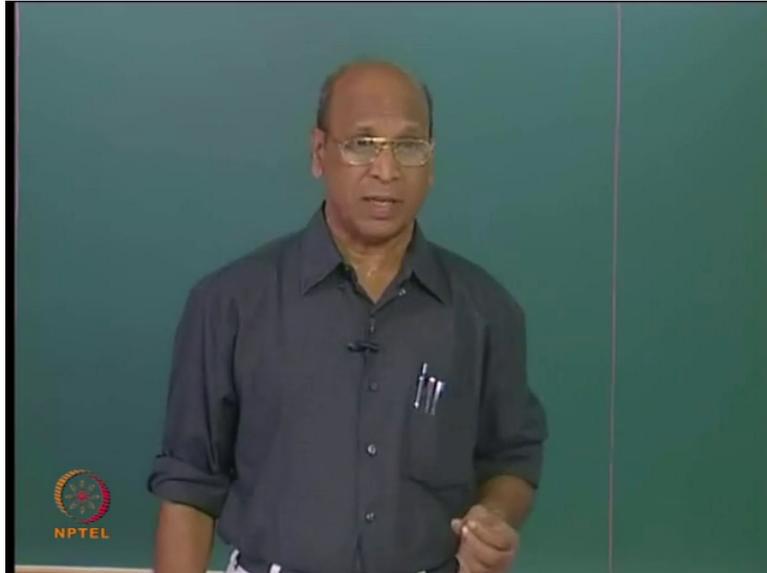


**Chemical Reaction Engineering 1 (Homogeneous Reactors)**  
**Professor R. Krishnaiah**  
**Department of Chemical Engineering**  
**Indian Institute of Technology Madras**  
**Lecture No 15**  
**Design of Plug Flow Reactors Part 2**

(Refer Slide Time: 00:13)



So we have been talking about this plug flow and I definitely now think that you will not forget about definition of plug flow, then mathematics are required. So you have that equation zero to, that simplest equation and I also told you why you should have this plug flow assumption, why I told you. Why you should have plug flow assumption? What will happen if you do not have plug flow assumption?

(Professor – student conversation starts)

Student: Each point will not...

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Professor: Why you are making noise? I want signal. Very clearly one, yes?

Student: 0:00:44.9

Professor: So what? You consider diffusion?

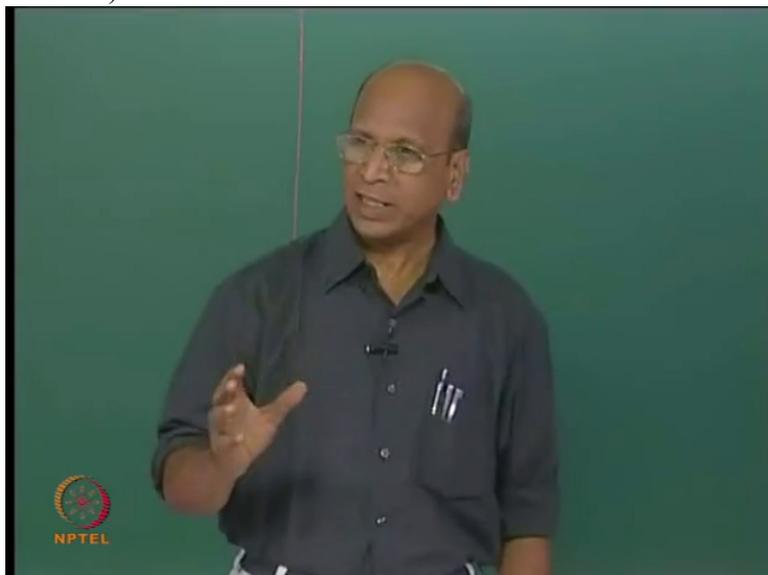
Student: It reduces mathematical complications.

Professor: Yeah. Straight forward action I say. Unnecessarily you do not have to use your brain for mathematics. When it is required you have to use it, right.

(Professor – student conversation ends)

So as engineers

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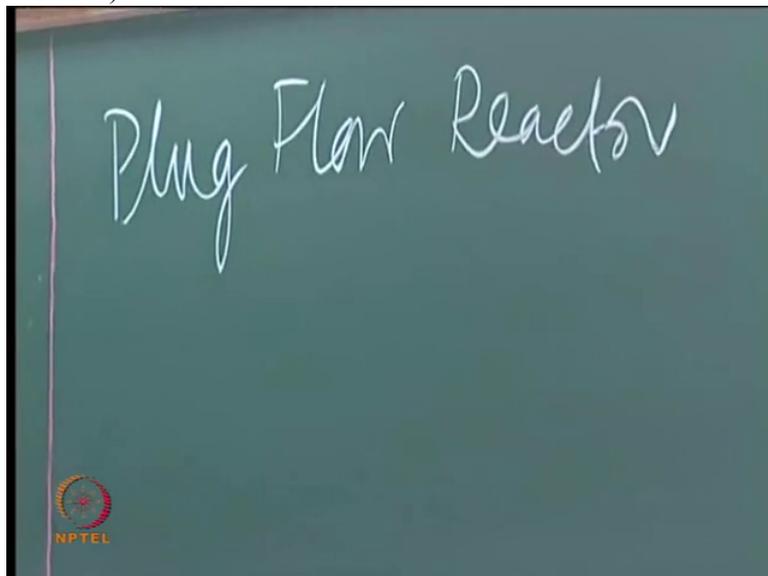


you first simplify things so that you will get the simplest design equation. Then we want to complicate, complicate, right? That is what is the thing. That is why you have to assume that. And in the beginning.

And if you are really fussy guy, so naturally you will now try to go for deeper and deeper and use all terms that you cannot neglect in the real flow and those are the terms that I am going to write for the plug flow. Plug flow, the actual, it is not plug flow, tubular flow the actual design expression I will write. You simply write here still plug flow, Ok.

It is a differential equation. I will explain, I am not deriving

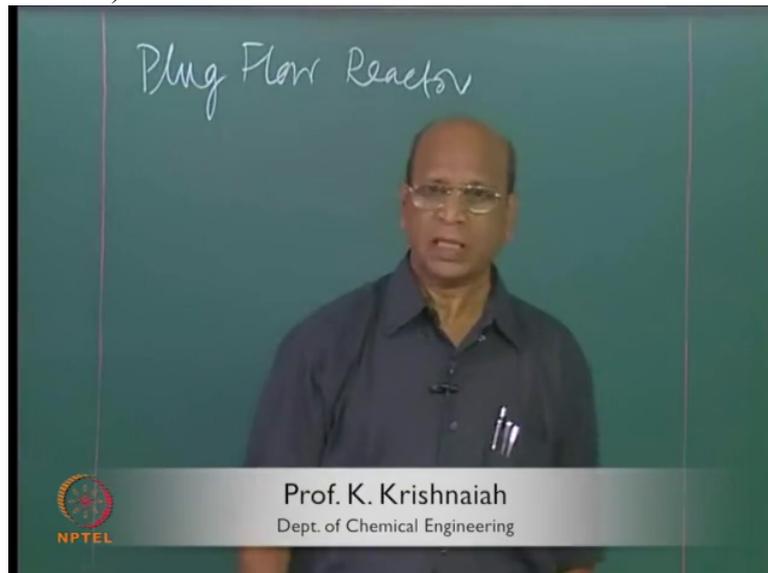
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that but I will give the differential equation. Most of you would have seen this equation but only thing is we will know what are the terms. I think in the equation you should know what are the terms, which term is representing what phenomena.

Equation always comes from physics, please remember that, Ok. Physics means no, you understand. Physics are the problem,

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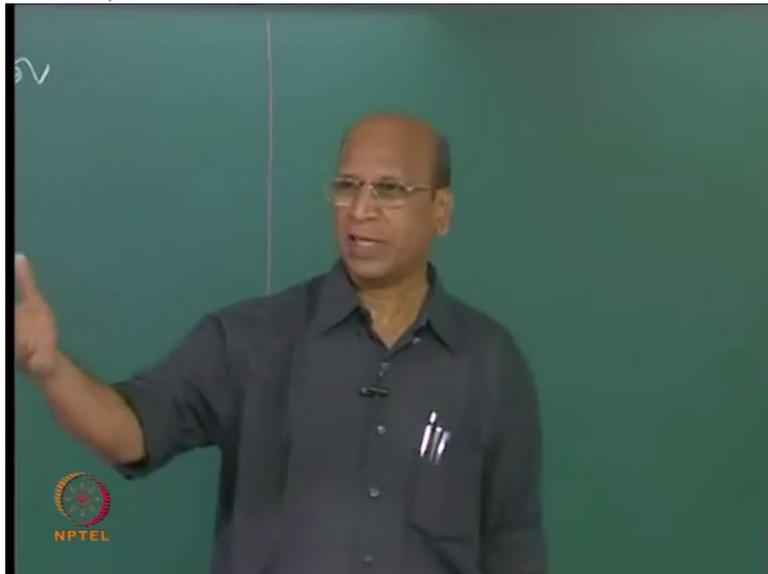
not Resnick and Halliday, physics means. Resnick and Halliday book is there no? Very famous. You have not seen? Oh my God! You have not prepared for J E E? Really. J E E it is Veda, you know Veda? Bible. Ok.

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So everyone uses this.

(Refer Slide Time: 02:21)



We say Vedam, or Bible or Quran because everyone suppose to use that every day. So that is why, that is the reason only we will say. So this Resnick Halliday, when I say physics of the problem, we are talking about physical phenomena that is happening. Not physics means immediately our minds should go to a book, you know Physics book. That is what...what physics book you have used?

(Professor – student conversation starts)

Student: 12 standard book, text books

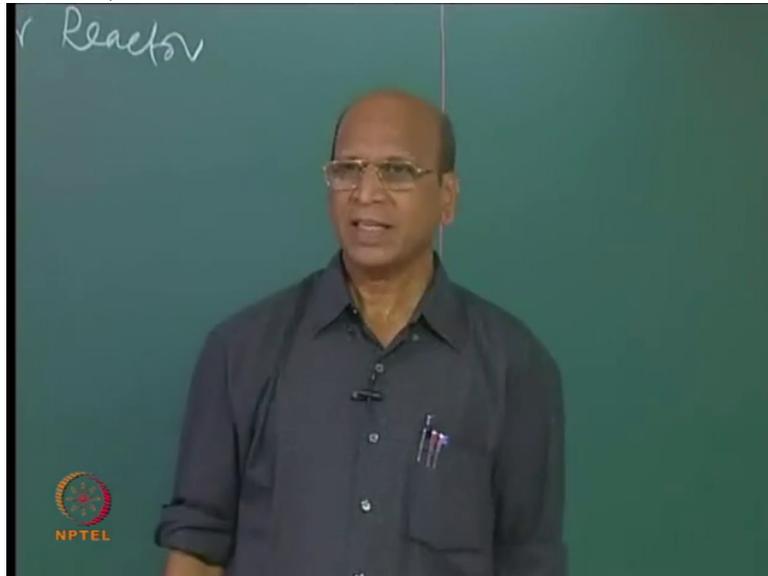
Professor: Text book, after that no more extension

(Refer Slide Time: 02:45)



of physics. Particularly in physics there are wonderful books. Because physics is a wonderful subject where every day we see, right?

(Refer Slide Time: 02:55)



(Professor – student conversation ends)

Chemistry you cannot see every day. You feel chemistry every day. Because in the stomach, reactions and all that. Ok (laugh), yeah and I think you cannot see a reaction. Even though you know there is some reaction you cannot see.

But advantage of physics is that everything you can see. So that is why many people try to explain and all that you know physical phenomena, Ok, and also physics around the world and the universe. That is why you have the maximum information on physics. And people are so much excited about physics.

The best physicians/physicists, I mean it is not physicians, physicists, Ok, physicians means again you will go to a different way, yeah doctors. Right now we do not want to go there. Yeah. So best physicist you know, Nobel laureates and all that, they started propagating in very, very simple language. That is why there are many popular books on physics.

Poems telling all the physics, if you are able to read those books your chemical engineering will also be very clear. If you are able to, and some of the time, you have to read, read, read I

say. Ok. Till at least 25 years, 30 years only I think you have to read, read, read, read and think about that. Ok. Because you have been seeing that physics every day.

What happened was you know it is Challenger? One spacecraft went into space and after 3 minutes or 2 minutes, it exploded and 7-8 people died. Ok. Challenger, no? Challenger I think yeah. It was Challenger. So there there was a committee to find out what was the actual reason for this explosion. You know, this is very good, this example.

You know then he was in the committee. And they called all the people who have design and who have also fabricated and who have operated, all these people, and then finally he only proved that, that you know between, they have the first part, I think is the people who sit there, the first part and the bottom part, sections, all the fuel is kept at the bottom.

