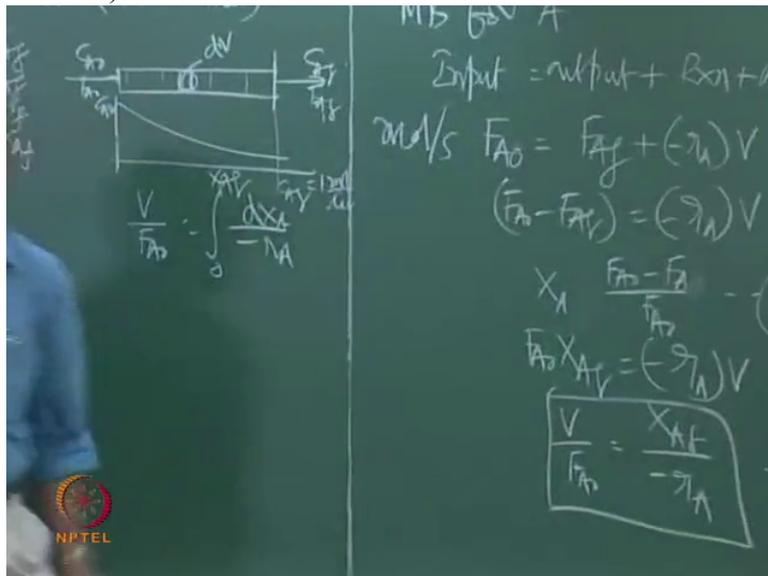
right so in this format when I want to compare this will be V by F_{A0} equal to X_{Af} by minus r_A . So this is equation what we get, this equation is 5, right? What is the difference between this

(Refer Slide Time: 40:15)



equation and this equation?

(Refer Slide Time: 40:16)



What does that tell you physically?

(Professor – student conversation starts)

Student: 0:40:25.9 different.

Student: 0:40:28.2 taken the average.

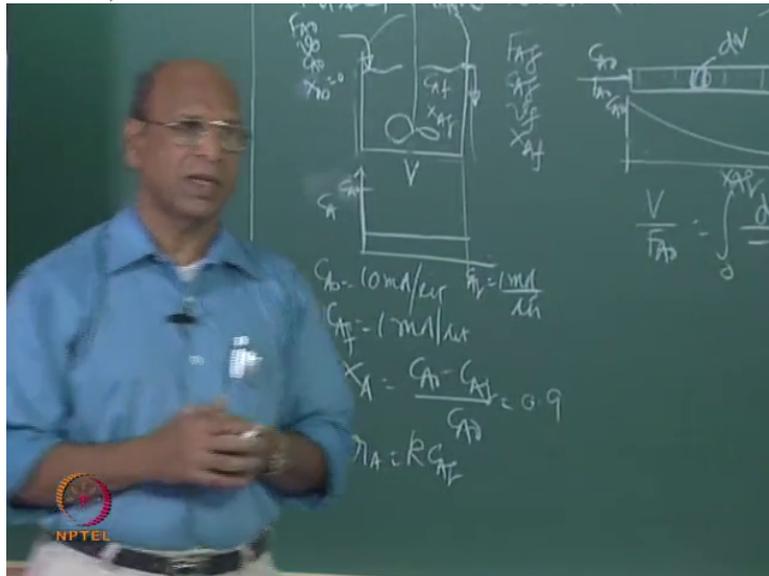
Student: 0:40:32.1 on a graph, minus 1 by r A and X A and there will be integral area

(Refer Slide Time: 40:35)



Professor: Yeah, within that integral you have that r A so what

(Refer Slide Time: 40:38)



does that mean?

Student: Different rates

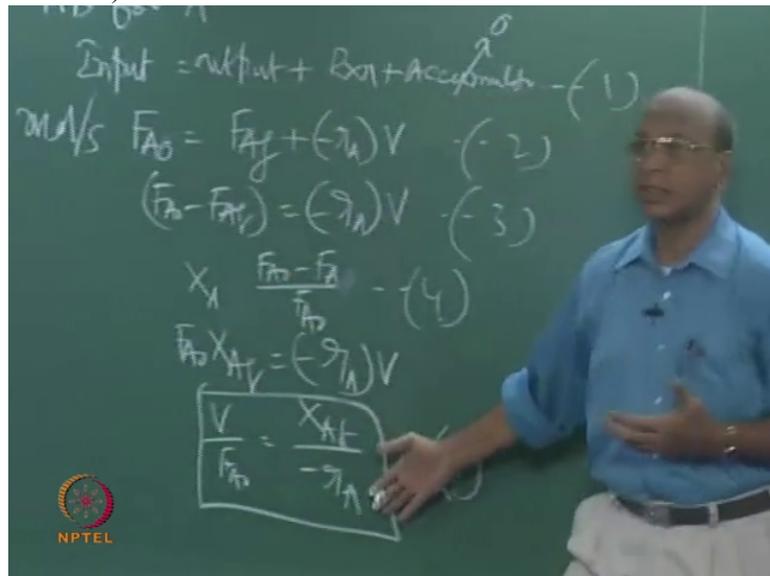
Professor: There are so many different rates where you are having some kind

(Refer Slide Time: 40:45)



of average of rates 0:40:47.0. Whereas here there is no

(Refer Slide Time: 40:50)



average. There is average but only one.

