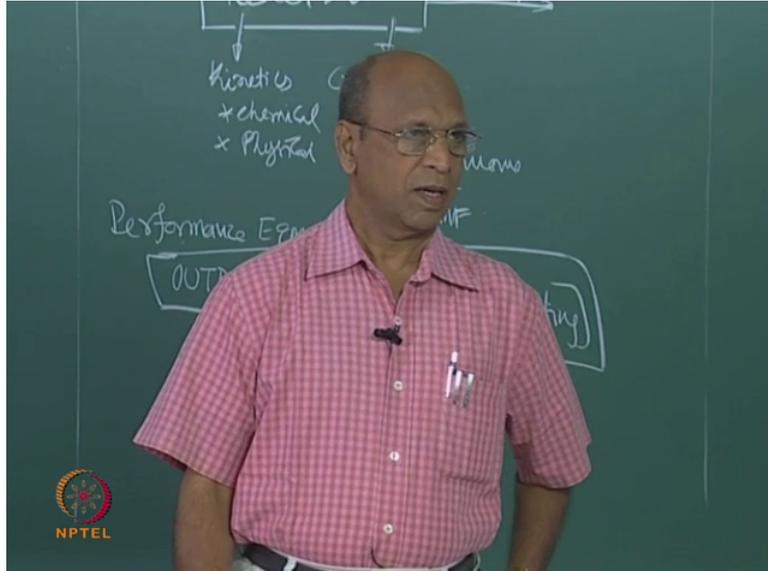


Chemical Reaction Engineering 1 (Homogenous Reactors)
Professor R. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology Madras
Lecture No 09
Basics of Kinetics and Contacting

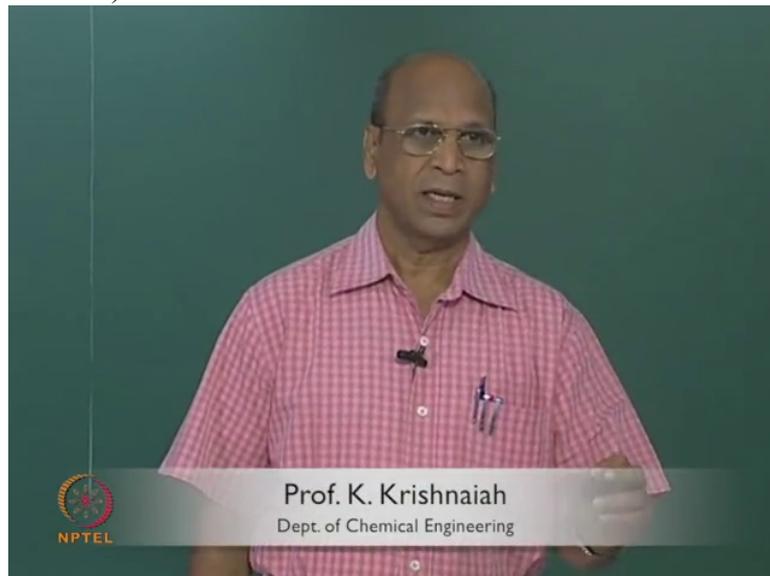
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Ok, so in the last class we have discussed about this chemical kinetics, reactions heterogeneous and homogenous, we also had a list of the combination of heterogeneity like gas-liquid that is one heterogeneity, or liquid-solid, liquid-liquid all that.

And we have also listed out taking only one reactor called packed bed reactor. It is catalytic packed bed reactor,

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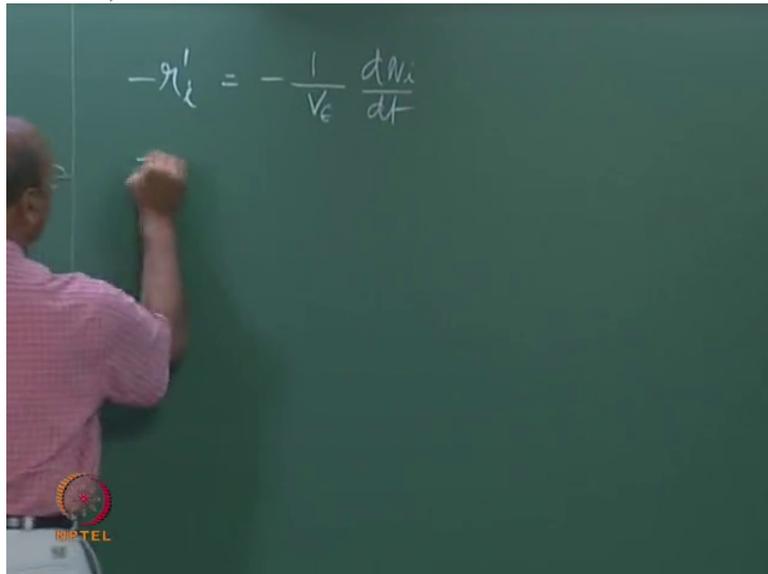


then we had written some 3-4 different rates for the same reactor, rate of reactions. But is there a connection between these 4 or 5 rates, one can be converted into other rate? They can be easily converted, if you look at those equations

But let me write. It is not obvious to everyone. I cannot only say, see 1 or 2 people say, yes, yes, yes we know. But all the other, many people who may not that at all. So that is why let me write that. And without writing the complete definition, we have written yesterday, yeah, this is equal to $1 - \epsilon$ I have written, you can correct that one, ϵ voidage, correct, voids we have told no?

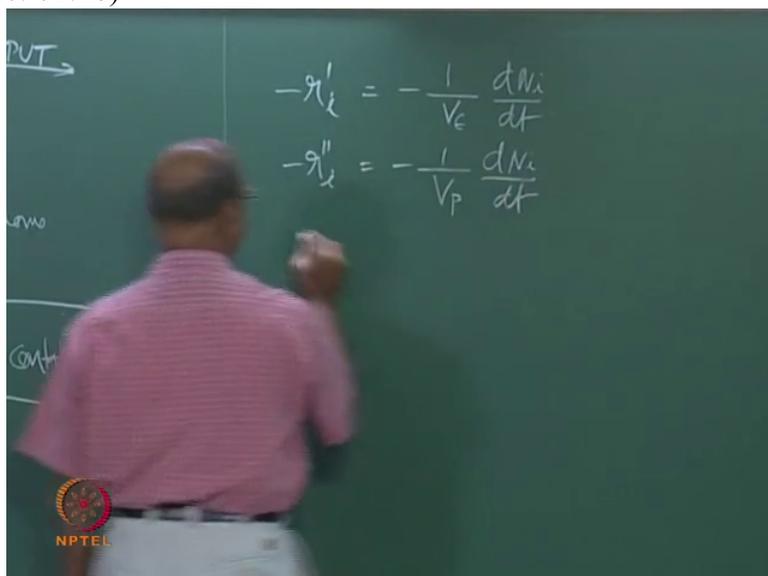
The first definition r_1 dashed was based on voids, voids of the bed, Ok, packed bed, yes. So this is dN_i by dV . Then we

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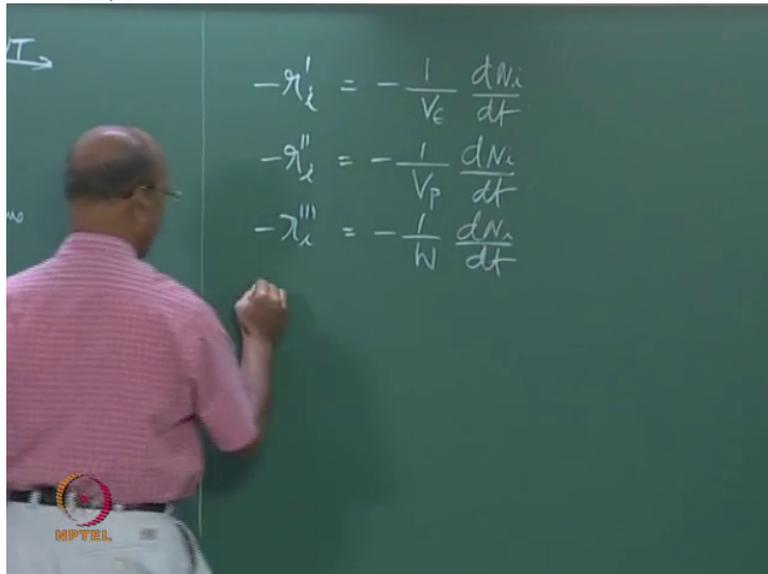
also have yeah, this is volume of particles, other one, right, so this is again dN_i by dt .

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then we also have yeah, weight

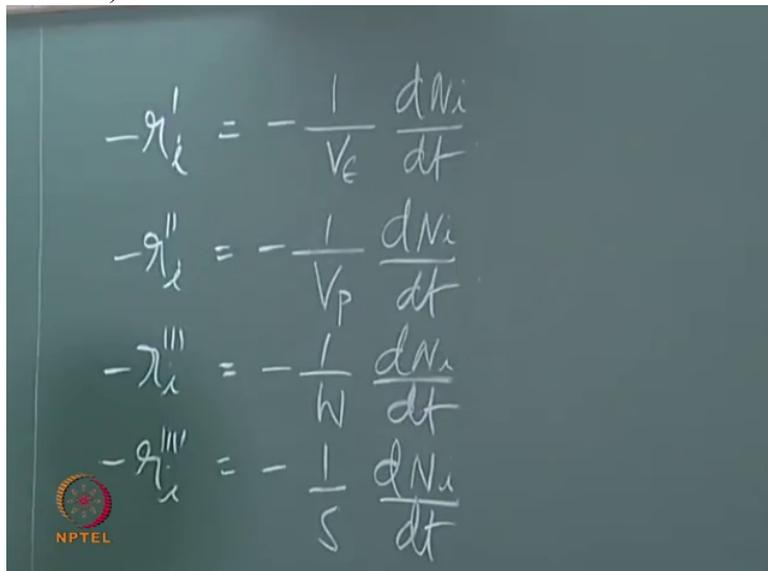
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and the other one is 4, surface area dN_i by dt , right.

So the common thing here is dN_i , right?

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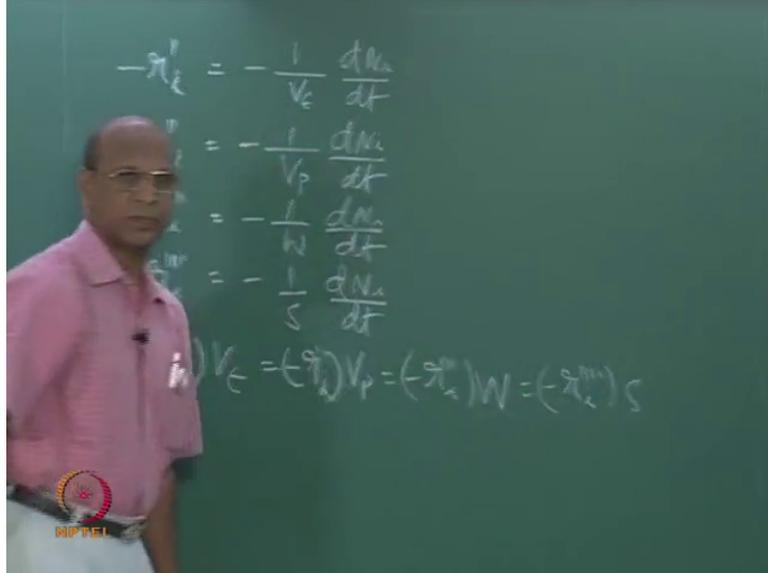


So using this particular one, I can now convert one rate into the other. That means if I know rate based on w , weight of the catalyst, then I can also convert that into per unit surface area, if you know the surface area, you should know that. So that is why general expressions can be written here.

So now taking this dN_i as, I mean equal, because dN_i , dN_i , dN_i we can write these equations very easily. This is V_e , V_p , W , S . So for example if I want to take these two

that means I know rate based on w, I would like to find out yeah, this r i over strikes, Ok so then this will be simply this r i 3 strikes, w divided by S,

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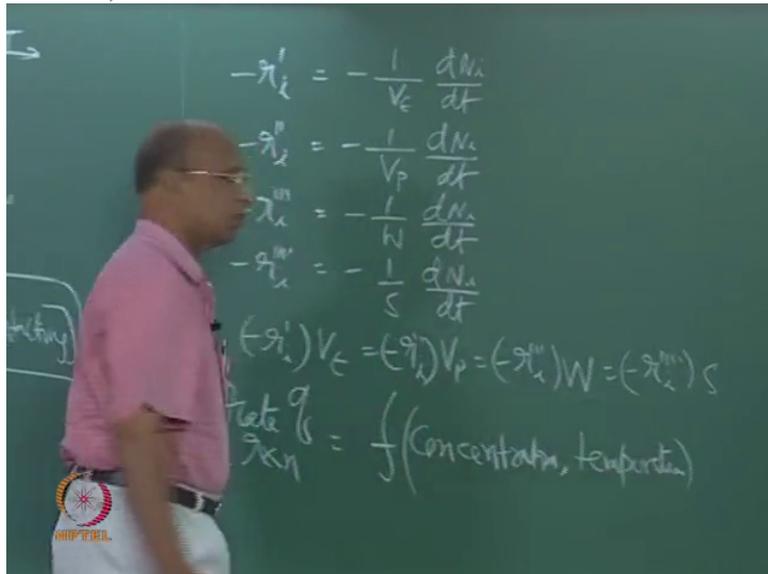
Ok.

So that is why, you know it is a big problem. You may not know now. Ok, in fact yesterday Ranganathan was also telling me about the same thing. Because he was trying to have some gasification, in papers he was reading, every paper gives a different one. Some people give on surface area, some people give weight of the coal, and some people give on the surface, I mean voidage of the bed.

So there are so many things, so I think it is very difficult to convert. So that is why unless you have the clarity here, then you know you will make lot of mistakes in defining rate itself which is the basic parameter for our design expression, Ok, which gives me kinetics and indirectly that gives me rate of reaction, Ok.

So finally our conclusion is that rate of reaction we know, Ok I do not want to write an equation, is a function of concentration and temperature. That is all. These are the two terms you will have.

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If it is heterogeneous reaction, this concentration term, this term will be a function of both physical kinetics and chemical kinetics.

I will again discuss with you once we understand the basic reactors. Then we will go to again kinetics and I will also derive one or two equations for heterogeneous reactions. Homogeneous reactions can be simplest one, zero order reaction, Ok, what is zero order reaction equation?

(Professor – student conversation starts)

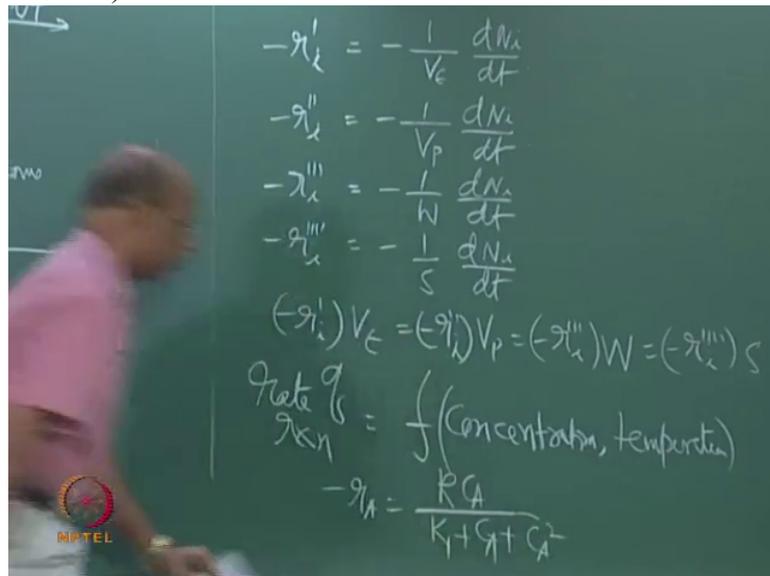
Student: 0:04:59.4

Professor: Yeah, zero order means it is not a function of concentration, actually it is C concentration raised to the power of zero. So fortunately that has become 1, so that is will be there only k, right. That is the easiest one, simplest one. Then first order.

