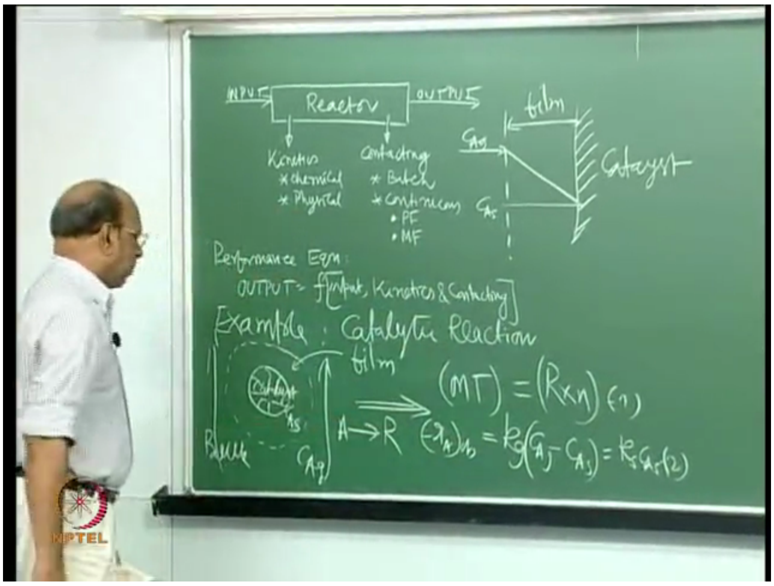
Chemical Reaction Engineering 2 (Heterogeneous Reactors)
Professor K. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology, Madras
Lecture 02
Introduction to Kinetics continued for catalytic reactions in different reactors

(Refer Slide Time: 0:15)



You know yesterday we have discussed about kinetics one example and ofcourse contacting we have already discussed earlier but this is the performance equation where using this information we have to have input, kinetics and contacting to predict what is the output from the reactor. Normal the output from the reactor is the volume of the reactor if conversion is more or if you know volume finding out ya conversion yes.

So now I said yesterday that I would like to give some more examples of the kinetics where you will see different examples how you can try to model the systems, we are not deriving the equations but we just draw the figures where it will give you a clear picture of our thinking and our thinking is more important first then actually writing the equations, right. So that is why the other day yesterday we have taken one example coal burning now we will take another example like catalytic reaction.

Example catalytic reaction ya so this catalytic reaction may be taking place in a packed bed reactor or in a fluidized bed reactor or even in a moving bed reactor and you know FCC fluid catalytic cracking and the use on system and you may say that it is fluid catalytic cracking or fluidized bed catalytic cracking but that fluidized bed is not the normal fluidized bed classical fluidized bed classical fluidized bed has the solids in the form of batch but whereas in FCC it is a moving bed or in other words sometimes we also call it is first fluidized bed, continuously the regenerated catalyst will enter and also it will come out that means the system should be operated beyond terminal velocities and there is what is called another term transport velocity.

And beyond this velocity if you operate the catalyst particle will go out of the system and during this (())(2:37) in the reactor then you will have contact between the FCC proved in the form of vapour and also catalyst and the catalyst will come out go out of the cyclone and those particles again taken for regeneration and sent back and gas is taken outside the reactor. So that is not actually fluidized bed it if first fluidized bed.

So the reaction can be this catalytic reaction can be even in first fluidized bed but in all these beds our imagination is one single particle how a single particle is contacted with the gas or it can be even liquid but gas liquid solid reactions are very very few. So our imagination is we have one single particle and we have ya this is the catalyst catalyst and definitely we know that what is highly exaggerated film this thickness and here we have the reactant going on around the particle and this is true if I take fluidized bed same situation, if I take packed bed it is also same situation one particle and ofcourse this particle is contacted by another particle but around that the gas is moving.

So if I isolate one particular and look at this this is what is happening, this is bulk gas bulk gas, this is catalyst and this is the film and now we have to imagine how should I model this that means first we have to imagine the process in our mind this is what beautifully Einstein did because when everyone was worried about Aether he did not worry about Aether he just imagine in his mind that do not worry about Aether at all let me take that in this universe the light velocity is constant and everything after words fallen in its own place beautifully.

So like that any process when you are thinking everything should be first clear in your mind till then you should not even put your you know pen and paper together it is only imagination and that can be when you are travelling that can be when you are simply sitting or in whatever position you are you may be thinking even probably as a good researcher you should think even in your dreams ya really otherwise you know you do not get ideas.