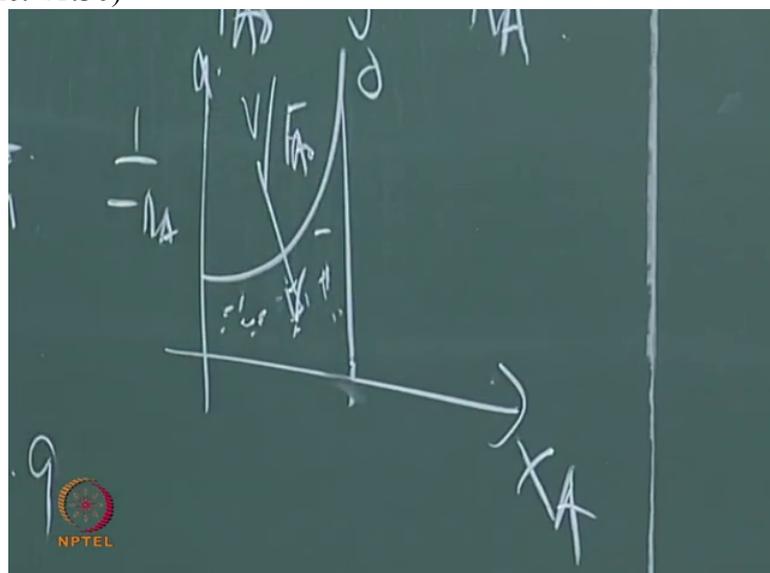
Student: One rate

Professor: Ok, so that is why here you will get here simple algebraic equation, there it is an integral equation because all these rates at various points I have to also average and that comes through mathematics under that integral.

(Professor – student conversation ends)

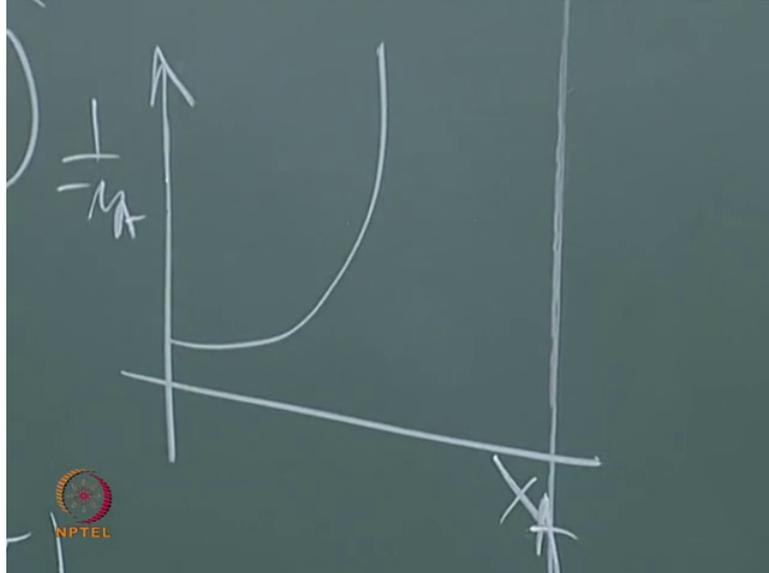
So that is the reason why if I plot this integral on 0:41:13.8 equation, I will get here, yeah 1 by minus r_A versus X_A , you will get this and this is the area under the curve, is equal to V by

(Refer Slide Time: 41:30)



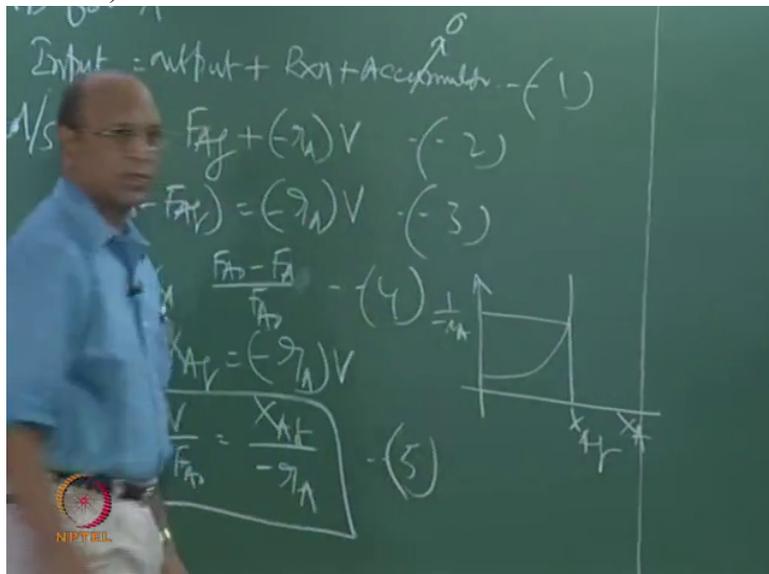
Same thing I also draw here, this is also $1 - r_A$ versus X_A . I get exactly no. Rate will not, $1 - r_A$ will not change. It is same thing, right?

