Chemical Reaction Engineering 1 (Homogeneous Reactors)
Professor R. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology Madras
Lecture No 23
Reaction rate for Homogenous reactions

Yeah, so this is what what we have been discussing. And the other day we had the data, one problem

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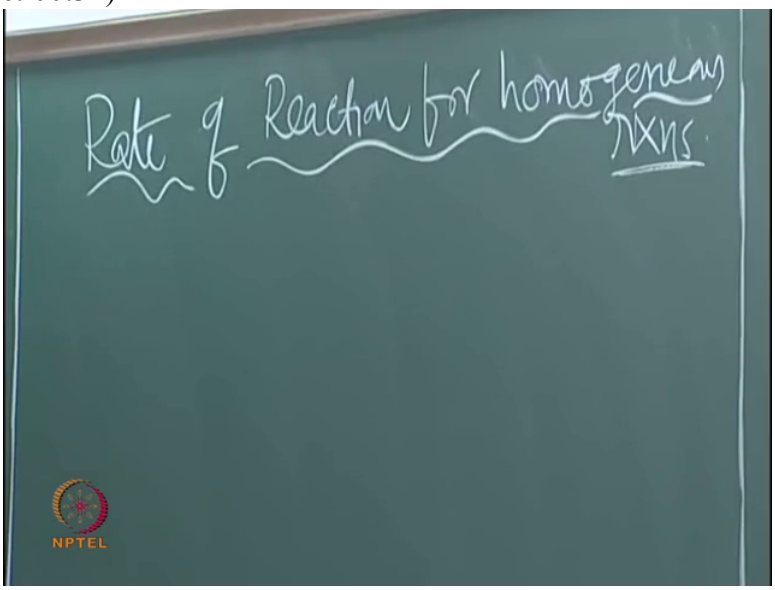

and what we discussed in the last class was about the integral rate. And you, if you want to try the integral rate, the first step is assuming you have first order reaction. Then you have to assume you have second order reaction.

For second order reaction, suppose, that means first order reaction you assume, and the test, try to arrange far as possible in terms of the straight lines. So that is why in yesterday's class what we had plotted was minus l n 1 minus X A equal to k T, T, versus T, so k will be the slope automatically.

If it is second order, then you know if it is not fitting, that means the data, Ok, if the data falls something like this, experimental points are something like this. It is not a straight line. Please do not draw straight line like this. Ok.

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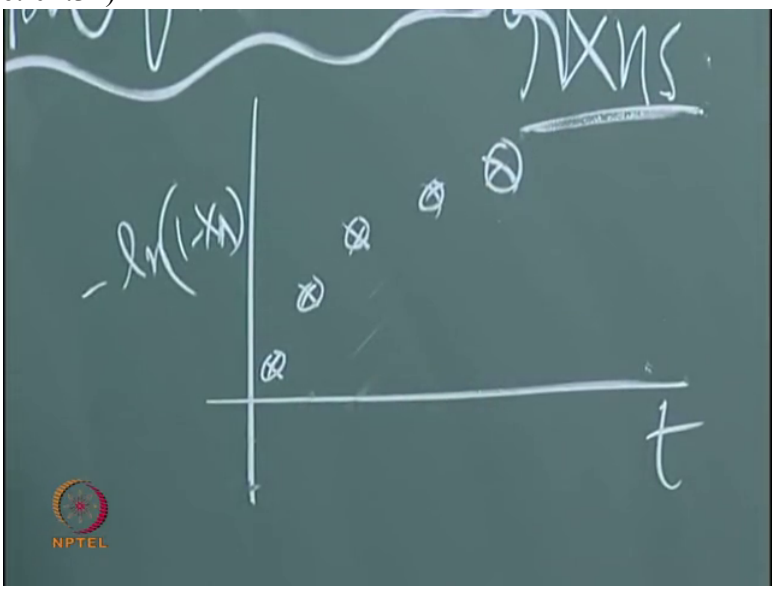

This is the problem.

If you go to Excel, definitely Excel will draw, you know you have options no, polynomial, straight line and all that, right. So that is why if you ask that first option without knowing when you click that, it will draw a straight line. Ok. If I draw a straight line there, Ok,

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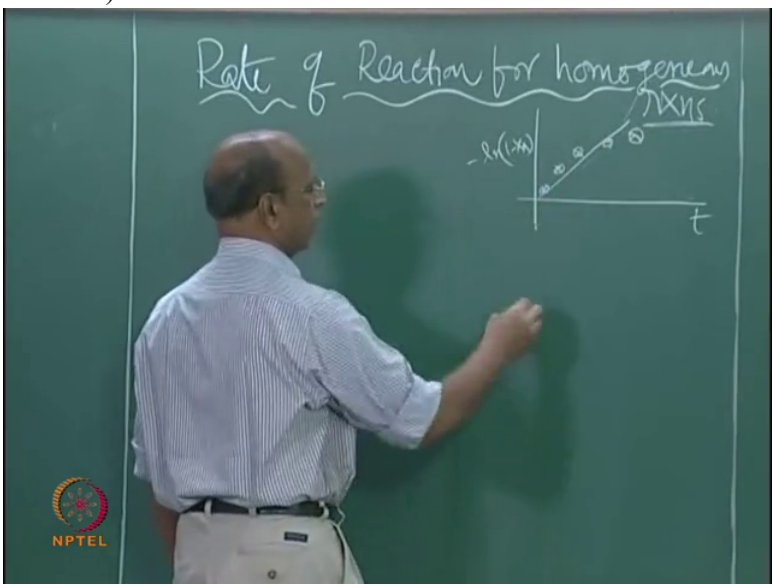

it is going through origin no, so that means of course, some points here, two points this side, two points that side, you may think that beautiful fit, Ok.

But actually if you look carefully, it is a curve.

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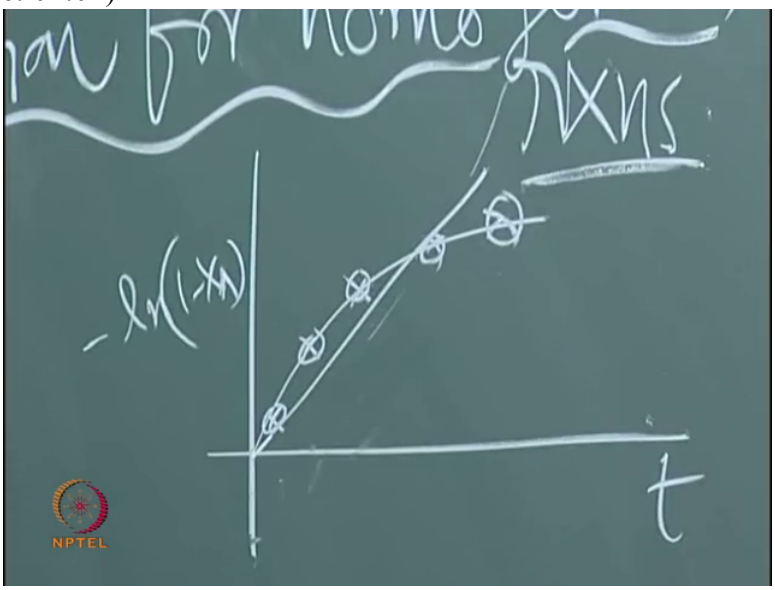

This is where you make the mistakes. Ok. So take the data as accurately as possible. I think that we have discussed you know, how to take data. There are many methods we have to use. Either conductivity method or simple titration method for analyzing the concentration.

Always in this rate equation finding, you have to first conduct the experiment and then you should have data concentration versus time. Concentration of the key reactant versus time, Ok. So then you can convert that data into first order reaction data, or second order reaction equivalent data, and if it is second order what is the equation we are going to use?

Again it is a batch reactor what you have used. So you have t by C A naught equal to because this is constant, that equation for any rate, that equation is same. So d X A by minus r A, now it is second order, it will be k, k C A square, right? So this k C A square again, you will convert that into yeah, so this is zero and X A

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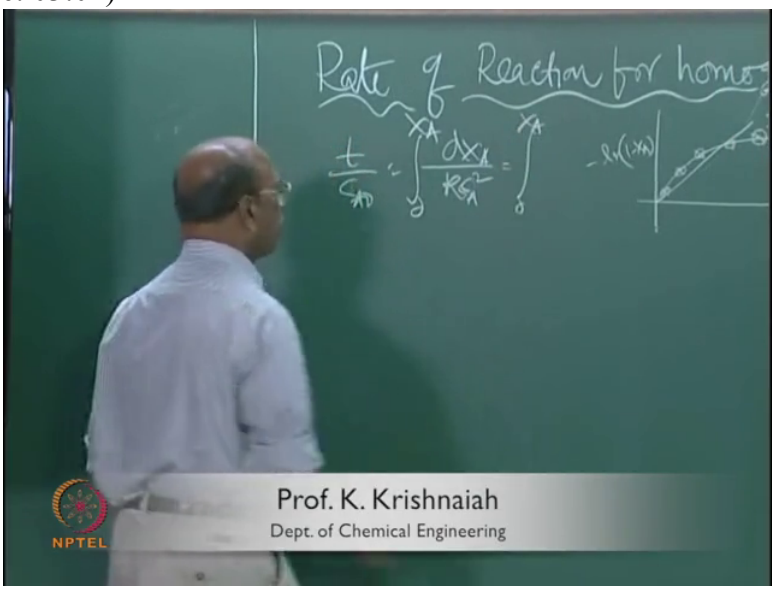

and you can also convert this, you know it need not be in terms of X A.

If you are comfortable, with C A also you can use.

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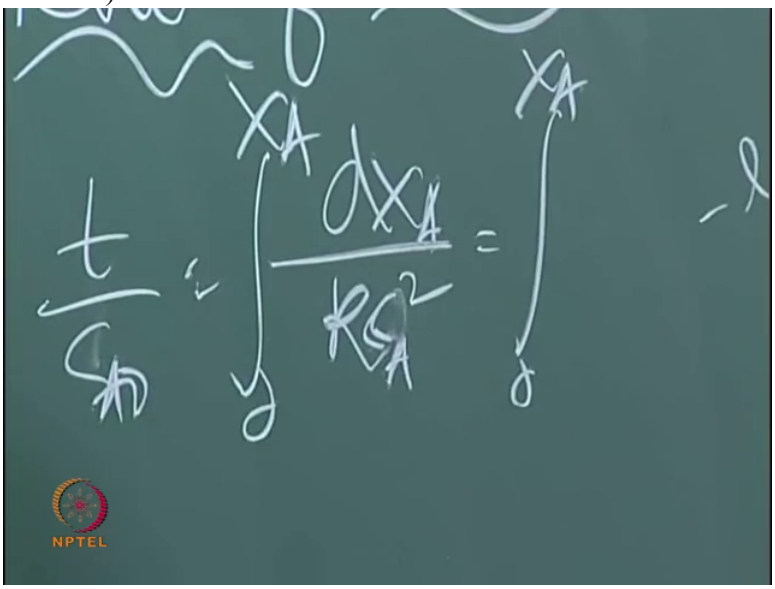

Yeah, C A also one can use that. It is not always only, you know only this format. And provided it is constant density system. That is very important. This is a general expression. So that is why concentration we are not writing.

But if you know exactly that it is a constant density system, or there is no mole change between the right hand side and left hand side, then we can use constant density system, and then the algebra will be a little bit simpler. That is all. I mean it is not going to change the entire thing. But it will be a little bit simpler.

So then you have d X A by, k C A naught, 1 minus 0:03:49.2 square, C A square also. Then you have to integrate this expression. I am not giving the integral expression, right?

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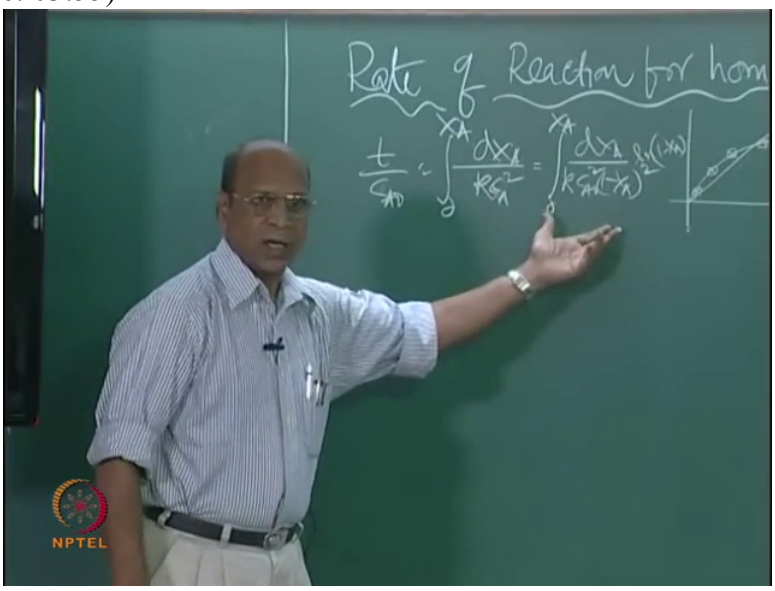

The reason is I am giving, particularly when you have, you know other people who have not been exposed to this; I am just trying to draw one or two, trying to explain 1 or 2 equations. And this how you have to now find out again, what is the, the relationship between concentration and time, or conversion and time.

And then you have to arrange that equation in form of a straight line, and then you have to plot, check again. If again if that is not exactly falling on the straight line, because you know straight lines are very easy to observe, whether it is really falling or not. Ok.

