Chemical Reaction Engineering 1 (Homogeneous Reactors)

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Lecture 56

Dispersion with reaction Model and Tanks in Series Model

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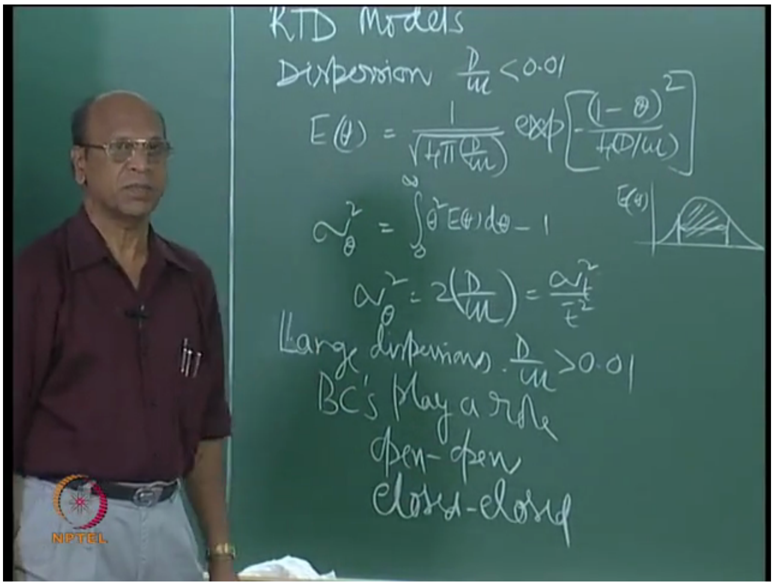

I think this equation already we have, right so where t bar and all that also we have written there but you see as I told you the procedure we have drawn the graphs somewhere there and then for different D by UL and best method is I think plotting on the same graph so somewhere it will match with one of those curves so that will be D by UL but there are many other techniques that is not the only technique because it is only you know Gaussian distribution if you are aware of the Gaussian distribution curve 68 percent of the area middle area, okay when I plot like this this is E theta versus theta so this 68 percent of this area 68 ya will have two sigma ya right 68 percent will have two sigma you know this width, sigma is the variance, right.

So now if you are able to connect variance and D by UL then definitely you can estimate D by UL our idea is to find out what is the actual value of D by UL, okay for that axial mixing which you are measuring experimentally, right. So what we did earlier was you plotted so many graphs and then one of the D by UL will match with the that simulated so many curves one of the D by UL will match with that so that is the D by UL that is existing for that set of run, okay that particular run.

Then once you know the D by UL what is the next step? Next step is using this D by UL you calculate actually what is the ultimately it is conversion what you want to find out, right Ramkrishna why not not able to follow, okay or no? Following okay good. So this is like that there are many other techniques so that is why how do I now relate the variance and D by UL you have an equation sigma theta square equal to we have from that equation know sigma theta square or sigma square what is the equation?

0 to infinity, anyone I think no one remembered theta square E theta d theta that is all something else is there? Minus 1 that theta bar will be 1, okay minus theta bar square actually minus theta bar square that will be 1, right so this is the one now you see I have this equation E theta here substitute this equation here integrate and it is 0 to infinity anyway minus 1 is there then you will get that beautiful equation if you do that 2 D by UL please remember in RTD our idea is when you are modelling our idea is to estimate the non-idealities for axial dispersion model there is only one parameter called dispersion number which contains D, U and L ofcourse I know I should know, right so D is the diffusivity if diffusivity is very very large you have large dispersions you know tracer will spread more and if D by UL is or D is small you will have very narrow distribution that means you are towards plug flow ya towards PF that is the idea, right.

So that is why we should not forget the actual purpose of the model, the model purpose here is to estimate actual quantity of D by UL non-idealities here it is D by UL, okay in some other case it will be dead space, in some other case it may be bypassing. So every time when you have bypassing here we assumed only axial mixing that is why this contained only a parameter which describes axial mixing in terms of D by UL, indicating D by UL small means you are towards plug flow, D by UL large means you are towards mixed flow, right in between you can also have 0 to infinity these values, right that is the idea.

So that is why the best method is going to MATLAB giving this equation and the experimental data asked for match but you have to give the guess value that is one of the excellent methods otherwise if you want to have a feel simulate all the graphs you know earlier we use to have tracing papers I do not know whether you have seen any you know anyone now know about tracing papers so it is a transparent paper you draw all those line on that and then put on this your experimental curve but scale must be same where experimental curve and all that then one of that thing will definitely match or if it is not matching exactly it will be between two curves. So that curve value approximately you take and then go to MATLAB give it and then you will get the final D by UL value, right good.

So and here this is very nice equation only for small dispersions dispersion less than D by UL less than 0.01 that is valid for that, okay so here boundary conditions will not affect whatever boundary conditions you get ya whatever boundary conditions you used to solve that equation you will get this kind of equation this is Gaussian distribution it is logical you know this is where engineering you know if you have engineering intuition you will simplify mathematics, what is engineering intuition here? I am expecting axial mixing, right so axial mixing very small mixing that means it is towards plug flow but a little bit of spread is there.

So what kind of spread you can expect? I can expect symmetrical spread that means if I draw the line in between at the mean so both sides you will have symmetry that is Gaussian curve, okay and that can happen only when you have small dispersions that dispersions people have tried long time back and then said that that must be D by UL less than 0.01 if you go beyond that you will have again problems.

So this is one of the methods and now you also have to how to calculate sigma theta square using straight concentration versus time data, do you have that in fact this is nothing but sigma t square by t bar square, how do I get sigma t square directly because you do not have to even calculate E theta and all that, right so you have that sigma okay 0 to infinity t square C dt divided by again 0 to infinity C dt so minus of t bar square, right that equation itself you can use to find out sigma t square and then divide by t bar square you will get sigma theta square which is 2 D by UL, okay so that way also you can find out D by UL, there are many ways how to find out D by UL so this is the one and this is about small dispersions.

And if I go to large dispersions that is D by UL, okay I think I have to write large dispersions large dispersions D by UL greater than 0.01 here boundary conditions play a role BC’s play a role and what kind of BC’s we have not discussed what kind of BC's till now, right but I said there till the boundaries will not boundary conditions will not affect so that is why we have not discussed there but here what kind of even there also the same boundary conditions will come but any boundary condition you use it does not matter.

But here what kind of boundary condition is I discussed this sometime back what is called open-open vessel, closed-closed vessel so that means whether we have open-open boundary or closed-closed boundary is the discussion, okay.

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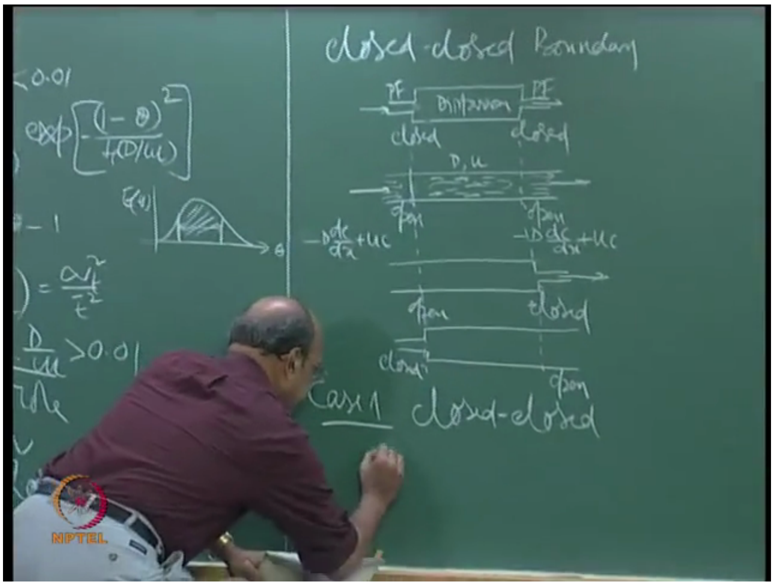

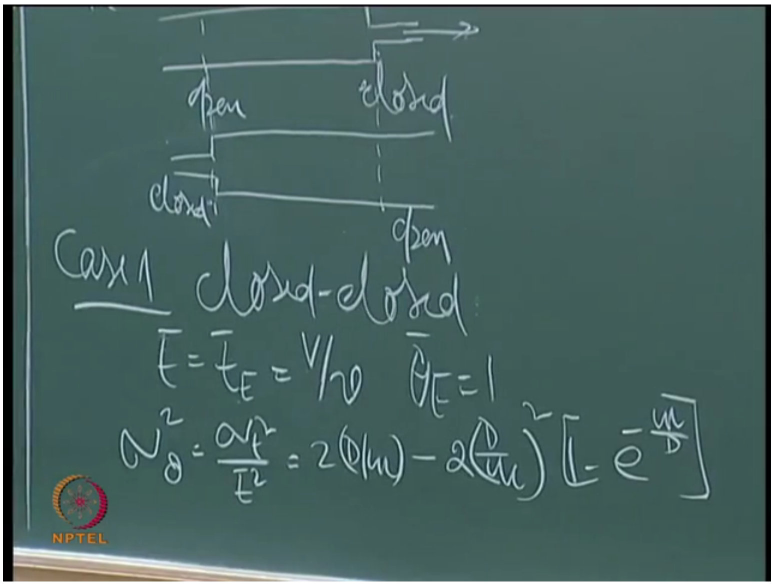

So you have when you say closed-closed boundary because already we did this so let me write that closed-closed boundary closed-closed boundary so you can imagine something like this you have a plug flow reactor and then okay so here material enters by PF and here material enters by or leaves by PF this is closed-closed boundary this is closed closed, closed does not mean English meaning closed, closed means you know okay so you close and then nothing will happen there you know nothing will enter, nothing will come out, okay so not that closed-closed boundary means PF material is entering by that means till here I have flat velocity profile oh now this source is closed, okay okay and also from here when material comes out you have flat velocity profile. So that means what is dispersion in that? 0, right that is the boundary condition so this is closed-closed.