So that is the kind of clarity in the mind should come before you start and this message particularly for the P.hd scholars, MS scholars ofcourse even B Tech also when they are doing the project in the project most of the times we expect that something new should be added to the adding literature that new should come first in your thinking otherwise you do not get any ideas, right.

And straight away writing equations does not mean anything and if you understand the physical process then for example if you take a FCC again how the catalyst is moving, how the gas is moving, how they are contacting, what is the time for this contact and during that time what is actually happening all that you have to think you have to think first after thinking what normally we try to do is that we will try to put on the paper qualitatively that is what we are doing here this is the qualitative treatment.

So I have imagined that I have particles and I have gas and the gas should contact the solid and if it is porous particle it has to even go inside the particle for the reaction to take place and once I imagine that process now I would like to put this information in the form of some equations.

So that is why we have to draw first this figure and now this can be imagined as the reaction steps, how the reaction should take place I have the catalyst and surrounding that we have the gas and we know that again fluid mechanics will tell me that whenever you have this kind of heterogeneous system at the interface you have the film, then the reactant gas has to go I mean if I just say that I have A going to R products simply very simple reaction then reactant A has to diffuse through the film and in the bulk ofcourse we do not expect any diffusion and then sorry we will expect a lot of diffusion so that you now have any concentration gradient.

And then it has to go through the film where there is some resistance and you may have slightly a different concentration in the bulk we call that one as C Ag and on the surface it is C As, right so this is the process and from here it can even go inside the particle, right. So now what are the steps yesterday also I have told you about the steps what are the steps you know step 1 is mass transfer of A through the film to reach the surface and step 2 is to go inside the pores you may have pores like this inside the pores all around and then during the movement of these molecules through the pores then they may get adsorbed on the surface then after getting adsorbed on the surface then the reaction takes place after reaction they cannot sit there if they simply sit there there is no use of that surface because only product is there it is not allowing the reactant to go and sit on that.

So they have to naturally dissolve they have to come out. What is the reason for desorption? Because the concentration outside of the product concentration outside is less when compared to the product concentration here by natural phenomena called diffusion because of the concentration gradient it will try to come out.

So through the pores it has to come out first and then through the film. So desorption and product coming back to the pores to the surface and from the surface into the through the film to the bulk these are the 7 steps, right. Now as an engineer now you can try to simplify many things. Like for example I will assume that I do not have a pores particle, what are the steps that will not be there adsorption, desorption will not be there? Ya diffusion of the reactants into the pore and also product coming out of the pore is absent adsorption, desorption will be definitely there but now it will be only limited to outside surface.

So and that is one assumption as engineer I can always try that because my mathematics are going to be very very complicated, okay let me try pores particle a non-pores particle, right. So out of 7 steps now 2 steps we knocked out. So now generally what we imagine is that adsorption, surface reaction and desorption all three also we will imagine that because all three will give me a rate equation that is what we call Langmuir Hinshelwood kinetics. If I take purely adsorption, desorption, surface reaction, right.

So it gives me only minus r A a rate equation what I imagine is that I am not also taking all that because I know already because of all these three steps I have a rate equation minus r A, now how many steps are there? Only three what are these three? I have now film through the film the reactant going and then we have the surface reaction, surface reaction now contains adsorption, desorption and reaction, right so surface reaction only one step and after words from the surface the product has to come into the bulk again through the film only three steps.

So now again my assumption is that this is irreversible reaction. So now how many actual steps I have? 2, what are the steps now ya mass transfer we do not say that one as normally diffusion because around the film or through the film convective flow also will be there around that that is why we will say that we will normally mass transfer and you know the difference between mass transfer and diffusion, you know diffusion is purely by molecular phenomena it is only concentration difference and whereas the convection and diffusion together in mass transfer normally mass transfer equation when we say we have both diffusion and convection together I think I gave you this example or shall I give once more this example like again I was telling you that if I have lot of perfume on my body and now this room is very very (())(11:35), right.

So and if I stand in the middle of the room then the perfume will diffuse by concentration gradient because there is no moment of the gas at all or air in the room because there are no fans, right. So then it is by natural diffusion the concentration gradient and if I stay there and then try to find out the time the person who is sitting in that corner will smell may be in 5 seconds, right.

So someone came just behind me and then he put a big fan the fan normal may be a standing fan. So then that will now push more amount of perfume from my body by convection and over the convection definitely you have again the original diffusion. So that is why in any flow what you have is convection and diffusion in mass transfer but most of the time whether the diffusion fluxes more or convection fluxes more we have to decide as engineers.

