Chemical Reaction Engineering 2 (Heterogeneous Reactors)
Professor K. Krishnaiah
Department of Chemical Engineering.
Indian Institute of Technology Madras
Lecture 12
Contd.

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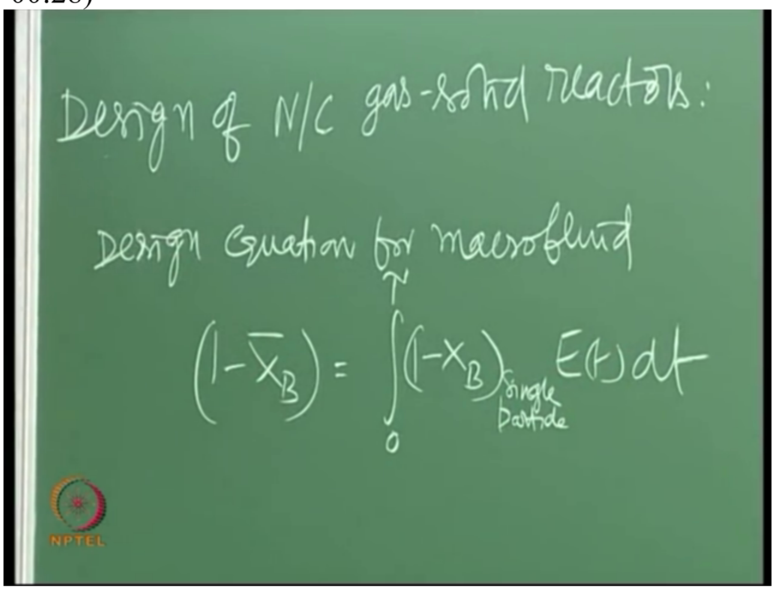

Yeah, in the last class, we have discussed the design equation, the general design equation for gas-solid non-catalytic reactors. If you are focusing on solid phase, because solid phase we take it as a macro fluid. So, the general design expression, design equation for macro fluid is 1 minus X bar B equal to 0 to Tau 1 minus XB single particle Et dt, this is the general expression. So, now, depending on your reactor whether it is following mixed flow or whether it is following plug flow this Et we have to substitute and this 1 minus XB has to be written in terms of, in terms of time and then we have to integrate, right.

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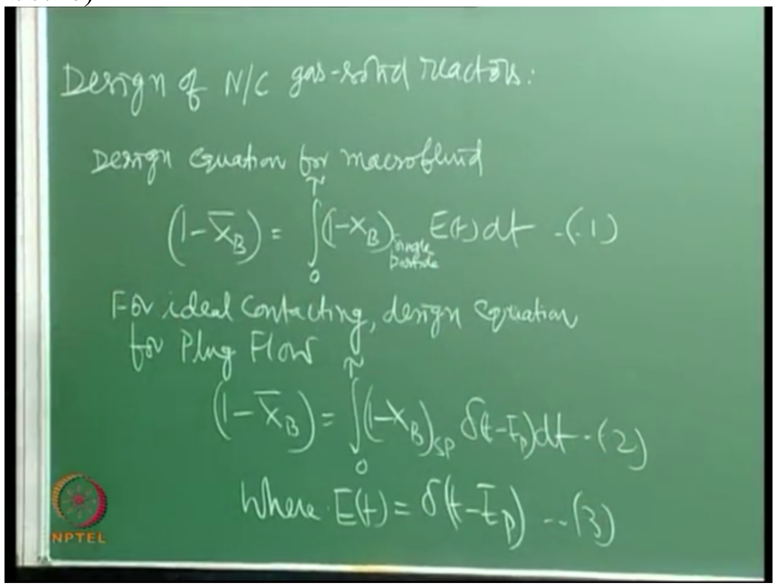

So, for ideal contacting we have mixed flow and plug flow. First, let us take plug flow for ideal contacting, design expression for plug flow, design equation for plug flow will be 1 minus X bar B 0 to Tau. This 1 minus XB single particle. We will write SP single particle, now onwards, okay, into Et dt is direct delta function t minus t bar p dt, where Et equal to delta t minus t bar p that is for plug flow. This is the equation number one. If I start giving numbers, this is equation number three, right. Okay.