Now you have open-open open-open is straight so material enters like this, leaves like this but now whatever ya okay whatever dispersion is there here okay same dispersion also you will have here and also same dispersion you have here that is what is open-open, okay. So this can happen in packed beds for example packed bed diameter will be 1 meter then the entry may be 7 inches, 8 inches, okay so then you know the velocity inside the packed bed will be less definitely because area is more and the entry point is small, velocity will be very high you can always assume that we have plug flow there.

So most of the time for packed beds you have closed-closed boundary and most of the time for tubular reactors where you have you know homogeneous tubular reactors where I have given you that problem know your design problem is homogeneous reaction there you do not use feed pipe small and also other pipe bigger in actual reactor you do not use, so whether use 4 inches, or 5 inches, or 6 inches uniformly like this, like this, like this, okay so test section we are assuming we have axial mixing and even before test section this side also you have dispersion, this side also you have dispersion, okay.

So now I told you on this oh that differential equation I have not written that differential equation which I have written earlier that differential equation I was telling you there are many papers on that, okay. So people try to I mean because academicians they do not have many much work know so in the sense that okay let us try what will happen. See same dispersion number throughout here, here, here that is one paper, right okay otherwise you use some different dispersion number here different dispersion number here same dispersion number here and here another paper, okay.

So now you use different dispersion number, different dispersion number, different dispersion number three different dispersion number or D by UL, okay or diffusivity then you have another paper. So like that you know just to show that what are the conditions you may get what kind of responses you may get when you change diffusion coefficients that is the reason why I have so many combinations I told you so many papers have come earlier and this is taking open-open and closed-closed, right.

See one example is at the this is the boundary, right you have dispersion and plug flow, what should be the equation? Equation should be UC minus or okay first minus I will write minus D dc by dx if I take this one as x direction plus u into c that is the flux that is entering, okay this diffusivity I am talking this diffusivity is 1 here. So because it is open-open you also expect the same equation to be valid here again dc by dx plus uc, okay.

Now you can ask okay and inside also I have same dispersion some dispersion and velocity velocity is normally taken throughout same, okay so what I was telling was that this will be D1, D2, D3 so in the outlet pipe there is some kind of dispersion may be size changed and all that and here inlet pipe you will have some other dispersion and here you will have some other dispersion or otherwise even if it is a packed bed with same cross section, okay or even different cross sections to you will put some packing here, some other packing here, some other packing here that will change the diffusivity coefficients, right okay.

Now extending the same thing here what should be closed-closed vessel equation I mean closed-closed boundary equation? This is plug flow, okay this must be simply u into c that must be equal to because here you have dispersion, right the moment it enter this is actual this is dispersion because please remember please remember we are talking about only dispersion equation you know axial dispersion is there that is what is the model.

So I have dispersion here but here when it is entering the flux, okay alone by UC and the moment it comes it will split into because axial mixing is due to so flux due to or okay dispersion flux and also convective flux here the moment it crosses there again UC only there is no dispersion there that is what is the different boundary conditions what we have and now you know our all intelligent people know why not open-closed, closed-open all combinations, okay.

So now if we say ya open-closed you will have the same pipe till here, okay same pipe but here what happens? Plug flow, so this is open ya this is open, this is closed reverse also all you know academicians are highly intelligent people in doing all this ya so this is oh sorry sorry ya so now till here this is closed, this is open so those are the boundary conditions what we have been talking.

Now when you have this kind of dispersion D by UL less than 0.01 all this does not matter whatever dispersion you know the boundary conditions what we have used you will get only Gaussian distribution which is described by this equation that is why in engineering you have to see how to use mathematics in a proper sets mathematician need not care that is his job not to care for everything he may complicate but as engineer you should be able to tell that okay.

So now for small dispersions all these boundary conditions will not you know will give me only Gaussian distribution and what is the equation that we will describe Gaussian distribution this is the equation that gives the Gaussian distribution nowadays you have the

MATLAB not MATLAB what is that laptops and all that you have XL, okay just simply go D by UL assume 0.001 and then theta vary from 0 to may be 5 or 6, okay and then think 0.1, 0.2, 0.3, 0.4, 0.5 intervals just calculate E theta and then plot beautifully you can see I tell you then only you feel actually otherwise you do not feel, okay good.

Now with these boundary conditions that means that open-open boundary and closed-closed boundary and when I have large dispersions what are the equations we are going to get understood, not understood, okay. So now first we will take closed-closed vessel, for closed-closed vessel what is the equation we are going to get you are very happy atleast for the examination there is no equation there, okay but you know the problem is we cannot solve that we do not have an analytical expression then what you do? Numerical, so numerically they solve and constructed the curve and took the variance and mean, right.

So please write that then for closed-closed vessel now that means we are talking about large dispersions large dispersions case 1, case 1 is closed-closed vessel closed-closed boundary under these conditions write that for closed vessel analytical expressions not available not expressions expression for closed vessel closed vessel means you know both sides closed-closed boundary or closed vessel analytical expression not available is not available however we can construct a curve by numerical methods and evaluate evaluate its mean and variance mean and variance exactly we can evaluate.

So the mean will be t bar also equal to t bar E the meaning of t bar is there t bar is volume by volumetric flow rate, t bar E is ya from E curve how do you get E curve from the experiment sigma you know all that same equation, right okay. So this is equal to ya volume by volumetric flow rate both are same again here in closed-closed vessel so that means t bar E experimental and t bar theoretical that is I mean I do not say theoretical volume by volumetric flow rate and this is from experimental observation both are same, okay so that is one thing and naturally what will be theta bar E, when t bar equal to t bar E okay so theta bar E equal to 1, okay good.

So now the other one variance sigma theta square which is nothing but sigma t square by t bar square equal to ya see now this equation 2 D by UL minus 2 D by UL square okay into 1 minus e power minus UL by D that is the equation, okay I think if you have just compared that one with this equation what is that because here dispersions are small in this case ya only first term is taken because because dispersion is small D by UL is small square of that is much smaller so that is why this term is neglected for for you know small dispersions, okay good.

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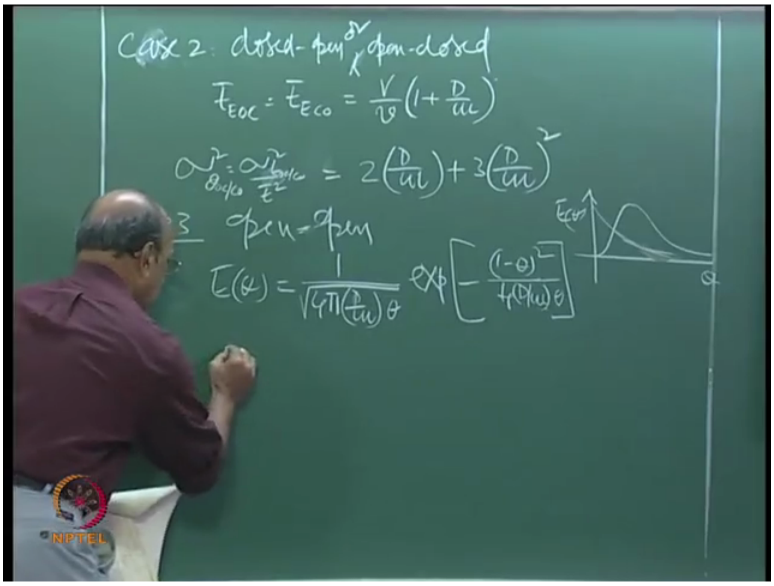

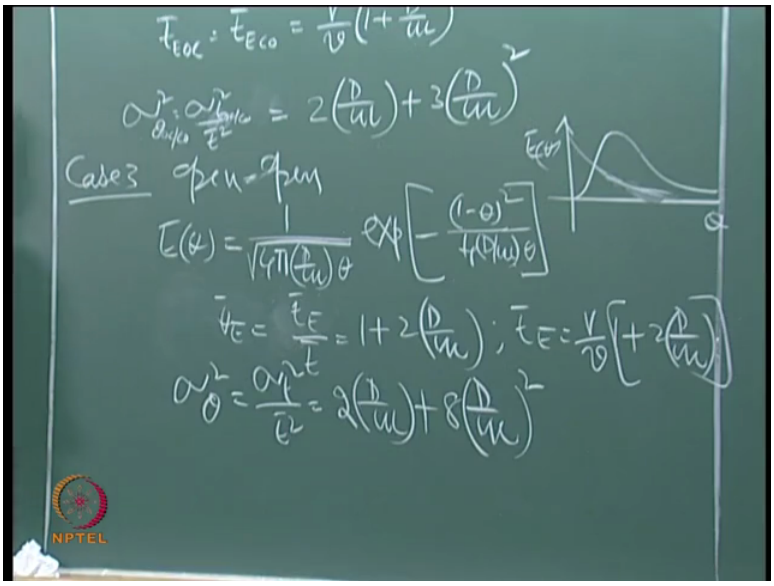

Next one also we are happy case 2 is case 2 case 2 will be closed-open or open-closed both are same so that means this case ya this case and this case ya right this is open-open this case and this case both are clubbed together but only thing is one end is changing that is all here this side is closed and here this side is closed but again here no solution is available for that closed-open or open-closed or open-closed, right please take that here also there is no solution available just below that you are writing here also.