I will now ask you the question in plug flow what is the component that you are taking, is it convection or diffusion or both plug flow we have defined sorry what is that I mean what is that we have really taken in a plug flow? Pure convection we have taken that is why we are telling flat velocity profile otherwise the velocity profile is not flat it will be slightly moving like this that is by natural diffusion, okay.

And ofcourse a little bit of turbulence where back and forth it is moving, natural diffusion means it should be slightly forward because it is as if another example most of you would have seen the conveyers belts now in the airports where you know you can just stand there and it will take you, right in conveyer belts and even super markets and all that they have the belts escalators they call, okay.

So if you are just standing there on the conveyer belt that is pure convection, if you are walking on that then that is convection plus diffusion and the velocity what you are measuring is with respect to flow which is stationary, right and with respect to the conveyer belt velocity if you are walking that is your diffusion. So in reality if you take wall if you take wally stationary with respect to wall you take in the reactor you will have diffusion and convection.

And for plug flow because we are not allowing any actual mixing so we will say that I have pure convection that is why you have the flat velocity profile, right. So that is the reason why this mass transfer and diffusion we have to separate and mass transfer what is the equation and diffusion what is the equation? Mass transfer what is the equation for flux and diffusion what is the equation use normally? Ya that is (())(14:54) gradient into diffusivity.

Whereas for convective flow or mass transfer normal mass transfer? Ya concentration difference is you know the flux is directly proportional to concentration there is no gradient there concentration difference concentration difference and the proportionality constant you are taking as mass transfer coefficient, okay. So that is why you know whenever there is a chance I would like to tell all these basics as many times as possible so that you will never forget atleast you know these basics, right.

So that is why the first step mass transfer is characterized with now this can be model with all the assumptions only with two steps and then if I write those two steps again mass transfer I am simply writing equal to reaction and ofcourse here it is hidden that mass transfer of reactant through the film to the surface equal to ya this rate of reaction on the surface that is what is at steady state ya on the surface outer surface because outers also you have surface only thing is if you have porous particle you have lot of surface inside available I have been telling you know I think sometimes it is the in 1 gram of catalyst depending on the pores and then how do you design this one? You will have one football stadium inside this 1 gram the area of the football stadium, okay.

That is why ambitious people as ambitious who will always take porous particle but in how many ways one can model the system I am trying to tell you and it is not totally unrealistic model because whenever you have noble metals like platinum, platinum particles are used and they are not porous and all the reaction is taking place on the surface and platinum wires are used wire gauzes are used as you know the catalyst which is just stacked inside the reactor that is also one of the wonderful reactors I think this is for in nitric acid fossil that is used I will also mention that at some time when we are taking about mass transfer coefficient.

So but here the assumption is that how simply one can model and as engineers we should model as simple as possible but nearest to the reality we cannot have totally unrealistic things like our all movies you know most of the movies 99 percent it is unrealistic hero hits like this 100 people will fly I think you know 100 people flying is impossible I think no human being here on this planet can do that it is only superman has to come here, right only he can do probably if he is existing.

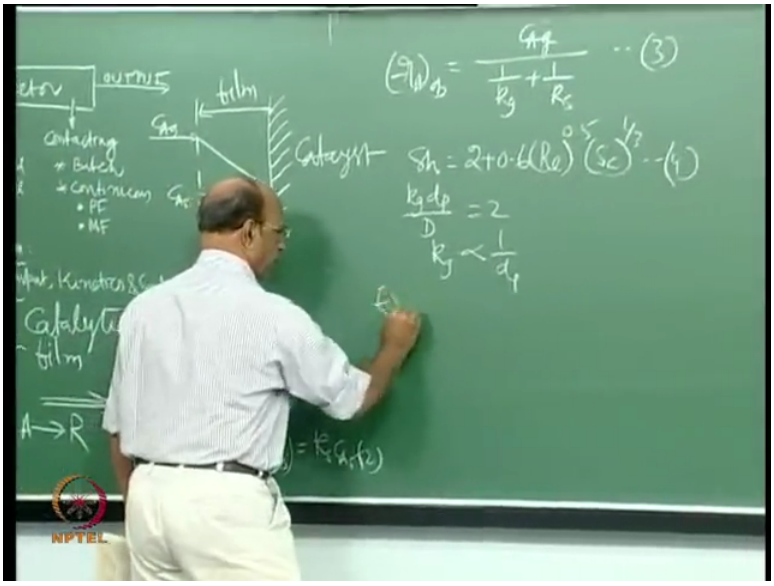
So all this unrealistic that is why model also should not be so unrealistic but all of us you know clap when 100 people flying so because we also like unrealistic things here because we are not able to do the realistic things. So atleast unrealistic things I think we are happy with that is what is fascination you know ya. So that is the reason why the model should be as close as possible again beautiful sentence you know Einstein said that it should be as simple as possible but not simpler, okay.

