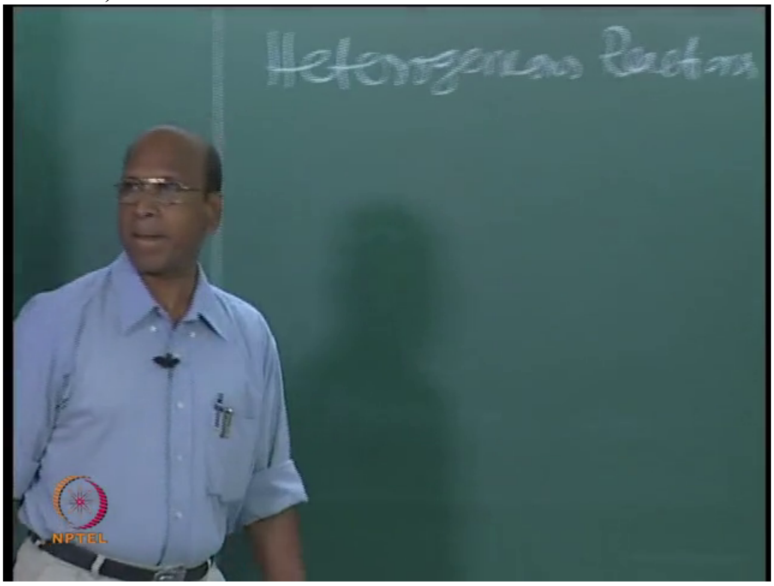
Chemical Reaction Engineering 1 (Homogeneous Reactors)

Professor R. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology Madras

Lecture No 21

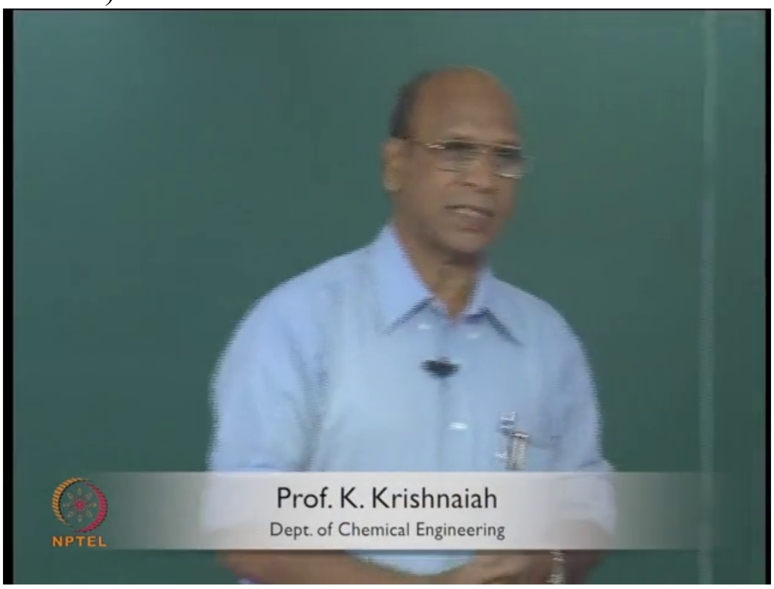
Kinetics of Heterogeneous reactions Part 3

(Refer Slide Time: 00:20)



Ok, so we have been discussing about heterogeneous because I would like to give flavor for heterogeneous

(Refer Slide Time: 00:28)



reactions, so that means what extra information what we require for heterogeneous reactions. Abdul, what extra information

(Professor – student conversation starts)

Student: Mass transfer

Professor: Mass transfer step but we have taken only isothermal reactions.

(Professor – student conversation ends)

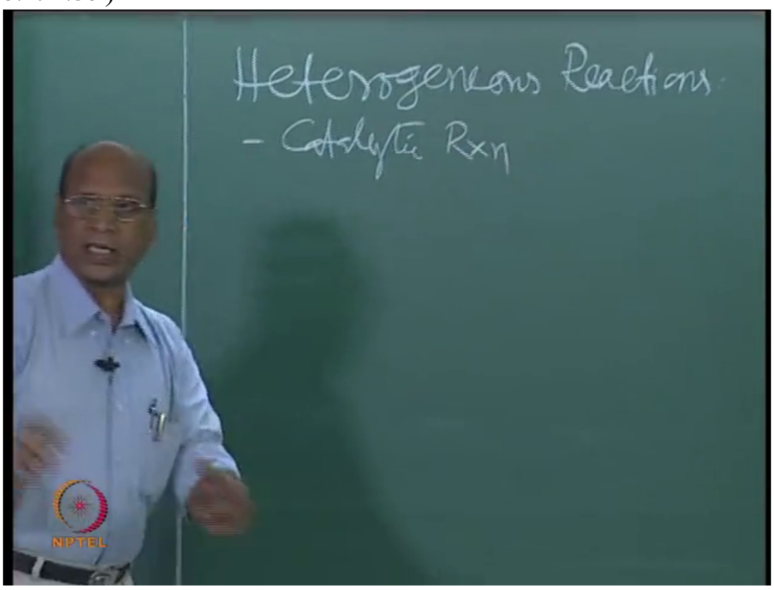
And if I have non-isothermal reactions, it is not only mass transfer; even heat transfer will come into picture. Why, because in the bulk, you have a different temperature. On the particle, if it is catalytic reaction, you have another temperature, right.

Or in exothermic reaction or endothermic reaction, endothermic reaction, the temperature of the particle will be less than the temperature in the bulk. If it is exothermic reaction, the temperature in the bulk is less than, yeah bulk, yeah I have changed the argument, so in the bulk it is less and at the particle, exothermic reaction, so you have more temperature.

So there is a temperature gradient also between the film and the actual particle, right. So that heat transfer also you have to take into account, right, so that we will do in the next semester but first things you know, simple things what we want to understand. We have derived equation for catalytic reaction, right.

Catalytic reaction and

(Refer Slide Time: 01:39)



you got a rate minus r A equal to C A B by minus, divided by 1 by k G and yeah, 1 by k and we also know that now in, under some conditions k that is reaction rate constant will not come into picture for design at all. It will come only; I mean the mass transfer coefficient that will come into picture.

That means my rate equation now contains only mass transfer rate, mass transfer coefficient rather than chemical concentration and also chemical reaction rate constant, you see. And that happens most of the time for combustion reactions. Why?

(Professor – student conversation starts)

Student: High temperature

Professor: All combustion reactions are at very high temperature, 600, 700, 800 like that. So the reaction, rate of reaction is very, very fast. So it is, yeah whenever you have rate of reaction very, very fast which is controlling?

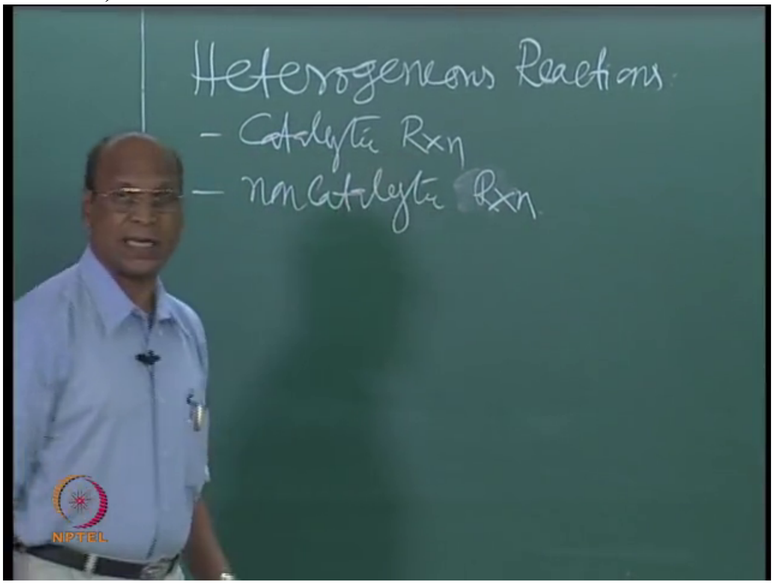
Student: Mass transfer

Professor: Mass transfer controls, so that is why only mass transfer equation will come for design of chemical reactor. Really surprising, no?

(Professor – student conversation ends)

So that is the beauty in heterogeneous systems. Now let me take one non-catalytical reaction, very simple one. Non-catalytic reaction, yeah. So before going to non-catalytic, one more word about catalytic

(Refer Slide Time: 02:57)



reaction.

I have taken, when you take step 1 and step 2 and step 3 for catalytic reaction, assuming you have porous particle, first step is mass transfer, second step is reaction, third step is yeah, not desorption, mass transfer back through the film. Desorption means on the surface it comes, all that we clubbed together.

So then I told that for first order we could, first order rate we assumed then it was very easy for us to eliminate unknown concentration that is C A s, unknown means I cannot measure that concentration. That is why we could get that very, simple expression.

I can give in the surprise test, some time now I have to start now the test also, simply that one equal to k C A square. Mass transfer step is same, k g into C A b minus C A s. Now that is equivalent to k into C A s square, C A s square. The moment I put that C A s square then you have a quadratic equation; because our idea is to eliminate C A s.

So you have to solve from this quadratic equation, C A s. And then that C A s afterwards you can substitute in any one, mass transfer equation or reaction equation. Totally the rate becomes very, very complicated but still it will be in terms of k and k g.

So depending on which condition, which is rate controlling; you can simplify that equation also in terms of only k g or in terms of only k. If you have very, very, very slow reaction, the fellow is not, you know, as I told you, you are not hungry at all. You have eaten sufficiently. Then idlis will be continuously coming throughout. And you have that concentration of idlis on that conveyor belt throughout.

So that means throughout the film you have the same concentration because the rate is not very fast. The particle is not able to convert the molecules that are coming to the surface into products. So then what happens, the entire surface will be covered by C A b.

So that is why, you draw that line you know C A b, constant line, you know what we have drawn in that, right? So that is the reason why that line and also it is zero line because on the surface, I think Swamy or someone was asking me that question, if there is no, yeah concentration how can it react?

You know it is not exactly mathematical equivalent of, you know, C b equivalent to zero. Whatever particles are coming to the surface, they are immediately converted. At any time I look at the surface practically there are no, yeah, there is no reactant left, yeah

(Professor – student conversation starts)

Student: It is a zero, we are not considering?

Professor: It is not zero in the mathematical sense, right?

Student: Say C A s minimum

Professor: What is minimum? How do I know what is minimum?

Student: No Sir, we are talking of the resistance of the mass transfer step

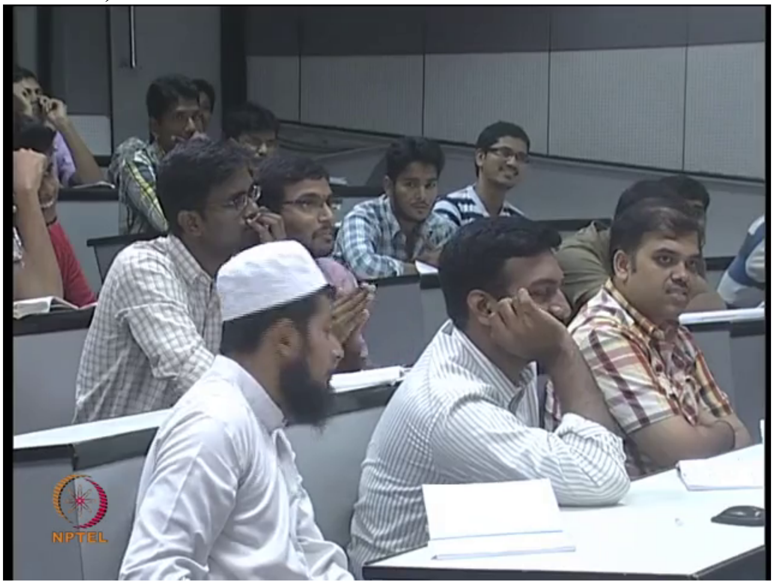
Professor: Yeah

Student: We are not talking about, I mean...

Professor: Ok, you tell me, I think, to understand the same thing. My example, all of you are tremendously hungry. You can eat an elephant also if you can see, so much hungry, Ok. Yeah. So then at that time, this is, the idlis are continuously coming, right. And you are able to eat. So then at any time, continuously they are coming, so at any time, can you see any idli on the surface?

Student: Idlis are there

(Refer Slide Time: 06:15)

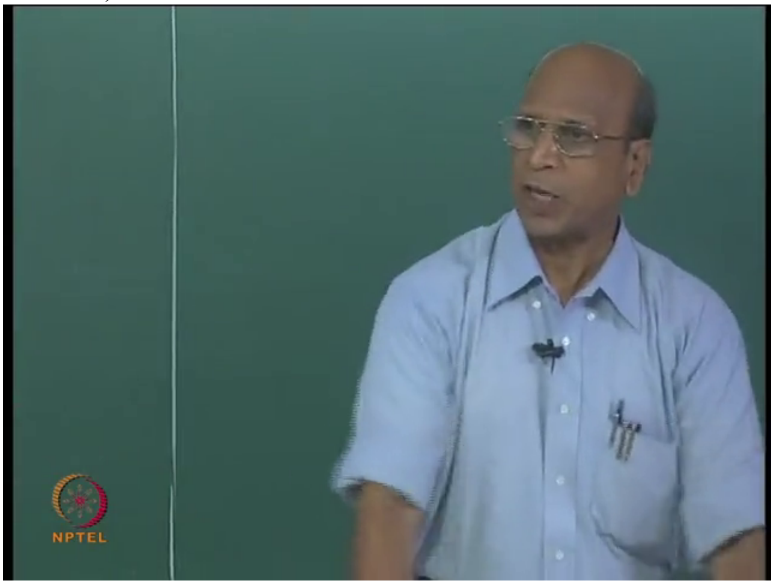


Professor: Yeah, they are there.

Student: But after coming to the surface they are getting zero.

Professor: Yeah, this is, you know, I have my catalyst particles starting from here. All the people are standing here. Both sides

(Refer Slide Time: 06:25)



people are standing, right? I may have conveyor belt before into the kitchen. The moment they touch the surface, surface is you standing, you know, waiting to take the, I mean whatever they give, whatever they give. Forget about idlis, Ok.

(Professor – student conversation ends)

So then the moment they started coming, first person takes like this. Second person, you know long hand, takes like this. Third person also pushes the second person and then takes. So what can you see there? You cannot see any concentration of idlis on that left.

Similarly on the surface you have the molecules just coming and then touching the surface, converted to product and now if you see that what is the concentration of reactant on the surface, practically zero. That is what is the meaning of that, Ok.

You are telling that concentration is decreasing like this, then these particles, few particles which are coming to the surface, they are very quickly converted. And the beauty there is now, if you are intelligent, you should be able to supply as much as possible, Ok, as much as possible so that you will get maximum rate.

Why? Because the particle is capable of reacting, converting

(Refer Slide Time: 07:41)

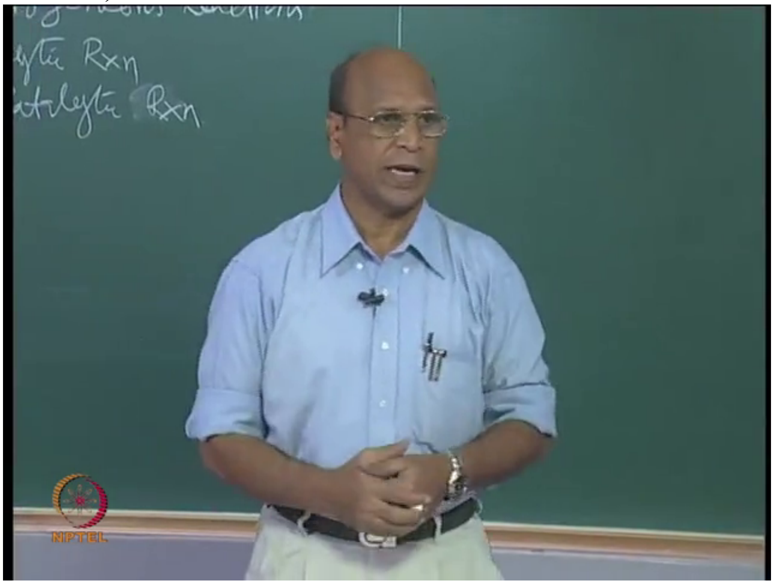
the molecules very quickly. Now if there is a film, then the resistance will come. If you remove the film?

(Professor – student conversation starts)

Student: No resistance

Professor: So directly you have lots of A that is coming to the surface where rate of reaction

(Refer Slide Time: 07:54)



is very high. How do you remove the film? Fluid mechanics will never allow you to remove the...yes?

Student: High flow rate.

Professor: So the moment you have high flow rate, film thickness will reduce. Then the concentration gradient will not fall that much, Ok. That the concentration on the surface, forget about idli, so the concentration on this surface practically nil, Debian?

(Refer Slide Time: 08:18)

Student: As Sir, because in this case, this idli is moving...

Student: (laugh)

Professor: Yes

Student: What you say, which time will idli will come and come and come?

Professor: Yeah

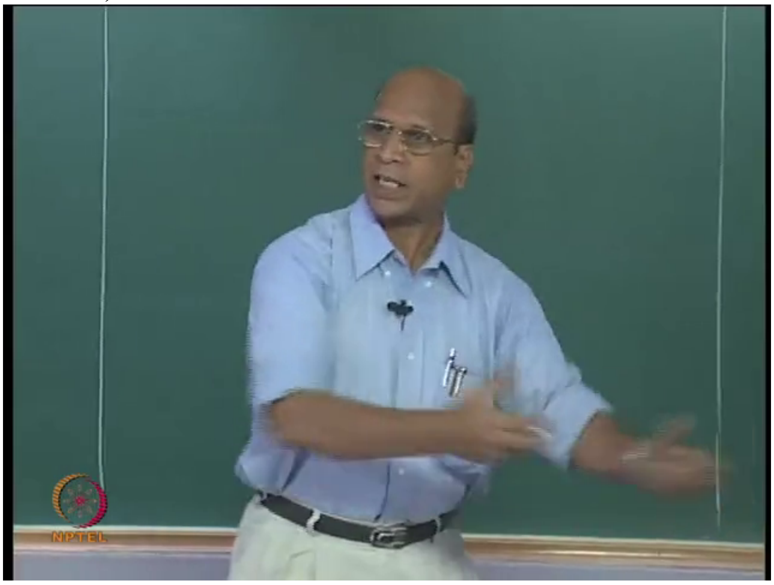
Student: When two persons will be standing there, they will be taking it up.

Professor: Yes

Student: If no person after them are standing there, so there idli concentration will be there, right? I mean...

Professor: No, no, the two people are so hungry, any number of idlis they can eat.

(Refer Slide Time: 08:44)



What do you mean? I think you know so hungry that means the rate of reaction is very, very high. Temperature is 600, 700, 800 degrees Centigrade.

Ok, so any molecule coming to the surface will be immediately converted to product. And that is why practically you see that, practically I said; practically you see that on the surface there is no concentration. Here also idlis example, there may be a piece of idli left somewhere, you know (laugh)

Student: (laugh)

Professor: Which is stuck to conveyor belt and all that, Ok? Yeah, like that there may be 1 or 2 molecules. But that won't give you any, you know rate of reaction in the sense, you know, significant rate of reaction.

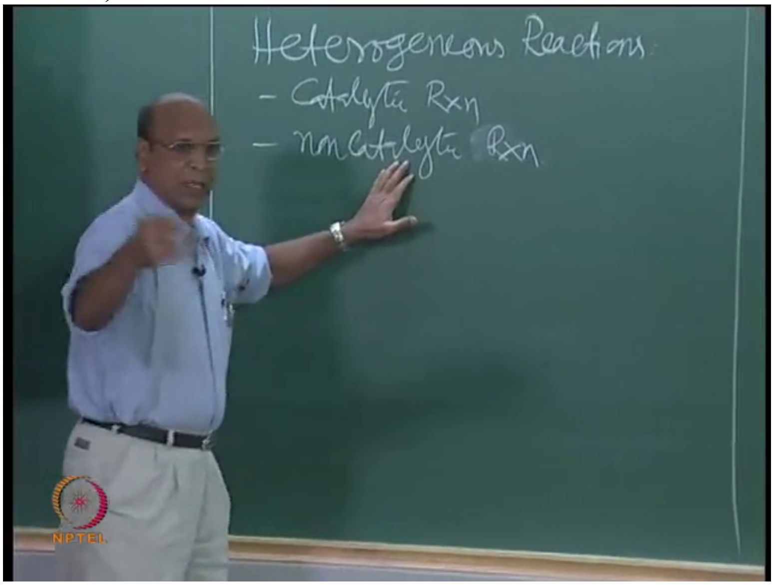
(Professor – student conversation ends)

That is why if you see my notes, I think I wrote that C A s is, yeah, almost zero, like this I put and then put zero. And you are really, see, Swami is taking, whenever mathematics are required he will not both about mathematics. But here mathematics are not required.

Ok, C A s is not exactly equal to zero but it is approximately zero, tends to zero, that means the moment you have any molecule coming to the surface, it is getting converted to product. So practically I do not see many molecules of A on the surface. That is what is the meaning of that. Ok.

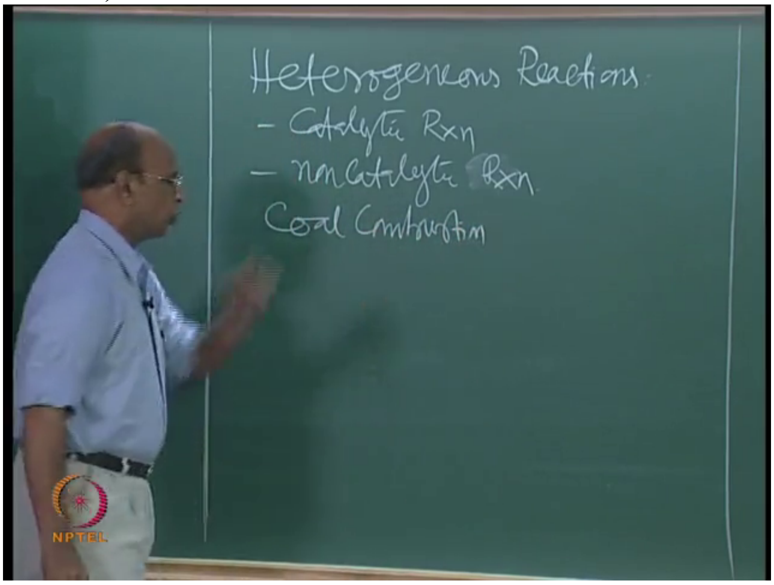
So that was the example what

(Refer Slide Time: 10:03)



we have given. So non-catalytic reaction what we take is coal combustion. Again I am simplifying many things. Yeah, so

(Refer Slide Time: 10:14)



coal combustion. You can use again the moment you have coal combustion, what are the various types of reactors used for coal combustion?