(Professor – student conversation ends)

But you should now onwards never should think about this sort of reaction at all. It can be any reaction rate like if I am talking about one particular instant, it may be k into C A divided by some constant again capital K 1 C A plus C A squared.

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It can be, it can be anything, right? Because that is why you cannot have a single idea in your mind that it should have some order of reaction. What is order of reaction for this? Please remember order of reaction you can tell only for

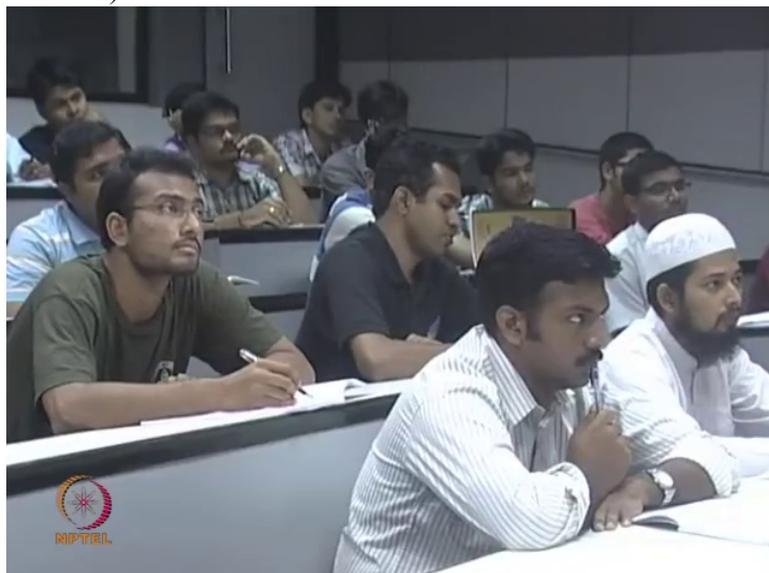
(Professor – student conversation starts)

Student: Elementary reactions

Student: No

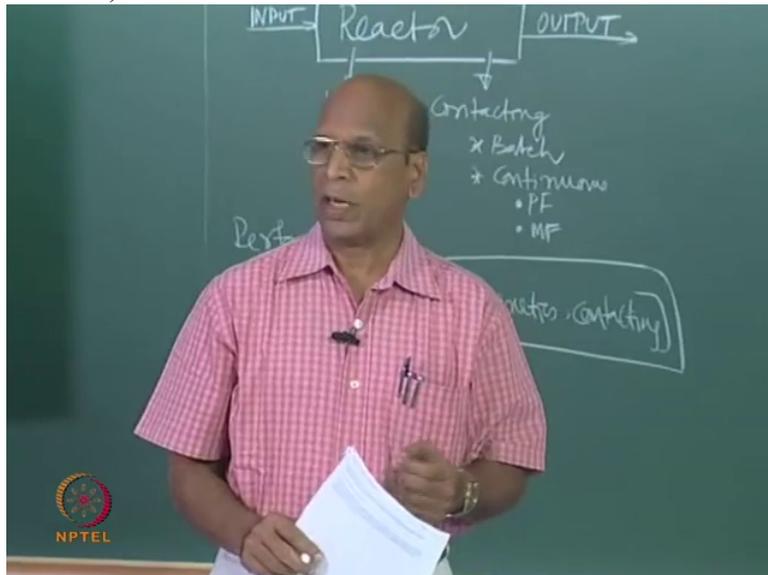
Professor: Elementary reactions, order of reaction we have 1, Ok. Yeah but you know

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even empirical, order of reactions where you find out sometimes C_A to the power of 1 point 2,

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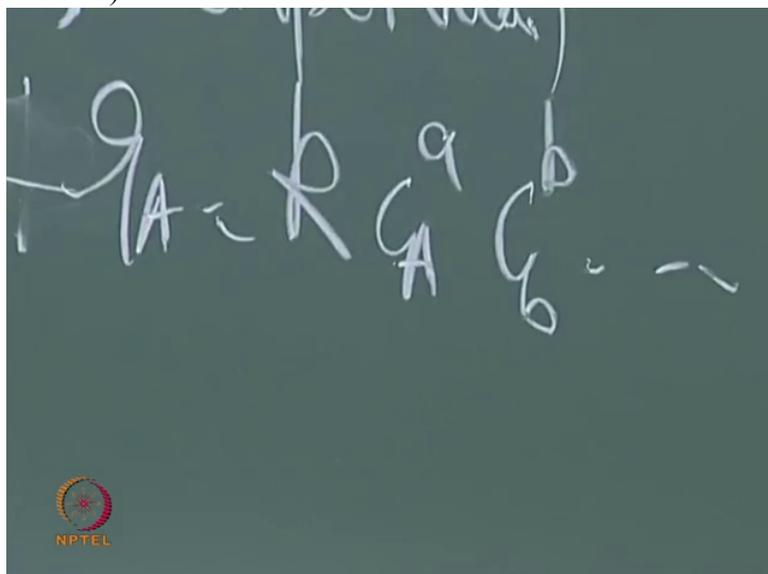


1 point 5, that is only possible if you have concentrations only raised to the power of something, Ok.

(Professor – student conversation ends)

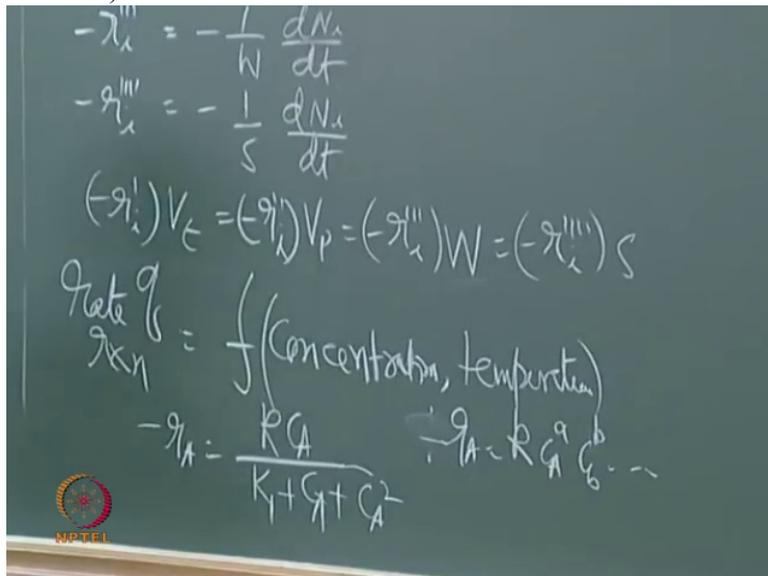
So it should be only in this form that is the yeah, Ok sorry, rate as some k , C_A to the power of a , C_B to the power of b etc, right? So there is name, I have forgotten that name,

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this is C_A to the power of a , only here you will have rate, but the moment you have something else there, like this

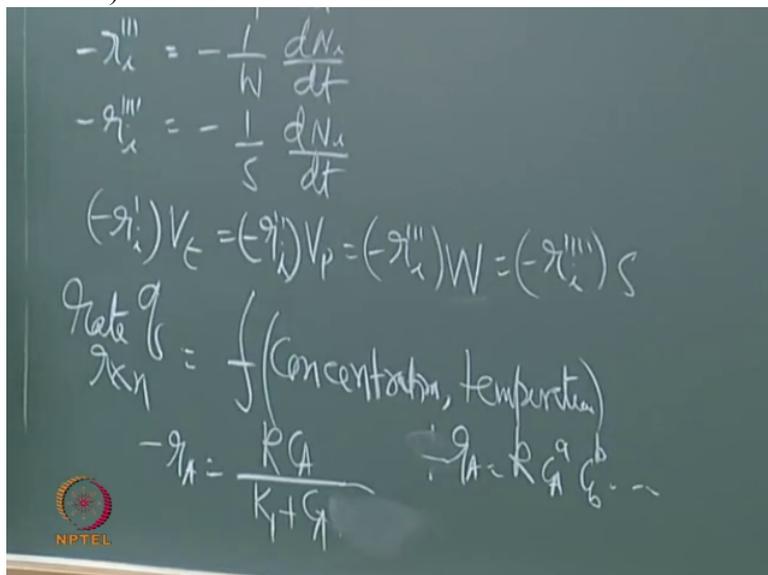
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you cannot tell about rate.

That is why even Michelis-Menten equation which is some format like this, correct no,

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some format like this, again you have to specifically say that at very high concentrations, Ok, so this K may be neglected, the concentration C A is 1000, this K is 1, then it becomes zero order.

So on the other hand, when this constant is very large and this constant is very small, that becomes first order. So that means unnecessarily you are trying to simplify things and then say that this is the order of reaction. It is not required, right?

So that is why, whatever reaction you have here, reaction rate you have here, somehow you have to introduce this in the reactor design expression. That is what what we are going to derive and integrate that and sometimes it is possible to integrate analytically.

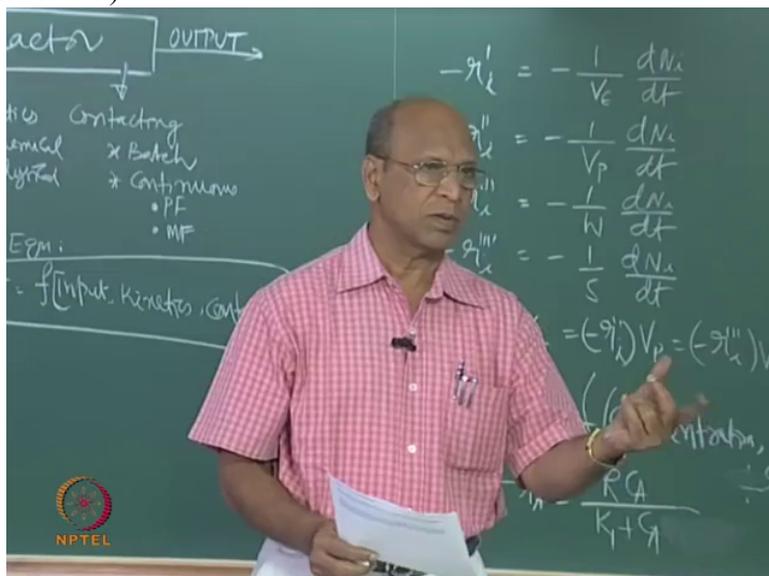
Sometimes it is not possible so

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you have to go for graphical integration or numerical integration and then finally calculate either volume if conversion is known or conversion if volume is known.

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That is all the entire, no, reactor design, good. So that is the one.

So now I think, this is the, here till now I just wanted to give an idea of what is rate of reaction and then how do you define it. The definition of rate is actually moles per time but we would like to have that one as intensive property. So that means, whoever talks, we will talk, all of us together would like to talk the same language.

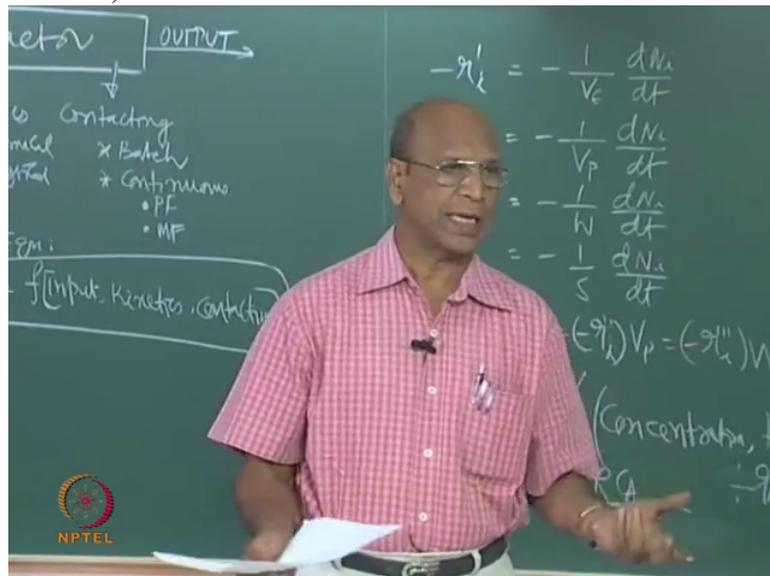
So that is why, take some parameter, volume of the reaction mixture or weight of catalyst, or volume of slurry or this, volume of slurry means volume of solids plus liquid together but some base which is uniform for all of us. So then automatically, all rates whoever do it, I mean you may do it in I I T Madras or Anna University

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or somewhere Coimbatore or somewhere you know Nagpur University you do same experiment based on the same volume you should get

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exactly the same rate.

So that is the reason why that intensive property is very, very important for us because all of us talk about the same language. Otherwise I take in I I T Madras 2 liters, Abdul takes I think, now currently he is in I I T Madras only, but I think he would have taken in his AC Tech, AC Tech only you, Ok, 5 liters, 5 liters. If you are talking about only moles per time, moles per second he will have a different value, I will have a different value.

But if we normalize that with the volumes which we have taken, I will divide by 1 liter or 2 liters here, and he will divide by 10 liters A and B, then automatically our answers should be same, if it is same reaction conducted at the same conditions. So that is the reason. Please remember all these.

These are simple things. Many people may not teach you or they would have taught you but you would have never cared. But you know these simple things are also very important. And do not try to forget the moment you leave the, this lecture Ok.

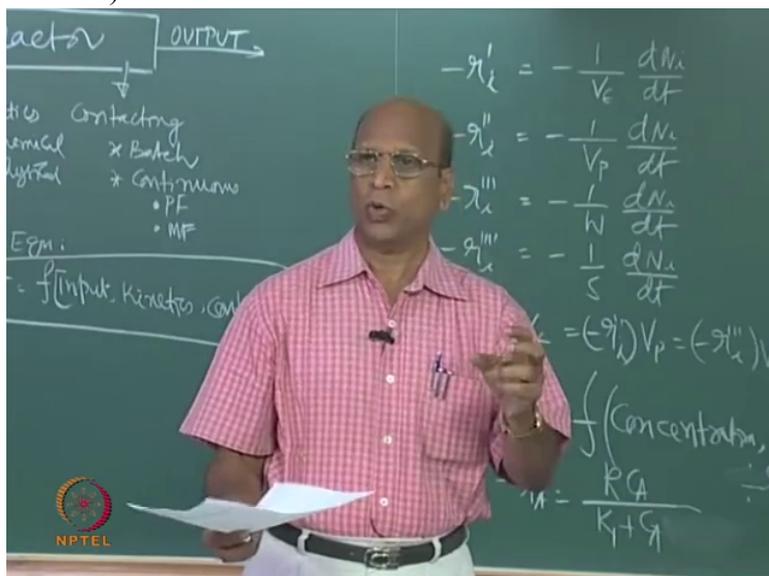
That is happy, because why unnecessarily taxing our brain so I think only at the time of examination

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we will see all that, but this is not burden at all because this is very, very simple language I am talking, you do not have to really feel or struggle to

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record the data in your mind. What is there to struggle I think? Very simply I am trying to explain. Ok, good. Very nice.

So now we will go to contacting. This contacting will give us, what kind of reactor are we talking about? And we are talking about ideal reactors, non-ideality is you know, you see ideal behavior of human beings anywhere in the world, on this planet, we do not know. This ideal behavior in some other planet will be different, Ok. We should not harm people.

There may be the law, I mean, the other planet it may be only the law that Ok, you should harm everyone. We do not know, I mean what kind of life they have? And we only have, what is called you know life based on carbon. If life based on silica or some other element, then the behavior will be totally different.