But here I can tell you there are very nice things here t bar t bar E OC, OC means open-closed equal to t bar E CO closed-open, right equal to volume by volumetric flow rate that is t bar 1 plus D by UL and sigma theta square equal to sigma t square ya for both ofcourse we are telling OC and also or CO this is sigma t OC, CO by t bar square this must be equal to we have 2 D by UL plus 3 D by UL square this is the equation what you have to use, okay and here see we tell always that volume by volumetric flow rate equal to t bar, okay correct know and no one knows how it has come, correct know you never question how it has come because we are happy because volume has meter cube, volumetric flow rate as meter cube per second then you get seconds very happy because time is there so we are very happy that is all what we do but actually that is not right that is only strictly valid for what condition not steady state we have the answer on the board, ideal what what (())(24:20) where no dispersion it is not for plug flow it is also valid for your mixed flow ya closed-closed vessels why closed-closed vessel?

Again there is beautiful physics there because in open-open vessel why it is not valid is that the material because of dispersion may go outside at inside the reactor but your volume by volumetric flow rate is only by for volume is for the reactor alone not for the entry section, correct know Swami lost lost where did you lose I think I am talking only English or Telgu shall I tell you in Telgu or what, what is the problem here I think so nice diagrams we have given here, okay if you are lost means you have not come with your brain better go and check that somewhere you left it, okay that may be the problem or may be in the suitcase or something or somewhere you have the bag know, you do not have bags so then definitely somewhere you left, okay.

This is so simple to understand know because always we say volume by volumetric flow rate as t bar which is not correct that is only correct for closed-closed vessel because the volume what you are taking is between these two boundaries but actually when you have that open-open vessel then the material is going like this that is what is the dispersion so that is why truly it is not valid and how much it is valid is given by this that is why I told you answer is there on the board itself this is valid only when D by UL equal to 0, right and that will be only for closed-closed vessel here you see here t bar equal to t bar equal to volume by volumetric flow rate this is another beautiful thing what you learn, okay.

And in fact you can also derive there is another equations is think in one of the old books I found when it is valid, it is valid only for considering the entry level and also exit level but not in the peak times but open-open vessel you will get this problem because material may exchange across the boundaries atleast at this point of time you should able to tell your juniors who are there in the other colleges do not tell that volume by volumetric flow rate equal to t bar it is not correct, it is only correct for closed-closed vessel. He will say that when you closed where is the vessel he will say or he or she, okay.

Then you have to explain again what is you know closed-closed vessel, what is open-open vessel so that is what is beauty in learning I say one point in your course where you should not forget I am sure your residence time is only 24 hours maximum that too I think before the exam, if there is no exam 0 resistance time nothing will be there just listen and then go away, forget so that is very nice things you know you have to learn here, okay.

So that is why you will not get this t bar as volume by volumetric flow rate but atleast that point you please remember this blind definition of volume by volumetric flow rate in fact I told this in the first few classes who told us volume by volumetric flow rate equal to mean residence time unless otherwise because mean residence time it should take mean size, correct no, either integral or sigmas you have to take we never take that and simply someone told teacher and you are happy because as I told you again it is volume by volumetric flow rate so volume volume get cancel seconds will come we are happy, okay hours also we are happy time is coming we are happy that is all but there is lot of things here no behind that definition when it is valid when it is not valid, okay.

Then these two we covered even though there are four cases this case in case 2 we have both combined closed-open and open-closed.

The other one is case 3 where we have open-open, okay Swami open open-open now do not open both sides only one side open otherwise it will enter and then go away, okay. So in open-open vessel analytical solution is possible again so that means they have used these boundary conditions, okay for open-open vessel and then solved that equation the analytical expression is E theta equal to 1 by 4 Pi (oh my God) 4 Pi D by UL into theta square root that is there as usual so exponential, then we have minus so minus 1 minus theta square here we have 4 D by UL D by UL and theta and ya okay so that is the expression.

What is the difference between this and that? Theta actually that will stretch the curve stretching the curve means for open-open the response what you get E theta versus theta will be it is not symmetrical but it will be like this it is not symmetrical symmetrical means it should come to 0 here itself, okay and why that is happening why that is happening ya because more dispersion so it is not nicely only moving like this like this, it is moving like this like this but one side you will have SQL, okay so that is the reason why you will get that kind of response there when you have large dispersion, if you have infinite dispersion? Priya, how do you draw if you have infinite dispersion? Ya 0 time to leave 0 ya straight line ya straight away it is vertical or horizontal? Horizontal any idea Swami vertical ya why straight line.

See infinite dispersion E theta what is the equation, I have infinite dispersion in the equipment that means it is equivalent to mixed flow, mixed flow has beautifully decreasing like this exponential decay without touching it goes to infinity I cannot go and draw okay so I think okay so that is what is E power minus theta you see I think these small extensions is the one where I am always telling you you should be happy to learn those small things, right ya small dispersions, large dispersions, infinite dispersions and all that, okay good so this is the curve.

Now you see our idea is to estimate again D by UL we have discussed already how to estimate go to MATLAB or any lab and then try to match okay or I think Rangnathan lab that is what you have just done the experiments right okay ya that is computer lab only ya I mean actually I will tell Rangnathan next time I he has to include this exercise in that, that is more relevant than telling stories, okay no no I think all the time when you are doing project if you have mathematical model as well as experimental data may not be your experimental data or may be your experimental data what you do is this and in see M Tech we may not stress that much, okay either you do modelling or experiment generally not both but for P Hd it is a must P Hd we should able to see whether they are good in doing experiments and also analysing the data and also using the mathematics to describe that experiments all these three we check then only degree is given, okay theoretically speaking (())(33:08) things you are not checking here that is different, okay.

So that is why this is a must the matching the data with experiments is a must and always when you do in P Hd also it is not your data in fact if the other data is falling on your equation that is fantastic people will really appreciate, your data your model there is no thrill, right but your data some other model or your model with some other data jump up and down thrill, okay that will be very good because people really appreciate my God because someone in America or someone in Russia doing that experiment, okay that data still your model is able to describe or vice versa your data which you have taken in India described by an

American model or may be Russian model or Japanese model, okay so that is why all these things are very important for us, okay good.

Now the next one is to estimate D by UL ya this one this equation I have just forgotten to mention I am repeating many times so I have to find out sigma t square by t bar square because from my C versus t data, right sigma C and all that then that will give me let us say 0.2 for example then calculate D by UL this is a quadratic equation you have to take the reasonable value, okay normally you will get one negative, one positive so then you can find out which one is the correct value D by UL for that particular you know equipment, okay good.

So here also same thing the procedure is same now so here also you will not get ya sigma theta square okay is also sigma theta square open-open o-o okay this is equal to we have 1 plus okay I think I will also write this one this is t bar E by t bar equal to 1 plus 2 D by UL or otherwise t bar is same equation I am writing it is not a new equation equal to t bar that is volume by volumetric flow rate 1 plus 2 D by UL, okay what is the difference between this and that? You have twice the D by UL because large dispersion open-open (I made a mistake that is the next equation) this is theta bar thank you.

So sigma theta square is the next one, sigma theta square will be this is sigma t square by t bar square which is equal to 2 D by UL plus 8 D by UL square so that is what is the story of dispersion, okay so we cover all the conditions and this is enough and there is a lot of literature on this and corresponding to this curve there is an F curve, right. Swami how do you do from E theta to F theta? That is all F theta equal to 0 to theta E theta D theta so you have to integrate and then you will get F theta, similarly here also you have get F theta, right so either F theta or E theta whichever is convenient to you one has to use that, right good.

Again here D by UL you can calculate using sigma theta square which you get from your experimental data and then say that this is the D by UL. Now the story goes to conversions, okay so now I have a reactor I designed it and then I was not very sure whether I have plug flow or how much axial mixing, right then we conducted the experiments we already design please remember you already designed and may be assuming that you have plug flow you design, right and then you conducted experimental you know RTD data RTD experiments then you know what is the response from the response you saw that there is a axial mixing there is axial mixing.

Now that you quantify after quantifying what you have to do is okay I designed for plug flow but actually axial mixing is there so now what is the actual conversion that is curiosity definitely know we designed for 95 percent assuming plug flow, when you have axial mixing Swami what will happen, conversion reduces or increases? So I would like to find out how much is that exactly, 95 I designed, right you are not lost I think you are there very much.

So when you are when you have 95 percent and then when you are able to find out what is the axial mixing now it is our interest to find out whether it is 90 percent or 92 percent or 93 percent that is the actual conversion. So for that there is another model required correct know D by UL you have now so using that D by UL you should be able to calculate, how do you calculate without an equation how do you calculate because it is calculation, it is not estimation and ofcourse you can do experiment and then find out what is the actual conversion, right that will not be 95 percent if you have actual mixing but can I also calculate?

So for calculation we have axial dispersion model with reaction, right that we will do very quickly now you can assure it will be till 12 midnight, you are able to understand the sequence know. See RTD will give us the non-ideal parameters, using these non-ideal parameters we should be able to calculate the actual conversion after all chemical reaction engineering is only to calculate conversions for a given volume or for a given conversion calculate volume that is all the entire thing.