Curves are very dangerous. You do not know how it turns, right? That is why you have to be more careful, right? So that is why try to write the equations as much as possible

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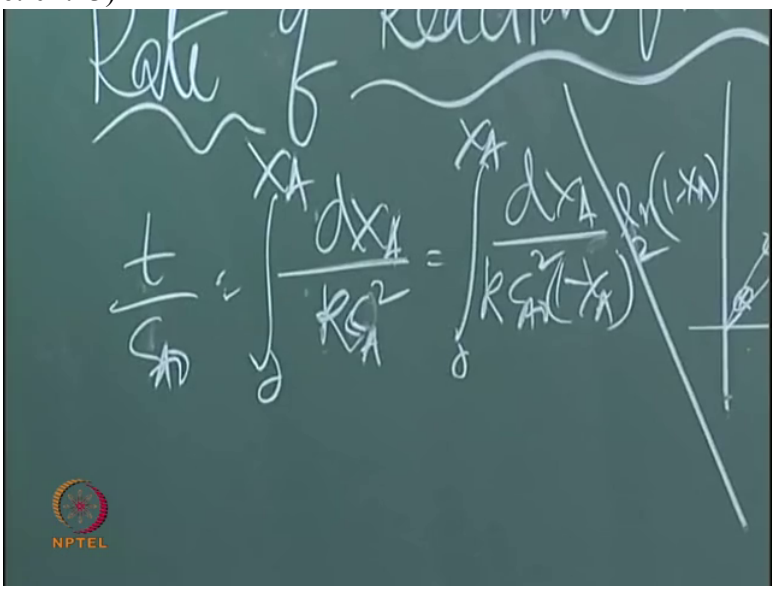

in terms of straight lines. If you now go back to Levenspiel and then see, entire third chapter you would like to plot only in terms of straight lines.

I am just trying to making you recall what has happened there. And I am sure most of you would have done that third chapter at least in C R E, right. So that is why, and I have given also many questions on this third chapter again, so that once more it is review for you and then you can quickly finish this right, Ok, good.

So like this you have to always try to find out for homogeneous reaction what is the rate of reaction. So this is, assuming that we have integral method. If you have differential method? Earlier I think I had written there, integral method, now you have the differential method and for differential method,

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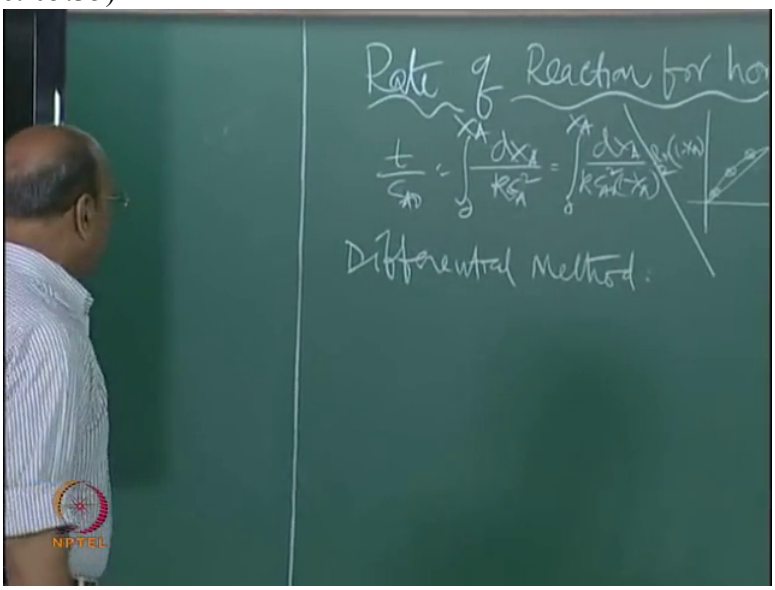

what is the starting point?

You have concentration versus time. And what do you do by differential method? Because we know that, yeah the rate d C A by d t is equivalent to

(Professor – student conversation starts)

Student: minus r A.

Professor: But it is not again correct for most of the things. If you have a constant, variable density system is not true. You will have some more things there. Ok, so that is why if you have a constant density system liquid phase, then straightaway minus r A equal to minus d C A by d t.

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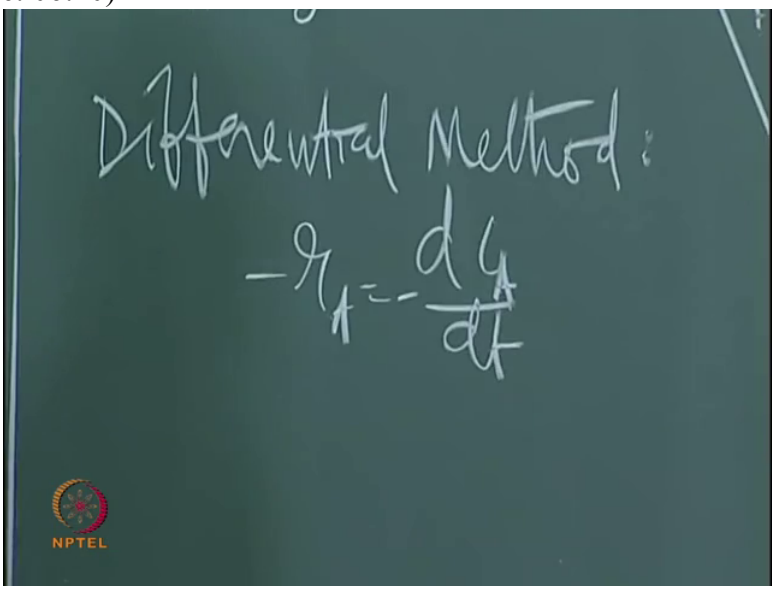

(Professor – student conversation ends)

This is the one, constant density system, right? So by measuring this d C A by d t from a slope, where you have concentration versus time, this is C A naught and because we are plotting for reactant, it decreases.

Maybe first I have to put the points, Ok, so now yeah, this is the rate, this is the concentration how it is decreasing, Ok. Concentration versus

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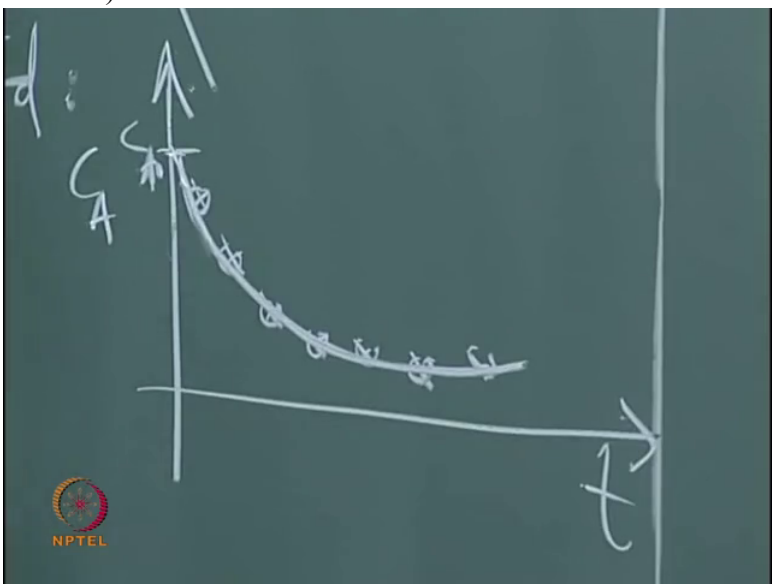

time, yeah so now slope at any point will give me a rate. But again it is not easy the way I am telling you. At least how many of you really done one problem using, by drawing slopes and then solving the problem? Anyone has done that? Frankly in your B Tech. You have done it?

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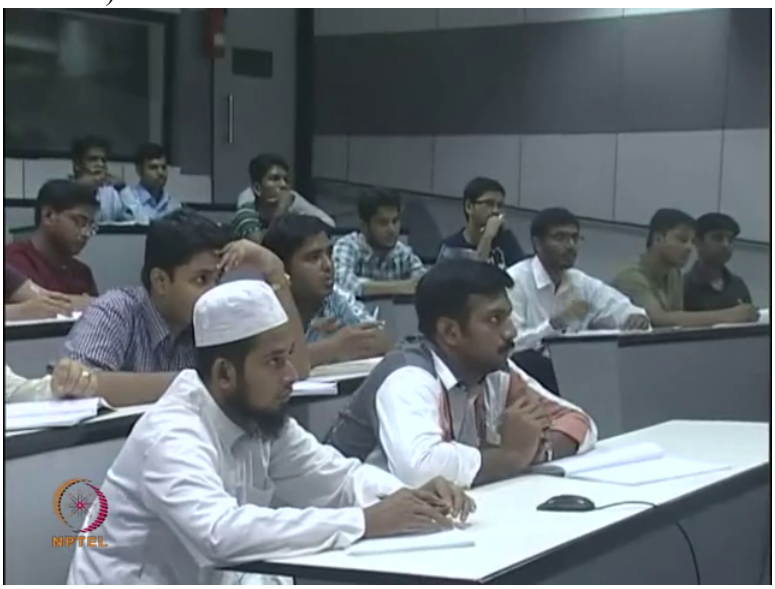

How did you draw the slopes? How did you draw the slopes?

(Professor – student conversation starts)

Student: Tangent

Professor: How did you draw the tangent?

Student: With capillary

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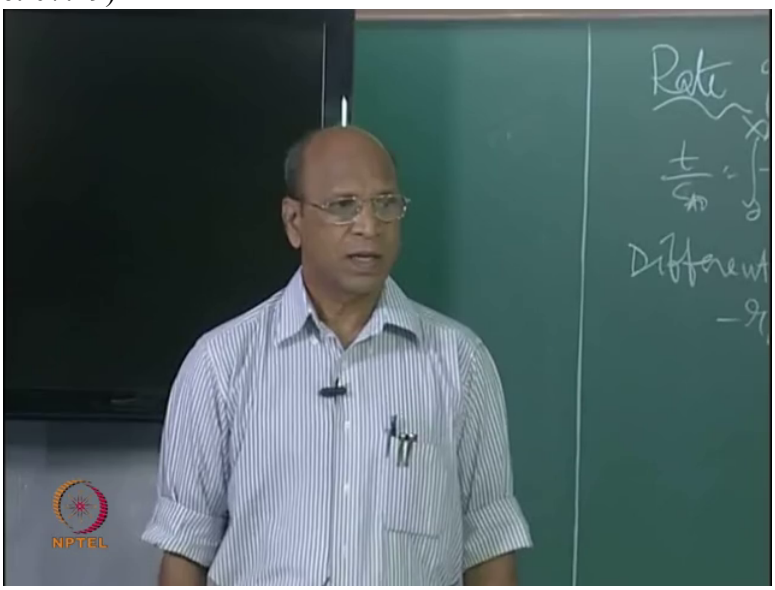

Professor: What do you do with capillary? Capillary tube, what do you do with capillary?

Student: 0:07:27.2

Professor: how?

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Student: Capillary

Professor: What is capillary? I mean glass tube?

Student: Yes sir.

Professor: It is available in the market,

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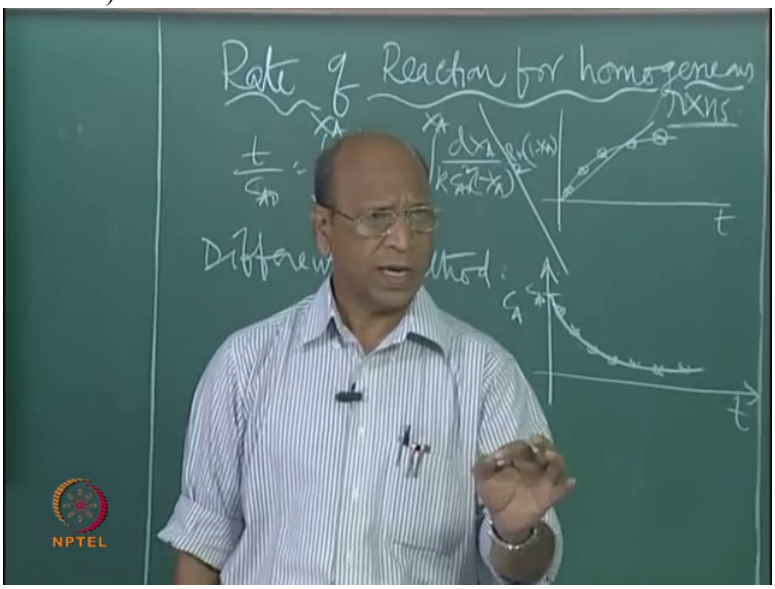

for drawing this? Because I am, first time I am listening to this capillary. All of you are from the same university or what?

Student: Osmania University.

Professor: Yeah, Ok. What is the capillary? What do you do? You have the tube. Then, you have the curve.

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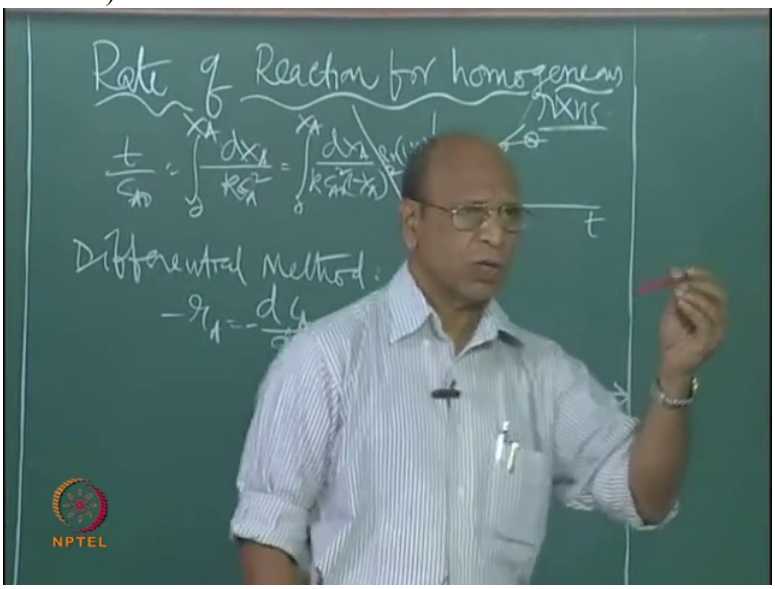

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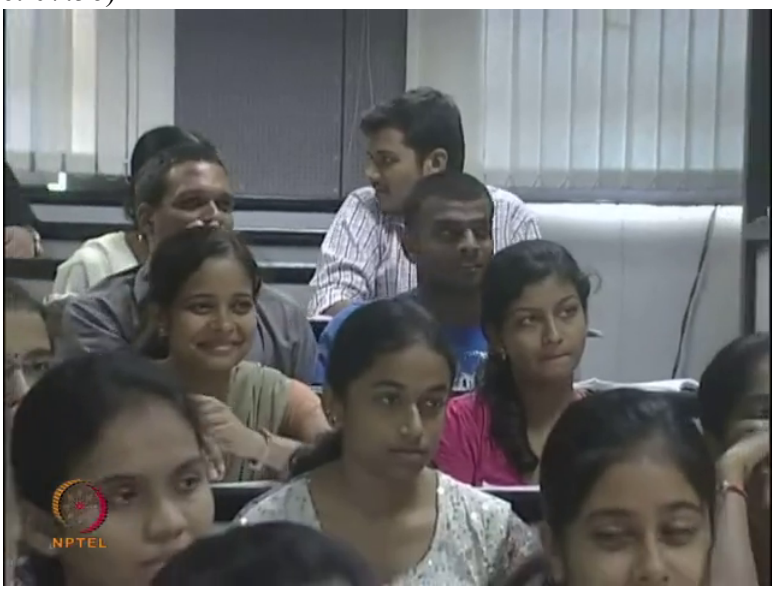

Where do you put what?

