Chemical Reaction Engineering 2 (Heterogeneous Reactors)
Professor K. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology, Madras
Lecture 07
Continued and Proof of Pseudo steady state assumption

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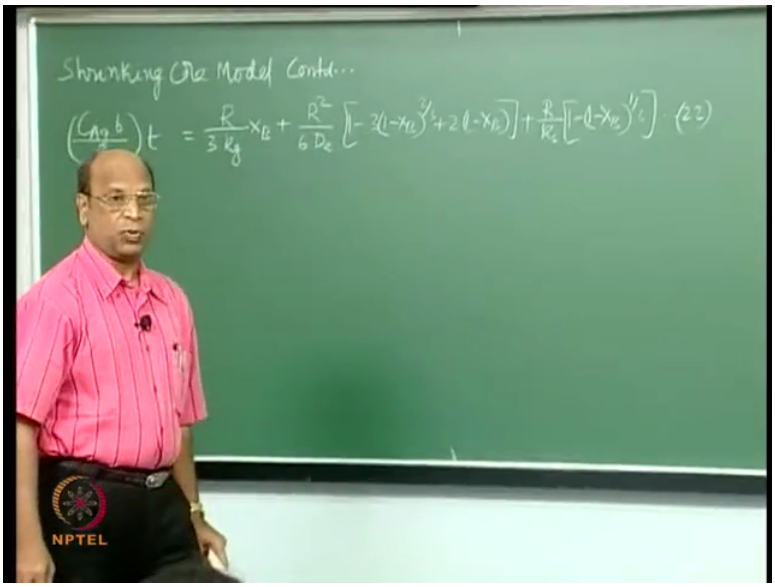

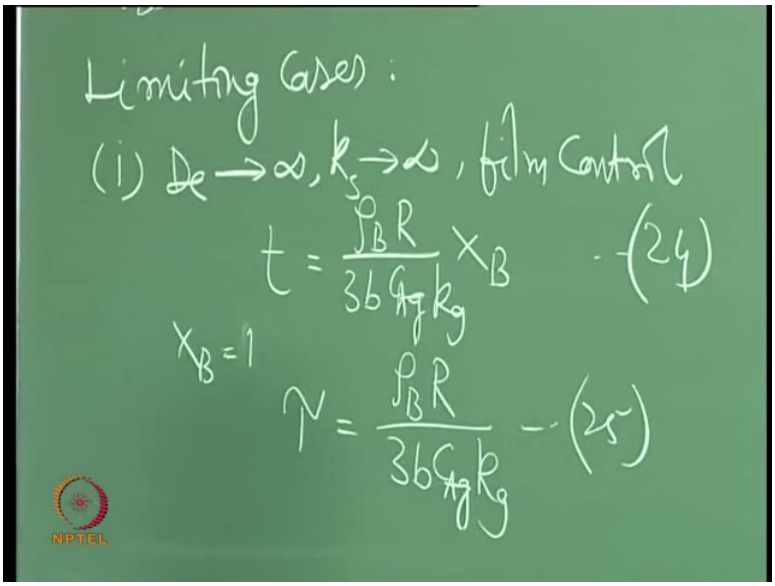

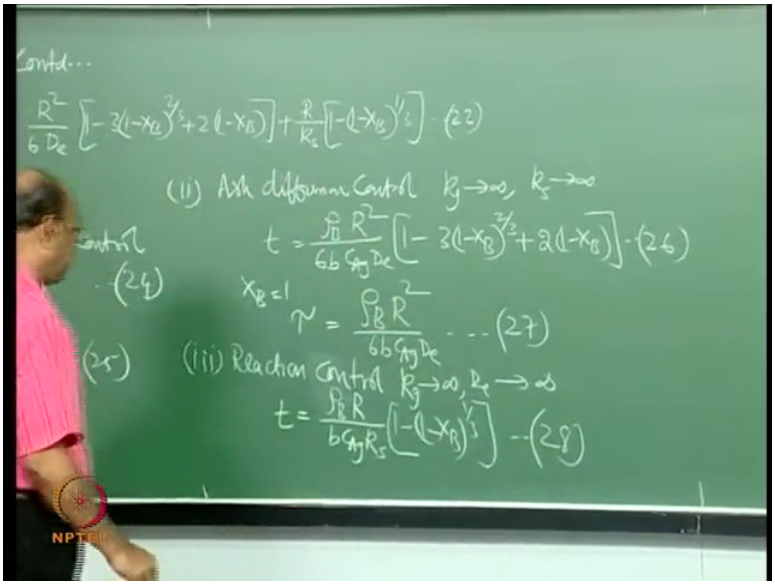

Ya this equation was derived yesterday and now we will discuss the limiting cases of this. The limiting cases are 1 is as effective diffusivity is very large or k s also is very large then we have film control under these conditions film mass transfer is the rate controlling step. So the equation what you have that means this goes to 0 infinity this is infinity this goes to 0 then only you will have these terms.