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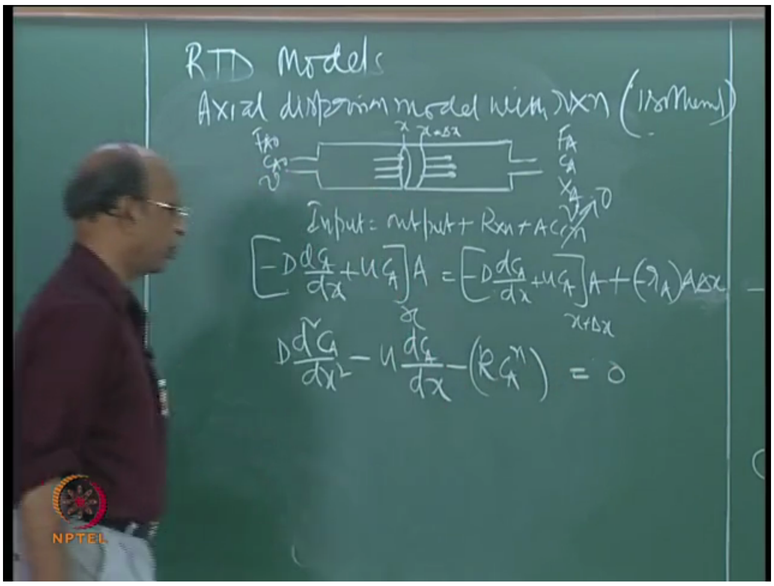

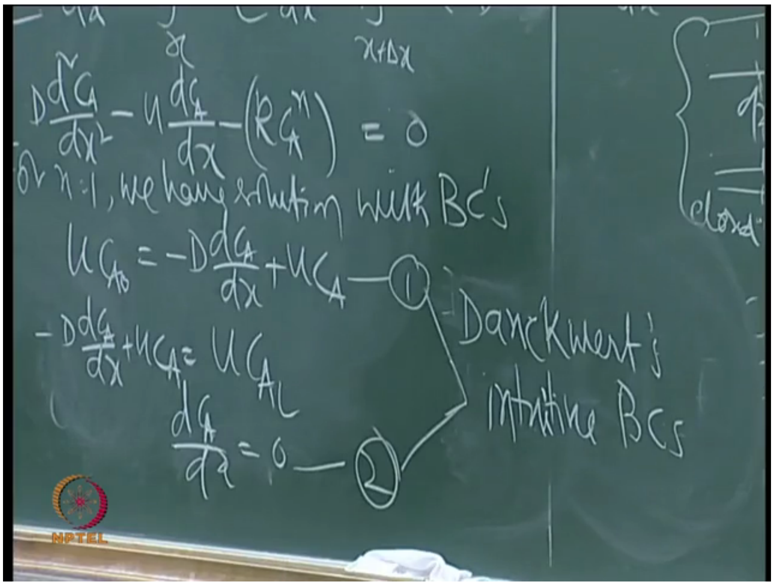

So now axial dispersion with reaction axial dispersion model dispersion model with reaction, okay here I think I will just draw the figure ya okay this is plug flow what you have good. So input okay this is volumetric now now I can write FA not, CA not ofcourse V and T not ofcourse isothermal we are talking about isothermal and XA not equal to 0 so this is FA, CA, XA and ofcourse volumetric flow may be V or (())(40:29) good.

So input output plus reaction plus accumulation all four will be there or which one I should take out because our reactors are always steady state reactor so this will not be there, in the earlier case reaction was not there but accumulation was there because tracer is by definition that experiment is on steady state experiment, good so this is the one. And here also the same thing what we have written in the morning dCA by you see now A has come dCA by dx plus u into CA this is A but this is at z at x, this is x, this is x plus delta x so that is input and output is exactly same uCA A but this is x plus delta x plus reaction in that volume ya minus rA (AD) A delta x okay that is the volume so I think this we must be having.

So now once you simplify that the equation what you get is that D that is the diffusivity coefficient dCA by dx square minus u dCA by dx minus rA so now this minus rA I am taking as kCA to the power of n which is equal to 0 so minus rA equal to kCA (())(42:31) here nth order reaction but as usual only first order reaction and zero order reaction will have the solution other orders will not have analytical expression and you will have for only you know for first order for n equal to 1 we will have solution, right and with BC's right okay we need two BC's here because second order.

So that means at the entry at the outlet it is closed-closed vessel but now you see Danckwerts comes into picture and then he tells some slightly different kind of argument for these boundary conditions and there were on that paper alone around 50, 60 papers again on the Danckwerts boundary conditions let us see. So when this is closed-closed vessel what is at the entry equation u ya what u into Swami alive, CA not this is reaction u into CA not that is the flux which has been dispersed into minus D dCA by dx plus u into CA, okay so that is what.

And at the outlet I expect exactly same thing minus D dCA by dx plus UC must be equal to UC but now if I take this as L this entire thing as L length that is what know D by UL when it comes this is at CA L just for example, okay so this is CA L. Now there was lot of discussion on this boundary condition and Danckwert said that you know he is an excellent engineer his intuitions are fantastic he said that simplest manner what you can understand but anyway so this boundary condition is okay but this boundary condition he says that it is not physically correct, right.

So why he says that is physically correct is not correct is that this one because when you have this CA U into CA that is the concentration where is that concentration when I look at this point you have this one L plus this is L minus let us say, right. So at that very very very very very thin boundary thin boundary and because till here only you have reaction and afterwards there is no reaction what should be the concentration? CA must be equal to CA L, otherwise what will happen either reaction or there is concentration discontinuity in it concentration discontinuity should not be alone because unless there is a reason you cannot say that there is concentration discontinuity.

So what should be the correct BC then, excellent that is all dCA by dx must be 0 and these are the two boundary conditions what he has used this one and also this one, afterwards many people try to you know prove that he was wrong, no I think there are so many papers and there is a big article also review article where finally he collected all the papers and finally said Danckwerts intuition was right okay.

So these two are called Danckwerts Danckwerts Danckwerts intuitive intuitive boundary conditions BC's I think handwriting is very bad Danckwerts I think I will write clearly because I think Danckwerts is very important. So these two are Danckwerts intuitive BC's intuitive okay intutive intuitive okay intuitive boundary conditions, okay so I think you know I tell you when you go for an interview somehow you bring them to RTD, tell Danckwerts boundary conditions your job is guaranteed because they do not understand much I think high funda guy so (())(47:45) that there must be something but you should explain very clearly without you confusing, you confuse yourself and then you know no job, I think other job also they will ask them to go away from there so if you have already sub job.

So that is why this is very clear and you know this and later many people try to prove that he is wrong but found that you know experimentally the conversions what they get was right depending on his (())(48:10) Danckwerts boundary conditions. Now using these two what should be the equation so that we can use that for our okay.

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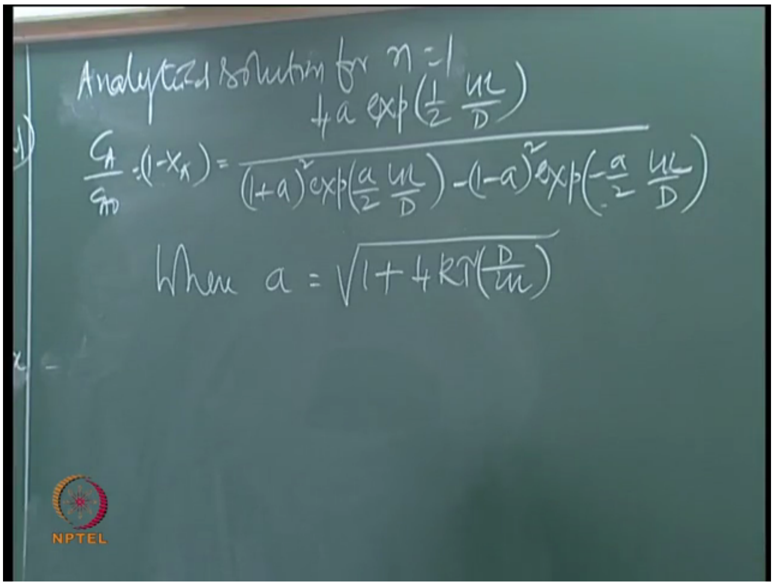

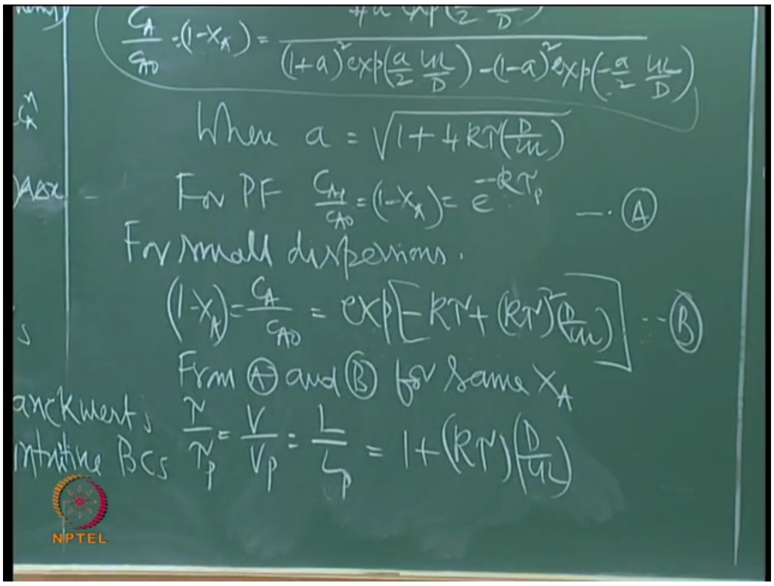

The analytical solution is for n equal to 1 is this, this already I have written once, okay I have also told you the beauty in assuming plug flow that is the equation. So now using those two boundary conditions you get CA minus CA not equal to 1 minus XA and I think today I do not know somehow I stopped writing the equation numbers exponential of UL by D 1 plus a square exponential a by 2 UL by D minus 1 minus a whole square exponential minus a by 2 where a equal to square root of 1 plus 4 k Tau D by UL, okay very simple equation know ya very simple and happy equation that is what you have to use just by taking one non-ideality called axial mixing just one non-ideality, right.