I do not know whether you have seen some old movies. I think you have to see old movies, I say and also observe the science in that. There were movies called Aliens, I do not know whether you have seen, sorry? Yeah, I think he is my friend. Most of the movies which I see, he is telling yes.

Yeah, see this Alien does not have blood, you know. It has only highly concentrated acid, Ok. If a small, you know spaceship goes there and then you know the alien enters and they try to kill, the moment they started, you know one limb will cut, and afterwards highly concentrated acid will ooze out from the body.

Then that concentration, yes it is so concentrated, the flight you know, yeah the spacecraft has some 3-4 stairs Ok and then through all that it puts the hole, something goes down. That much concentrate. It falls also on one person, I think, immediately his face will become almost dissolved and then he dies. So that is the kind of thing.

That means the planet, you know, on that planet life is developed in that way. That is why at least on our planet when you talk about good people, we should not harm others. We should try to help. You take any religion. These are the only things every religion tells. That is why I do not have a religion. Because all religions are same.

Everyone tells the same thing. Do not harm anyone. Do not I mean, try to help. What else you have, be good to others. That means all, same thing only I am telling many times. Ok. So like that, that it is very simple to identify good people with these three rules, easy helping, good, right? That is all, only one rule.

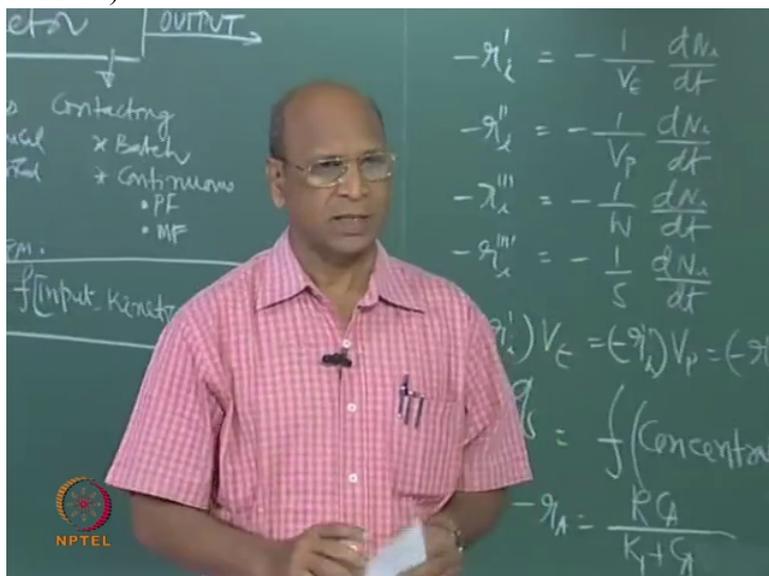
That is exactly the same reason why also we would like to

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assume ideal reactor. Because if I have something ideal in my mind, it is very easy for me to remember. That is the most ideal case.

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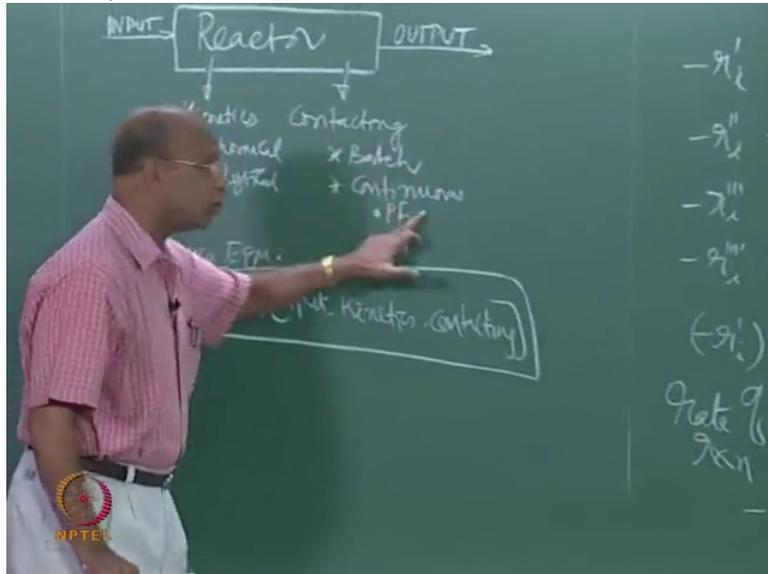


Non-ideality means you know, you deal with non-ideal people, it is very difficult. We do not know when he will get angry, when he will harm you, when he will come and just stab your back, all these things. Why so many problem?

If all of us are good then absolutely there is no problem on this planet. You need not fear about anyone and things will be very, very happy. You do your thing and they do their thing and it is excellent. So that is the reason why we first think about contacting, ideal contacting where we have some definitions for ideal reactors.

Now these ideal reactors happen to be in chemical engineering, only two, and that is batch and continuous reactors.

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And in continuous reactors again we have plug flow and mixed flow, Ok. And these are again two extremes. And this is one way there is no continuous feeding and continuous removal of the product. You just put all the things in the reactor and wait for some time.

That time is now, you have to calculate from the design expression and then after that time, discharge and then pack it and send it if it is pure product. Otherwise you have to send it to distillation column, absorption column or whatever, Ok.

So that is the one for ideal batch reactor and now the first question I would like to ask you is, when did you choose your batch system and when do you choose a continuous system? Do you have any rules for choosing continuous system and you know, for example, after M Tech or after Ph D you got a job in...?

(Professor – student conversation starts)

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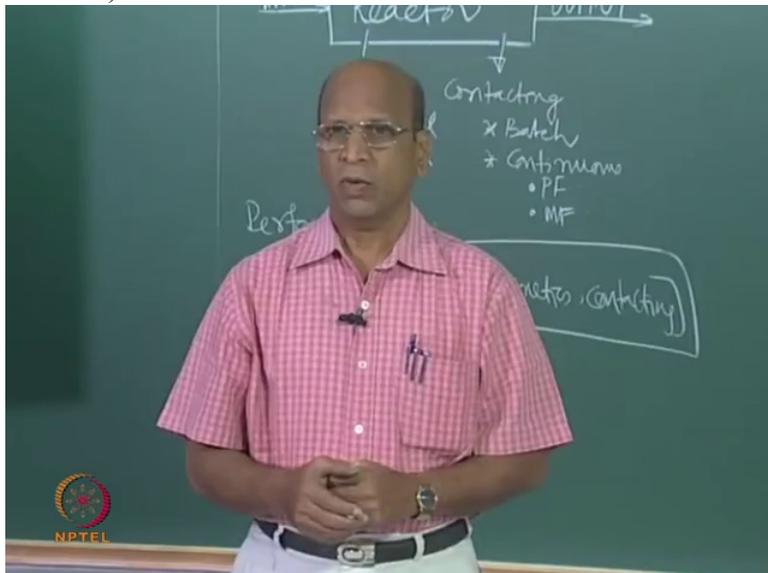
Student: Batches we go to

Student: Flow rate, for slow rate

Professor: Flow rates

Student: For slow rates we go for

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Professor: For slow?

Student: Slow reaction rate

Professor: For slow reaction rates, you choose what?

Student: Batch reactor

Professor: Why?

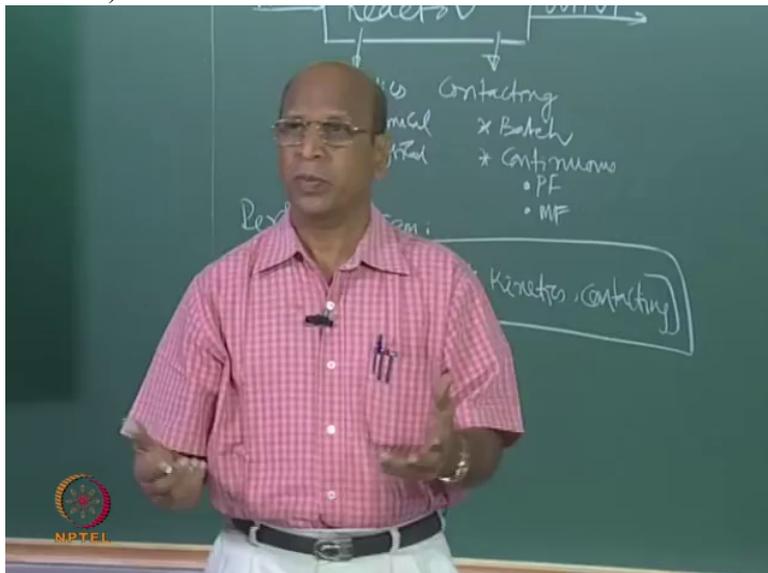
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Student: It is...

Professor: No, you 0:14:34.

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Because you know

Student: It will occupy more volume 0:14:40.4

Professor: No, you tell me in terms of batch reactors.

Student: Batch reactor...

Professor: Yeah, I will come one by one.

Student: You take continuous reactor;

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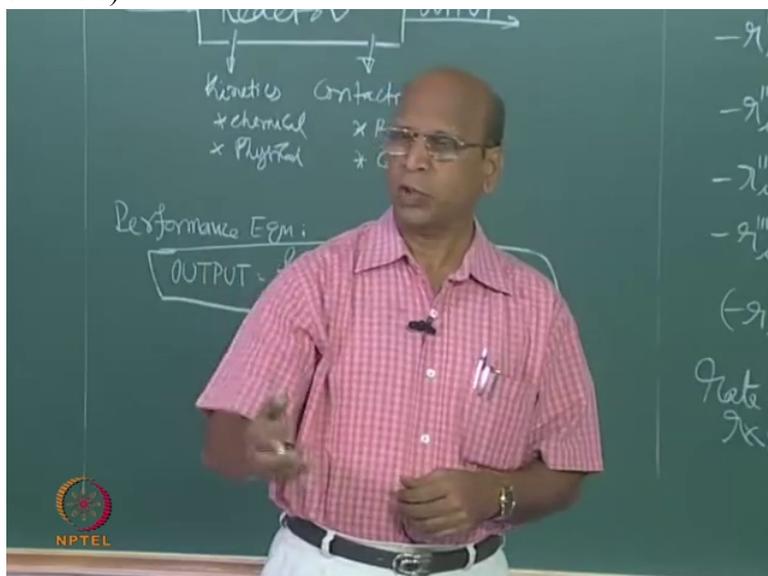


that will take more volume. In terms of batch reactor...

Professor: Why should it take more volume?

Student: To provide

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Professor: Yeah Abdul. We will discuss. Everything will be clear later.

Student: In batch reactor, Sir we can produce

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many chemicals, 0:15:03.3 seasonal chemicals. But continuous reactor we only use it for specific...

Professor: So you are asking for flexibility?

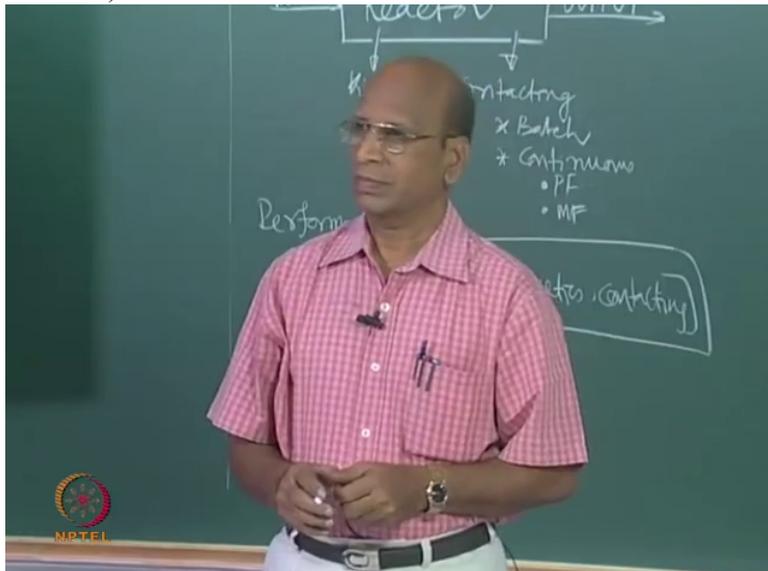
Student: Flexibility is there, and batch reactor is for small outputs that is small quantity. Whereas continuous gives us higher quantity

Professor: Ok, yeah

Student: Continuous 0:15:25.1

Student: Batch

(Refer Slide Time: 15:26)



Professor: Totally wrong concept. Totally wrong concept because when you want to increase conversion means what? I mean we can only reach 100 percent, right?

Student: In batch, some reaction in batch has very low conversion. Say for example if you want to...

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Professor: You can wait for long. You are from industry?

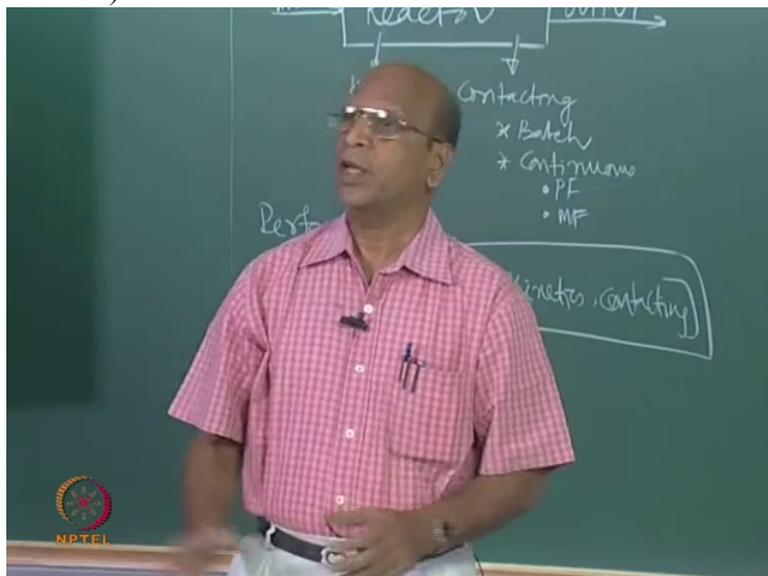
Student: Yeah

Professor: Yeah, Ok. You can wait for very, very long time and then still you get 100 percent conversion

Student: Time is the main 0:15:50.5, in batch reaction...

Professor: But here we are not discussing about time, because

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a batch reactor cannot give more conversion compared to any other reactor, or less conversion.

(Professor – student conversation ends)

Because all reactors if you wait sufficient time, you may get 100 percent conversion. Or equilibrium conversion. Because 100 percent conversion is not possible for all the reactions, if it is equilibrium reactions, reversible reactions then may be 60 percent is the maximum. Afterwards what will happen to rate?

Yeah zero, again when you are designing the reactor, you need again infinity when you reach zero. Because minus r_A will come in the denominator. That is the reason you cannot, right? Ok. Anyway that is not correct. Next time you see, here we are only discussing about, we are not talking about the timings.

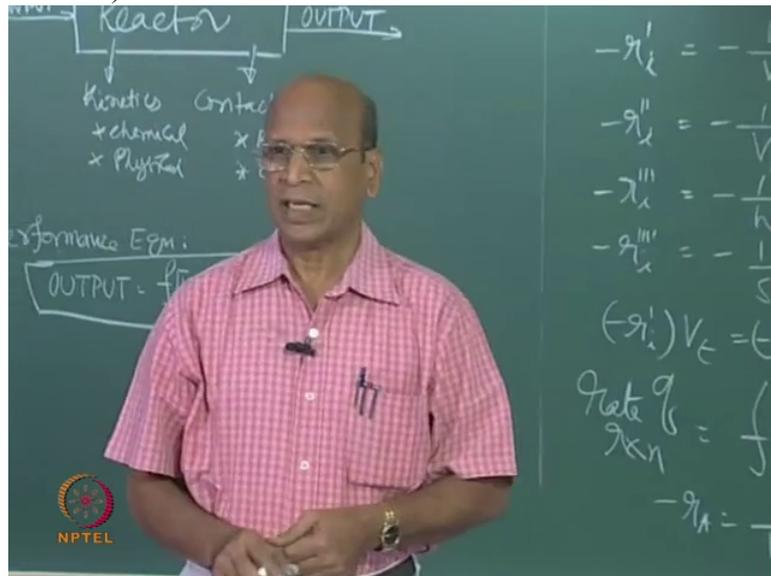
We are talking about; there are 3 ideal reactors and I mean of course first batch and continuous, 2 systems. I am just asking the question, when do you use a batch system, when do you use a batch system, when do you use a continuous system?