So that can be arranged as t equal to rho B R 3b C Ag k g into X B so this equation is (20) now what was the last equation earlier this is 24, okay this is 24 and we can also try to find out what is the time required for 100 percent conversion. For X B equal to 1 that is 100 percent conversion, X B equal to 1 we call this as Tau as simply rho B R by 3b C Ag k g so this is equation 25.

Similarly we will have let diffusion control Ash diffusion control that is 2 Ash diffusion control which means that we have ya k g is infinity and k s is tending to infinity that means again these two will disappear these two terms and the equation now can be simplified as t equal to rho B R square 6b C Ag De 1 minus 3 into 1 minus X B to the power of 2 by 3 that is the equation this is equation number 26.

Again here for X B equal to 1, I will tell you why we have to simplify this and then we can get lot of information from these equations that is why I am just writing. So when X B equal to 1, this will be simply rho B R square 6b C Ag De so this is equation number 27. The third possibility is that we have reaction control reaction control where we have k g tending to infinity and De also tending to infinity.

The equation is rho B R by b C Ag k s into 1 minus 1 minus X B to the power of 1 by 3 this is the equation this is equation number 28, right.

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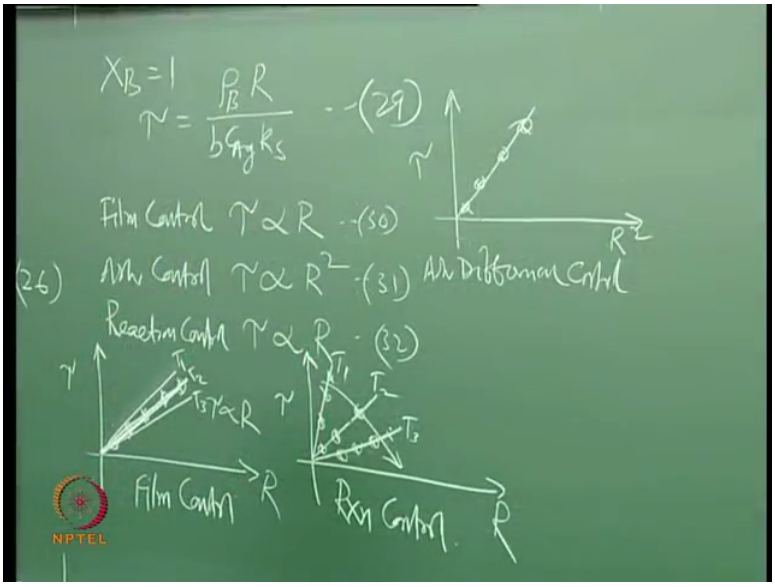

Here again if X B to equal 1 for 100 percent conversion Tau is rho B R b C Ag k s so this is equation number 29. There is some information here hidden unless you see it carefully. Now for film control Tau is proportional to R, for Ash control Ash diffusion control Tau is proportional to R square and again for reaction control Tau is proportional to R, so this is 30, 31, 32 okay good.

So what do we get from this I think this okay all nice equations have been derived but finally we have to use them how do you use for example that information? Use in the sense that what do you imagine normally I imagine that my non-catalytic reaction if it is a non-porous particle we imagine we have one particle and then surrounding that you have the gas and it is diffusing through the (())(6:12) film and also through Ash and reaching the surface and then the reaction is taking place, fine based on that that is the phenomena.

Now based on that phenomenon we have derived the equations, right. So after deriving the equations then we have now simplified to find out really what is is it true what my model is I have to find out that, how do we find out? We have to find out most of the time with experiments. So that is why in any research the experimental part is definitely required for whatever amount of mathematical modelling you do, unless otherwise because it is mainly for simulation people they declare that very proudly that I am simulating many things but all simulations unless it is valid no one is going to believe that, right.

Ya no one is that is why experiment if you do on your own and then trying to find out whether your model as well as experiment both are same or not then that is the best, otherwise if you expert in modelling so then you have to model and take some others data and then also you can check, in fact that is also very good it is not your experiment but still you should be able to model their experiments if you are able to do that, right.

So one way of doing this is to find out which one is controlling? This is one of the simplest test, how do I do this? I want to find out whether film is controlling? Or Ash is controlling? Or reaction is controlling? Controlling the rate that means I do not have three steps, I have only one step film control, how do I experimentally find out that whether this film control is there really controlling the film.