So instead of that I think you can happily assume plug flow and correspondingly what is the equation for plug flow first order 1 minus XA equal to ya for PF CA by CA not CAP I will write equal to 1 minus XA equal to t bar equal to Tau, you see how beautiful innocent looking expression and how complicated idiotic expression you choose what is that you need beauty or you need complications? Beauty yes very good ya you need so this is so happy simple equation know ya so this is why you know this is complicated anyway but anyway after sometime I think life goes to complications so then that is why you have to conduct RTD you have to conduct RTD experiment and normally closed-closed vessel or now D by UL you have to estimate go to this particular equation and then calculate what is the exact conversion.

Because for a given reactor you know Tau, right volume by volumetric flow rate you know you know volume because given volume. So that means you already have the reactor and now you want to find out what is the conversion in that that is what normally we do, this comes only after designing assuming you have plug flow but you are not very sure again I am repeating.

So then you conduct an RTD experiment, right so I think Arya getting tired okay. So then you conducted an experiment and then you see the response curve it may be very nice small Gaussian curve and then you may say that you have small amount of axial dispersion and that dispersion number is estimated D by UL and you go to this equation and calculate conversion, just imagine for a new reactor for you do? In the beginning itself you want to take this axial mixing into into account and then design a new reactor what is the procedure Swami? I am asking you because I think you know you said you are lost I want to bring you to the class that is all, what is the procedure now, question is clear or not clear, smiling is not the answer you have to tell something ya first of all you tell me what is the procedure, that I will answer later how do you assume because you are now considering that already you have D by UL, okay.

So now there is lots of data available in terms of Reynolds numbers and D by UL, if you go to Levenspiel book for packed bed there is separate graph, for tubular reactor there is separate graph, Reynolds number versus D by UL, okay it is not exactly D by UL it is D by udt dt is the diameter of the tube multiplied by dt by L dt dt will get cancel you will get D by UL, okay that is the geometry expect ratio what we call this is the dispersion number express (()) (53:24) slightly different, okay good so that is what.

So what is the procedure Swami? You know the other procedure you know I already have the volume I want to calculate conversions straight forward I am asking now I want to have the volume but conversion I assume 90 percent and also dispersion number I will assume because normally you know Reynolds number means sorry plug flow means what kind of Reynolds number you should have very high so you have to have definitely some Reynolds number when you are calculating based on your plug flow alone, okay so you have to assume okay my plug flow will be only 40000 Reynolds number then go to that graph and read that D by UL, okay.

So then even if it is packed bed we have that data then what do you do, now I know D by UL so what else you should know there Tau only you have to calculate, right so because conversion I know conversion I know okay and D by UL I know ofcourse here a I do not know a means again I have Tau, okay k k I will know because whether I have the kinetics so now you have to solve this equation for Tau see how difficult it is that is why best thing is assume plug flow again same story, okay same thing okay.

And now ofcourse here you have a you have Tau and this a you have Tau, this a you have Tau all that, right D by UL you are assuming D by UL you are assuming, okay you do not know L at that time but D by UL as a number you are assuming, right okay good. So like that you have to do that is why again one of other greatest engineers after Danckwerts the logical engineer is Levenspiel, okay and earlier to him also people have done he now said that this equation need not be used completely if you have again small dispersions we can now expand this this exponential expansion you remember that is why we read mathematics earlier, okay M1, M2, M3, M4, M5 only for this okay that exponential expansion is what is that x x square ya that expansion we use and drop out all D by UL squares because dispersion is small we are assuming that.

Using small dispersions that means dispersion square will be smaller D by UL square will be smaller and you take only D by UL values. So when you do that for small dispersions for small dispersions the above equation will be CA by CA not equal to exponential minus k Tau plus k Tau square D by UL so this is the equation, okay and this is very easy to get from this that is not difficult at all when you expand this, this, this and then yay a finally you will get only this if you expand and then simplify, okay no no I think his problem is now you wrote there UL by D but below you write D by UL how do you get, then then what else ya so if you do not like this I will write here UL by D below over right know that is all this I think UL by D I can write there so thereby that is not a problem but you do it is very simple, it is not that complicated that equations are threatening but if you put on the paper and then write you know that expansions it is not that easy because all second order terms you are removing whenever you have D by UL square you are removing or UL by D square then you will end up with this, okay.

So this is the equation what you have, you see now straight away for even non-ideal reactor I can now calculate what is the conversion, right so D by UL estimated, okay and if I want to find out conversion now you know Tau I know I can calculate easy CA by CA not otherwise even reverse is also not difficult, reverse is what I know CA by CA not I do not know Tau D by UL I am taking you know like from that graph and you can calculate what is Tau, good okay.

So now using this information we can even find out what should be the logical length of or L by dp and also L by dt if it is empty normal homogeneous reactors what should be the length by diameter value for maintaining almost negligible dispersion that is again some simple exercise is there using this okay are you able to understand me, Swami? This is the same straight forward equation simplification of this but using this and also this equation CAP this is ideal, this is non-ideal okay because D by UL is there for me, right.

So now if I take the ratios of these two for a given conversion for a given conversion 1 minus XA equal to 1 minus XA this is also 1 minus XA okay ya these two equations I will take and now for a given X atleast I think I have to write this equation I think A I will say because there is no serial number ya from A from A and B for same XA, okay Pooja, nothing? Till further simplification, no no D by UL when it is smaller square of that is much small it is mathematical simplification it is not we are neglecting dispersion, yes ya for small dispersion I can further ya for small dispersion means D by UL is value must be what? Small so then only I can expand and then D by UL squares I can neglect, no you will get only D by UL here D by UL here only, there also you will get only ya this is a analytical expression that is fine, no no I think you know this mathematical details you can find out you will get only this expression, okay.

So then there are other equations here, Pooja there are other terms here D by UL squares those things are neglected because that is not contributing for the value let us say let us say I have kt square or kt equal to 10, okay and D by UL equal to 0.0000001 what do you do so you do not get any value there, right in engineering sense. So that is why we neglect those terms, right.

So that is how only we are simplifying this and I think thereby and still not come out of UL by D and D by UL, okay you expand this and you will get that I think you know ya that is not a problem at all, okay good. So now the question is this is non-ideal, this is ideal. For a given conversion can I find out length or volume which one will be more? For a given conversion I have non-ideal reactor, okay I want 95 percent conversion and I have ideal reactor which length or which volume will be more? That way you can now estimate using these two equations, that length you can estimate.

How do I estimate that, how do I estimate from this? These two are equal right correct no so 1 minus XA is 95 percent, this is also 1 minus XA 95 percent conversion so now both are equated and then separated for Tau P and Tau, Tau P and Tau nothing but LP by or okay Tau by Tau P is nothing but L by LP, correct know volumetric same volumetric flow rate. So that is what is the estimation now.

So that will be V by VP equal to L by LP if you want you can also write here Tau by Tau P, okay this is equal to from this two equations what you get is 1 plus k Tau again D by UL that is the volume, okay this equation good and this is again very simply one can do that I think it is not that difficult to do that again here when you are doing this when you are equating you have to also expand this I am just giving you the clue you have to this is E power minus k Tau plus k Tau square by D UL know you expand this again in terms of that 1 plus X 1 minus X square X then plus X square by 2 or 2 factorial, okay all that expansions.

Again neglect there D by UL squares and then you will get this expression you see now so the length of non-ideal reactor will be 1 plus this is LP plus this is the extra Tau, correct know if I just (divide) multiply by LP, L equal to LP into the whole thing so L equal to LP plus this term will be the extra length, right. See these are all just to give an idea you know how nicely how simply how beautifully one can simplify the mathematics for actual engineering purposes, okay so that is the one.

So there is another question also that can raise now what is the other question? Here we have conversion same so it need not be that always conversion same, it can be also ya volume same then how do you calculate that means Tau equal to Tau P.

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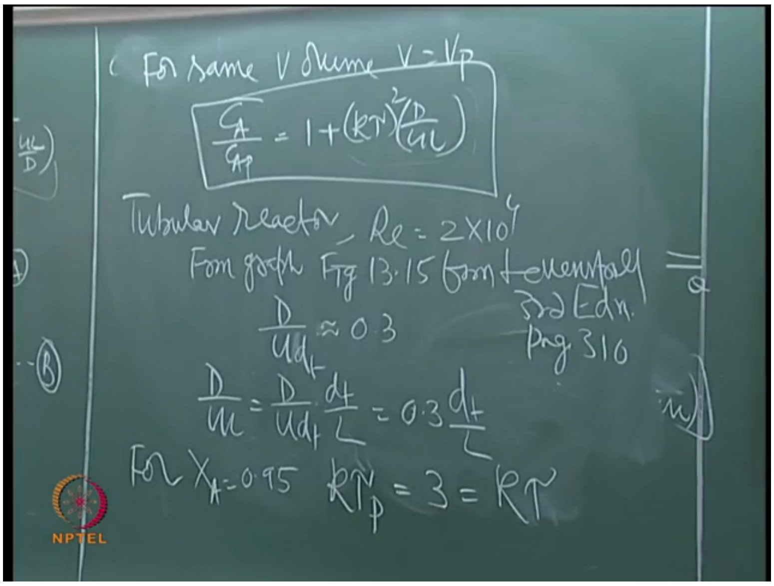

So for same volume that means V equal to VP, right volume same but in one you have non-ideal parameter like axial mixing, in other case it is ideal so now conversion must be different, right so how do I find out that ofcourse we can write this in terms of CA by CAP that means the concentration coming out of ideal reactor and the concentration coming out of the non-ideal reactor so that is 1 plus k Tau square D by UL that is the equation, right okay good.

