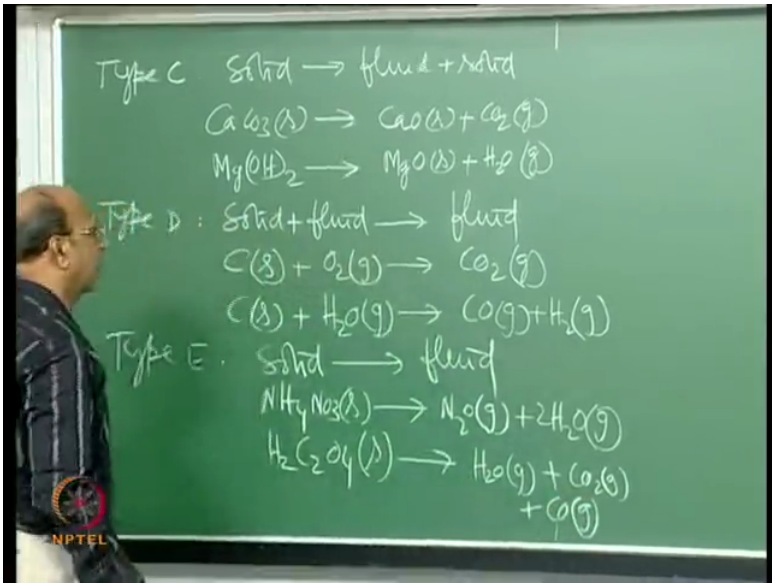
Chemical Reaction Engineering 2 (Heterogeneous Reactors)
Professor K. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology, Madras
Lecture 04
Basics of Kinetics of type A & B reactions (Shrinking core model & Porous particle Homogeneous model)

Okay yesterday we have been discussing about various types of catalytic and non-catalytic reactions and we have given examples two types type A and type B.

(Refer Slide Time: 0:24)



Now let us continue that and for type C reactions classified as solid going to fluid plus solid ya example Ca wonderful that is one of the again one of my favourite reactions Ca Co 3 solid giving us Cao solid plus CO 2 gas, right ya any other example ofcourse most of the decomposed reactions like for example magnesium hydroxide Mg OH twice giving us Mg O solid plus H 2 O gas like that there are many but I am just only giving the sample you know one or two so that you can just appreciate these reactions, right.

Again conducting these reactions and most of the time even zinc hydroxide all these reactions we will conduct to generate these oxides in the form of porous particles, right. So if I take Ca Co 3 why it should become porous is that the gas is evaluating from the solid so when the gas is coming out it is not that only outer layer gas comes out you know throughout the reaction throughout the particle the gas may evolve and then just come out, right.

So that is why it produces a porous particle and in most of these reactions the input what you have to give or the rate controlling step may be heat transfer and these reactions are one of

the wonderful examples of heat transfer controlling. Like for example this calcium carbonate decomposition I have to supply sufficient heat, right if I do not supply sufficient heat there is no reaction, okay and there is no other reactant where mass transfer commutative picture like you have carbon plus oxygen giving you C O 2, you have carbon solid and oxygen as the gas but unless oxygen is there that is mass transfer, right how much oxygen you sent to the surface of the coal that only determines the rate of reaction.

But here it is the heat transfer, right I have some derivation earlier but I do not know whether I can cover all that in this course because we have to do many other things. So this is one type of reactions.

And then we have type D reactions where solid plus fluid giving me only fluid ya you know many examples in this Na Cl and Na Cl and water what do you get? Ya okay salt solution it is not a reaction, it is simple dissolution, okay it is not the one. And you know we have our famous reactions like coal combustion in this. So solid is carbon plus O 2 giving us C O 2 gas, you have another famous reaction many of our you know department people they are being work on this gasification reaction gasification also is you know belonging to this group that is C s plus gasification H 2 O gas giving us C O gas plus H 2 gas and this is one of the very important gasification I mean reactions now, okay we felt you know by 2020 all the results of coal throughout the world, wrong estimation we have still lots of coal, in India also we have still lots of coal.

So for energy that is why we try to look at the solar energy, wind energy all kinds of things but still we have this natural resource called coal and that we have not yet still used and we do not have good technologies clean technologies, right one of the clean technology is what we think is this, why? Because if I use coal and oxygen giving C O 2 I will get lot of ash tons and tons and tons and ash but here I will also get definitely some solid material rejected because impurities in this carbon, in this coal but still this is more decent one because H 2 O will give me C plus H 2 O will give me C O plus H 2 and this can be used for many many chemical stocks as a chemical stock that means as a reactant which can be used for producing many other chemicals.