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That means if

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you take batch, in between you have to stop and again wait, that time is lost in the production. That is why if you have the continuous system, so then continuously you feed and continuously you get. All large scale productions like for example, ammonia, sulphuric acid, nitric acid, HCl, all these you know heavy chemicals what we call, Ok, so large amount you produce. So for those things the best design is only continuous design, Ok.

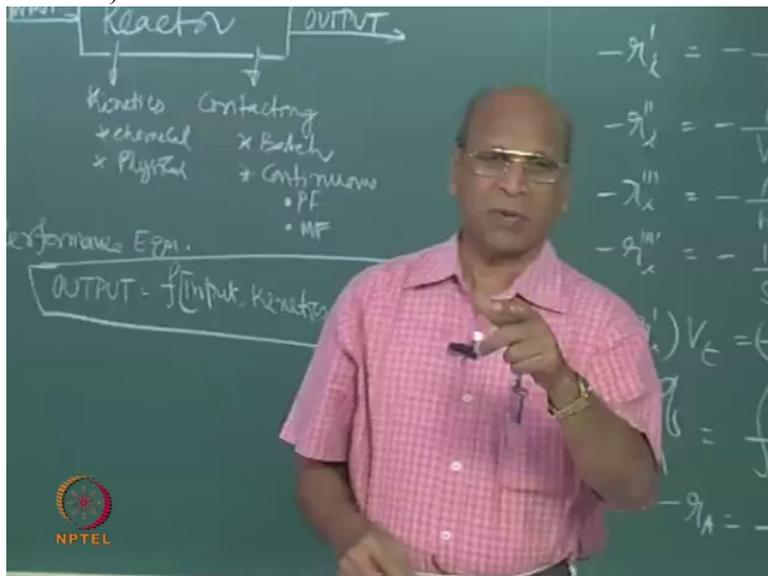
Small production rates, normally you know pharmaceuticals. I mean you won't produce millions and millions of tons of headache tablets, Ok, as one of the drugs, so like that. Because it depends, because everyone is not getting headache. Someone may get stomach ache, someone may get headache. Ok so, for every disease you have only one medicine, that is excellent. That is poison, Ok.

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Anyway. So that is why

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you know pharmaceuticals.

For example paints, Ok. But you know, like that depending on the sales and depending on the demand you can have flexibility in batch system. That is the main criteria. That is why pharmaceuticals, food industries, pesticides, herbicides, all these industries if you go and look, you know, I think you have this penicillin and all that you know, pharmaceutical industries, all these industries will have only batch systems.

But you may see one particular factory where continuous system is used even in pharmaceuticals. But there must be a specific reason. Because they want to produce very large quantities or they would like to have very good control. Advantage of using a continuous system is that you will have a good control.

Because it is flowing, if the flow rates are fixed nothing is going to change. But whereas in batch system every time you are feeding, every time you are discharging, then you are starting, Ok and also batch system, is it unsteady state system or is it steady state system, batch system?

(Professor – student conversation starts)

Student: Unsteady state system

Professor: Intrinsically all batch systems are transient state, unsteady state system

Student: Unsteady state system.

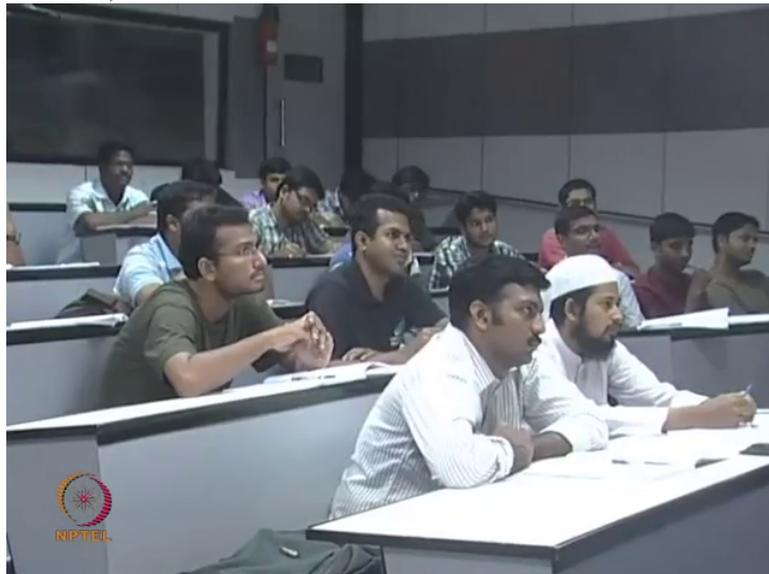
Professor: So during unsteady state you know, you will not get uniform product. Of course in batch reactor if you use good mixing and all that you will get it. But anyway there is some uncertainty. Whereas in continuous systems once you design, you will get beautifully the steady state and also the steady product within plus or minus some small range. Which industry you work? Which industry you work?

Student: 0:19:18.3

Professor: What are they producing?

Student: They are producing dairy products.

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Professor: Ok, are there in chemical reactions or chemical reactors?

Student: No, in context to the previous company I was saying. Before that I was working in a chemical company, then I

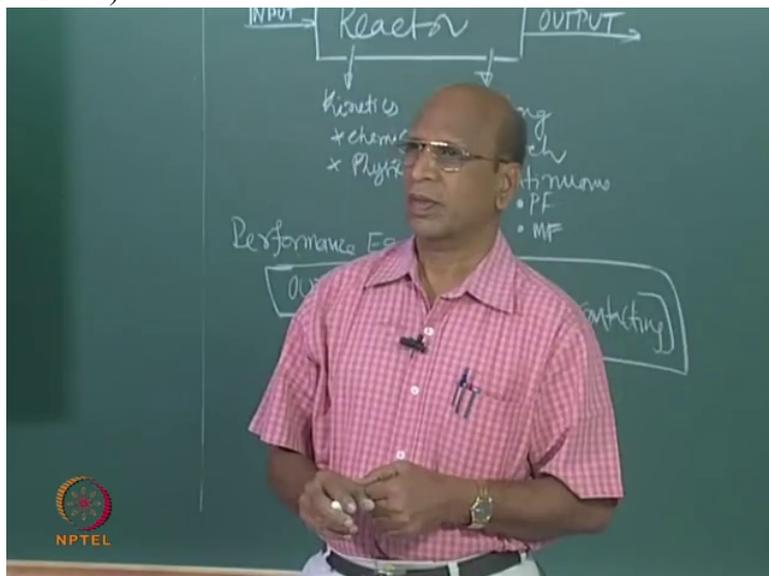
Professor: That company, what were they producing?

Student: Potassium nitride.

Professor: Ok, so yeah, what are the production rate?

Student: Production rate is actually

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900 k g.

Professor: That is nothing. For a chemical company, that is nothing. So that is why,

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probably they are going for

Student: Batch systems

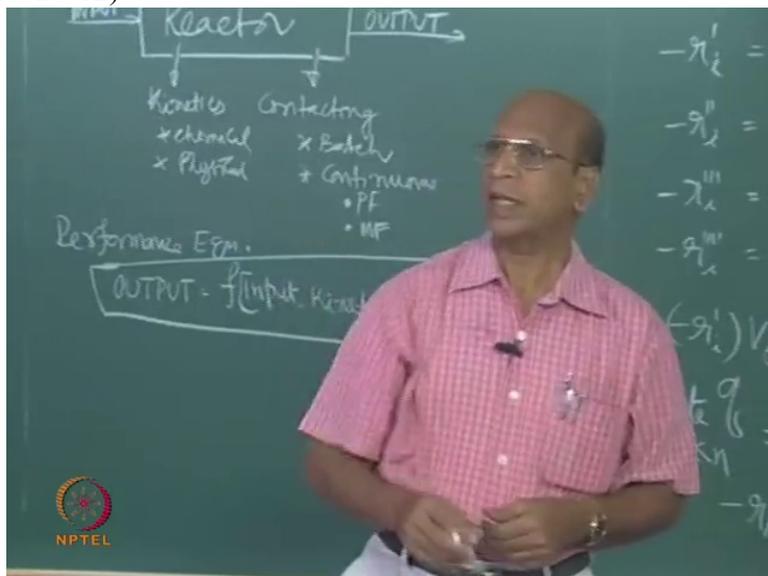
Professor: Yeah, what is the reaction?

Student: Reaction is sodium 0:19:59.4 plus K C l

Professor: That is solid and this is melted. You know that is gas-liquid reaction which is normally very slow, Ok. And I think one answer was there what he told. What is your name?

Student: Rahul

(Refer Slide Time: 20:12)



Professor: Your name?

Student: M 0:20:13.4

Professor: Yeah what you said is one point is right. If the reactions also are, rates are very, very slow then we will go to batch system.

(Professor – student conversation ends)

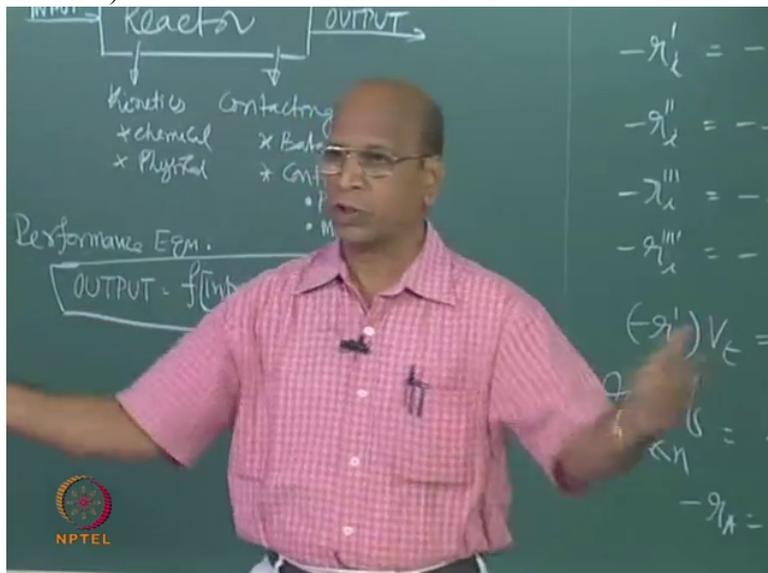
The reason is it is not the volume and all that. You can give whatever amount

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of time that is required in a batch system. Simply, I mean, if I do not allow you to go out

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of this room whole day I can arrest you here and then talk theory. Ok. Really no, that is all.

That is why; you have the time to, to keep the material till the reaction is over. Because it is slow, it takes more time. So in batch reactor you can provide that much time. Similarly of

course in continuous reactors also you can provide. The length will be very large Ok, yeah. And you can also provide the same thing in a mixed flow reactor.

Correct no, mixed flow reactor if you cut off both limbs it is only batch. Both limbs means entering, leaving, cut both then it becomes, because there is also stirring, right? Then automatically it becomes. So we will see which is efficient, which is not efficient, why and all that.

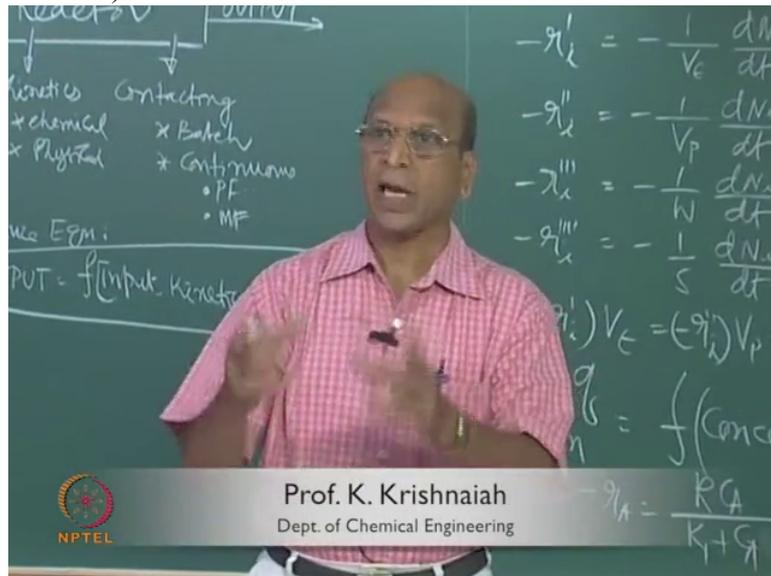
Efficient in the sense that for a given volume which will give you more conversion. Or for a given conversion which will give you less volume here, less volume, less volume is our criteria for a given conversion and more conversion for a given volume. Those are the main objectives of the entire reactor design, Ok good.

So that is why, batch system and continuous system you know now how to choose, Ok. But normally if I want to give the names, I mean not names, the numerical values for how large; I can definitely tell you for 1000 tons per day you will go for only continuous, Ok.

But I have a problem to tell, you know, 10 tons, 50 tons what do you use? There economics will come into picture. Design will come into picture. You have to calculate separately for continuous system. You have to calculate separately for batch system. Compare the economics. Then your labor and all will come into picture there. Because in-between someone has to discharge, all that criteria.

All that you take and then

(Refer Slide Time: 22:23)



now decide which side you are in? It may be economical if you go for batch. Or it may be economical if you go for continuous. This is the gray region where we cannot tell. But definitely as he said you know, 900 kg, 99 percent of the time you go for only batch system, right, yeah. That is how you can say that Ok, around 1 ton or less definitely we will go; we can go for easily batch system.

Or 100 and above per day, again you can go for continuous. But in between somewhere, you have to check the economics and decide which reactor is the best. That is why we have the computers now, calculating power is very high, so just, you know, you know Excel you can use for finding out, Excel sheet there is a program where you can use, automatically if you change one, everything will change.

One parameter you change, all the other things will change and finally your parameter in the last column is either reactor, either conversion if volume is known, or volume if conversion is known. See how the volumes are changing or conversions are changing given the other one, Ok. That way you can try to simulate and then try to find out which one is the best system, right?

But general thumb rule is for low production rates, flexibility in production rates and very slow reactions, batch reactor is used. And continuous reactor is used for very high production rates and also good quality and which one will be costly? Initial cost? Continuous, definitely

because it needs more instrumentation, all that but still we go for that because that is why you have done your project, right, by taking depreciation cost and also break-even?

(Professor – student conversation starts)

Student: Break even

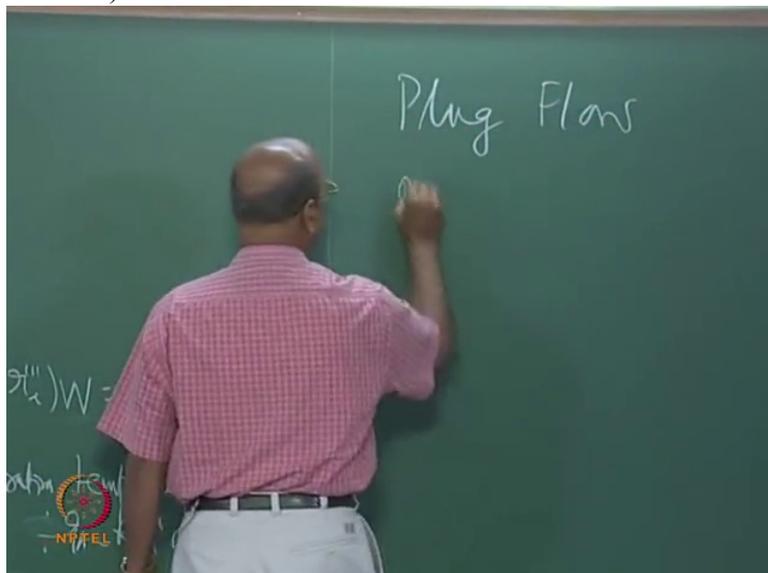
Professor: Yeah, break even, all that you calculate. The break even should be as quickly as possible.