(Professor – student conversation starts)

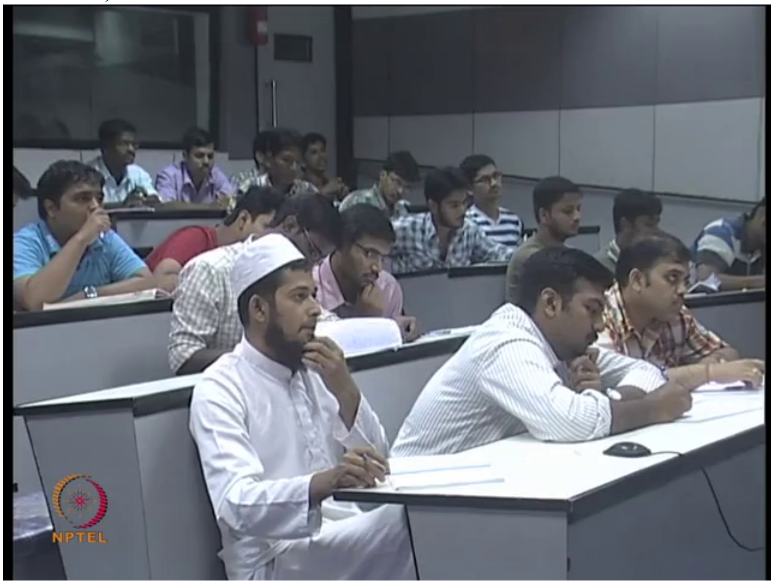
Student: Fluidized bed.

Professor: Because, first of all, yeah excellent. Fluidized bed is one, anything else?

Student: Moving bed, Sir

Professor: Yes, who is telling moving bed? Yes, Ok, moving bed, yeah. Still, because

(Refer Slide Time: 10:31)

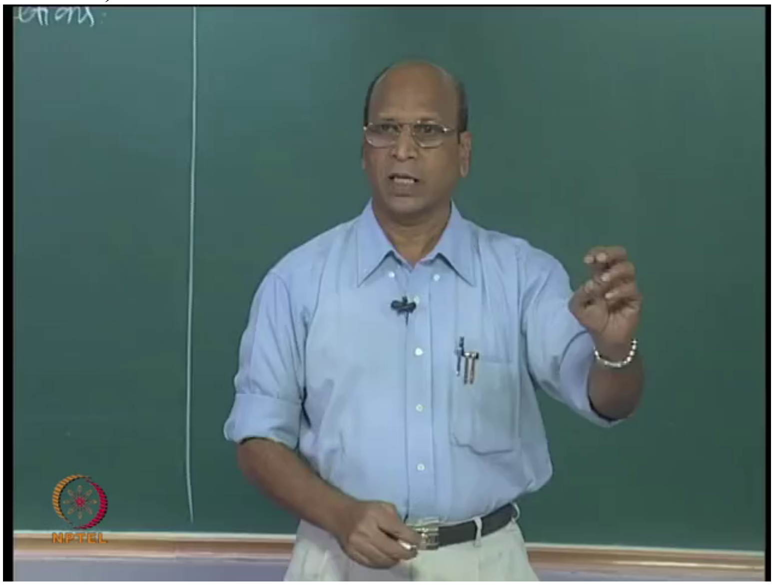


that has to come to your mind first.

(Professor – student conversation ends)

When we say coal combustion, Ok, what are the possible, because in chemical engineering, that is the beauty I am telling you. The beauty part in chemical engineering is

(Refer Slide Time: 10:41)



we do not have a single solution problem. We have many possibilities, right?

So this reaction can be conducted in many, many ways. For example, coal combustion. Even catalytic reaction can be conducted in many, many types of reactors, right? But all those reactors will be simplified in ideal, in ideal reactors wise, either, only those two.

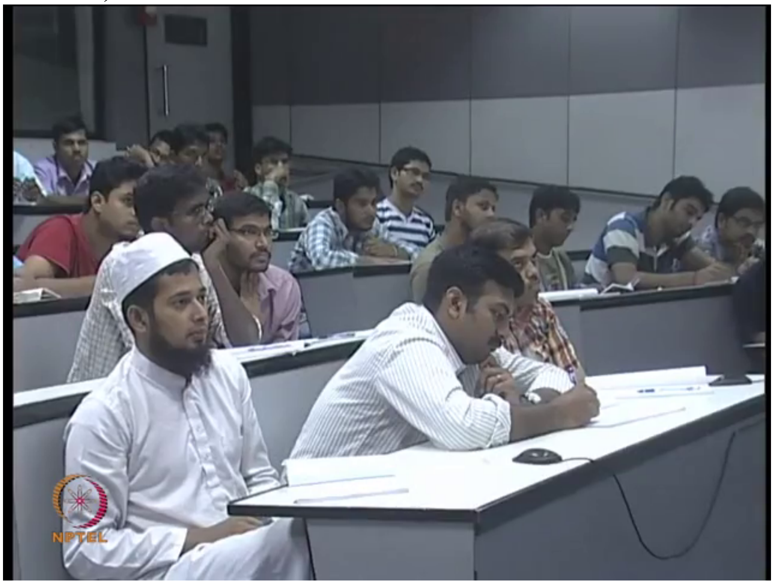
Either mixed flow or plug flow if it is continuous system. If it is batch, anyway batch system. So any reactor you bring. Ok, what about, cannot you use rotary kiln for combustion? We can, we can. What about packed bed?

(Professor – student conversation starts)

Student: Yes we can

Professor: Why?

(Refer Slide Time: 11:26)

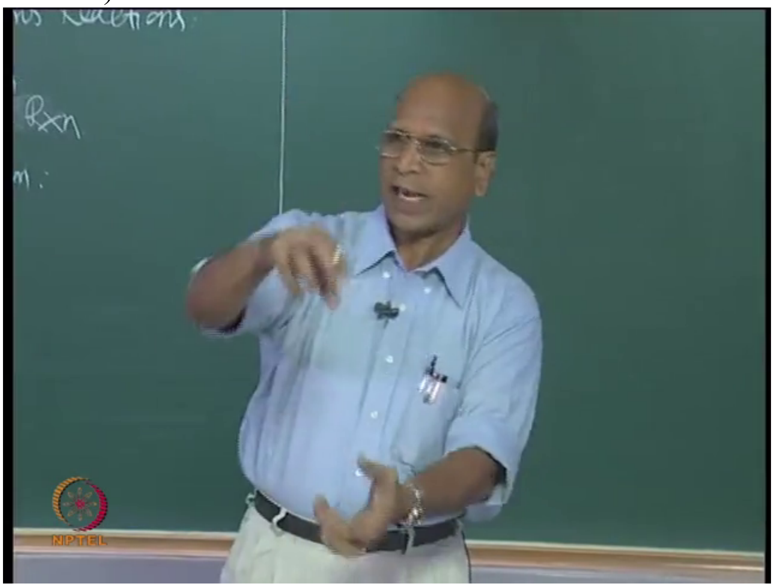


We can, definitely. Why? What is the problem?

(Professor – student conversation ends)

So that is what no I can put all the coal

(Refer Slide Time: 11:31)



inside, burning. But only thing is it is not steady state. We need steady state energy that is coming out of this combustion. But that is not steady state if I take batch. Because initially you may have big fire, initially slow fire again, when it catches, all the particles catching fire then it becomes to peak and afterwards it falls. So that kind of situation I may not require. Ok.

So that is the reason why continuous flow only we will go. Yeah only that, or you have any other thing? You have not heard moving grate conveyor, you know combustions? Moving belt, Ok on the belt you have the thing, I think, Ok of course, the material what you are using to design that belt should not melt, Ok.

So even that also continuously it is fed, continuously it is burnt, so this will go and then come out, go and come out like a conveyor belt which is again recycling on its own. That also can be used. So that is why, but in all the systems as I told you for catalytic reactions, I have to pull out a particle to understand what is the phenomena that is happening around the particle.
Why the reaction is taking place, how the reaction is taking place. So that is why all heterogeneous systems, first imagination is what kind of reactor I have. And please remember when I am talking about a single particle out and then talking about the reaction rate, reaction rate will not change. Actual chemical reaction rate will not change.

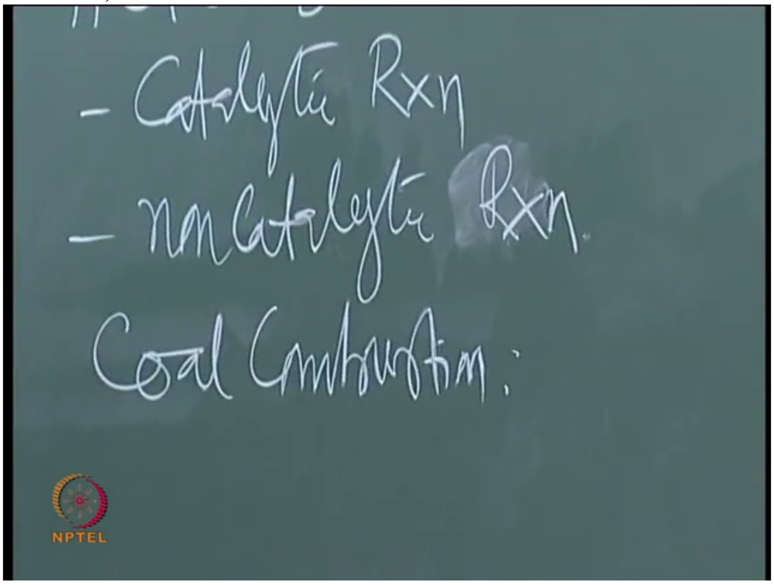
What will change? Mass transfer will change. Mass transfer in a packed bed is different. Mass transfer in a fluidized bed is different. Mass transfer in moving bed is different. Mass transfer in a rotary kiln is different. That is how that controls the reaction.

But chemical reaction is same. Chemical reaction, actual chemical part is same, Ok. So that is the beauty again in heterogeneous systems where you have to find out now which one is now rate-controlling? Whether both rate-controlling or only one step rate-controlling, all that.

So that is why I take fluidized bed which is also very widely used, right, very widely used. Then you also have pulverized combustions. I do not know whether you have heard of them, pulverized coal combustions, right, Ok?

This pulverized coal combustor is simply, it is used in Neyveli

(Refer Slide Time: 13:56)



and many power plants. It is a cylindrical column; big size may be 2 meters or 1 and half meters or 2 meters diameter. So from the top what you do is you spray powder of coal, pulverized coal.

The particle size will be around 1 m m, point 5 m m like that. So actually they send with gas, they just like a jet, you know these particles like jet they just introduce. So inside already combustion is going on, steady state combustion.

When I am talking about terms and conditions before starting, right, not startup, under steady state conditions. This will, very quickly enter the combustion chamber. Sufficient amount of heat is there, you know, that is why combustion reactions are also auto-thermal reactions.

Once you started combustion, then it is auto-thermal. You do not have to do anything. Auto-thermal means on its own its combustion is going on. So this very fine dust of coal will just enter and then quickly burn, and burning efficiency, combustion efficiency is very, very fast in that.

You know what is the problem there? Because when you are sending very, very fine particles combustion efficiency is so strong. So you have the ash also melting into solids. That means temperature control is not there, temperature control.

And in combustion, temperature control also sometimes required. Particularly when you have lot of ash like Indian coal. Indian coals have lot of ash. So those ash will come together and then they melt and then they form solid rocks. Because ash is silica.

So that is why, and I have seen one problem particularly in Neyveli, we have a place called Neyveli here. They have Neyveli Lignite Corporation. Ok that is one of the deposits we have in the country, largest deposits in the country, in Neyveli. So they have been digging for so many years now.

And one problem what they told me was that, they also tried to do something on that. So they have this ash fusion and it seems that particle size will become half meter, half meter and it will stick to one side of, they were using pulverized combustors, Ok, that means simple tube, right and then they spray and they put also lot of heating, you know, the water coils inside. Because idea is to produce the power.

How do you do? In this combustor you put the water, right? So that will become steam. So that steam will go to turbine and the turbine is attached to generator. Then only we will get all these things here. Right. That is why, that is what they were doing there and unfortunately in that lignite what they have is F e S 2.

So this will become now, again it will make the ash to further melt at lower temperature in the presence of this F e S 2, let us say this melting temperature of ash is around 900 degree Centigrade. This will bring to around 600 degree, 700 degree itself. And unfortunately this F e S 2 is part of this coal, lignite. They have to eliminate that. They could not eliminate.

I mean I suggested something. It worked well but I do not know whether actually in practice they are doing or not, we do not know. Yeah so then, this big half meter diameter stone after forming slowly starts attaching to one side and then it becomes bigger and bigger and bigger. So no more that weight can be hold by this, you know that surface attachment, then it will fall.

Where does that fall? That falls happily on the tubes, internal tube, water tubes. So they break. Then our power goes. We will not have power. And it seems to cut that, it is not that easy. I think biggest hacksaws also you cannot use, mission type you know, hack saws also you cannot use to cut it seems. They starting breaking and then cutting and then finally somehow they removed. That is the problem what they have.

So that is why in all these things you know, that is also, because you should know all these, different combustors and combustor is a beautiful non-catalytic reaction. So that is why I can pull a particle there also. But the kinetics and what we are going to learn, the kinetics part is same for any kind of reactor.

But only thing is that k g value will change. If it is a fluidized bed, k g value is different. If it is moving bed, the k g value is different. Because k g value depends on what is called hydrodynamics. Hydrodynamics means how the phases are moving in the system. In the fluidized bed how the phases are moving?

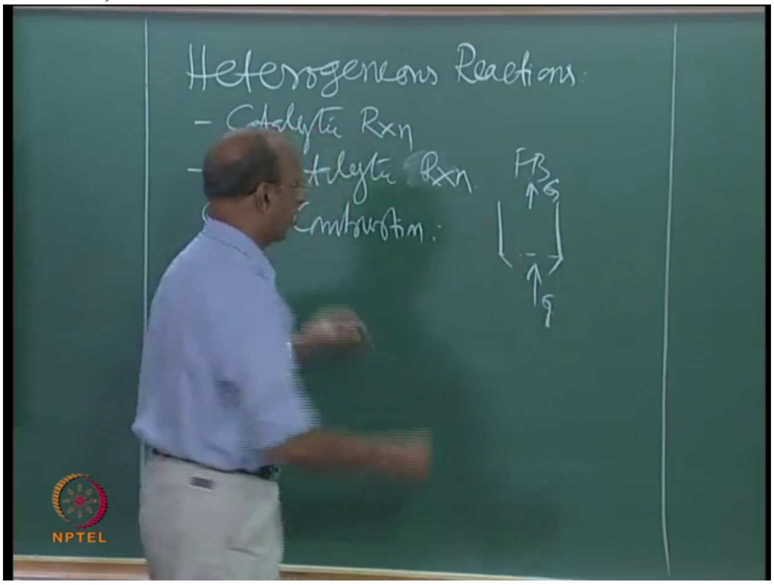
Solid will jump up and down, like this, like this, like this, anywhere it is a mixed flow, particles. Particles can be imagined as mixed flow in a fluidized bed. Right, so that is why, the definition of mixed flow is this particle can be anywhere anytime, right and even it can come outside also if it is continuously feeding, anyway. Continuously I am feeding; continuously it comes out, right?

But now you see, its mass transfer will be, around that particle will be totally different than compared to packed bed where packed bed is just sitting there. Particle is just sitting. Even moving bed. What is the problem? Moving bed, the entire bed, you know packed bed is slowly moving. It is not very fast moving, in moving bed.

So and then the oxygen is going in the opposite direction, counter current if I take, so that is why the mass transfer again between gas phase and solid surface is different. Those are the things only different. Same thing, yesterday also I told catalytic reaction. It is same thing again, right. Catalytic reaction we also talked packed bed, fluidized bed, moving bed all these beds can be used there also. So that is what you have to be more careful, Ok.

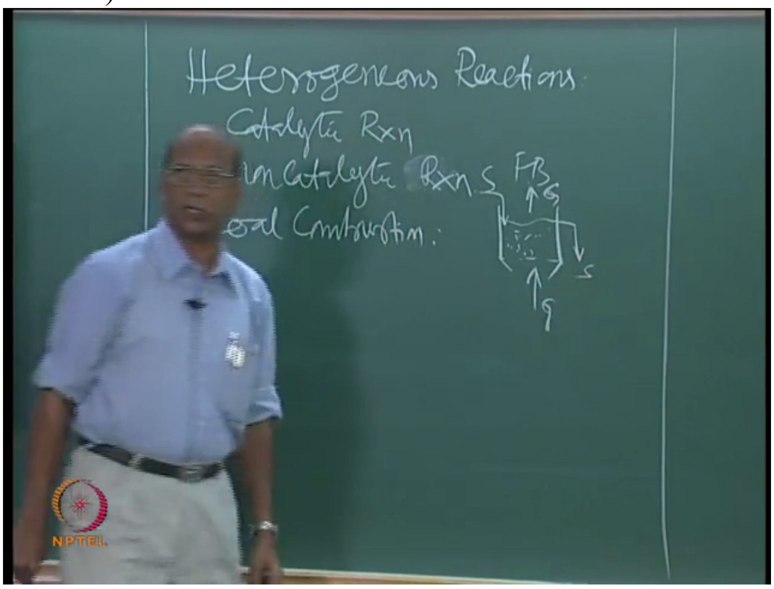
Coal combustion, I just take fluidized bed F B, gas is coming out, this is gas with oxygen

(Refer Slide Time: 20:12)



and all that. Solids are continuously fed and ash is coming continuously, that is also

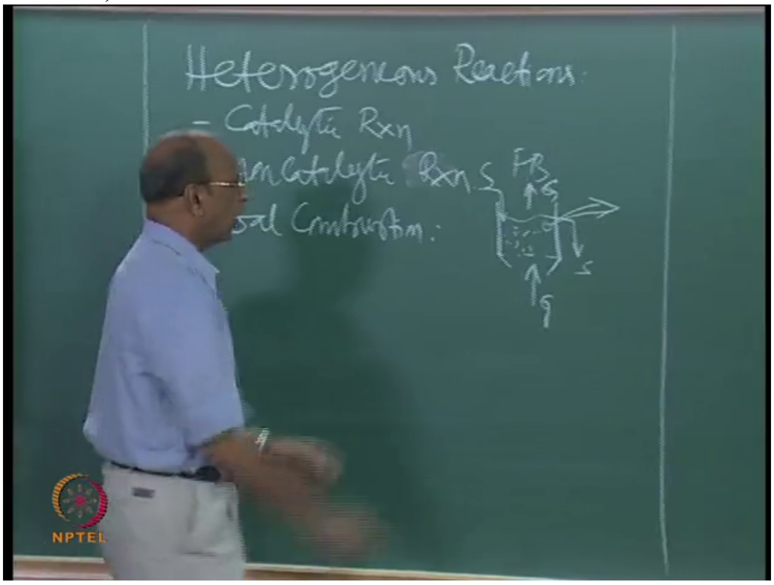
(Refer Slide Time: 20:20)



solid, right. So what I do is one particle I will just pull out, right.

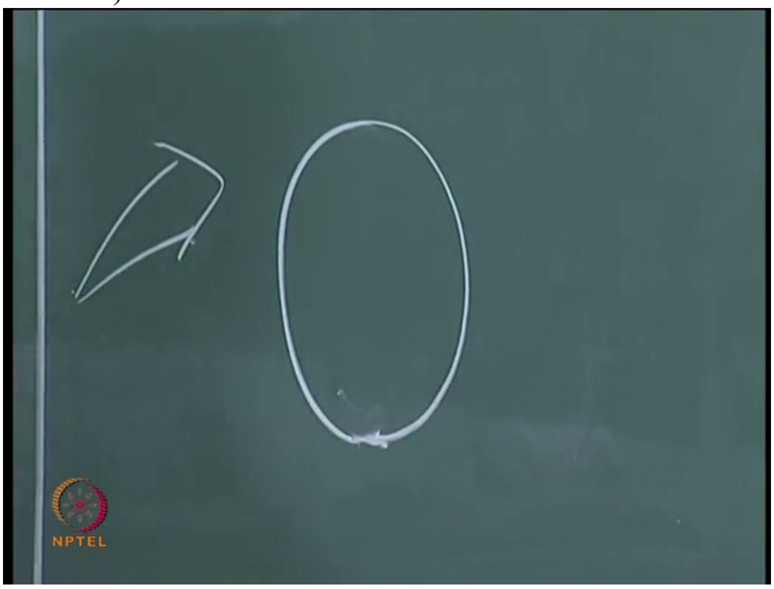
So if I pull out and

(Refer Slide Time: 20:31)



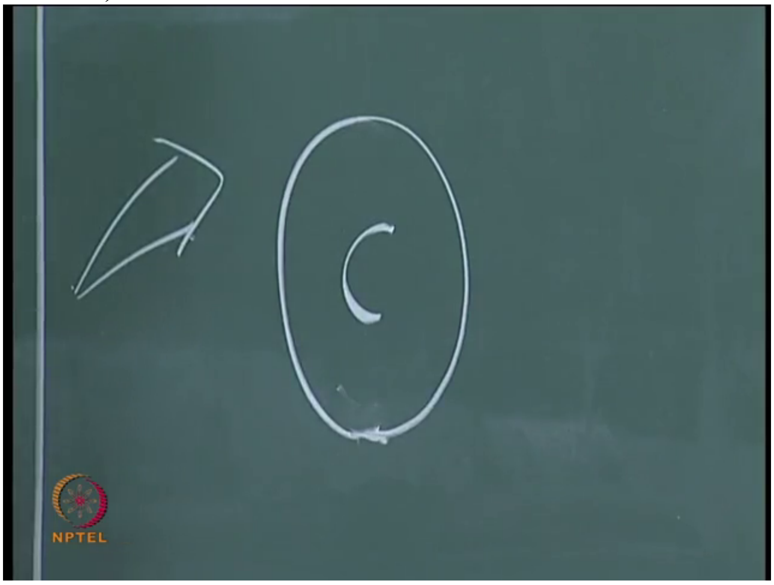
bring that one here, Ok that same thing if I bring it here, now I can imagine, I have a not so, you will never have so nice particle because in coal digging and all that, you know

(Refer Slide Time: 20:48)



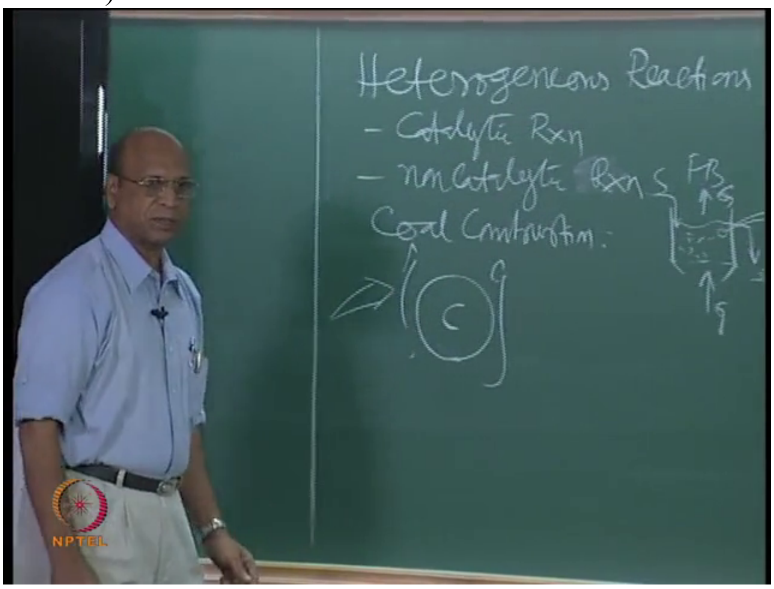
mining you will never get that kind of particle but anyway, for academic purposes this is the coal particle.