And this also can be used as energy source because we can burn C O it goes to C O 2 and also (H 2 O) H 2 energy you know, right and this is also one of the routes people are trying to get how do you separate C O and H 2 get only H 2 model, you know we are now trying to

design hydrogen cars, right for many things we would like to use hydrogen and getting hydrogen is not that easy, okay this is also one of the steps.

And you see here at the end there will not be any solid particles here that is the beauty here and how do you really design this? It is not that difficult if you understand that but as I have been telling you all the time universal steps are again identifying how much steam going and identifying how much carbon and where the mass transfer or heat transfer controlling developing the overall rate, using the overall rate again to design the reactor that is all I mean that is universal process we are not going to change at all that, good.

So this is another type of reaction there are many but only I am just giving one or two and you know carbon di sulphide how they produce carbon plus sulphide? So all kinds of the many many reactions and this is what I have been telling you you know the beauty in chemical engineering is that every reaction has a wonderful story every product through a chemical reaction, right and it is not one particular reaction through which I will get C O 2 for example there are many many sources or for example Cao there are many many sources may be single steps or multiple steps and which one is the most economical process that is what finally we are trying to see as an engineer and then develop a process for that.

That is why we never have a close ended problem we always have open ended problems and open ended problems have to closed only depending on economics, okay this is where I will concentrate because finally that may give me the least you know cost for the plant then I can produce more and I can earn more, right. So that is what is the overall picture in all these chemical processes.

And type E the reactions are simply solid going to fluid very famous reactions are there in that if you are able to get some idea. One example nowadays on the (())(8:03) is not reaction is just simply evaporation ya I mean on this planet now many people are happily using these kind of reactions to destroy people not nucleoid, dynamites and all that and that is what what also you do in your Diwali time, right solid making lot of noise suddenly disappearing fluid, okay ya.

So this is you know dynamite is one of the examples and the equation thermal decomposition of ammonium nitrate. So NH 4 NO 3 this is solid giving us N 2 O gas and H 2 O gas and I think I have already told you why you know the crackers give lot of noise and if you want to produce more and more noise what do you do with the crackers? You know you have

different kinds of crackers and I think I do not know this name how it has got there is one Laxmi cracker name that gives the maximum sound, okay and there are also some other small pellets like thing where I think I do not know what they call and that also gives bullet bombs see expert that also gives lot of sound, okay why why do you think it gives lot of sound?

And you know the simple one that red one ya that will not give you know nice fellow it will not give much sound, why why? It is simply PV equal to RT, okay ya you know you tighten it so much with so many layers of paper and if you take that red one not many layers of papers is there, whereas this Laxmi cracker will have lot of things and that what is called bullet bombs ya bullet bombs will have some kind of I think twine or something around that.

So you are not trying to you are not allowing to expand so easily so that is why when it is very very hard then you know suddenly the ya this solid will become gas and pressure is developed if you are not allowing it to come out. So if it reaches beyond certain value then it breaks that shell, when it is breaking that shell it makes noise because that energy has to be released so that is why I think you know practically you can also design one vessel ware the pressure of this gas is less than the the strength of that shell then it will not give any sound it will stay there simply, okay you see how much technology involve in these crackers and there are many many small ones also that red ones with circular things, caps or something they call, okay that is only for children so it is not allowed.

So that is why different things I know it is all wonderful things if you are able to concentrate on any subject I think you know you have many many pleasures but somehow I think the present generation lacks that pleasure I know most if you are coming by the first thing what you do is this idiot is coming at 8'o clock we have to go to the class ya no really most of you I think otherwise just giving the degree after you pass JEE or GATE or whatever exam you have then all of you will be very happy and what is the use of that in between you have to learn something, right I know most of the JEE people are very happy is they are allowed to come to in gate main in gate and near that security check you give the degree and ask them to go out get.

I think they are the most happy people if you do that because simply that passion is never created in their minds never created in their minds in the schools unfortunately, okay and school system was one of the best system in the country, right but I think we destroyed that through coaching. I mean in Andhra you know I think you know all schools they have a collaboration MOU ya memorandum of understanding with the coaching centres, okay and

from the time he is borned till he completes that 18 years he will be there only in coaching centres.

And in the school everything will be going on as if he has attended, he has attended the laboratories and you know the what that attendance everything will be given, right and then in the coaching centre what do they do? I told you know Ramayas many people are there ya they will take the cane and then show you that okay if you are not solving this problem I will beat you okay I may be exaggerating little bit but I think that is the truth most of the time.

