Chemical Reaction Engineering 2 (Heterogeneous Reactors)

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

Lecture 16

General Performance Equation for Non-Catalytic Gas Solid Reactions

Okay, I hope you remember what is going on in this class. So we have completed the elutriation problem also in the last class. Elutriation is the more realistic problem where in a mixed flow if you have mixture of solid so then you will have some fine particles and some large particles. So the fine particles may go out which is more realistic. So that is the problem which we have solved, okay. So with that about mixed flow slight complications have been done.

There are many problems still which we cannot discuss here, okay. So now we will also try to do for any RTD is it possible to have the design equation. That means the general performance equation what we have for any flow I hope you remember this equation, very general performance equation. Anyone can tell for specifically non catalytic gas solid reactions?

Student: Theta.

Professor: Design equation. Performance equation is the design equation. 1 minus x equal to or 1 minus x bar B.

Student: 0 to tau.

Professor: Single particle, then E t d t. This is the one and this E t takes care of any kind of reactor. This we have done already, okay. In the last few classes also what we have done is only this. I think maybe you would have forgotten. So this E t for plug flow we have substituted, right? Equation is same, okay, in the sense that equation you will get one equation if you have E t for plug flow.

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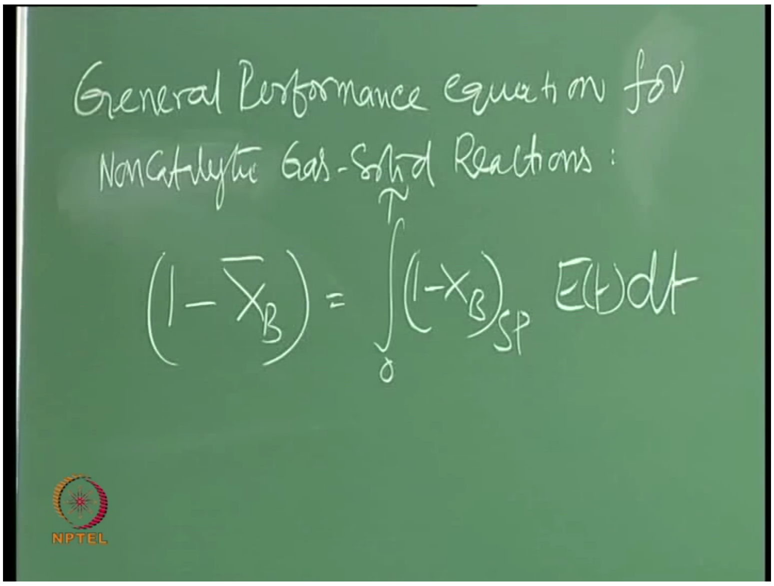

Then you use this same equation for multi particles, mixture of particles. It is only weighted average. So then we have changed this E t to mixed flow, right? Again in mixed flow we have done for mixture of particles and mixed flow normally good representation is the fluidized bed. In fluidized bed you will have the elutriation, okay. So that also we have taken into account and then solved. But the equation is only one in fact, only one.

That you take it and then take weighted average for mixture of particles and also the same equation but only thing is you have to now calculate for each particle what is T bar in elutriation case, okay. So essentially you will learn only two equations, one plug flow another one is mixed flow. Then various conditions we have applied. So now we can also extend this E t for number of tanks in series. If I have number of mixed flow in series, right?

One situation can be as I told you mixed flow good representation is fluidized bed. If I keep this fluidized bed one above the other or side by side so then I can take a case where you will have tanks in series model. Like if I have a fluidized bed you have that is the distributor plate, this is the down comer, down comer, down comer, okay. So this is the outlet for solids. Gas, solids coming out and this is inlet for solid and of course gas goes out.

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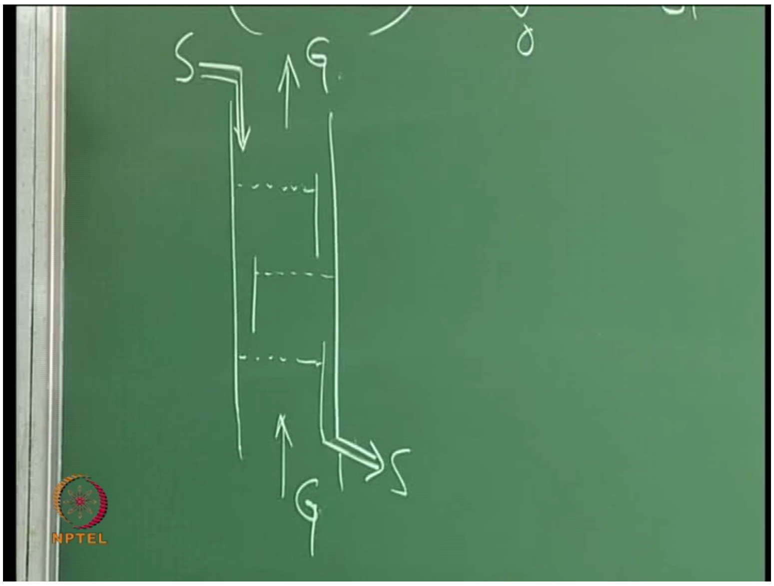

How the solids move? They go like this, come here, again they go like this, come here, they go like this, come here. Good. So each plate is your fluidized bed and on each plate you have perfect mixing of solids and this is considered as one mixed flow. Then it goes to the second, third. This is as if we have tanks in series. That is one. So the other model also what we can have is you have a normal fluidized bed. This is gas, gas, solid here. This solid will go to another fluidized bed.

Again gas and this will go to another fluidized bed. This is solids coming, S, S and finally solids will be coming out. So this is solids. This is also another type of multi series system, okay, multiple tanks in series, good. So in these two cases either this or this, what is the difference?