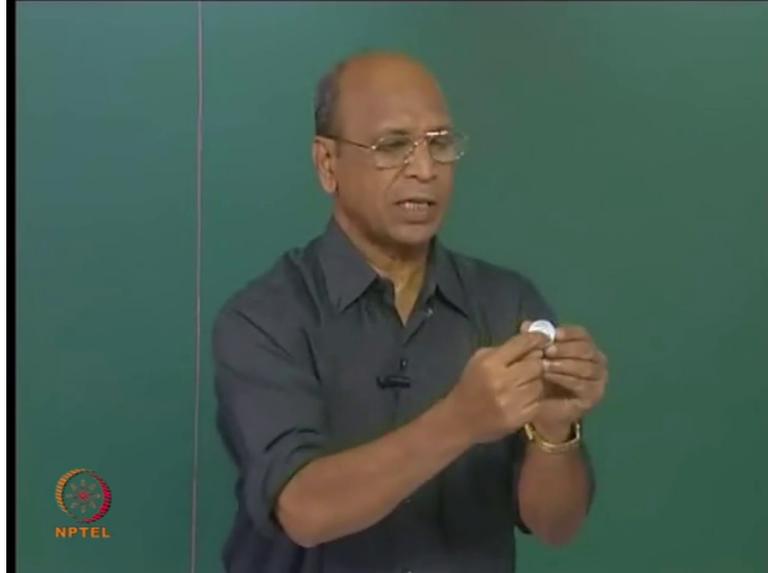
Ok, either solid fuel or liquid fuel. Solid fuel I think what they have used there. Ok or liquid, liquid hydrogen, liquid hydrogen they have used. Ok. So that fluid is used, different sections. We can also see. When our people also send, ISRO people also send, first part will fall first. Second part will fall first. Third part also will fall first. That third part should not fall. Ok. That should go. But anyway, I think, I am not joking about ISRO.

Because I think in every history of any rocket science it seems everyone has faced this problem once. Even Americans also lost many rockets like that when they were trying. So that is why it is only a learning curve. So we are on that learning curve. So that is all. That is why. But our people are successful no, in many things now they are sending and all these satellite connections and cell phones and class rooms various places, all that is through that one only. I think we are also doing excellent job in that.

So that parts will come. In one, and between these two, Ok first part, bottom part I am talking where the fuel, second part another fuel tank, and may be depending on how far it goes, may be third part, fourth part also they will have, right? So in this one, I think between third part and first part, second part I think, so there was a gasket, O ring they call. I do not know whether you have heard of those things.

Because when you are joining two metal parts, yeah, these two metal parts will have groove. So Ok like this, Ok, so here,

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here they will have a groove. The other side also they have another groove. Right? And in that groove you put that nice O ring, circular, this is circular. And the diameter also is circular diameter, yeah. That is like that. Ok, circular. So that they put and then they tight.

Right so then what happened was they found that, they know that the reason is the explosion occurred in the hydrogen tank when it is coming to the second stage. First stage has gone and that has to propagate to the second stage. So when it is going to the second stage, something happened, and then suddenly it broke. And explosion occurred and then died. All the people died. I think we can see, you know two parts it came and even now they will show in TV sometimes on that same day when it occurred.

That is what I was thinking. You know there are moving bed reactors? Right? One beautiful example is you know gas phases can be used as; gas phase reaction can be conducted in moving bed, not packed beds. So that means the entire bed will be moving. When the entire bed will be moving, depending on slowly you know, the conditions inside and how much is coming, there will be some gaps between the particle.

Those are the gaps which are between, you know there is on group which is talking, another group which is talking, there is voidage between that. So throughout I was thinking, now

what should be the voidage, what should be the porosity, so all that I was thinking you know. So that is why, I, I enjoy those kind, I do not get bored.

Because I am now thinking that Ok, all these are particles. They are moving, some with different velocity, some with same velocity, Ok, same velocity means another velocity. So if it is, if all the people are moving with exactly same velocity, plug flow (laugh), yeah so all that kind of things. If you are able to relate you will never forget that.

So that is why I am trying to tell you all these stories, because by story-telling you will definitely remember, at least few people will change. They won't erase the files immediately the moment they cross the door. Ok. You have no delete. On deleting files computer will tell you how successfully you have deleted the files.

(Professor – student conversation starts)

Student: (laugh)

Professor: Most stupid (laugh),

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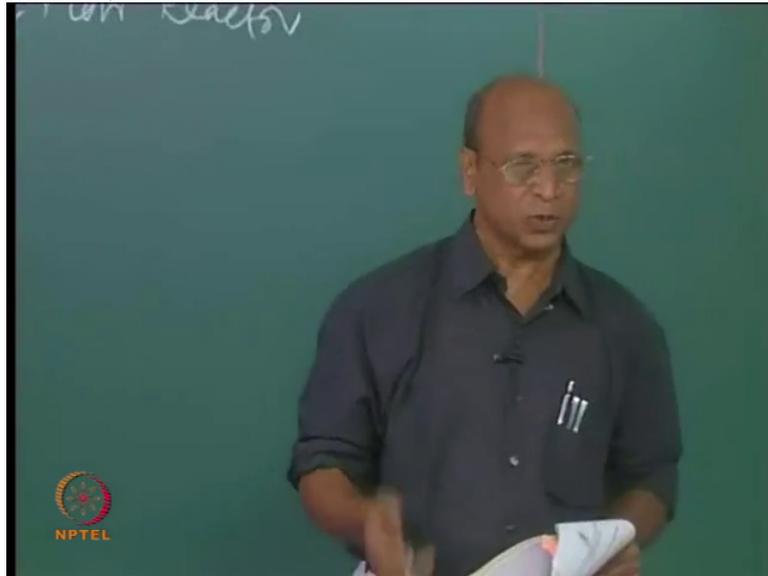


you know, stupid congratulations I have ever seen, that we have not done anything. Computer deleted itself, that you have successfully deleted the files. So that is like that only.

(Professor – student conversation ends)

Another thing

(Refer Slide Time: 08:47)



also you know, Windows. To switch off, to stop the computer where you have to go? Start. What a wonderful comment! (laugh) To switch off the computer, you have to go to start and then open, find where is switch off and then you switch off.

Ok that happened because this Bill Gates was not educated. Correct no, he was not educated in the sense that he drop out from some time. Ok, if he could have formal education, that is my edition, formally he would have thought where is it correct, the correct button. But anyway.

The final expression which we have to use is that  $\frac{dC_A}{dt}$ , this is unsteady state also, Ok I think I will write everything together,  $-\frac{dC_A}{dt} = k_1 C_A - k_2 C_A^2 - k_3 C_A$ , minus  $k_4 C_A^2$ , plus  $k_5 C_A$ , plus  $k_6 C_A$ , plus  $k_7 C_A$  by  $k_8$  equal to  $-k_9 C_A$ .

(Refer Slide Time: 10:17)

Plug Flow Reactor

$$\frac{\partial C_A}{\partial t} - D_a \frac{\partial^2 C_A}{\partial z^2} - D \left( \frac{\partial^2 C_A}{\partial r^2} + \frac{1}{r} \frac{\partial C_A}{\partial r} \right) + u \frac{\partial C_A}{\partial z} = -r_A$$

NPTEL

Ok, so this is the real equation for tubular reactors where there is no plug flow, right? So now this equation is with, this is unsteady state, unsteady state, tubular flow, tubular flow reactor with...axial and radial dispersion.

(Refer Slide Time: 11:02)

Plug Flow Reactor

$$\frac{\partial C_A}{\partial t} - D_a \frac{\partial^2 C_A}{\partial z^2} - D \left( \frac{\partial^2 C_A}{\partial r^2} + \frac{1}{r} \frac{\partial C_A}{\partial r} \right) + u \frac{\partial C_A}{\partial z} = -r_A$$

Unsteady State tubular flow reactor  
with axial and radial dispersion

NPTEL

Ok, what are units of that equation?

(Professor – student conversation starts)

Student: Moles per 0:11:19.1

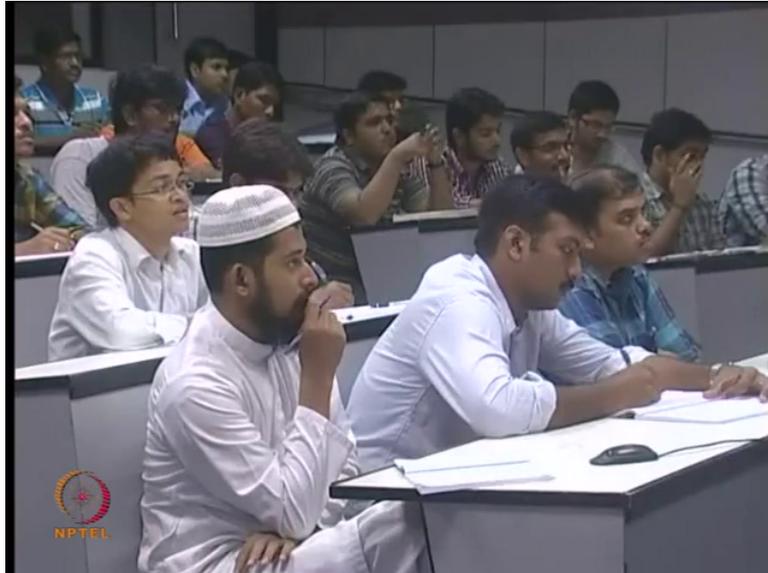
Professor: Yeah moles per

Student: volume time

Professor: Yeah, per unit volume, per unit time, Ok, yeah. So this you see, can you identify where is the axial dispersion now?

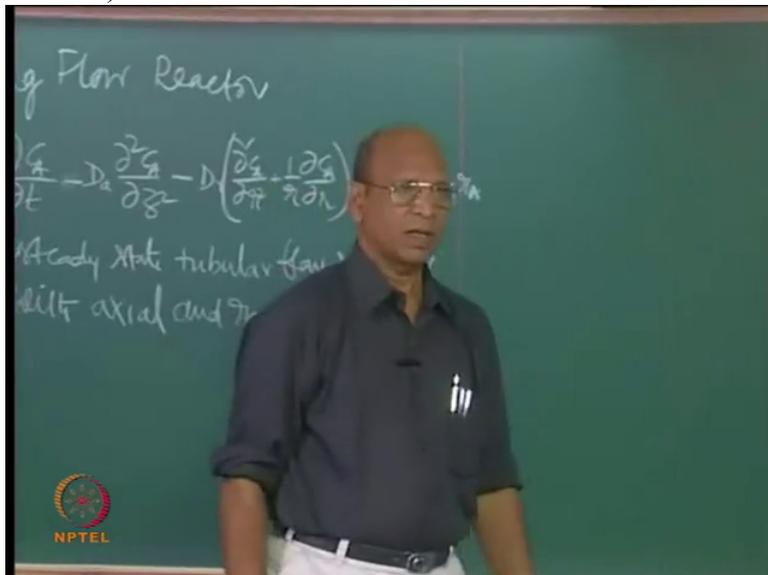
Student: d 0:11:32.9

(Refer Slide Time: 11:31)



Professor: I am asking you. You are telling something.

(Refer Slide Time: 11:36)



You, yeah what is your name?

Student: Anupriya

Professor: Anupriya, yeah.

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Do not be afraid I say. Yeah, tell.

Student: d

Professor: I am asking axial dispersion now. Where is the axial dispersion? What is axial direction for us?

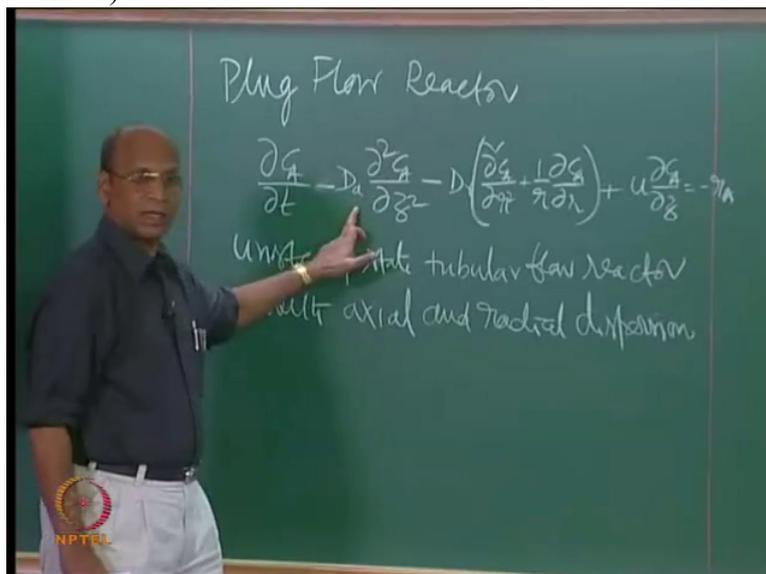
Student: z

Professor: Ok where is that, Anupriya?

Student: z

Professor: D a,

(Refer Slide Time: 12:00)



that is why I also put A there, this is diffusivity coefficient in

Student: Axial

Professor: Axial direction. And what is this one?