But reality we have to be very close to for this in this modelling that is why and when I assumed all this I am not very far because if I do not have this porous particles there are many situations where non-porous particles are also used for catalytic reactions so that is the reason. So once I have these two steps rate of mass transfer equal to rate of reaction of the reactant A then the equation again minus r A Ob this is the overall rate this also you should not forget minus r A Ob all heterogeneous systems will have only observed rate, measured rate, overall rate different books used different names for this.

And if you do not have mass transfer at all and the reaction is taking place on the surface somewhere where there is no mass transfer effect at all so that concentration is also equivalent to bulk concentration and if there is no mass transfer commutative picture and the system the reaction is not effected by any external factors like mass transfer, heat transfer then what we have is in intrinsic rate of reaction that is the difference between intrinsic rate of reaction and overall rate of reaction, overall rate of reaction takes into account over you know the transport processes like external heat transfer and mass transfer, right.

So overall rate of reaction and the intrinsic rate of reaction, so this is the overall rate or observed rate or measured rate this is what normally we write r A Ob equal to this equation already you know k g C Ag minus C As and okay I think in between I have missed something here the model for this for writing the this equation that is what I have ya this is catalyst and then this is the film and this is C Ag and in general I may have this one as C As it is exactly same as yesterday's example what you have taken correct no. So that is why this equation also is k s C As and this is equation 1 and equation 2 ya.

(Refer Slide Time: 20:57)



So in this case if I take now the rate expression like yesterday minus r A Ob equal to C Ag divided by 1 by k g plus 1 by k s, okay so this is equation 3 for catalytic reaction now I will ask your brain to open and then just think about this equation and yesterday's equation both are same, right ya but is there any other factor coming when compare to catalytic reaction and non-catalytic reaction just think in the process I have a coal particle I have a coal particle where ya so then what happens I mean what is is there any change in this equation because I am using the same equation for both the cases, right ya.

And is there any parameter which change as with the phenomena what you are describing you are telling that catalyst will not change with time because ya k s changes which one will change.

Student is answering: The thickness k g will change.

Ya k g will change because now k g depends on the size of the particle also, right and again how do you find out k g as a function of size? Ya yesterday's equation if I have a single particle, from yesterday's equation what I have done there Ranz and Marshal equation Sherwood number equal to 2 plus something you can now say that for very small particles there are two terms for Ranz and Marshal correlation, okay.

So those two anyway let me write again that one Sherwood number equal to 2 plus 0.6 Reynolds to the power of 0.5 and Schmidt to the power of 1 by 3 this is the equation what we have and now imagine if I have very very small particle then I can neglect this term when compared to this 2, then that means Reynolds number is small because of the size maybe I am using 1 micron particle and catalyst are used as (())(23:26) micron particles also I mean fluidized beds and even in FCC, FCC they used around 100 microns particles because they have to transport (())(23:37).

So that is the reason why and slurry reactors also it may be 50 microns, 100 microns like that and that is why this Reynolds number may be very very small and then in comparison to this 2 term all this product may give me may be 0.01 as an example so 2.01 and 2 does not matter for me I will take 2, so that means now you can find out what is the relationship between dp how k g is varying with dp this totally neglected.

So then I have here k g dp by diffusivity then you will know k g is inversely proportional to dp, right because dp will come down here, okay I think maybe people are blinking so that is why I think I will write this one as k g dp by D equal to 2 when that is 0, I am just neglecting that. So then this gives me k g is okay inversely proportional to dp. So similarly I can also now say that yes I have now large Reynolds numbers now 2 can be neglected when compared to ya this product.

So then I can also now find out because remember here also you have dp Schmidt number ofcourse also has dp no okay good ya and so this dp this is dp to the power of all 0.5 ya so from that also you can find out how k g is varying with dp you may start with big particle in the beginning okay in coal combustion for example slowly the diameter is changing so that means k g also changing.

So that variation you have to take into account in the design only to have that difference I thought I will also have this one that means you may have the same equation but unless you understand how process is taking place we cannot really appreciate all this and these things have to be taken into account that is why most of the time it is our brain which will give the clarity for us think, think think think but unfortunately in our education system we are not giving you any time for thinking, okay immediately quiz once starts next week and you are always worried about you know which aspect of this will come in the examination.