Student is answering: convert the whole component and product and then we establish a relationship for different particle senses.

Ya see that is the meaning of this equations why we have written all this is that this is the simplest one which I can find out that if I am able to take let us say 1 mm particle, 5 mm particle, 10 mm particle and 20 mm particle four particles I have taken. So now I found out the total time required for complete conversion and how to find out is again a big problem I think it is not easy the way we discuss here, okay I just ask you to imagine that I have a coal particle, coal particle also can be done on this and also similar to derivations what we have done except Ash control may not be there.

Otherwise okay I will take the realistic example not coal the again iron ore reduction, right iron ore reduction. So then we take Fe3O4 particle or Fe2O3 particle and then send hydrogen around that and we know the reaction is taking place, how do you know that it is completely converted? Because we are waiting till complete conversion this is the time required for complete conversion all these Tau's capital Tau.

So for that again you have to imagine a lot what is the experimental technique you use to find out whether you have really this reaction going on or whether it is changing with time during reaction and at the end if there is no reaction it has to get some property which you should be able to measure, okay I mean the best thing if it is possible is that you take 1 centimetre particle and then after 5 minutes take out cut it open and then see the difference between product as well as the reactant, okay. So outside you will have the product and inside you have still reactant.

So like that you can see if you are able to see the shrinking core you take the spherical particle so that is one way to find out whether really you have this possibility or not, okay people have done that. So that is why doing experimentation is also is really thrills me most of the time, it is not the solving equation because doing a particular experiment based on your own thinking so that means you have to think a lot because nowadays the mathematical techniques are most of them are available on MATLAB, okay.

So unless you want to develop a new theory and new way of solving the problem that is fine that is excellent again you will get the real thrill there but most of the times as engineers what we use is packages, right. So if you just keep that one aside and if I tell you that okay now you take this particular problem and then try to get me the experimental data, everything you have to imagine.

For example what sizes you have to take and where do you measure, how do you allow now it is very easy for academicians to say that you can take a particle send hydrogen it is very easy. But when you are actually doing what you do? And I do not know whether you heard what is called TGA thermal gravimetric analysis TGA, TGA is one of the sophisticated instruments where you can find out thermal gravimetric analysis you know the changes in the weight during reaction but you should have that change really, if you do not have much change in the weight you cannot find out again.

So in TGA what they do is they just put a small balance and one side of the balance they hang the particle, the other side they measure you know balance in the beginning time t equal to 0 then you start the reaction and slowly if there is increase in weight that increase in weight is recorded that depends on what kind of reaction you are taking, okay and for example calcium carbonate going to CaO plus CO2, right.

So you have taken let us say 10 grams of the particle of certain size. So during reactions CO2 will come out definitely there will be change in the weight so like that in some reactions there may be weight increased so that you can record and that can be converted as X B that means you know initially how many moles and at any time you knows the weight that you can always convert to moles.

So then that differentiation of X B will give me what is the conversion. So if I am able to plot X B versus ya here for example X B versus t small t not Tau, Tau is the easy experiment to do, right. So that means I am now finding out the variation of the conversion and then time.

So if I plot this equation this is nothing but y equal to m X there is no even C. So it has to go through all this is constant because I am keeping my temperature constant, I am talking one particle size so R is there, then C Ag, okay at that particular temperature and pressure this concentration of gas I know and ofcourse this entire thing will come as constant the slope, right.

So X B (())(13:11) have plot and then it goes through origin and then if it is a nice straight line then I know all these things rho B I know, rho R I know and this b is stoichiometric coefficient that I know already and C Ag I can calculate because I know pressure temperature so I can calculate. Now I can calculate what is k g? See how beautifully one can do that, same thing similarly here or similarly here, right.

But before doing that entire kinetic studies first I have to find out whether which one is the rate controlling step? So for that this experiment is very easy, right again if there is a possibility of using TGA that is the best go to this take a particle and then just hang it there and weight till weight is always constant that is that indicates the reaction completion. So at that point of time you record the timing, okay. So that is the total conversion and corresponding time Tau.

Now if I plot juts radius let us say 1 mm particle, 10 mm particle, 5 mm particle and 20 mm particle (())(14:16) I said that in the okay this is Tau versus R right. So here again this equation if this is the controlling one, right now k g is constant because I am putting the same flow for different particles same temperature, same pressure, right. So around this that gas will be going and the reaction is taking place and then I wait till the complete conversion X B equal to 1 so this is the equation, we plot this versus this and k g also I need not know k g actually so only R if I know I will just plot then that also goes through the origin and then ya this is the flow origin it should not change, first I do not want to draw and then put points I mean you also do the same thing no.