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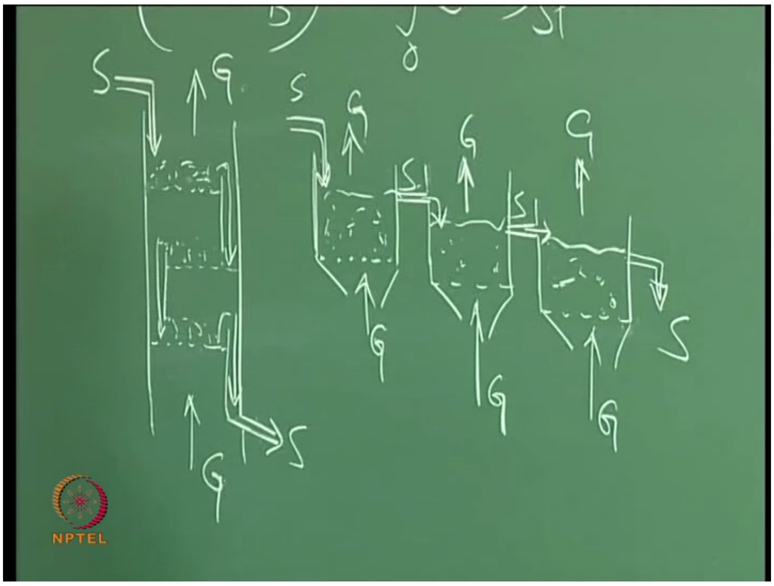

Student: Fresh gas is contacting.

Professor: So here you have fresh gas contacting every time whereas you have the same gas that is going. But what was our assumption? Weather in deriving shrinking core model we have one concentration C A G whether it is here or here, that concentration is not changing. So the same analysis can be also applied if I know what is E t. I think it is too much to ask you what is E t for tanks in series . Single tank what is the E t? Kavya?

Student: E power minus t by tau by tau.

Professor: Yes by tau. That is (())(0:46). So if I have N number of tanks we also have an equation for E t. So that I will write first and then we will substitute. I will ask you to integrate in the examination hall but right now I will give you the final solution, okay. Good. So E t, let me say this is equation 1. I will write here R T D function for N number of tanks N tanks in series will be this is called R T D function. 1 by N minus 1 factorial, t by of i to the factorial to the power of N minus 1. Then we have e minus to the power of t by m i. That is the equation. So this is for E t.

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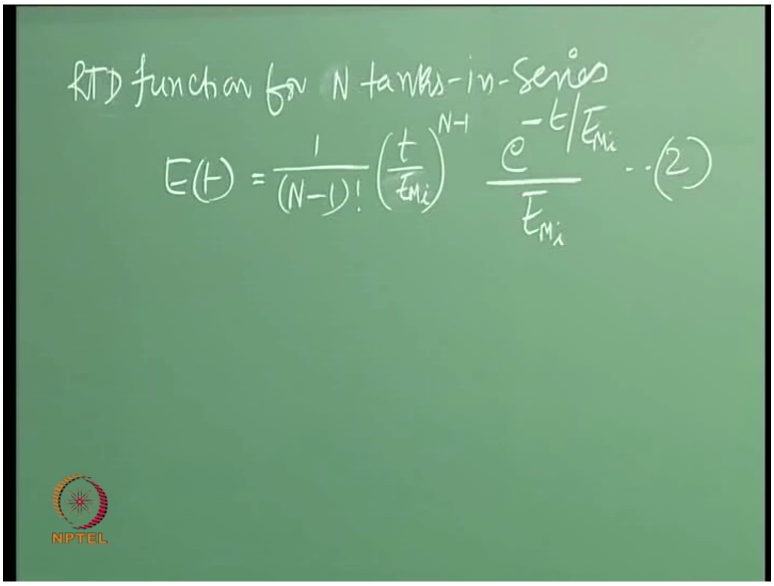

This is slightly complicated equation because we have N number of tanks so this will come in the (())(09:33) formula N number of times. So then you will get a series solution and if I write equation 1 in terms of 2 that will be 1 minus x bar B equal to zero to tau, 1 minus x B for single particle and all of these factorial N, N minus 1, okay. Then e power minus t by into d t.

This is equation number 3. In reality can see how complicated it is you know if I put here all three controlling for single particle, okay, or it may be two controlling or the simplest one which we take here is reaction control. The same equation for reaction control what is the equation for 1 minus x B? For reaction control 1 minus x B single particle 1 minus whole cubed, right? So this is equation number 4. So that you have to substitute there so that this entire function will be in terms of t, then you have to integrate.

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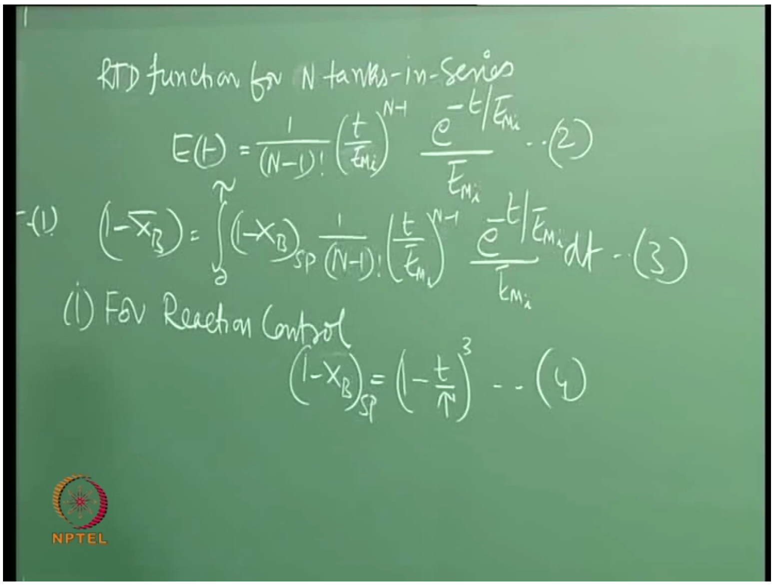

Please make a note there. That mathematical detail I can ask. You cannot also write that without integrating, okay, because I think I do not want to give marks for the memory. You have to show the details. Good. So for reaction control if I substitute equation 4 here, let me also write that equation. Zero to tau, so 1 minus t by tau, it is a single particle so only tau, this one into all this, e power minus t by t bar m i, t by t bar of m i N minus 1. Then I have e power minus t, correct. This equation you have to integrate.

Yes, so if I write the solution for this then I will write here. 1 minus x bar B equal to sigma of m equal to zero to m equal to N minus 1, factorial, m factorial, t bar m i by tau all to the power of 3 m then e power minus tau by t bar m i. That is one term plus m equal to zero to m equal to 3, N plus yes you have factorial there, N minus 1 factorial. Then you have 3 factorial, m factorial 3 minus m factorial into minus, that is the equation. So this is equation number 6. This one?

Student: Yes, it will be t m i by tau.

Professor: This one or this one?

Student: Yes, that one only.

Professor: This one is to the power m. That is minus t bar m i by tau only. So we can simplify this for N equal to 2. For N equal to 1 you know for N equal to 2. For N equal to 2 what you get is x bar B. I think now you cannot draw pores no. 6 by y square, 3 plus e power minus y plus 24 y cube, 1 minus e power minus y. Yes this is equation number 7.