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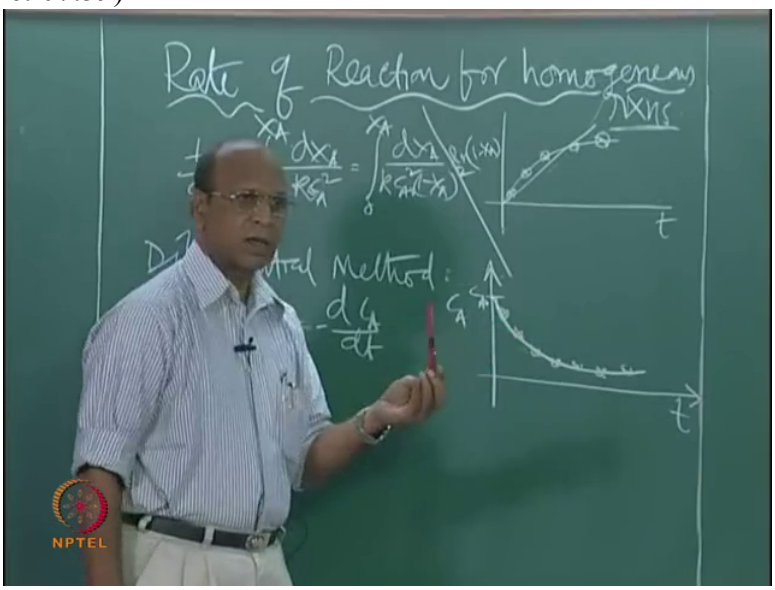

Student: On the point.

Professor: Point, like this?

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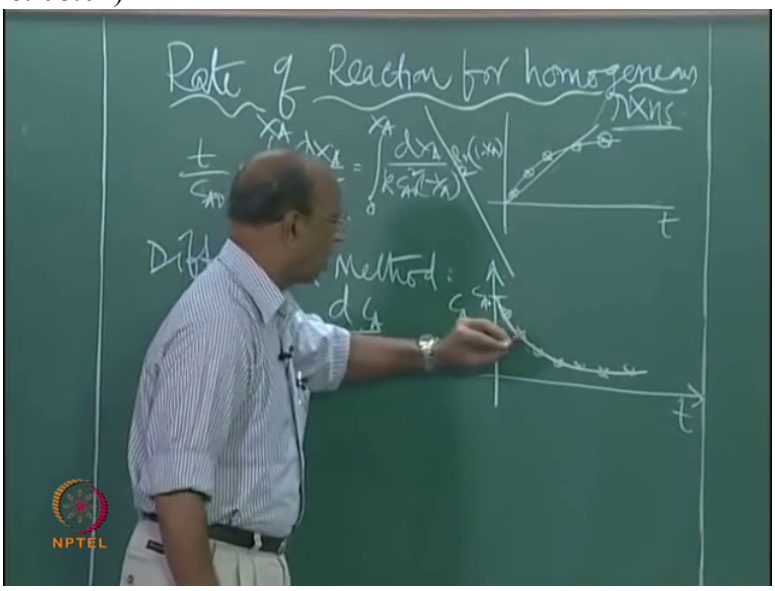

Student: No Sir

Professor: Like this?

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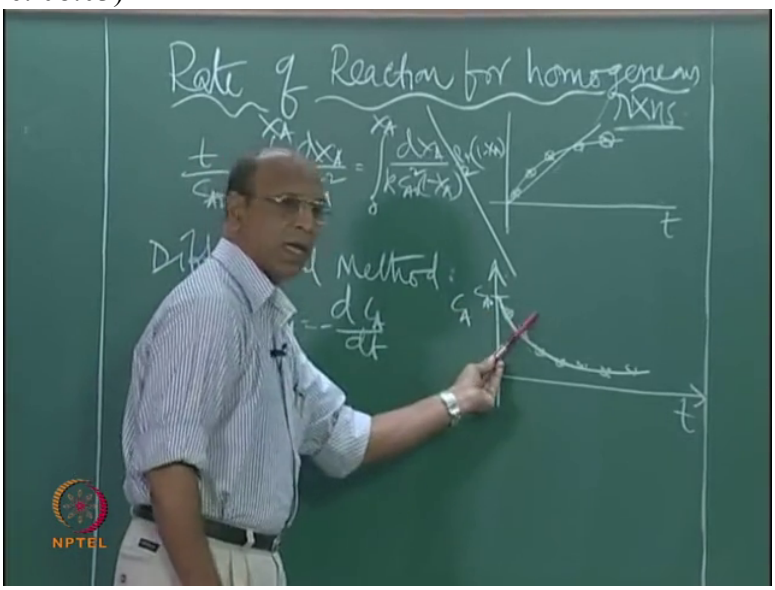

Student: And we turn it so that

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Student: Inside that we can see the curve, Sir. If that coincides with that Q inside, then we plot points on that.

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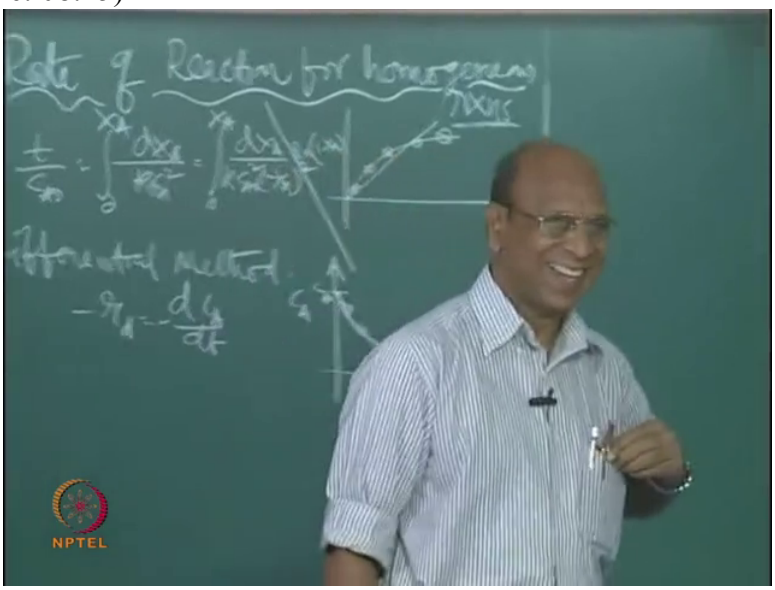

Student: We will get normal and with that we will draw tangent.

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Professor: Because I think you know it is good.

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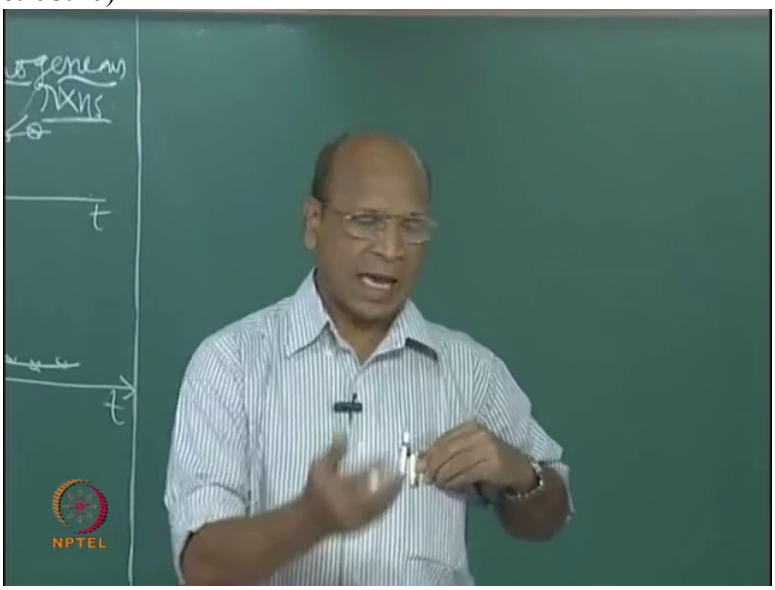

Because capillary may again distorts also, because it has curvature and all that.

(Professor – student conversation ends)

And if you look the old book by Walus, W a l u s, Stanley Walus, I think Kinetics for Chemical Engineers or so, that is the title; he has also written a book on equipment design. There he gives in Appendix how do you measure exact, otherwise you know differential method is one of the most difficult method.

You should not touch that method at all. Unless it is inevitable, you do not have any other choice. Because we make easily mistakes when we draw the slopes, I mean the tangents. Easy mistakes and you will get tremendous, you know, error. That is what he says, I tried also. I think it is beautiful.

I mean when I read that in the book, he takes a mirror. He is using capillary. But again capillary has curvature. It is a round tube, no. Yeah, so that may also distort a little thing, it is not straight. So what he does is he puts that like this. This is mirror. He puts like this, Ok. And then he sees this image as a continuous image inside the mirror. It should look as continuous.

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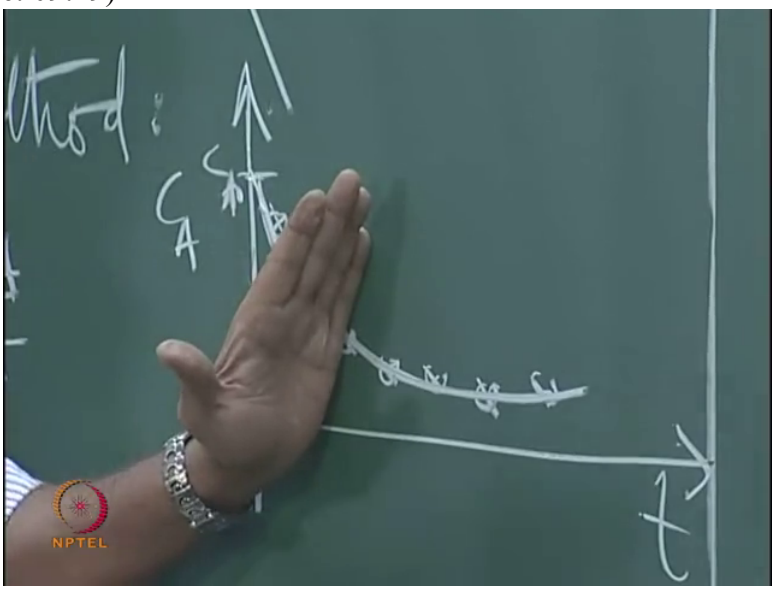

Then draw the line,

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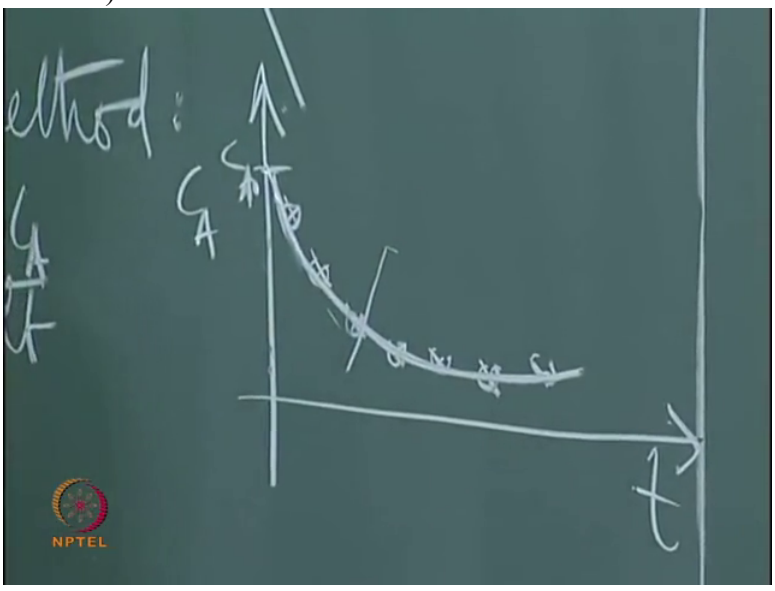

normal. So once you have the normal, tangent is very easy to draw and because I think 90 degrees you can measure and then

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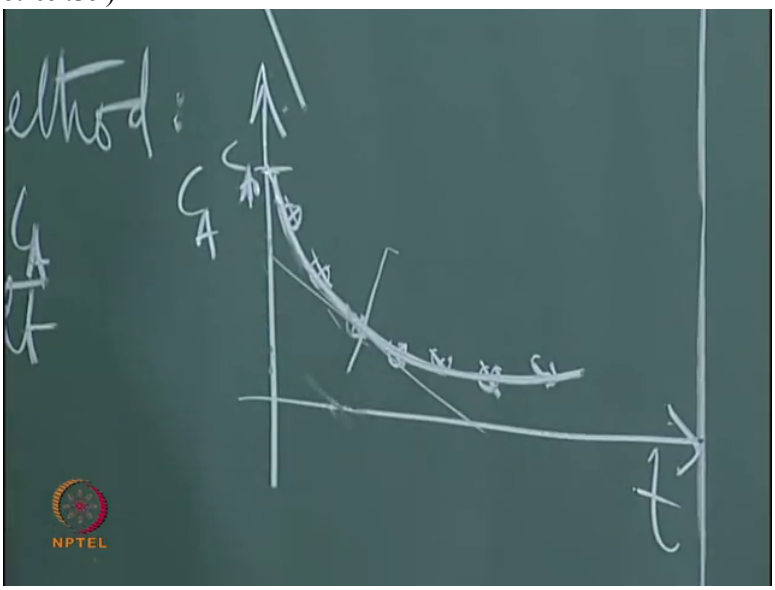

draw it. That is one of the very foolproof method, Ok.