So that is why where is the passion for you, for the subject where is the liking you know that something is there in this world I want to produce I mean have you ever thought how this bulb is operating, working and why it will not immediately come into the light you know that is why we say that people like me call tube lights because we cannot react very quickly, okay.

So why is to take time I mean just around you there are thousands of things where you know we never care, what we need is a degree and job and that job also nowadays only in terms of lakhs, okay ya I think we proudly put all our advertisements in the not advertisements I think that news in the newspapers saying that IIT Madras beat IIT Kanpur by 10 lakhs, 75 lakhs and 85 lakhs. I mean at that age if you are only worried about money I tell you cannot do anything in your life, you have a tremendous corrupted mind already ya I mean atleast it takes time I say slowly that is why last time convocation before convocation is Gopal Krishna Gandhi you heard of you know he is West Bengal Governor I think now he is in Chennai only we call him as a Chief Guest, he has given a wonderful talk I do not know how many people really got it and ofcourse students would have definitely not got it, okay I am sure about that because they were talking when he was talking we can see know as usual like in the class, okay and there were 800, 900 people sitting there they were making only slow noise but this man was reading.

And he told that so beautifully it seems for everything there is a measure he said in some Tamil (())(14:43) or something I do not know correct a measure and he says that if elephant has 6 legs because he is very heavy it looks very awkward or 2 trunks it looks very awkward, right. Like that for everything on this planet there is a measure. So similarly he says for money also there is a measure, beyond some value there is no value for the money.

I mean what you do is okay I am a billionaire what do I do with that money I cannot eat 10 times per day because have money, so I cannot sleep on 2 (())(15:20) or 10 (())(15:22) you

know that is impossible again, okay I cannot travel by 2 cars, I cannot go by flights at the same time so then what is the use you know that is the measure that is the minimum thing required and how much you can eat I mean this has the certain volume capacity your stomach beyond that you cannot eat, may be maximum 2 litres or 3 litres, okay.

So because I am billionaire I want to eat 10 litres means you will die immediately that is all there is no I think any result at all only death. So that is why that measure is there so at the end that measure also slowly comes not you know suddenly getting 10 lakhs that is why many people do not how to spend money if you suddenly give them and people like me particularly, if you give me even 10 lakhs I do not know how to spend that is because we are born in brought up in that way, right may be billionaire some may spend on that you know they may go and then take 1 drink which may costing 1 billion dollar, okay may be there are drinks we do not know, okay ofcourse what happens to him we do not know but I think you know this is the one.

So like that for everything there is a measure and nowadays I think I also told you this JEE counselling fortunately they removed the counselling I told you I think in 80's and till 85 the question was what is chemical engineering they use to ask, then we use to explain this is what is chemical engineering and where do go my son and daughter after joining then we use to say ya there is opportunity to go abroad and that is how you know (())(16:54) Kannan all these people have gone Kannan is not our B Tech student all these people have gone and then they have come back and they are doing very well absolutely no problem about that but that was the questions and as usual mainly the questions are from the parents, okay that fellow who wrote the exam he will never ask because he already over his life, okay ya.

So that is why he cannot even talk there anyway and these people ask and then after words it was saying that you know okay this internal jobs and all that they have forgotten straight way they use to ask that can my son or daughter go abroad? Because abroad means dollars, dollars means multiplied by 50, general thumb rule I think Qatar give 90 I think they do not go to Qatar because you know you have to put dress like this or you know you have to put like this there are some things you know you cannot enjoy there.

So anyway now I think people are coming and just asking ya in between what kind of jobs my son or daughter may get. Now how much my son or daughter will get that is all, okay this is how changed that fellow has not even joined and they ask you know how much my son is

going to get or daughter is going to get, in between what happens they do not care in between there is a learning called you know the thing you call learning where everyone has to learn.

So like that you know that passion is not there in non-catalytic reactions alone I can talk 2 years really because there are so many wonderful reactions and one reaction is not same the other way that is in fact the beauty you know in mechanical engineering there is only one IC engine and that has not changed for the last 100 years, right what is that it has changed? Fuel may change, people are asking hydrogen or asking alcohol okay ethyl alcohol also they use know or may be petrol may be something else or what do they change? Outside bonnet, dicky different shapes you know all different shapes they create.