For N equal to 3, yes I will write where y equal to tau by t bar m i, okay. So for N equal to 3, x bar B equal to 3 y, 3 minus e power minus y minus 12 by y square, 3 plus 2 e power minus y plus 60 by y cube, 1 minus power y. So this is equation 8, okay. Like that of course N equal to 4 also equations are available.

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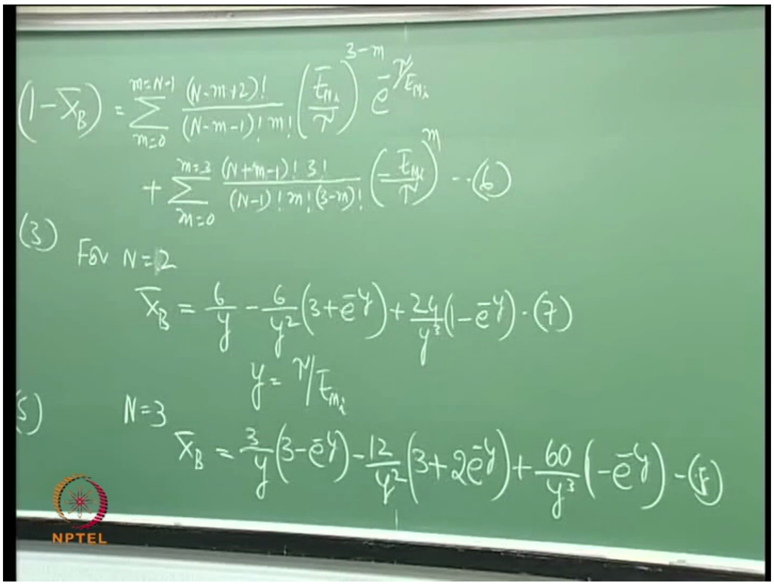

How can I change fluidized bed as a plug flow? I cannot. Fluidized bed is mixed flow, single stage. If you go to seven stages here, okay, then you can use plug flow equation. That is why you would like to have seven.

Student: 2, 3, 4. We can write like we mix all fluidized and we can get overall equation for plug flow.

Professor: Yes, see this one if I write N equal to 4, 5, 6, 7 onwards if you try to simplify that that equation will tend to plug flow, okay. Yes, but you cannot avoid 2, 3, 4 and all that. Yes, beyond 6, 7 only you will have plug flow, good okay. For comparison I will ask you okay, 2 and 3 with plug flow. How much deviation between these two plug flow and two tanks in series or three tanks in series? Okay good. So that is the one and who told you it will be more than seven? Where did you see first of all?

Student: I went to Essar, there were more than seven.

Professor: You went to where?

Student: Essar Oil sir, Jamnagar.

Professor: Essar?

Student: Essar Oil Limited.

Professor: Essar Oil where they are using fluidized bed first of all?

Student: Purification. I remember.

Professor: They are not reactors no, purification.

Student: Sorry?

Professor: Purification steps are not reaction steps.

Student: Sir, I do not exactly remember the purpose but I remember they were using the fluidized bed and they had some 10 to 15 series in that. I do not exactly remember.

Professor: What is the process?

Student: That I cannot remember exactly.

Professor: See handling one fluidized bed in industry is a hell. If you want to have 17 hells yes.

Student: No, not in series like the second arrangement, the first one with seven stages. That one I believe.

Professor: But what for they are using? Fluid is such a beautiful technique where this can also be used for adsorption. It also can be used for drying. But those are physical operations, okay. Yes, so drying operations I do not know which process you are talking. In fact is it reaction? Cracking process you have only one. Drying one can use. But drying this thing will not apply because this is the reaction.

In cracking they use fast fluidized bed where they have a single tube where solids will go very fast like moving bed then there I have also discussed that. Actually the contracting pattern for that will be both are in plug flow. Solids will be in plug flow and gas also will be in plug flow. Yes, Ashok Kumar you are asking something?

Student: Cracking only one reactor.

Professor: Only one reactor, yes. Cracking only one reactor but you know depending on the capacity it will be only one single tube and because you asked me let me tell that. So this is how cracking reactor looks like. So there are many variations of slight complications but simplest thing is here you have the gas entry, then solids will move so there is a cyclone, okay. So then you have the regenerators and after regeneration solids will come here so solid line is this. Solid of course here solid then here solids will come, this is again solid, solid back, okay.

Gas line is gas, gas, gas, okay. This is how. But why they have to do this? This is regenerator. Yes, catalyst is getting deactivated because of the coke formation. So then you have to regenerate this that means the coke deposit again will be burnt out. Actually it is not burnt out, it is gasification reaction. C plus H 2 O. What they send here is H 2 O, okay, steam.

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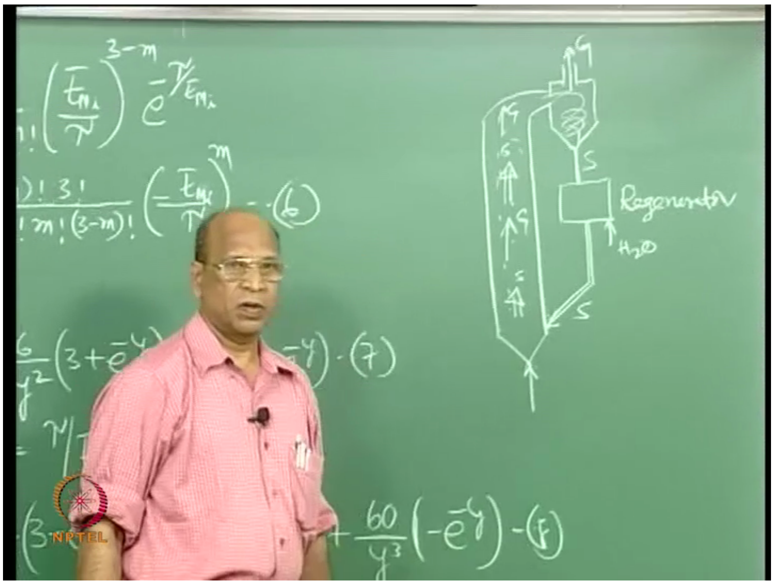

So then you will get C O plus H 2 there. That can be used for some other energy management because that can be burnt and then that can be used as some other energy management and here again this can be a fluidized bed, right? That can be a fluidized bed and there are many reasons why a single stage fluidized bed cannot be used there also, right? Packed bed is the best or moving bed is the best there because if I use a single fluidized bed here then because of the fluidization some particles will get regenerated quickly, some particles will not get regenerated at all.