(Refer Slide Time: 41:47)



For a given conversion, same X_A f, it is X_A f. Here also X_A f. What volume I have to take now? Not area under the curve. Because there is no integral there. So I have to have this

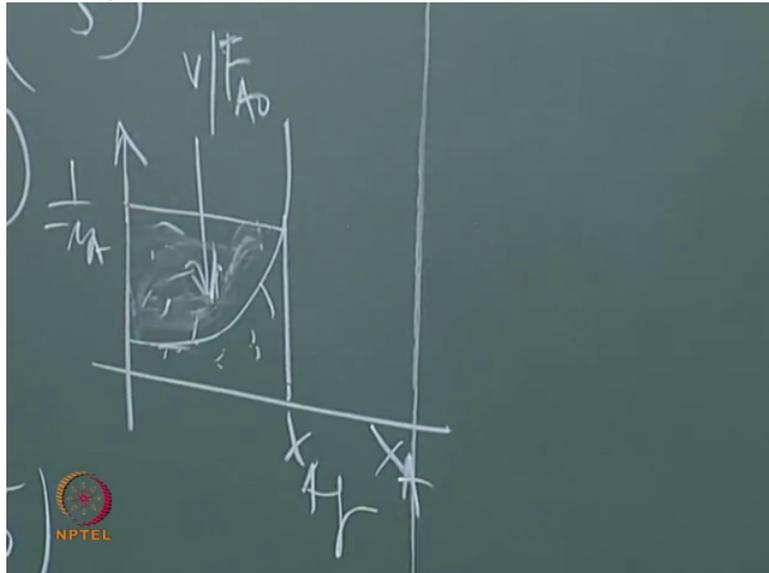
(Refer Slide Time: 42:04)



integral, sorry that rectangle area, Ok. So then this entire thing now will be V by F_A naught. And you see this is the area in terms of volume what you have to spend or what you have to provide more to compensate all that Residence Time Distribution.

That is why you know; again I can tell you that. yeah because this volume, this is the extra volume where, why this is happening? This is happening because I have more and more

(Refer Slide Time: 42:38)



Ok, more and more packets spending less and less time inside the reactor. So to compensate that I should have this much area more. And why should I take rectangle? This is another question which I ask many students may not answer. Why should I take, yes sorry? Tell me Anupriya.

(Professor – student conversation starts)

Student: No

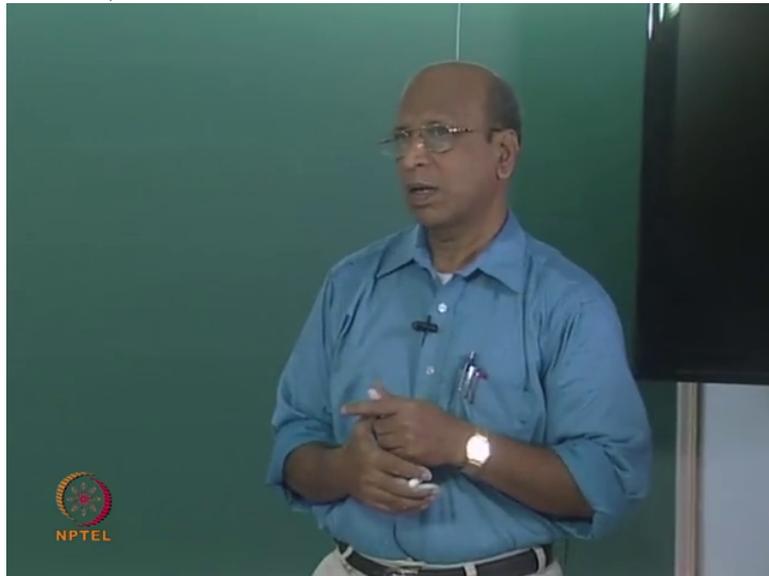
Professor: No idea? Yeah. Who else? 0:43:08.2 Why should I take here rectangle? There of course the area under the curve is that integral what you are talking. Many people may not know. 0:43:15.1 do you have any idea?

(Refer Slide Time: 43:16)



Student: The right hand side consists $X A$,

(Refer Slide Time: 43:21)



if I am plotting 1 by $\sin r A$ to $X A$,

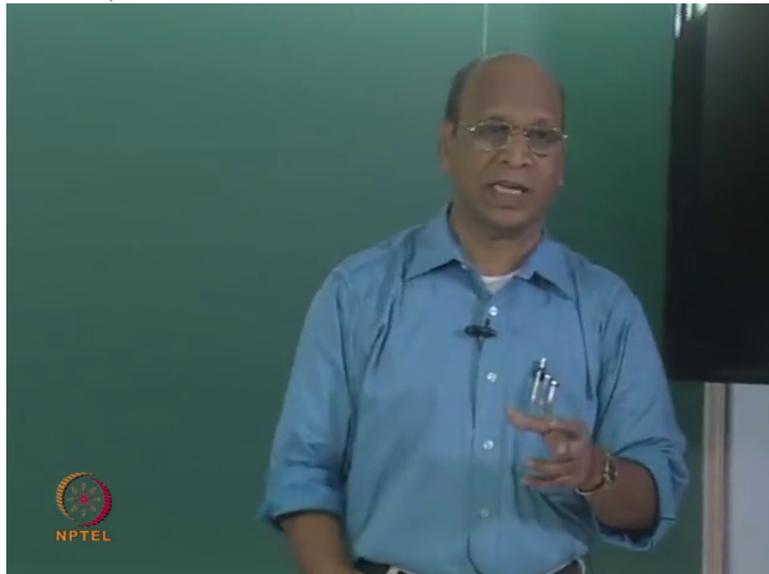
(Refer Slide Time: 43:25)