(Refer Slide Time: 20:54)



And around this the gas is moving. That also we know. So we have this kind of gas

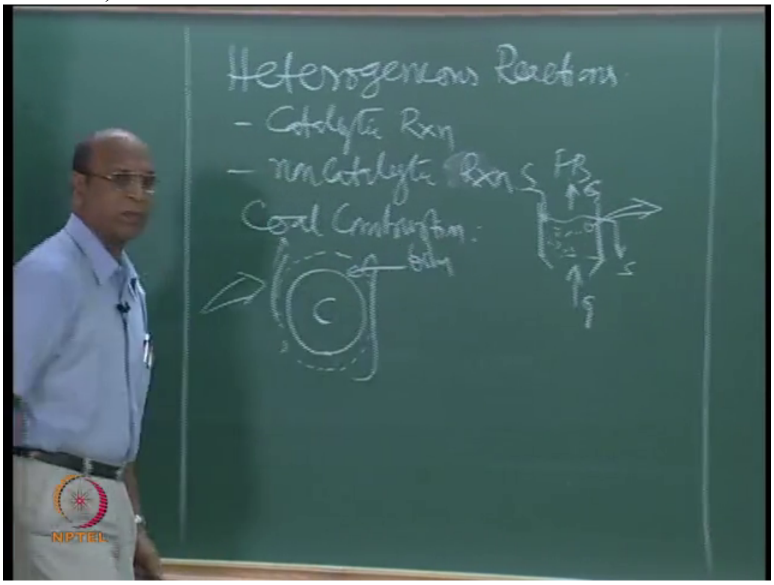
(Refer Slide Time: 21:02)



going around that.

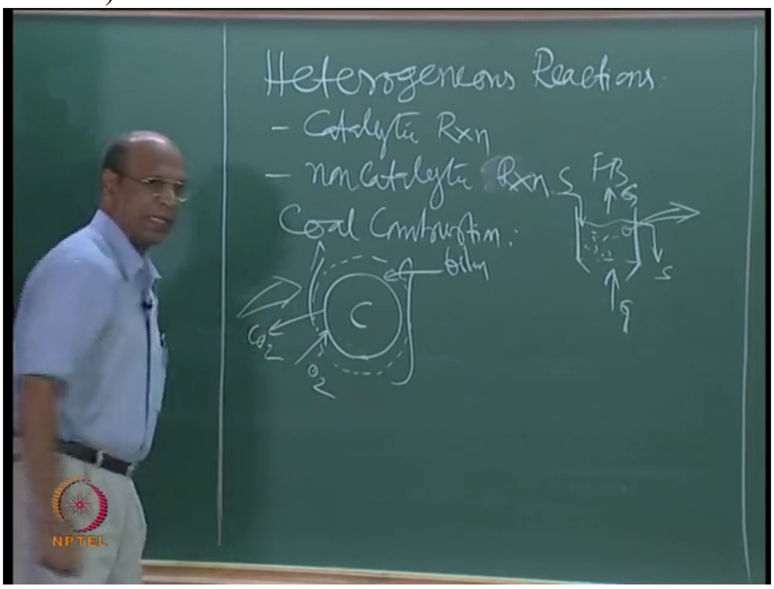
And the fluid mechanics will tell me that I have a film around that. All these things are already known to us.

(Refer Slide Time: 21:14)



Film, right and then through the film oxygen has to enter, and out of the film C O 2 assuming that

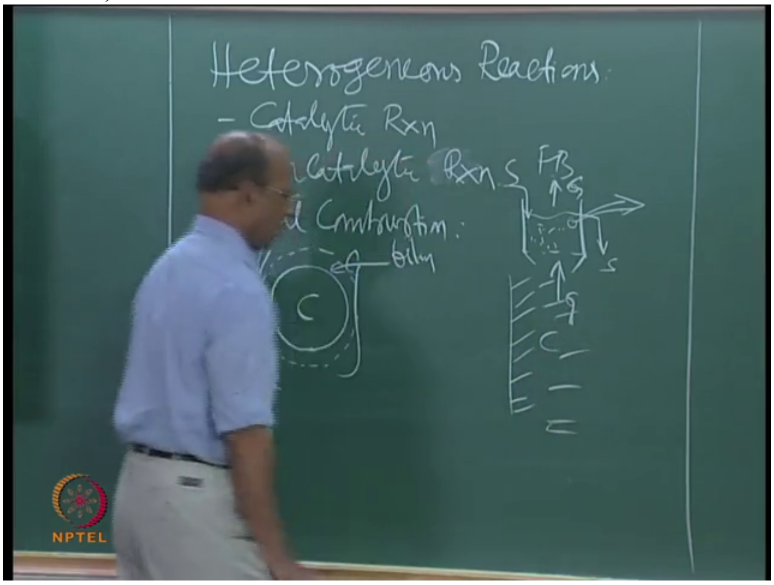
(Refer Slide Time: 21:28)



only C O 2 is the, the gaseous product. Ok, that comes out.

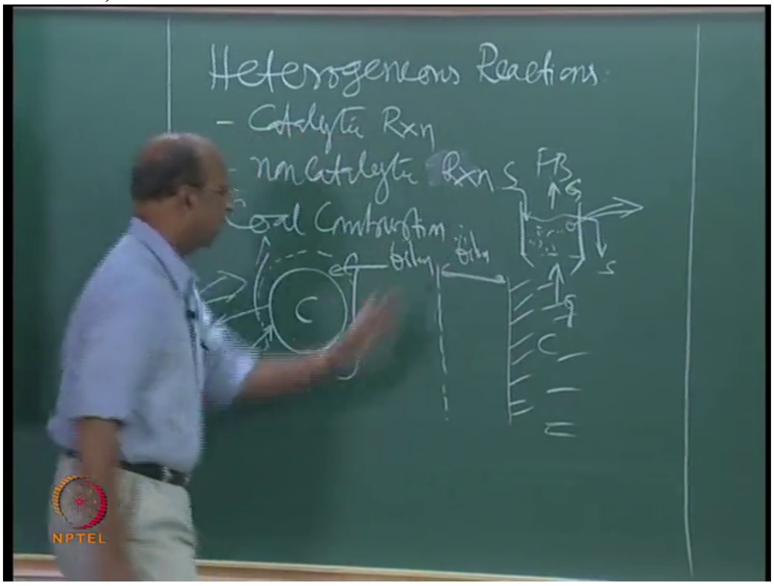
Now so and this also I can imagine. That I have the solid surface, this is carbon.

(Refer Slide Time: 21:41)



Ok because the combustion starts only first on the surface, right? Ok, then I have here film, exaggerated, Oh my God! I thought I had so many things today.

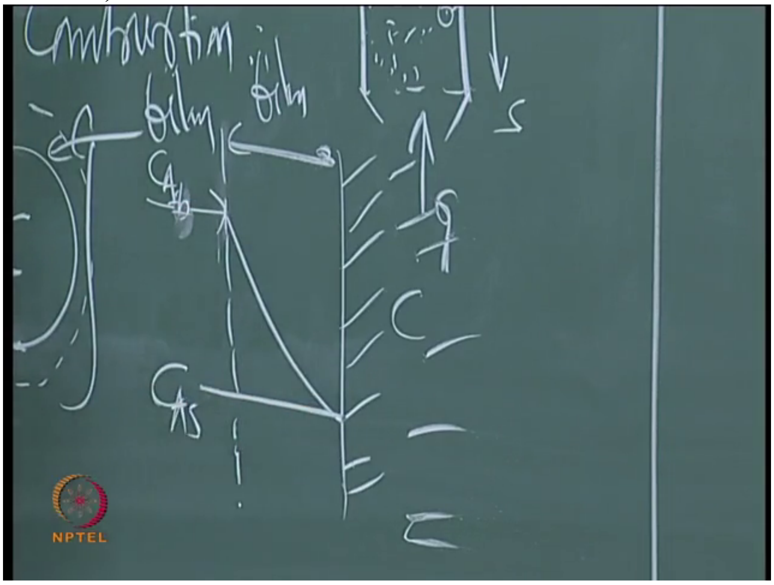
(Refer Slide Time: 21:56)



Yeah, good.

So now if I plot oxygen concentration, this is, again I can call C A g or C A b whatever, Ok, so I think I will call C A b like yesterday. Good that is C A b. Now on the surface, this is C A s.

(Refer Slide Time: 22:19)

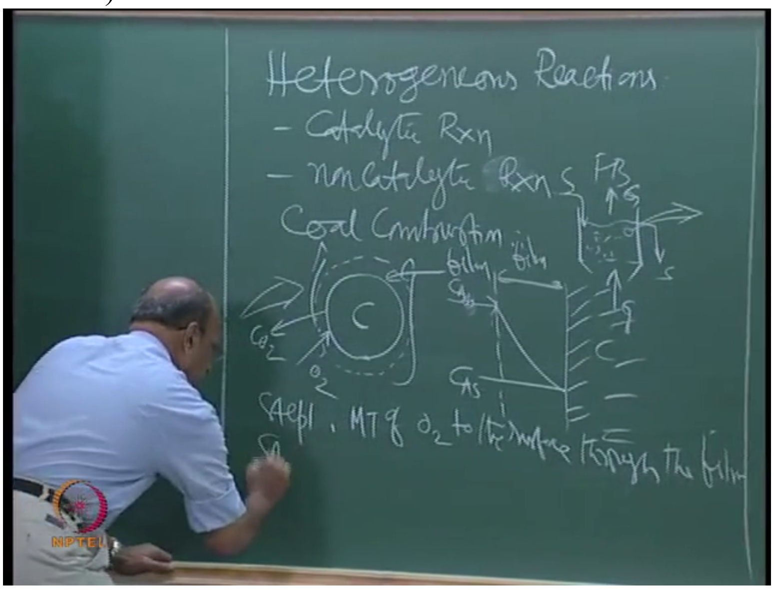


This is what is the picture. Correct no?

I have a particle, around the particle, oxygen is going. Not only oxygen, other gases are going. But our interesting compound is only oxygen because C O, C plus O 2 giving me C O 2. My reactant is O 2. So that is the reason why we take C O 2, right? Yeah. Then what is step 1?

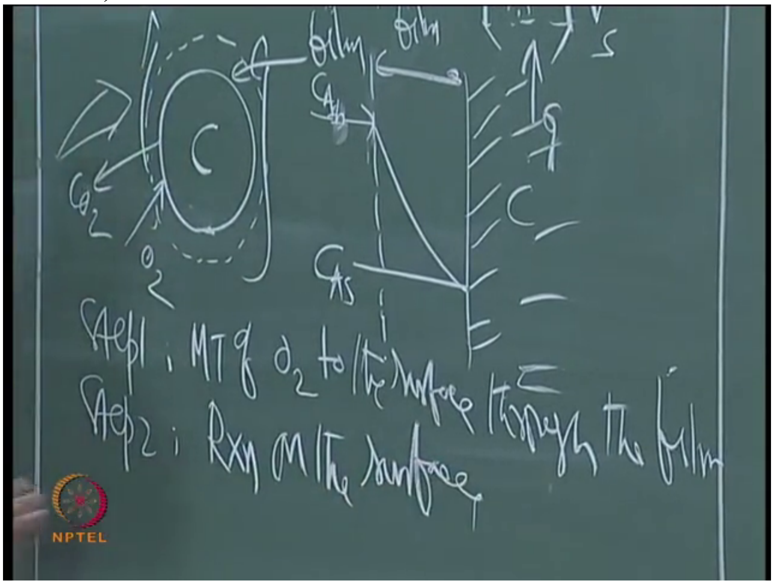
M T of O 2 to the surface through the film, correct? Through the film, good? Yeah. Step 2,

(Refer Slide Time: 23:03)



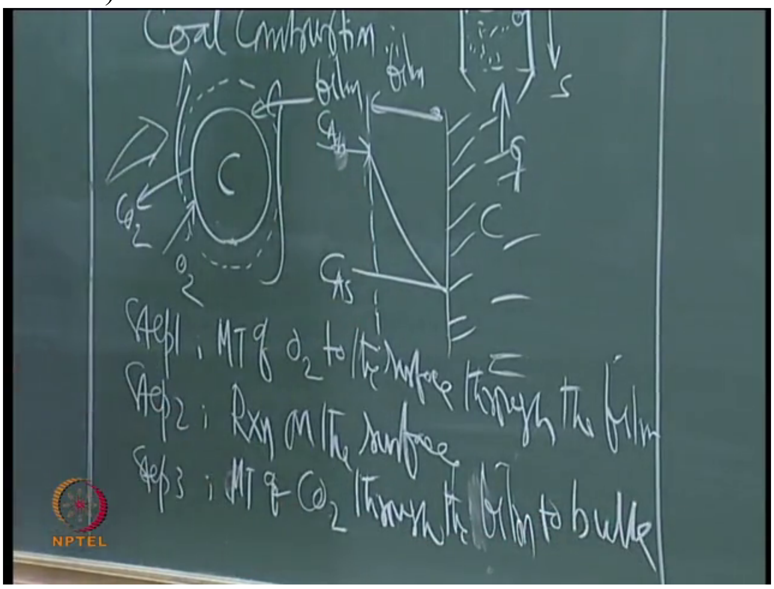
reaction or combustion on the surface. Reaction on the surface. Step 3,

(Refer Slide Time: 23:11)



the product gases coming out. C O 2, mass transfer M T of C O 2 through the film, through the film, to the surface, sorry to bulk.

(Refer Slide Time: 23:40)



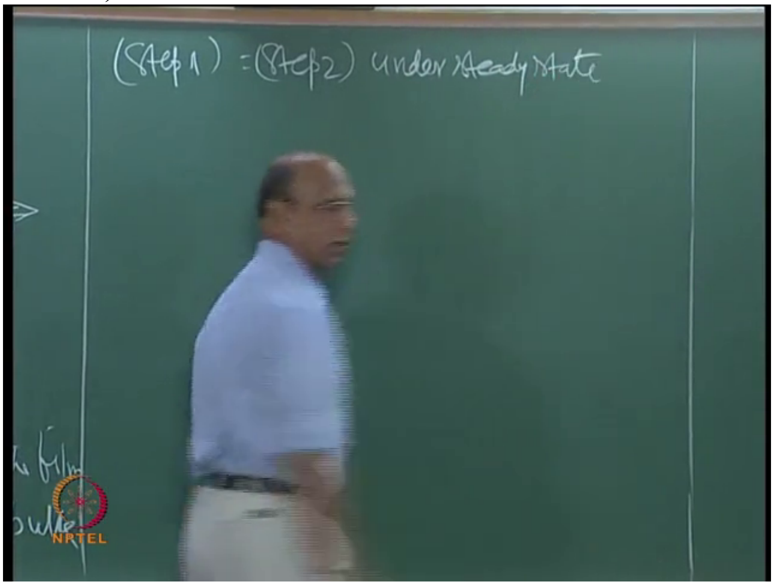
Ok.

So under steady state conditions, Step 1, step 2 and step 3, all three are equal, good. So now, again as far as kinetics are concerned, will step 3 change my rate of reaction? This could have been very good also, if the reversible reaction is possible, we will also get some carbon out. Ok. C plus O 2 giving me C O 2. If it is reversible reaction, C and O 2 again decomposed to give O 2 and carbon. But that is not possible. That is not the reversible reaction.

Ok so that is the reason why now you can neglect this. Because we are neglecting, please remember that concept, Ok. What is the concept there? The third step is not really changing our rate of reaction. If it is reversible, then automatically, Swamy, Ok. The third step is not participating in the rate of reaction. That is why it cannot change rate of reaction.

So that why only these two steps are, step 1 and step 2 are, step 1 must be equal to step 2, step 2, under steady state conditions. Ok,

(Refer Slide Time: 24:56)



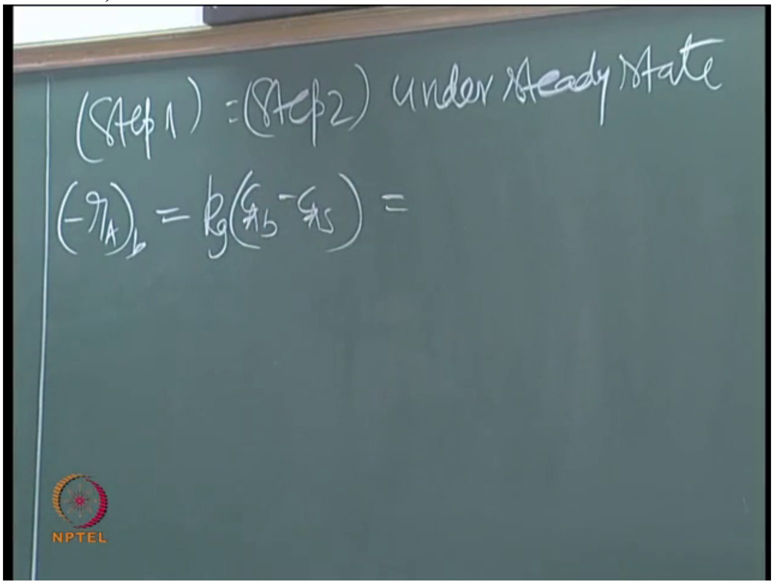
good. What is step 1? Mass transfer through the film. What is the equation now? Ok minus r A b have written, o b r, observed. Yeah we have observed rate, we have global rate, we have bulk rate, all that is there. What did I write?

(Professor – student conversation starts)

Student: b

Professor: b. So this is equal to, in terms of equations, so this is k g C A b minus C A s. And again we have an assumption here. Ok, yes.

(Refer Slide Time: 25:30)



Student: 0:25:31.7 there cannot be 0:25:32.6.

Professor: What do you mean by taking care 0:25:36.4?

(Refer Slide Time: 25:37)

Student: You are neglecting...

Professor: Step 3 is neglected because that is not affecting my rate. When should I?

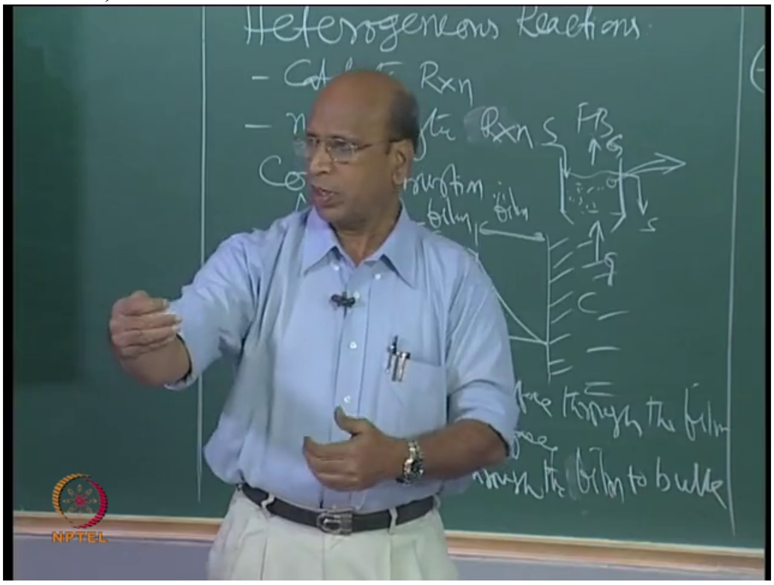
Student: This you have to consider too much when you are 0:25:47.3

Professor: Yes

Student: Then like non-reactive C O 2 will react with the particles.

Professor: Yeah, but under steady state condition whatever is possible only, it is diffusion of C 0 2 coming out

(Refer Slide Time: 25:57)



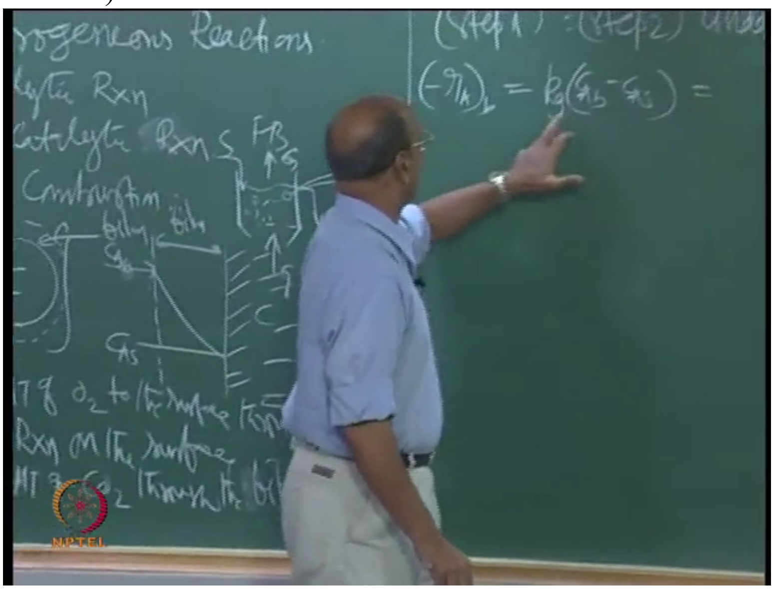
and the diffusion of O 2 going in, right, a balance between those two only will give me what? k g. So k g will be affected, that is all under steady state conditions.

(Professor – student conversation ends)

That is why we assume we have equimolar counter diffusion or if it is not possible we have to go for multi-component diffusion, Ok. So that is why, under steady state conditions, I have a k g and how do you get k g? You know, that I will come to that later, how do you get k g. Ok, yeah.

So then

(Refer Slide Time: 26:28)



k g, yeah that is the reason it is not affecting, right? But in the diffusion-wise you will have some dynamic equilibrium between C O 2 coming out and O 2 going in. And that results in some kind of diffusion. And you know the relationship between k g and diffusion coefficient?

(Professor – student conversation starts)

Student: D a v by R 0:26:48.4

Student: Film theory, Sir?

Professor: Film theory, we are talking about, yes?

Student: D a v is proportionate to R

Professor: Proportionate to?

Student: D a v

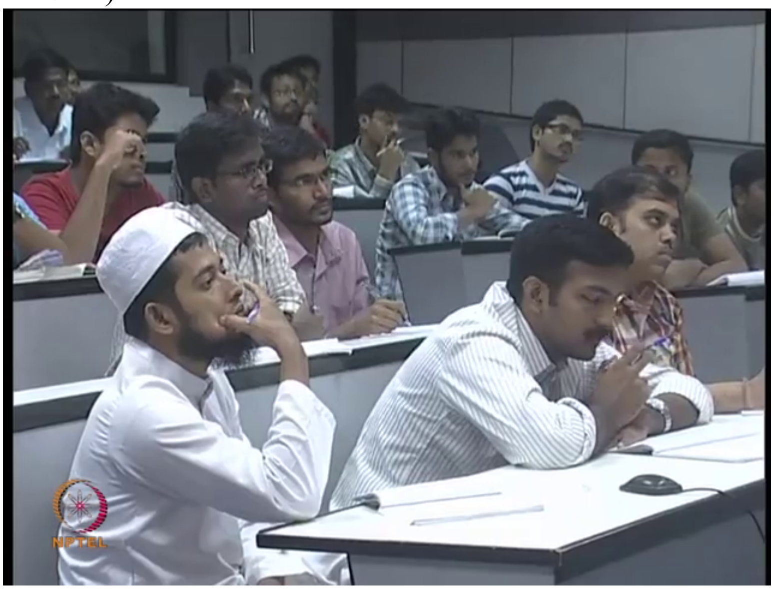
Student: Root D a v

Professor: In film theory?