That means those particles which are straight away entering because it is a mixed flow, right? So some particles will immediately come into this line outlet. So under those conditions the carbon cannot be gas at all. That time is very small so reaction may not take place. So that is why you will have particles with carbon coated again plus a completely converted particles also. That means all carbon deposit part.

So that is why there they can be use generally moving beds where you have plug flow. Plug flow gives for each and every particle the same resistance time so that you know exposure reaction conditions are same for each and every political whereas single stage fluidized bed will give you distribution of solids, okay good. So that is why I do not know what you are talking but I think 17 I have not heard of in any industry using 17 fluidized beds. By the way what is the size? Do you have any idea?

Student: Sir I do not remember exact data. I can try.

Professor: What is the diameter on this?

Student: 2 centimetres.

Professor: This is diameter.

Student: 1 centimetre.

Professor: Okay, logical guess. I am just trying to check you whether you have that estimation of sciences, okay. So if you are able to estimate this approximately, there also probably you can. But beyond 15-10 you cannot differentiate. But definitely 2 and 5 you can differentiate, okay.

Student: Usually how many stages are there usually in industry?

Professor: Beyond 7 there is no use because you get almost plug flow with 6 or 7. This in reactor theory course we have done it you know. We have actually calculated two stages together, three stages together and all that. I also like to do now one demonstrative problem where we can see what will happen if I take one tank and two tanks, okay. So, that I would like to tell you. So these equations when I take equation 7 and 8, if y is small then we can also expand that in series. Like for example these things there, okay.

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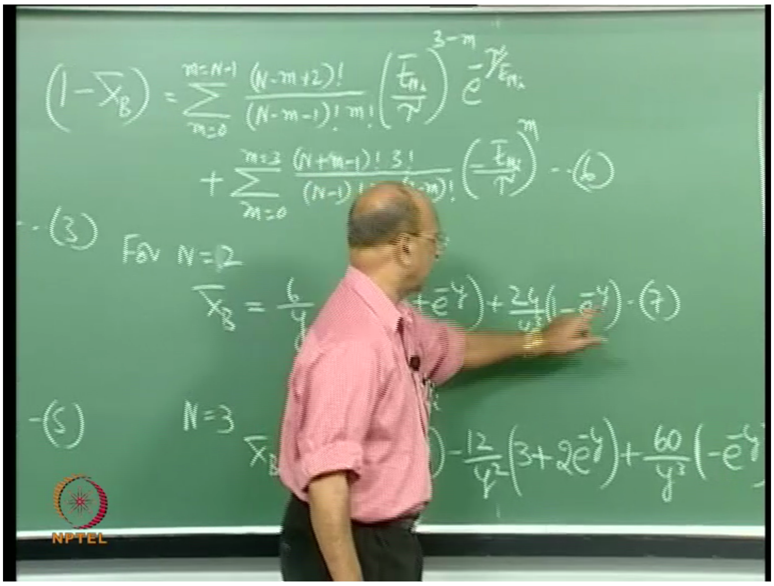

So when you do that then my diagrams are nice diagrams. I think I will remove this, okay. At high conversions, normally we need high conversions, y is small, right? What is y? Tau by t bar m. So for large conversions t bar must be large. So that is why y is small, okay.

So y is small then the equations 7 and 8 can be written as for N equal to 2 again we come back here, 1 minus x bar B equal to y square by 20 minus y cube by 60 plus y to the power 4 by 280. (())(27:36). So this is 9. So for N equal to 3, 1 minus x bar B equal to y cube by 120 minus plus, okay. This is equation 10 for reaction control, okay.

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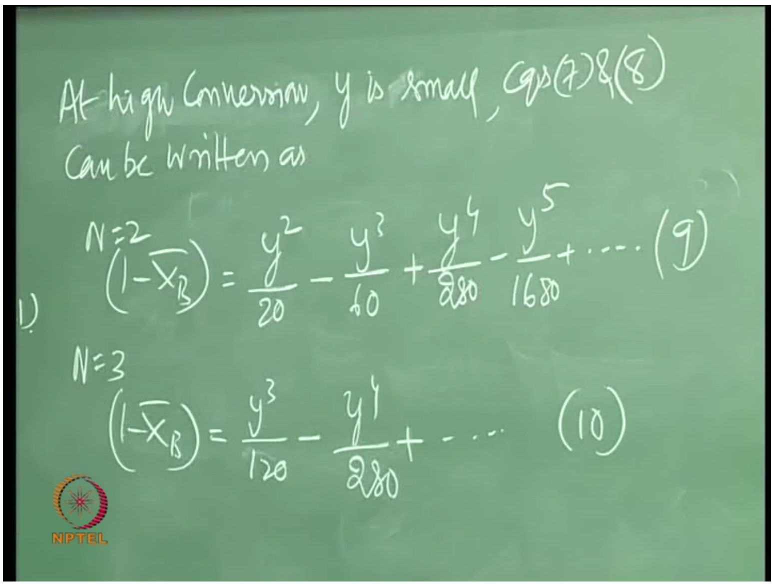

Then I can also write for film control. I think I will go there. For film control this I will remove. These are all reaction control. For film control what is the equation? X B equal to or 1 minus x B equal to 1 minus t by tau. That is the equation. That you have to substitute in the general expression here and then for N number of tanks, okay. So, E t is for N number of tanks. Then you will have for N equal to 2, these are slightly better equations, e power minus y.

So I lost my count. This is 11, this is 12, then for N equal to 3, x bar B equal to 3 by y minus, equation 13. I will also write for 4 stages, 4 by y minus 4 by y plus 3 plus y plus y square by 6 into e power minus y. Of course one can also expand this e power minus y for small y in there, also right, okay. I think you should appreciate.