x into y that will give you the rectangle

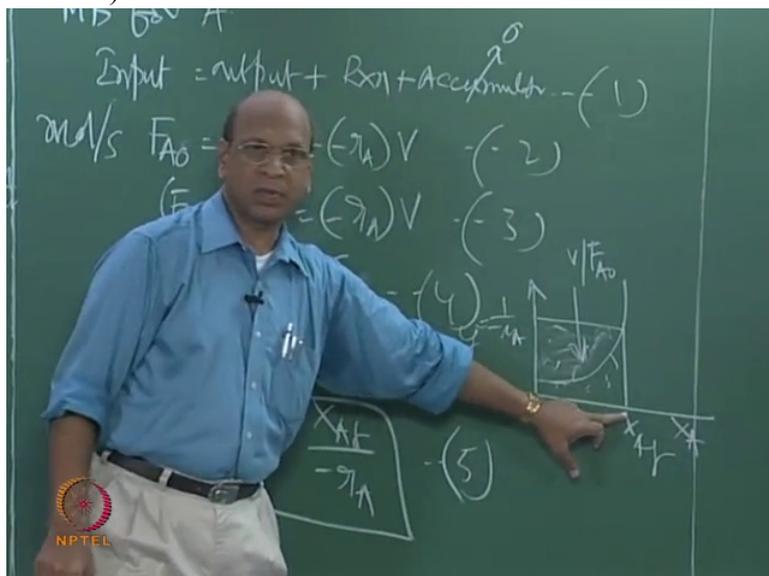
Professor: Yeah, I think you know most of them may not get that. Because

(Refer Slide Time: 43:30)



this is 1 by $\text{minus } r A$. Just assume 1 by $\text{minus } R A$ equal to y . Ok, simply 1 by $\text{minus } r A$ equal to y . Now this is y into $X A f$.

(Refer Slide Time: 43:45)



So y is, x into y , area of a

Student: Rectangle

Professor: That is all. I think but many people do not know that. Many people do not know.

(Professor – student conversation ends)

In my experience I talked to many students. They are not able to answer that. Why that is coming? Because simply instead of writing y , we are writing 1 by $\text{minus } r A$, so that is what you know we are doing wonderful things in mathematics because mathematics course is

mathematics, totally segregated, we do not know how to bring that information to our engineering.

That is why we started talking of you know, mathematics of chemical engineering so that once more can we combine? Yes, I think $\frac{dy}{dx}$ you know how to solve. $\frac{dy}{dx}$ as a function of some x and y . But the moment I write $\frac{dC_A}{dt}$, no idea. $\frac{dC_A}{dt}$ also is another first order differential equation, function of some concentration. So then we do not know how to do it.

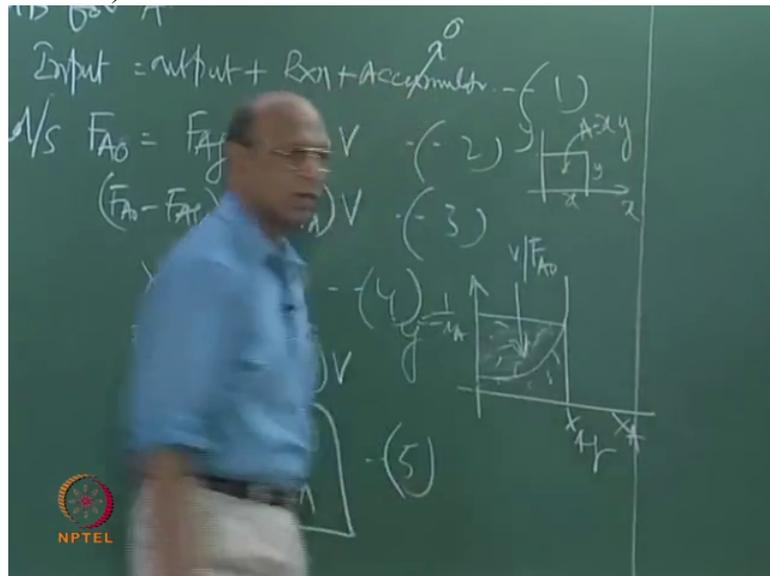
So that is why I think you know those mathematics are taught only for you to make comfortable in these subjects wherever this mathematics come. That is why this is simply, I think followed no, all of you...