Now let us take this equation and now try to estimate for tubular reactor for tubular reactor that means you know empty cross section you have, right that is this is not a packed bed homogeneous tubular reactor then I may have axial mixing in this and here we would like to find out what is the effect of this term k Tau square by D by UL what is the real effect of that so that means what should be the ratio of okay or what percentage of conversion we will lose or concentrations you will have when you have depending on these values of D by UL, D by UL need not be one value it can be different values which are connected with are you able to see, not able to see Gyaneshwar ya this is for tubular reactor and this one is for packed bed this one is for packed bed, right or otherwise I think if I keep here (())(66:52) I think you cannot project that, this is for packed bed, this is Reynolds number and this side we have dispersion number.

Similarly here we have dispersion number and this side we have Reynolds number. So if I know my Reynolds number some value I can go and get that D by UL, right and then we will do some kind of slight small calculations to get some important points here, okay ya please take this one let us estimate the rough order of magnitude the rough order of magnitude of effect of the term k Tau square D by UL k Tau square into D by UL that entire term for tubular reactors.

Let us also assume Reynolds number equal to 2 into 10 to the power of 4, how many 20000 ya 20000 Reynolds number so now go to that Levenspiel graph, okay I will also write from graph okay from graph that is figure 13.15 from Levenspiel 3rd edition most of you have 3rd edition, okay so there it is not D by UL but it is D by Udt, okay. So D by Udt value D by Udt value is approximately 0.3 from graph good okay page number also I can tell 3rd edition page number 310, okay good.

So now D by UL of this will be D by Udt into dt by L so this value I know so this will be 0.3 into dt by L simply substituted this value only we substituted. Now let us assume that we have XA equal to 0.95 XA equal to if XA equal to 0.95 what will be k Tau P okay k Tau P ideal, ideal reactor, XA is given what is k Tau P? I know you tell me the value 3 excellent. So k Tau P for XA equal to 0.95 k Tau P equal to 3, okay.

Now what is our assumption this equation is valid for V equal to VP then that is also must be equal to k Tau still some minds are working so okay I think this side totally dead I think they went to darkness (())(70:18) you are still in (())(70:20) worried about ya. So that is also k Tau now substitute that k Tau and also D by UL there why why you will find out you find out now dt by you know dt by L to find out dt by L, Sushmita gone?

Okay you understood know why we are doing that we would like to find out what should be the logical dt by L or L by dt? So length by diameter of the tube you are deriving that tubular reactor, okay ya so there it comes nicely ya you have the equation what equation what equation (())(71:16) what equation you lost it already, what did I say there k Tau is 3, but what do I do with that 3, idea is to find out L by dt I have this equation right you know for D by UL it is 0.3 dt by L and for k Tau it is 3 and where is the equation this equation.

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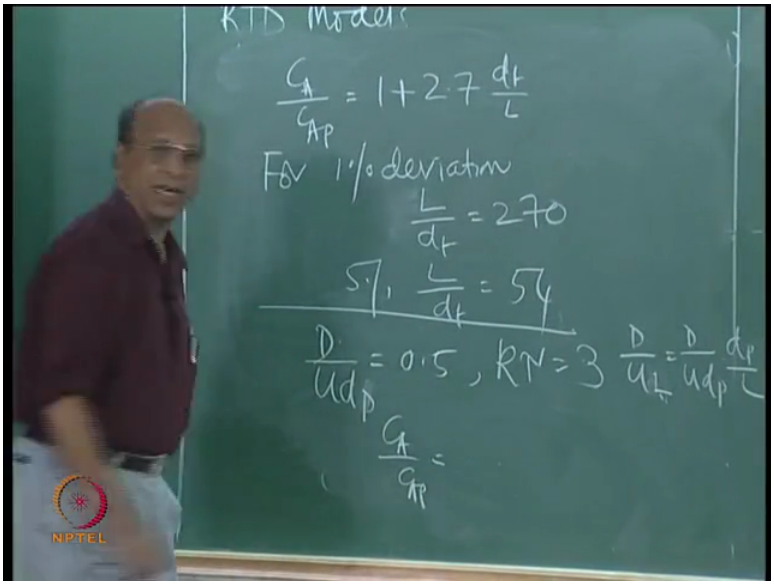

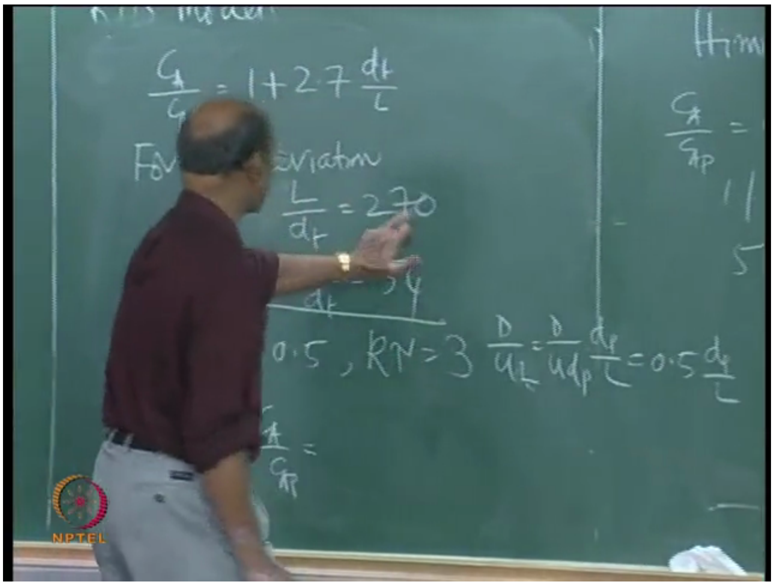

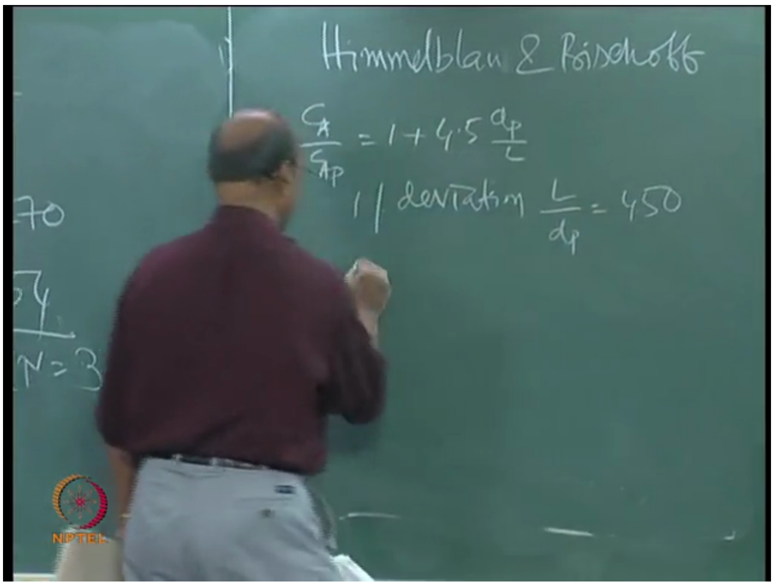

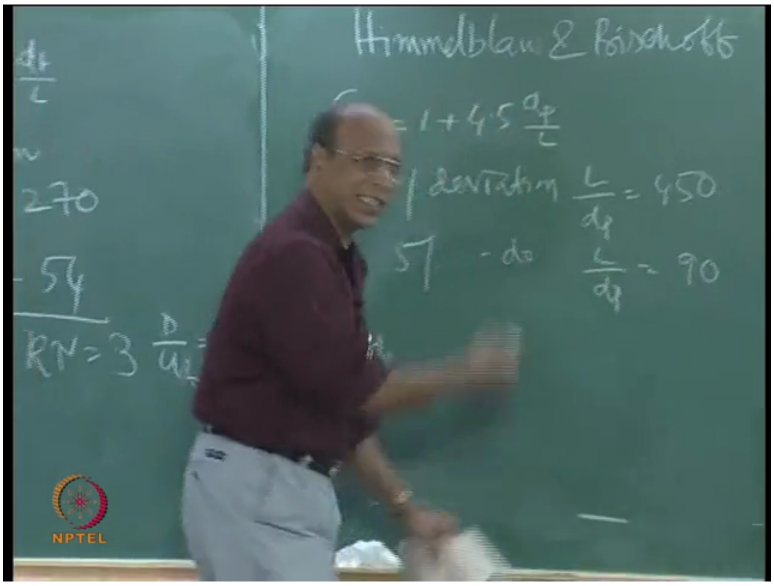

So now what is CA by CP? Now you tell me, how much is that 1 plus 1 plus 2.7 dt by L, now you calculate if I need 1 percent deviation from ideal CAP CAP is the concentration that is coming out from ideal plug flow, right I think see Pooja with time she is becoming more and more active, okay good Pooja for you I think till 12’o clock class because you are becoming more and more active now it is very good I also become like that you teach more and more I think you know go on teaching that is all life long, okay good.

So now the deviation is from CAP CA should be 1 percent deviation, right so you tell me what is L by dt that is beautiful information this is I say CAP and CA CA must be 0.01 CAP ya for 1 percent how much L by dt 20, 270 excellent L by dt equal to for 1 percent deviation 269.9999 okay so dt by so for 5 percent because as engineers you can discuss you know you can decide whether you want 1 percent deviation or 5 percent deviation ya for 5 percent what is that? Very easy I say divided by 5 know, 54 okay so what is the conclusion simply I wrote something you said 70, 270 and then I wrote is there any meaning in this what meaning you can make out of this.