Any problem with this technique? No, not no? But it is real experience. It is very good if you are able to draw that. So like that, and also you do not have to take the, draw these,

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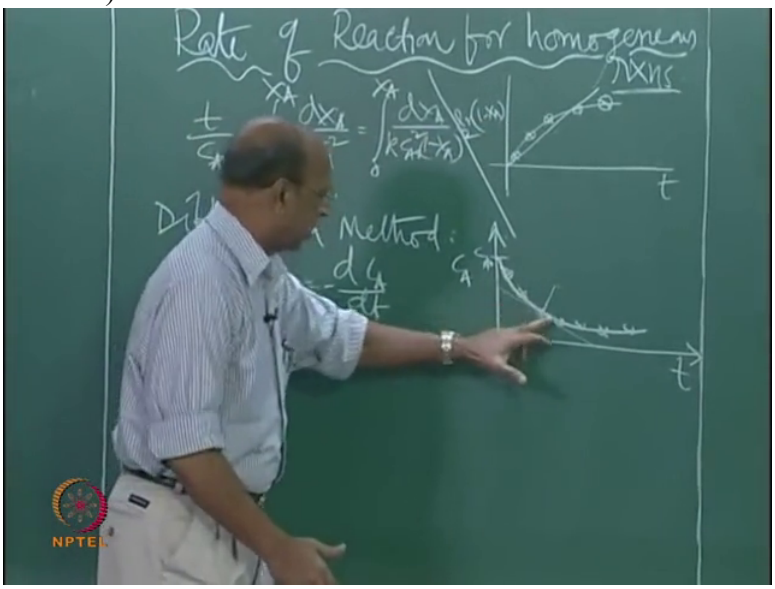

I mean the tangents on each and every experimental point. You can choose for example, you can choose your own, because it is a continuous line.

So you can take convenient, may be 9 moles per hour, 8 moles per hour, 7 moles per hour, 6 moles per hour, like that you can choose and then, because you may not get that exactly C

versus time, it may not be exactly 1 mole, or 1 moles per liter, 2 moles per liter, 3 moles per liter or 5 moles per liter.

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Because whatever you take the sample, whatever you measure, that only you plot there.
So for convenience you can also do that. So once you have that slopes, you are now going

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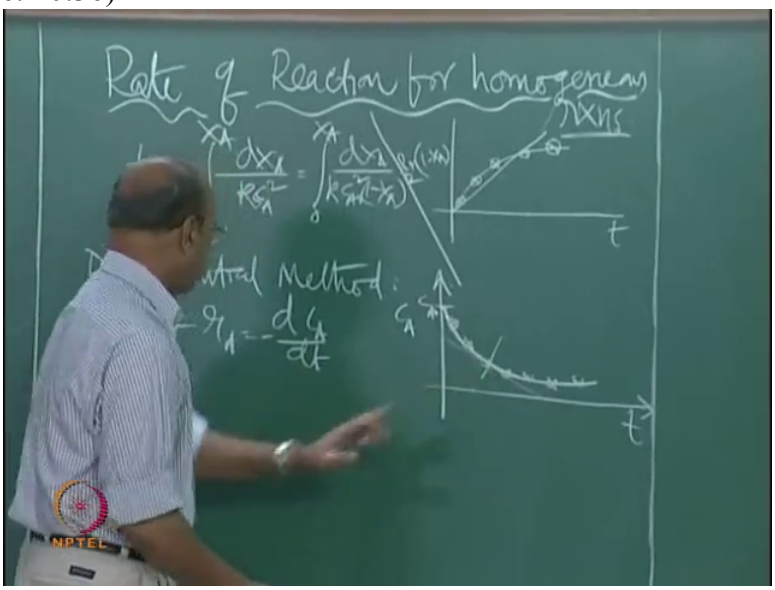

to list out all the slopes, right which is nothing but minus r A. minus r A 1, r A 2, minus r A 3 etc. And corresponding

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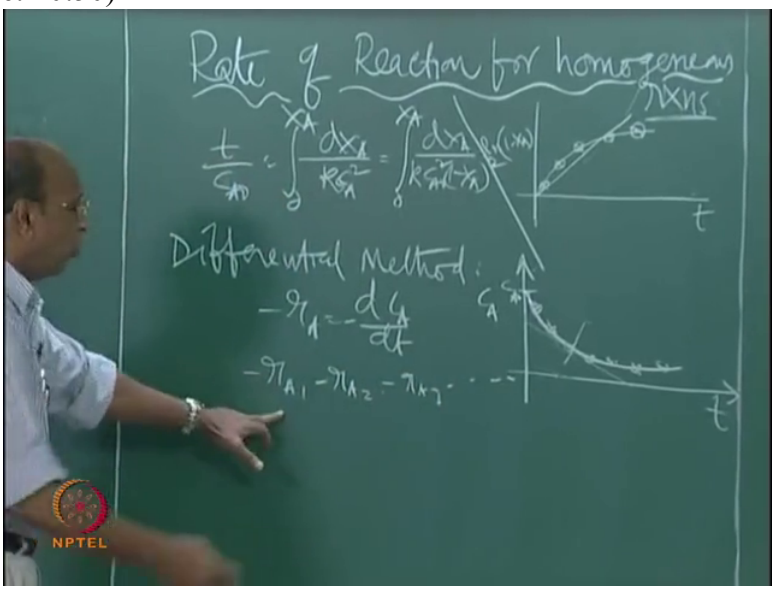

to these concentrations, these concentrations,

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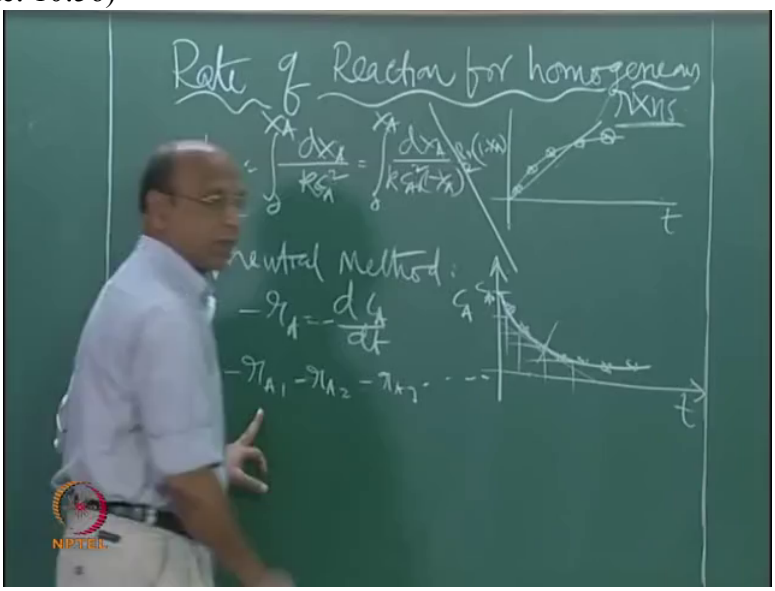

right. So then you have C A 1, C A 2, C A 3 etc.

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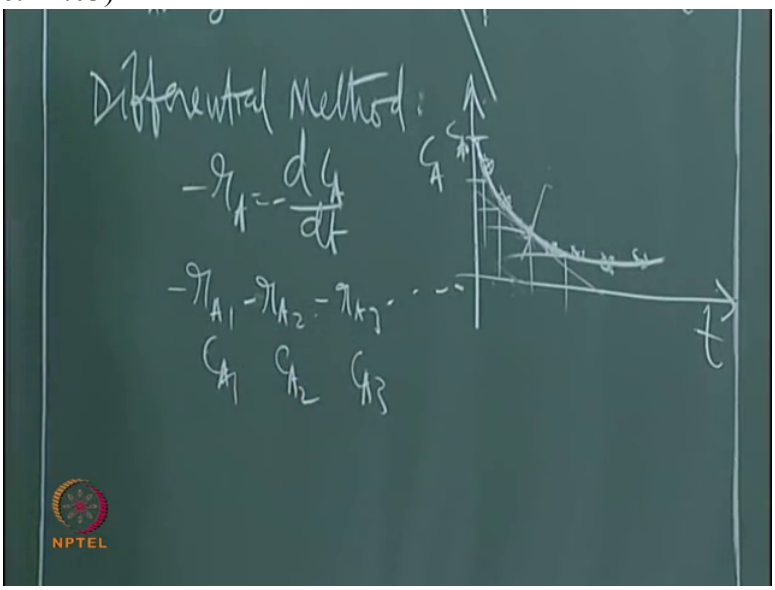

Ok. So what is the assumption here?

We assume now that we have minus r A equal to, now I think I convert d C A by d T into minus r A, equal to k into C A to power of n.

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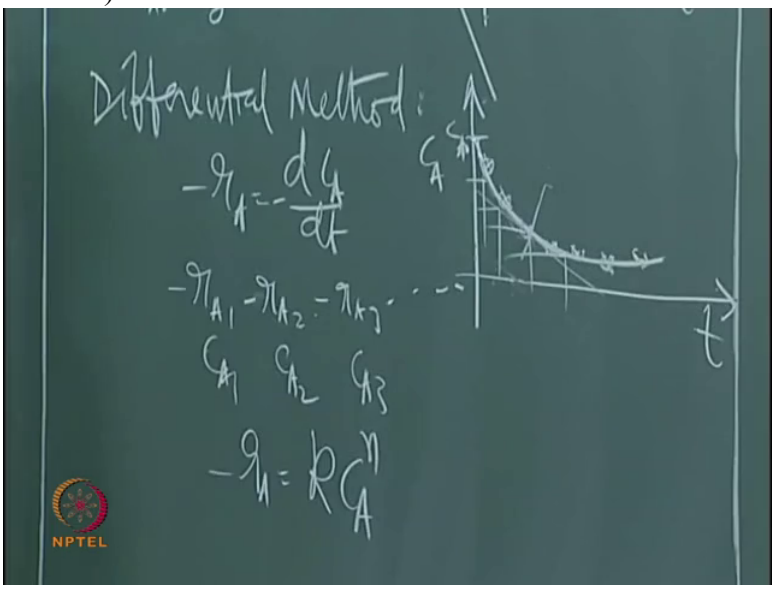

Now take logarithms. So l n, l n minus of r A because minus of r A is not a negative number, Ok. Minus is only a indication that it is for reactant, that is all, yeah.

So then this is equal to l n k plus n into l n C A.

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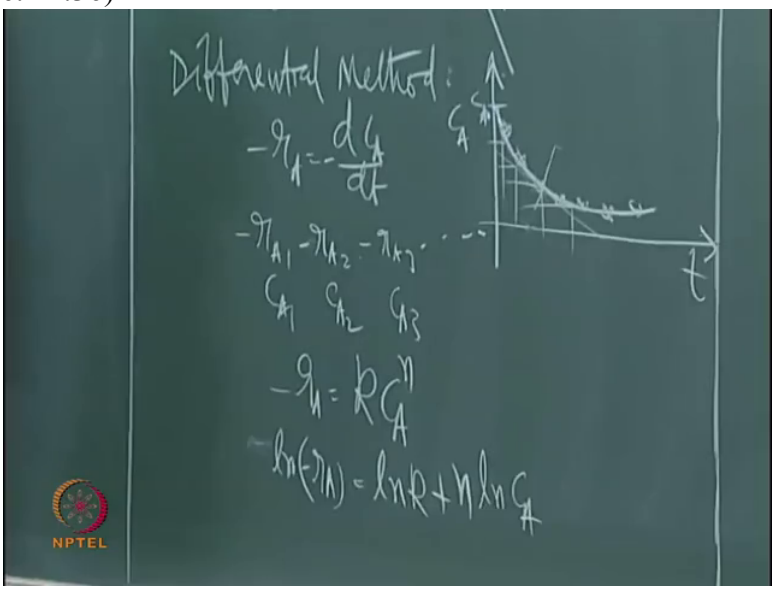

Now you plot this on log-log graph. Minus r A versus l n C A, yeah. What do you expect from this? First of all, you should expect no, straight line. It should go to straight line, I mean

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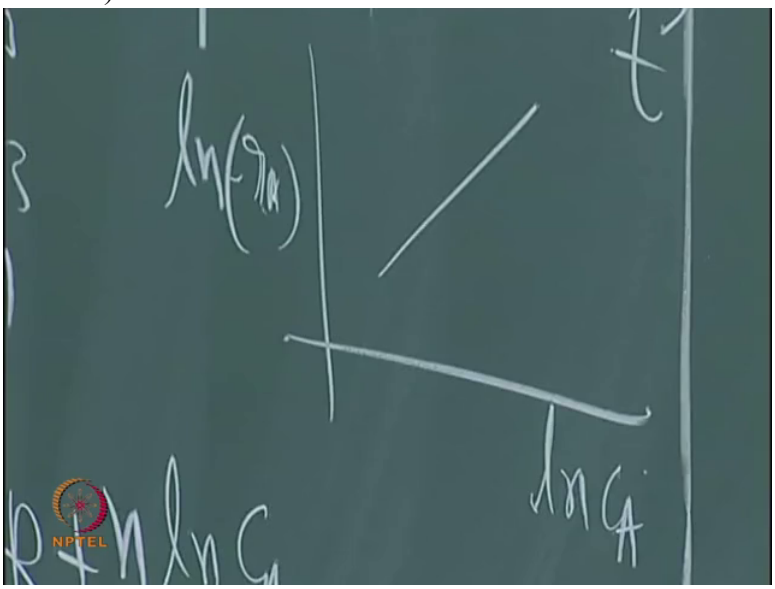

and it has to go through origin, no? Why?

(Professor – student conversation starts)

Student: l n k

Student: Zero

Professor: L n k is there, first of all there is no origin for logarithm. Ok, zero is not there. Ok, point naught naught 1, point naught naught naught 1, like that only it goes.