(Refer Slide Time: 44:49)



See whenever I have a graph like this, this is y , this is x , and this is y , this is x so what is the area of this, x and y ,

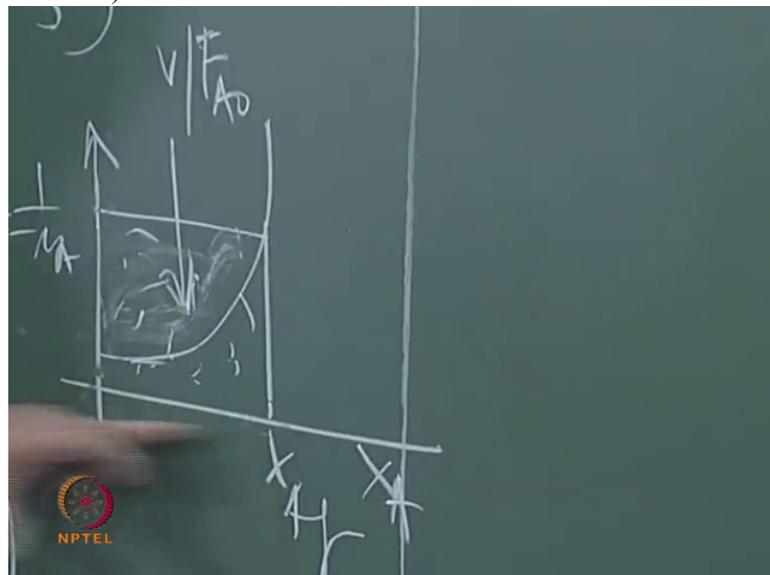
(Refer Slide Time: 45:03)



Ok.

So that is what we are doing. Instead of writing 1 by y, we have written 1 by minus r A which is a parameter like, you know y,

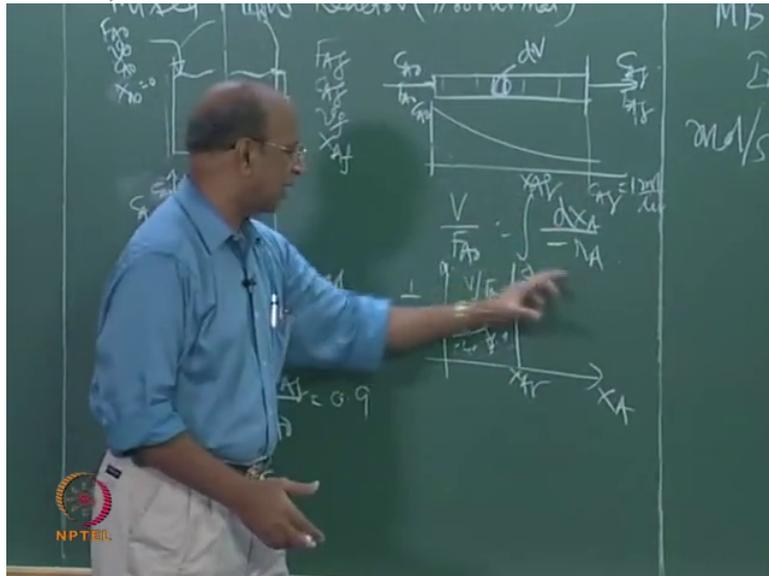
(Refer Slide Time: 45:13)



y into x will give me the total area which is coming from this equation. I have not done something else. It is coming from this equation.

Whereas here this will tell from

(Refer Slide Time: 45:24)



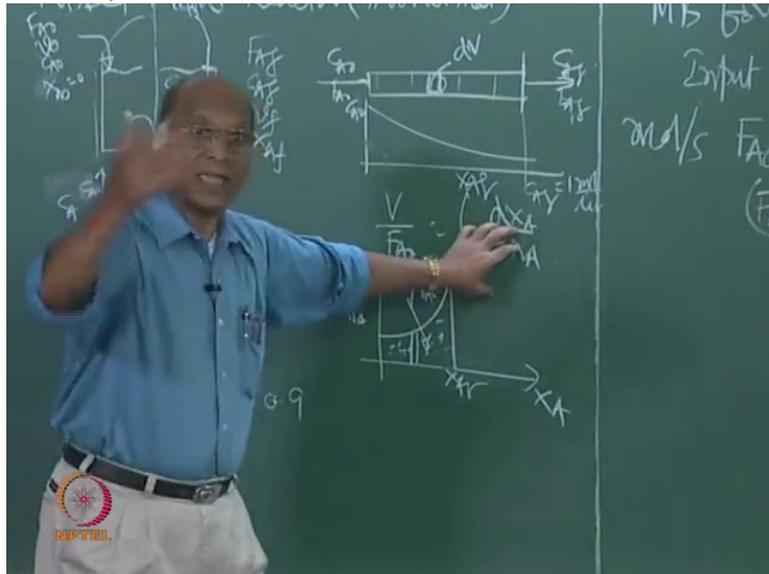
calculus, that this is area which I have taken a small strip, calculate what is the area, what is the area there, it is delta x multiplied by y, what is y there again, $1 - \frac{r}{A}$. So $y \, dx$. And then y, not $y \, dx$,

(Refer Slide Time: 45:49)



this is what is this, where we are averaging all these in this equation, so you will get