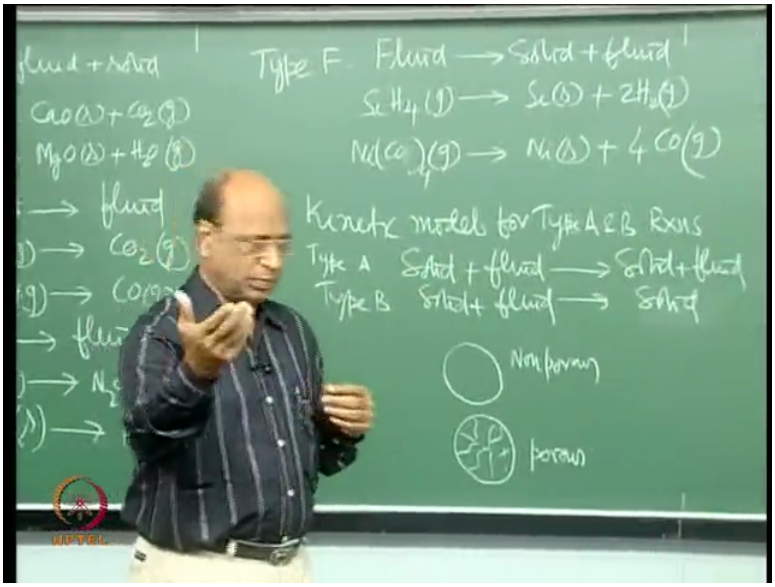
What else is there? 4 tyres are there all the time, okay I think they have not designed with 3 tyres you know like auto, may be nano may come like that earlier also, right. So engine is constant except data exchanges but in chemical engineering process for sulphuric acid alone there are 7 processes that is what what we know and if you your mind is working much much deeper you can create another 10 processes.

But what we choose is the simplest one to operate as an engineer and most economical one that is what we do that is what is happens in every chemical reaction and how many chemical reactions you can list out? I mean just if I give you you may not list out anything because you are not bothered, okay but in general if you go to any chemistry book and see okay and then see the number of reactions every reaction has a beautiful story particularly when you are when you want to produce that in industrial laboratory, okay and that is what is chemical engineering producing at industrial laboratory, okay good anyway.

So like this I think you know we have so many reactions and this is one of the reactions, the other one is not that exiting because thermal decomposition of oxalic acid, okay that is also another example and but this is what exciting you know many people are misusing on this planet I do not know I think that is why Alfred Nobel felt very very sorry and at the end I think you know he created so many nobel prizes because he himself felt that you know this invention was totally wrong dynamite invention was totally wrong thing that has happened.

It is never used for good purposes now although originally they were (())(20:26) always war ofcourse now. Ya this oxalic acid this is oxalic acid (N 2) sorry H 2 C 2 O 4 the solid giving us H 2 O gas plus CO 2 gas plus CO gas also, good.

(Refer Slide Time: 20:56)



So now the last one type F in type F we have fluid going to solid and fluid, okay. So yesterday I was telling you know one example you know the silica Si H 4 that is Silane this is (())(21:29) silica plus 2 H 2 gas and I have been telling you this reaction has tremendous commercial value now, okay if someone wants to do this, okay. Then another one I do not know in chemical technology again the chemical technology one subject we never like it we hate all that subject but I think most of these reactions I do not say almost all many reactions are mentioned in the chemical technology books, right either organic chemical technology or inorganic chemical technology books.

And there is a process called mond process what do they produce in mond process mond ya right ya nickel, who told that oh you remember very good nickel mond process. So in the mond process what we do is nickel C O 4 this is gas, okay ya so then you will have Ni solid plus 4 C O gas balanced this should be outside okay ya so we have so many types of reactions now and what we have to do for non-catalytic reactions see who will take some of the more popular reactions and the more popular reactions I mean types are type A and type B that we will take first and what is the objective? We take those reactions and then try to develop the kinetic models for type A, type B.

And type C problem is that with time particularly ya here type D the problem is that the size of the particle is continuously decreasing with time during reaction, okay ya and in type C it is the heat transfer control most of the time, right. So that means I have to sufficiently put the

heat and heat transfer must be also very very quick and reaction can control or heat transfer can control, if heat transfer is very very slow reaction will not be that fast.

Whereas if you have sufficient heat transfer then reaction may be controlling that is slow when compared to that. So that is the peculiarity in type C and type D what we have is that the particle size continuously changing and if you look at type A and (type D) sorry type B then we have a solid plus fluid giving us either solid fluid or fluid because these are irreversible reactions I do not have to worry about the products so these two we can club as one category, right.