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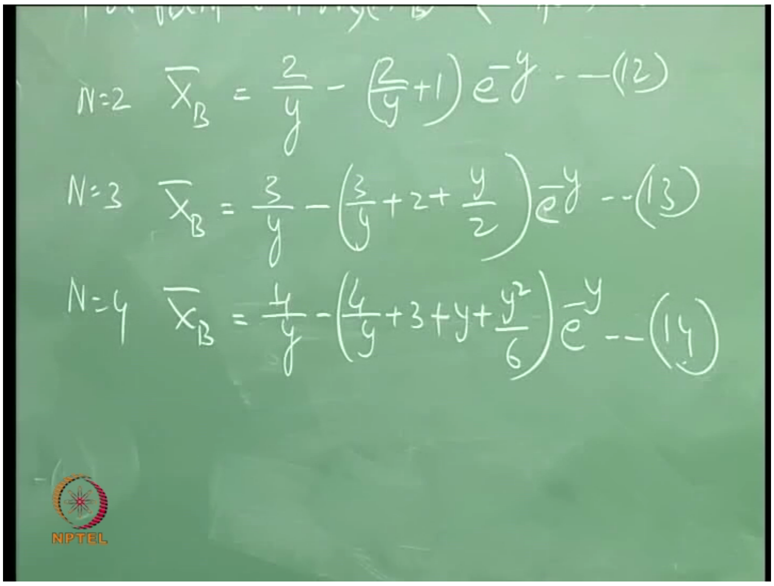

It is not simply you know. I am writing there, you are writing there, because how much mathematics we also use in chemical engineering because beyond certain concepts then everything is only mathematical, okay. But in a classroom I cannot make it as a mathematical course you know rather than conceptual course, right? So that is why in any academy institution the concepts are told and still if you go to higher level then you know the mathematics you have to use and then solve them, okay.

Yes, you now of course for examination you have to solve them and that is why you know we have only 6 courses per semester you know maximum. I think in chemical engineering we have reduced it to 4 or 5 I think for M tech I am talking so that you can work more. You have to work more, okay good. So this is the one and you know it is not that easy to write these equations.

You will not get in fact this kind of closer form solutions or if you have the other what is this is film control the previous one was reaction control next (())(31:46) equations if you have the other devil. What is the other devil? This is film control. The previous one was reaction control. Next one is as diffusion control. So you do not have equations. I can give your numerical problems there, good okay. So now let us illustrate the effect of multi staging, okay, the effect of multi staging.

Very simple thing what we take for example I have to solve this equation, I can write this y square in terms of what is that tau by t bar right? So I can write this tau by t bar square cube to the power of and all that but we do not take all these terms to demonstrate the concept but we will take the first term this one, first term this one and also you have similar term for single tank when you expand that in series, okay.

When you expand that in series so we will take one tank, two tanks and three tanks and we will try to find out what is the holdup? Flow rate is same. For the same given flow rate and conversion if I take one tank, so what will be the holdup? If I take two tanks what will be the holdup? Because conversion we are assuming, right? And three tanks what will be the holdup? So holdup means it is indirectly your volume of the reactor, size of the reactor, okay good. Let us do that. So please write this.

Let us illustrate the size reduction achieved by multi staging, comparing the size requirements for single stage, two stages and three stages for 99 percent conversion of solids where reaction at the shrinking core controls. Good, so I have to also write here for N equal to 1.

Do you have it in your notes? Can you kindly tell me? At least you can once more see what you have written there. Excellent, y by 4 minus y square by 20, okay, etc. and y cube by plus 120, good okay. But for our present discussion we take only these terms.

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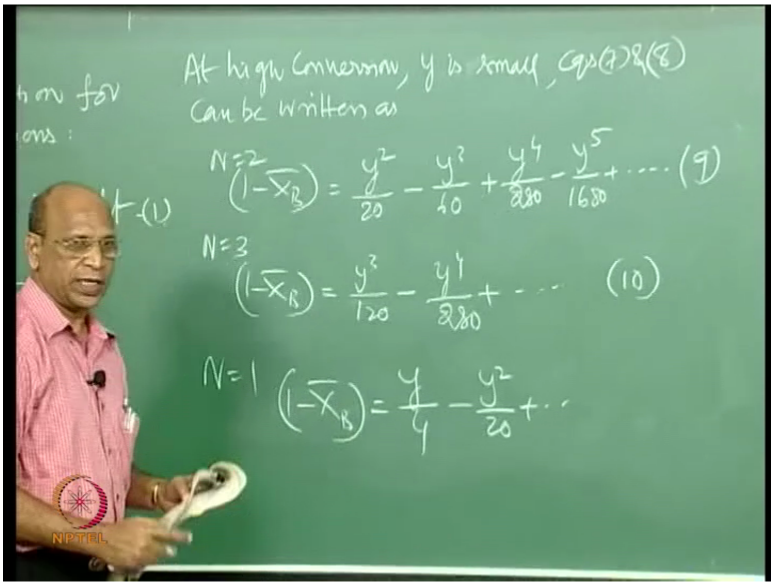

Actually what you have to do is that you have to solve this equation either cubic equation or quadratic equation and then calculate what is tau by t bar, okay. That we can do. What is the conversion? Conversion equal to?

Student: 99 percent.

Professor: 99 percent. I have told there, okay. For 99 percent conversion, right? Okay, so can you tell me what is t bar by tau for 99 percent conversion if I have only single stage? Take only one term. What is W? What we are taking is 1 minus x bar B equal to for N equal to 1. What is the equation here? Y by 4, y by 4 means tau by t bar m by 4, right? So this is equal to point not 1 because x bar B equal to point 99, okay.

So now tell me W. That is tau equal to point not 4 t bar m. T bar m equal to W by F not. So W equal to W by F not, correct? So, W equal to 25. This is 15, okay.

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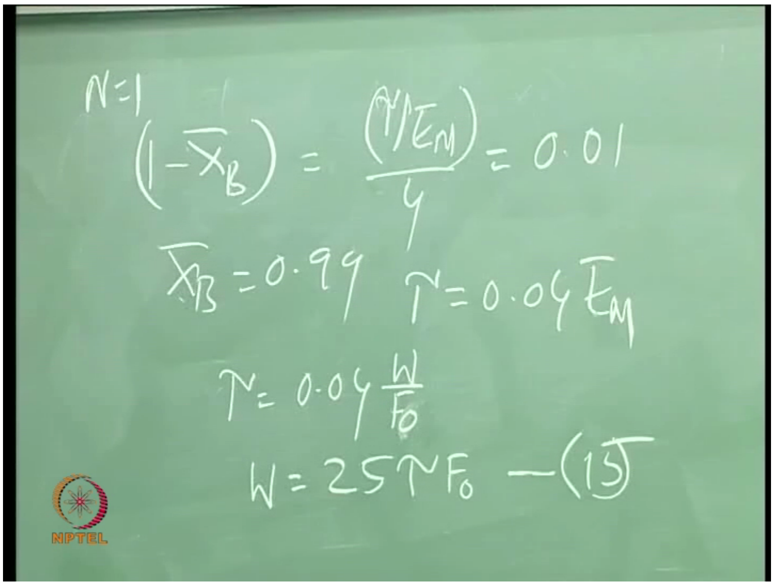

It is very easy now. For two tanks you can find out because you are taking only one term otherwise you know the quadratic equation have to solve for two tanks. For N equal to 2, 1 minus x bar B equal to tau by t bar m i whole square by 120, correct? How much you got? Waiting for someone else to tell you. 20 yes, good. So here W equal to 4 point 5 tau F not. So this is equation number 16, okay. This is W, N equal to 2 to be more specific, for two tanks together. You calculated for one tank t bar i, okay.