(Professor – student conversation ends)

So that is why after designing the reactor and also taking all other components, all other equipment then you have to again calculate using your economics, finally say break-even point, break-even point cannot say 100 years. Ok, it should be as short as possible.

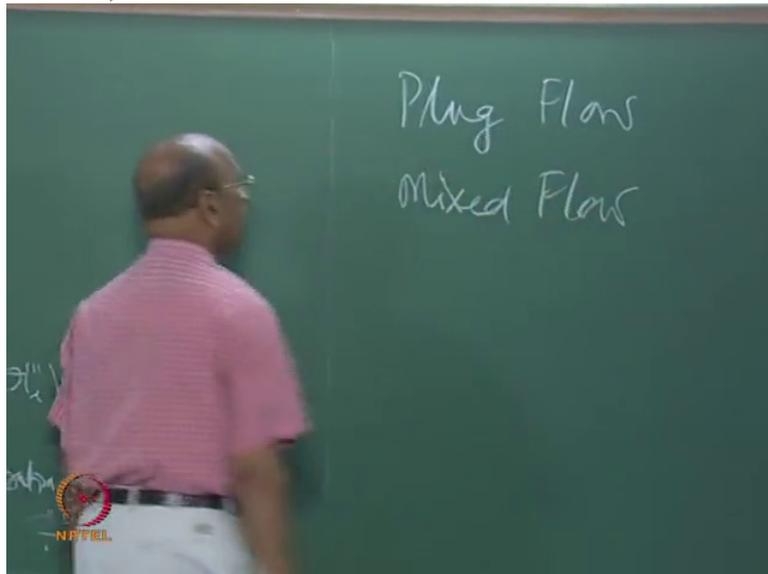
If you are able to, as short as, make the system as short as possible, then your profits start coming for you. So that is the overall picture of this batch and continuous systems. Ok, good. So now in continuous now, we have two, again, plug flow and mixed flow. Let me write that, I think for the sake of others who do not know about this, plug flow and

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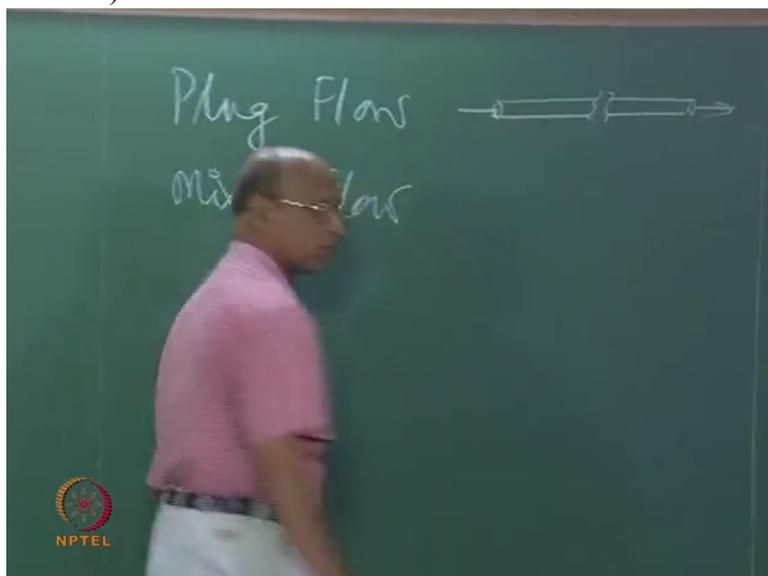
mixed flow, Ok

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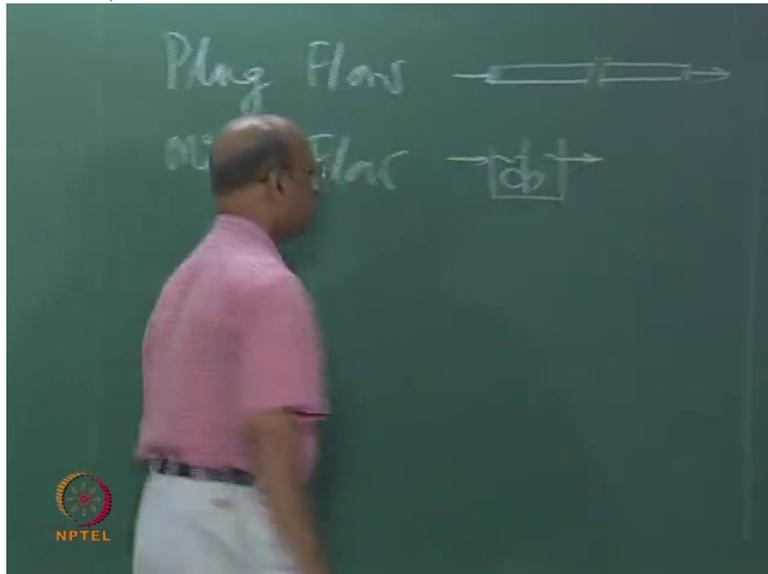
So this plug flow is normally tubular reactors, Ok. So it can have of course any length depending on the system. It comes out,

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Ok. That is plug flow. And mixed flow generally you will have tank reactors where

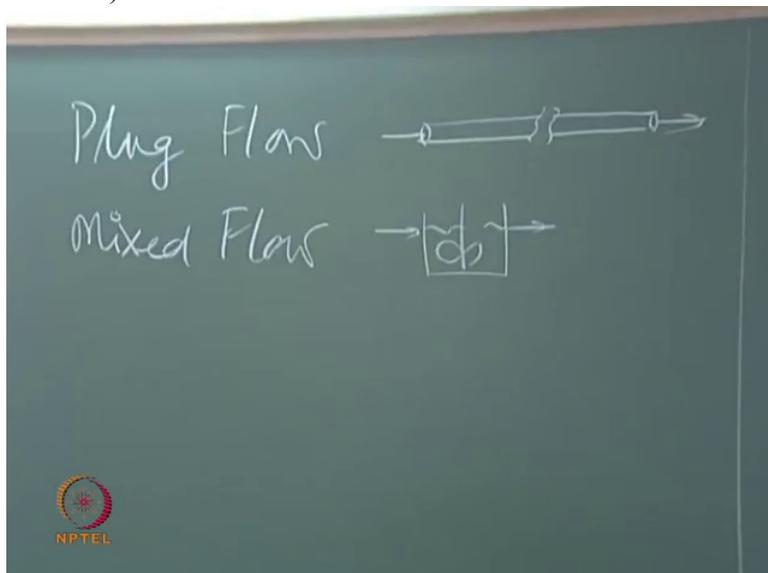
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it is continuously entering and continuously leaving. As I told you if I cut off these two, then that will be nothing but batch reactor.

Ok so

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we have to, we are supposed to use plug flow reactor and mixed flow reactor, I am hesitating to ask the question because I have not explained what is plug flow, what is mixed flow. I do not know how do you give that answer. Because you have exposed to 2 courses earlier in your B Tech and, in your B Tech and M Tech, so that is why now I am asking this question, Ok.

So given a chance to you in the continuous system, continuous system you have chosen, now there are 2 alternatives. So you got job in some industry and then your boss asked, now choose the reactor. Ok, good. Yeah. So I think, of course I have not told many complicated things yet but I think only simple things only we are discussing, right? Yeah, anyone? When can you choose plug flow reactor, when can you choose mixed flow reactor?

(Professor – student conversation starts)

Student: Gas phase reactions

Professor: Why?

Student: Pressure 0:26:30.4

Professor: Pressure?

Student: High pressure

Professor: Why high pressure?

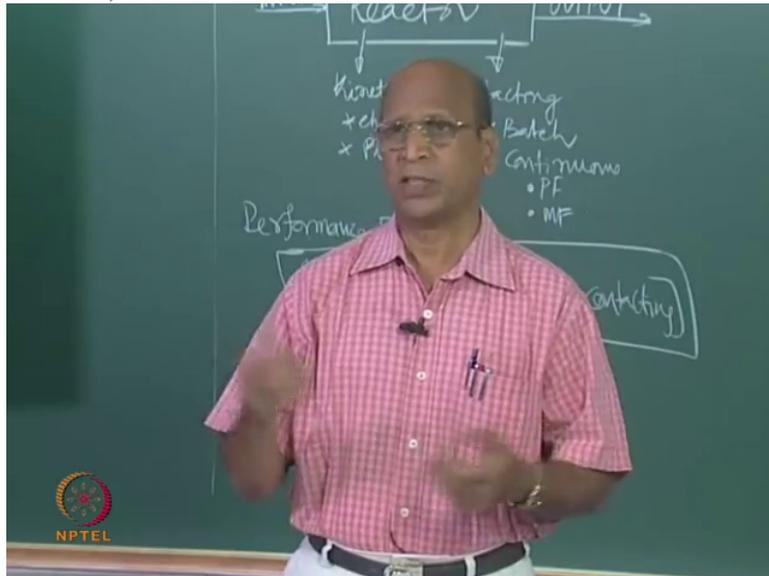
Student: Gas phase

(Refer Slide Time: 26:36)



Professor: There are many reactions without much pressure

(Refer Slide Time: 26:39)



also. There are many gas phase reactions occurring at only one atmospheric pressure, normal pressure. High pressure is not the criteria

Student: We do not want the concentration

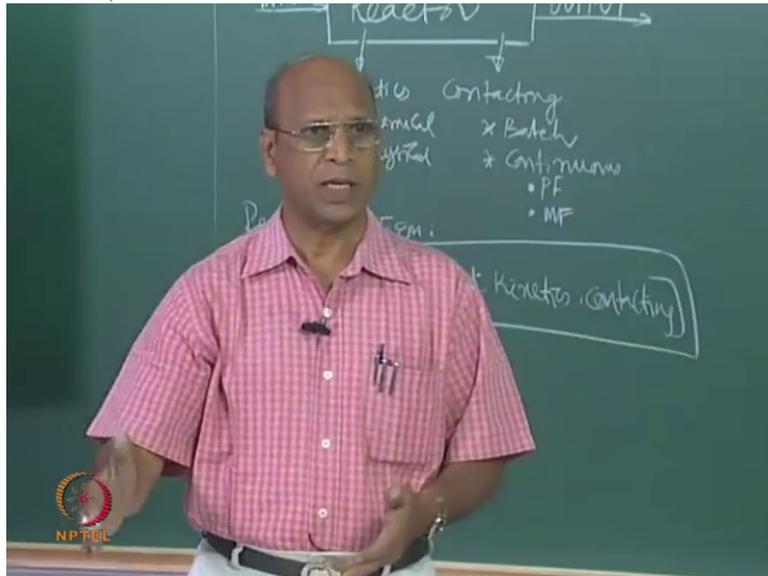
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to fall rapidly.

Professor: Why you do not want concentration to fall rapidly? You want. Because when concentration is falling rapidly,

(Refer Slide Time: 27:02)



rate of reaction is high. When rate of reaction is high, time is very small and then I will get very small volume.

(Professor – student conversation ends)

No please tell. I mean please tell your mind because these are the misconceptions in the mind. That you should not keep them. That is why I told you no, cobwebs, cobwebs there you have to remove them. That is why please without any fear, please talk if you have anything.

And also it is worse to have a wrong answer than not having any answer. If you do not have any answer in your mind, it is very bad, after two courses of C R E. But even if you have wrong answer, no problem. So that is why you have to tell something. Where is Janhavi?

(Professor – student conversation starts)

Student: It occupies more volume than packed bed.

Professor: Again repeat?

Student: Mixed flow reactor has more;

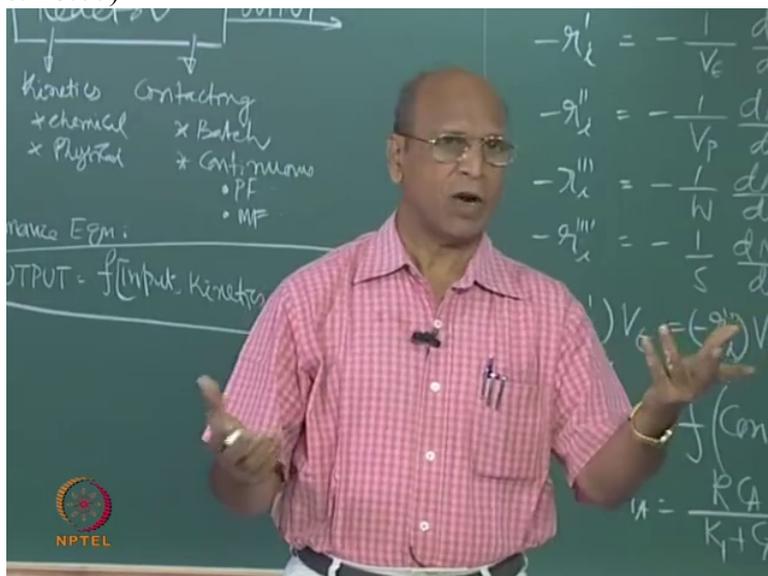
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it occupies more volume than plug flow, so we prefer plug flow.

Professor: For all reactions? Yeah tell me now, as you said

(Refer Slide Time: 28:07)



always mixed flow will give you more volume so that means always we should take only plug flow. But we do not do that. We also use mixed flow, we also use plug flow. That means there is a choice.

(Professor – student conversation ends)

No, this is the problem. Do not worry. You are in the good company of our brothers and sisters. In this course of reactor theory I am again starting all the basics, the reason is for this also no one gave the answer. And even for batch and continuous also, many people do not

know the answer. When do you choose batch system, when do you choose continuous system? Now at least you know.

And please remember, these kinds of questions only are asked in the interviews. No one will ask you very, very complicated mathematical equation in the interview. They start only with these basic things. Ok. What is the reactor? That is why the question that I gave, they are very simple and very nice questions for, in terms of Gopi's language, general knowledge. General knowledge in C R E, Ok, that is what is the first, you know, I think you would have, you would have definitely attended some interviews before coming here. Ok.

Anyone asked you what is the dispersion equation to write? If he has asked you really he does not know how to interview. Really no one will suddenly start and then ask dispersion equation. They will start slowly, Ok what is reactor, and then what is plug flow reactor. In plug flow reactor, is there dispersion? Now you tell me what is dispersion equation. So many steps are required, Ok.

That is why this question also, when do you choose plug flow, when do you choose mixed flow, is many people cannot, I mean not able to answer. One answer was there, who said gas phase reactions? Oh, you said gas phase reactions. That is right.

Not easy problem. Gas phase reactions, the reaction time is very, very small. Most of the time it happens within minutes. If you calculate ammonia residence time in that reactor, or SO_2 to SO_3 residence time in that reactor, or any gas phase reaction, there are many, many gas phase reactions, the rate of reaction is so fast for gas phase reaction because you know molecules are easily moving.

They are colliding and so easily rate of reaction can occur. So when the reaction time is very less, we choose plug flow reactor because it is very easy to provide short residence times in your plug flow. Ok, why? It is a pipe, right. And you know, of course because already you know what is plug flow, right? Yeah.

In terms of Reynolds number can you tell me under what Reynolds number you can say that you have plug flow, the value of the Reynolds number?