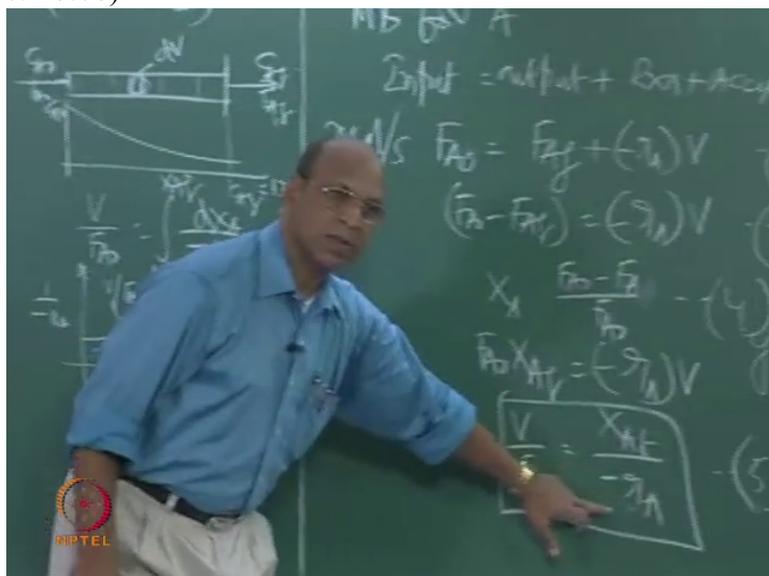
(Refer Slide Time: 45:55)



the average rate definitely more than the average rate of this, Ok.

You have understood no, this average rate is more than the

(Refer Slide Time: 46:06)



average rate of this. So that is why, this is more? More means you are dividing $d X_A$ by minus r_A , larger number. So volume will be

(Professor – student conversation starts)

Student: Less

Professor: For a given conversion. That always you have to tell. Ok.

(Professor – student conversation ends)

So because it is, minus r A is small there, that is why when you are dividing with smaller number, this volume will be larger. Ok good. So now when you compare this equation and this equation where is τ coming there? Why do we worry about τ there? In fact τ is not required, correct no.

By writing the natural material balance, material balance means moles, you automatically V . Why should I again calculate τ and τ equal to again volume by volumetric flow rate, another subroutine in the mind, so many things I have to remember? So simply that is why straightaway go for V by $F A$ naught. But why that τ has come? Can you just think? Why that τ should have come?

You have class no, yeah. Can you just think why that τ would have come?

(Professor – student conversation starts)

Student: It is more

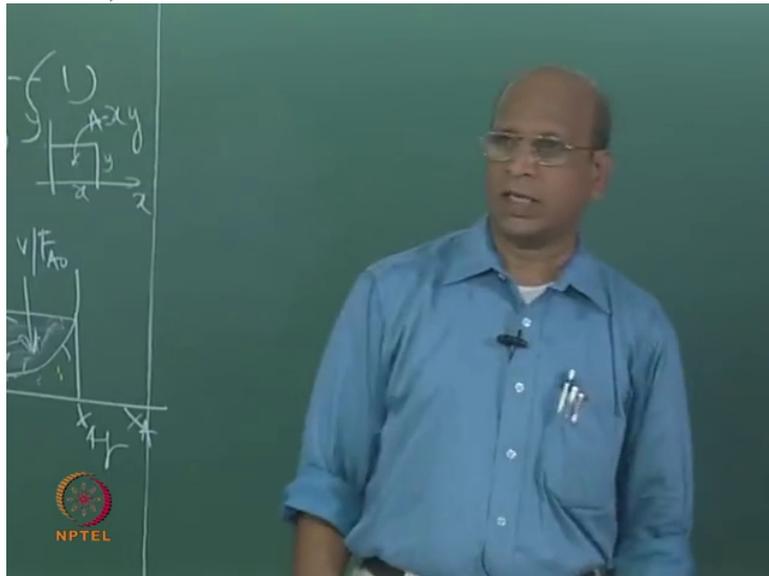
(Refer Slide Time: 47:20)



fluid.

Professor: Yeah so what? I know moles also

(Refer Slide Time: 47:28)



you can calculate, concentration also you can calculate because these two are known. Volumetric flow rate also you can calculate. But why? Why this another headache, or you know in Tamil that song, why this Kolaveri? Kolaveri only, correctly pronounced? I am here 35 years but I do not know how to speak Tamil. I understand. So why that Kolaveri? (laugh)

Student: (laugh)

Professor: It is not required, no? Can you think why then? Savita?

Student: 0:48:04.6

Professor: What is that?