So, now, in this equation we have two terms 1 minus XB for single particle and then the exit-age distribution function equation, because it is a plug flow you know clearly, so, we have written that. Now, depending on what is controlling whether film is controlling or ash diffusion is controlling or reaction is controlling, corresponding equations we have to substitute here, right. And then we have to integrate that. And we know integration with the direct delta function, I think you had some examples which I have given you some time back in reactor theory, right.

So, with that help how the direct delta function can be used for integration and all that. So with that help you cannot get the equations, okay. So, now, this is mathematics, but logically what we expect? If I have plug flow, I have single sized particle maybe all are uniformly one centimeter particles, right. And I have plug flow, right. So, this equation will it give the design expression as single particle equations? Like for example single particle equation, you know for film control. What is the equation for single particle? You should remember that.

Student: (())(04:17)

Professor: Yeah, t by Tau equal to XB. Now, I will substitute that instead of t by Tau there that is XB equal to t by Tau, t by Tau equal to XB. So, 1 minus XB we have to put here, so, 1 minus t by Tau. So, what do you get? Yeah, so, for all plug flow the single particle expressions directly will be used for the design, but only difference is or the difference between that single particle equation and plug flow equation. What is the difference?

Renita, not able to follow at all. You are there in the last class, yeah, I am talking about single particle. Single particle film control you have an equation 1 minus XB equal to 1 minus t by Tau, okay, single particle t by Tau. So, when I use the same thing some equation here and then integrate this equation. What do I get? You said that, the same equation must come but seem the same.

Student: t bar equal to Tau.

Professor: How can it be t bar equal to Tau? You see again this equation gives me the relationship between X bar and...

Student: tp bar by Tau

Professor: Yeah, 1 minus tp bar by Tau. So that t is simply replaced by t bar, okay. That is all. So, that is why, for all the for example reaction control you can take, but only slightly difficult thing is even though it is same, I mean integration wise it is same thing only you will get and the ash diffusion you have two terms and then you have to separate XB separately, right? XB alone, because, you have t by Tau equal to 1 minus 3 into 1 minus XB to the power of 2 B 3 and other slightly complicated equation is there. But instead of the - even then we have to substitute for single particle and then integrate.

But the lesson what you learnt is here, now is for as far as plug flow is concerned the same equations for single particle equations are also useful for the design of plug flow reactor. Is it logical? Or not logical? It is logical, no? You have a single particle and you have the relation between XB and t. So, these particle when is kept inside the plug flow reactor depending on its time which we prescribe, okay, maybe 10 minutes, 20 minutes like that the same relationship is valid.

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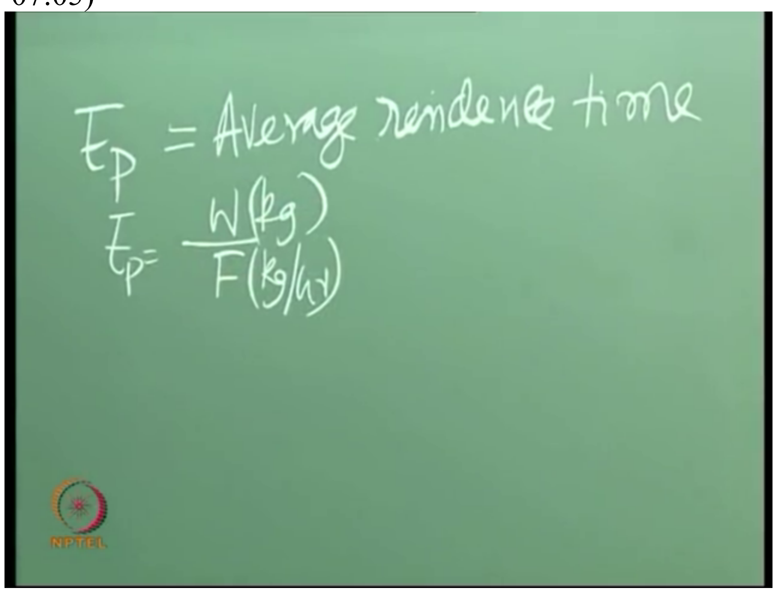