So two tanks you have to multiply then you will get. That is where you make the mistake in the examination and you think that you have solved correctly and then you scold me I am not giving the marks, okay. Now take the ratio between these two.

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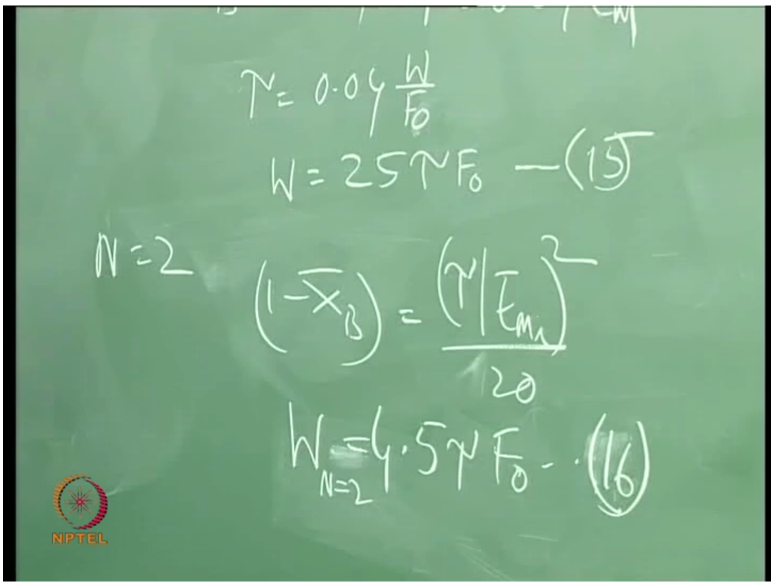

What will be the ratio of the W? W N 2 by W N 1 , point 18 is correct. So what is the meaning? W for two tanks equal to point, wonderful result. So that means the holdup what you have to use is 18 percent of single tank. Kavya, able to get that? What it is, say now?

Student: 18 percent is the holdup.

Professor: Yes, now the question is why?

Student: Sir, is the holdup for two tanks in series in total or for each one of those?

Professor: That is what you wrote no? For each one that is half of that. It is 2 point 246 for one tank, okay, W equal to. So for two tanks multiplied by 2, okay. So then this is the total for two tanks together. That is why N equal to 2 I have put. That means N equal to 1, N equal to 2 together in one setup you will have 4 point 5 tau F not, obvious constant because same particle size and same conditions and all that. So F not is the given flow rate. Conversion is 99 percent.

So then you see just to tell you if you are using 100 tonnes in one single tank and you are going to use only 18 tonnes for two tanks, okay. Now N equal to 3 can you kindly repeat. Then we can discuss for N equal to 3. N equal to 3 what is the equation? Yes, let me write 1 minus x bar B equal to tau by t bar of m i whole cube divided by 120, okay. This is equal to point 01. Now, that you have to solve. And what you get for W N 3? All three together. What you get for single stage? How much Anurag?

Student: 2 point 82.

Professor: 2 point 82 for 3 tanks. How much did you tell? I do not have that calculation. 2 point 82. So this is the equation now if I write. I am writing this for N equal to 2, this is 17. So now W N 3 by W N equal to 1.

Student: Point 113.

Professor: Point?

Student: 113.

Professor: Excellent, point 113. This is another wonderful result.

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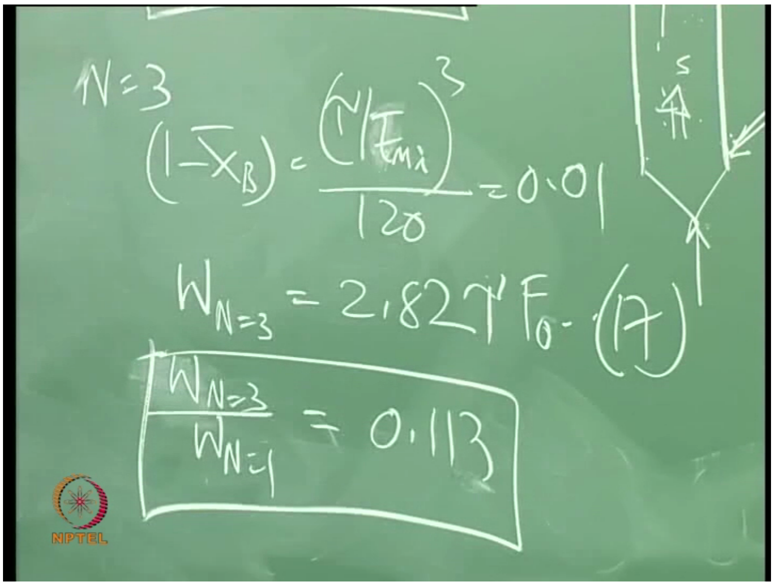

Now you can discuss a lot. And for N equal to infinity, single stage reaction control. So N equal to infinity plug flow, correct. For N equal to infinity plug flow of solids, single size. You have the equation already. Single pallet equation itself is useful. Reaction control, what is that? Before I ask the question you should have told that. Tell me the equation. T bar P by tau equal to 1 minus?

Student: 1 minus x B.

Professor: X B should be there.

Student: 1 minus x B whole to the power 1 by 3.

Professor: X B equal to point 99, calculate t bar P. T bar P equal to W P by F not. Or W P means no plug flow. How much is this point?

Student: 784.

Professor: What is point 784? T bar P you are telling or?

Student: W P is equal to point 784 into tau.

Professor: W P equal to point 784?

Student: Into tau F not.

Professor: Okay, so now W P by W N 1 also equal to W N infinity, W N equal to 1 equal to point 031. Yes, this is another very beautiful equation. I am not giving this. This is the one which I am giving numbers so this equation is 18. You see now.