So that is why I think someone was telling in India that you know in India we have only exams but no education really because I think all the entire thing whatever we talked and entire think what you also convert most of the time in the form of examination whether this is coming in the examination or not that is only the problem all the time, okay. So that is why you have so many things here which we can always which simply depends on how deeply you are involving in the thinking process that is what I think most of my lectures will be only to make you that mind-set different, okay that thinking more like that.

So is why one has to take care of all these things and for that initial process is very good thinking that is why I think the first one semester for P.hd scholar should be given only for thinking you should not have you have to be (())(26:59) and kept in the hostel or whatever wherever you are okay but I think you know if you are in hostel most of the time DC plus plus you know DC plus plus should be removed and then just allow you to think it is so wonderful and then you come up and even without writing an equation I can always write like this this profile and you can also say that okay I have a packed bed reaction is going on I would like to it is a (())(27:27) reaction, right.

And now so many assumptions in your mind that is why always thinking thinking and we can also say that yes I have adiabatic packed bed reactor exothermic reaction. So can I now plot along the height of the packed bed the concentration and temperature profiles, can I also plot temperature and concentration profiles across any cross section, right and is a packed bed. So that means packing is inside a solid, can I also imagine how the concentration varies inside the particle and how the concentration varies okay between the particles across that it is not uniform everywhere and also I can I may imagine how the temperature is changing.

So that means if I have a single particle like this can I draw the concentration and temperature profiles across all this. So if you are able to imagine all that in your mind then automatically I tell you that you have clear picture of what is to be expected mathematically, okay in engineering always mathematics come when you have to quantify something, you have to say in terms of some numbers either 50, 60 or 100 how do you know 50, 60 or 100? So you have to use equations, calculate and then say that it is either 50, 60 or 100 but before that all this process should occur.

In fact my P.hd students also I use to tell them that you know when the problem is given you have to understand and then you have to draw the graphs on your own without even doing any experiment. It is not that easy like I told you packed bed, if I ask you to draw the profiles in the packed bed, temperature profile and concentration profile along the length across the cross section within the particle, right.

So now you draw them and then keep it in your diary go actually for doing the experiments and after doing the experiments compare what was your imagination and then what you actually got by experiments and also through calculation, modelling and all that. If you are thinking and if that is exactly matching then you are excellent researcher because you should visualize the entire process in the mind first and then able to convert this is what all the great scientist did.

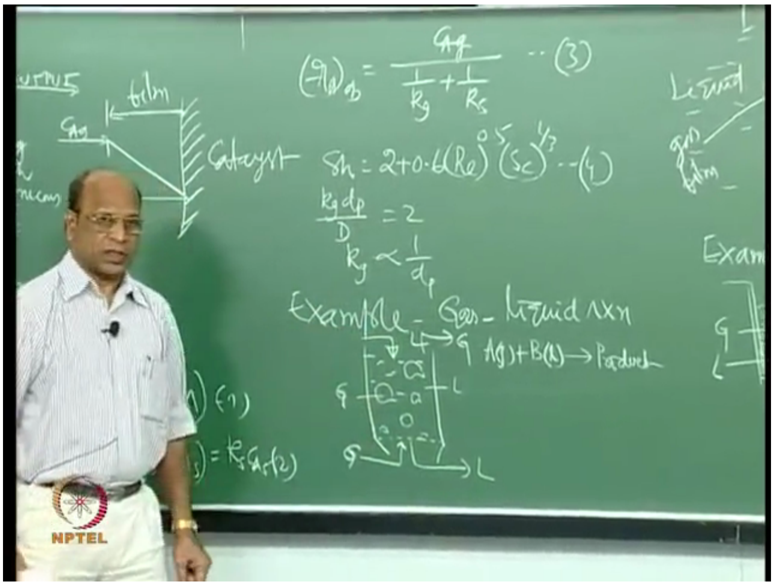
For example again Einstein everyone tells but Einstein did only that I think simply sitting in that Switzerland patent office and then thinking about the universe and he could get the beautiful ideas okay and also this is the mistake all of us do researchers we simply believe what has been published till this point, okay based on that we try to visualize what is happening but you have to question now till now whatever is available is right or wrong again Einstein example so till then people are fighting for Aether Aether Aether there is something called Aether everything is moving related to that all kinds of things they were thinking this mane said that throw away Aether and only one assumption that the light velocity in the universe wherever it is it is constant, okay.

So based on that he started driving everything has fallen beautifully and then Aether has disappeared till than people are imagining Aether is there, that is there, this is there in various medium and then finally now this is the reason why we remember always Einstein because totally different thinking you have to also do that that is why I think all P.hd scholars particular because other projects are only term bound projects so whatever they have to do they will do just now within the time.