(Professor – student conversation starts)

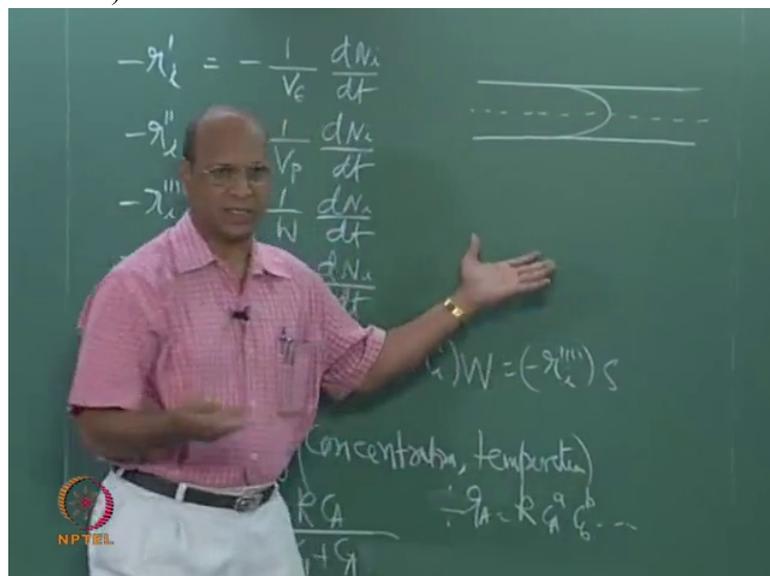
Student: 2000-4000

Professor: Good. Ok, I will now try to give the answer in indirect way. You know fluid mechanics, right? Ok Now I will draw laminar flow velocity profile, Ok? So this is the pipe. How I have to draw laminar flow velocity profile?

Student: Parabolic

Professor: Parabolic, Ok. Ok that is the one. And turbulent. This is only fluid mechanics knowledge what you are using.

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Now turbulent. Ok. I have Reynolds number may be 40000, what kind of profile I get?

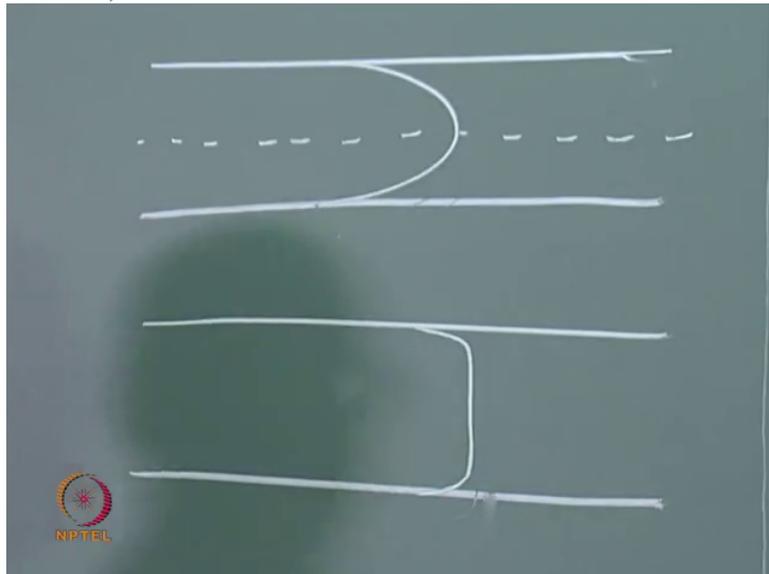
Student: flat

Professor: Yeah, so it is not still flat

Student: Boundary curve, boundary, yeah.

Professor: Like this,

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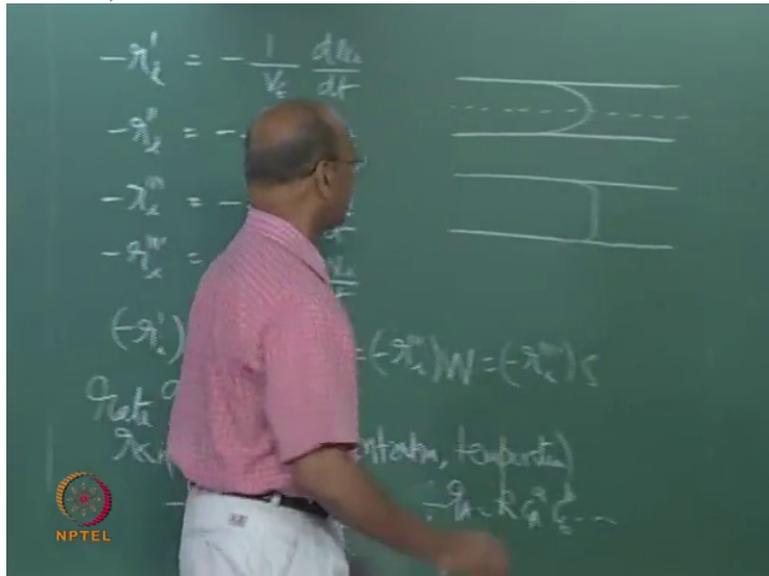
good. So what is that you have written the answer in your first examination that, you know the definition of plug flow? Those who have written. Those who have not written I think it is Ok.

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It is theoretically speaking;

(Refer Slide Time: 32:02)



the Reynolds number should be equal to

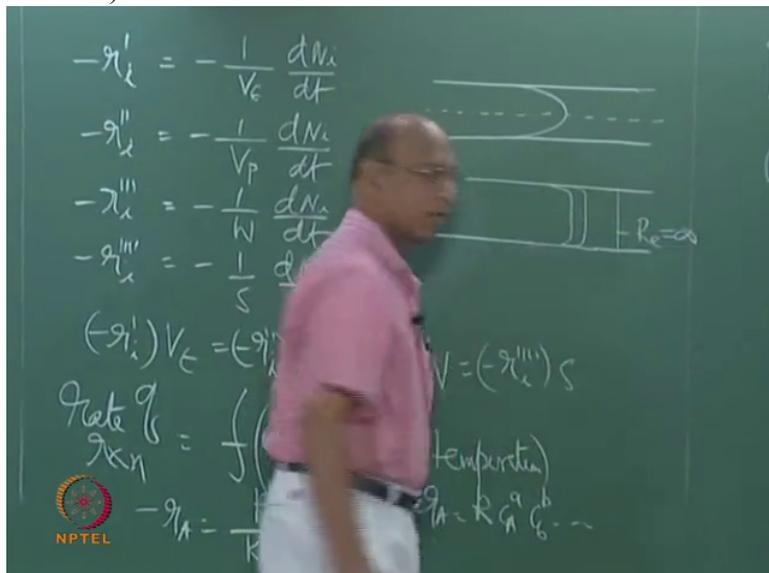
Student: Infinity

Professor: Infinity, very good. Infinity, then only you will get ideal

Student: Plug flow.

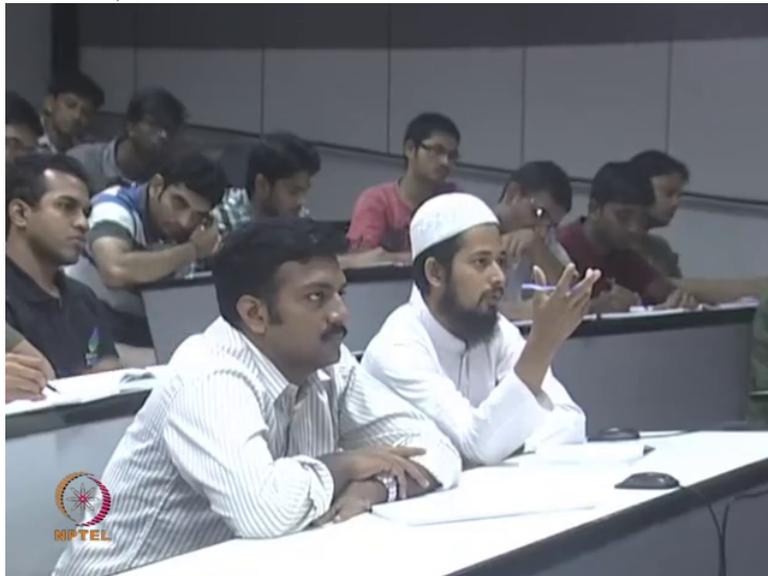
Professor: Plug flow, what you call with flat velocity profile, otherwise whatever Reynolds numbers you use, may be 70000 if I go, what will happen? It may be like this. As long as you have the walls still you will have some molecules clinging to the wall and then you will have zero velocity profile there and then from zero to flat velocity there must be some continuity, right? It suddenly cannot jump. So that is the reason why, theoretically speaking, R equal to infinity

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Ok, yeah?

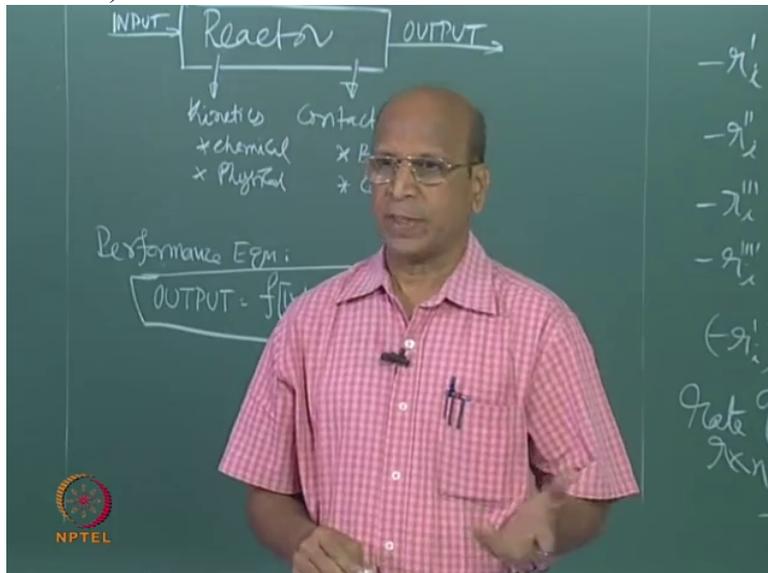
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Student: Sir, in mixed flow reactor, turbulence will be more, may be higher than the plug flow rate.

Professor: Yeah by definition

(Refer Slide Time: 33:04)



of mixing I think you know you should have infinite mixing there, infinite turbulence.

Student: In 0:33:09.5 also we have lot of mixing.

Professor: Where is mixing?

Student: Sir, molecules somehow

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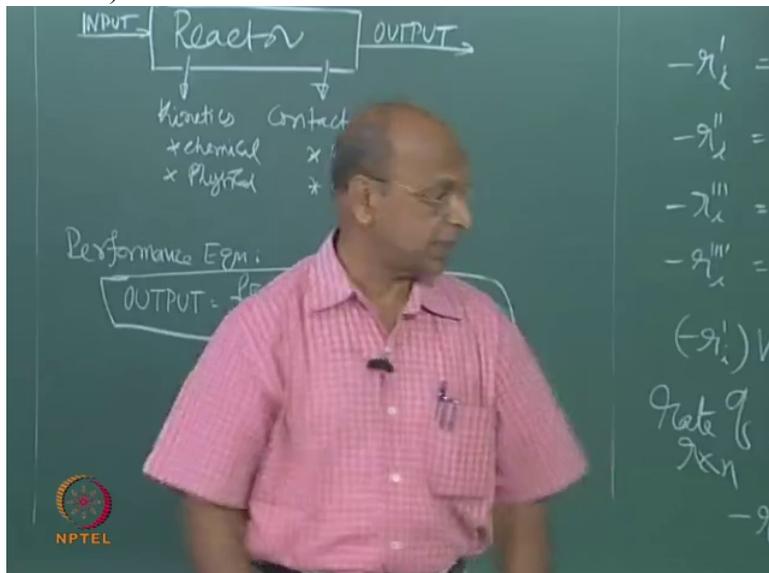


mix with each other...

Professor: No, I think that I will explain when you come to definition of plug flow. Ok, yeah, all these cobwebs are there, I know. That is why I think I will again teach all these things.

(Professor – student conversation ends)

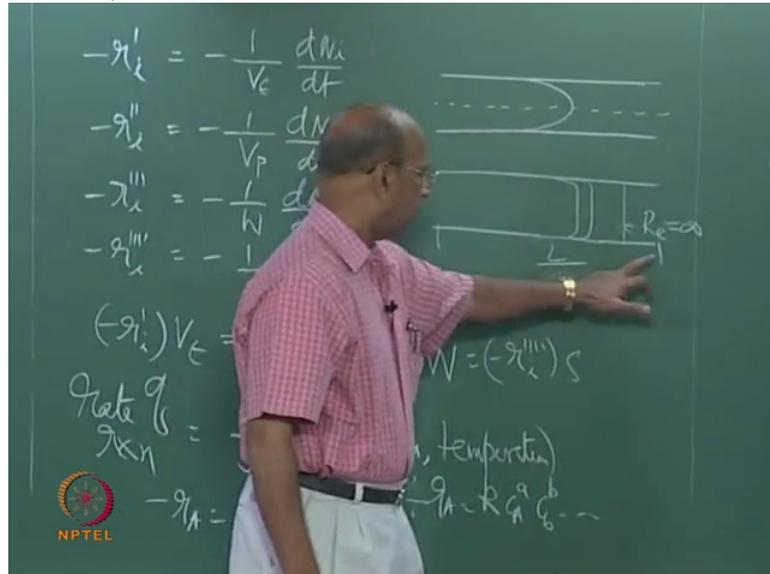
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Ok now we are only talking about plug flow and mixed flow. I am now, you know, how do you choose? So that is the reason why I have given this example, Reynolds number. Reynolds number is a form of velocity, right? You should have, for fixed liquid, that means properties, rho and the diameter, then only as you are increasing velocity, you are increasing the Reynolds number, Ok.

As velocity is increasing what will happen to the residence time? Residence time is defined as this length divided by velocity, right? So I told you know, when you said the gas phase reactions are, because of the low residence time required for gas phase reactions we go for plug flow, the reason is

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for, and when you want to maintain plug flow you need very, very high Reynolds numbers, right? Ok.

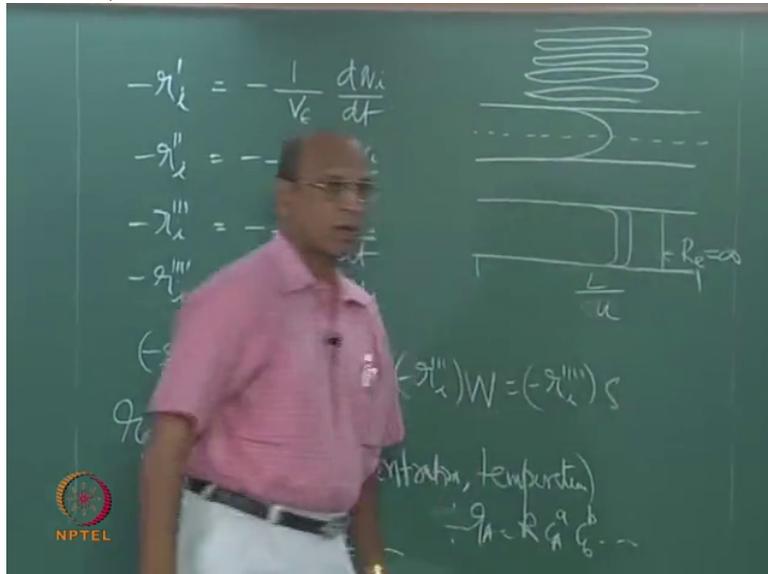
Not theoretically, theoretically you cannot go to infinity. But you need very high to maintain that plug flow, ideal plug flow. So that means you should use very, very high velocities and if the reaction time is 10 hours, then what is the length of the pipe you require? 10 hours.