Student: 0:48:07.3

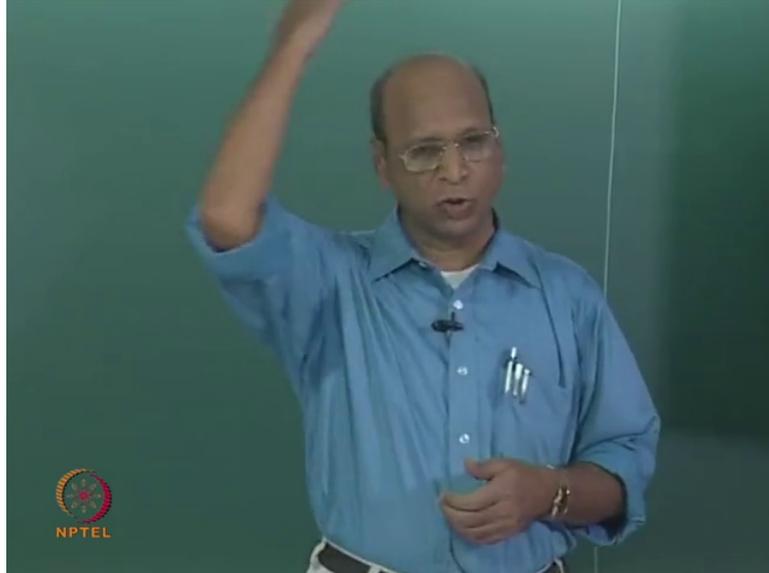
Professor: It is steady state no? See

(Refer Slide Time: 48:10)



this is steady state reactor, why do you need time? Do you need time? For steady state, steady state means

(Refer Slide Time: 48:15)



once you start it goes to how many years if there is no problem? Correct no, time will not come here. If you have batch reactor then I have to tell time.

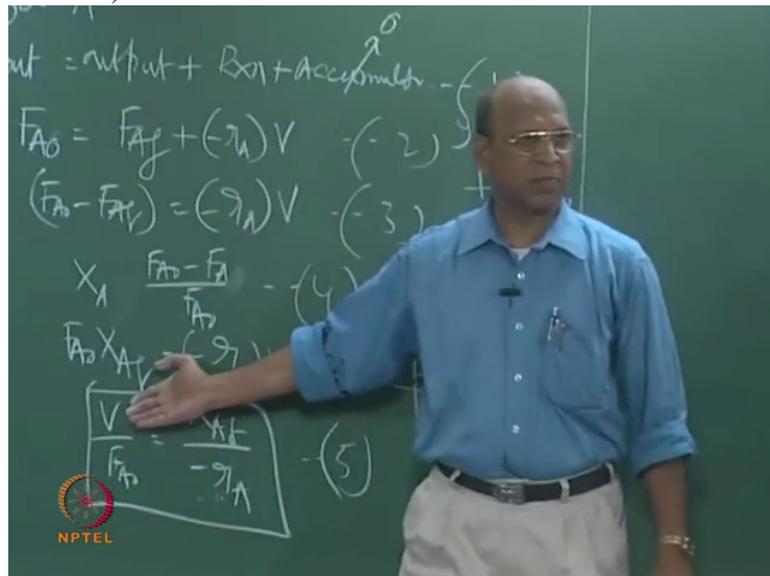
Student: Volume 0:48:27.5

(Refer Slide Time: 48:27)



Professor: Volume directly I am getting.

(Refer Slide Time: 48:30)



Student: 0:48:34.3

Professor: But why do I want to know that?

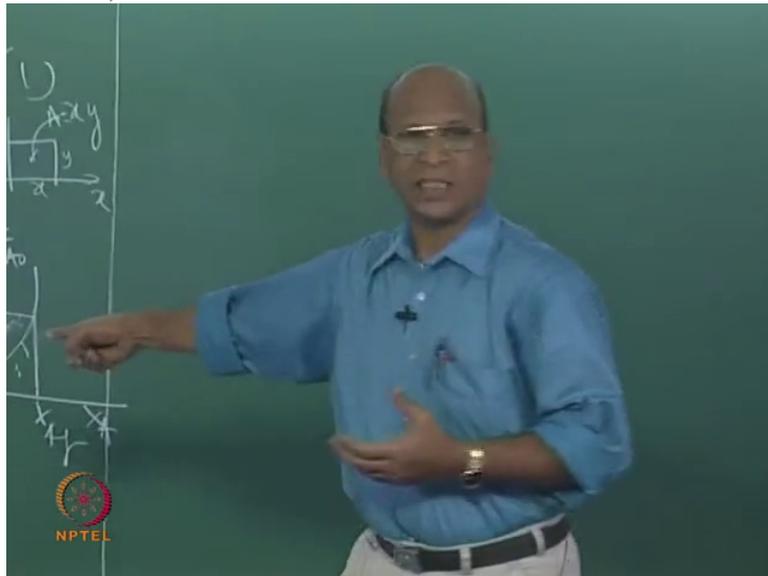
(Refer Slide Time: 48:37)



Student: There is

Professor: Because I do not need no, because

(Refer Slide Time: 48:39)