If you want 1 percent deviation from ideality you maintain 270 times L by dt value then you do not have to worry about that complicated equations, so it is logical 270 times what is the diameter of the normal tubular reactors normal ya you take 6 inches 150 okay 15 centimeters or 150 150 mm okay 6 inches that is 0.15 meters now you multiply how many meters length you have to maintain 0.15 into 270, is it logical 40 meters I mean will you get this kind of values in industry Arshad I do not know he is seeing like this or like this what is that you decide like this or like this, will you get around this 40 meters length in plug flow reactors in the industry and what is the design problem ask him, what is the length he got?

Ya usually you will have kilometers length if you need you know that kind of big production rates what we are trying to do in industry, okay so that is why that condition is easily met condition is very very easily met this is what what you have to really remember.

So okay I will maintain my L by dt as more than 300 I mean approximate value then I do not have to worry about my non-ideal axial mixing at all wonderful know it is not there in any book except in one book called (Froment and not Froment) Himmelblau and Bischoff Himmelblau and Bischoff ya anyone has seen this book you would have not even known that book exist but once upon a time this was an excellent book particularly for control people and also mathematical models same Bischoff, Himmelblau is different.

Why it is unpopular? Because no one is teaching you from that that is the problem, Himmelblau separately you may have some book and you know that process calculations know ya same guy only Himmelblau this is called deterministic systems and above that there is another title main title process analysis or something process analysis, control is there, RTD is there, transport phenomena is there wonderful book and the book is A4 size it is not small book, okay from there about reactors this particular thing when I saw I thought what a wonderful analysis I have to tell and I have been telling this last 20 years, okay.

So that is the kind of wonderful information Himmelblau and Bischoff I think in our library there must be one copy. See same thing let us extend for packed beds, okay packed beds also you know plug flow reactors so the same calculations but now let me tell ya DL by Udp, D by Udp Udp equal to for you know 0.5 from the other graph you know in the same page we have for packed beds also another graph and k Tau is same again let us say for 95 percent k Tau equal to k Tau P 3 now tell me what is the equation for 1 percent or okay first we have to calculate for CA CA by CAP ya so now this equation I can write now D by Udp no no D by UL equal to D by Udp into dp by L, okay.

So this will be 0.5 dp by L for 1 percent deviation it is 450 I think they have anything thereby and accepts no whatever you say you say minus 450 also you will say yes so he has to come to that situation now, okay not over another thing also I have to do now, okay. So I think the equation is you have CA CA by CAP equal to for others who are still sleeping ya 1 plus dp by L so for 1 percent deviation okay L by dp equal to 450, for 5 percent okay.

Is the values logical, what is the catalyst diameter? Swami, what is normal catalyst there? we have our (())(80:15) you dealt with only batch reactors, 1mm to 5mm is only (())(80:25), half an inch also is higher side most of the time it is around 8 to 10 millimeters, okay maximum half an inch is 12 maximum because larger and larger 12mm, okay 12mm, 8 to 12mm in the industry okay.

Let us take average as 10mm 1 centimeter, how many centimeters length will be there here? 4.5 meters 4.5 meters again is quite logically industry you know height of the packed bed 4.5 feet meters means how many feet that is all around 15 feet, around 15 feet. So 15 feet height packed beds are very very you know that is why axial mixing is not a serious problem in industry that is what is the conclusion from academic you know understanding.

So what you have to tell is if you get unfortunately a job in chemical industry you have to because most of you want to go for some other jobs so then what you have to tell your Boss do not worry about axial mixing, okay worry about only radial mixing radial mixing is very very complicated and also difficult to analyse as well as because radial mixing is always present mixing means radial non uniformity in mixing why?

All packed beds, all tubular reactors whether you have a endothermic reaction or exothermic that means you have to remove heat or add heat so that will definitely create at any cross section some kind of radial non uniformity it is a wonderful conclusion at the end, okay really wonderful conclusion that axial mixing is not a major problem, again I will tell you this kind of explanations when you give when you go for even faculty positions and all that you know most of you I tell you again faculty is wonderful position, okay when you do P Hd and after P Hd you go for faculty meetings somehow you have to bring them to RTD you know the entire interview then you tell what is ET, what is FT and all that and finally you end up axial mixing absolutely do not worry I will take care of it, okay then I think job is guaranteed, good.

So that is what is the conclusion here, right so the main conclusion is that axial mixing is not a serious problem because these kind of dimensions L by dp equal to 450 in industry is easily ya available for all reactors. Similarly the other one what is that 270 is also easily available most of the time they use either 3 inches or 2 inches, 6 inches also is I am telling very large you know for plug flow for plug flow homogeneous 6 inches is definitely large, normally 4 inches many many places 4 inches means 200mm, right (20) so 100mm 4 inches is 100mm.

So 100mm means 0.1 0.1 meters, right ya 0.1 meters into just 27 meters know 27 meters is chaise play in industry, right so that is why it is very very Kanya asking anything no no okay good.

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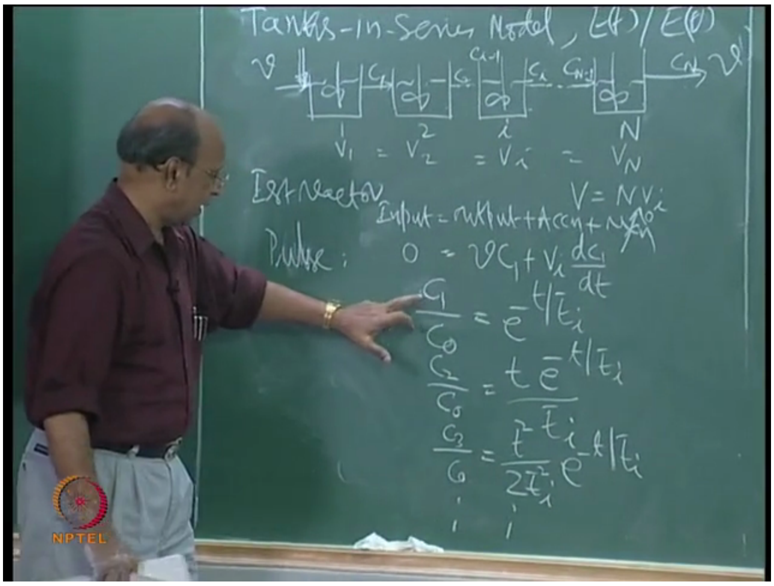

So the next model it will not take much time is till 8'o clock we have time know and also you came at 6:30 okay we started at 6, anyway the other one we will not take this is now Tanks in series model very simple not much complicated not much complicated okay actually I thought I will finish today even the other one also Tanks in series model as well as CSTR with dead space and bypass this two I thought I will finish then I think Monday you do not have to come at all, Friday also we can play here, okay.

So in Tanks in series model we have n number of tanks all equal number equal volume. So here we want to find out Tanks in series model ET or E theta that is what what we want to find out so this is 1, 2, this may be ith tank, this may be nth tank ya we have volumetric flow rate V, volumetric flow rate V there and we give a pulse input so this is the symbol for pulse input definitely you do not get pulse input out there so you will have ofcourse N equal to infinity you will get there otherwise you will not get.

So now we have to write for the first tank what is concentration entering, concentration leaving and there is no reaction because it is tracer, right. So I think I will ask you to derive that it is after sometime t, right after sometime t only you have you have to write the one material balance and here you have pulse input, right for first tank and also V1 equal to V2 equal to Vi equal to VN and total V equal to N into Vi I mean total entire thing you can take, good okay.

For first reactor ya what is input okay let me write input equal to output plus accumulation plus reaction so this fellow is 0 then accumulation we have this is 0 for pulse input, okay pulse okay so output okay C1 C1, C2, this is C i minus 1, Ci, this is CN minus 1, this is CN, okay so what we have to do is we have to find out C1 and ya so accumulation is V into small v Vi into correct know vi is uniform for everything ya so vi into dc by not dc dc1 by dt dc1 we are writing for first.

So what is the solution for this Ramakrishna will tell me instantaneously C1 by C not equal to yes e power minus t by t bar i for individual tanks, right I think this you should have done now ofcourse if I ask you to find out ET for this then you have definition for ET, ET equal to C divided by cdt, right that you have to find out but we are not finding out ET immediately. So then for C2 similarly you write but that will be slightly complicated than this because there is input continuously input will be there continuously, C2 by C1 equal to oh achha so again I think we also expressed here the other one it is not C1 by C not I have but again I have C2 by C not that means two tanks together, okay two tanks together we have t e power minus t by t bar i by t bar i, okay.

C3 by C not you know all these things can come in the examination also because I may give 2 tanks and then try to find out what will be the concentration coming out for tracer C3 by C not equal to Abhishek will say not fair Sir you are blackmailing all the time, no you do not tell now, okay serious 2t bar square i and e power minus t by t bar i so like that for N tanks one can do and what you get is after finding out finally CN by C not and then converting that into ET and ET converted into E theta we will finally give E theta you understood know first concentrations and convert into ET, ET is the same definition for N number of tanks you have to write CN by C not, okay.

So then you will have I think after deriving this you will have some logic it will be N here and all that you know this is N minus 1 for third tank this is N minus 1, this is also N minus 1 but this will be t by t bar i so it is logically it will come.