There are many reactions with 10 hours. And 10 hours no gas phase reaction is there. It is only 10 seconds. 10 hours liquid phase. Ok. So that means if I am taking a liquid phase reaction where the time required is 10 hours for the reaction, if I want to provide 10 hours in a pipe with velocities almost, Ok I mean reaching infinity velocities. Because plug flow, you have to maintain plug flow. Otherwise you cannot call it is a plug flow reactor, if you do not maintain

So you have to go for very high velocities, then you need a pipe which will go around the world once. Ok, or if it is not enough, it has to go to moon, from there Mars, Ok, from here, starting from earth. So that length of reactors you have. But that is why I do not know

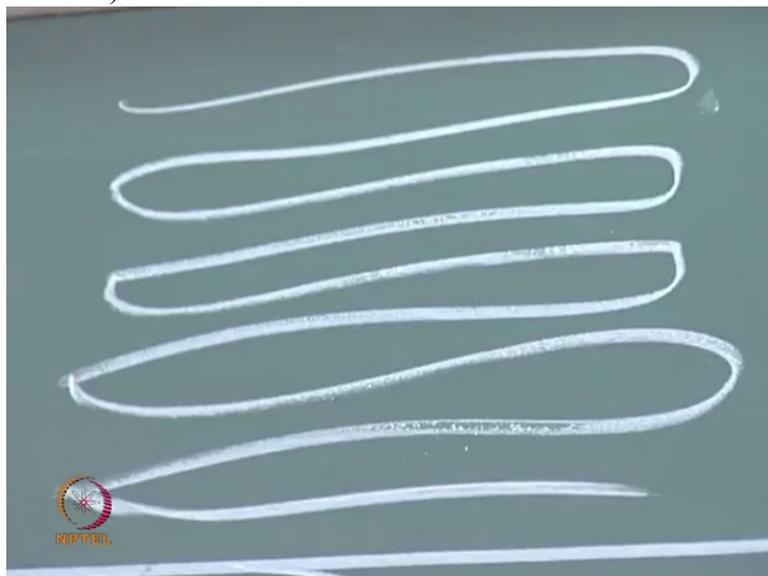
whether you have seen any plug flow reaction in industry most of the industrial plug flow reactors are designed in this fashion.

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And you know sometimes in industry, you will have 2 kilometers, 3 kilometers length of plug flow. That means like this, many, many, many, many, each one will have 30 feet or 40 feet length. Ok like that you can now count how many numbers you have to put and the join at the these ends and you can guarantee that they will not be a plug flow. Even though we say that it is plug flow reactor.

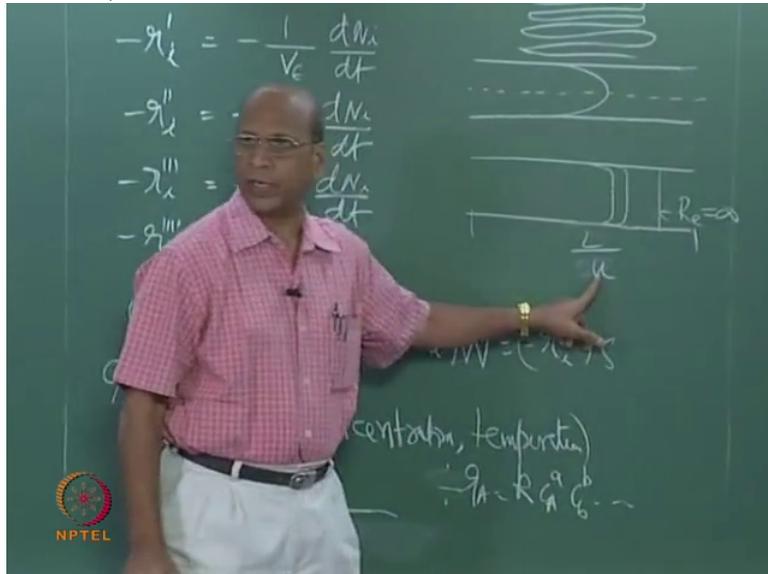
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That is why you have non-ideality coming there, Ok.

So the ideal plug flow is only existing when you have velocity equal to infinity that means you cannot provide even zero second, correct no, infinity, 1 by u , this u equal to,

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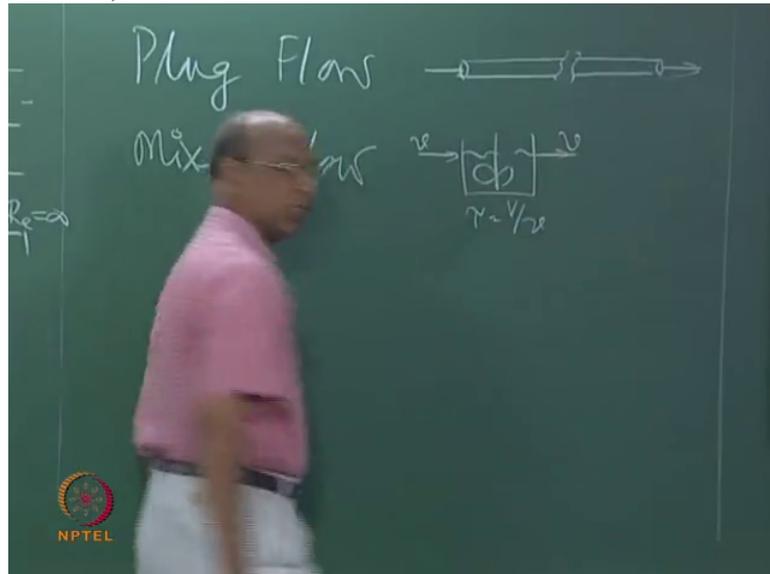


u equal to infinity, then it becomes zero and with zero reactions I think you know, zero time if some reaction is happening you do not need any reactor at all. You simply do not need any reactor (laugh).

Because even before you mix them they are reacting, why do you need a reactor, you do not need anything there. So that is why you have to choose the plug flow reactor for residence times which are very, very small and most of the times that happens only for gas phase reactions. And if there are some liquid phase reactions whose reaction times are very, very small, there also we can get. But criteria is time. That is one thing, Ok.

Next one is when do you choose mixed flow reactor, opposite of that? That means whenever you want large amount of residence times, large amount of residence times, 10 hours, 20 hours, because it is a tank, it is a tank reactor, so then you can definitely provide that much time, right. Again we have an equation, we do not know who told you that, τ equal to volume by volumetric flow rate, this is volumetric flow rate,

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this is volumetric flow rate, Ok, this is volumetric flow rate.

I want to provide two years residence time, 2 years, Ok, exaggerating to just make a point that is all. So I can still provide that in that reactor? I may take let us say 1 metric cube and I want 2 years residence time, can I provide? Is it in my hands? How? Cut off the outlet, it becomes batch.

(Professor – student conversation starts)

Student: Volumetric...

Professor: That is all, drop by drop, drop by drop I will add. Then I can provide not only 2 years, 10 years' residence times. 2 years I told that because your M Tech time (laugh). Ok I know.

(Professor – student conversation ends)

You would have seen that big waste water treatment plants. Why do they need that big size, have you ever thought? Because of exactly the same reason. The residence time required for waste water treatment is 3 weeks, 4 weeks, 5 weeks. Ok, that is why and also depending on the effluent, sometimes they will have, my God, big swimming pools, 5 or 6 together. This goes from there, this goes from there, this goes, that is tanks in series. Ok.

Because the liquid phase reaction there, it is very slow. On the top of it, they are all microorganisms. They are also as lazy as us. Ok, they won't work properly. If the temperature

is very hot they will sleep. Like you know, but we will put A C and then we will sleep, Ok. But microorganisms...if the food is not good, what do you do? If 2 days I think if the mess is closed you will never come to the class. You take rest.

Same thing. Microorganisms also like us. Because we are also part of this planet and microorganisms also part of this planet, life-wise. So our behavior is same. So give them; that is why you put very good nutrients in a biochemical reaction, right and also you give correct condition, Ok, 30 degrees, exactly maintain 30 degrees. Like we are maintaining in our rooms, for our body comfortability is 25 degrees, Ok. So that is why A C and all that we use.

So exactly these microorganisms also like us. And if you make them anger by not giving food, or by heating it because if the sun is very hot, they will say, Ok leave it, I think, just sleep for some time and then come in the afternoon. So all this we have to take into account that is why biochemical reactions are very, very slow. Because exactly like us.

But the molecules are different, chemical molecules. They do not behave like microorganisms. Fortunately these molecules, they do not have life. They cannot think. Given a chance, they will go and react, that is all what they know. Increase the temperature, more rigorously they go. They won't go for A C. So they will go for more and more collisions and more and more reactions. Because you are giving them more energy, that means more food by giving the temperature.

So that is why, as you increase the temperature the rate of reaction is very, very fast in the actual chemical reactions whereas up to some point may be 25 to 30, in many biochemical reactions it increases. Afterwards, Savita? If you go to 40, it starts decreasing. Not for many but there are specially designed by God, specially designed microorganisms where even at 60, 70, 80 degrees also they are surviving. You know hot springs; you know sulphur heating and all that you know, those things that is fine. That is only few.

Though they are designed only for some specific purposes the other organisms have been designed for some other purposes, Ok. That is why biochemical reactions is one of the examples where always they go for tank, either batch or mixed flow. Plug flow reactors are very rarely used. Yeah, you can use,

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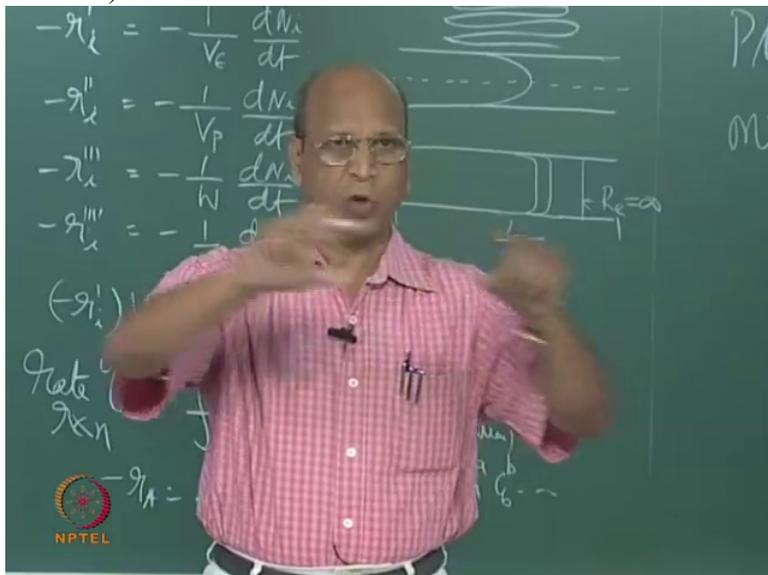
provided that

(Professor – student conversation starts)

Student: 0:41:35.9 tube length

Professor: No you can use, provided that

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tube length is one diameter of the earth.

Student: (laugh)

Professor: The length, not the diameter. The length of the reactor will be one around, you know, one circumference of earth. What is the earth diameter?

Student: (laugh)

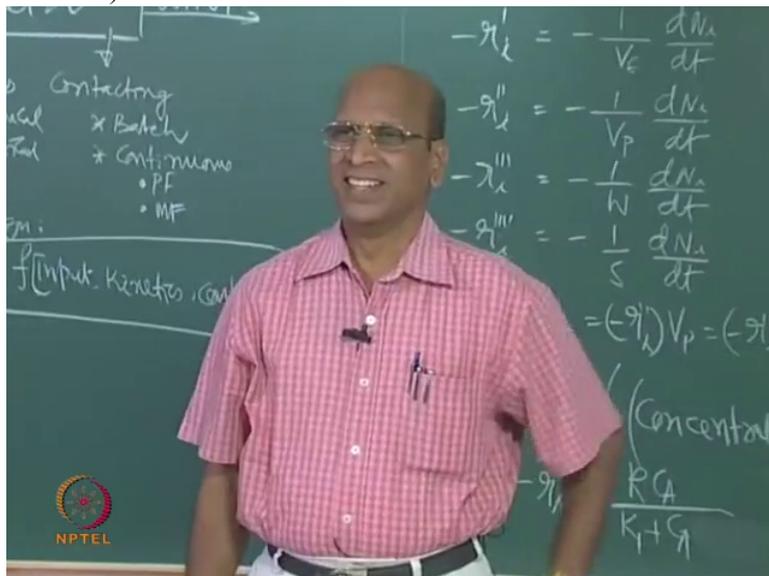
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Professor: We have Encyclopedia Britannica.

Student: (laugh)

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Professor: Excellent, give a clap for him

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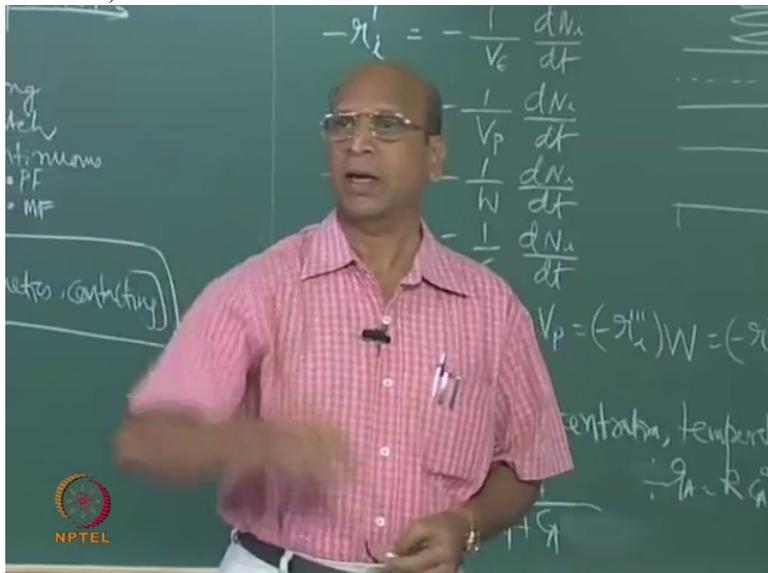
(Applause)

Professor: In diameter or radius you tell?

Student: Radius

Professor: Radius, that you see that $2\pi D$, $2\pi R$.

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Student: Sir? Tank volume is also very big in comparison.

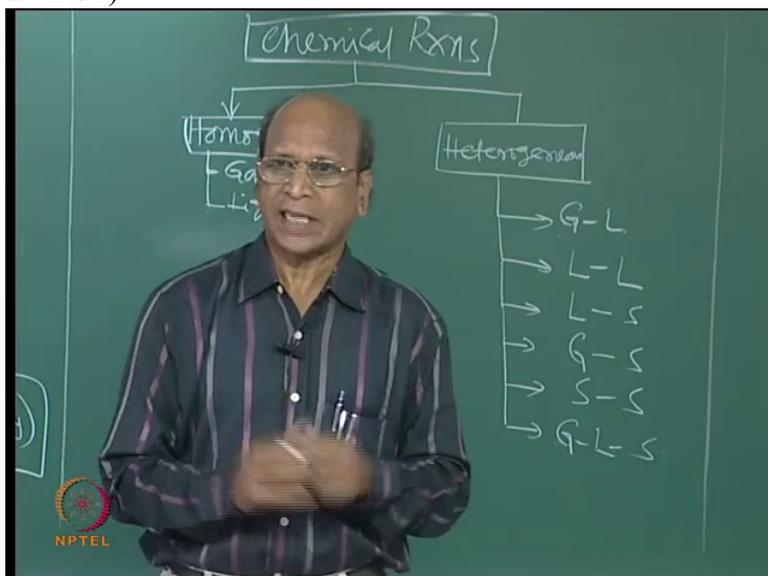
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You can use plug flow...

Professor: But you know, in a, in a

(Refer Slide Time: 42:31)



length there, there the diameter is fixed most of the time, Ok. You cannot go to so big diameter in plug flow. Ok, what is the diameter you can guess in any plug flow reactors? Diameter? In terms of centimeter?

Student: 1 centimeter

Professor: Or inches?

Student: 5 centimeter

Professor: 5 centimeter. 15 centimeter yeah, any other values?