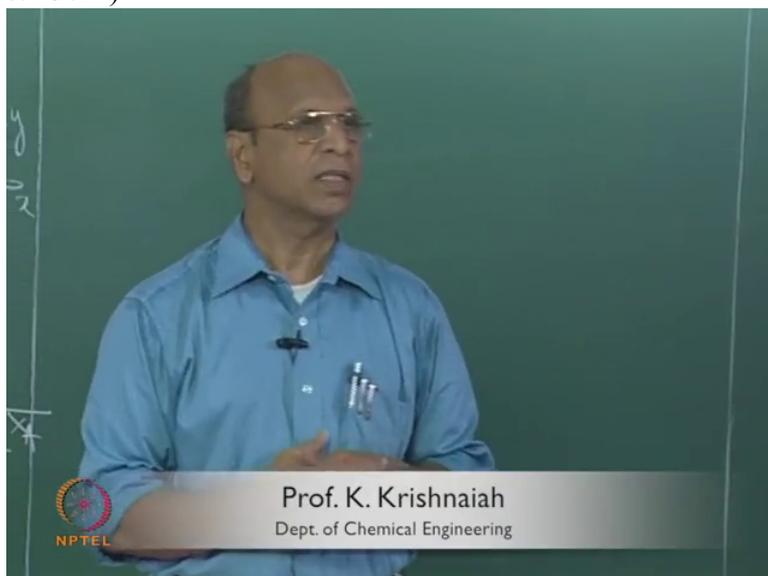


for producing that much conversion, I need that much volume. It is steady state reactor. And volume let us say 2 meter cubed I got. Why do I want to know again time? I am not saying whatever you are telling right or wrong. I am just making you think. I cannot teach you anything so I am just making you think.

Student: Flow rate

Professor: Flow rate, M B A, first I think, management, market survey. Flow rate is, that is one thing which you should know before even starting the calculations, correct no. You should know what is the capacity of the plant. What do you do? Either you do market survey or you will hire M B A guy and then come on, you go and get all the data,

(Refer Slide Time: 49:24)



how many tons.

Student: How much time when you get this much dispersion

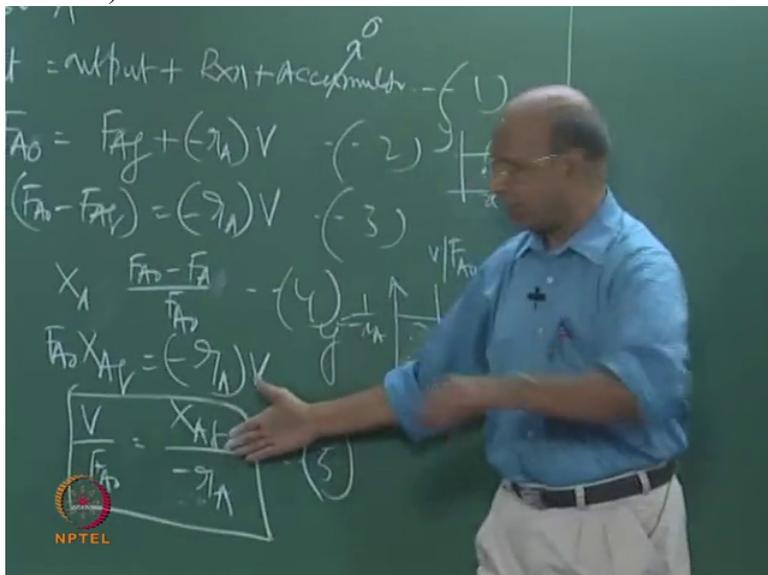
Professor: It is a steady state,

(Refer Slide Time: 49:31)



why do you want to know how much time? Continuously it is coming. Once

(Refer Slide Time: 49:36)



it is, once it attained that conversion, Ok, under steady state conditions, where is the time coming there?

(Professor – student conversation ends)

Answer is very simple. Because unfortunately we started derivation batch reactor. Because batch reactor has t by C_{A0} equal to...now whatever we studied in

(Refer Slide Time: 50:04)

The image shows a chalkboard with a handwritten equation:
$$\frac{t}{C_{A0}} = \int_0^{X_A} \frac{dX_A}{-r_A}$$
 The equation is written in white chalk on a dark green background. In the bottom left corner of the chalkboard, there is a small circular logo with a red and white star-like pattern and the text 'NPTEL' below it.

L K G only, that is strongly printed here, correct no? We do not forget alphabet also in L K G. But this is L K G for us. Batch reactor was the first.

So there it is in terms of time, now we thought you know always other reactors, you know also in terms of time, which is not required. Ok. So this time, this time is the batch time, batch reaction time. So because I have this t by C_{A0} , I would also like to write this equation as τ by C_{A0} . So that you know I do not have to remember. That is all, only for that reason.

Otherwise if you want to really calculate volume of the reactor, you do not need. That expression is sufficient. That is why just remember that. It means it is not a great thing what I am trying to tell here, but you know some things which are not useful, not required for us. That you understood no? Only for similarity, because that is τ , right?

This is t by C_{A0} which we started our B Tech, you know the first reactor. So that is why our mind goes, Ok let me also write in that same term so that, same format, so that I will remember what is the, uniform format. So now this we can convert as τ by C_{A0} and write for mixed flow. That also you can convert as τ by C_{A0} and write, because V by F_{A0} equal to τ by C_{A0} , no. You know how that comes?

Where τ equal to, τ is defined as volume by

(Professor – student conversation starts)

(Refer Slide Time: 51:34)



Student: Volumetric flow rate

Professor: Volumetric flow rate.

(Professor – student conversation ends)