Student: Radial direction

Professor: Radial direction. Ok this is a cylindrical coordinate because there is a cylinder, right? So that is why this term will come. Transport phenomena, all of you must have been experts, I think definitely all of you would have taken no, transport phenomena?

Student: No

Professor: Right? Not, not taken.

Student: Second sem

Professor: Yes, I am talking about you.

Student: Yes, yes

Professor: Flashback?

Student: (laugh)

Professor: Do not forget your past, I say. Yeah. Otherwise I will tell you like this. Every movie tells you...like this, that is a flashback. Ok. Ok good. This is your radial dispersion. And this one?

Student: Dispersion 0:12:54.8

Professor:  $u \frac{dC_A}{dz}$ .

Student: Convection

Professor: Convection term and this is the one, this one?

Student: Unsteady state

Professor: So now, actually in reaction engineering what are the terms we have used from this equation? In our class, when we were deriving that equation  $C_A \frac{dV}{dt}$  is equal to  $X_A \frac{dV}{dt} - R_A V$  and all that, so what is the equation I have used? I mean what are the terms I have taken from this equation? Minus  $r_A$  alone? If minus  $r_A$  alone where do I put it, I say. (laugh)

Student:  $U \frac{dC_A}{dz}$

Professor: You check, is it  $u \frac{dC_A}{dz}$ ?

Student: No 0:13:46.0

Professor: Yeah convection and?

Student: 0:13:53.8

Professor: 0:13:55.5 I told you all reaction engineers are steady state people, correct no? I told that.

Student: Convection

Professor: Yeah, where is convection term there?

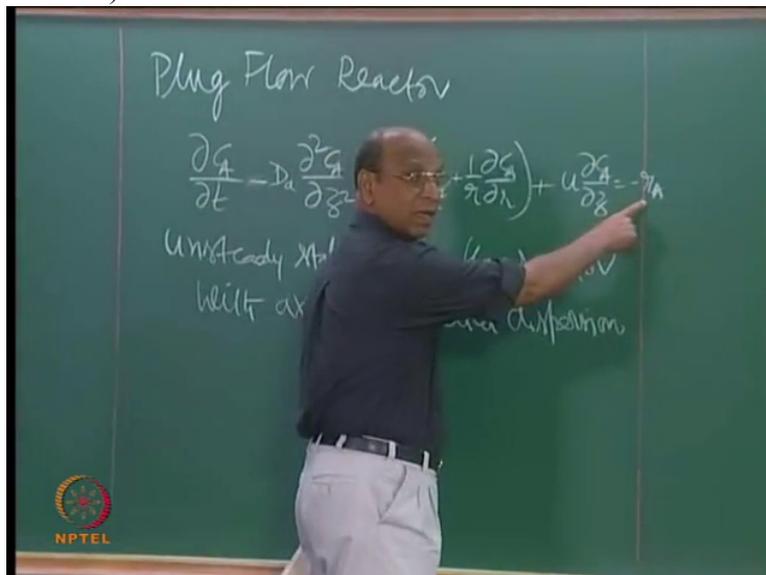
Student: u d C A

Professor: Ok, this term, Ok so out of all these terms how many terms we have taken? And what are those terms?

Student: minus r A

Professor: minus r A

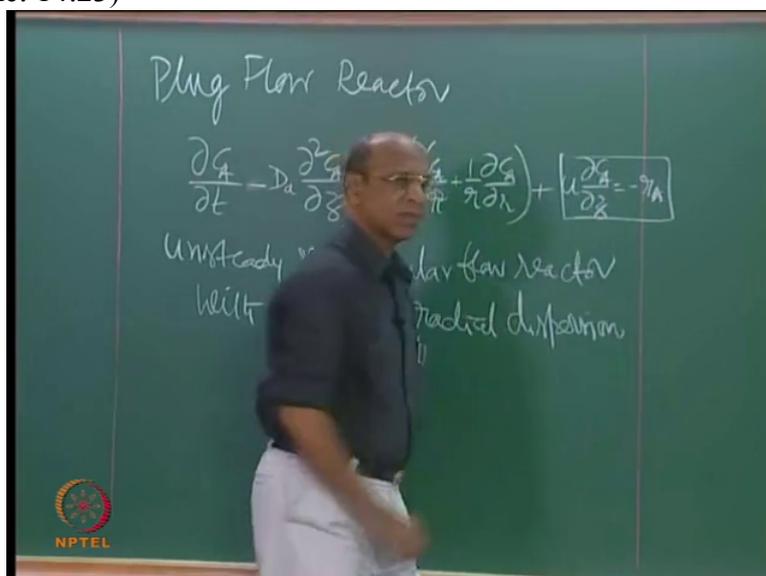
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Student: u d C A by

Professor: Yes, that is all, only these 2. Really only those 2.

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You see how much simplification we have done.

(Professor – student conversation ends)

So he said that unsteady state, I am not bothered, because I am not a, I am only a steady state guy. Ok. So this term has gone. So by plug flow assumption, we have been telling all the time that for axial mixing equal to zero, without understanding why. Ok. So when axial mixing equal to zero means  $dA$  equal to zero, right. So then what is the radial mixing?

(Professor – student conversation starts)

Student: Infinity

Professor: Infinity. So this is infinity. So I cannot put infinities in the equation. So then how can I eliminate this term?

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Good question.

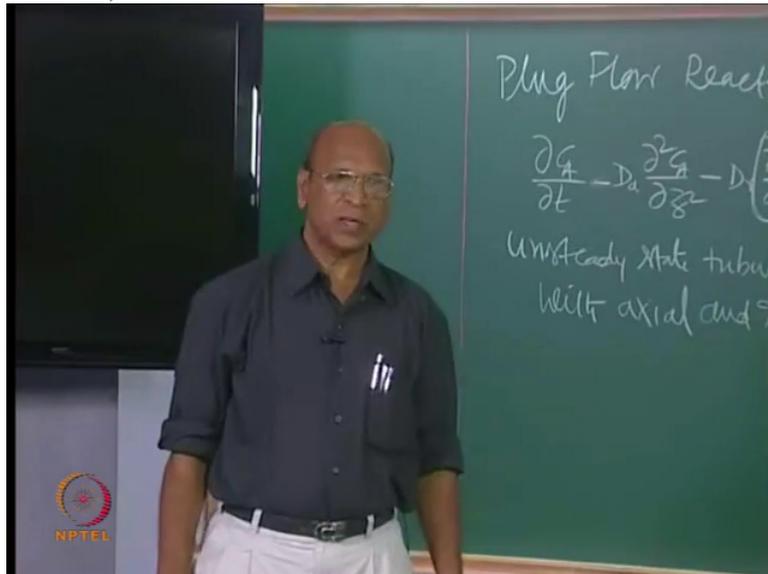
Student: Put  $d = 0$ :15:02.7 is equal to 1.

Professor: Question also I have to appreciate myself (laugh)

Student: (laugh)

Professor: Yeah,

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we said infinite diffusion. Infinites you cannot put in any equation. We cannot solve them.

Student: R tends to zero

Professor: R tends to zero means there is no reactor, very happy.

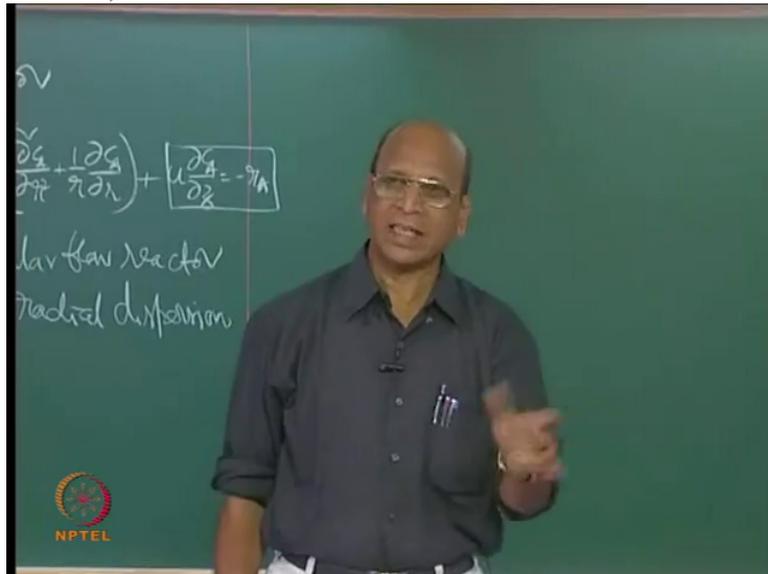
Student: (laugh)

(Refer Slide Time: 15:20)



Professor: Correct no, when R tends to zero, where is the reactor?

(Refer Slide Time: 15:23)



Reactor disappears.

Student:  $\frac{dc_A}{dz}$  is zero

Professor:  $\frac{dc_A}{dz}$  by  $\frac{dc_A}{dr}$  is zero. Gradient is zero.

(Professor – student conversation ends)

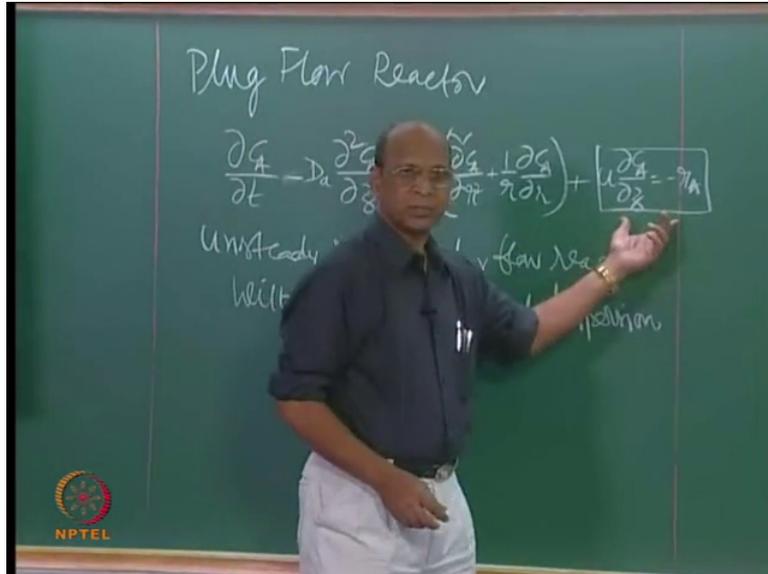
Because it is uniform no, throughout, where is the gradient? Those things I said. Please try to sharpen your brain, Ok. Go to Central Workshop, Take a pipe. Open your tail and then start. Ok, so otherwise I think it is not happening. So many things I am telling you but still it has not yet sharpened. You have not yet caught the, you know that ignition point. Ok, so I want to see that ignition in the minds.

Ok, you see now, this is a very general expression. And you know, teaching wise also I can tell you, highly mathematical people, there are very large number of professors who are very happy writing equations on the board. Ok, so they are not wrong. Because their approach is different. And engineer's approach may be different. Ok. I mean practical people approach may be different.

So what I do is I take whatever is necessary and we write the balance equation. Whatever is necessary for plug flow? We said that by assumption, there is no axial mixing, the radial mixing equal to infinity and flat velocity profile these two also enough and of course all the time taken by each and every particle is same.

All that assumptions will tell me that you do not have axial mixing, you do not have radial, sorry you have infinity radial mixing. So these 2 terms I drop and then I write only this equation,

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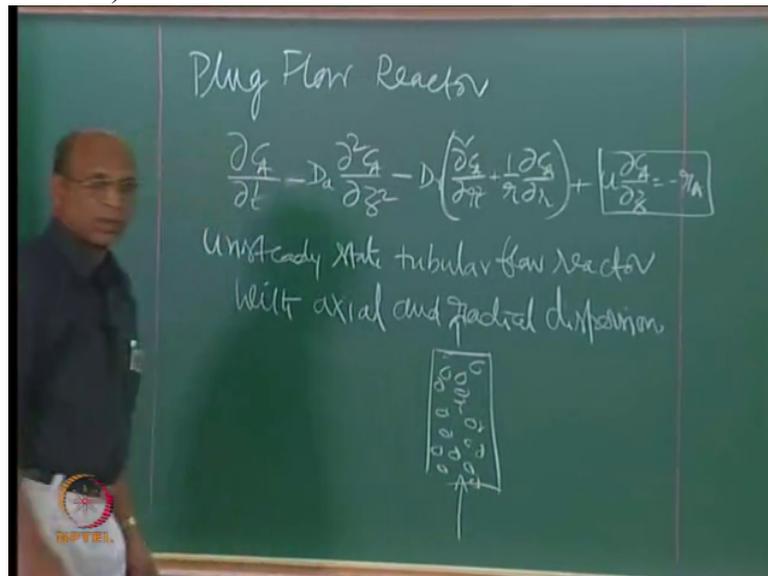
simply what is entering, what is leaving and we write and develop the equation. That is one way of approach.