But the difference is that t is replaced by t bar p, where t bar p is, yeah, Average Residence Time, which is also defined as t bar p equal to W by F. W is holdup kg and this is mass flow rate kg per hour or kg per second whatever unit, okay. That is what is t bar p. For Tau bar p also, I am sorry, for t bar m also same equation W by F, okay, good.

So, now, this is one. That means all single particle equations are simply valid for plug flow, okay, good. So, now, that will come later I think that is okay, you can make a note of that somewhere, okay. All single particle equations can be directly used to calculate t bar p, if X bar is given and X bar, if t bar p is, yeah. What did I say? t bar p, if t bar is p is given, X bar you calculate or X bar is given t bar p you calculate, okay, good.

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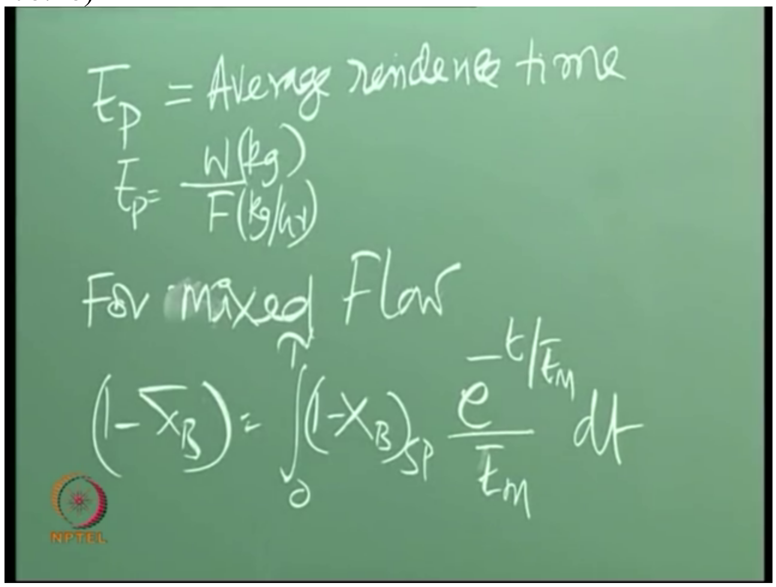

So, now, for mixed flow for ideal contacting again, if I have for mixed flow of particles, right? You know what is Et for mixed flow of particles, good. So, I think, yeah, okay, let me say that for mixed flow of particles you have again 1 minus X bar B equal to 0 to Tau 1 minus XB single particle SP Et dt. Now, Et is here is e power minus t by t bar m by t bar m dt. This is the equation which we have to use, good, ok.

I think when you separate again we will take mixed flow and plug flow these are the general expressions and we do not have any other reactor, if you are not considering a non-ideal reactor. If you are considering non-ideal reactor then Et has equations for different non-ideal parameters, right. If I have a moving-bed where the bed is the particles are slow like blast furnace. The particles are slowly coming down, but they are not coming down so smoothly. Some particle may be staying a little bit up above and then some particle may slide more so. So on the whole you may have slightly a diffusive region that is what, what we call, yeah, dispersion, okay.

I think, I have told you last time my example in the Tirupati queue, right? So, that is what is the dispersion, axial dispersion. So, the people will be pushing you forward and the people front also pushing you backward. So you will be moving back and forth, but that movement region may be maximum one meter, okay, or may be two meters, right? So, like that only restricted region you just move. So, similarly, here when the particles are simply sliding down some particles may go faster some particles may all are at uniform size particles we are talking here, okay.