So that is why I just want to put the points first and then draw the line okay so that is the line if it goes like this then the slope of this will give me information ofcourse again k g also I can measure there but this again proves that it is film control formula, okay but there is a (()) (15:47) this also which one is controlling how do I find out now? If this is R square then it is fantastic no problem if I plot okay if I plot this as R square okay or otherwise there are so many ways you know we can plot that on log log sheet log log sheet and then this will be slope will be 2 then that means ofcourse it is R square and ofcourse again when I plot on the

normal sheet and then take the slope I can evaluate De that is fine but between these two we have a problem to identify which one is the correct one, how do I find out just can you think, how do I differentiate I have now film control and reaction control both are valid if I get you know Tau is proportional to R if this is the condition.

But definitely I have to tell they have two possibilities what is the correct possibility, what is that what is really, do you have any other parameter which you can change? Which one, how do I change mass transfer coefficient? Ya so even if I do what will happen? I change the concentration as you suggested, what do I see the change, what changes you expect ya why? Mass transfer coefficient also (())(17:19) answer is right but I think you know still a little bit deeper you have to think.

So that is why doing experiment is not that easy I say so much thinking is required and not only doing experiment anything to do I think so much thinking is required, only joining IIT do not require anything and after joining nothing is required, okay somehow we will pass you, somehow you will get marks and somewhere you will get because brand name is there you get 10 Lakhs, 20 Lakhs salary and all this reward is for not using our brain ya.

So this pressure of doing things you know really I do not know mainly even this Saturday, Sunday I went to that (())(17:59) for conducting a P.Hd examination on the way normally always I take some book this time I have taken The Grand Design Stephen Hawking book one of the latest books, the way he explains things so beautiful, in fact he changed my mind of you know this teaching I write less equations and then more talking because of that because I would like to tell the entire subject as a story and stories can be understood by even LKG people the way if you are able to tell that, okay.

So then such a complicated equations and you will never write an equation complicated theory is so beautifully explained so (())(18:38) excited when I am reading that book, he was talking about you know string theory, M theory of the universe, okay all this but the way he explains it is so beautiful but everything you know that in his body nothing is working except his brain, okay may be heart still pumping ya so that is why he is alive.

But otherwise you know he is only brain that means he simply sits down and then thinks thinks thinks all those theories and also his explanations, everything is in his mind similarly for us also. So that is why I think you know when you the doing experiments there are so

many possibilities and you know my students if they know how the what kind of hell they are going through not hell, hells many, okay ya.

Because simply if you are able to plan very beautifully thinking every point is not that difficult but I do not tell them every point because they have to also go through that meal you know buffet is very easy to eat you know because everything is there you just go put it there and then eat but if I ask you you cook and eat then you have to plan many things I say first of all you do not know where rice is available, okay and you do not know where vegetables are available and how to cook, what temperature should be used, how to stir or do not stir so so many things are there everything is a question, okay.

So that is why even in teaching also we should not tell everything you know that is why we give assignments, we leave something in between steps so that you also will participate in this, okay but anyway I think as he said and you need lot of information also to identify which is really controlling here I think that correct answer is that use temperature, why? We know that reaction is very very sensitive temperatures because of Arrhenius equation, whereas k g is not that temperature sensitive, right.

Because why k g is not that temperature sensitive I do not know who invented this word why it is really very good ya tell yes something just tell right or wrong no problem (())(21:01).

Student is answering: Exponential but this is inversely proportional.

k g why what way? First of all it change or not changes? It change but in what way it changes? Here it is exponential the other one, directly proportional why inversely? Ya why power 3 by 2? You see how much thinking is required again, okay so that is what I just want to tell you all this try to find out, okay you take one equation which k g you know.

For example we have that our famous equation Sherwood number equal to ya 2 plus that okay neglect 2 for easy thing and then now you tell. In Reynolds number you have some properties, right you have density, you have viscosity, okay and in Schmidt number ah okay you have Mu, rho both will change with temperature, what about D by the way what is D there? Diffusivity will it also change with temperature? Ya so you have to individually know that how temperature is varying, viscosity is varying with temperature, okay density is varying with temperature, diffusivity varying with temperature all that you have to substitute and then get what is the overall change of mass transfer coefficient with temperature, okay.

But if you do all that it will not vary much I think it is only 1.2 t to the power of 1.5 and depending on different theories, okay but it is not definitely exponential. So that is why if I change the temperature I may get like this and I may also get may be something like this with different temperatures. So maybe this is T 1, T 2, T 3, etc so the change is not that much but on the other hand if it is reaction control this is film control, okay if it is reaction control Tau versus R so I may get like this this is one temperature, like this, like this, okay ya and right now I am doing wrong thing, okay.