The other way of approaching is that you take the most general expression. Take all non-idealities into account. Ok. So then you now develop an, write an equation, this is the that kind of equation where all the terms you have taken. All the phenomena that is happening in the tubular reactor we have taken, right?

We have taken that we have axial mixing. We have taken that we also have radial non-uniformity. That means it is not infinite. Ok, there is some change with the, change in the conversion along the radius. You know when that can happen? It can happen in packed beds. And I told you all packed beds can be imagined first approximation as plug flow.

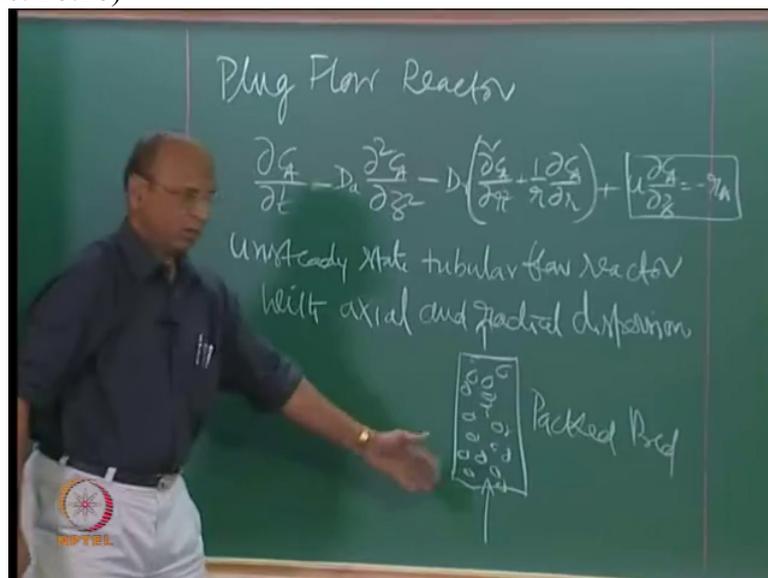
Why you know? Flat velocity profile. What is the kind of velocity profile you will get in a packed bed? So I have packing here. Ok I am sending the reactant. There it is coming out. This is

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packed bed. Yeah. So when it is entering we assume that you know, it is

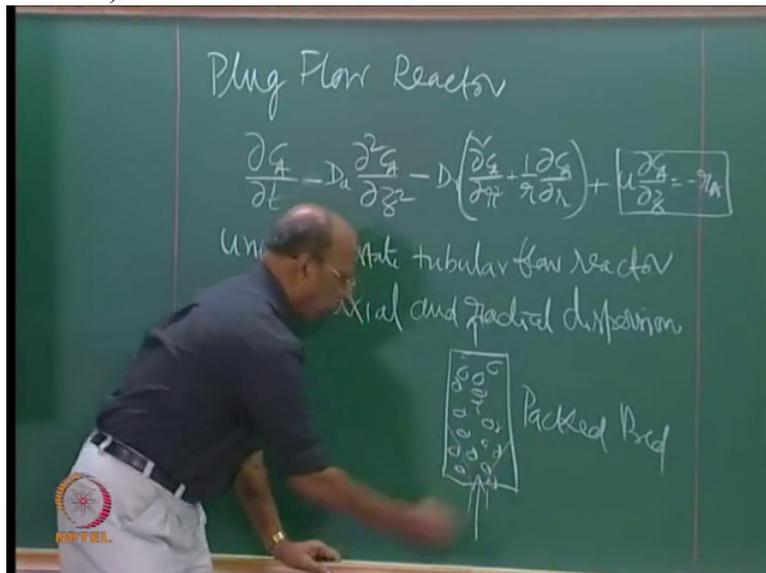
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entering straight as it is, entering by plug flow, that means before that I have uniform velocity profile and you know there are many assumptions like this is only academician way of representing the packed bed.

But in reality you will never have packed bed like this. So you will have a pipe like that. If you have a pipe then all this

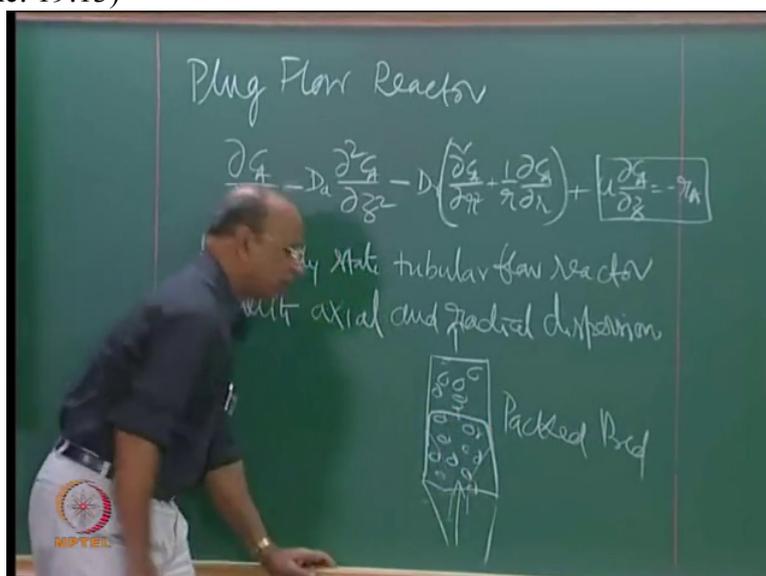
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will go. Because it has to expand slowly, no. So that is why before putting all this into the packed bed, you just draw here itself. Good. Your actual reaction should start from here.

Why are we doing all this? I am doing all that so that I can easily quantify in terms of mathematical equation. So if I do that then it approaches almost, you know this plug flow. And from there it moves as plug flow. The velocity profile is assumed most of the time like this. And again you have to use here

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high Reynolds numbers. What are the high Reynolds numbers for turbulent region in packed bed?

(Professor – student conversation starts)

Student: 0:19:20.2

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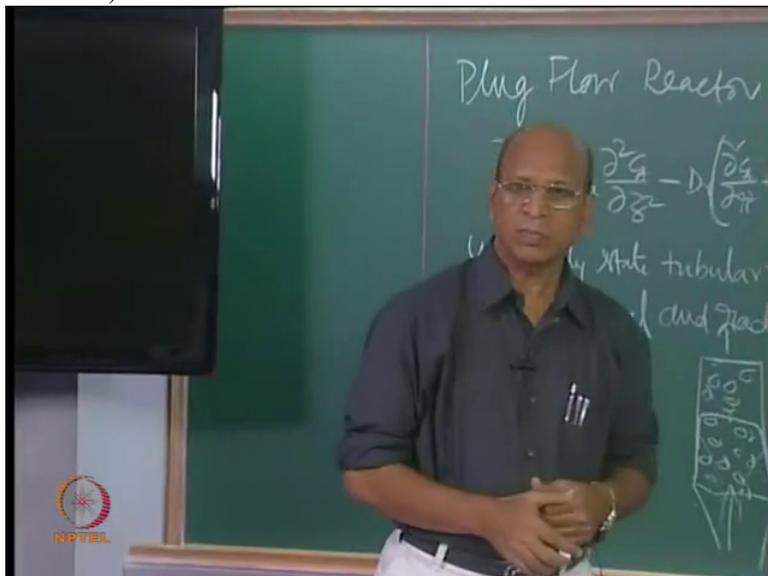


Professor: Yes?

Student: 500 and above

Professor: Yes 500 and above.

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If you do that then you will get almost flat velocity profile and in packed beds, you can easily get this. That is why in low Reynolds numbers itself you are able to get that.

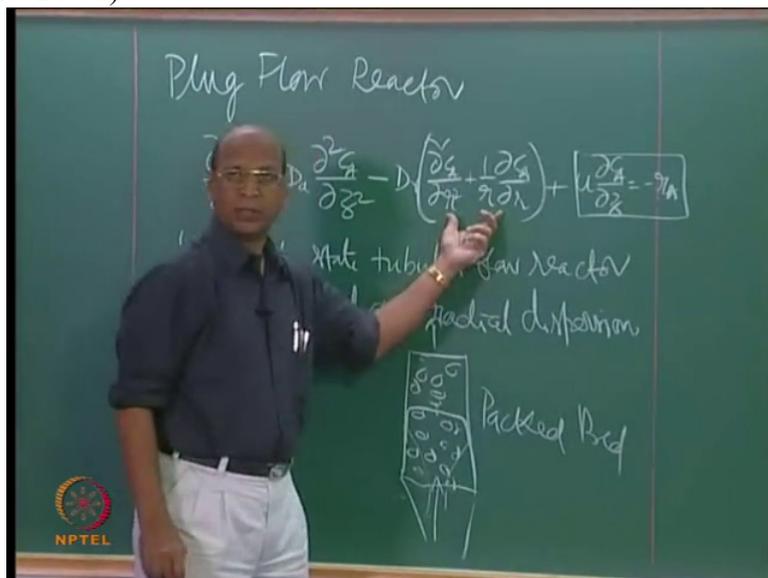
(Professor – student conversation ends)

Because the, the, there will be small fluctuation. That is later, right. So because, this kind of uniformity will come because of the solids presence. When you have the solids, those things will try to balance the flow.

Somewhere here, it goes faster, somewhere it goes slower. But on the average, that goes faster, this goes slower so if you look at that, on the average you have only flat velocity profile, Ok. That is our assumption at the end. So that is why remember that, all packed beds are imagined as packed bed reactors. This is the first assumption. Right.

Then if you say that Ok, now I do not want to take only ideal plug flow, so I want to take axial mixing. That is the first non-ideality. Ideal mixing is a non-ideality because ideality will simplify my equations, Ok. Good. That is the one. So then second one is radial.

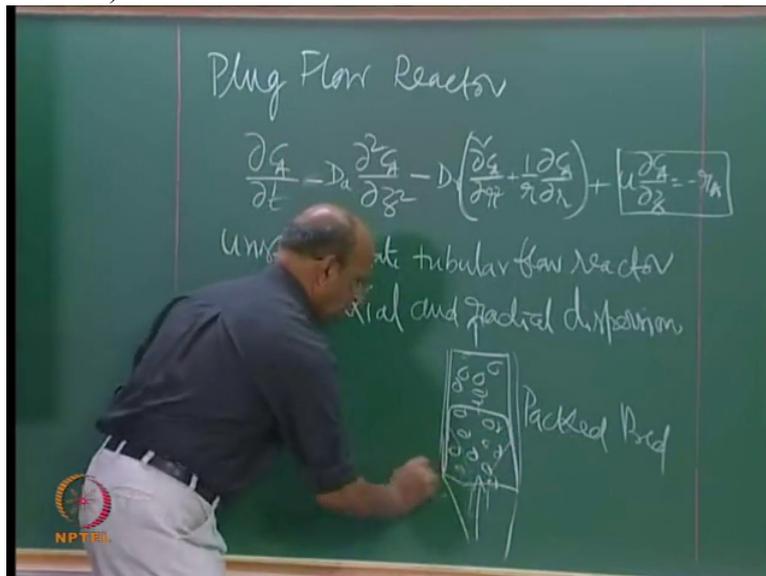
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Radial can occur here because you know an reactor or any reaction will be either exothermic or endothermic reaction.

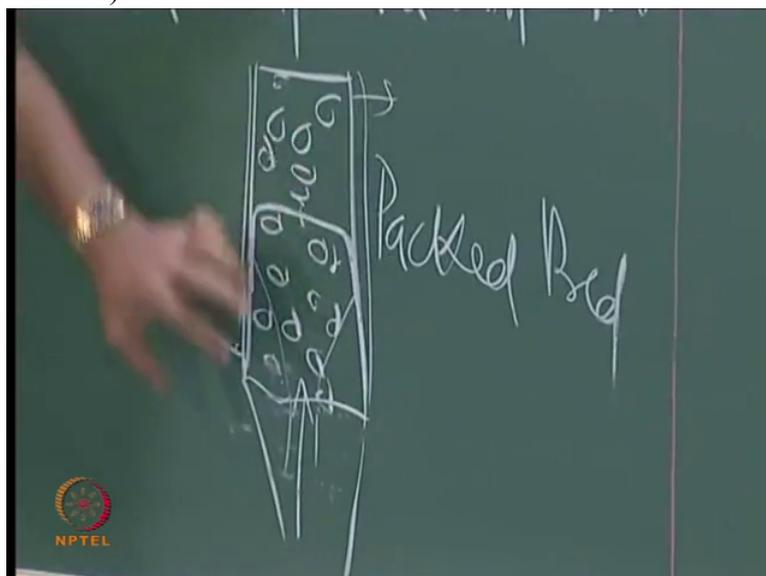
So imagine that I have exothermic reaction, easy to remember. Hot means easy to remember. So I will put a jacket outside.