So what we do is we now concentrate on type B and type A and type B particles reactions. So let me do that kinetic models for type A and B reactions and the general nomenclature what we give for type these two types okay I have solid plus fluid giving us either solid plus fluid or fluid so this is type A and this is okay let me also write this for type B fluid ya sorry that is type D this is solid ya thank you ya this is type B solid plus fluid, right.

So here the situation is same when the reversible reaction if it is not reversible reaction then we have to worry about how this solid and fluid both are reacting, right. So for the kinetic models as I told you first we have to visualize okay I mean every time you have to visualize whatever you do, right without knowing yourself you do this visual process that is what I have been telling earlier also to some of the people that we have what is called our mental screen and most of the time we have forgotten about our mental screen and that you do without knowing yourself, okay.

Suddenly if I say Delhi what do you remember? Or Bombay what it comes to your mind? I mean it depends on different people correct no ya that too it depends on what part of Delhi you have seen or what part of Bombay you like and you know that kind of things that is the mental screen effect even for me immediately Delhi means that you know gate what is that? India gate that comes to my mind because that road I like so beautiful that is a wonderful road you know that Rashtrapati road or something I do not know that name of that road but it is so wonderful, okay.

And you also know that Bombay means immediately Shahrukh Khan may come to some people correct no ya or may be Aishwarya Rai may come to some people, speed what is speed? Ya fast life ya okay I thought speed there is a movie or something ya that may come to that you know Gateway of India may come to some people so like that what is that we are

doing in that process you know there is a mental screen where you are trying to project whatever you know all that, that we do not know we have forgotten about that.

That is why even in chemical engineering processes that mental screen should come automatically I think that you know if the moment I say distillation column most of you may not see actual distillation column you may see either McCabe Thiele diagram or you know what we draw like the tower with plates, okay that is a mental screen nothing wrong in that because actual distillation column you would have not seen real one, how many people have seen distillation column in real? You have seen Kavya where did you see? Which industry you went? Bharat Petroleum, Abhinav you have seen? (())(28:34) you walked in industry area, okay Prabhu you have not seen Essar oil okay ya distillation columns are there.

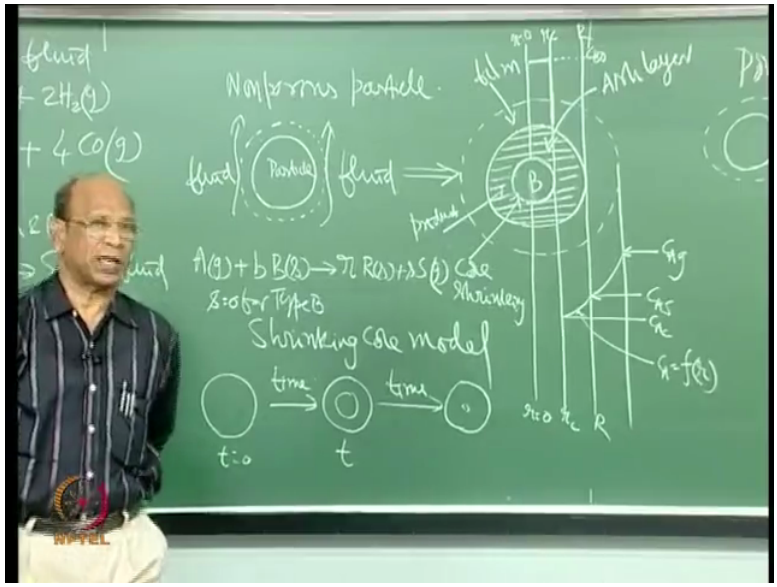
So what do the Essar oil crude oil they okay they will have (())(28:50), so Swami you have also seen? Distillation column, who have not seen you do not have seen a distillation column, okay. So but anyway it may not come but do you remember the diagram for distillation column? I mean I am not talking about those people other than chemical engineering but I think in Biotechnology also you have a course called unit operations, okay good.