(Professor – student conversation ends)

So, so like this if you put, Ok, do not do this. First do not draw the line and then put the points (laugh). First put the points

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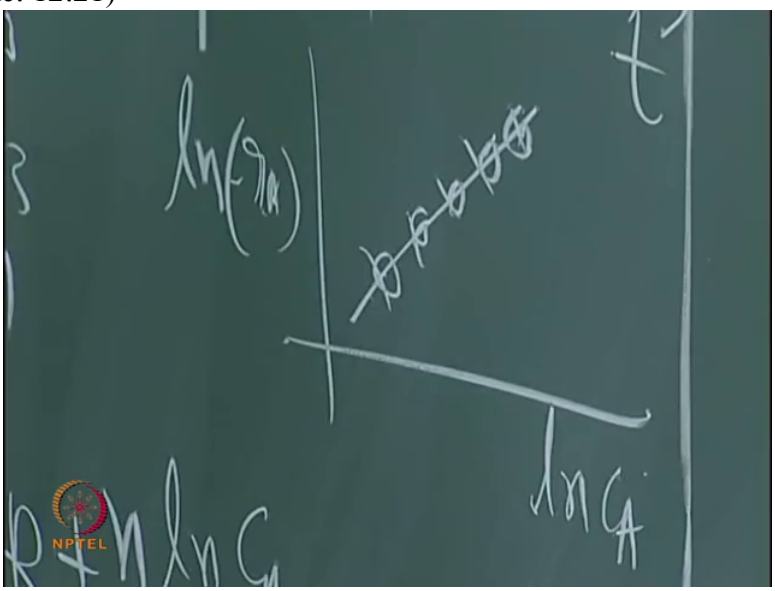

and draw the line. Because I am simply drawing there. So the slope will give 0:12:25.5 slope is n. And this one, Ok. I made something like this, Ok.

So this intercept will give me l n k,

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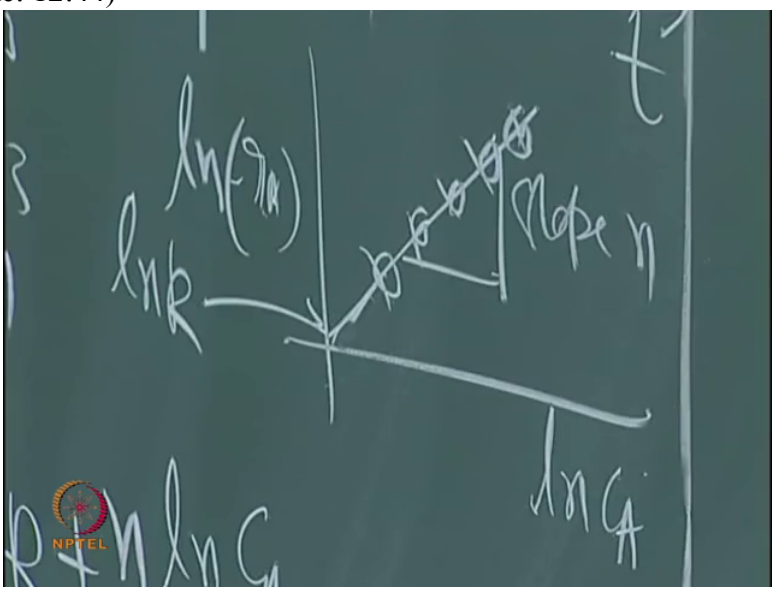

right? So if you want to find out again activation energy with k, that functionality also, then now you do the experiment with various temperatures. Then you will get various slopes. Then you have to plot again

(Professor – student conversation starts)

Student: l n k

Professor: Yeah again l k versus 1 by T and you know l n versus 1 by T slope is a disaster. I think most of the students will make errors there. Because it is semi-log in fact. It is not log-log graph. And Fogler explains how to find out, you know for semi-log graphs and all that. In Appendix I think he gives. At least in...Latest volume I do not know. I think it must be there. What book you followed, Gopi?

Student: Sir, Levenspiel

Professor: Levenspiel. Ok. Levenspiel somehow do not tell all these things I think in the Appendix, Ok good. So that is what, this is the method what you follow for differential method. Yeah.

Student: 0:13:36.9

Professor: Mirror?

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Student: How will I know which angle we have to keep?

Professor: That is what I am telling no, this is the line.

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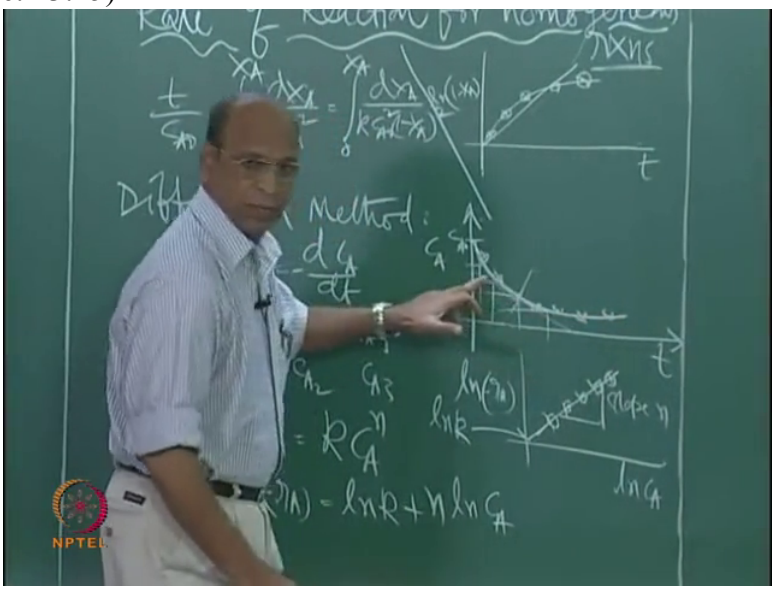

Wherever you put, I put here for example. And then if I put wrongly like this,

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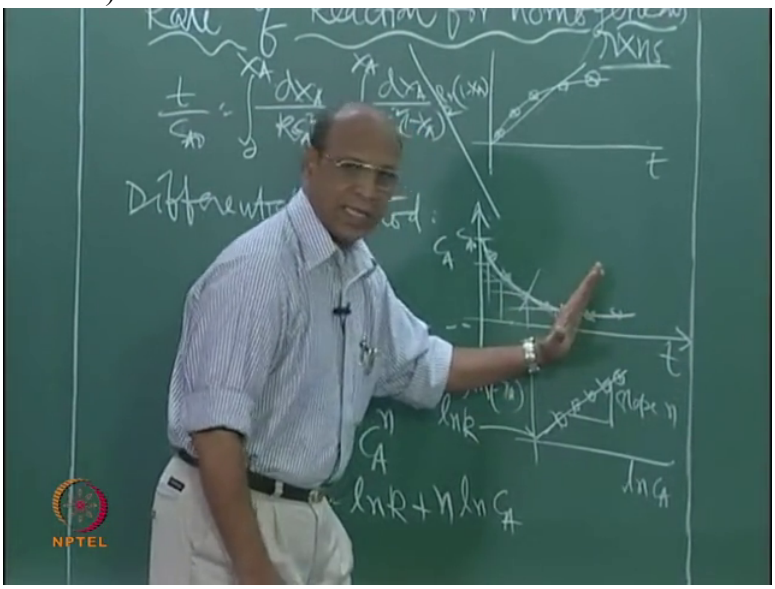

then this curve will go like this. It is not continuous. So you have to turn the mirror such that you have this line continuously going. You know mirror, no? Because this side, you cannot see. Only this side you see the image. May be, people think in that glass. Ok, that is why.

Student: When you see on that...

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Professor: Inside this mirror?

Student: And we can see that side.

Professor: That side you cannot see.

Student: How can we say image is coinciding or not coinciding?

Professor: I think you better try that in your room, Ok.

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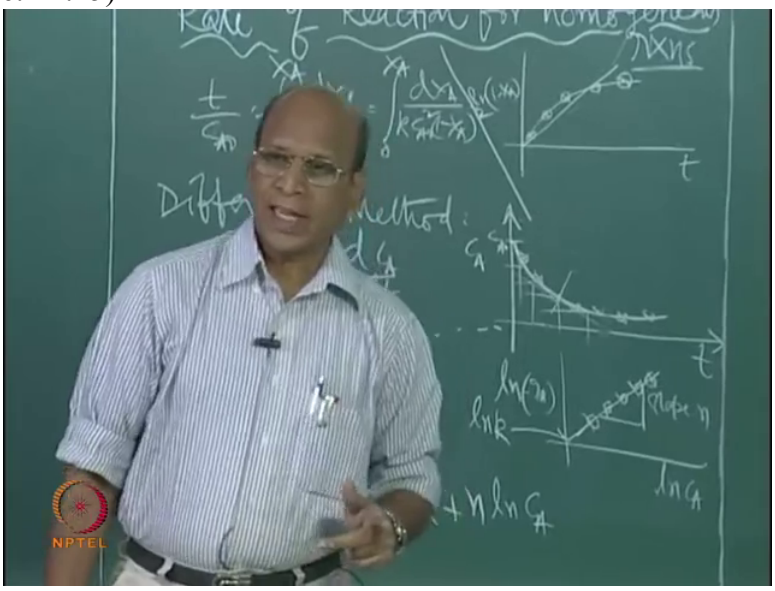

Yeah you can see, I say. You see, this is the reflection. You know here I have the mirror where I can see my face. Ok. Yeah then you put that here, right. And then look at this curve.

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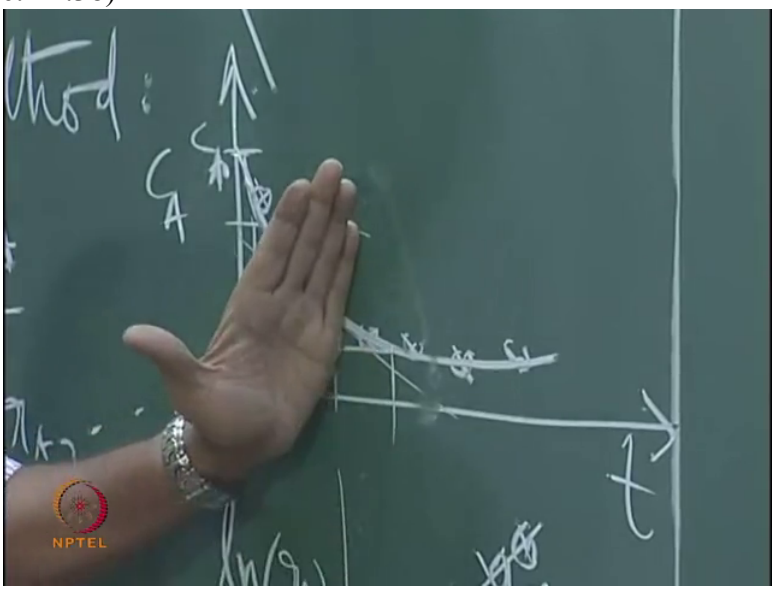

From here you just see, whether this line, this line is distorted, because this reflection comes, no. In the mirror this reflection comes. This entire curve you can see that. But you have to turn such a way that this entire curve looks a continuous curve, Ok. So then only that is the normal to that point. It is a very nice method.

Student: We have two tangents right? Invert the mirror and see

(Refer Slide Time: 15:08)

the other side.

Professor: What is inverting?

Student: That I will see one copy

Professor: Yeah.

Student: May be I get different angles.

Professor: No, you do not get. You try.

(Refer Slide Time: 15:16)

I think the other way you put again, why you should always put this way or that way? You try, you won't. That point is same, no. At that point you will have the continuity. You are not checking the entire curve. At that point it distorts. That you have to turn such that you will have, I think it is a good experience I say. You have to do that. It is a very nice experience.

(Professor – student conversation ends)

I think some data problems also I gave no, yeah, if you do not have, I will send another 10. (laugh) with only data points where you can plot and then see. It is a good experience. And you will never forget once you do. That is why I think it is very good if you are able to try. And other that, I do not know any other method which is very, very accurate.

Even this capillary tube also is not, I mean in my view, it cannot give accurate because that curvature again distorts

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a little bit. Whereas this is flat mirror, so where you will get the continuous curve.

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The very accurately you get. And before that what you have to draw is a smooth curve through all the points, as far as possible, all the points. If you take very bad data, you cannot draw.

So that is why experimentalists should be first, an experimentalist who guarantees that the data is reproducible and also very accurate data. And I tell you it is humans who behave very erratically every second, every minute, every day. Because I think you know all things with life behave like that. Fortunately experimental setup does not have life.

So once it is acting in one way, it acts always in that way for the same condition.

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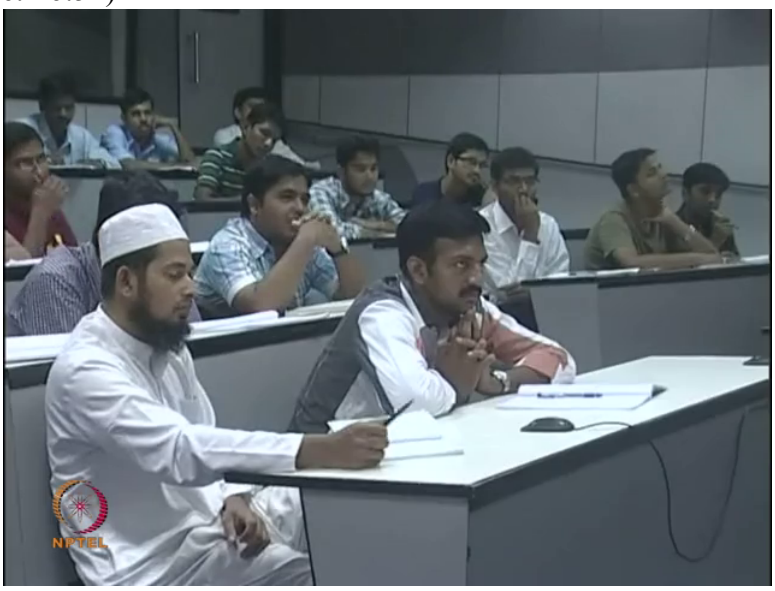

That is why my students come and tell me Sir, it is not reproducing. I will scold them first. Ok, because

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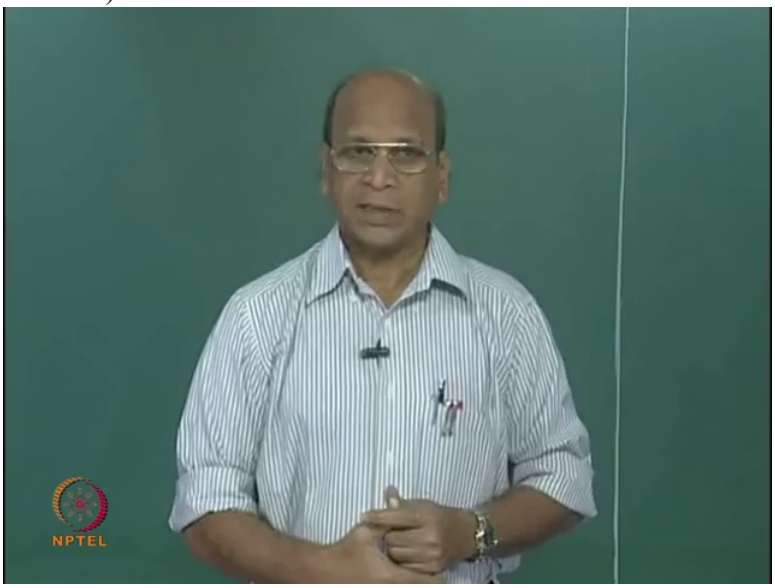

that fellow does not have life, equipment. So that is why it will not behave differently. You should get exactly the same readings. And if you are not getting exactly the same readings means it is not the, that fault. It is your fault. Ok.