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Then of course, it enters and then comes out, right? So it is an exothermic reaction throughout the

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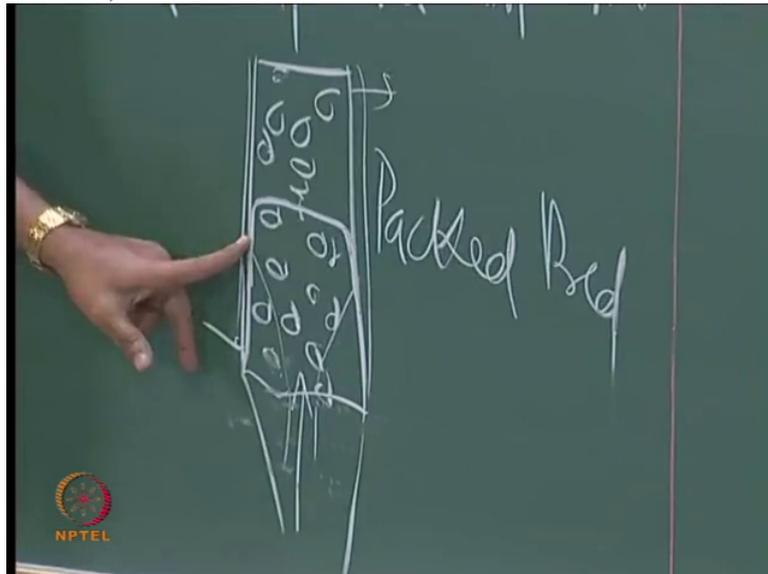
bed, the reaction is taking place. Right? So when reaction is taking place throughout the bed then you will have now temperature maximum where? And you are removing heat continuously.

(Professor – student conversation starts)

Student: Center

Professor: Yeah, at the walls

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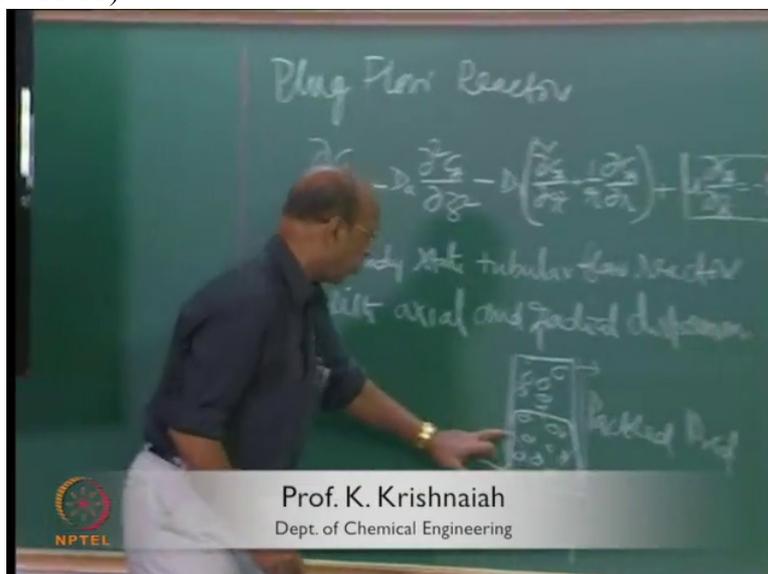


you will have, yeah at the center you will have maximum temperature. And at the walls you have...

Student: Minimum temperature

Professor: Yeah, some temperature which is, you know, which depends on the coolant and all that. So that is why now

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you have a temperature gradient.

(Professor – student conversation ends)

At the center you have more and at the wall you have less. So temperature gradient is there. So whenever we have the temperature gradient, now concentration gradient also comes into

picture. Correct, no? Why? Because you have, if it is a gas phase reaction, how do you calculate concentration?

(Professor – student conversation starts)

Student: 0:21:41.5

Professor: I have a gas phase reaction. I know only pressures.

Student: Partial pressure

Professor: Partial pressure divided by?

Student: moles

Professor:  $R$  into  $T$ . Now the temperature is changed. At the center you have high temperature that means you will have low concentration. And at the wall you will have low temperature that means you have high concentration.

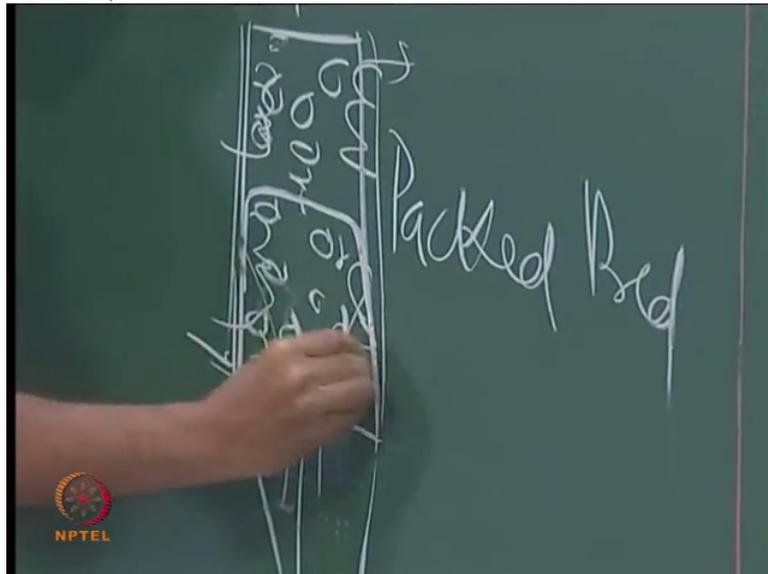
(Professor – student conversation ends)

That means there is a concentration gradient which is not allowed for ideal plug flow. So that has to be taken into account if you are really worried, because I think in packed beds you have to really worry about that. You know the size of the packed beds in industry?

It starts with maybe, 1 point 5 foot, feet right, 1 point 5, 2, 3 and it can go to even 5, 5 foot means, yes 5 feet, 5 feet means may be, Ok, 6 feet means 2 meters. Ok, so then you can imagine how much that. So that big diameter packed beds. So that is why heat removal is also the biggest problem in packed beds. You cannot put only outside jacket.

Sometimes you have to put also inside heat removal systems, inside here like this.

(Refer Slide Time: 23:04)



So all this will disturb the flow, right? So that is why, the real expression what you have to use and when you are also studying the first time, then unsteady state will also come into picture. You have to solve the equation and then you have to find out when the steady state comes.

Like you know most of the process control graphs will be with time and variable, how it goes, it goes like this, like this, like this, like this, like this. That is what is steady state. Ok, so we are not bothered about all that. We are only bothered about that particular thing. You know, you have seen no, many times response curves.

How the response curves will be? Always it goes up, goes like this, goes like this, sometimes it goes, shoots up, like this, like this, like this, goes like that. Ok. So that is why for starting point you also should have this term, this term, this term, this term and all other terms you should have

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Plug Flow Reactor

$$\frac{\partial C_A}{\partial t} = D_a \frac{\partial^2 C_A}{\partial z^2} - D_r \left( \frac{\partial C_A}{\partial r^2} + \frac{1}{r} \frac{\partial C_A}{\partial r} \right) + \boxed{u \frac{\partial C_A}{\partial z} = -r_A}$$

Unsteady state tubular flow reactor  
with axial and radial dispersion

NPTEL

and then you have to solve. That is what is the most difficult expression. It is not that easy to solve.

Ok, so you do not have analytical solution for even first order reaction there, right. You have to go for some numerical technique where you have to use delta r here, delta z here, delta C A, delta t, so finite difference methods, various methods are there. You can always see. You see, I mean how complicated the reactor design expression, the moment I go to the real world.

That is why I want to be in Levenspiel's world. Levenspiel's world is imaginary world, beautiful, very simple problems, and also very nicely done. And with jokes and all that. So, but real problems you will see in Smith book.

J M Smith, Chemical Engineering Kinetics, particularly if you see the last few chapters, thirteenth chapter I think, fourteenth chapter is non-catalytic reactions, thirteenth chapter if you see, you will definitely see wonderful problems solved by him, this is one dimensional, this is two-dimensional, this is two-dimensional, Ok. That is the axial direction and radial direction also he has really solved the examples.

All this of course we will discuss more in Chemical Reactor you know,

(Refer Slide Time: 25:15)



Chemical and Catalytic Reaction Engineering next semester, Ok. Good. So this is what is about packed bed reactors and, yeah?

(Professor – student conversation starts)

Student: Minus  $r_A$  sir or minus of minus  $r_A$ ?

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Professor: Just minus  $r_A$  only.

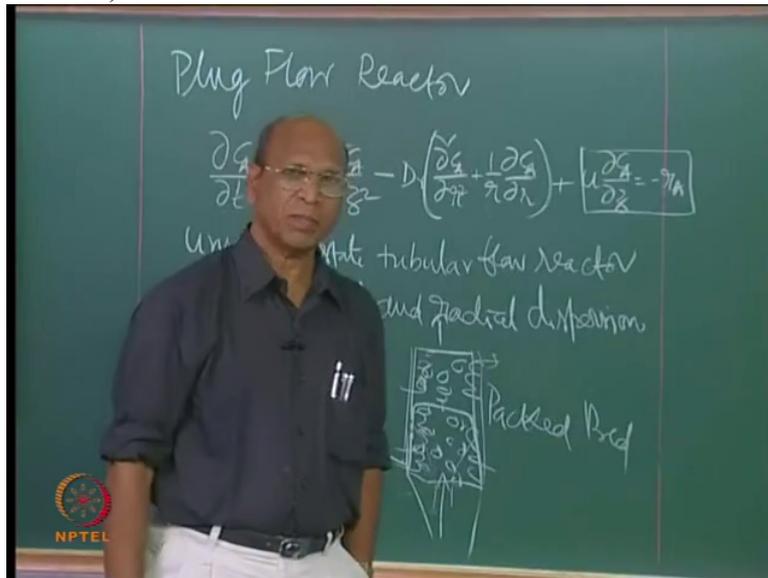
Student:  $k C_A$

Professor: Yes?

Student: In place of minus  $r_A$ , if it is a first order reaction,  $k C_A$

Professor: Yes it will be  $k C_A$ .

(Refer Slide Time: 25:37)



Student: minus...

Professor: Sign problem?

Student: Yes

Professor: Yes, Ok, that you can take care of when you are writing for, when you are writing for, you know which component? Ok. Yeah, that is Ok, that minus sign you can take care of that properly when you are writing for either reactant or product. So that is not a problem, Ok.

(Professor – student conversation ends)

So but only thing is you have to see that correctly what are the other terms that are there and you have to also bother about sign. Because you can also realize that, when you use wrong equation, concentration will be increasing instead of decreasing. Correct no, if you mistake that. So then I think you can really check.

But I do not think any student as far as I know has solved this equation using all the terms. Do you know anybody who has solved? I do not think, yes M Tech also, who will solve? M Tech only I am talking now. I do not think. Even B Tech I am telling

(Professor – student conversation starts)

Student: Nobody

Professor: Yes, project we do not know, project also I do not know anyone who has done it. That is what I am trying to tell. Ok so that is what, this is also good project for you where you have tremendous learning.

(Professor – student conversation ends)

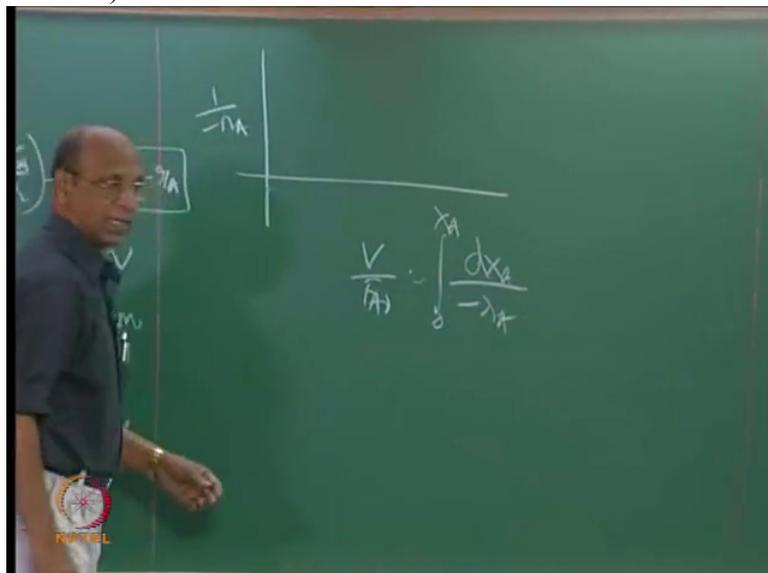
Good mathematics you have to use, good physics you have to use and then you have to calculate. What do you calculate? Concentration, if it is isothermal reaction and if it is non-isothermal then similar equation exactly will come for temperature.

So concentration profile and temperature profile that is what Smith has solved in that book, temperature profile and concentration profile. Ok. Transport phenomena approach, it is just nothing but transport phenomena approach. And even transport phenomena also I do not think anyone will, will talk about this equation so much because this mass transfer reaction is coming in the last chapter no, by the time you come there, you are already tired.