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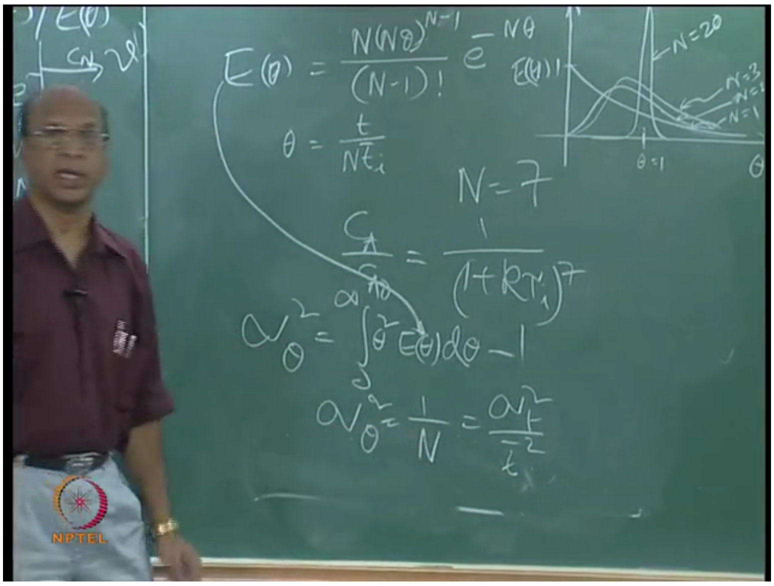

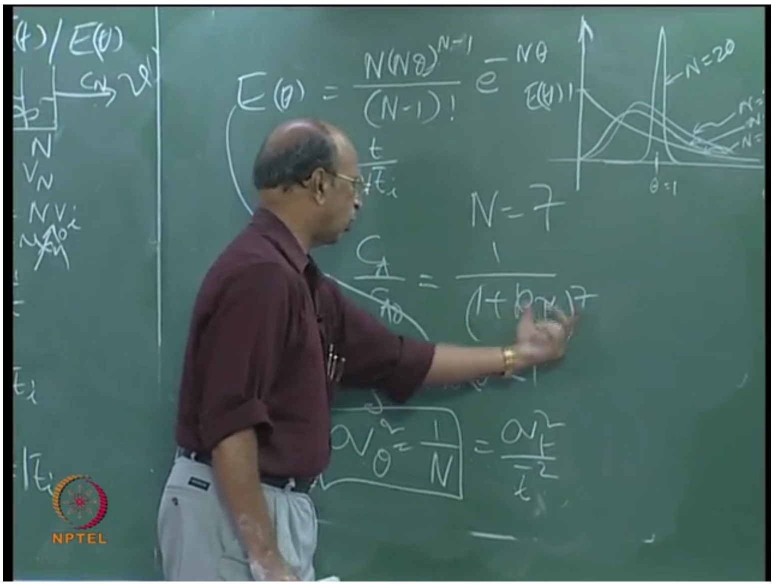

So once you get for CN by C not convert into E theta then you will get this is nice expression some of you may be remembering this equal to N N theta to the power of N minus 1 by N minus 1 factorial into e power minus N theta so where theta equal to t by N into ti bar that is overall theta. So ti is volume by volumetric flow rate of individual tanks so this is the equation.

So this equation is it is again one can plot this equation for N equal to 1 E theta versus theta so let me say this is theta equal to 1 that is t by t bar equal to Abhishek for N equal to 1, n equal to 0? 00 there is no reactors, so let it start theta Rahul? 1, E theta equal to 1 you will have somewhere here then exponential that is N equal to 1, N equal to 2 where does that start, what is the value of E theta for N equal to 2, E theta is exit please remember exit so you can substitute for N equal to 2, theta when we starts what is theta equal to 0 E theta for theta equal to 0 E theta equal to 0 but what is that same thing for N equal to 1? That is 1 because that equation is simply that means I have only 1 tank, right so that is e power minus theta for 2 tanks but theta comes almost in the equation not almost it is there, so theta equal to 0 it will become 0 so it starts from here and goes like that this is N equal to N equal to 2.

N equal to 3? Again 0 it goes like this, this is N equal to 3, okay N equal to 20? Almost plug flow this is N equal to 20. See even though I am telling many times you are not really enjoying what is happening in the subject because that enjoyment comes when you plot, right and plotting nowadays is not that difficult all these things I do not want you plot with hand, okay give that equation in your Laptop you know in Excel and then give some theta values and N equal to 1 what is the plot, N equal to 2 what is the plot, N equal to 20 then only you will have feeling I say otherwise you will never have any feeling you are all living without any feelings, correct and you will have that feelings when you first fall in love then only atleast fall in love first and then fall in love with the subject later because the same thing can be extended there, Abhishek is very seriously thinking very seriously thinking, okay.

So like this again you see I gave this RTD assignment know and for atleast particularly the first assignment can be solved on your computer okay after Rahul you left I plotted all that it comes almost exponential decay that shape is that 4th problem in seventh 4th problem in seventh assignment, okay it must be only ideal CSTR because the question is what is the ideal reactor there so I have not fit the model but when I plotted concentration versus time ET versus t and also FT versus t it did not take more than 6 or 7 minutes for me because excel know you just add data and go and have the corresponding equations and then just click you will get the answers and plot very fast.

So like that all of them when you calculate it will be very good ofcourse calculating t bar and all that it may take time but plotting itself is very very simple. So like that even dispersion numbers these values I mean these equation all these things are very easy to plot but I told you again know you are losing in your life something okay if you do not plot Gopi really you are losing something if you are not doing experiment, okay really in project also if you are not doing experiment you are losing many things in fact.

Simulations are good but when you do experiment first of all you have to deal with people in our workshop, if it is not in our workshop you have to go to central workshop, if that is also not possible then you have to go outside the workshops outside workshops that is what all of our students are doing, okay and we wanted to find out small particles those particles I think those people are I think entire World they search, okay World is ofcourse through Google and Madras ofcourse they know each and every corner who is making what kind of particles and that will teach you lot of lessons how to handle people, otherwise if you are sitting before computer all the time doing only computer simulations you do not know how to deal with people and that will be a drawback in the job actual job unless you go to IT where you always talk to your own computer that is all nothing else then it is fine no problem you and your computer, okay.

But otherwise if you want to go to the management job or some industry job this is very important or even if you want to go for faculty positions this is important talking to people and I know managing them, managing them means we are not manipulating them, right manipulation is very dangerous word that is not the one what I am talking just to looking at them and talking to them and then getting answers or also you are trying to explain that makes lot of difference, I feel one of the reasons why most of us I think most of the young people are nowadays not able to get the jobs also one of the reasons is they do not know how to talk because where are you talking, the moment you go to your room go to Google that is all Google who is there to talk maximum you can only song sing songs that is all because you know same humming and then doing all Google World know what songs you use Kolavari Kolavari or something so some kind of songs ha ha ha hu hu hu you know these are all natural reactions when you are seeing you know because you do not have any other thing so you click on that song and all that that is all but you are not even going to your next room and talking to people, right.

So really when you want to do all this I think you know then only you will become perfect man I say other perfect man or perfect women otherwise it is not possible I think technology is really killing this planet, right really because you do not know how to talk to people, how to manage people, how to move with people, right so what is technology connected that is all actually it also connects Nokia connecting people you know that also advertisement I really like but there is no physical it is virtual connection matrix connection, it is not the real connection, I think side by side you know both of them this fellow will be talking turning this way other both are standing in the same place they can switch off the cell phone and then talk they do not do that you know and sometimes they do not know that they are side by side that is also possible that is another thing group talk you know free offer really technology is really spoiling our planet I think.

Okay anyway we will come back here this this one this graph what we have again my question is how do you you have to find that here what is N because I may have physically here N number of tanks I know but even all physical tanks are really behaving as ideal tanks 10 means 10 tanks in series or they really behaving as 10 tanks in ideal tanks in series, okay that is one thing otherwise the same model we can also imagine for packed bed, right instead of axial mixing we can use this model saying that the performance is equivalent to 10 tanks in series because if you plot this is nothing but your axial mixing curve very very low axial mixing also you get the same curve correct know experimentally if you do for 10 tanks you get only this kind of curve.

And for packed bed also if you do you get this kind of curve that is why that equivalence in modelling same N number of tanks can also be used for axial mixing or axial mixing can also be used for N number of tanks but normally the other way we do that is for axial mixing using this what is the advantage? Advantage is first we use this graph again same techniques go to MATLAB and then find out what is correct there, okay.

Let me say that the N equal to 7 now I have a parameter now called number of tanks in series this has to be used now for calculating ultimately what is that you have to calculate conversions. So how do I now use this number for calculating conversions if it is first order, tell me if it is first order this you should remember ya 1 by 1 plus k Tau i or t bar i that is all that is why beauty here you do not have to go to that terrible equation where you have exponential terms and all that that is why many people prefer this model even for packed beds when compared to axial mixing model simple know for first order.

Even for second order you will get that quadratic terms and all that but again you know 7 square roots will come there Levenspiel beautifully gives that okay. So that is all that is why this this model is very simple than the other complicated model, right so that is what I just want to tell and we have this equation sigma theta square, how do you get that that you get only because of this theta theta square E theta okay E theta d theta minus 1 so substitute this equation here and then integrate what you get is sigma theta square equal to 1 by N which is nothing but oh no no this is total that is total.

So it is much easier now that means sigma theta square how do I get sigma theta square I get from my C versus t data itself I do not have to go to this graph and then plot also simply go to C versus t graph calculate data, calculate sigma t bar square sigma t square divided by the average residence time that will give you sigma theta square that is nothing but 1 by N, this is another model again I beautifully love in chemical engineering sigma theta square equal to 1 by N simplest equation.

So now if N equal to if sigma theta square equal to 0.1 N will be 10, so calculate from the data let us say you got 0.1 then you will have number of tanks (())(103:03) so go to this equation if it is first order, this is 10 to the power of 10 this not (())(103:09) 1 plus k Tau to the power of 10 calculate CA by CA not what is XA, okay. So this is what I think the single parameter models, okay thank you for your patience and I am very happy I hope you also enjoyed.