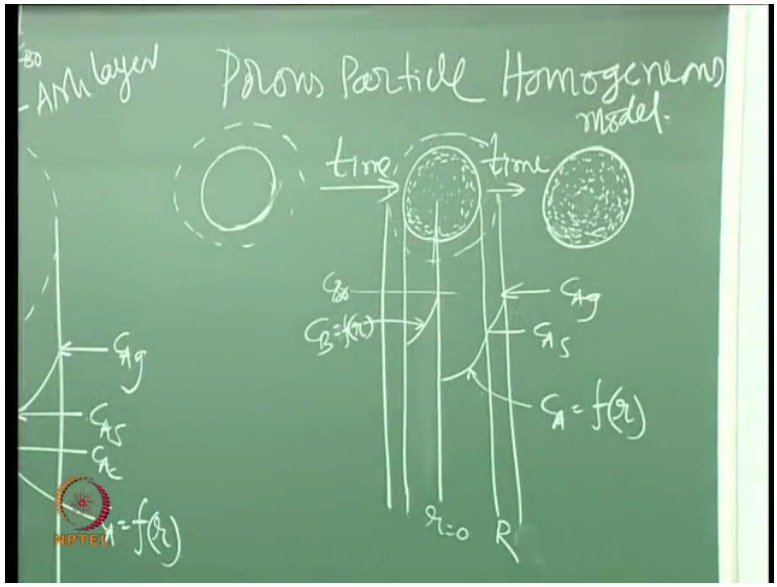
So like that for any process we can imagine that has to come to our mind first. Similarly here our simplest imagination is I have a solid, I have a fluid and I have to develop the kinetic model for that kinetic model should give me minus r A, okay good. So what do I imagine here I have a solid and maybe I will say that ya I have the solid like this, right and this solid can also be a porous particle or it can be non-porous particle and is there any other possibility? Porous or non-porous or any other thing? And all particles for discussion they are spherical particles, okay I think real spherical particles will never exist in industry but all academicians like us will first draw only circle not even sphere only circle we draw and you imagine it is a sphere, okay.

So that is what we are also teaching beautifully to you all the time but it is only imagination you know circle can you imagine as a sphere? We can, right because of most of us would have seen sphere so that is why, okay. So this is the particle it can be porous particle or non-porous particle. So now if I want to ya I mean just what normally we show for non-porous particle is sorry this is porous particle this is porous particle and this is non-porous particle non-porous ya this is again just to show cracks you know as if there are pores, good.

So now once I have this first I have to visualize my process and then we should draw the profiles and after drawing the profiles profiles you know solid profile and fluid profile what is happening inside the bed inside the particle or outside the particle or in the film all that we have to imagine. So that is why these are the possibilities in these reactions non-porous particles and porous particles the moment you imagine you have a non-porous particle you have a different model, the moment you have imagined a porous particle kinetically you will have a different model, okay and these models depend on you know what kind of process that is going on through these particles, right.

(Refer Slide Time: 31:37)





So let us take first non-porous particle simple to understand non-porous particle this may be any reaction like you know type A and type B we have so many reactions, right. So once I

think (())(31:52) for example iron ore reduction, okay iron ore particles when you take them out most of the time all ore particles they are not porous, they are very very strong dense particles, right.

So if I imagine that what kind of reaction should be going on around that? That means I have a porous particle, right and then I am sending I am just isolating always my imagination is that one particle first because that is easy for me then extend it to number of particles, right and this one particle I may take from a packed bed that is the contacting pattern or from a fluidized bed or from a moving bed or from a rotary kiln, right any kind of reactor I can just take one particle the process is same in that, right the process in all of these reactors the process is same there should be a gas, this is fluid and then this is particle and the imagination is that now the particle the fluid has to reach the surface of the particle for the reaction to take place and my experience in fluid mechanics will tell me that there is a boundary layer, okay between these two phases, right so this boundary layer is this fluid boundary layer and then the fluid has to go to the surface and then react.

So if it is a non-porous particle it is a chemical reaction, okay so that means the moment if you have sufficient temperature and other conditions and if I have mass transfer to this particle then the reaction takes place and how do I imagine this we can imagine now this that we have a ya let me write bigger one this is the film and we are now talking about reaction after sometime already I started may be if total reaction time is 20 minutes may be at 8th minute, 10th minute what is happening how the particle looks like, right.

So I should so show here okay this is the film I think you should not cross this, this is the film, this is the particle, okay I will also write here the general reaction the general reaction where do I write may be I write A gas bB solid giving me rR solid plus sS gas, okay and if this small s equal to 0 then we have this small s ya type B ya s equal to 0 for type B. So now after sometime how the reaction is taking place? First step is through the film it has to the A has to go diffuse and reach the surface and after reaching the surface then it has to first react it is a non-porous particle so first this surface has to react and then that product should be porous product, okay if it is not porous product then you know that is all only outer layer only you will have the reaction.