Yeah, so then even if they are not uniform particles the same dispersion should be happen very limited region. Some particle may go like this and go-up, go-up, come-down, come down, go-up like that it may happen. That is what is the diffusion region. For that we already have an equation for Et. That equation you have to substitute here again for plug flow means, yeah, here, this is ideal plug flow. If I have dispersive plug flow then that is also called dispersive plug flow, generally, DPF people call, okay. So, there also you have to substitute the corresponding Et equation. And if I have a fluidized bed, bed with the dead space and bypass we have an equation, right? So that equation can be used here for finding out the relationship between conversion and t bar m.

Tau is fixed, Tau you get from kinetics, right? This is this comes automatically when you are putting the integration limits and the Tau is known a priori to you. Which Tau is that? For example, it may be Tau for three controls or two controls are each individual step controlling that information you have. That is why, we said, first we should know kinetics and then contacting and of course before that you should know what is a input, right. So, all that three will give you the output. Output again so many times I am repeating, the output again can be in the form of given conversion what is the Residence Time?

What is the volume? Ok. Residence Time is related with volume. This is kg and a, you know, flow rate. This W, if you know the bulk density then you can also calculate what is the volume of the reactor. And, so, at the end finally it is the volume of the reactor but should know conversion or otherwise, if you already have a reactor where volume is already known to you then you can calculate conversion. That is all. All the time, these are the two design parameters which you should know either this, if it is the conversion is known volume, if volume is known conversion. You have to find out, good. Yeah, so this is the equation which we have to use.

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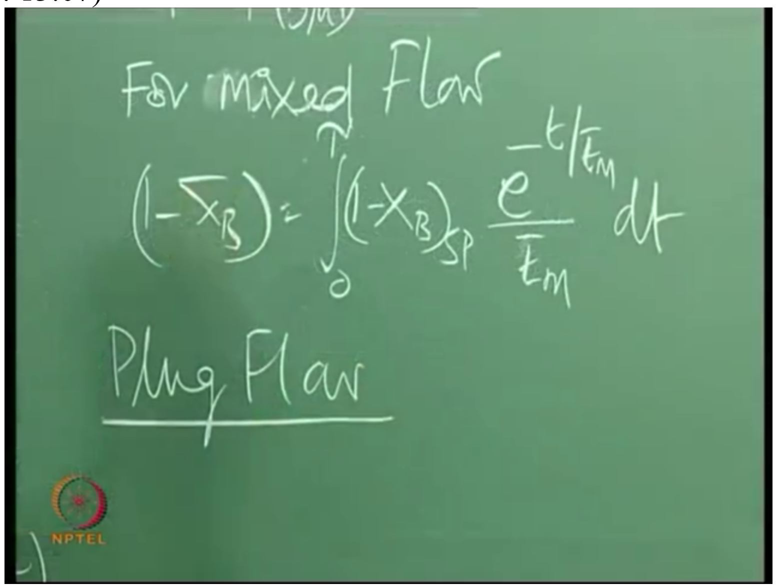

And, now, we will take one by one like for example first, let us take plug flow for details. For plug flow, if you have the each individual step controlling, yeah, and there are assumptions also here. I have plug flow, but you are nice students, so, normally, you do not ask any doubts. Yeah, all the assumptions what we made for kinetics also should be used here like for example spherical particle, okay, and to start with constant size, okay.

And also there is another assumption where you have lots of reactant gas around the particles, okay. That means the entire bed even though the moving bed is completely moving from top to the bottom, okay. This gas composition is so much inside that there is no depletion of gas for the reaction to take place, able to follow me? Yeah, I mean imagine that you have a batch system. You put all the particles there and then you are feeding with the Ca naught and Ca naught concentration is not changing outside concentration, I am talking.

But, once the particle starts going through the film concentration drop maybe there, controlling or not controlling. Then, afterwards, you will have concentration drop in the pores. Again, you have to take whether it is controlling are not controlling, but in reality generally they may be there and then reaction may be smaller, slower or faster.