Student: Directly proportional to

Professor: What is the proportionality constant?

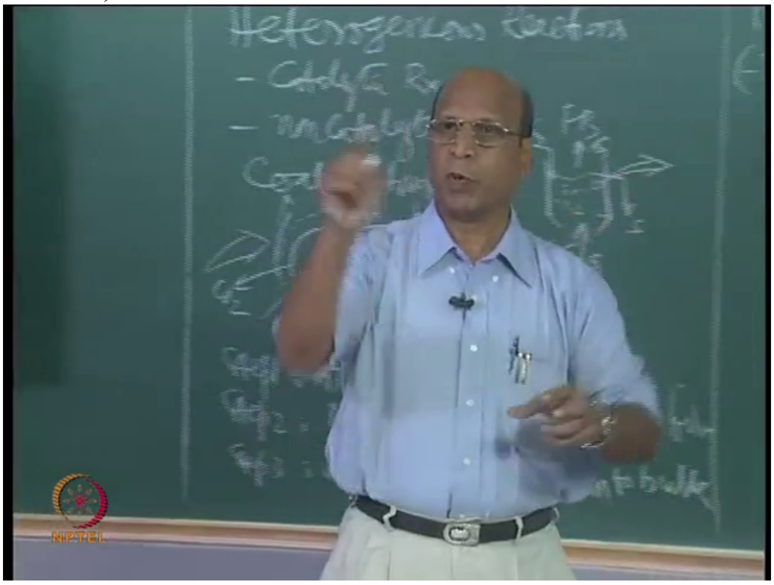
(Refer Slide Time: 27:03)



Student: 1 by k

Professor: What k? You have again k g. Diffusivity; k g is proportional

(Refer Slide Time: 27:11)



to D, what another k you are talking?

Student: No but

Professor: Not even one know about this?

Student: 0 point 5 2 7

Professor: Yes?

Student: Delta 0:27:23.4

Professor: Excellent, what delta?

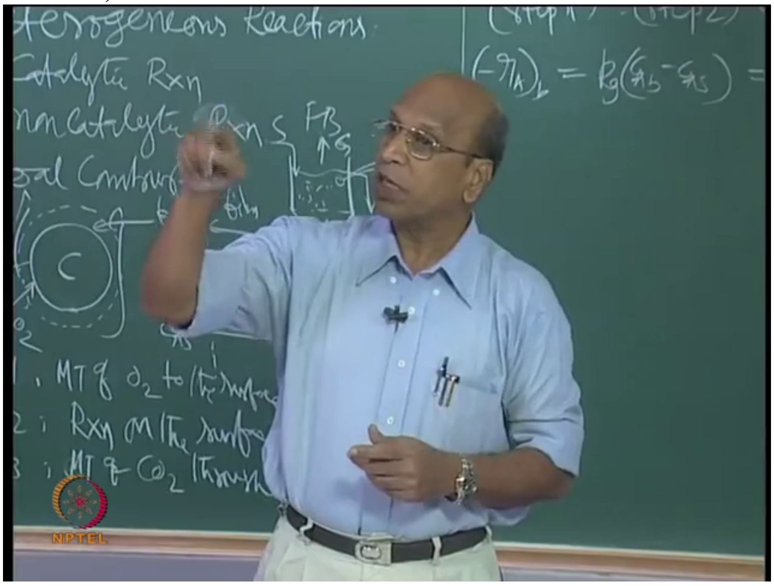
Student: Thickness, volume.

Professor: Yeah.

(Refer Slide Time: 27:27)

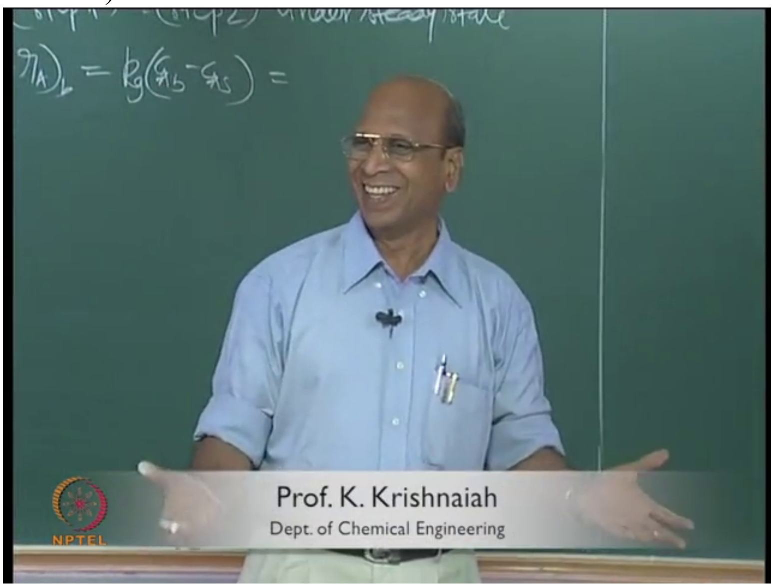
You have diffusivity

(Refer Slide Time: 27:29)



by delta equal to k g under simple film theory. Oh my God! How many, three courses of mass transfer, 2 courses of C R E, 100 courses of Fluid Mechanics, I think (laugh).

(Refer Slide Time: 27:45)



Yeah, it is simple I say. D A v by delta where delta is the thickness of the film.

(Professor – student conversation ends)

And why we are not measuring that? Because no one can measure the thickness of film. So that is why, k g is an empirical equation. You measure. It is an experimental based equation. That is why you have many correlations for k g in terms of which number?

Sherwood number. Sherwood number equal to k g D by D A B, the diffusivity coefficient there. Because you are converting that in terms of dimensionless quantity. That is why that D A B comes there, Ok. So that is why k g is terms of most of the time, correlations, the reason is, theoretically one theory, film theory tells me that D A B by delta equal to k g.

And we also have other theories. In Penetration theory only I think it comes as square root. Yeah. Some other theories are there. It will come to order 3 point 2, not order 3 point 2, yeah, point 6 or many things are there. Yeah, Surface Renewal theory, you know these 3 only we know. But there are combinations of Surface Theory and Penetration Theory together. There are many, some 4-5 theories. But these 3 are famous. What is that, film theory?

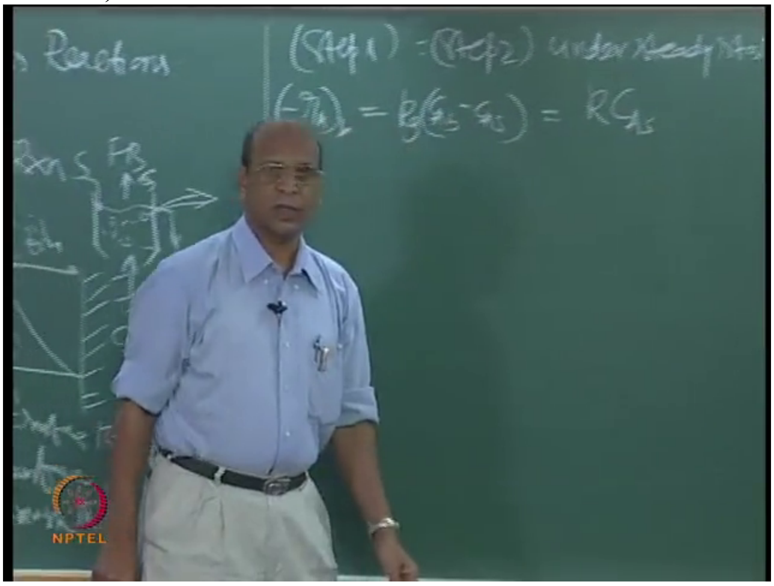
(Professor – student conversation starts)
Student: Penetration theory
Professor: Penetration theory and?
Student: Surface Renewal theory
Professor: Surface Renewal theory, Ok. And you know Surface Renewal theory who proposed?
Student: Danckwert
Professor: Ok and who proposed Penetration Theory?
Student: Higbie
Professor: The name itself is Higbie's Penetration Theory. Ok, who proposed the Film Theory, the first one?
Student: Lewis
Professor: Who said Lewis? Yes. Lewis and Whitman. Lewis and Whitman, these two. These are all our grandfathers I say. You should not forget that.
Student: (laugh)
Professor: You should not forget them. The moment you come to I I T or Engineering, you forget all the people, except may be the nearest people are parents. Ok.
(Professor – student conversation ends)

So that is why I think you know this information also is required. And that is what I am trying to do and I am using time. But if you know all this I think you know, I should have given freedom (laugh). But because all these things not known I have to tell.

Otherwise you know even after this course, I do not know, if you want to remember, you can. But if you want to forget you can always forget. Ok. But as chemical engineers these are the basic things you have to remember.

So this is the one and now I am assuming that I have k into,

(Refer Slide Time: 30:18)



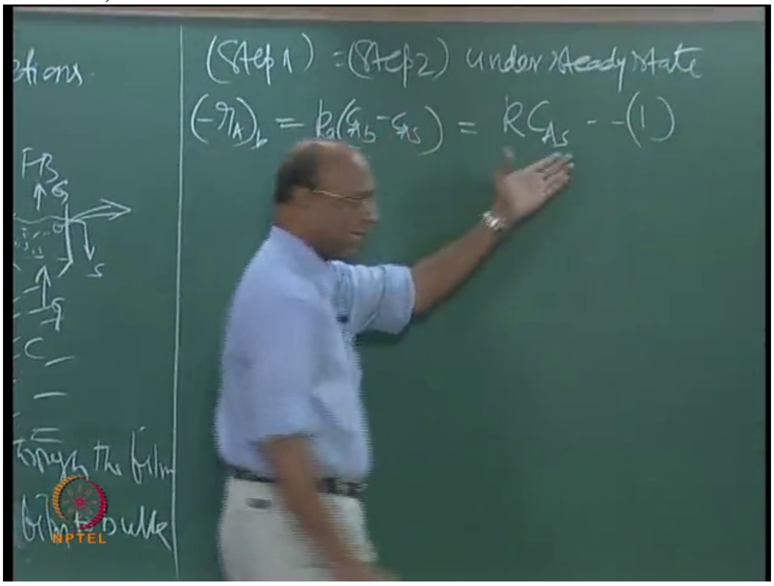
and it is not required only to have here k into C A s. It can be square, it can be cube. It can be another crazy equation divided by another constant plus C A s square but procedure is same, approach is same. What is the approach?

First identify what is the reactor. Pull out one particle. Write all steps, right and then try to eliminate mathematical steps like that. So then try to eliminate indeterminate concentrations which you cannot measure so easily. But bulk concentrations can be used easily.

So that is why we call that as rate based on bulk, Ok, global rate, overall rate. Overall means mass transfer is affecting, reaction is affecting, what is the overall rate? That is why the name overall rate. Global rate means there are many things happening but at global level what is the rate? Bulk rate means bring everything to bulk conditions, temperature and pressure, that means concentration and temperature. So then call that as bulk rate. All these names are existing, right, Ok. Good.

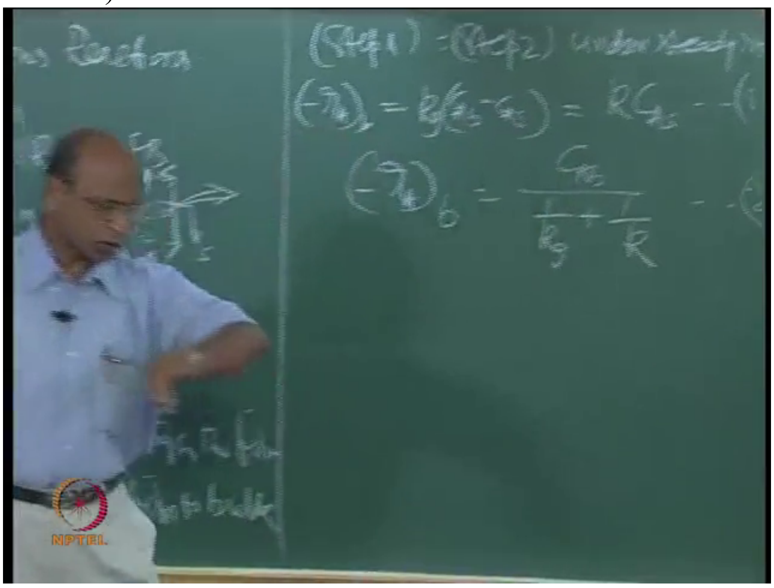
So now this equation you are already masters.

(Refer Slide Time: 31:29)



Exactly same equation only what you have derived in the last class. So that is why the final rate I will write here, C A b by 1 by k g plus 1 by k, yeah. Now I will

(Refer Slide Time: 31:45)

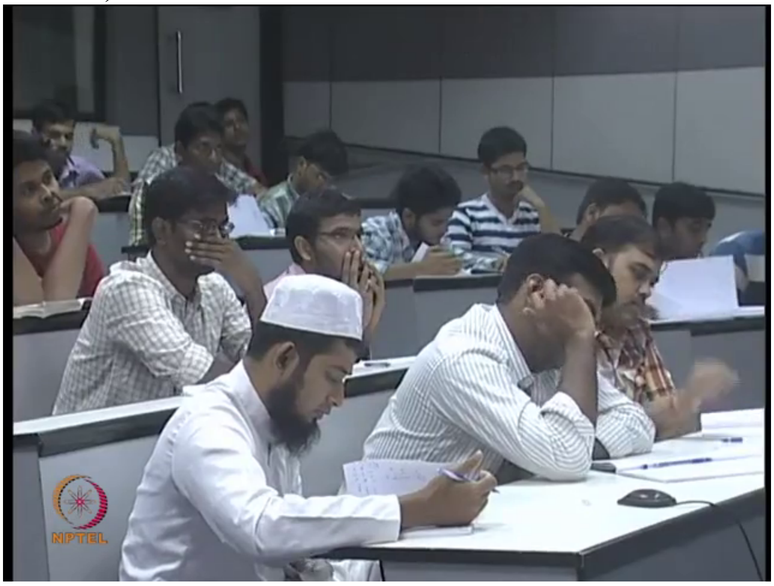


ask you to extend your imagination a little bit further.

Is it exactly same or in this equation there will be something which I have to take care of? It is not that easy for your imagination but still? Nothing. Swami? So nothing is impossible for the imagination, right. But you tell me and you have to justify, why you are imagining that.

You know this is exactly same equation what you get for catalytic reaction, right? But is there any actual difference between this and that? Something, something which you can do, which you have to take into account?

(Refer Slide Time: 32:20)



That means you should now, that is what I have been telling all the time, you have to understand the basis of combustion. What is the phenomena? Why 0:32:31.8

(Professor – student conversation starts)

Student: The surface area of the particle is decreasing all the time

Professor: Yeah. So surface area is decreasing, phase increases. Film is same, film nothing is happening.

Student: Actually in this case, 0:32:50.6

Professor: No, because the temperature is high, you cannot say mass transfer is high. Reaction only we can tell, it is very high. Yes?

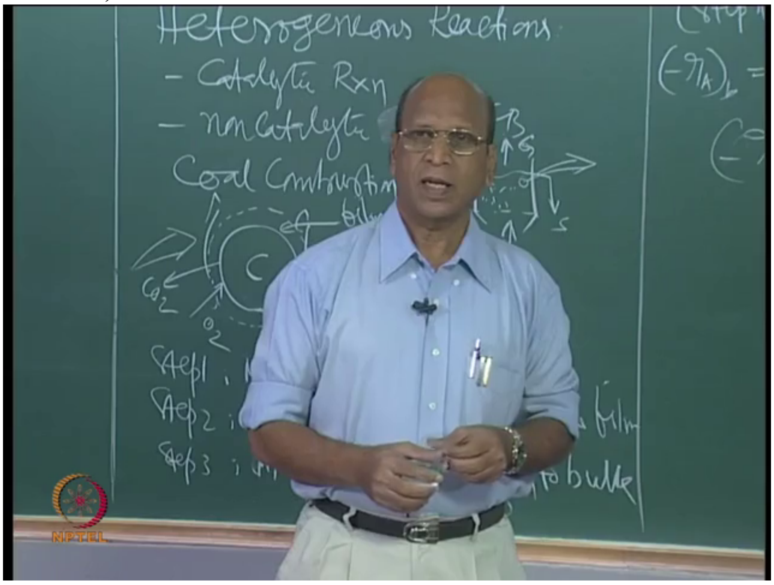
Student: Mass transfer increase k g

Student: Ash thickness increases.

Professor: So ash thickness what do you do?

Student: size decreases.

(Refer Slide Time: 33:05)

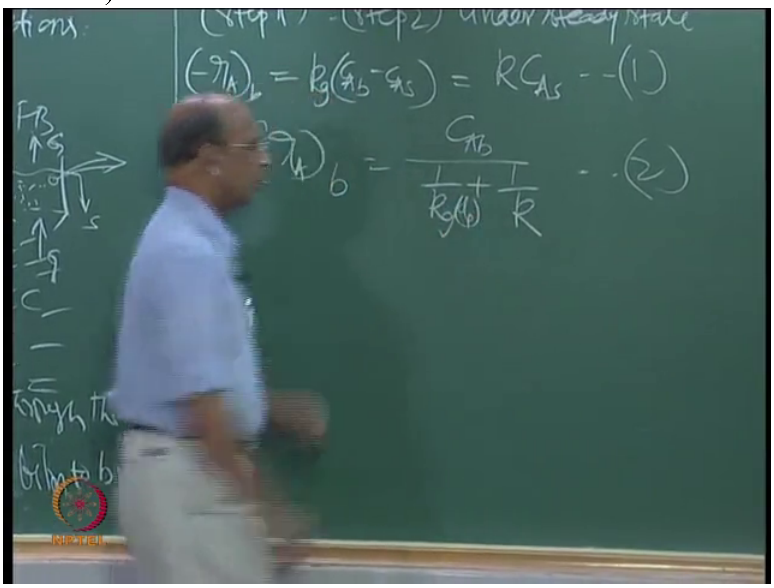


Professor: Yeah, that is what. The difference between this reaction and catalytic reaction is, in catalytic reaction the particle has constant size. It won't change with time. Whereas with time this fellow changes. Ok.

(Professor – student conversation ends)

So this fellow changes and you have to write k g as a function of

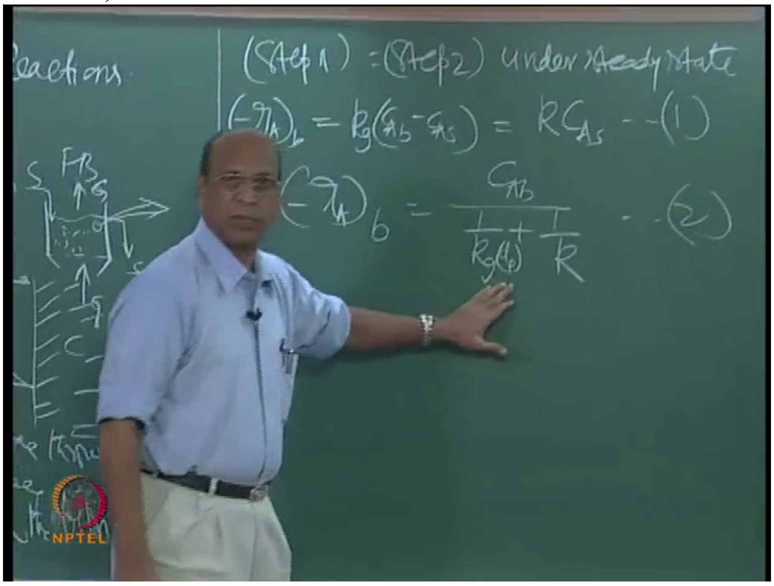
(Refer Slide Time: 33:27)



d p. And d p goes from certain finite value to zero. It disappears totally at the end. How do you take care of this? This can be beautifully taken care of, you know, in non-catalytic reaction, Shrinking Core model and all that, that comes in the next semester. So beautiful that non-catalytic reactor design.

Ok so that is the difference. Because otherwise it is exactly same.

(Refer Slide Time: 33:51)



And how do you calculate mass transfer correlations, the k g value, do you have a correlation if I have, I told you, mass transfer changes from reactor to reactor. Because hydrodynamics change from reactor to reactor.

I will give you the simplest case. Any reactor, you have one single particle hanging. And then equations are available. And you have around this, some gas going; can I now calculate what is the mass transfer in this case? It is also one of the pet questions in GATE.

Single particle mass transfer, how do I calculate? No one? Sorry? It is a single particle; you will have a mass transfer correlation, Ok from a single particle that is from gas to particle or particle to gas, both are same.

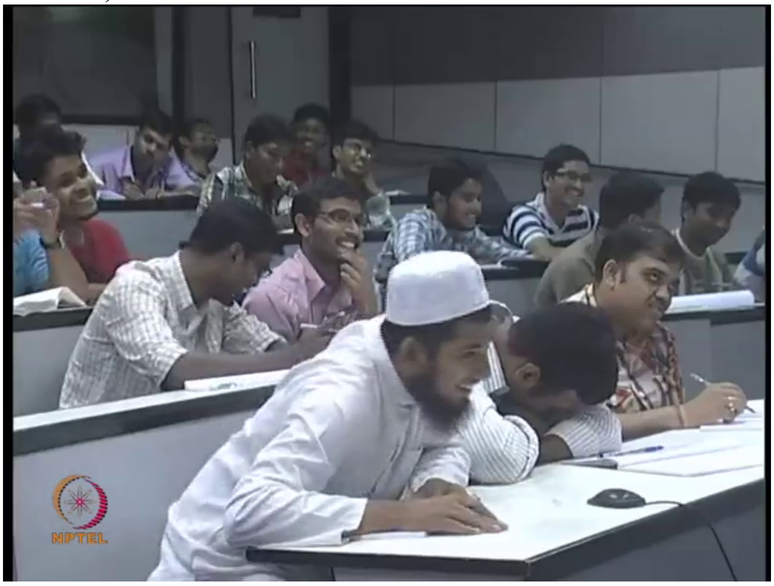
Have you not done a problem with naphthalene balls? You have done it. But only thing is, you have P h D in forgetting. Excellent. You know how many ways you can forget. But I think what we expect you as teachers is you should have P h D in remembering. In how many ways you can remember once it is told? I told you no, one way of remembering, I do that.