So which temperature you know temperature is increasing in this way or in this way? Which is the direction of temperature increase in that graphs this is lightly complicated for you but that one is easy, not able to understand question. So this is T 1, T 2, T 3, okay now the T 1 is greater than T 3 or T 3 is greater than T 1? Let me write T 1, T 2, T 3 so which is higher from that graph can you tell? T 3 is higher why?

Student is answering: Mass transfer coefficient decreases as temperature increases.

No no I am telling that you know there is no mass transfer here you know this is film control, this is reaction control but it is giving clear difference between you know T 1, T 2, T 3 whereas here it is not that much different they are almost close, okay. So this will tell me that this is reaction control and this is film control but what I am asking you to make you think is that whether T 1 is greater or T 2 is greater or T 3 is greater in what direction it has to go? Ya why? From that graph ya slope is okay from that graph can I tell that graph as Tau versus R.

Ya straight forward I said for large temperatures time required is less so which direction I have to show this? I have to show this direction, okay everything again I tell you I think most of you I think luckily we do not have these B. Tech guys except Rinita because most of you are going to do some projects because in B. Tech they have a escape class that you know if you do not like project escape you do not have to do project they can do two courses and the way they are attending they can attend those courses and then they can get the degree, okay ya not even one day all B. Tech have come to the class, okay statistics ya.

So but you know as research scholars all these are very important for us when you are doing experiment because you have to think a lot to do the experiment, I am not saying that you should not think at all when you doing theory, theory also requires lot of thinking but everything origin is here, either theory or experiment, right. If you are planning experiment atleast one week you have to sit in your room, close the doors and ofcourse take food also in

between and then think what to be done otherwise after one week you will not be there in the room, okay alive ya.

So I think that is required even when you are trying to do the theory same thing again just sit down and then think and frankly tell me how many of us are doing that if a problem is given how many I think it is a rat race, okay that is why I like that movie 3 Idiots that fellow wrote a simple word there what is that (())(26:49) of something like that ya ya the moment he writes that everyone started seeing you know go to the index and then see whether it is given and then pulling the books from others and then trying to find out without thinking whether that kind of word is existing or not, that is what is the directories what we have in education no time for thinking that is why all of us are lucky you know 50, 60 years back happily when you are reading no happy that is all I think no motivation if you pass pass, if you fail fail that is still okay.

But I think when you are doing that you know lot of time is there at that time we do not know we have to think about the problem and all that particularly for us who came from villages but maybe the Professor's son, son, daughter's and maybe educated families they would be thinking that, they had sufficient time. So that is why they have done wonderful work in fact. Now a days all these things is rat race, okay.

So this is one clear way of finding out which is controlling there, right because here also Tau is proportional to R, here also Tau is proportional to R the other one is very simple because this if I if Ash is controlling then if I plot Tau versus R square then I have a straight line but you have to plot R square this is reaction control, right.

And if I plot R square and Tau if this is again straight line R square I am plotting now so this is diffusion control, okay Ash diffusion control so this is the one and now once I know this I can even find out what is effective diffusivity or if it is reaction control I will find out what is k s and if it is mass transfer coefficient I can find out what is k g, right and this k s I have now three slopes okay so then I will have ya I can find out from those three slopes three different k s and now if I plot 1 by T versus (())(29:08) k then I will also get activation energy all that information.

And if I repeat the same experiment even with diffusivity this is changing even I can find out with different temperatures, again diffusivity varies again with t to the power of 2 by 3 R no 3 by 2 I think I get ya diffusivity with temperature.

So if I am able to get that variation with different temperatures then I can get information on even how diffusivity is increasing with temperature it is not that blind you know when we say that D may increase with what d to the power of 1.5 because that maybe purely for gas gas diffusion but this is effective diffusion where we have other things also coming into picture, what are the other things we have three different kinds of mass transport in that pores we have Knudsen diffusion, we have bulk diffusion and we have configurational diffusion, right.

So all the effect of all these three only giving me mass transfer across the that shell whatever shell I take inside the particle. So all that information we can very nicely get that if we understand these equations how to be used to conduct experiment and then get the overall thing. But what do you do if you have two controlling, or three controlling what do you do because always we will go from simple to complicated.

I mean do you have any thumb rules in your mind I mean that all this depends on you know what kind of (())(30:40) we have in the subjects. I have three steps, what is the first possibility I can remove that this may not affect most of the time in the in my experimentation one step, why? Answer is right by why again you have to tell. Pure gas Sarita? What is less resistance is less unit ya.