But for P.hd scholars there is no end you can do 10 years also, okay (())(31:25) only 7 years time but you know ya but I know the reason what I am trying to tell is that you should not believe the literature that does not mean that you should not see literature at all that is what always we try to misinterpreted things, okay what is the point you seeing but anyway I am not believing it no you know have to decide whether it is right or wrong, what is right, what is wrong, what is correct, how the people have done whether it is accurately evaluated or inaccurately evaluated.

And if something is missing that is what where you have to (())(31:55) that is what we have to do all of you have to do P.hd in that because that gives you more time for thinking ya all other ofcourse MS, MS and P.hd all other courses course work programs will only brave you for examination (())(32:14) for madness. So that is why more time and then more thinking will give you the clarity first, okay.

(Refer Slide Time: 32:34)



So let us now take another example this is catalytic reaction, okay so if I have a gas liquid reaction another example gas liquid reaction, right again you know what kind of reactors we use for gas liquid reaction we use what are called bubble columns. So bubble column normally can be shown something like this I have ya it can be simply ya liquid may be continuously coming this is liquid, liquid may be continuously going out then we have gas entering, gas is coming out and we have the liquid and we also have bubbles ya so this is liquid L and this is gas, okay.

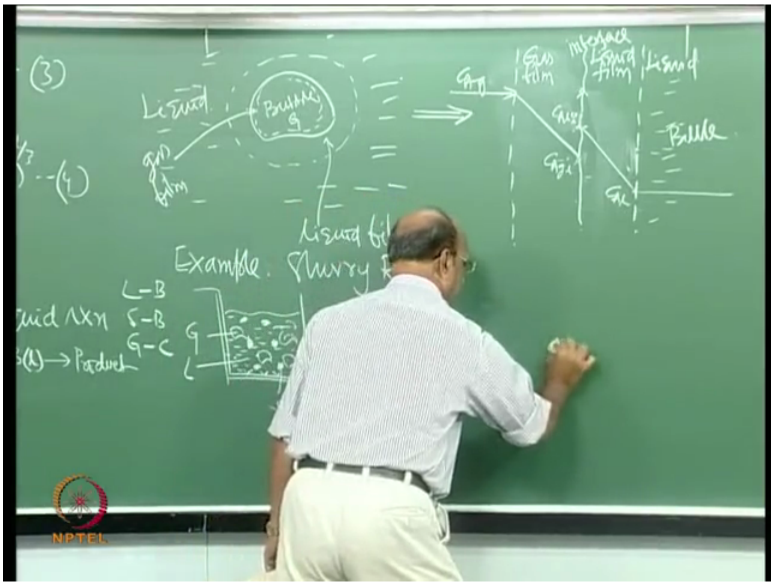
Now how do I model how do I imagine what is happening, liquid is one of the reactants and also gas is another reactant. So I can write this one A g plus B l small l I will write giving me product again I am taking reversible system, okay. Now how do we imagine, Naidu can you tell how do we really imagine this the process that means you know you can now see what is the you know the procedure for this imagination, first of all I should know what kind of equipment I am talking so gas liquid systems we can have bubble columns, okay.

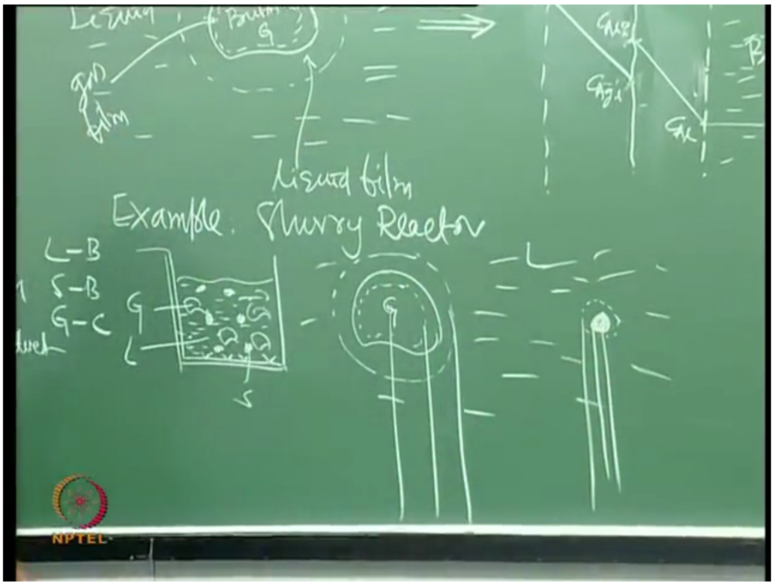
So then using this how do I imagine my process that is taking place inside this bubble is the gas that is one of the reactants and then the liquid and in the liquid you would have seen all of us would have seen I think 99 percent are of us would have seen how the liquid how the gas moves in the in liquid you know aquariums and many things you can see or soda or coca cola, right you have the gas inside stored the moment you open it will try to equalize its pressure inside to the atmospheric pressure so bubbles will come out, okay ya.