I am not talking about some heat transfer experiments where you know, heat may dissipate depending on you have summer, winter or rainy season or all that. We are not talking about

that kind of things. For example, kinetics if you are able to reproduce today, tomorrow, day after tomorrow,

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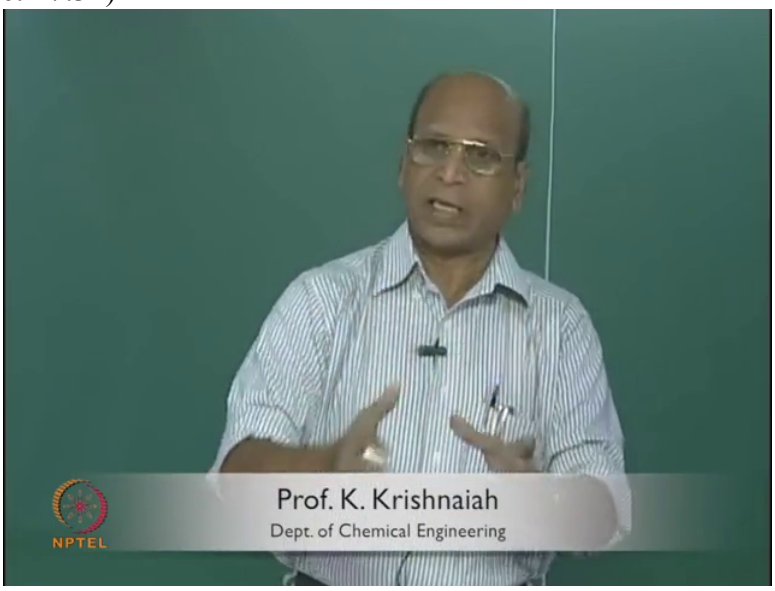

every time, same equipment, same stirring, Ok, same temperature you should exactly reproduce the data.

And we are imagining first we have that kind of data and then only we are talking about all this. If you have the wrong data, that is why my student will have hell with me. Ok. First I will suspect that these people have not taken data correctly if it is not logically correct. If they have logical errors then I also do not know how to find out, Ok.

Logically, I mean the curve seems to be logical because we have this phenomena in our mind no, so if something is happening inside, something should come. That is why all, I think, now another, I do not have to tell about research scholars. Because all of you also are research scholars because you are also doing a project. All M Tech students are supposed to do the projects.

So when you are doing, this expectation is very, very important. When guide gives the problem to you, Ok, to find something, Ok, he may say that again my simple example is, Ok, you find out friction factor in packed bed. Ok. So now, definitely you are not that dumb where you do not know what is friction, what is factor, and what is packed bed and all that. Because

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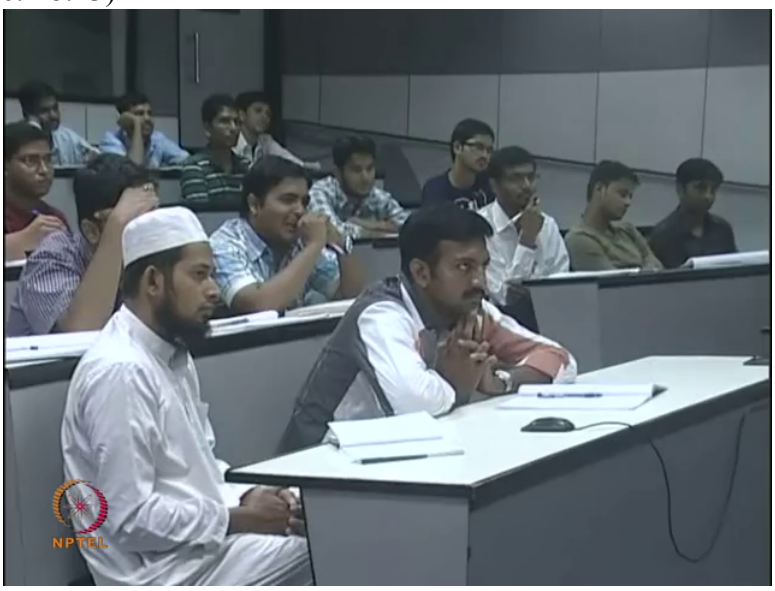

you have sufficient knowledge no, to understand what is the packed bed, how the friction is acting in packed bed, and what is happening when the fluid is moving through the packed bed.

All that phenomena must be in your mind. That is why in Fluid Mechanics, that is what what you learn.

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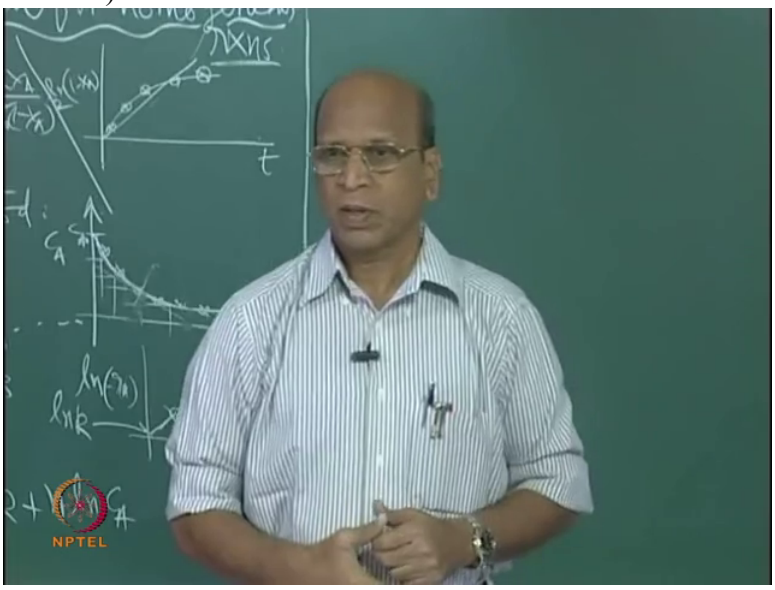

Then you draw the graph, just you know, analytical graph putting x and y coordinates, Ok, friction factor versus packed bed. You draw the line, how it should be. Whether it is straight line or increase or decrease. Or increase and decrease both.

Now if you have that good imagination, now you go and then do the experiment. If you are able to get at least the shape, I am not telling that, you know exact values Ok you have to get. You cannot get exact values because you do not know what is the flow rate, you do not know what is the, you know particle size and what is the porosity and all that, you do not know when you are imagining all this.

In any packed bed, when the fluid is moving, it will definitely experience drag, that is friction and now the material, the flow cannot simply enter unless I pump, that is why you call pressure drop. So that much pressure drop unless I overcome that, material cannot go, I mean the liquid cannot go. Or gas cannot go.

That is why all packed beds we use Ergun's equation to calculate pressure drop. Because if there is less than that pressure drop, for example blower, we also use sometimes blowers without knowing the difference between compressors and blowers. Blower whenever it sees some resistance it stops. Correct no, blower, it does not have sufficient energy to rotate. But whenever it experiences some drag inside, some resistance inside, then the speed of the motor will decrease here, where, in the blower.

But whereas compressor, it has got very high, because it compresses, compresses, stores in a tank and from there you are drawing, in the tank also you have 8 atmospheres,10 atmospheres, whatever you set there and whereas blower is working at slightly above atmosphere, that is all, just atmosphere pressure.

So that is why even if you put your hand there, it will not turn, you try your hair dryers. Hair dryer is a blower. Many people may be using. That dryer you put your hand? The speed of the, you know that fan will decrease; the sound also changes the moment you just put there. Ok, that is why it cannot have sufficient pressure drop to push the liquid if you are using a blower through a packed bed. Right, so that is the expectation.

Ok, pressure drop should increase or decrease when you plot pressure drop versus velocity

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in a packed bed?

(Professor – student conversation starts)

Student: Increase

Student: Decrease

Professor: yes, decrease, increase, remain constant?

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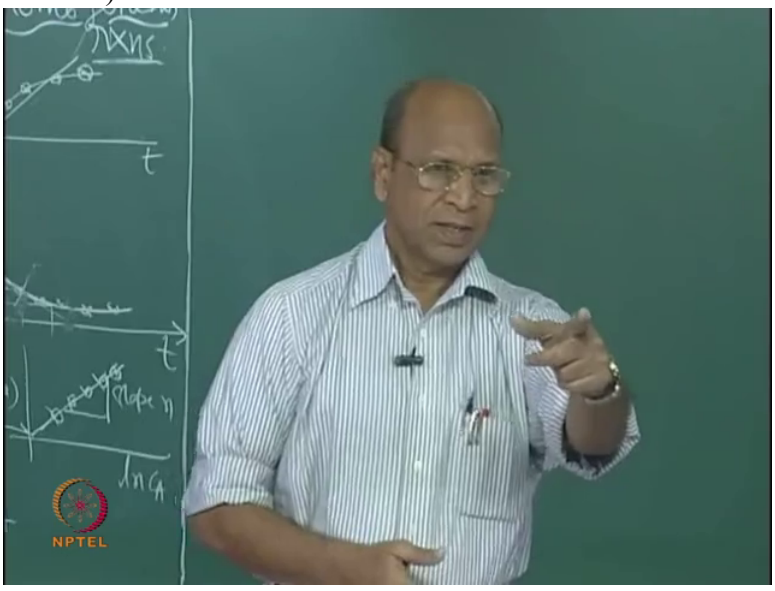

Student: Then it will stay constant.

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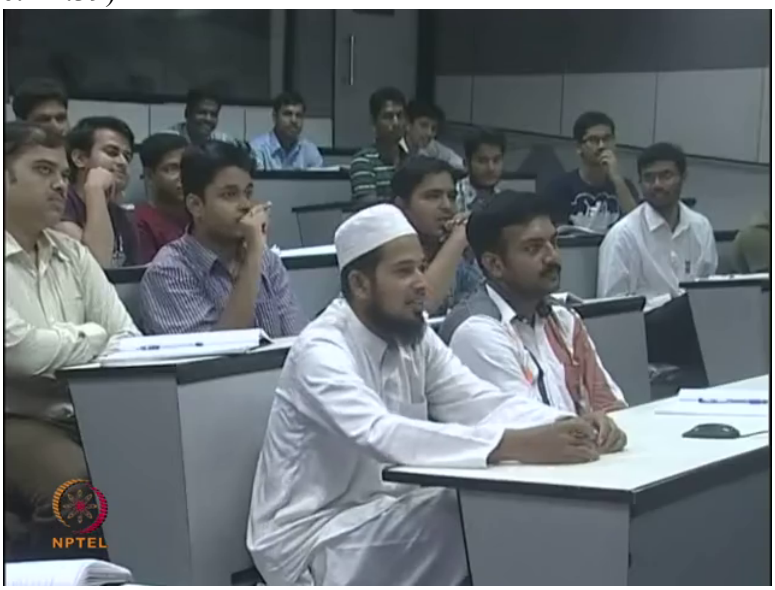

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Professor: Why? See, what is actually happening for the pressure drop, it is a phenomena. Something is happening there. Some physics is going on there, right. So he says you know it increases and then stays constant. You explain to me why it increases, why it stays constant? It is a packed bed.

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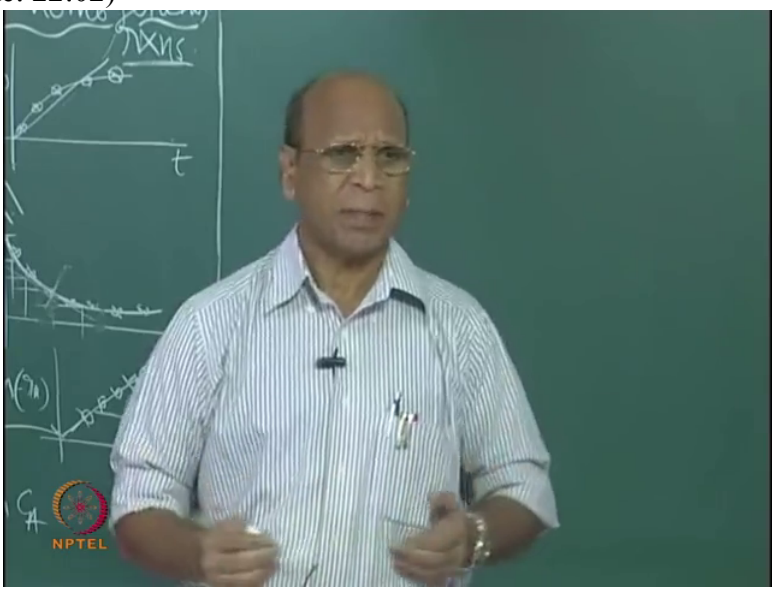

No not only packed bed, even if take empty tube also same thing happens, increases; yeah why?

Student: You know the tube.

Student: This is a 0:22:12.5, small portion is there.

(Refer Slide Time: 22:15)

Professor: Yes, so

Student: Small portion is affecting, the pressure drop will...

Professor: You are telling increasing or decreasing?

Student: Increasing

Professor: Yeah, what about you?

Student: Increasing

Professor: How it increases?

Student: (laugh)

(Refer Slide Time: 22:30)

Professor: And at this point of time instead of asking reaction, easiest thing for me is to ask a know thing to you and fluid mechanics and pressure drop you know, generally known to us.