If I do not have pure gas most of the time may be you get pure gas in industry, how ya but till what point you can go because the boundary layer is almost 0 if you have infinity velocity, if you go to infinity velocity particle will not be there this planet will not be there this also will be blown out, okay. So that may not the one, think some more deeper normally you will forget a small pain if you have a big pain, okay ya so which one diffusion is difficult or mass transfer through the film is difficult?

Mass transfer mass transfer what mass transfer you are through the film or through the Ash layer is difficult.

Student is answering: When comparably.

Ya because the Ash layer diffusion through the pores for molecules is difficult when compared to diffusion through the film so that is why general thumb rule is whenever you have a porous particle because after reaction porous particle you know porous product only you get. So most of the time it may be controlling when compared to mass transfer. So that is why most of the time we simply ignore film.

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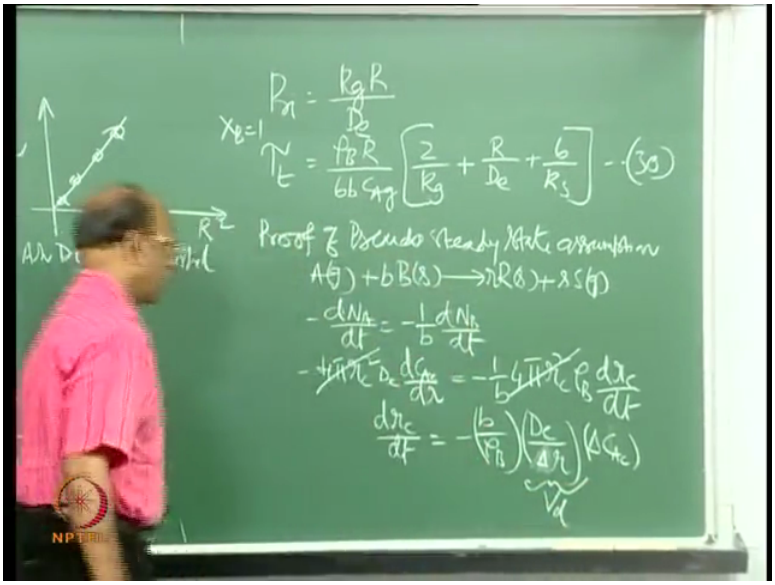

But technically doing it yesterday we had one number Biot number, okay Biot number what is the equation? Biot number equal to k g R by De okay whether this Biot number should be very large or very small?

Student is answering: Small.

Small means what you can neglect or wrote like that? See you said that internal diffusion is difficult when compared to mass transfer through the film, okay. So which one should be more there in that equation? Ya because always the slowest quantity will control I said I have been telling all the time all stupid examples also I am giving okay you have a Benz car which can go to which can travel with almost 250 kilometers per hour and just you know mount road you have the bullock just before that bullock cart.

So then what is the use of having this that is the fellow who is controlling you and that goes only 5 kilometres per hour where if you make it run it may go to 15 kilometres per hour, okay. So this is the smallest we say and this is very large but when this si controlling this is small you are dividing this by a small number where Biot number equal to large. So that is why in the beginning itself if we have the parameters like De and k g you calculate this, if it is around 1000 or 2000 or 5000 happily you can ignore because people also ask you scientifically whether what you are thinking is right or wrong?

We may say that yes diffusion is small when compared to diffusion through Ash layer that rate is small when compared to the film, okay these are words only but I think unless you prove that with an equation no one will believe you. So that is why if you know these values

you can go and then try to find out, otherwise you have to do these experiments, right how do we do that now because three are controlling we do not know which one is controlling?

So that is why if I conduct at very low temperatures what will happen which will control if I am conducting at very low temperatures? Reaction controls, okay. So if I am able to really do that and then finding out you know only this is valid this equation is valid so now I have atleast one step, right. So on the other hand if I have very very fast control I mean high temperature not control very high temperature ya mass transfer may be controlling but unfortunately here you have two mass transfers, right.

So that is why with two mass transfers now you can neglect this in the sense that you know when compared to very high very high temperatures this term can be neglected you have the remaining two. So with remaining two you can try to find out you find out X B at various points now you have this equation, okay. Now again straight lines are better than curves, curves are always dangerous we do not know how they go, right.

So that is why if you are able to use this equation and then arrange this equation such that you will get a straight line you can you can try to do that that again depends on your mathematical skills that is why as engineers you need mathematics and also the experiments even for scientist it is always required and generally that combination is very difficult you know good in mathematics and also good in experiments if you are really able to do both I think that is really excellent combination, right.