Because this momentum transfer and heat transfer will you. So I think, that I think in only first chapter you do and then you read other things. You never read anyway. So that is how I think transport phenomena also, we do not go deeper, right? Good anyway.

So that is the one and I have also not given the actual graph for that equation  $v$  by  $F A$  naught equal to zero to  $X A$  d  $X A$  by minus  $r A$ ,

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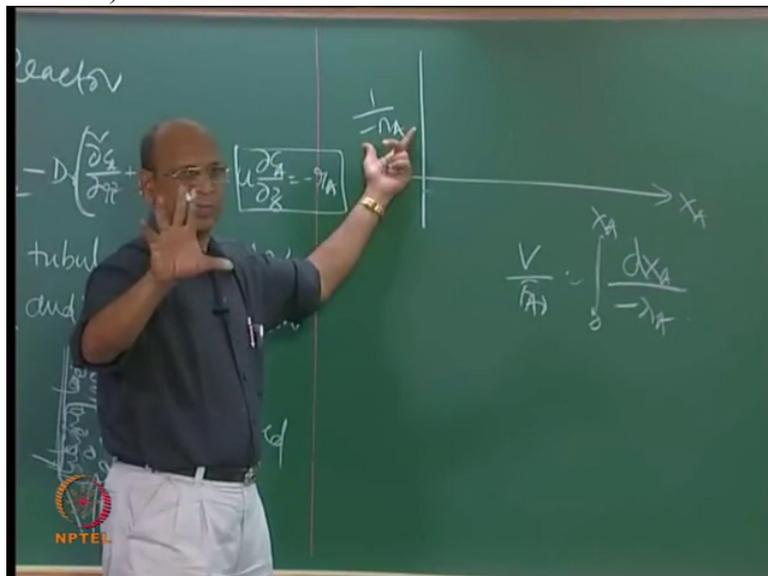


right. So this is plot what we are plotting. So you can tell me how I have to plot?

This is  $X_A$ , this is  $1 - r_A$ . Please make a habit of immediately marking x and y coordinates. What is that? Simply do not draw two lines and then draw the curve, right? I mean that, that should go to into your blood as engineers. Not only engineers, anyone has to do that. Yes?

Initial conversion zero. Yes. First I have to draw  $1 - r_A$  versus  $X_A$ , right. So initially  $1 - r_A$  into  $k C_A$ ,  $k$  into, see first order if I take, for example,  $k$  into  $C_{A0}$ , is  $C_{A0}^2$ , if it is second order reaction, then I will have some value. It is not

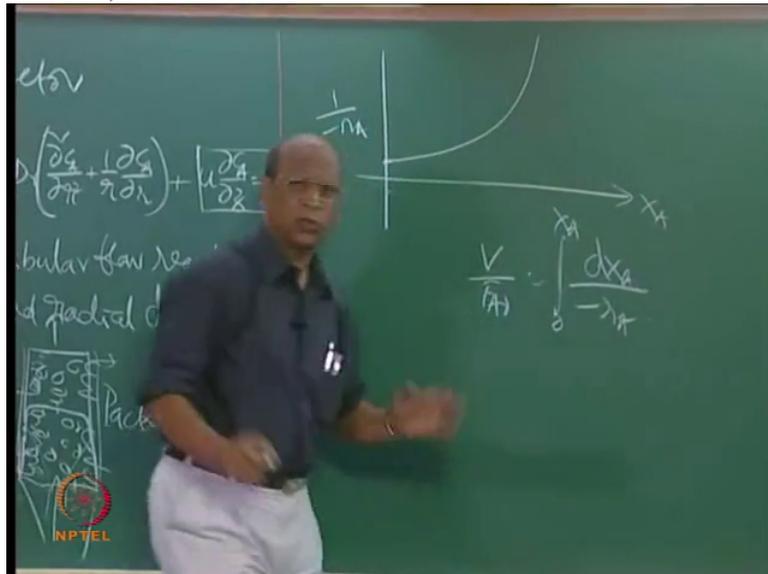
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zero, right?

So somewhere it starts here and then finally when  $R$  is zero that should happen. When I have 99 percent conversion, almost it is going to zero. So it goes, so in-between it may go like this. But this is not the

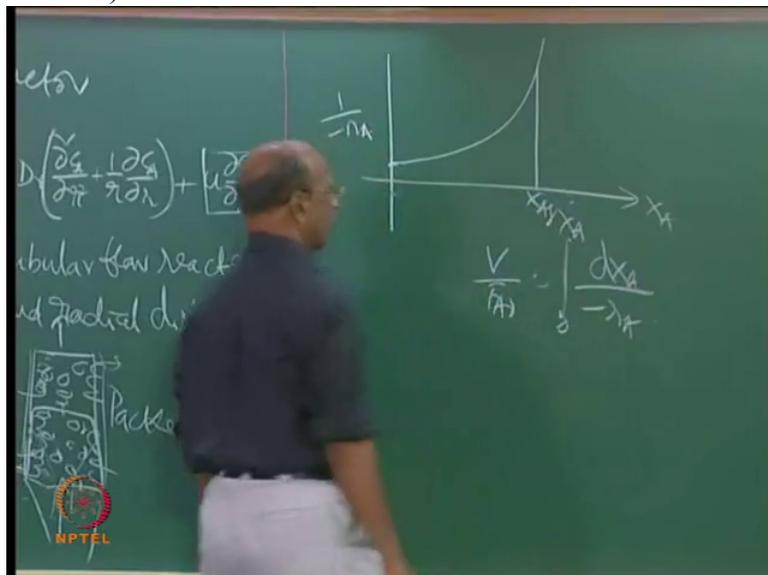
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universal shape that I am drawing there.

Actual first order, half order and also zeroth order all that you can plot, you will get slightly different curves, right? So general curve only I am drawing. So X,

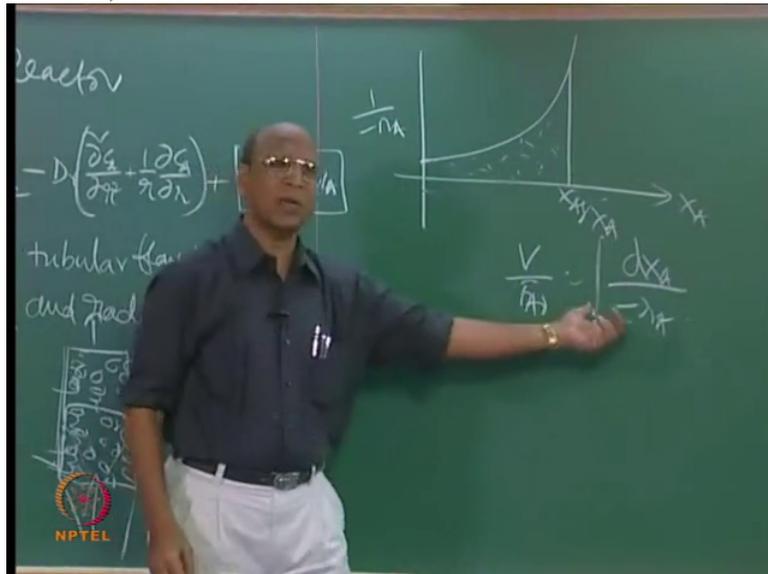
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F I am just showing, that is what my conversion is, 90 percent conversion for example. So then area under the curve will be, yeah in fact I just plotted only this side.

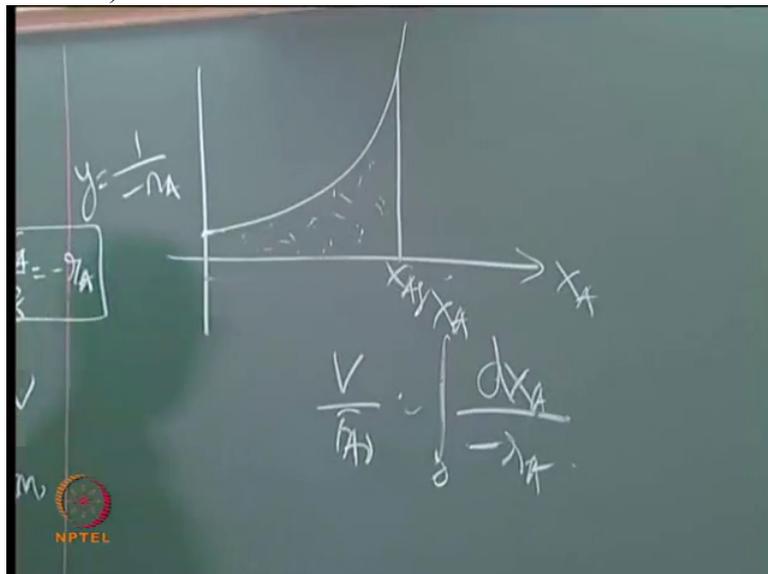
It is our elementary

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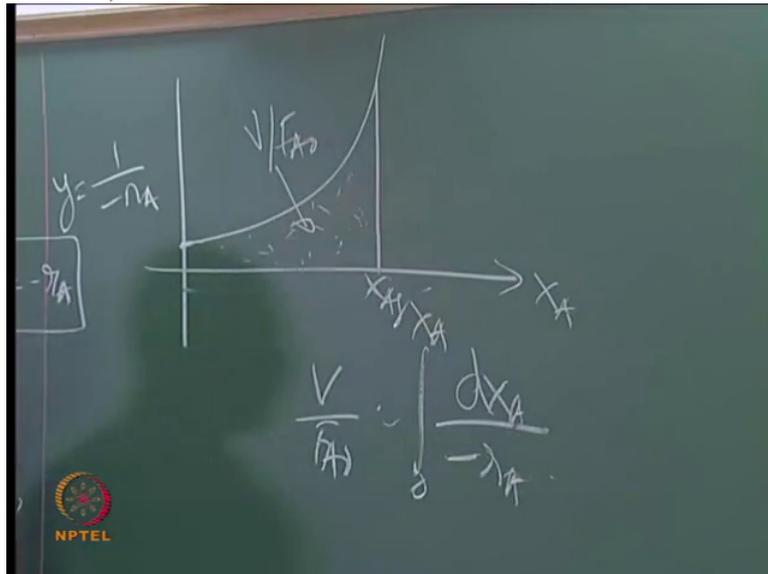
calculus that we learnt in school and probably we have forgotten also in school, right? But here we are using that. Elementary calculus,  $y \, dx$ , this is nothing but  $y \, dx$ ,  $y \, dx$  means you will remember. Correct no, integral  $y \, dx$  is area. This  $1$  by minus  $r \, A$  is  $y$  for me.

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So that simply becomes  $y \, dx$ , right? So that is area under the curve. This will give me  $V$  by

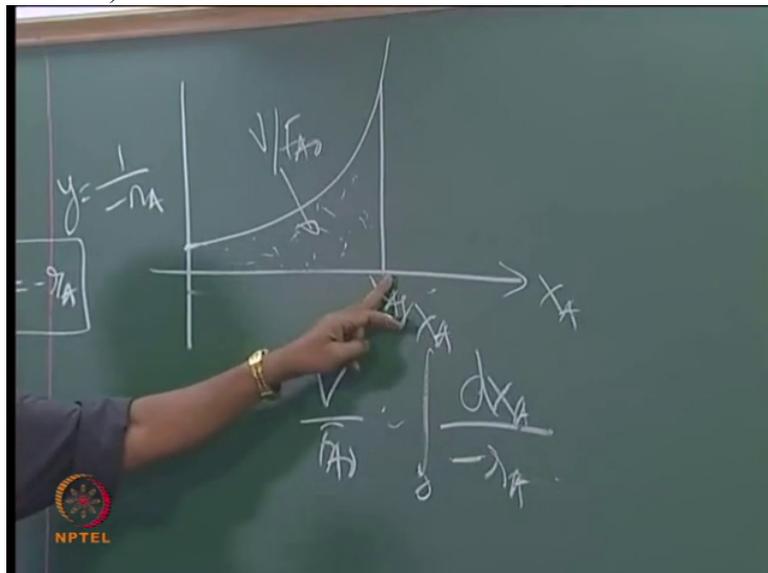
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$V/F_{A0}$  naught. Ok,

So then if it is a new reactor, I should assume what is  $X_{A,f}$ , correct no, for a new reactor,

(Refer Slide Time: 30:17)



you are designing a new reactor. So then you have to calculate volume. That means you draw a line because  $X_{A,f}$  you know.  $X_{A,f}$  you know you assume 90 percent. Draw a line and then count the area if you are doing simply graph integration. Then that will give you  $V/F_{A0}$  naught. What do you do, if I have the volume already? And then I want to find out conversion. What do you do?

know the volume I have 1 meter cubed. What is the conversion? How do I use this graph? Why so much time? Gopi? Tell us.