Magnetic, what is that haematite and magnetite. I told no, one simple thing, H comes first, haematite so F e 2 O 3. So like that, some thing. And also you have hydrophobic and hydrophilic. Again these words I think you know, how do you remember? You know, hydrophobic, pho, pho

(Professor – student conversation starts)

Student: (laugh)

(Refer Slide Time: 35:24)

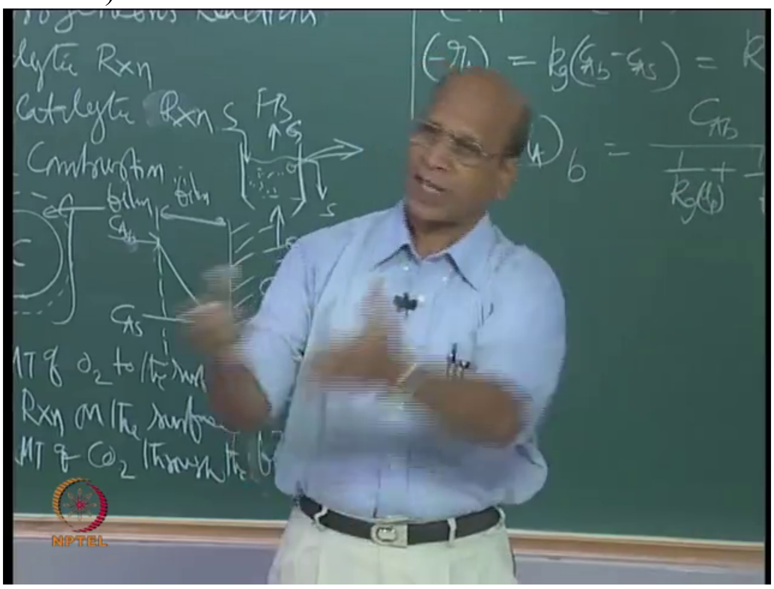


Professor: (laugh) Ok, yeah so that is why I say Ok, hydrophobic do not like, you know water. Right, hydrophilic means

Student: Lic, like

Professor: Happy, like. So that is why, once

(Refer Slide Time: 35:37)

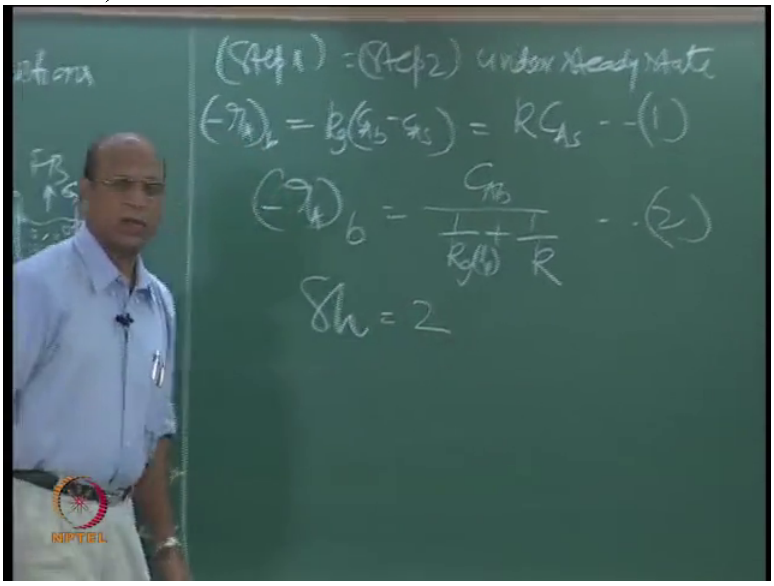


I know the other one I can imagine. Because it is only 2 things no. So like that you have to remember, you know.

(Professor – student conversation ends)

You should have P h D in that. In how many ways you can remember. But now you are experts in the other one. In how many ways you can forget. Ok, somehow I should not remember this aspect at all. Ok, you have done that. Some, I think many; it is a favorite question also for many mass transfer teachers. Sherwood number equal to 2, Ok. Is it always or is it some special case?

(Refer Slide Time: 36:06)



Yes?

Spherical is Ok, yeah. Spherical is one. But under what...

(Professor – student conversation starts)

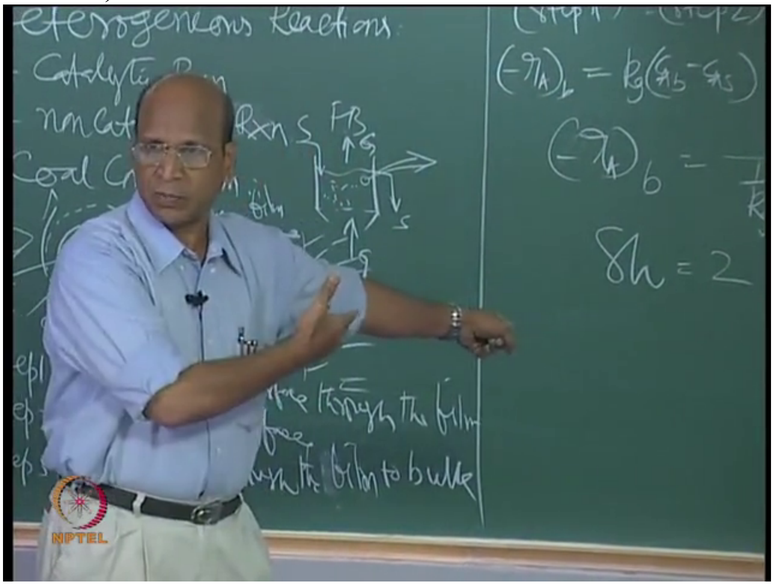
Student: Stagnant

Professor: You have to tell the condition, under what conditions? This is simple diffusion I have told you, no, with lot of things and then stay at the thing. No convection at all. When you have no convection, that means velocity equal to zero, convective velocity, then you have Sherwood number equal to 2.

(Professor – student conversation ends)

This is what I told; this is the GATE favorite

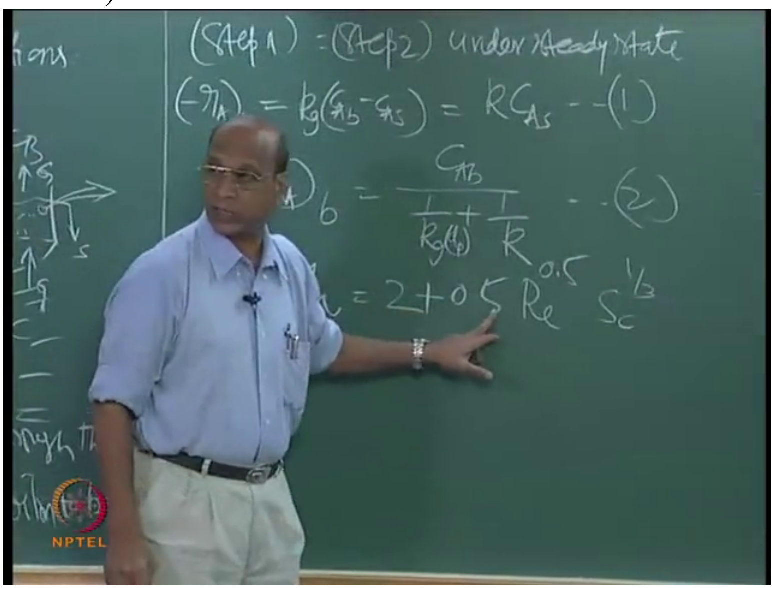
(Refer Slide Time: 36:29)



question, Ok. So that means prove that Sherwood number equal to 2 for a single particle without any, convection equal to zero. Right I may also give. Because reaction engineering cannot survive without mass transfer. Mass transfer also must be there. In homogeneous you may not see, right? Ok.

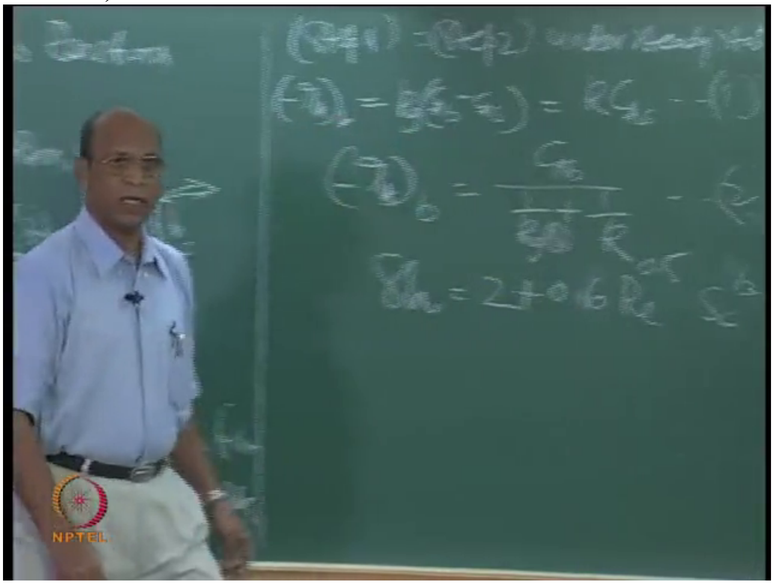
So plus something else is there when you have convection? point 5, Reynolds number to the power point 5, no, not point 6, Schmidt to the power of point 3 3, 1 by 3. What is 6? Oh this one is 6?

(Refer Slide Time: 37:06)



This is point 6, Ok. Yeah.

(Refer Slide Time: 37:10)



You know what is the name of this correlation? Another grandfather, another 2 grandfathers, another 3 grandfathers.

(Professor – student conversation starts)

Student: Ranz and Marshall

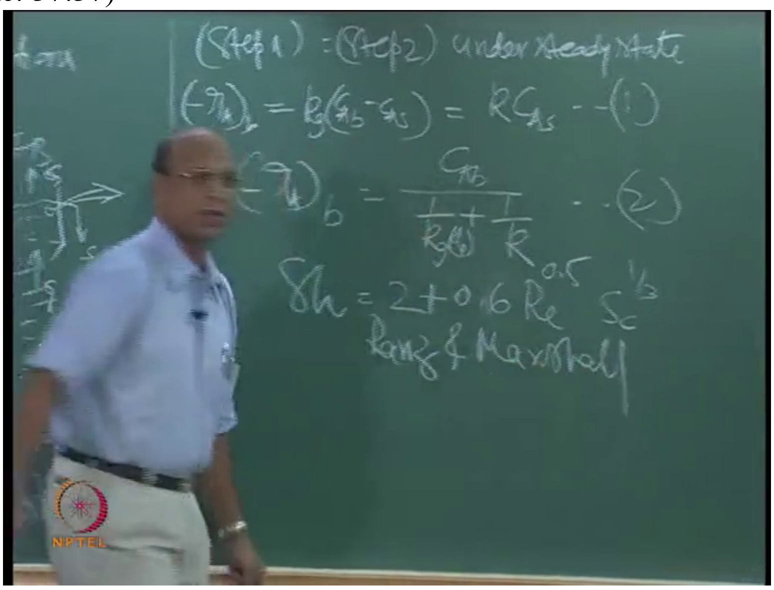
Professor: Excellent. How do you know this?

Student: AC Tech

Student: (laugh)

Professor: Gopinath is trying to catch that, AC Tech. Ok, Ranz and Marshall, that is right. And you know another name for this,

(Refer Slide Time: 37:37)

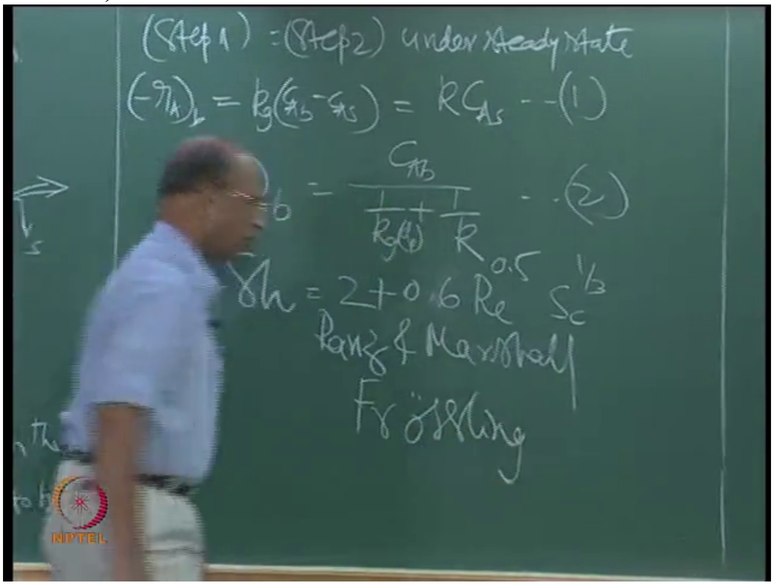


which is in third chapter of...

Student: Froessling

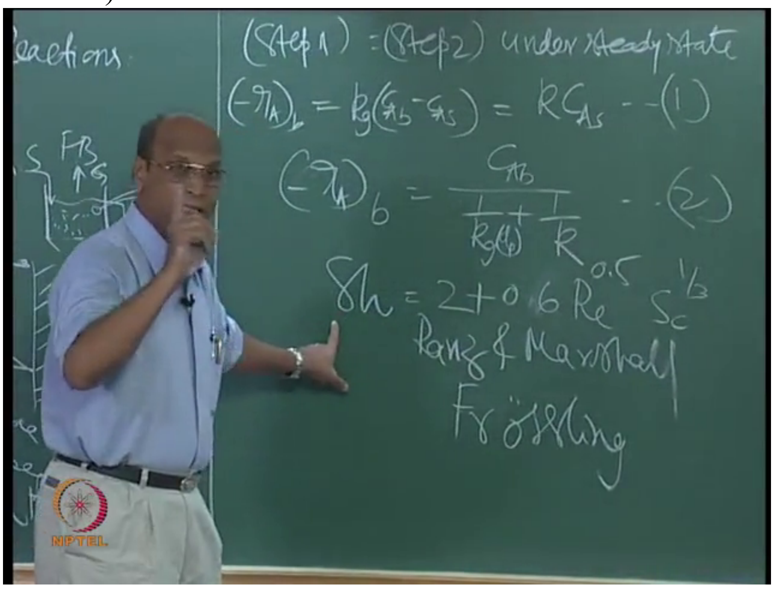
Professor: Froessling. Third chapter no, if you go, exponents may be slightly different, but it is same. Froessling equations. Froessling. That is why

(Refer Slide Time: 37:57)



I said you have 3 grandfathers. Ok. So that is the Froessling equation. So this is what what one equation we use. So if I want to calculate, this is for single particle,

(Refer Slide Time: 38:08)



just single particle, Ok mass transfer. We have similar equation for heat transfer, exactly you have same, similar equation for heat transfer but only thing is this is Nusselt

Student: Prandtl

Professor: This cannot be Prandtl. That is Reynolds again because Reynolds number comes because of the flow. Ok, so that convection must be there. And whereas this is

Student: Prandtl

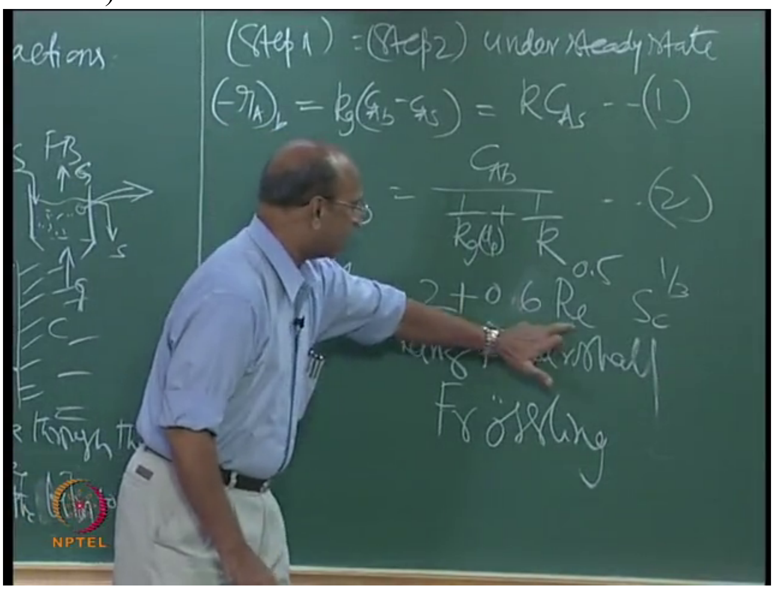
Professor: Prandtl number. Now you remember, you know. How many ways to remember. That is why I told you this.

(Professor – student conversation ends)

There are so many ways to remember. Do not be experts in so many ways to forget, forgetting. Ok, good.

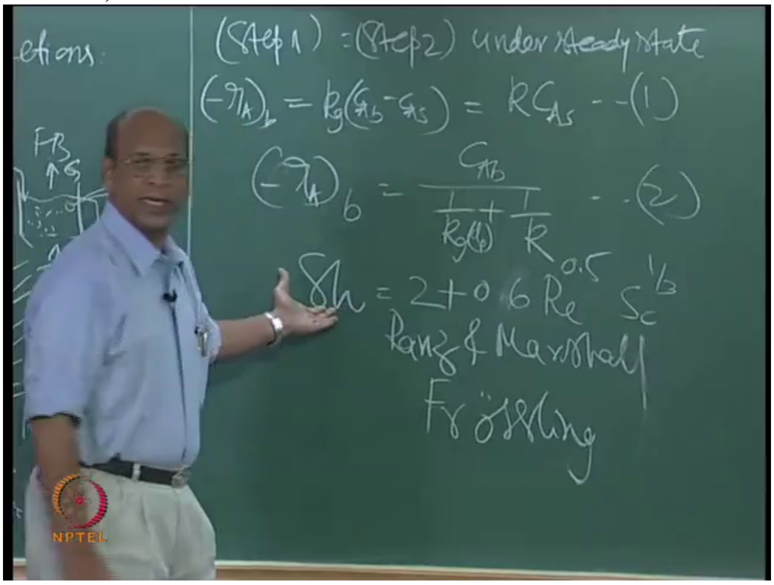
So this is the equation. You can see, as Reynolds

(Refer Slide Time: 38:47)



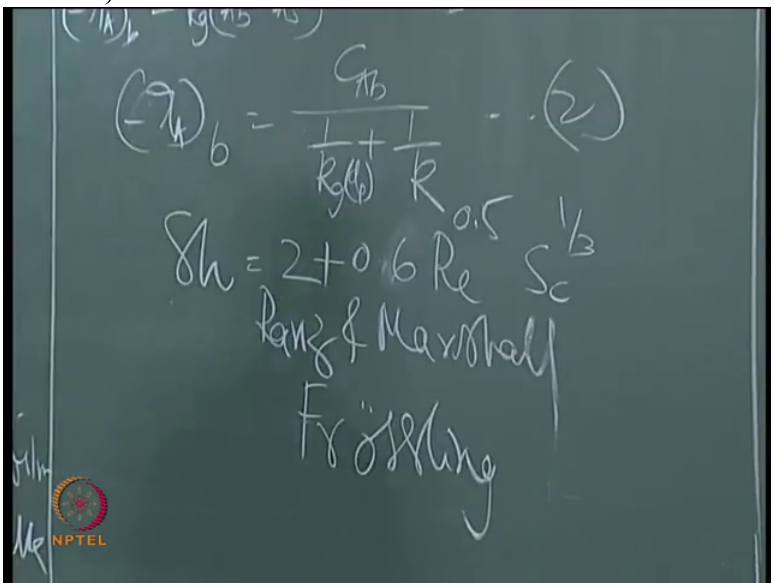
number is decreasing, you know d P is changing size. It is slowly disappearing. So then you can also calculate what will be the corresponding

(Refer Slide Time: 38:56)



k g value and that we have to take care of, somehow inside the one

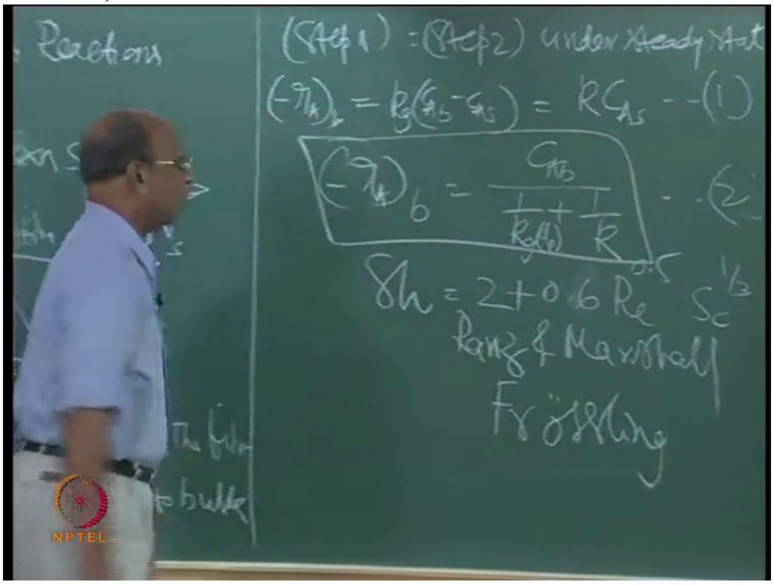
(Refer Slide Time: 39:00)



and I will tell you in the next semester, how to take care of that in the, in the actual design.

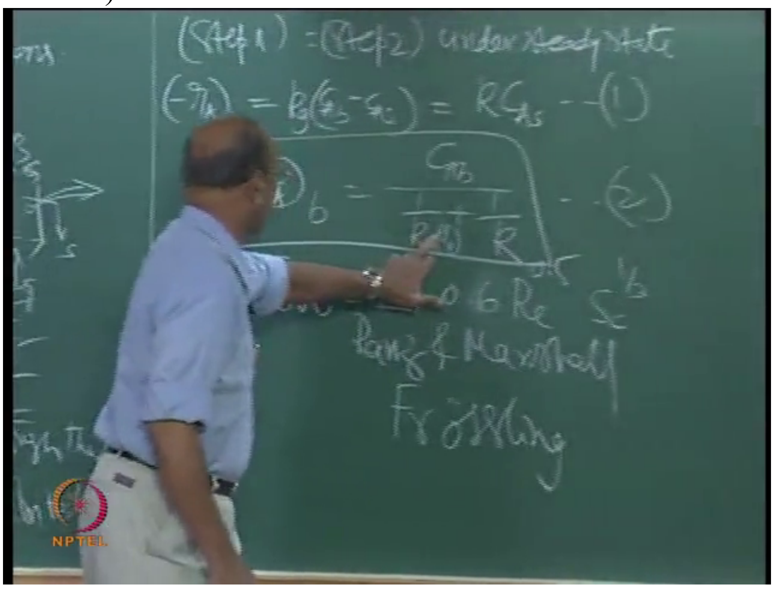
So now I think, idea here is again to have this

(Refer Slide Time: 39:09)



equation as heterogeneous system where k g

(Refer Slide Time: 39:12)



is very important parameter, very quickly. Now you are experts. So now we have many, many systems. Like I have taken only gas-solid, right. We can take gas-liquid system. What do you call gas-liquid system? What kind of reactor do you use for gas-liquid, yeah Swamy, gas-liquid? No what kind of systems you use, systems means equipment?

(Professor – student conversation starts)

Student: 0:39:34.1

Professor: I cannot say reactor, because there may be reaction or no reaction.

Student: Distillation column

Professor: Yes, distillation column is one, right, right

Student: Absorption

Professor: He also told absorption, yeah anything else?

Student: Bubbling, bubblers

Professor: Yeah, bubblers. Bubbling columns, bubble columns

Student: Bubble columns

Professor: Then you can also have simple tank and bubble gas, and you can also have very tall column and bubble gas, yeah

Student: Spray and sprinklers

Professor: Which one you spray?