So, all these steps are there but in the enrollment of the reactor you will not have any depletion of, yeah, that means uniform gas composition throughout the reactor. Otherwise, what will happen imagination, just imagination, yeah, (()) (14:59) Otherwise, what will happen?

Student: Gas will mixed up the concentration from others from outside.

Professor: Yeah, your CAG is not CAG throughout, okay. Just imagine that I have a very lengthy reactor and then the concentration somewhere at the bottom you have less, okay, or if I am sending counter current it will be more of course, okay. Counter current, it will be more and then slowly when the gas is going up, you will have less concentration of gas and when you are coming down that means the particles will see first the low concentrated gas at the top, correct, no? Counter current, so, particles are coming from the top. So, the particles will first see, the gas with low concentration and the particles at the bottom they will see more concentration of, yeah, of gas.

So, that is why, I have to take that variation also into account. That design is slightly complicated mathematically, but conceptually it is fine. And you know one thumb rule as in industry what they do is, okay, I will take the arithmetic average. Let us say here 5 moles and on the top maybe 3 moles, okay, decreasing, you know, counter current. So then I will take, so, this is, I said how much? 4 plus, so, 7, 5 plus 3, 8. So, 4 is average. So your CAG is 4, okay.

So, of course, all kinds of thumb rules are used in industry, because their idea is not to understand and then not to solve the problem you know mathematically. But they are understanding their aim is to run the plant, somehow, so, that is why, even before chemical engineering was there excellent chemical engineering factories were there, okay. But, only thing what we are doing now is that, okay, when you are operating that, are you able to understand what is going on in the plant? Otherwise, we own without understanding also we will produce many things, okay.

Simple example is, are you not producing everyday curd? And are you not eating curd every day? Particularly, now, I mean South-Indians, North-Indians may not use every day, okay. Yeah, then do you know how it is actually produced? Do you know this scientific basis for a curd production? There is a lot of biochemical engineering there. Lot of biochemical engineering, okay. So, that is why, temperature should be maintained if it is very hot.

You know, you put in the in a earlier previous days, you may not know, but, you ask your mother. So, she will put in a earlier days curd or buttermilk and she will not pour for one liter of milk. She will not pour 10 liters of buttermilk. Very small, that is why, she simply touches, that is all one drop. .And after 6-7 hours beautiful. And again in the winter it may take more time. In summer, may take less time, if it is too hot, too, much summer. You may not get any curd, because microorganisms die, because they also need air conditioned like us. I mean correct temperature like us, okay. So, that is why, I think you know all these things are possible, but, I think without learning anything about curd we are happily eating. So like that I think without knowing anything people have been producing the chemicals but only when you have the knowledge you know how to handle it.

That is why, I give another example always that you know a mechanic driving a car and people like us driving a car is totally different. His confidence is totally different. I mean most of us we do not know except steering where it is and where is the brake and where is the other, you know, clutch and accelerator. That is why, sometimes human will get confused for clutch for break, break for clutch and also accelerator. These two is okay, at least, but, initially, if you confused with the brake and the accelerator instead of stopping you are accelerating. So gone, accidents. But, mechanic will not do that, because experience-knowledge, experience-knowledge, so, you will happily stop. I think even without touching the steering also he will run the car. So that is the confidence.

So, after doing this chemical engineering degree when you go to industry you will be in that driver seat, if something happens you should be able to tell that, okay, this distillation column is not well because of this reason, okay. A reactor temperature is falling so. So, I think conversion will be less. So this not correct, I again increase the temperature. So that is the kind of thing, okay. So that is the reason why we are trying to discuss all these things. Which one?

Student: That averaging you said (())(19:41) that…

Professor: This averaging is very easy, you know, it is automatic average.

Student: Why we are going to normally averages to make mathematical simple, so, that everybody can understand.