Student: Point 1

Student: 15 centimeters

Professor: 15 centimeters.

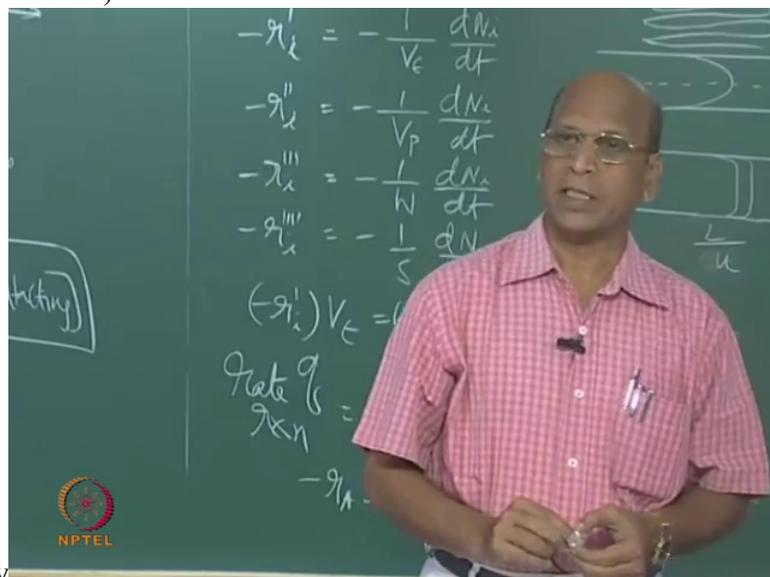
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Student: 5 centimeters

Professor: 5, centimeters or inches? Oh, centimeters you say, yeah.

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Student: 5 percent

Professor: That is 5 percent, not tubular here.

Student: Yes 5 centimeter

Professor: That will have time also. I will come to that also. 0:43:21.6 learn here. What you are saying is right but why we are calling that also as a plug flow I will explain to you later, that diameter, big diameter, yeah.

(Professor – student conversation ends)

So that is the reason why most of the time we won't go beyond 6 inches or 8 inches maximum. 8 inches means 200 mm, 20 centimeters or 15 centimeters, most of you told 15 centimeters. So that is fixed. So then when you are going for plug flow the velocity required is almost very, very high.

So the residence time is, to provide that much residence time, then you have to, then the length will be very, very long. So that is the reason we do not go. Ok, your, her doubt is then why, the same thing is happening in the mixed flow also, right? That is correct. What she asked is right. But here I have the flexibility in increasing the diameter and also length.

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(Professor – student conversation starts)

Student: 0:44:17.7

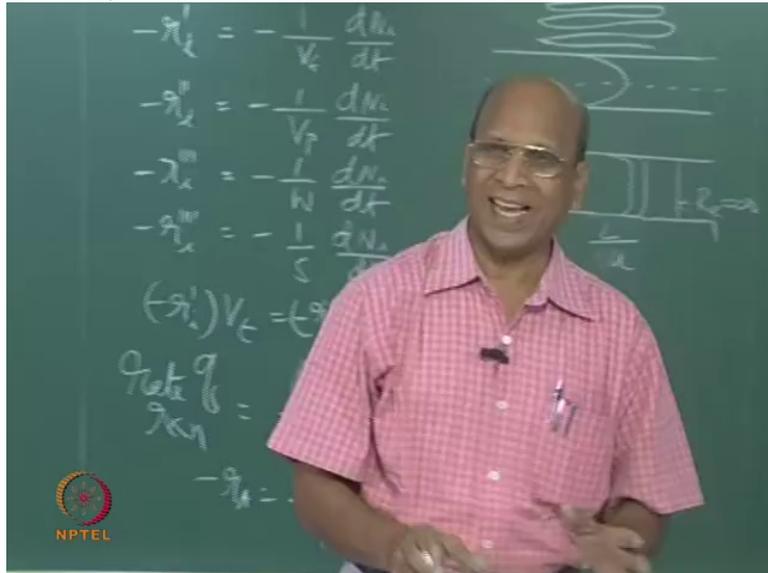
Professor: You can do.

Student: 0:44:20.8 does not

Professor: You can do it, theoretically you can do it but no one will do it.

Student: (laugh)

(Refer Slide Time: 44:26)



Professor: Why, the reason is that the concentration of gas inside that will be very, very less, diluted.

(Professor – student conversation ends)

Unless otherwise you go for very high pressures in the C S T R, you can go to very high, 100 atmosphere, 200 atmospheres then concentration is $P A$ by $R T$. As partial pressure is, if it is a pure reactant then you will have the total pressure itself is that one, so pressure by $R T$ will give you that concentration.

But at room temperature, if you calculate that concentration that will be very small. As concentration is very small, you have rate of reaction, yeah very small and then you will again take more time. So that is the reason why you do not go for, most of the time. But we use mixed flows for C S T Rs in the laboratory to find out kinetics for gas phase also.

For kinetics because you are using a small reactor and then small amount of gas at different pressures or at atmospheric pressure and you just find out what is entering, what is leaving, perfect mixing is there, then you can find out what is the rate of reaction for gas phase reactions, Ok.

Homogenous only we are talking here, when I am talking about these two reactions, I mean these two reactors. Now at least you have an idea when do you choose plug flow? Plug flow

you chosen when you have the reaction times are very small, so most of the time gas phase reactions will have small residence times required. So gas phase reactions is one answer.

And liquid phase reactions most of the times we conduct in, yeah. Then I will ask another question. What will happen, which reactor is the best if I have highly exothermic reactions? Is it mixed flow reactor or is it plug flow reactor? Your question also there is valid. You know I am not saying that whether you have gas phase or liquid phase. Gas phase also may be very exothermic, highly exothermic. Exothermic, either liquid or gas phase which reactor is preferred and why?

(Professor – student conversation starts)

Student: Plug flow reactor, temperature

Professor: Plug flow reactor is preferred for highly exothermic reactions. Ok.

Student: Mixed flow

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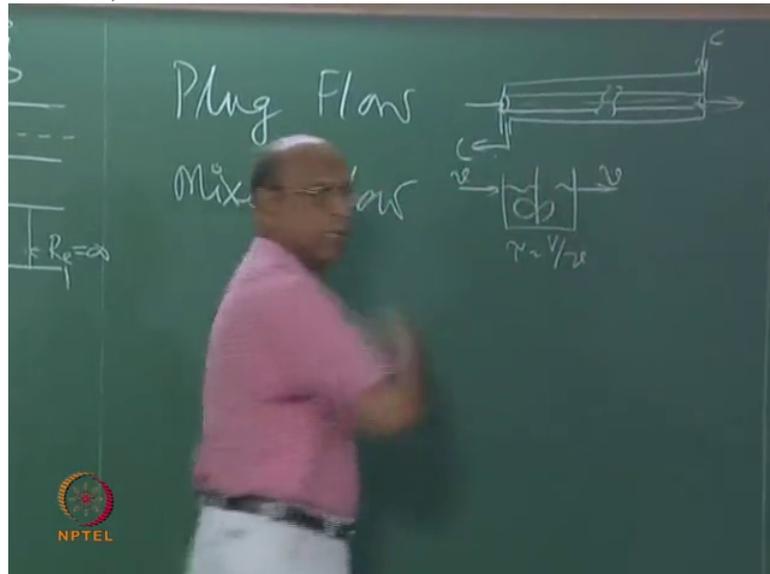
Professor: Why mixed flow?

Student: Temperature control

Student: 0:46:38.2 discussing

Professor: Yeah, you have to put only jacket around this, Ok which is, sorry, this one is going inside, oh, yeah, so this entire coolant enters and coolant comes out there, yeah.

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Savita you were telling something?

Student: 0:47:04.0

Professor: Yeah, this exchange is never perfect.

(Professor – student conversation ends)

You can never maintain isothermal condition in a plug flow reactor. And you will have what are called hotspots, Ok. That is why plug flow reactor is a lousy reactor for heat exchange. Remember that. Really lousy. You can never have uniform temperature throughout.

You can have, theoretically in your mind, Ok, if you have infinite number of heat exchangers, so that means I will put here one heat exchanger, here one heat exchanger, here one heat exchanger, so almost every, I do not know, 1 m m, 2 m m, one heat exchanger if you put, probably you may get almost isothermal. And will you design so many heat exchangers, so many feeds, so many outlets, so many pumps no one will do. Ok.

So that is the reason why whenever you have exothermic reactions we go for only, even for very high exothermic reactions, gas phase reactions, because there I do not worry about the timing. I do not worry about conversion. I worry about the heat, where it may explode after some time, if the heat is building up, the hotspot is reaching, it may reach the flash point and then everything may burn, so safety is very important, that is correct no.

So safety is very, very important. So that is the reason why, even gas phase I have to go sometimes for mixed flow reactors if it is continuous, if it is highly exothermic. So these are the main two criteria for choosing between plug flow reactor and mixed flow reactor. Now can you repeat, when do you choose mixed flow reactor?

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(Professor – student conversation starts)

Student: When temperature control is required

Professor: When temperature control is required...

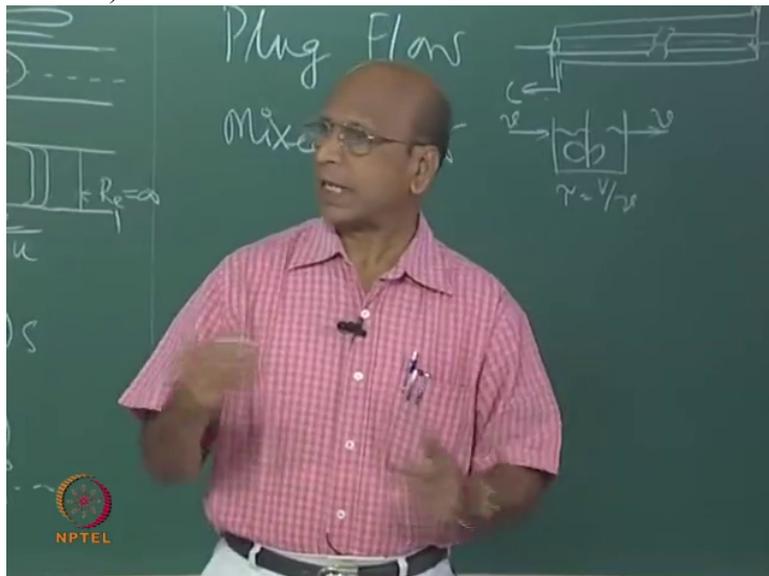
Student: 0:48:54.4

Professor: And when?

Student:

Professor: Large residence times that is all. Ok any other criteria?

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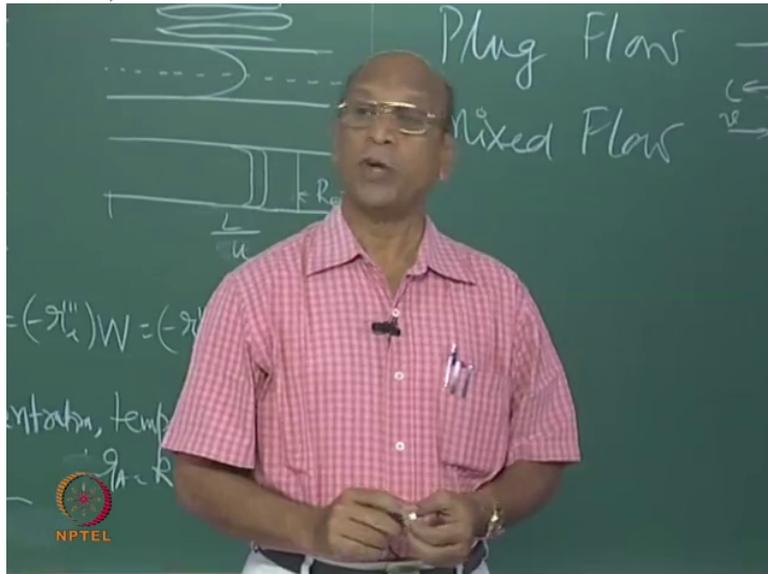
Any other criteria?

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No other criteria except these?

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When do you get clogging?

Student: Solid particles

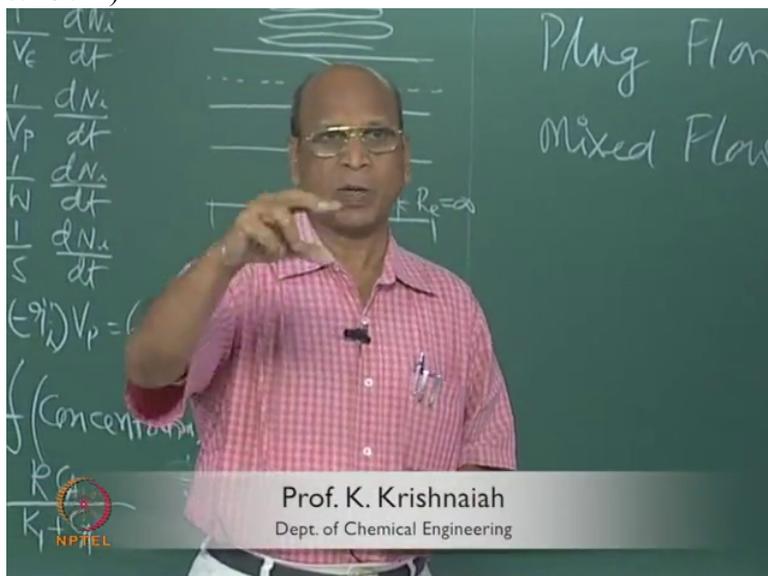
Student: Catalyst particles

Professor: Yes, catalyst particles when you have that, we will discuss later, when we come to heterogeneous reactions, heterogeneous reactors, that we will discuss. Yeah, so it can happen. It can happen.

(Professor – student conversation ends)

But whenever you are using even

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packed bed reactors, a gas phase, clogging is very rare unless you design your catalyst lousily. I told you no, you may go for large surface area but what you do; you will finally get only powder if you want to use very, very large surface area.

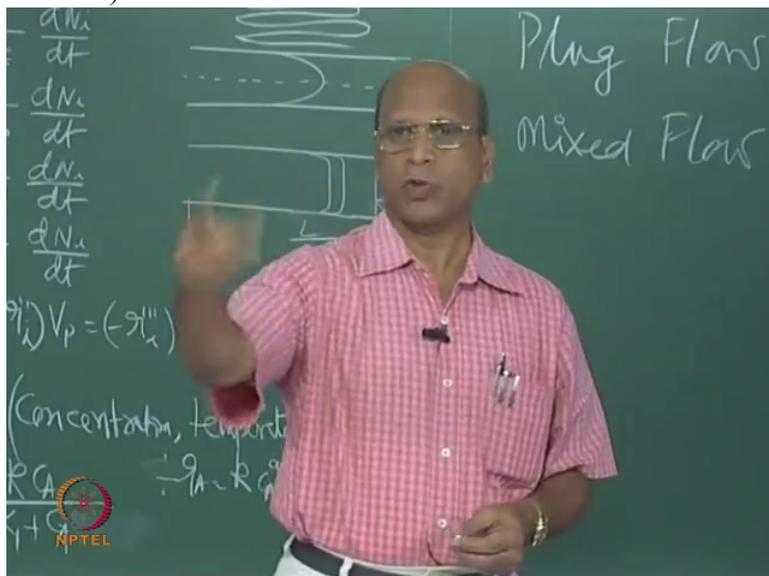
So there powder may form. That powder may be transported from one place to the other place and then

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may block. So those are the problems

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which you have to separately deal with when you are talking about catalyst design, right?

So that is why these two are the criteria which normally we take for choosing between continuous, I mean continuous and batch you know how to choose, and also in continuous between plug flow and mixed flow when do you choose, Ok? How do you choose? So this is very good information you should remember and again you know, you discuss among yourselves, otherwise you will forget very easily.