Student: Spray

Professor: Then you won't get bubbles

Student: Gas

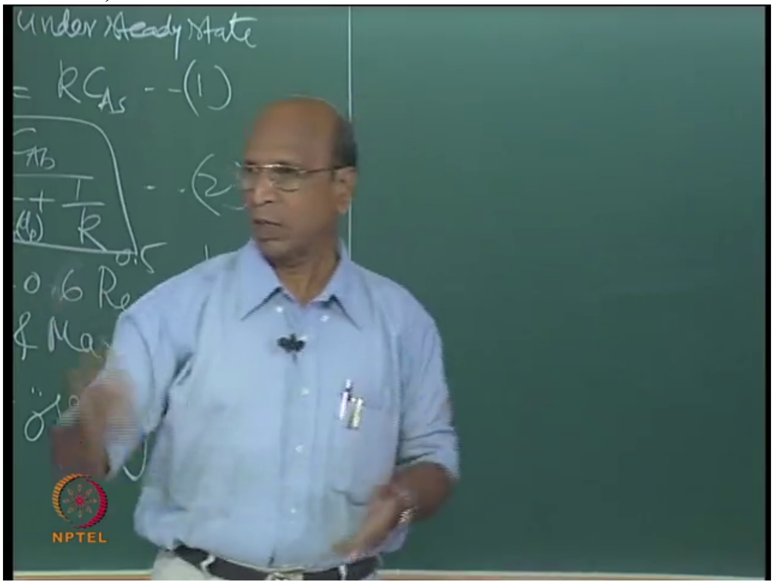
Student: Liquid gas atomizer.

Professor: Yeah, but I think you are sending liquids in the form of droplets. And gas is going. The contact is totally different. What we are talking here is liquid continuous

(Refer Slide Time: 40:18)

and gas is bubbling. Then only you call bubble beds, Ok, bubbling beds or

(Refer Slide Time: 40:23)



bubble columns, right? We have all that.

(Professor – student conversation ends)

And yeah, you also have liquid-liquid reactions, or liquid-liquid extractors or liquid-liquid extractors can also be used as reactors. What is the difference? I have one liquid, continuous, another liquid dispersed, now how the reaction should take place? Same again, imagination, that is why that imagination is very important.

Just imagine how that droplet is moving in continuous liquid. If you do not know, you go home and take kerosene, one or two droplets and put into water. How they move? Right. And you know definitely bubbles how they move. Because that is what many times we did, we see wherever you go, soda when you take or cool drinks if you take, Ok. Then how the bubbles are coming, that we know, right?

So there also I will take one droplet. Around the droplet I have liquid moving. Because one is continuous fluid, I say. The other one is dispersed fluid. Even bubble column. Bubble is moving. Liquid is again coming, whether it is co-current direction or counter-current direction. So bubble is moving and if I sit on the bubble I know that bubble is moving, I cannot see. I can see only liquid is moving around it.

That is also with respect to which coordinate, your coordinate, Ok. That is why you have Lagrangian coordinate, Euler coordinates only for that. You see how many things you have to learn now, right? So that is why procedure is same. Take one droplet and see what is the liquid flowing around. And again film, interface between these two. Where is the reaction actually taking place?

If you have these droplets dissolving in the other liquid and then reacting with the bulk, that is one thing. The other thing is if this liquid is able to get to transferred on this surface, and the reaction is taking place on the surface, and again diffusion of these molecules may also go into the droplets, yeah, droplets with respect to what?

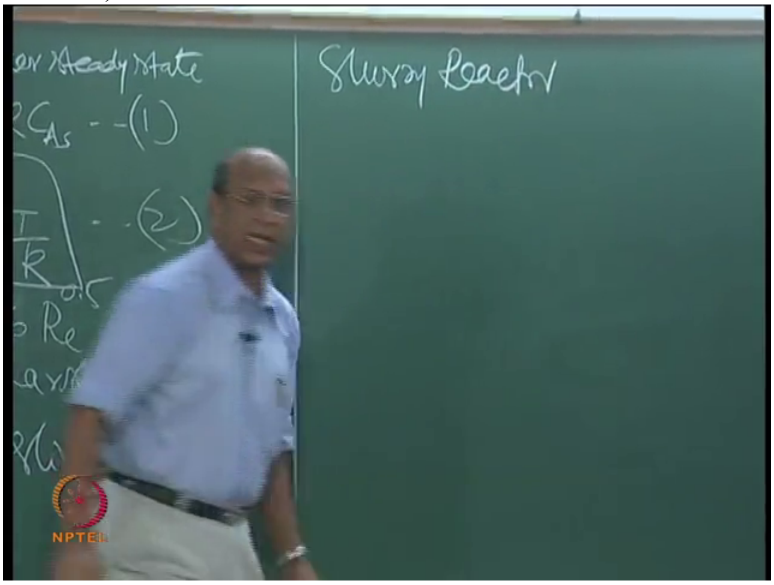
So that is why you have to understand the physical properties of both the liquids, gas and bubble, what will happen in gas and bubble, sorry I mean gas bubble and liquid? Bubble is moving up, right. Again liquid is moving around that. So I have a bubble liquid.

So now imagination easily for this is, liquid-liquid is slightly difficult imagination, is normally this gas will first dissolve in the liq/liquid, in the liquid. Then the reaction will take place. But before it is dissolving, it has to pass through two films. One is within the bulk, within the bubble. Other one is outside liquid film. That is what is absorption, you said.

In absorption that is the two-film theory. Right in absorption, I have the gas bubble. It is getting absorbed in the liquid. But what is the imagination? I have the bubble. Outside I have a film. Because Fluid Mechanics tells me whenever I have 2 phases I will have film. How strong, how small al that later, depending on the conditions.

And inside also I have a film, right? The gas has to first pass through the gas film inside the bubble, touch the interface, from interface to again through the liquid film to the bulk. That is why I now take slurry reactor. Slurry reactor is a three film,

(Refer Slide Time: 43:56)

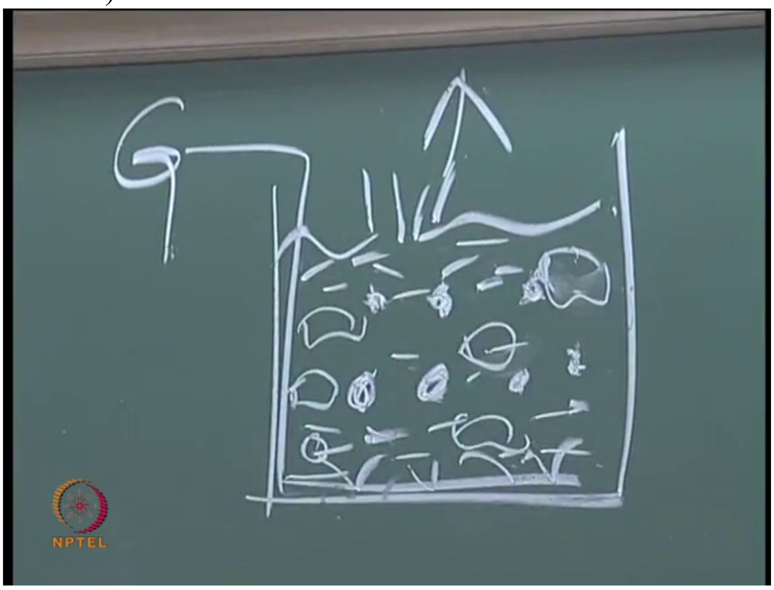


I mean three phase reactor. So we will see these things there.

So again slurry reactor is easy to imagine. Normally you will have distributor here, gas distributor, gas comes out. You have the catalyst particles because it is a slurry reactor, catalytic reactor. Then you have the bubbles. Sometimes you will get very nice bubbles. Sometimes you will get this kind of bubbles. And this bubble exploded. Yeah.

So this kind of bubbles are moving. Here I have this side,

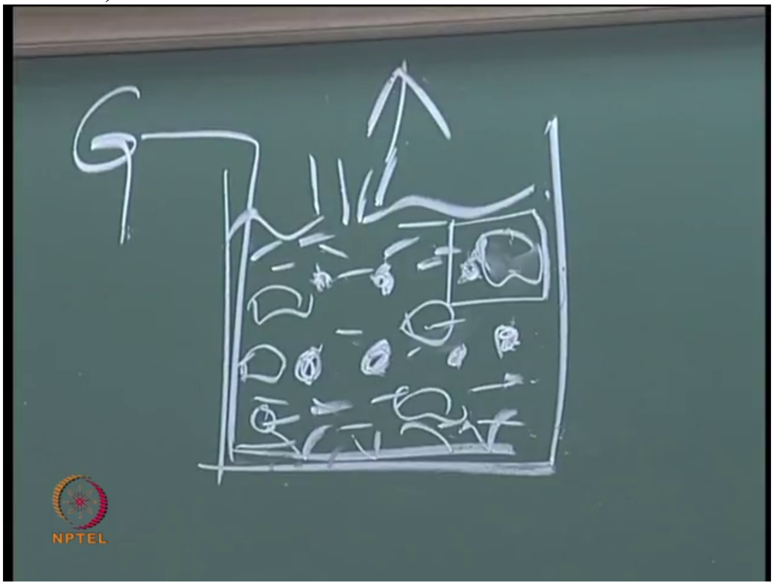
(Refer Slide Time: 44:47)



yeah inside liquid, Ok, good. So now again here, I have to find out the rate of reaction. What is the procedure? Now I have 3 phases. Earlier I have 2 phases and pulled out solid phase and gas. Now I have 3 phases.

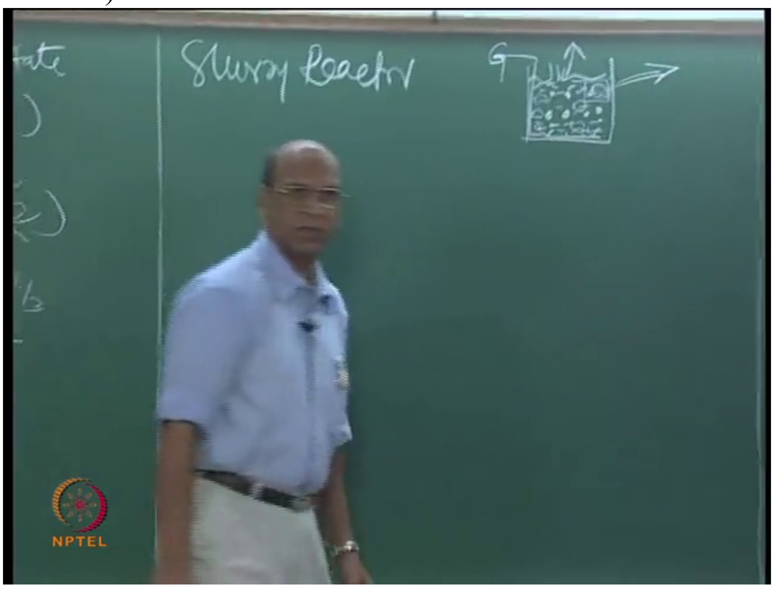
So I have to now see there is one bubble and there is one solid particle.

(Refer Slide Time: 45:13)



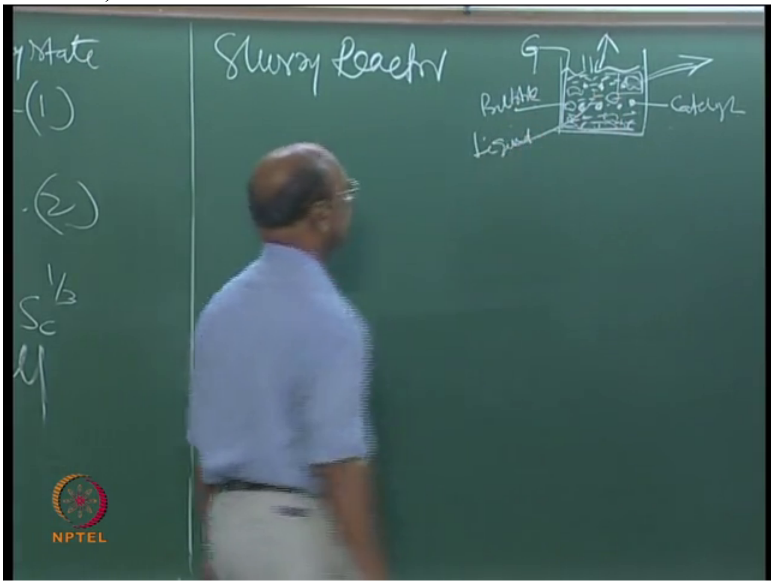
In between definitely there will be liquid. So you just pull out this, imagination.

(Refer Slide Time: 45:19)



One gas bubble, Ok, I have to also write here, this is catalyst, this is bubble and this is liquid.

(Refer Slide Time: 45:37)

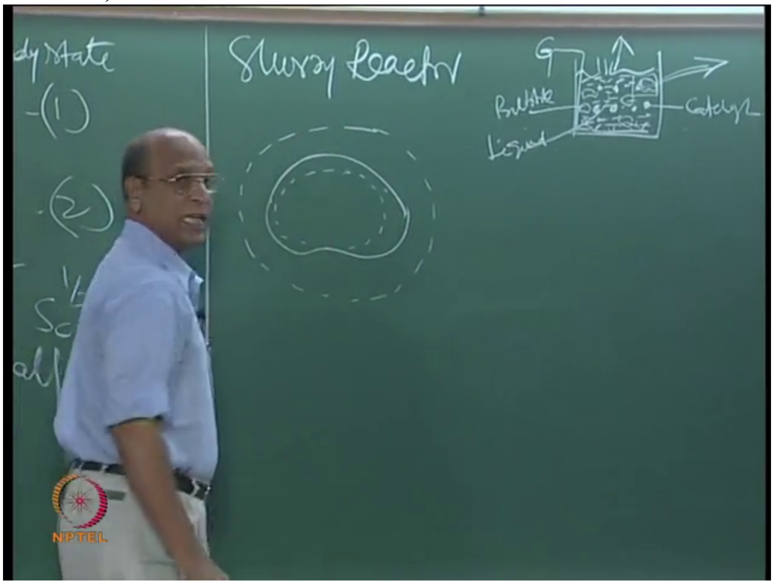


Those are the 3 phases, right.

But here what you are taking is, bubble is, gas is continuously bubbled, the other two are in batch, batch condition. Liquid also in batch. I will take only certain amount and then leave it there. If I want to make, I can also make liquid continuous. If I want to make solid also, solid continuous also I can make. You see how many possibilities for one reactor.

Simplest possibility is bubble you cannot take gas Ok, gas sorry, not, like batch yeah. Bubble you, I mean gas you cannot take as batch. So that is why it is continuously bubbled. So now what is the imagination? I have the bubble, you see imagination now bigger. This is the liquid film, this is

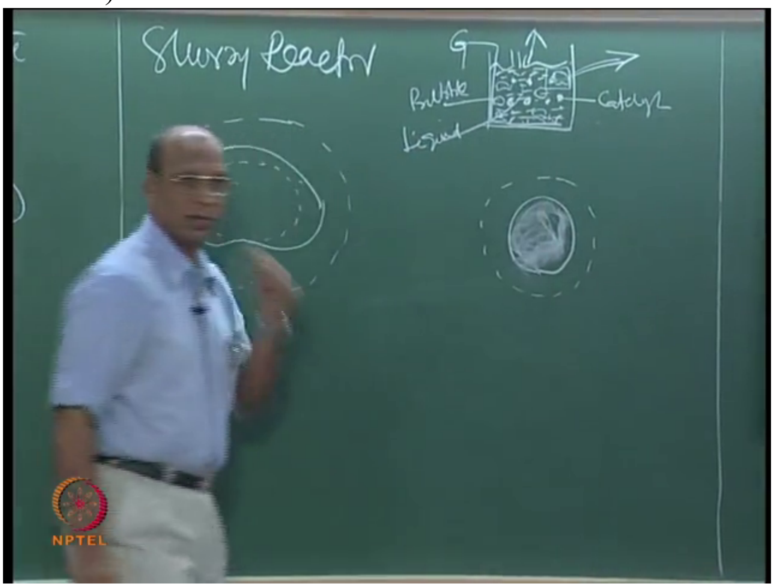
(Refer Slide Time: 46:24)



the gas film, somewhere here I have solid particles, Ok, that is catalyst.

And here also it tell me that I have film,

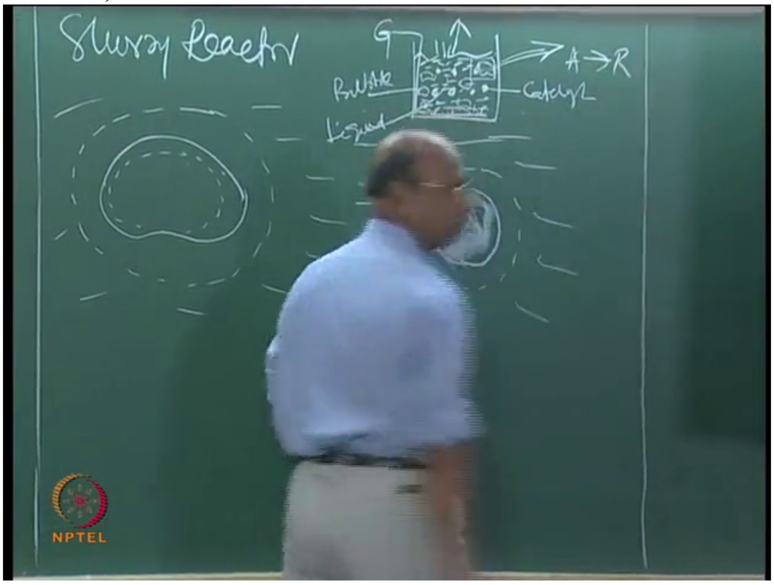
(Refer Slide Time: 46:36)



right. So in-between what I have, liquid. Ok, liquid. Now where the reaction is actually taking place? See that is why that imagination, that process what is really happening, the phenomena, phenomena that is what physics we say. That phenomena is very important.

What is the phenomena now I have to imagine here? Yes, I have the gas bubble. Gas bubble has to first come and dissolve in liquid. Let us say that gas bubble has reactant A. Reaction may be this is A going to R.

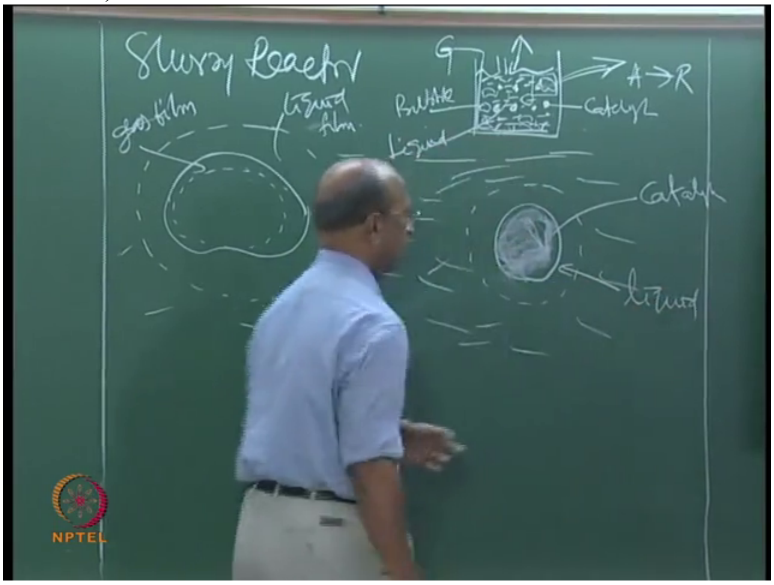
(Refer Slide Time: 47:15)



Ok simplest one. You know, for easy imagination.

So now this A has to come out of this bubble. So when it is coming, it has to, it has to go through the film. This is gas film. And this is liquid film.

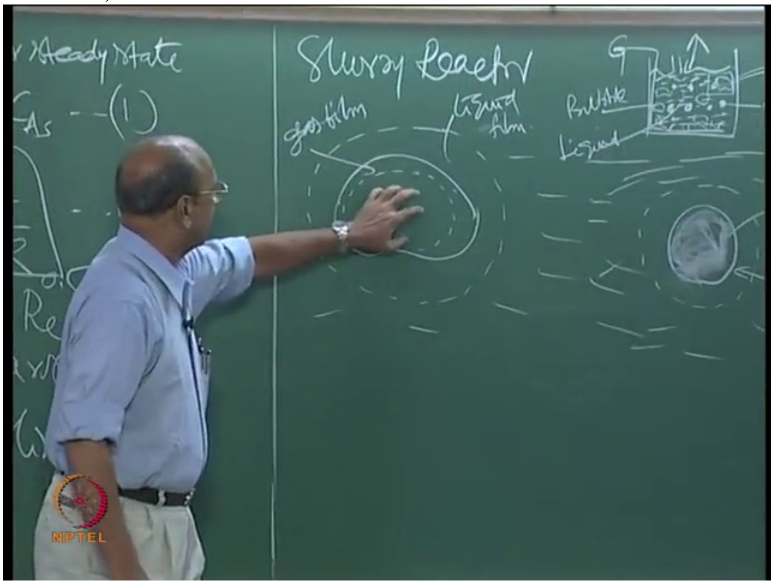
(Refer Slide Time: 47:45)



Ok. Then this is catalyst and this is liquid film. What is my imagination now?