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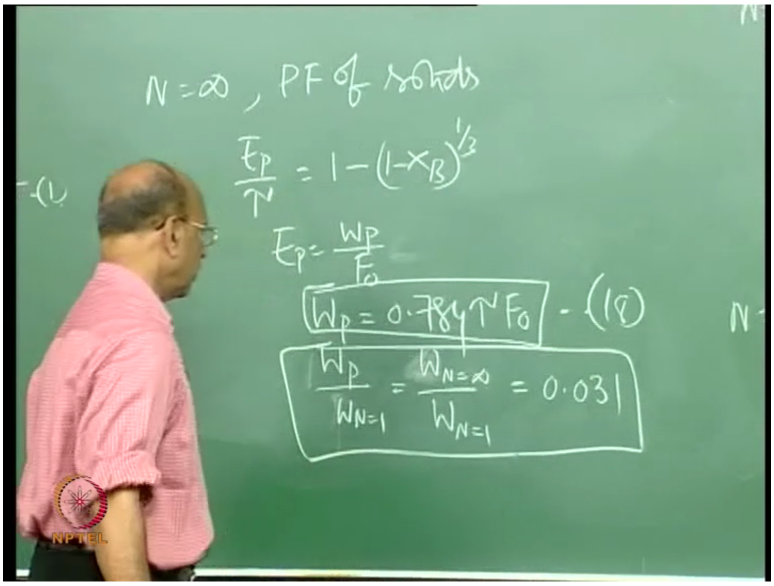

When we use a single mixed flow and then if you make the same conversion and same low rate, make that into two equal reactors. You know size is equal for both because t bar i is same, okay. So then only 18 percent of single stage holdup you have to use. That means indirectly the size reduces by so much, 82 percent, okay. From there if you want to put the same thing into three reactors, single stage you make now into three smaller reactors so then it will be 11 point 3 percent, right? And then you go to infinity.

It is yes, 3 point 1 percent, okay good. But the maximum change that is from single tank to second tank. That is very drastic. From there it will not change much, right? You can calculate for example for 4. It will not still further reduce. This is N equal to 3, this is N equal to point 18, then point 11, then next one maybe point 09, okay. Then maybe point 07, maybe point 06. Like that comes till point 031. Beyond this you cannot. This is one extreme, single stage is another extreme. Where is my single stage? Here equation number 15, okay.

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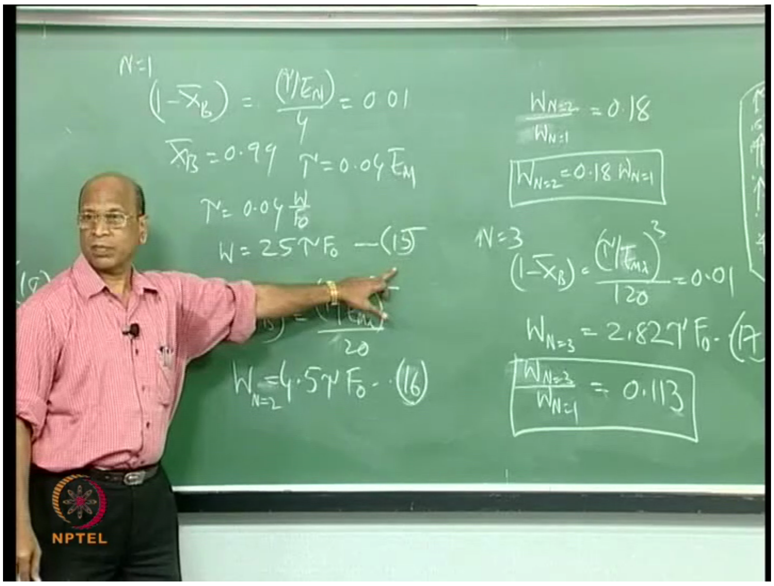

Why do you think this is really happening? It is good. Equations are beautiful, nice. Why do you really think that this is happening? Particularly from first to second, this I discussed also last semester.

Student: It is exponential from first to second.

Professor: Again mathematics you are talking. What is really happening? Not exponential detail and all that. What is that really happening to the particles so that there is so much drop in the size? Just two tanks if you take instead of 100 tonnes I am taking only 18 tonnes. (()) (45:34). All intelligent chemical engineers will do that whenever they have mixed flow. It is a really beautiful concept, okay. Now how do you define mixing? How do you define mixed flow?

Uniform temperature and uniform concentration throughout and what is happening to the particles inside? Same thing, uniform concentration is uniform conversion uniform temperature, okay good. But still what is happening when it is coming to the second reactor? And did you calculate at any time. Even now you can calculate why at anytime, okay. What is E t d t or how much of the material will come out in the first one mean residence time?

Student: 63 percent.

Professor: 63 percent. The moment you take two reactors that mean what? See the by definition mixed flow is a bypass type reactor . What is bypass? Not spending sufficient time in the reactor, just coming out. By definition of mixing itself 63 percent has to come out within one mean residence time. And the same thing when we extend to plug flow what is the percentage that comes in one mean residence time? Nothing will come. Only after one mean residence time only all that batch will come.

So that means each and every particle exactly spends same amount of time. The conversion in that is the same. Then the average also is the same. But when you look into mixed flow when you are measuring the mean residence time, 0 to 1 second you get some fraction. You can calculate infant using that equation E t equal to e power minus t by t bar m by t bar m. This is the only equation. Now the fraction will be E t delta t equal to e power minus t bar m by delta t.

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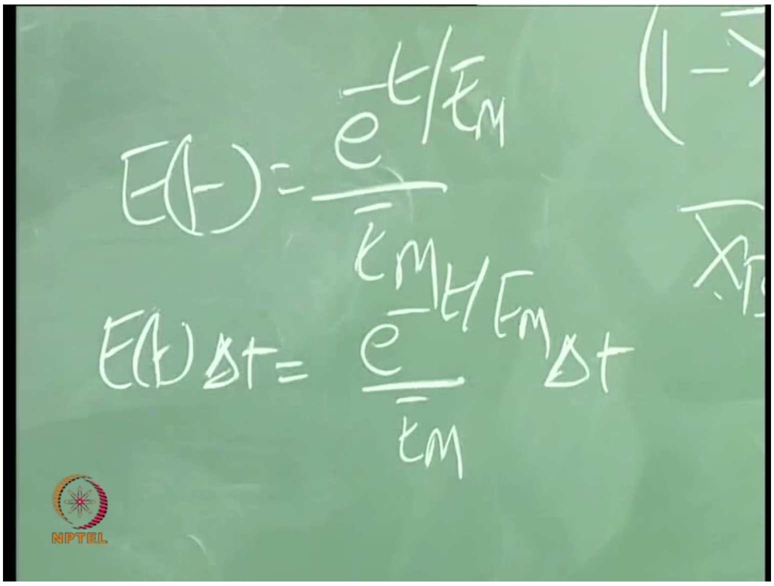

One can calculate from this. So this is the fraction. This delta t is between 0 to 1 second, 1 second to 2 seconds, 2 second to 3 seconds. So like that whatever time interval you take so you can calculate how the concentration is coming out or the fraction is coming out. If I plot E t versus t then you will have very steep drop and then slowly going. This is what you are telling. But that is related with bypass. So inherently mixed flow reactors are the reactors where bypass is already there but that bypass is a (())(48:19) bypass.