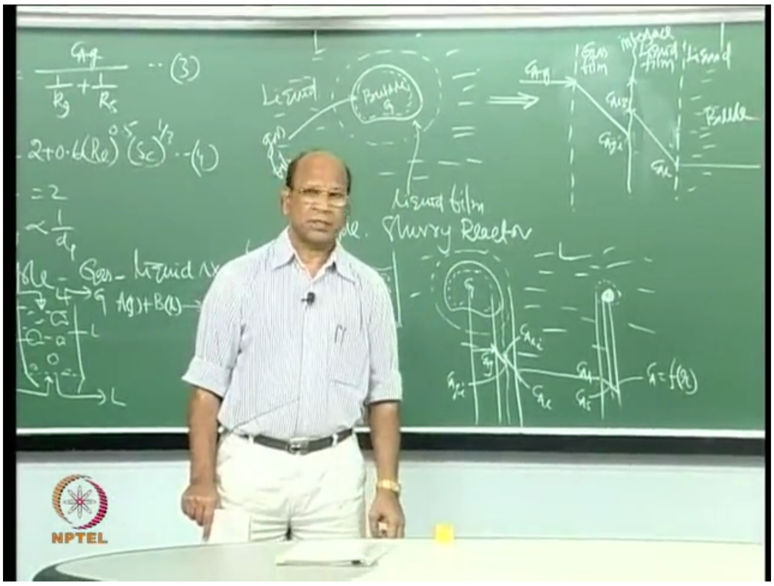
So and you should assume bubbles and liquid that is why I am telling the that example. So how can imagine this process.

Student is answering: Gas is diffusing through the bubble to the liquid so reaction is taking place.

(Refer Slide Time: 35:29)







Okay, good so I will now again imagine that I have one single bubble almost spherical bubble but most of the time this is the realistic bubble. So this is bubble gas and all surrounding I have liquid, right ya and then in the process we also imagine that we have a gas film inside inside the bubble. So now I can imagine this in terms of my profiles that I have liquid here I have first interface here this is the interface interface then we have here gas this side, then we have liquid, right.

So bulk liquid may be somewhere there but here I have liquid film that is this part this is the liquid film, okay so this is the liquid film then here I have noted also I have gas film ya, right. So now ya this is bulk liquid bulk and this is bulk gas, right. Now we have to draw the profile first before writing the equation so I know that inside everywhere here I have the same concentration of gas. So I may show that one as like this C Ag, okay.

So now this has to go to through the film this is C Ai, okay C Agi okay good. So now it touches the interface that is the liquid gas liquid interface sorry gas film I have not drawn ya this is gas film, this is liquid film ya here I am sorry here we have C Ag then I have C Agi this is the gas liquid interface gl interface and at this gl interface we have what is called Henry's law what does that tell you, okay gas has reached this film and after words this gas has to dissolve in this liquid film at that interface and then it has to diffuse further in the liquid that means liquid concentration A how much that is dissolved inside the liquid that has to diffuse through the liquid film.

So that is why depending on your Henry's law it can be either top or it can be either bottom. So that means here I have now C Ali at this point I have C Ali okay and from here again this will come here so this will be C Al and from here it may be constant please remember this connects these two are connected by Henry's law C Ag, C Al, okay ya those two are connected by your Henry's law constant so this is the profile.

Now I have to draw I have to write now three equations ya and now again you have so many assumptions here that is why deeper and deeper when you think you will get more and more information, what are the things simply saying that okay I have this is the bulk and I have here the film and then at the interface it will reach thermodynamic equilibrium Henry's law constant from there it will diffuse and then go to the bulk where the reaction taking place ya this assumption is that it is inside the bulk it need not be.

If the reaction is very fast where the reaction takes place? Almost at the interface because it does not have time to even diffuse here or if it is relatively slow most of the reaction may be taking place only in the film, okay right and if it is further very very very slow then where the reaction taking place? Entire bulk, at that time your batch equations are directly useful there. See it is heterogeneous system but the presence of gas will only occupy some volume but it is not really reflecting in the rate of reaction because rate of reaction is so slow then the reaction is taking place through the entire liquid, okay.