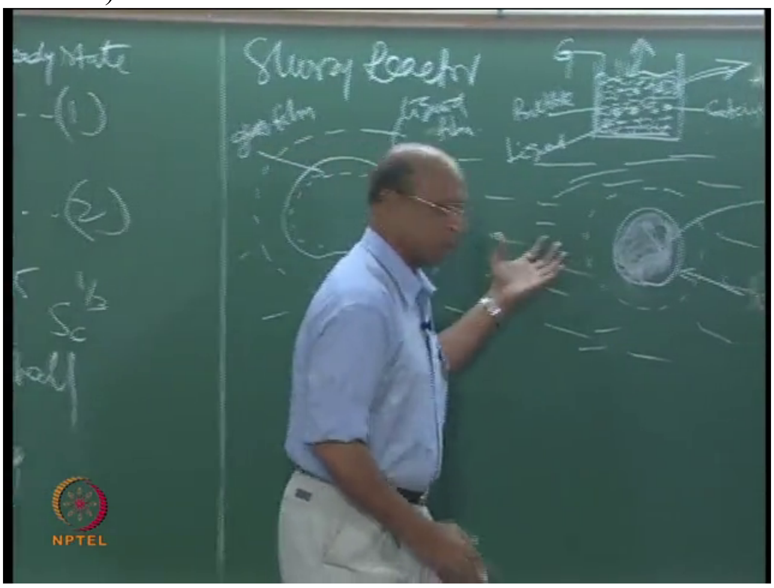
You should first have the gas

(Refer Slide Time: 47:51)



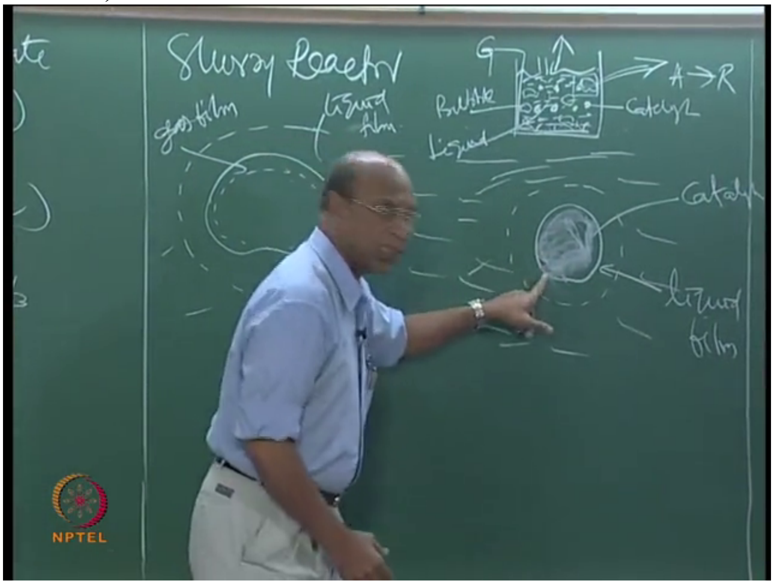
which is coming out and then touching the interface, there depending on its solubility it will dissolve in the liquid and then that liquid when it is dissolved, throughout you have A in this liquid. Now that liquid,

(Refer Slide Time: 48:05)



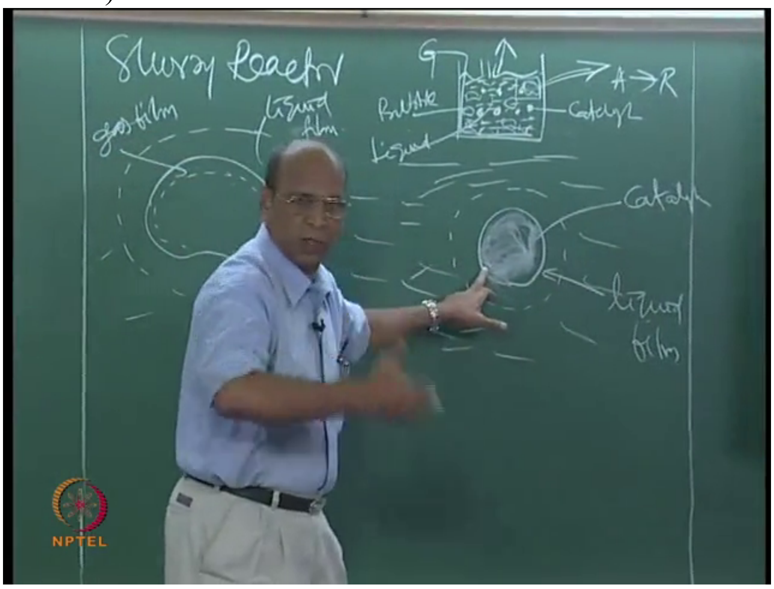
in that liquid this A has to be transported to

(Refer Slide Time: 48:08)



the surface and on this surface, you have the reaction taking place if it is non-porous particle. If it is porous particle, again that liquid will diffuse

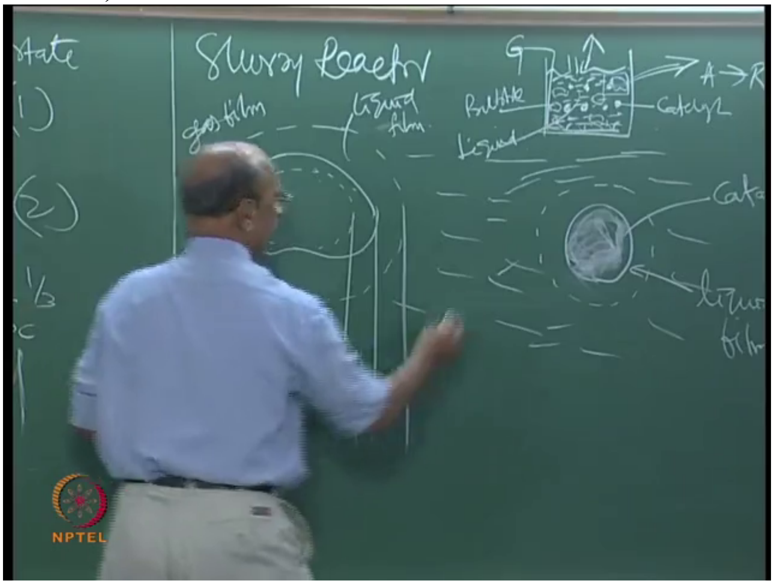
(Refer Slide Time: 48:19)



with that A and A will get reacted inside the surface.

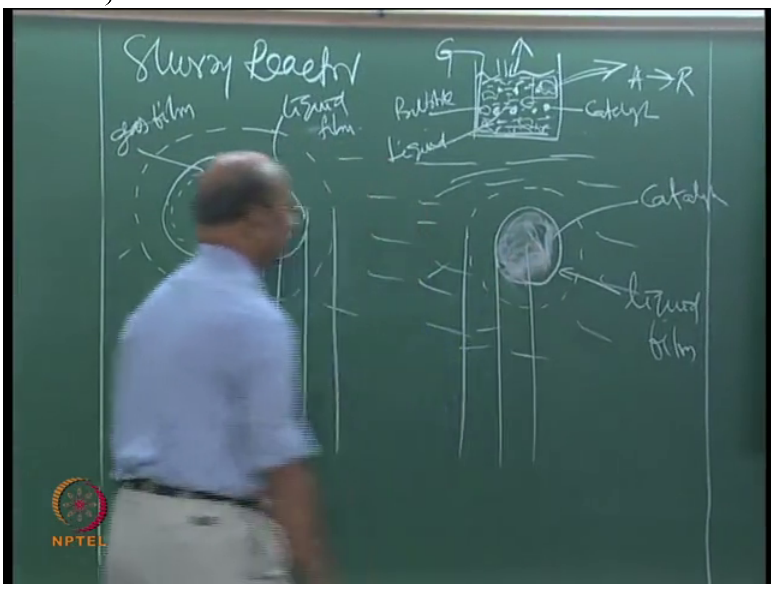
So now what are the steps? So yeah, before steps I will also draw the profiles. So this is one profile,

(Refer Slide Time: 48:30)



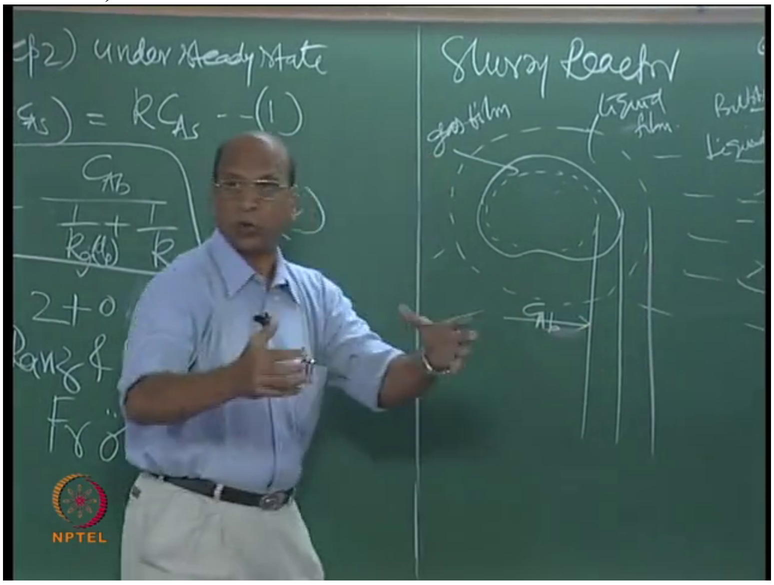
Ok. This is one profile. This is one profile. This is one profile. Ok This is the center.

(Refer Slide Time: 48:34)



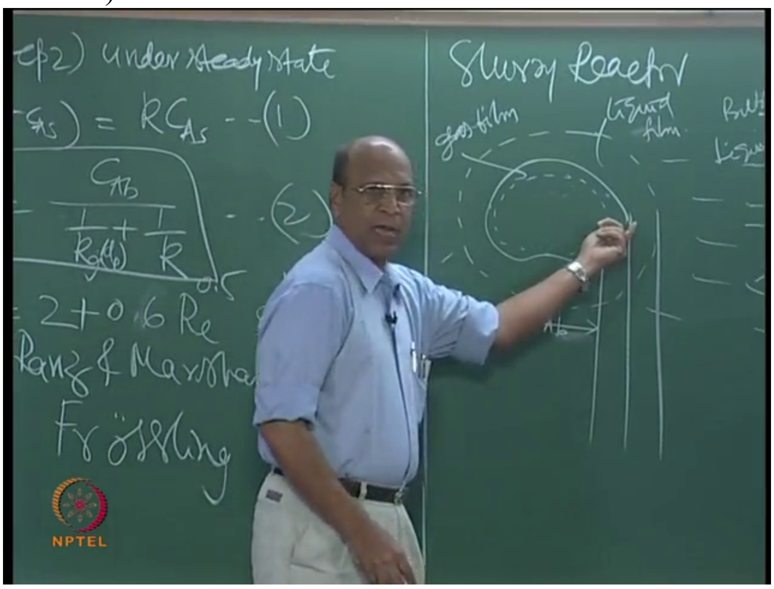
Ok, so now you should have, this is, Ok, so in the bubble inside because it is gas everywhere, so I may have the bubble concentration as C A b which is uniform throughout

(Refer Slide Time: 48:50)



but in this film, I will

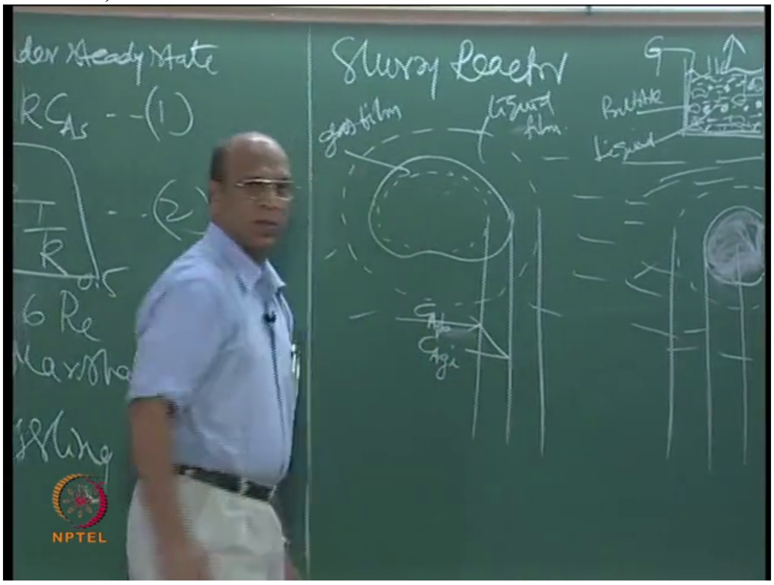
(Refer Slide Time: 48:53)



have some drop in the concentration.

So I may have like this, this is C A, C A Ok; I will also write here C A g to be specific, C A g. This is C A g i, this concentration.

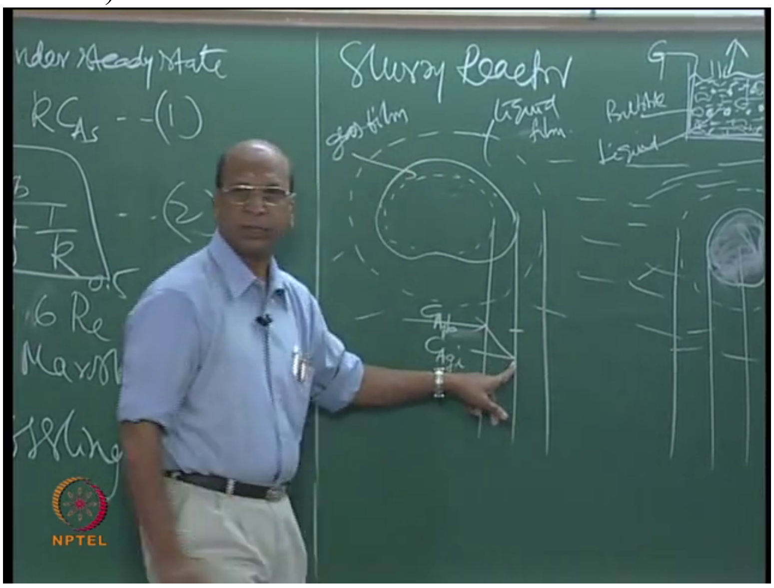
(Refer Slide Time: 49:14)



Now you have the Henry's Law here. Because whenever gas is dissolving, Ok, you get the interface you have this Henry's Law acting and that Henry's Law will tell me that I have, this is C A g i equal to H into C A i l, liquid.

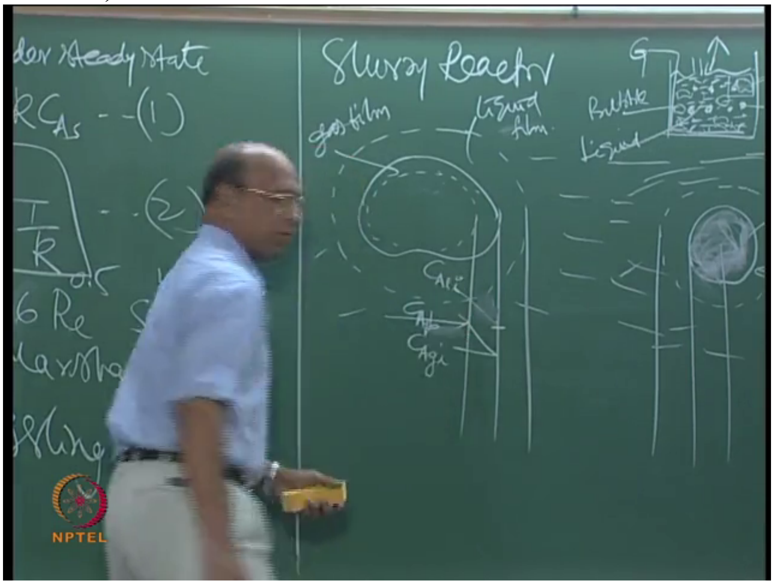
So depending on the H value, you will have either starting above, below or equal.

(Refer Slide Time: 49:40)



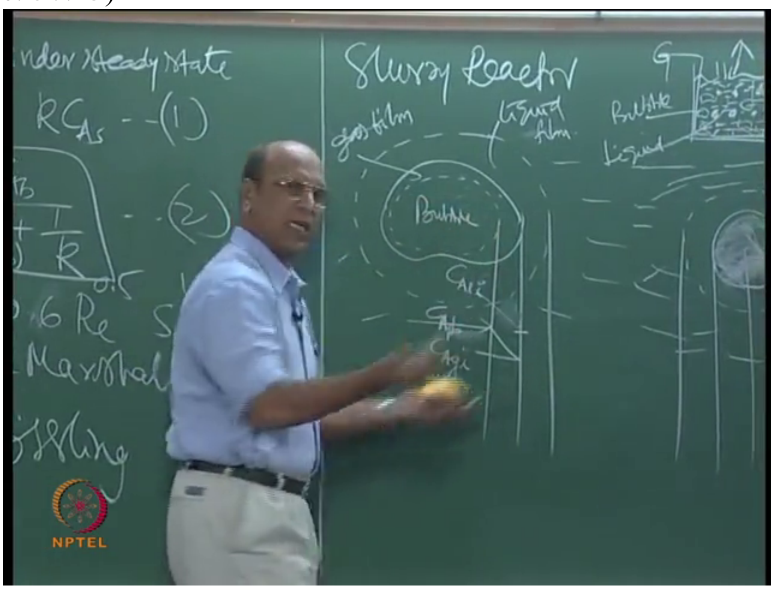
Equal when H equal to 1, right? And above, below you can imagine. So now this is C A i, no C A, now it has become liquid concentration, so C A l i, so this concentration here at this point is, I will write here, C A l i,

(Refer Slide Time: 50:04)



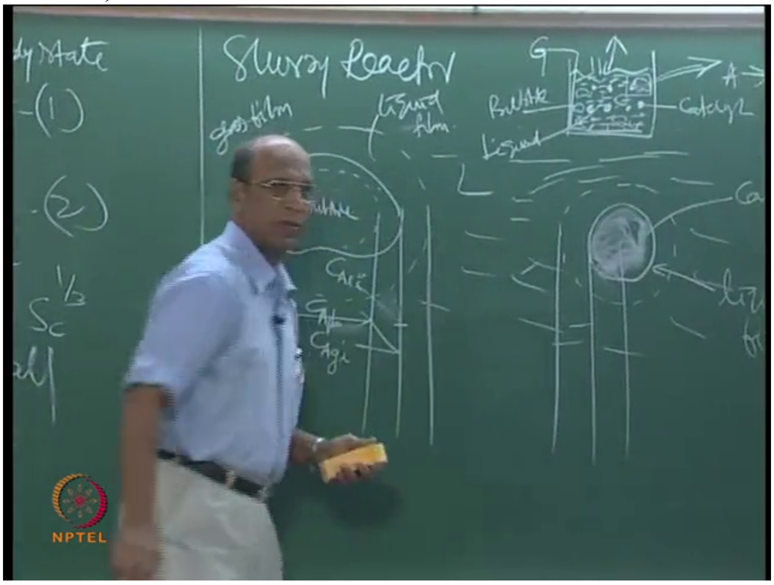
that means at the interface, this is what is interface. Interface between bubble and, yeah gas and liquid. So

(Refer Slide Time: 50:13)



this is liquid,

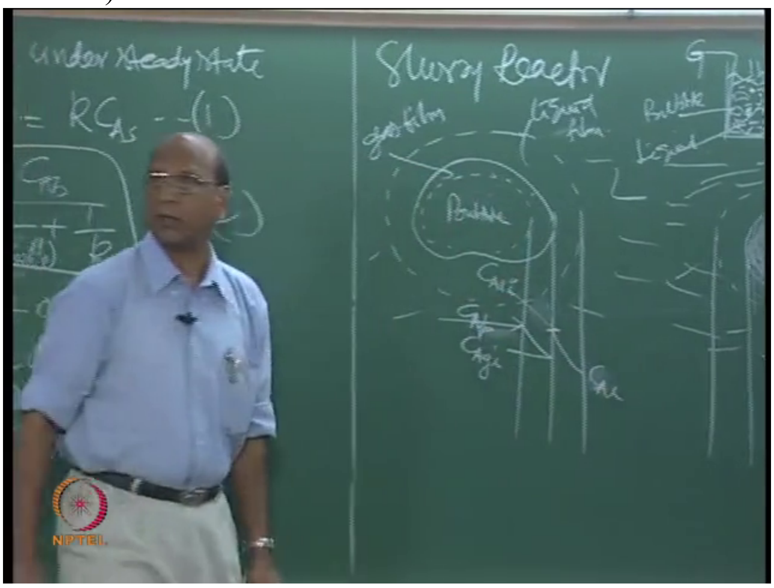
(Refer Slide Time: 50:15)



right? Ok.

So then I will also have next. A liquid film, yeah from here this will again go to some concentration which is C A l.

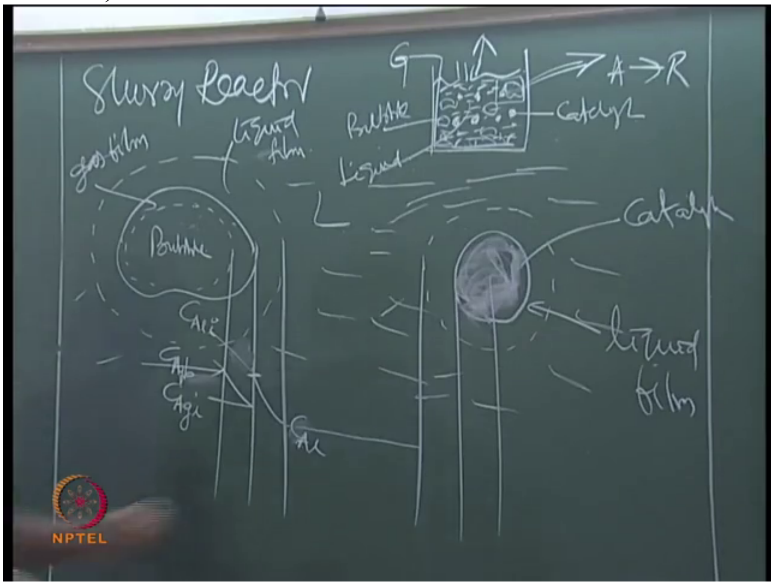
(Refer Slide Time: 50:28)



Assumption here is that this l is almost, that C A l is almost constant. Why? Because we are putting a mixer, or even if you do not put a mixer, you have the bubbles vigorously moving. So then you will have good mixing. So gas will uniformly distribute and throughout this liquid, we will have uniform concentration. That is why that constant.

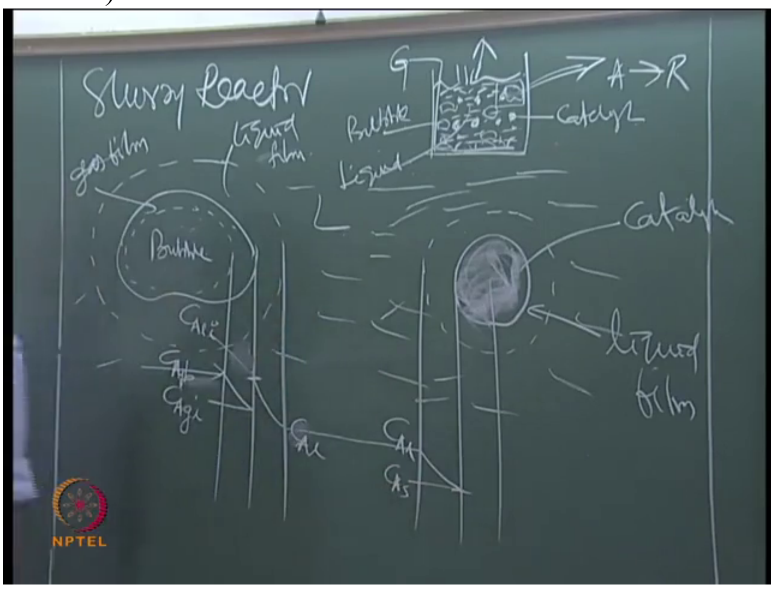
So afterwards, again here

(Refer Slide Time: 50:56)



you have, this is C A l again, same thing; then you have another concentration. This is equal to C A s.

(Refer Slide Time: 51:07)

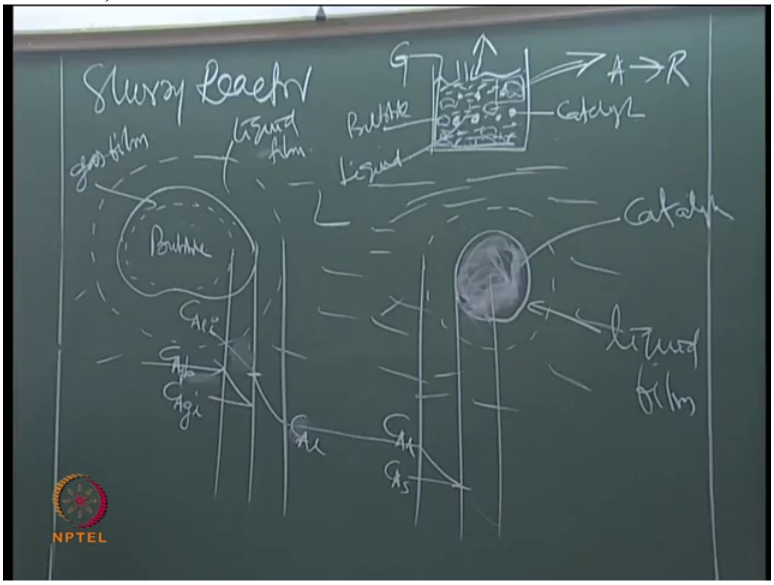


If it is porous particle we will stop here. If it is non-porous particle again you will have a concentration drop within the particle because of the diffusion of A through the pores. That is nicely taken care by effectiveness factor. Ok, good.