So like that you have to now think that how to arrange this part as a straight line and then plot okay time versus X B or it may not be now time versus X B plotting the way you arrange you will arrange as y equal to MX plus C straight line. If you are able to do that intercept should give you one parameter and slope should give you another parameter this is what what we do most of the time but may be you might have not recognized because you are only worried about whether that problem comes in examination or not most of the time okay after the exam is over delete all files from the mind for next course again you are ready fresh with hard disk, okay that is what is most of the time happening that is why absolutely even if I ask you next semester what is that I have thought I think your hard disk is so clean nothing can be told in that, okay good.

So this is what and also we have an equation for total time required if all three steps are controlling very easy what is that X B equal to 1 all X B equal to 1 and this t becomes Tau

total time, okay so that is just to give you Tau t X B equal to 1 will be rho B R 6b C Ag 2 by k g R by De 6 by k s this is equation number 30, okay this is only just for information that is nothing that ya.

So one more thing I have to give you is the proof of Pseudo steady state yesterday we have assumed that we have Pseudo steady state and why is it really valid or not? I think I can use this part itself. Proof of Pseudo steady state assumption, okay the proof is very simple which I got from Professor Anand he told me how to do that, it is not there in any book when I was teaching in the beginning I asked them Sir this proof how do we do it? fortunately it seems he has done for something else earlier in US and he told me very simple proof that is why every time whenever I am telling this I still always remember professor Anand it is very beautiful way he has told me how this can be proved that Pseudo steady state assumption is valid for gas solid reactions, okay.

So the equations are same we have already you have the equations which you have written in your book yesterday, right. So the first equation okay first the stoichiometric equation is A gas plus bB solid going to R solid rR plus sS gas this equation we know and we have this mole balance dN A by dt equal to minus 1 by b dN B by dt so all that you have, right. So now I can also write dN A by dt as 4 pi r c square which you have already done De dC A by dr that is the flux, okay and flux multiplied by ya that is dN A by dt this is the flux ya C Ac now ofcourse C Ac that means I am evaluating it ya it is C ya also equal to this is minus minus 1 by b and you have this equation 4 pi r c square rho B dr c by dt can you check that yesterday we have got this equation dN B by dt, right.

So this this can be cancelled and this equation can be arranged as dr c by dt equal to ya okay let me write this b by rho B this is one then I will write De by diffusivity dr and dr c by (()) (41:51) and delta C Ac, is this okay? This delta okay I think let me write this also delta, this I have written delta Ac by delta r and then De by delta r what are the units for De by delta r? Ya so that we call it as diffusion velocity this is as Vd diffusion velocity, okay I think I use may be this part.

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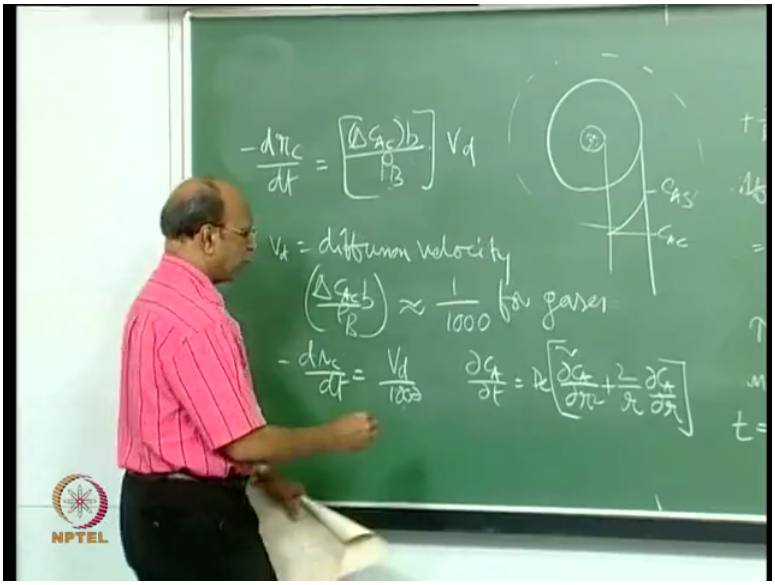