Then if it is a porous product then slowly it has to go inside and at one point of time may be out of 20 minutes it may be 15th minute or may be it is 12th minute then you will have ya this one is the product so product I will draw simply like this and this is the core which is

shrinking and finally this core has to go to 0 that is unreacted core this is one of our imaginations this is the core core shrinking this is one of the imagination that is why we call this one as shrinking core model shrinking core model, okay one of the wonderful example I always feel whenever I eat Gulab Jamun is shrinking core model correct no if some not properly cooked Gulab Jamun if you take the central portion will be hard, the outside will be very soft so outside is the really cooked one, the central one is the core, right so that is one example of the shrinking core because it is mouth-watering example all the time for people, good you like Gulab Jamun? What do you call Gulab Jamun or Rasgulla? I do not know what is the difference between those two both tastes sweet that is only thing I know, okay that is one.

So that is why shrinking core model always you know we can see for example even our uncooked rice is an example of shrinking core model only thing is you may not have ya spherical that is cylindrical example, right cylindrical size if you take the thing. So that is why we see daily I think our shrinking core models but here in this shrinking core model in our course we have to develop an equation for these to get a kinetic model, right.

So if I want to plot the concentration profiles for this how do I plot in mean where is the concentration we have to plot for both concentration profile for solid, concentration profile for fluid, right. So fluid this is the film I cannot go that side I think shall I move this side? This is C Ag, this is C As see I am trying to draw the same thing what we have been discussing in general you know in the beginning also that is all and all these things procedure is same.

And now this is ya this is core this in fact r equal to 0, this is r equal to capital R and this we call r c, now we have to also show there is no reaction or this core cannot shrink inside let me say this is B so the core cannot shrink inside if there is no reaction so that is why there must be diffusion of this is C Ac on the core and this one this particular one okay this C A as a function of r that profile I am talking.

Now you see here what are steps, step 1 is concentration of gaseous reactant which has to go through the film and if there is a resistance there will be drop and then step 2 is concentration on the surface ya step 2 is the diffusion sorry step 1 is mass transfer of gaseous reactant through the film, step 2 is diffusion of this reactant through the Ash layer ya we call the product layer as also Ash layer that is the general word people use Ash layer there is also

history about this because I think the first model I think was in Japan by one (())(40:14) and he used the shrinking core model for coal, right.

So coal outside layer if the Ash is not leaving the surface then you have the Ash layer outside so that word people use you know normally we do not want to change if someone first paper writes something wrong we always try to defend that, okay Ask layer, Ash layer, Ash layer so like that we do not call product layer we will always say Ash layer this is what is the lesson to know I will be asking in the synopsis meeting of research scholars ya I think they said that is it is also it is there in the literature then I use to ask them you know then what is the guarantee that the literature people are right? Why do not you change that convention if you feel that that word is not suitable, first you have to question whether they are right or wrong, second you have to question that whether the message using those words is clear or not, right.

Ash means if I say the same shrinking core model applied to Fe2O3 plus H 2 giving me Fe plus H 2 O, if I give that example when I say Ash you will blink because Ash means we know we have seen Ash or Cigarette, we have seen Ash when you burning paper that Ash only always in our mind again mental screen, right our imagination. So that is the reason why this Ash layer is a word which normally used it is a product layer for us, right you may not forget so that is the one.

Ya and how do I now draw for the solid solid profile? I may extend this to this side that is the center r equal to 0 ya this is r equal to 0, r c and capital R right. So how the concentration of solid will vary with time there will not be any concentration gradient, whatever concentration you have that concentration has been converted that means you will have if it is C B not in the beginning, right.

So you also should have here C B not which has been converted totally then you will have this C B not this is only this much left, this is C B not and how do you express the concentration there? What are the units of concentration of solid, okay what are the units of concentration of gas (())(42:51) question? Moles per unit volume, okay can we also express similarly for B? Ya we can why not ya because I know the molecular weight, I know the weight of the solid, so if I divide by that then you will get moles per unit volume, okay per unit volume if you take, right number of moles (())(43:15).

So that is why C B not again you know it is solid but you know if I do not mention I am sure 50 percent of the class will get doubt in the examination, now you may be you may not care

but all doubts will only come in the examination hall generally, right. So that is the reason why I am just mentioning all even the silly thing. So this is the one and symmetrically if I show this will be like this and this also will be like this symmetrical both sides because it is happening this side and this side it is a symmetric diffusion, reaction is also symmetric around the particle that is why we have taken spherical particle for our easy imagination and then we do that, this is the one, right this is the model for shrinking core model if I take a non-porous particle you know the moment you imagine you have a porous particle things are quite different if you have a porous particle.