So now I have now how many steps? What is step 1? I think I have sufficient time, no or? Two minutes? Oh my God! Now again I have to draw tomorrow all this. Ok, we have to stop here? I think now, yeah, good now, step 1, step 2, step 3, what are the steps? What is step 1 for example?

See for reaction to take place, how this A fellow has to travel? That is what what you have to imagine. Reaction is taking place in the catalyst, one the surface of the catalyst.

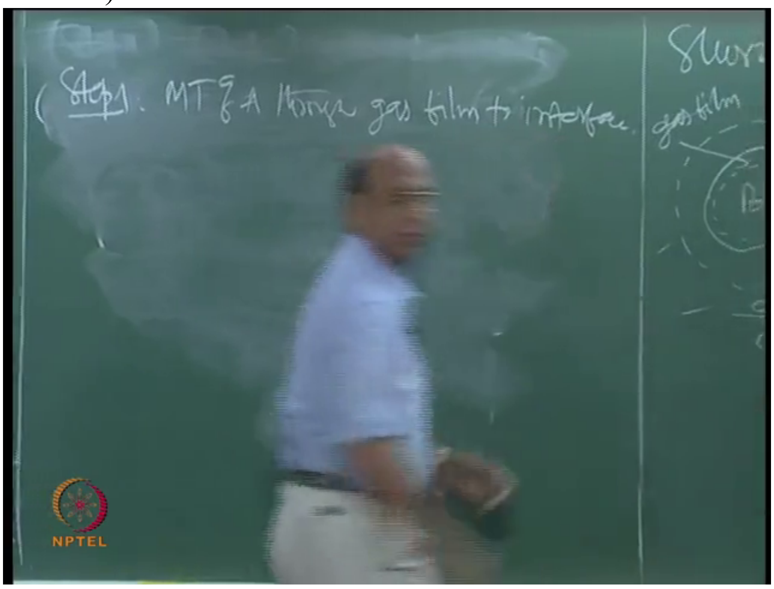
(Refer Slide Time: 51:54)



For the A to reach that surface what are the steps now?

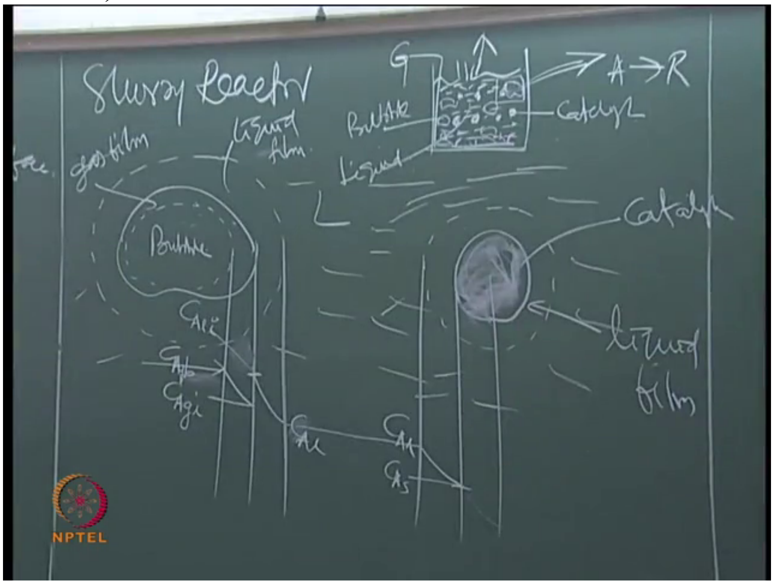
Step 1 is M T of A through gas film to interface, correct no? That is

(Refer Slide Time: 52:17)



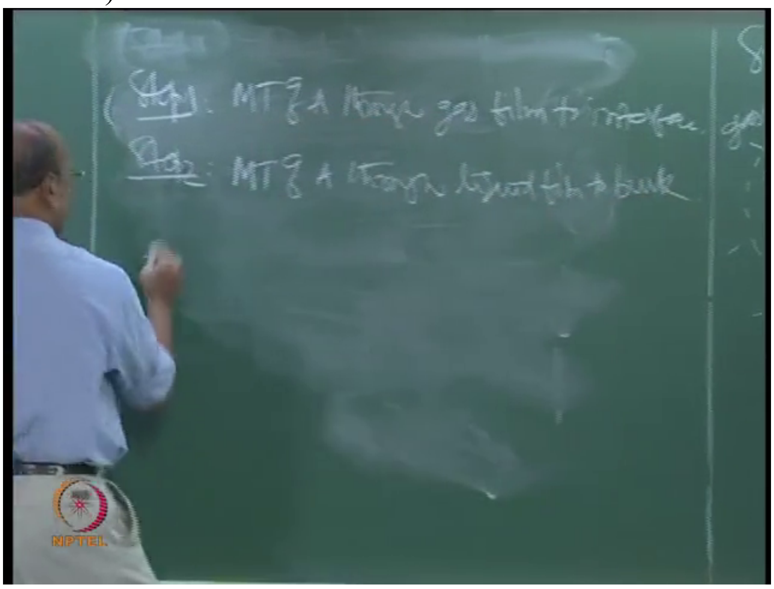
here.

(Refer Slide Time: 52:17)



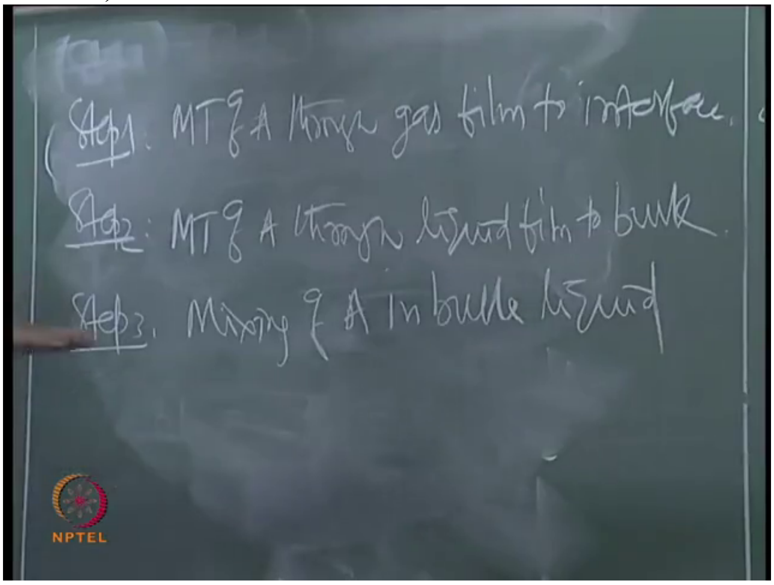
Step 2, again mass transfer of A through liquid film, through liquid film now to where, bulk very good. So step 3

(Refer Slide Time: 52:37)



is mixing of A in bulk liquid, mixing of A in bulk liquid. That also is a step. That can also, if it is not infinity, then we have to take into account. Because it is infinity you may neglect because concentration is uniform,

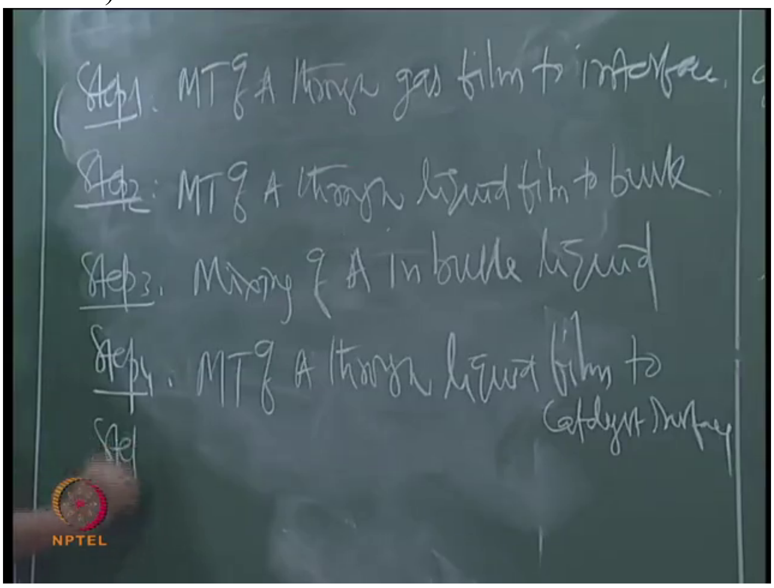
(Refer Slide Time: 53:00)



Ok, good.

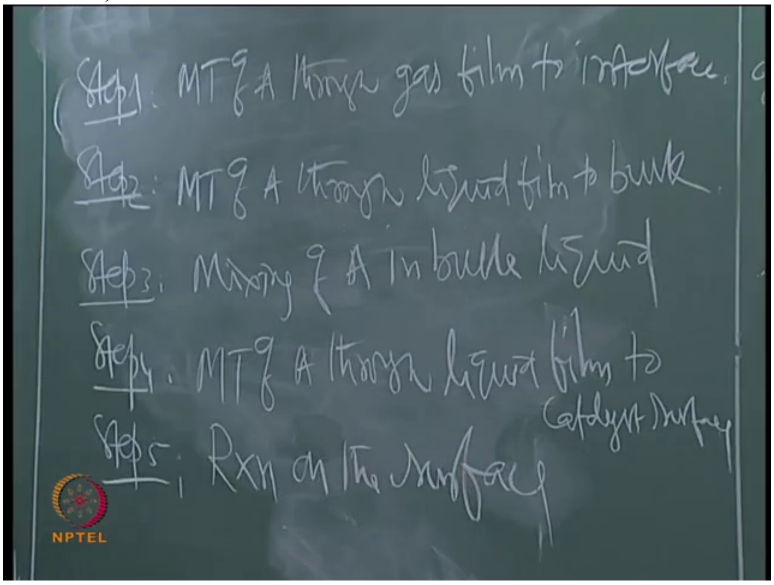
So now step 4, again mass transfer of A through liquid film yeah to, yeah catalyst surface. Then you have step 5,

(Refer Slide Time: 53:25)



yeah reaction on the surface, reaction on the surface. So reaction on the

(Refer Slide Time: 53:35)

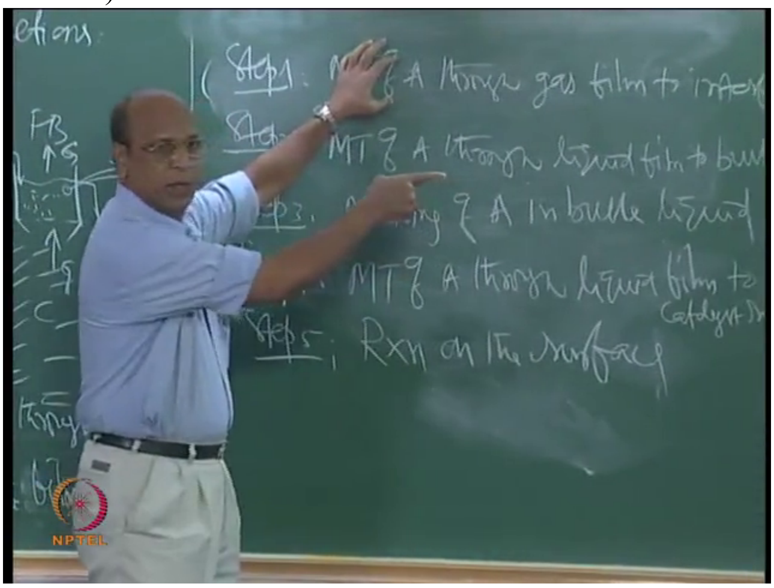


surface. Because of quick writing only this is happening. Ok.

So now at steady state 1,2,3,4, 5 all steps are equal. Now we also have sixth step, if it is a porous material. That means fifth will be again diffusion of A through the pores of the catalyst. Then reaction inside the surface of the catalyst. Now procedure is same.

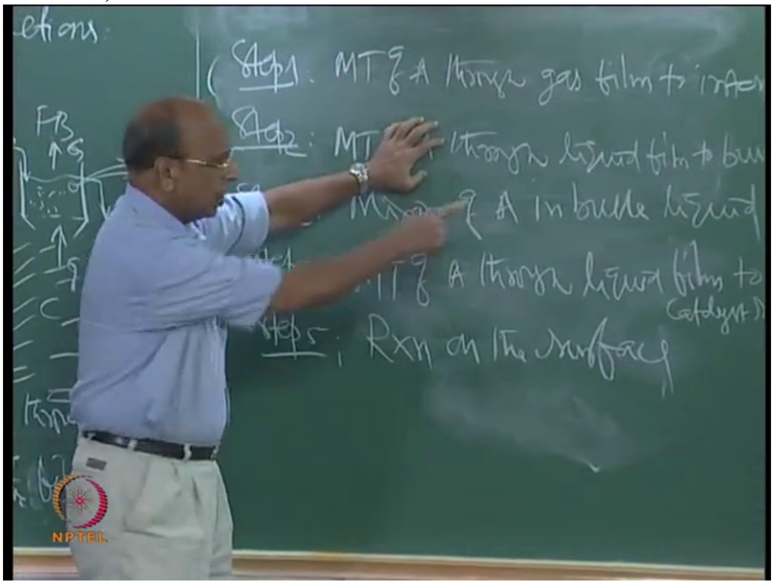
I have to write mass transfer equation through film,

(Refer Slide Time: 54:03)



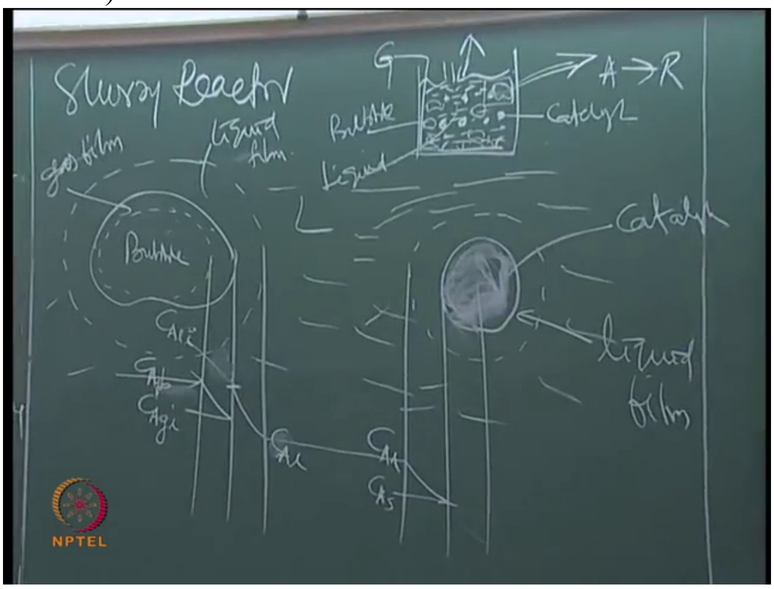
mass transfer equation through

(Refer Slide Time: 54:05)



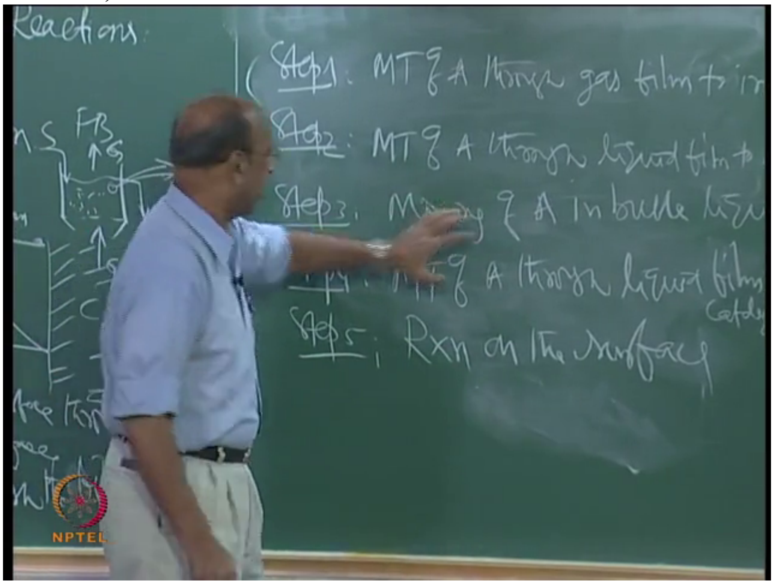
liquid film, and

(Refer Slide Time: 54:07)



because this is not offering any resistance so we do not have to, yeah, again, you asked, Swamy or someone asked no, yeah, this step can

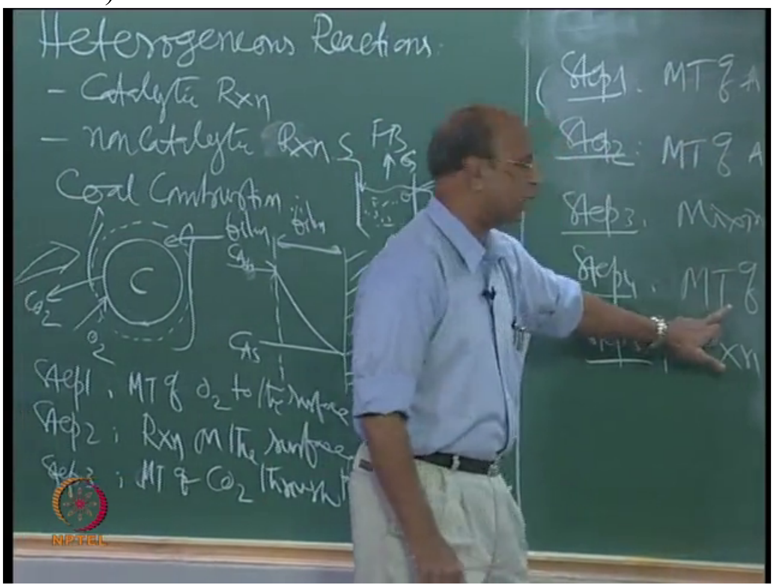
(Refer Slide Time: 54:14)



be neglected now because it is not changing my rate.

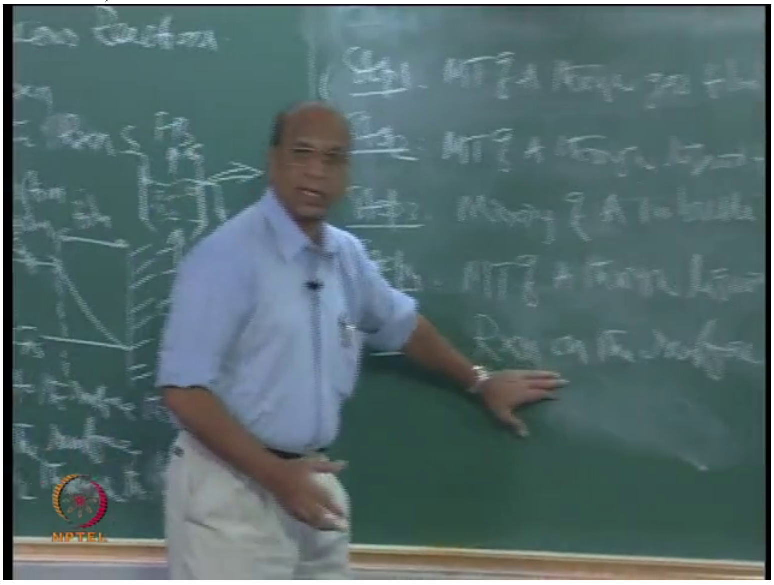
Why? C b, C A b is constant throughout, right? So then I may have to take this step, this step, now another

(Refer Slide Time: 54:24)



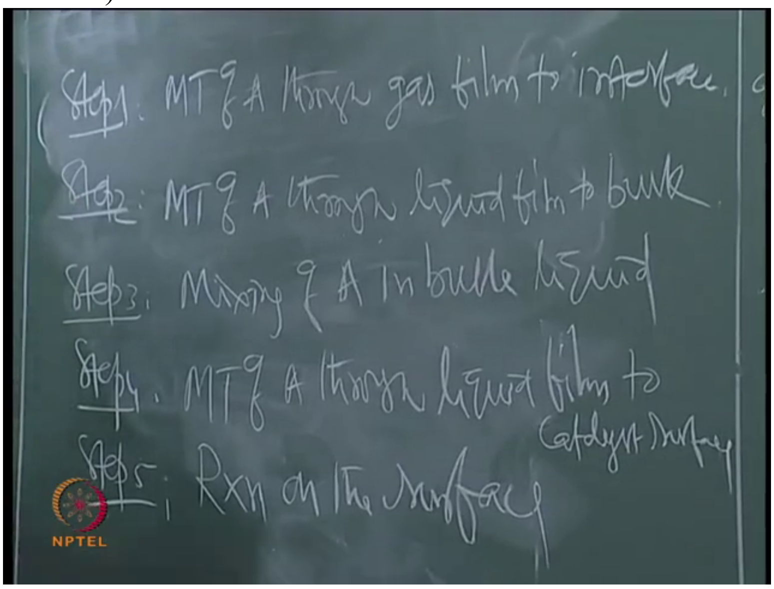
mass transfer step through the liquid film around the catalyst,

(Refer Slide Time: 54:29)



then rate of reaction under steady state condition, this equal to this equal to this equal to this. How many

(Refer Slide Time: 54:34)



mass transfer steps are there?

(Professor – student conversation starts)

Student: 4

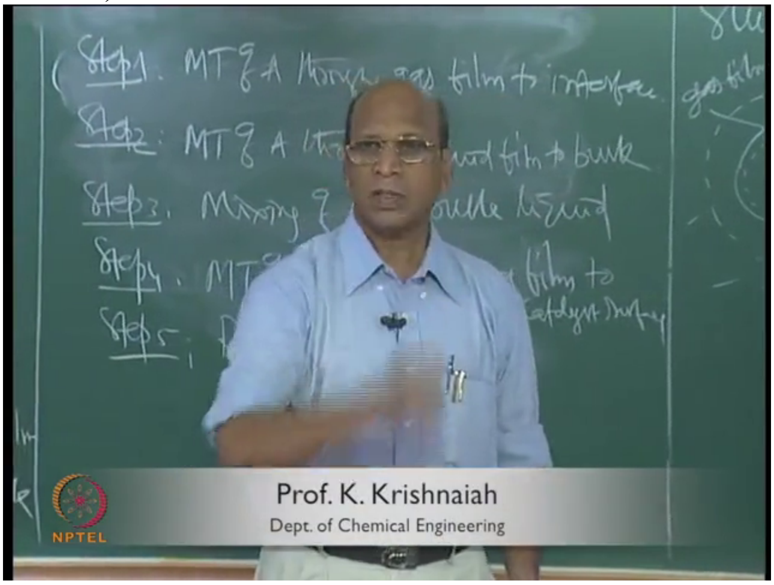
Student: 3

Professor: You take even mixing. Sometimes if mixing is not very good, inside this also you may have concentration gradient. It is not uniform. So you see.

(Professor – student conversation ends)

In fact in a heterogeneous reaction, there are mass transfer steps than

(Refer Slide Time: 54:55)



reaction steps. That is what is the beauty in heterogeneous reaction. And again, yeah Ok, again we have to take, whatever is controlling and all that we have to do, that we will do tomorrow. Controlling I do not do.

I will just only develop an equation. Ok. So that again we will do C C R E. In fact C C R will be more exciting than this. Ok because you know all applications, whatever you learnt, now these all fundamentals, basis. So there I think all those things are applications.