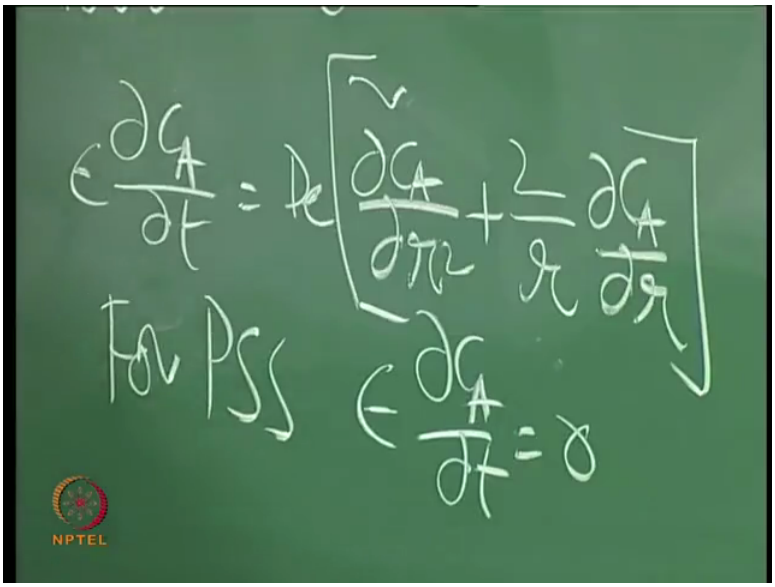

So now that equation I can write minus dr c by dt equal to rearranging that delta C Ac b divided by rho B into Vd let me write this, correct, Shekhar? Ya that is fine no. So now there are two quantities yesterday we have discussed one is the diffusion velocity, the other one is rate of shrink of core so these two are present in this equation, Vd is the diffusion velocity, okay I have not written, okay Vd equal to diffusion velocity and dr c by dt is core velocity shrinking core velocity of shrinking core, okay dr c by dt that is also velocity ya.

So now you have another term here which is relating these two, this is delta Ac by rho B, what is rho B? Molar density of solid. What is (delta Ac) delta C Ac? C A is concentration what are the units of that? Again molar concentration so now this ratio for most of the C Ac

rho B into ofcourse this is Stoichiometric quantity is most of the time for gases that is the one, okay.

Ya if I substitute this there minus dr c by dt will Vd by 1000 this is for gases. So what is the meaning there? ya the velocity of the core is 1000 times less than diffusion velocity or in other words diffusion velocity is 1000 times core velocity. So that is the reason practically at any point of time when I look my core look stationary during my analysis, okay. So but on the other hand and you know the reason why we have to assume this, Swami do you remember? Why we have to assume Pseudo steady state, what will happen if I do not assume that is a good question always.

Okay you may ask that Sir why you should assume that ya accumulation term will come into the picture that is mathematical but physical mathematically I have to take accumulation term because I cannot neglect that but physically what is happening, why I can neglect accumulation? First of all why I have to assume that I have Pseudo steady state? I explained that but again I know you will not remember so that is why again I am asking you.

I have to establish that profile inside the Ash inside the Ash diffusion inside the Ash. If this is the particle this is the one so this that is film C As film is there outside, okay so this profile this is C Ac I need a value that the difference between C As and C Ac where I can use this to eliminate my intermediate concentrations but if the C Ac if this is slowly continuously moving inside C Ac which C Ac I take because C Ac also is moving continuously inside.

So that is why in my mind when I am solving the equation that I should imagine that that is stationary at one point of time and that is very well valid for (gas liquid) gas solid reactions where the density difference molar density difference between these two is 1000 times for particle and the ratio of particle to gas is 1000 times or reverse is 1 by 1000 times. So that gives me automatically the connection the core receding velocity is 1000 times smaller than the velocity of diffusion of gases where that means immediate any point of time it is (()) (47:34) it is constant almost it is 1000 times by the time it is let us say 1 mm decreasing so this should have moved almost 1000 mm but what is the particle size you are not taking 1 meter diameter, okay.

So that is why most of these particles are 2 mm, 3 mm, 6 mm that is all I think 1 inch also rare ofcourse for 4 inches they use in blast furnace you know blast furnace, okay ya. So that is why here the 1000 millimeters it will move when it is moving 1 millimeter so that is why

Pseudo steady assumption is valid, otherwise the equation what we have to use is this ya the equation for complete analysis is dou C A by dou t that is accumulation term in fact equal to De dou square C A by dou r square plus 2 by r dou C A by dou r ya, okay this comes from input and output and this is accumulation, reaction is 0 because we have inert Ash, okay.

So this is equation used sometimes people you know this all this is happening in the pores correct no I am diffusion is only through the pores. So that is why some people also write for (())(49:08) epsilon there epsilon is the porosity, okay but for Pseudo steady state for PSS Pseudo steady state epsilon dou C A by dou t equal to 0 this is what is the equation which you have solved yesterday, right this De dou square C A by dou r square plus 2 by r dou C A by dou r equal to 0 that is what what you have solved yesterday to get that equation, right good excellent. So I think we can close here.