So in porous particle you have ya one more thing which I have to draw here I think is initially I have this is the particle time t equal to 0, this anyway this is again you know model discrimination in the beginning but when you are developing equations again I have to draw the same picture and then we have to write the equations but this information is only to give you in the beginning how do you discriminate model, when do you take porous particle porous model and when do you take non-porous model, how do you draw the diagrams and all that that is what what I am discussing now.

So this one at time t equal to 0 after some time size is same but this core and after till ya some time t and after sometime size is again same, core is almost changed this is with time, okay that is why we move and for non-porous I mean the porous particle you have initially a particle, right with film also is there, it will not change with time same size and again same size so every time I do not have to show the film we are only talking about how this is moving.

So now you have the cracks here and the first step is anyway the mass transfer through the film, then second step is diffusion into the pores and when it is diffusing it is also reacting that means at any point of time depending on what kind of porosity you will have, right what kind of porosity you will have depending on porosity that is why porosity also is a parameter here, depending on that where the reaction is taking place we have to imagine, imagine that you know we have very very very very small pore volume or pore sizes.

So then practically that is nothing but your shrinking core model because at any time the gas cannot go to the centre of the particle. In the other extreme which we call truly homogeneous model I have lots of porosity that means the molecules of gas gaseous reactant can easily go through all these pores, right that means at any point of time if I look into the (())(46:52) everywhere I have uniform concentration of gas because there is no resistance.

So at that time the reaction is uniformly taking place throughout the particle as if it is a batch reactor correct no in batch reactor that is imagination. So when you have a batch reactor you started very well and everywhere you have the same reaction. So under truly homogeneous conditions the conditions are exactly like our batch reactor but if I have somewhere in between porosity one is non-porous, other one is truly homogeneous where the porosity is very very large then between these we have this what is called homogeneous model that is shrinking core model for porous particle homogeneous model even though it is not that homogeneous.

Ya we have this homogeneous model where the imagination is after sometime t you will have more of product near the surface and slightly inside then like this because here the rate of reaction is not that much because there is some concentration gradient, okay and at this point you have most of it is reacted may be small portion is left I am making noise now but ya here I may not have that kind of product formation where I have just some ya still that central point might not be reacting completely.

And ofcourse if I wait for some more time then ya completely it make it reacted and here I can tell you later because we are only trying to do shrinking core models because most of the time they are on non-porous particles, porous particles are very few. But if you have a porous particle homogeneous model we do not even know how to define the conversion because at any point inside I mean very accurately, right.

So at any point inside this solid reaction is going on whereas here I know clearly the boundary I can calculate clearly the number of moles in this volume because I know concentration moles per unit volume this volume I know how much depending on r c so then I can calculate conversion very easily. Whereas here it is everywhere I have to calculate how many moles and then I have to totally integrate from ya this to centre and then only get the average conversion throughout the particle.

If I draw the concentration profile here, okay (())(50:00) ya there is no core here and C Ag, then you will have C As, then you have throughout it may happen so this is C A as a function of r and coordinate is r equal to 0, this is r equal to capital R, this is r equal to R and that is the film, okay. So now if I draw for solids, how the concentration looks like? Let us say I have C B not is this, okay here I do not have C B not anyway inside the particle after sometime how it drops, where it will be more at the centre C B ya at the centre then how do I draw?

Ya so you have a concentration drop something like this, this is C B, C B again as a function of r that depends on the diffusivity ofcourse diffusivity depends on the porosity and all that. So now these are the two models what I have one is homogeneous model, another one is shrinking core model and now we are going to in this course only study about shrinking core model and homogeneous model mathematics we cannot develop you know we can develop but I think I will not have time to do all that but I can give you the basic information like this on homogeneous model and all the non-catalytic models for gas solid particles type A and type B have been based on either this model shrinking core model or homogeneous model either this or that.

Homogeneous model I will do one equation that is the simplest one truly homogeneous model, right that means I have large porosity where everywhere we have the equal concentration of the gas then the reaction is uniformly going on throughout the particle that is like a batch reactor, in fact if it is a first order with respect to A then you will get almost batch reactor this is an expression, okay for the kinetic model r A, right.

So now the overall picture is that we have now identified shrinking core model and homogeneous model which depends on the state of the particle whether it is porous or whether it is non-porous, if it is non-porous then we use shrinking core model, whether if it is porous then we use homogeneous model and now using these models how do you actually develop now the rate equation.