So you need normal batch reactor design expressions for the condition where you have very very slow reaction. If you have very very fast reaction most of the reaction may be taking place on the interface. So that is why to exactly find out what is the reaction rate because it is interface you have to very accurately estimate what is the interfacial area, interfacial area between gas and liquid, right. There are few methods available to measure interfacial areas that is why in heterogeneous systems whatever you know you only you have to think the limitation is only your mind and ofcourse you have to also find out which one is faster, which one is slower and all that, right.

And most of time when I have the bubble phase here and then the liquid film, this is the gas film, this is the liquid film that is what is given here most of the time we neglect this part why? Neglecting in the sense that we assume that there is no concentration gradient inside the bubble that is true particularly if I have pure gas, if I have two gases and only we are talking about A diffusing through B our assumption is that all the resistance is in the gas film near to the interface but if I have only pure gas most of the time we use only pure gas for example hydrogen (())(42:57) vegetable oil this is also one of the very good pictures for that too.

So then if I have that kind of assumptions like pure gas then this will dissipate totally. So then I will have only liquid film which is coming into picture, right. So with this assumptions one can now write the actual equations like we have develop the rate adsorbed, good. Another example which I give is okay slurry reactor imagination I have the reactor first, I have the particles, we have the bubbles which are fed like this these are the bubbles and then in between I have liquid so this is gas phase, this is liquid phase slightly exaggerated soil phase, okay.

Now here also I have not discussed about this one this particular one here I have taken liquid is continuous, gas also is continuous but in fact here I can have liquid as the batch, right the moment I have the liquid as the batch I do not have to worry whether it is plug flow or mixed flow because it is batch system. Now at the moment I have the gas as continuous system then I have the plug flow.

So similarly here I can have liquid batch liquid batch and also solid batch, gas is only continuous and most of the time we take it as plug flow. Now my imagination is that I have okay we have the particle sorry we have the first bubble surrounding this we have the film, inside also we have the film and here I have the particle, here also we have the liquid film, right what are the steps now? The gas which is inside the bubble has to first go through this film then at the interface, from interface to the liquid film ya this is all liquid, right.

So assumption is that liquid is sufficiently mixed so that is why the gas dissolves here faster and then no concentration gradient and then finally it has to come through this film and go to the surface and the react on the surface if it is only non-porous particle, if it is porous particle again it has to go inside very quickly drawing now I think you definitely know about all these things so I can simply draw this ya so now inside the bubble till this gas film I have a flat profile, okay and at the interface this is the interface there is some drop and from there again depending on Henry's law constant there is another drop, okay and from here it is almost constant and again from here you have the drop and if it is porous particle you have again a drop, right again if I write this thing this is C Ag, this is C Agi, this is C Ali, this is C Al, this is also C Al, this is C As if it is non-porous then this concentration C A has a function of r where r is the (diameter) radial distance inside the particle, if it is non-porous then this is stopped beyond this it is not there.

So all the steps we have to take into account. Now you see step 1 Anurag not able to follow ya because I explain those things so I just went a little bit faster here. So then the first step is mass transfer through the gas film within the bubble reaching interface from interface to liquid film that is liquid side but surrounding the bubble then inside the liquid I have same concentration because of vigorous mixing if the vigorous mixing is not sufficient which has been created by bubbles then we will also put a starrer, okay starrer also will help the solid particles not to set in, okay.

So that is why sufficient mixing we will create so this concentration is almost same throughout the liquid then it goes to the surface of the solid sorry the film surrounding the solid that is C Al then from there it goes to surface C As and then this one and then this entire thing we model in terms of a fitness factor ya it will not be same it will not be same that is why I have just shown a little bit of curvature there like this because if it is a spherical particle we can solve that and then it will come like that.

So the concentrations are analytically just draw but not the real shapes but still I wanted to show the difference so I have shown it here. So all these concentrations we have to evaluate this, this, this, this, this and then finally we can express in terms of measurable concentration of the gas phase that is one possibility, other possibility is also using the rate based on volume of the liquid these two possibilities are there in this, right.

So that is why in heterogeneous how do you define the rate also is very important. So in the next class I will tell you how do you define the rates, what are the possibilities for the rates, right I think I have already told you once but let me also write those equations then you will have a clear picture of under what conditions you have to choose it only depends on your convenience, right. So this is one example I can also come out till here and then say that yes I will now express based on gas phase, bubble phase or I can also express based on liquid phase or total volume it depends on how do you mean what you like and what is the simplest one, okay we will stop here and next class we will discuss all this.