(Professor – student conversation starts)

Student: Concentration

Professor: Where is the concentration, we are talking about the same graph. We are not redrawing any other graph and all that.

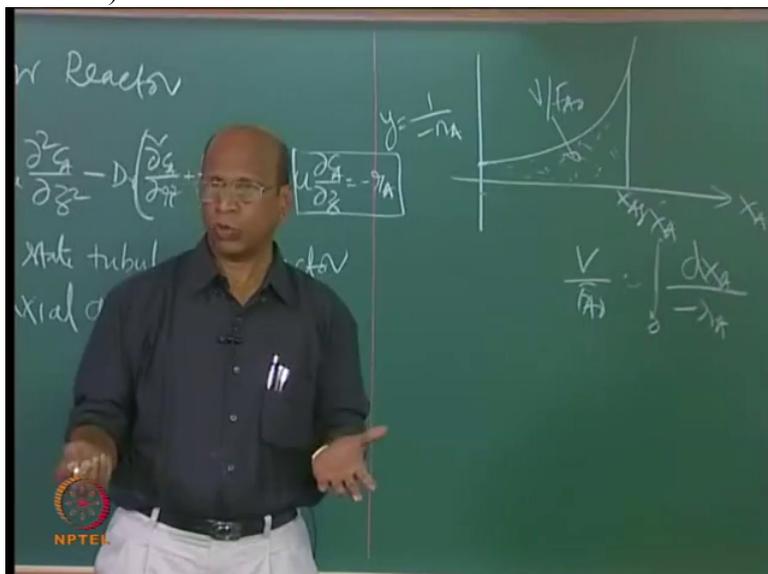
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Student: 0:31:10.5 we have to find out concentration

Professor: Because these are things which you are going

(Refer Slide Time: 31:14)



to do, when I give the assignment. Yes, anyway I think, this Moodle and all, you know it depends on its mood or my mood. If moods are matching...

Student: (laugh)

Professor: So please collect all that and we will go to the plug flow assumption, simple assumptions and then I think we will go, I will upload whatever I want. Because that is only for high funda people like Ranganath,. Ok (laugh).

(Professor – student conversation ends)

Yeah it is simple for me. If you collect, already many people have given, no? Please give your emails, yeah and when I really expert, become expert in Moodle then I will tell you, you also go and see Moodle. Because I am not, you know, restricted. Every time, I do not have that much time to learn also. If I have that much time, I will learn.

(Professor – student conversation starts)

Student: 0:32:02.1

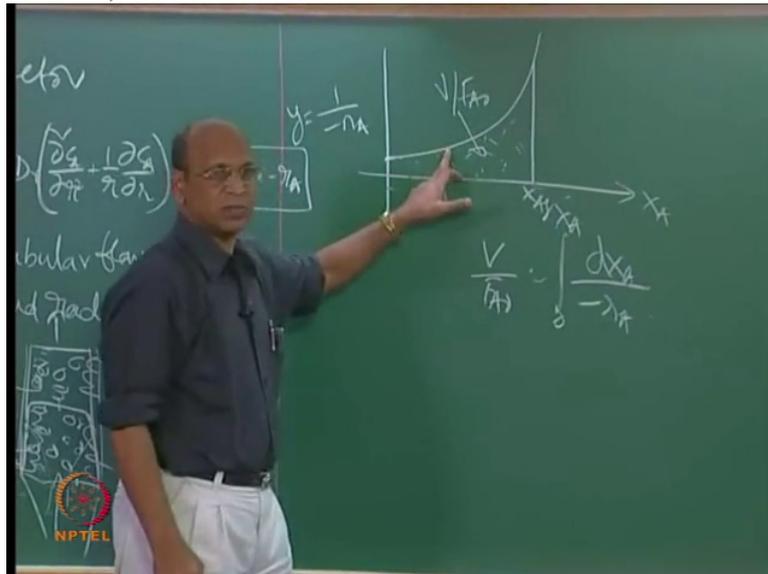
Professor: M Tech all added? Yes. Otherwise there another simple, oh I cannot.

(Professor – student conversation ends)

Because I think you know Smail will go to all the people. Throughout the institute. Maybe Smail for M S, I mean for chemical separate we have? Only for C H E? You do not know? Anyway. Ok.

So but here what we do is we now start counting the area first. So V by F A naught I know.

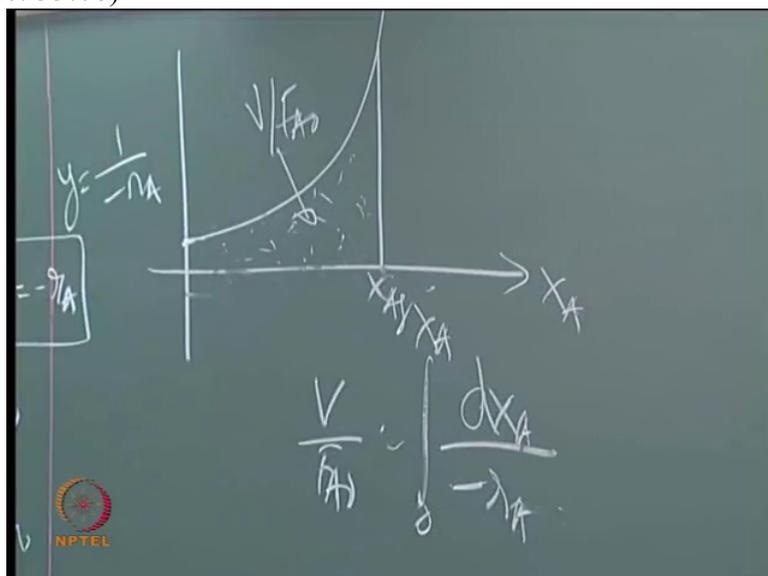
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Because 1 meter cubed I know, divided by F A naught I know, because F A naught is input for us. Then you start counting the number of, you know that area, the number of squares. And then finally whenever you are getting this value, draw the line that is the conversion.

And that you have to do anyway when you are not able to integrate analytically. Otherwise you can go for some other numerical technique. So these are the things which you have to. And now we have to stop. Yeah, there are some applications also for this

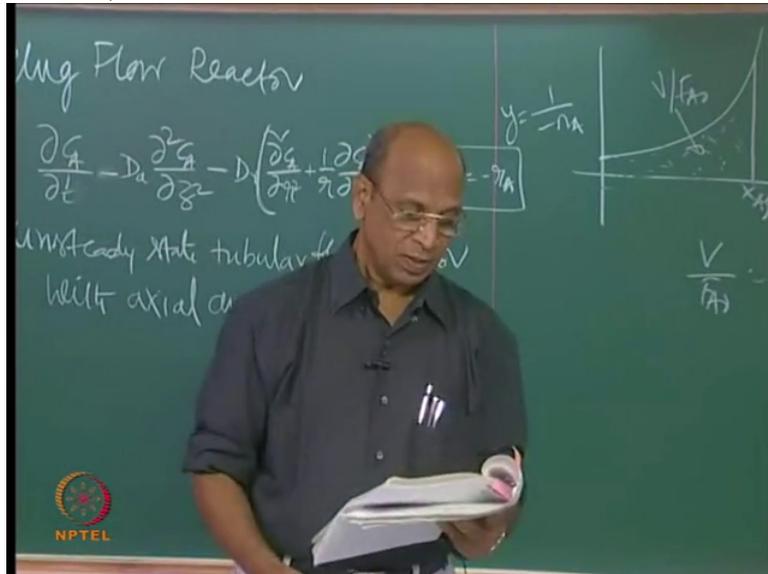
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plug flow reactor.

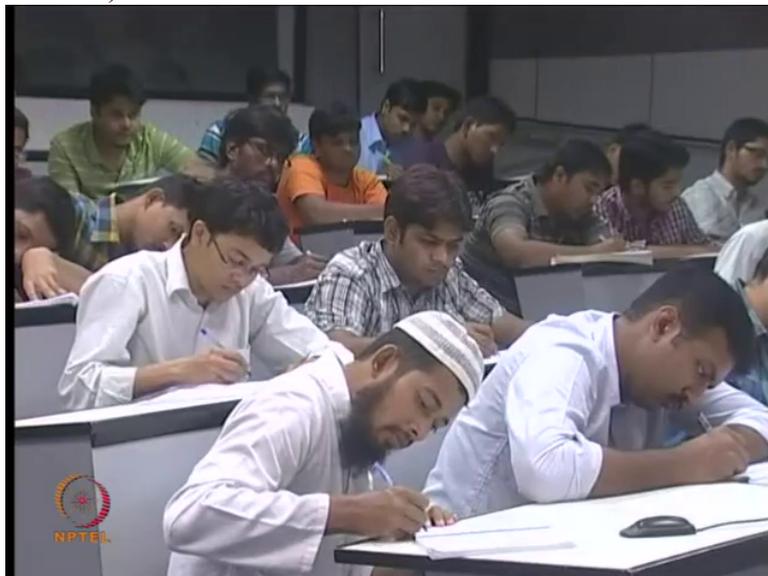
You know applications since I wanted to give you some real life examples like thermal cracking of hydrocarbons quickly.

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You know that reactions conducted in P F R, that you write, reactions conducted in P F R. Because then you know you will also have a feel you know that we are not talking just like that, right. Reactions conducted in P F R, just

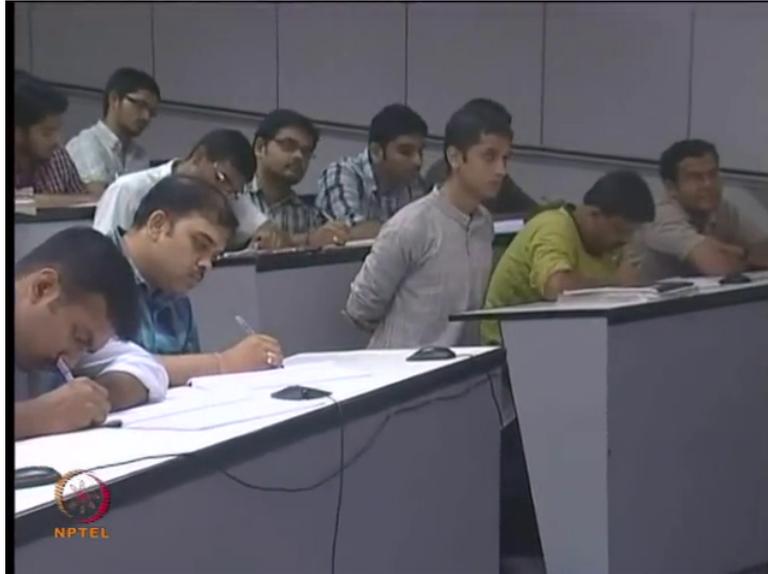
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below that what you write, homogenous reactions, homogenous reactions, you would have heard of the, these things, but probably you may not know this.

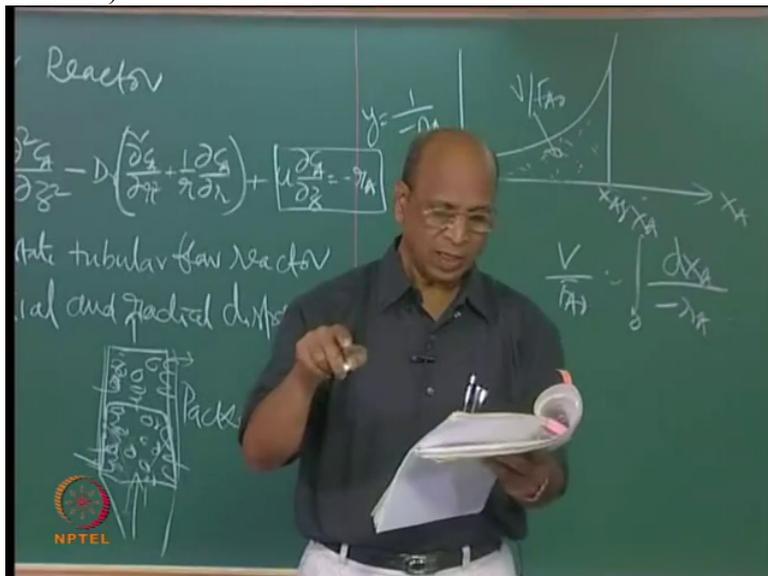
Thermal cracking of hydrocarbons to ethylene that is one, thermal cracking of hydrocarbons to ethylene,

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you know ethylene no,

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yeah, what do we get? Ethylene we are producing, what is use of ethylene?