That means (())(48:21) bypass in the sense that I know clearly what is the way past, okay. If someone asks me, okay your mean residence time is 10 minutes, can you tell me how much material has come between 0 to 1 minute? I can tell because of that equation I can calculate that. So clearly I will find out and the same time if I take 0 to 1 minute, 0 to 1 minute I can calculate what is the fraction here. The same 0 to 1 if I go to plug flow reactor and look at, what will happen? You will not see that material.

You know that batch material coming out in the outlet. So that is why mixed flow inherently gives the bypassing and when you have bypass, solids will not have sufficient residence time to get converted. So that is why you get some unconverted particles, practically no conversion particle also 0 to 1 second or 0 to 5 second, 0 to 1 minute depending on mean residence time, okay. So what you see at the outlet is on the average the concentration of all these particles. What you see at the outlet of the mixed flow, okay.

So that is why the moment you put this second reactor that bypass is tremendously limited. Why? The same particles are not going to come out. The chances are very less, okay. For the moment you put second reactor after first reactor, the particle which has bypassed the first reactor need not bypass the second reactor in perfect mixing condition, okay. That is the reason why you put N equal to infinity, we say you get plug flow.

What is the meaning of that? Meaning is all the particles will experience the same bypass, the same you know time and at the end if you look at all the particles every particle would have spend exactly same time. That is the funda there. We have number of tanks as N tends to infinity, you will get plug flow. The particle residence time, the probability for the particles to stay more time is more when you put more and more tanks in series. So wonderful concepts, really wonderful concepts.

Mathematical you can just try to enjoy but I think you know physically if you are able to imagine that is the thing what is happening. So that is why whenever you have a mixed flow reactor if there is no other constraints, definitely it is better to go for multi staging. In fact plug flow really you cannot maintain plug flow in reactors. But whereas mixing you can fairly do that. So that means you can calculate and then show that when it is almost equal to this, okay.

Normally you know beyond 6 only it is almost maybe 95 percent, 98 percent you can touch this value, okay. And if you want to get pure plug flow you have to have reactors from 7 to infinity but if you are able to say that, okay around 5 percent also I can tolerate as an engineer then 6 tanks are used. And where used in industries in ammonium sulphate.

When they are making ammonium sulphate in ICI Company, they were the first people I think 6 tanks in series, okay, to make ammonium sulphate as a fertilizer, okay. So, 6 tanks are just side by side not one below the other. These are liquid phase reactions so one tank, another tank, another tank, another tank. By gravity it flows and you will get almost plug flow conditions. They cannot use directly plug flow there because some precipitation comes during the reaction.

So if you have plug flow and precipitated single pipe reactor as plug flow reactor, the precipitation will damage the plug flow, okay. So you cannot have that. So, that is why these tanks. Many wonderful things are there in chemical engineering if you are able to think properly, okay good. So this is what I wanted to do in non catalytic reactions but what I have not done also I will tell you, okay. I just only try to tell you the beauty in non catalytic reactions by taking simple concepts.

All other things are the same type of analysis only we use, okay. But only thing is mathematics will be slightly complicated the moment you relax the assumptions one by one. Like you know (())(52:38) in his book also gave that if it is not spherical particle, if it is a cylindrical particle there are equations. If it is flat plate there are equations. So that takes care of geometry, okay. Of course now we are assuming that it is isothermal reactions all the time. Non isothermal reactor analysis is more because energy balance, material balance both is required.

But most of the time in non catalytic reactions the particle maintains isothermally because the conductivity of the solids are very high. So whatever temperature is generated there immediately it is distributed across the particle so that you can always think that the particle is isothermal particle. Same thing even with catalytic reaction because the thermal conductivity of the solid is high. So that is why you can take isothermal particle. That I will also prove when we come to catalytic reactions, okay.

That is one and what we have not also done was that you know like for example calcium carbonate particle, that will react in the presence of heat. That is heat transfer control problem. All the time we have been talking about mass transfer but the analysis is again same. But only thing is energy balance we have to write. Similarly gasification is again a kind of heat transfer problem. It is endothermic reaction so you have to supply sufficient heat first of all to the pole particles.

If there is not sufficient amount of heat that is going to the particles, gasification reaction cannot take place. That is again mostly heat transfer control. Most of the time endothermic reactions, okay. Then we also have some reactions where gas phase solids are getting formed. This is again wonderful reaction. For example your silica chips what you make, pure silica is made only because of this particular reaction. The vapour phase reaction is taking place.

They send this gas towards a surface like a coating, okay, like jets and then there nucleation starts and then fine particles will form. Again wonderful reaction but mathematically it is also very complicated because what we have to use probably is population balance models and all that where different particles at what time, what size and all that coming. So that we have not done and what else? Type A, type B, type D we have done. Type C is your calcium carbonate particle, okay.

Then E F. E F are you know I think E is that bombs, ammonium nitrate and all that explosives. So there you do not need any reactor, okay, because the reaction is instantaneous. There again it is heat transfer control. That is why during Diwali time if your fuse is not sufficiently getting heated up, you know fuse means that white thing will come out like tail and then we stay half kilometre and then try to burn it, okay. So if there is not sufficient amount of heat that is passing through, it will not.

Do you think that it will catch the fire? It has caught the fire and you start running. You start running but nothing happens to that. So again you have to come and heat it, okay. So these are the overall pictures of you know our non catalytic reactions but most of the reactions are iron wore, zinc wore, copper wore all these reactions. Most of them behave as shrinking core models, okay.

Then the next one with the particle change is all coal combustion processes coal gas. So in the next class we will happily do catalytic reactions. And for the examination and all that I think you have to prepare a lot for non catalytic reactions, okay good. Thank you.