Because that is the first course of Thermodynamics, Fluid Mechanics, that is the reason why I started this, Ok.
(Professor – student conversation ends)

And earlier batch also it seemed did not get. And because our department changed some structure now, so that is why many people are not taking, you know these two courses. First course anyway you do not have a choice. This is compulsory for most of you, you know, except for M S or P h D. Ok, so that is why I am trying not for you to get the jobs but if you come, probably you will have you know more knowledge in all these things. That is the reason I am telling.

And particularly M Tech is a course basic program. Whatever course you want you can take. You do not have to even listen to the guys. The project is partial fulfillment for the courses, for the degree. It is not the main, but still you have to do that, some part you have to do that whereas P h D and M S, research is the, courses are the partial fulfillment of the entire degree, you know the research.

So that is why I think you know whatever courses you like you have to come and learn. Wherever you are feeling that you have learnt something in that course, if the second course of that person is coming, I think you better take that course. Once you have this course, I know my own experience.

I think in 2000, I was H O D but I also went to I O C L for recruitment, chemical engineers. Totally we have interviewed almost around 120, 130 students. So every day, so that 120 by 5, you know, 5 days, around 20, 25, morning to evening and also I think they were very good, not only just 1 or 2 questions and throwing them out. Sufficient time is given given to, that is why 5 days for 120 people.

And there are universities and companies also, 125 I have interviewed in 1 day also. Ok, yeah, so then from I I T Madras 7 people have come. 3 M Tech and 4 M S. And the committee, committee one Professor from Kanpur, one Professor from Delhi and another 2-3 people from I O C L so totally some 6 or 7 people were there.

So then normally for any interview, those who have gone for interview, you also should have experienced. They will ask, what is your favorite subject. Many people. Because probably we do not know how to ask questions in all subjects, so that is why probably we will say that what is your favorite subject and out of 7, there will be one person, now you ask. That is what normally we will say.

But anyway, you know general questions also should be asked. Then I think all these I I T guys, I I T Madras guys told only reaction engineering. Really they have taken my two courses. So then believe me all 7 got the job. I have not asked any question and they have, they were only discussing among...I just kept quiet. I did not say anything. Ok, they were thinking.

There was my friend; afterwards he became very close friend, one Ghosh, now he retired. He was the R and D Head. He was the Chairman of that committee. He was telling that why I I T Madras is very good in reaction engineering? Everyone is very good here, all that he was talking. I did not tell him. Only last day, I told. He was asking me who is the teacher, and when I told him, Oh, you have taught them?

But I think that has become a favorite subject. Not only that batch. After that even here, when students go, when they ask you know what is your favorite subject, many students

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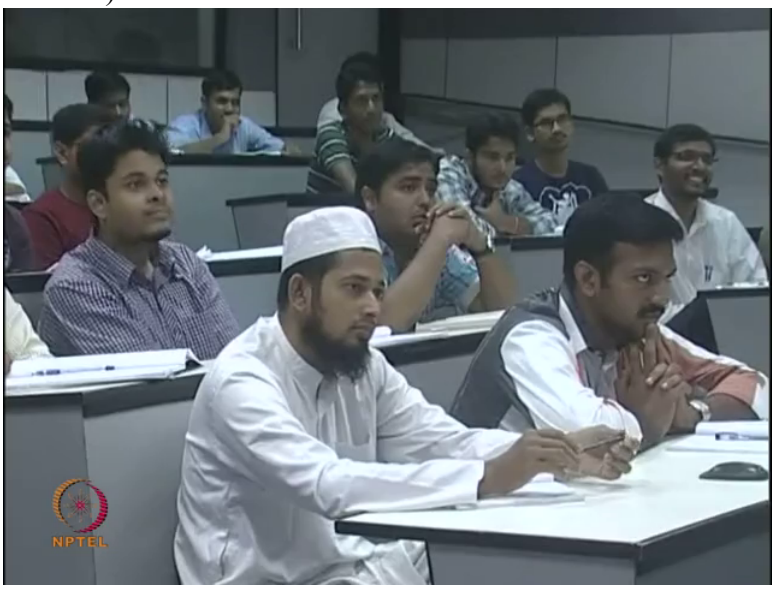

used to tell C R E. Ok but it happened only when they took 2 courses, not 1 course. Because

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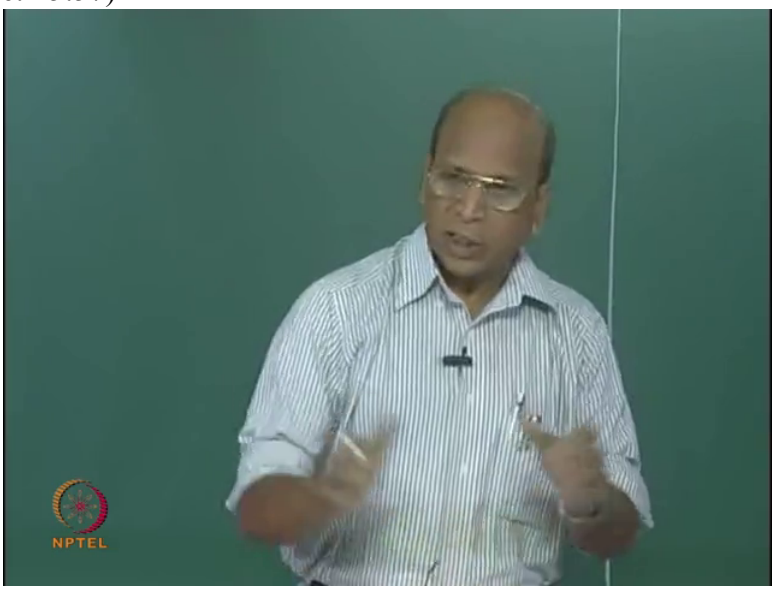

this course is only general things you know, the concept and theories. That is why chemical reactor theory what we say.

But actual applications for heterogeneous systems and all that will come in the next course, packed bed, fluidized beds, moving beds, moving beds I am not covering, and you know slurry reactors all that we cover. So with that knowledge, again some of the things will be repeating, repeating there also. The same questions why I asked you pressure drop increases, decreases, I may again ask in that course also.

That is why you have that information going to your blood. That is why you will feel that you are more confident. When someone asks the question, yeah you know which subject you are strong. That is the reason why, I mean if it possible, I think better take any course whatever you like Ok, and then spend time on that. And this is very important.

I am not talking about only my course. I am talking about research where you have to plot that graph. When pressure increases if someone tells, I will give you that example because that thinking, thinking, thinking is very important. I think at least most of you would have gone by bike, two-wheeler, not cycle, cycle you may not have that kind of effect, Ok. Bike if you are going, when you are going at 30, 40, 50, 60 whether drag on you is increasing or decreasing?

(Professor – student conversation starts)

Student: Increasing.

Student: Decreasing

Professor: Increasing. You do not feel that? You actually...if you have something loosely tied and all that, that may fly off. Correct no?

(Professor – student conversation ends)

And beyond certain velocity you may also fly off. Correct, that also happens. Ok, that is the training that they give for these paratroopers whether they have a big blower, I have seen that in Discovery Channel, so this fellow jumps from the top and the velocity is so much, he is floating, he is fluidized. And the velocity they said if I remember correctly, 127 kilometers per hour or may be 127 miles or kilometers I do not remember, you know per hour.

That is where they are floating, they are practicing. Because that is what they experience when they jump from the flight. Ok. So that is why. Theoretically it is possible, you know. Afterwards if the blower is having much more capacity than what they are floating, if the blower speed is increasing then they will be pneumatically conveyed. They are really; they will go away from the building or otherwise hit the ceiling. Ok, all these things may happen.

That is why, now if I ask you to drop you know, all these drag is measured only in terms of, drag you can never measure directly. You can never measure. How do you measure drag? You feel that. You feel that you know your body, like that even particles feel. But how do you measure it? It is measured always, as far as I know; it is measured always in term of pressure, pressure drop, Ok.

That is why you put on manometer and then try to measure that. So now if you plot that, because now if you know the phenomena, as the velocity increasing, this should increase. Now if I ask you to plot friction factor versus velocity how do you plot?

(Professor – student conversation starts)

Student: Increases

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Professor: It also increases.

Student: Increases

Professor: Increases. Ok, how do we define friction factor? You know,

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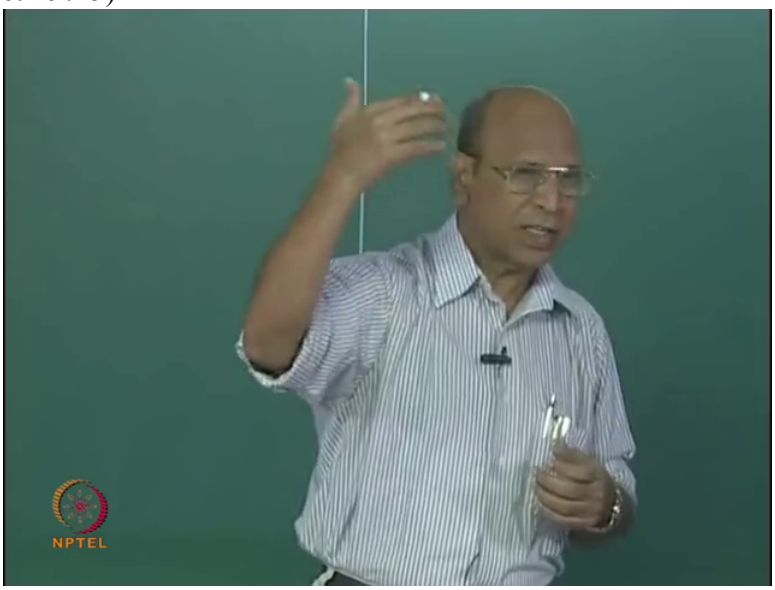

just recall the Friction factors graphs. You remember friction factor graphs of the pipe, no. Yes, you remember no? Are they increasing or decreasing?

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You do not remember?

Student: Laminar flow, it is decreasing.

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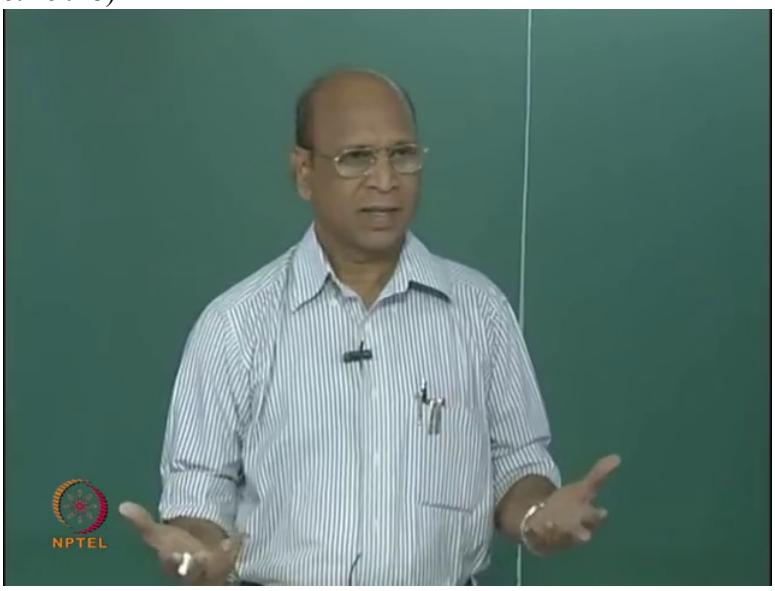

Student: Reynolds 0:29:33.9 decreasing

Professor: Yeah, equation wise, he is correct. But I am, see, equations may be difficult to remember. I think at least diagram when you see, you may remember more time.

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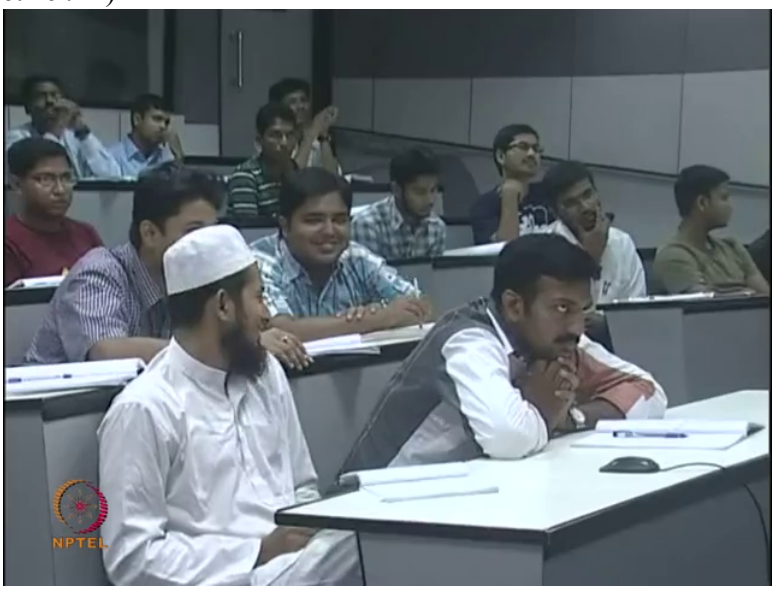

Student: 0:29:43.1 it is decreasing and...

Professor: So much discussion on the first course what you have taken in your B Tech. Ok and also you have done the experiment. You have done experiment in the lab also, fluid mechanics. Even packed bed also it decreases, why?

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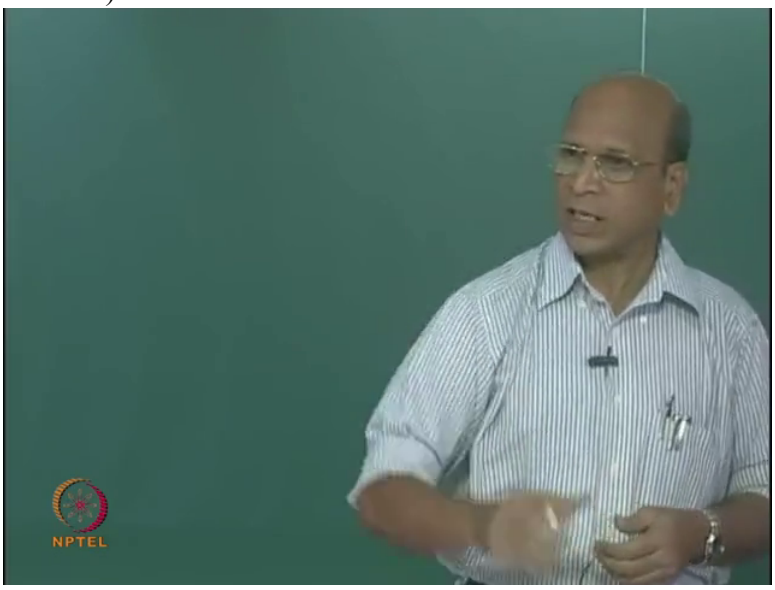

First of all increases or decreases? You said increasing. Oh increasing, yeah.