(Professor – student conversation starts)

Student: polyethylene

Professor: Yeah, polymerization. Ok,

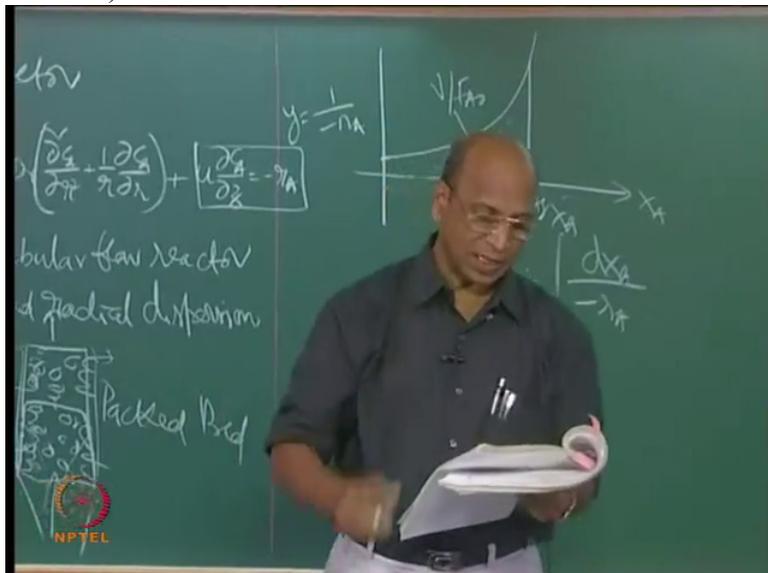
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so that is what. I think you also should know what is the use of that. Ok,  
(Professor – student conversation ends)

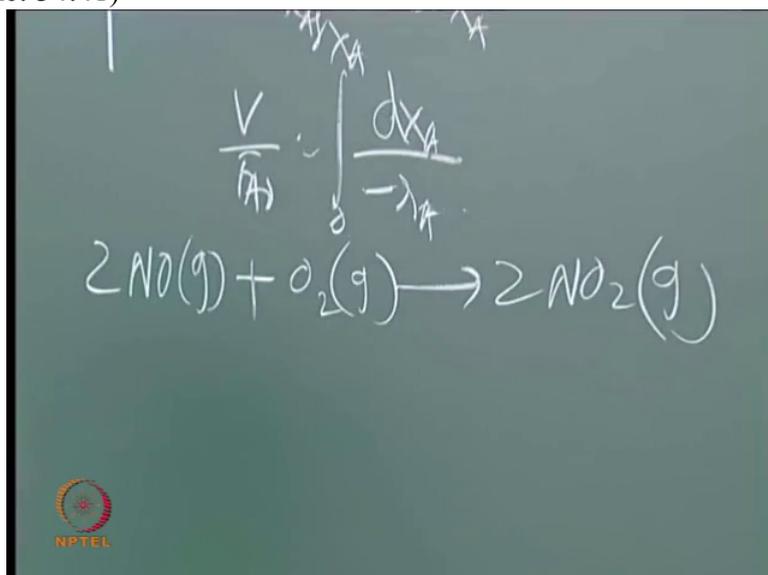
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one is oxidation of nitric oxide. You know why oxidation of nitric oxide is done one of the steps? All gas, gas, gas, gas, homogenous reaction, yeah. This step comes for producing nitric acid. That is intermediate

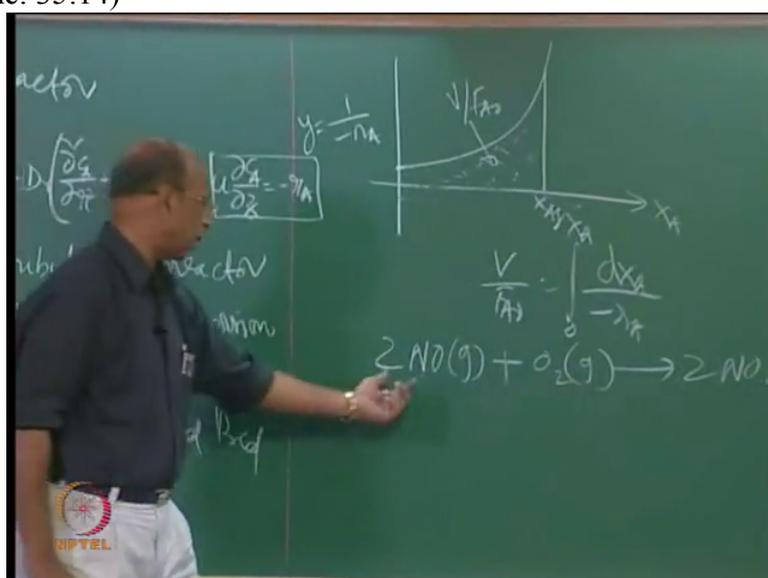
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step for nitric acid. And incidentally this is the only third order reaction example, Ok.

I do not know other reactions but this is one of the, if someone ask you in interview, what is the third order, because third orders are not many. Ok. First orders are many. Second orders are many. Third orders are not many. But if someone asks you, because it is not many, people may ask, you know what is the third order reaction? Can you give an example? This one, this goes straight to stoichiometry, this is 2 moles, this is 1 mole, 2, ordered.

(Refer Slide Time: 35:14)



With respect to this second order, with respect to this, first order, third order reaction. Ok. So I think the step comes in H N O 3 production.

Next one, sulfonation of olefins. What are olefins, you remember, organic? That is why chemistry, Gopinath we should have, when we studied we studied 5 chemistries, Organic 1, Organic 2, Inorganic 1, Inorganic 2, and General Chemistry, yes physical chemistry later I think totally in 3 years we have studied, 6 semesters, at that time it is 5 years course. Yeah, around 6 semesters we have studied.

So I mean, does not mean that we remember everything but you know, that much chemistry exposure is there, I think you will really appreciate chemical engineering, right. What is olefins?

(Professor – student conversation starts)

Student: Double bond

Professor: Alkenes can also be called as olefins?

Student: Yes

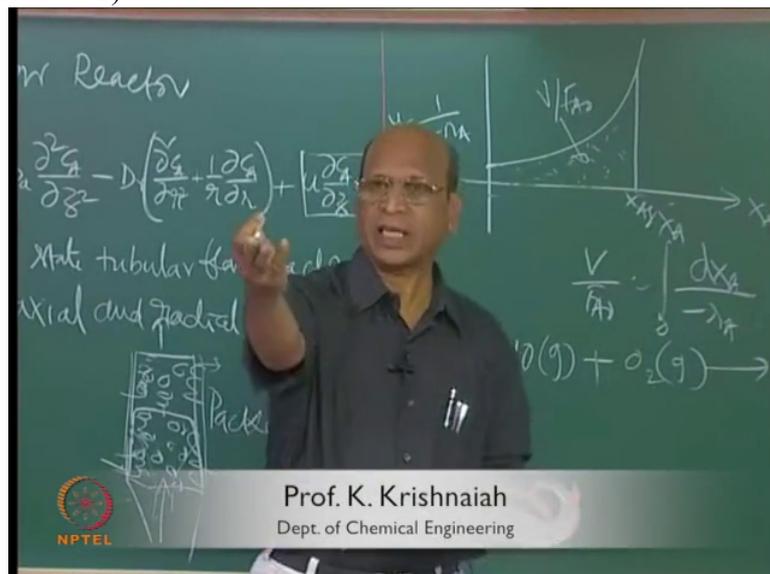
Student: Double bond

Professor: Yeah, C N 2, C N H 2 N Ok or olefins, Cracking of them, sorry sulfonation, what for you do sulfonation?

Student: Detergents

Professor: Exactly, detergents, soaps

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That is why for every reaction we have some use. But unfortunately we are not telling you, you are also not bothered to know, Ok good that is one.

(Professor – student conversation ends)

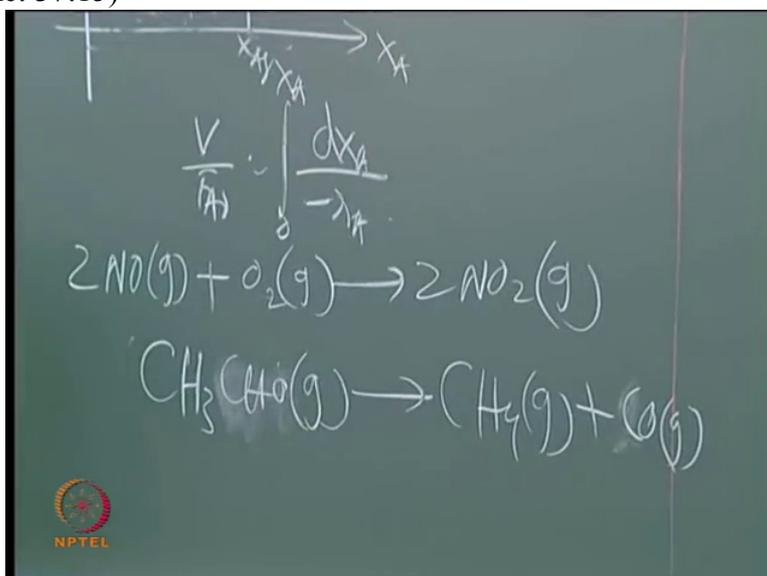
So next one is fourth one, decomposition of acetaldehyde,

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decomposition of acetaldehyde, the reaction is  $\text{CH}_3\text{CHO}$  gas, sorry  $\text{CH}_3\text{CHO}$  gas giving us  $\text{CH}_4$  gas plus  $\text{CO}$  gas,  $\text{CO}$  gas, so to get methane

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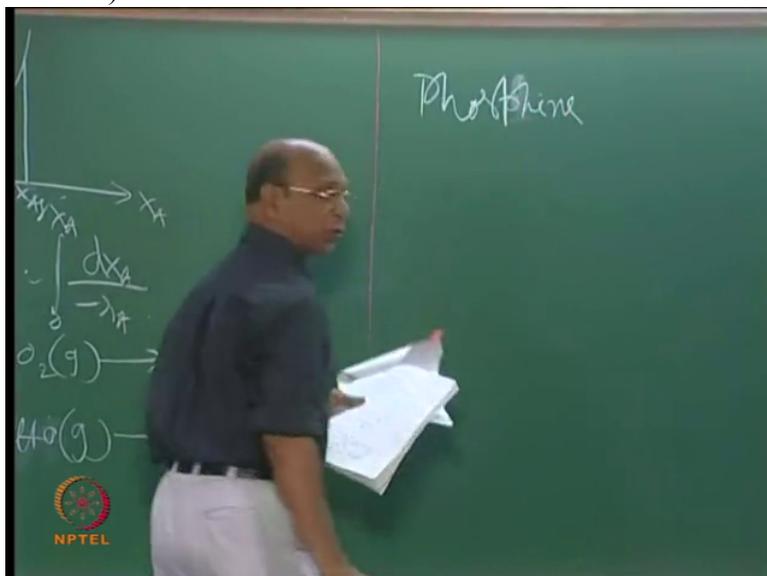
Acetaldehyde decomposition, Ok and  $\text{CO}$  also, then phosphene decomposition, you heard of this reaction, phosphene decomposition, phosphene?

(Professor – student conversation starts)

Student: Gas

Professor: I think we are getting late now.

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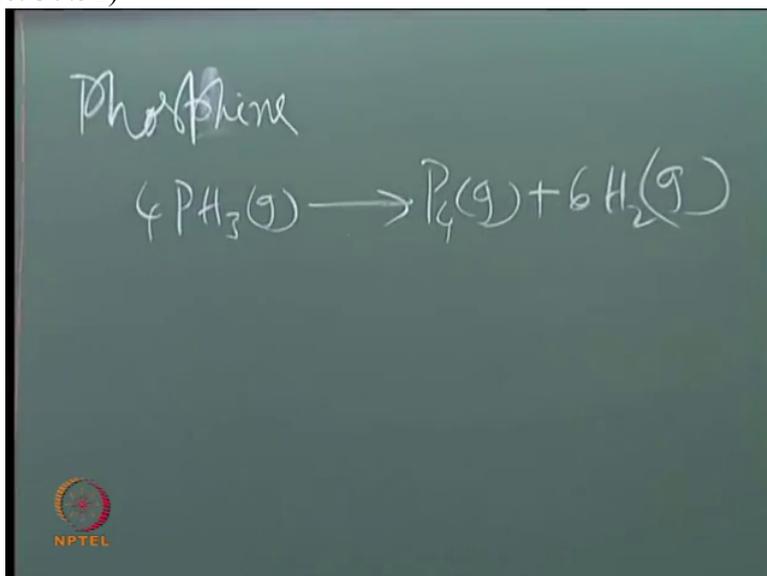


Phosphene decomposition so that is 4 P H 3 gas giving us P 4 gas plus 6 H 2 O, sorry 6 H 2 gas.

(Professor – student conversation ends)

You know beauty of the reaction?

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4 moles giving 7 moles. So disaster if you put this in plug flow reactor, expansion is too much no, yeah so then you know, here beautifully it comes what is  $\bar{t}$ , mean residence time and what is  $\tau$ , all that will come here.

So these are homogenous reactions. For heterogeneous reactions sulphur dioxide oxidation, ammonia synthesis, ammonia synthesis and sulphur dioxide oxidation, Ok these two are enough.