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Yeah Ramesh, you have any idea? Yeah, according to equation?

Student: 16 by N R e

Professor: 16 by N R e is Ok, but friction factor, what is the definition?

Student: 0:30:13.3

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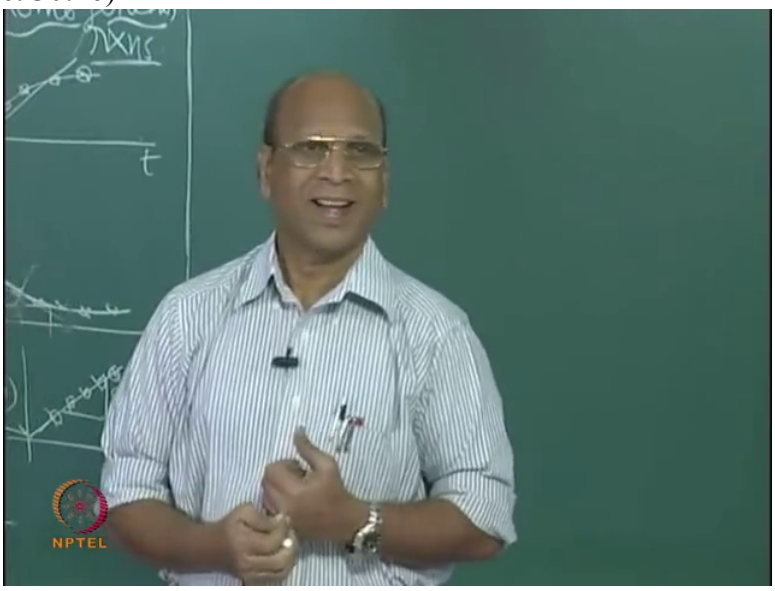

Professor: Definition of friction factor, yeah, high funda, shear stress by...

Student: Velocity

Professor: Velocity? It is delta p by half rho u square. Kinetic energy, It is delta p by, Kinetic energy half rho u square into you have again H by d t or d t by H and all; next length will come, if you have a packed bed. Ok. Otherwise you know d by l of the tube or something will come there.

(Professor – student conversation ends)

Now can you tell me why it decreases? u square you have in the denominator. As velocity is increasing, u square again tremendously increases. So that is why friction factor decreases. Normally our logic is, our intuition is friction also should increase, correct no? Like drag, friction also. That is why we make the mistake, that is in fact one of my favorite questions in interviews.

Ok. Yeah, because I think many people think that Ok, friction factor increases. Right, but I think you know, by definition, by definition it has to decrease because you have rho u square. u square tremendously increases. And that 16 by N R e also when you will use this derivation only, you will get that.

You know both sides when you put properly the units and all, then only you will get 16 by N R e for laminar flow Ok and for this one, for Stoke's Law, single particle and all that...

(Professor – student conversation starts)
Student: 24 by R e
Student: C D is 24 by R e

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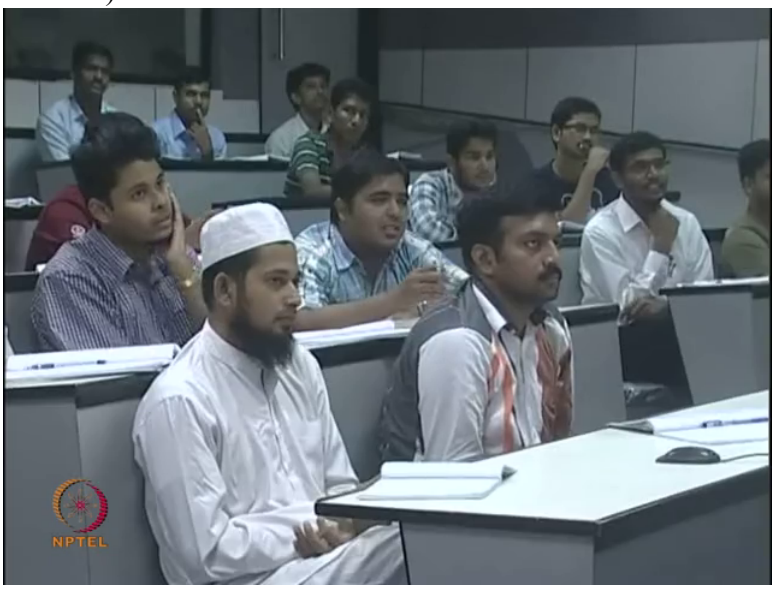

Professor: Yeah, there CD is also defined using

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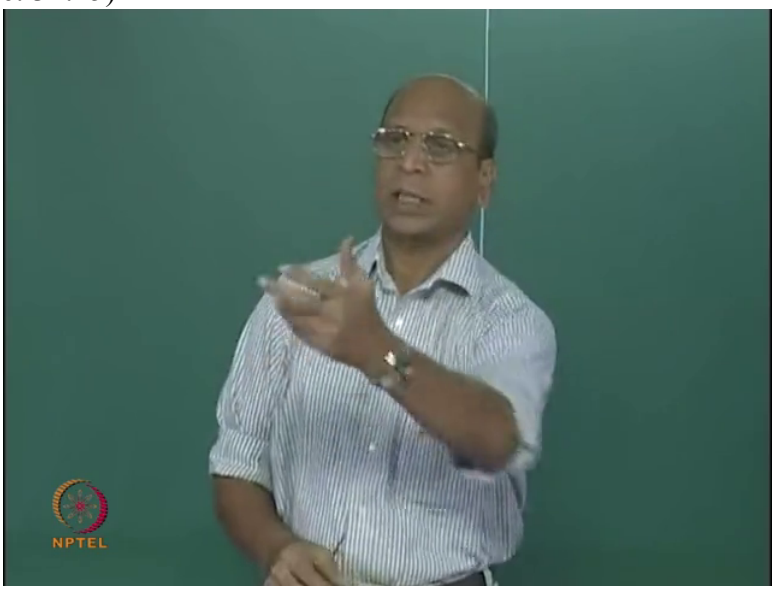

the same thing, half rho square in the denominator. So that is the reason, Ok, good.

(Professor – student conversation ends)

So that is why when you are doing experiment, because I started all this because of the experiment. When you are doing these experiments or in research, you should have this kind of, it need not be experiment. Even theoretically also, if problem is given you write the theoretical equations or to solve the problem theoretically you should have this expectation, what is happening inside.

That is why you know last 15-20 years my teaching is only explaining phenomena, phenomena, inside what is happening. If you are able to think, mathematics will be automatic. Ok, good. So that is the reason why we should have, you know expect that because now I am plotting only

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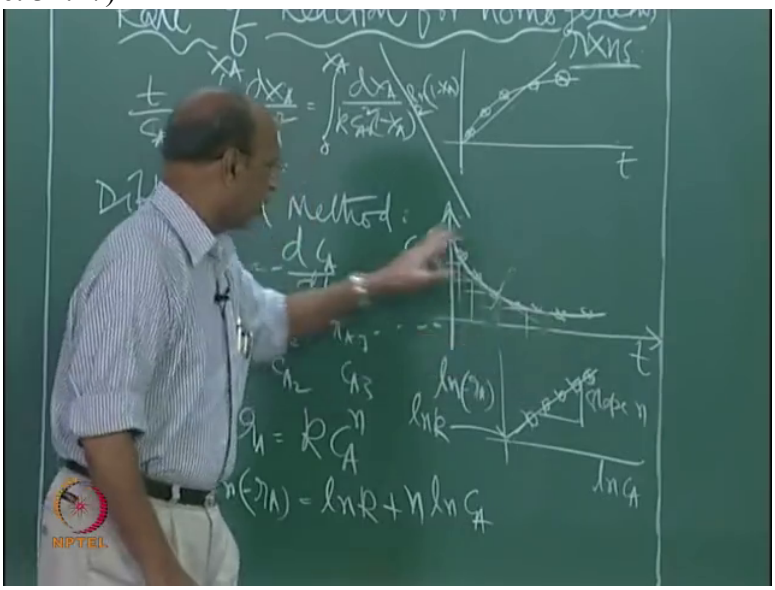

concentration versus time for a reactant, then automatically it should decrease.

If you are increasing, if someone plots that is increasing, there is something wrong. He may be measuring only product. Ok, that you have to be careful, good.

So like this now you have to repeat the, you know all integral expressions. That is why I request all of you, where you lose in the examination, because examination is also important for you is in the mathematics. Conceptually now onwards you do not have to learn anything new except when you put 2 reactors what happens, 3 reactors, they are not so big conceptual things. They are all simple.

Now you know what are kinetics, you know how to find out kinetics, right, differential method and as well as integral method. I prefer always integral method because that gives you very, very accurate fitting. Whereas if you are able to do this kind of,

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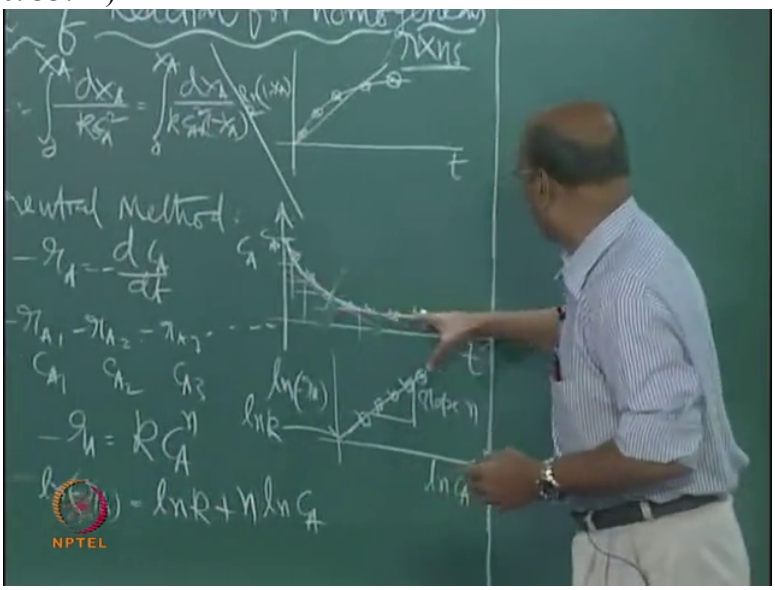

you know some very accurate technique to go for this

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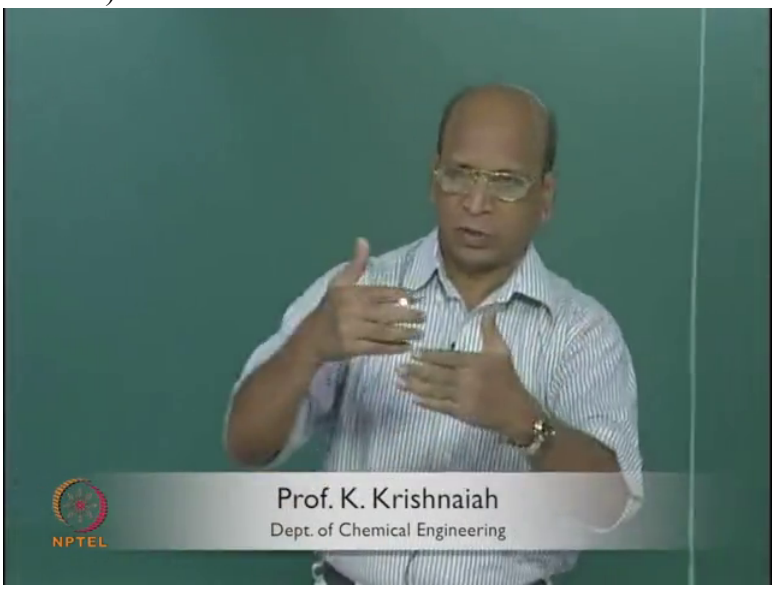

slope measurement and tangent measurement, then you will have also good there, right? So this n will give you the order of reaction and k will give

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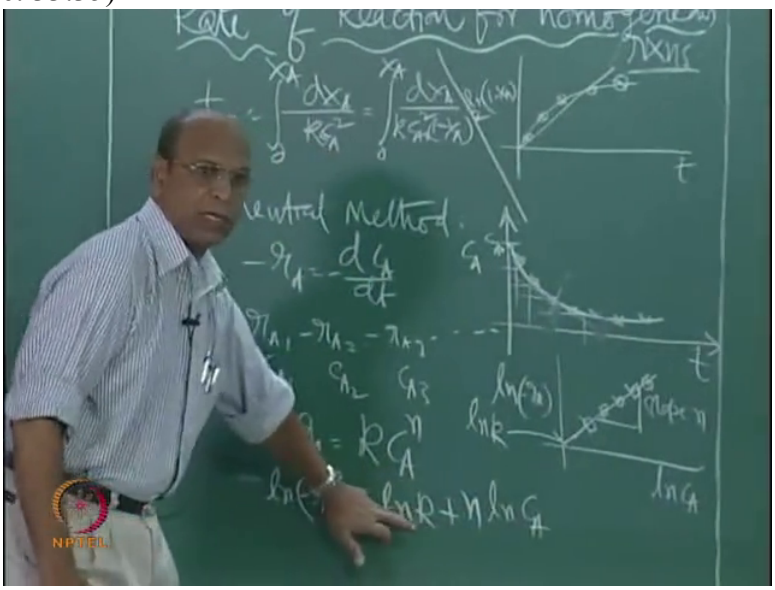

you the rate constant. Ok so when you go to actually the heterogeneous systems how do you find kinetics, we will also discuss later, right. That is also not easy

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because there it is mass transfer most of the time. You know, in slurry reactor there are 4 mass transfer steps and one reaction step. In every heterogeneous reaction, there is only one reaction step. We will close here.