Professor: If you understand the physical phenomena you know where to simplify, okay. Yeah, if you know understand, but without understanding also people are able to simplify things, because, that is experience. Through experience maybe 5 moles and 3 moles or 4 moles there is not much difference for them as far as conversion is concerned. Why? Because, always, you have factor of safety in industry, okay. So, instead of getting 90 percent exactly even if you get 85 percent is, okay for you. That is the reason why, but, nowadays, that is not correct in a chemical industry, okay, still, bulk industry is no problem. But, very that, what you have been telling you know that a pharmaceuticals and there is a name for that specialty chemicals.

Specialty chemicals you cannot, 90 percent means, if you get 90 percent it will be economically viable. Otherwise, if you get only 85 percent then you have to again purify that to 90 percent. Then it may be that may be another big process for purification itself, okay. So, the cost will further increase. So, that is why, nowadays, chemical industry also is going deeper and deeper into what is called the product design. Product design we did not have till now. It is the only mechanical engineers we had product design all the time, okay.

But, I think Chemical Engineering now also started thinking not now, I think even 10-15 years back they started thinking, what is the product design? So, that means if you want a particular type of soap, okay, so, I will ask maybe by market survey. I will collect the information okay now 10 million people wanted only this kind of particular soap, you know, like, nowadays, you see the advertisements, you know, okay, I think, Google you, I do not know you are get advertisement for soaps are so. So, now, what is that called soap is not soap, it is only milk or something, you know, what is that? That white.

Student: Dove.

Professor: Dove. Yes, correct. Yeah, Dove soap. Yeah, I think you know it is not soap it is milk and then one bucket will be pouring milk there, okay. So, then if it is a really milk then why do we go and buy milk, we have milk in the house, you can use. You can happily use that, so, those are very, those people are very-very quality conscious. Oh my God! My daughter also purchases so many things, I think, you know, in her bathroom so many not one, two, three, four, five, six, seven, ten and I do not know what are those ten. I will only look for shampoo, because I have to wash sometimes.

So, I have to see ten times, you know all these bottles, which is shampoo? So, this is shampoo with the color removal. Shampoo with more color and shampoo with the hair. Shampoo without hair. All kinds of things are there, I think, I know it is really funny, but they are making a lot of money, I say. Yeah, she purchases this much and then say it is 500 rupees. Yeah, I think those people they have to be very-very quality conscious, so, the process parameters should be very thoroughly controlled.

So, that is why, that averaging well that will not happen there. But, bulk chemicals like you know, producing millions of tons of sulfuric acid, okay, plus or minus 10 percent does not matter for us. So like that even sulfuric acid or the hydrochloric acid nitric acid all bulk chemicals. So, that is why, this, you know, the product design again is a very engineer, very interesting course in chemical engineering, I wanted to introduce, but, I do not have time now. I think this Cussler, there is a book product design, chemical product design. It is a wonderful book. And I think someone who knows all chemical engineering will only must teach that. It is not that specialized, now, we had told you know specializations. So for car left back, back side tire only, I know or wheel, I know. I do not know anything else. That kind of people cannot teach that.

You should have the entire picture of chemical engineering and then teach product design. It is simple problems again. So, what he has discussed you know, for example ammonia, how do you make a quality ammonia? Whatever you require. So, if I want a 99.9 percent ammonia or what do you do? Okay. So, bulk industries we never bothered about the quality. It is only quantity, but, now, it is quality and also quantity. Because on this planet people are just coming, no? I think, now, 7 billion. When did you see? Yesterday. So, maybe by this time the class is over maybe another 1 million, 2 millions also would have been added to the planet, ok. But, death is not that much, because of again chemical engineering, ok. Because, we have so many pharmaceuticals and so many medicines, so, if he is about to die also you give him an injection keep him another one day, two days like that you know.

So, that is why, you death and the birth, if both are equal it is steady-state, I think will happen to the planet. All of us would have not been here, if that is true, ok, good. Let us take now plug flow and then write those equations, ok, the assumption, why all these started? Because of the one assumption that uniform composition of gas throughout the reactor, ok.

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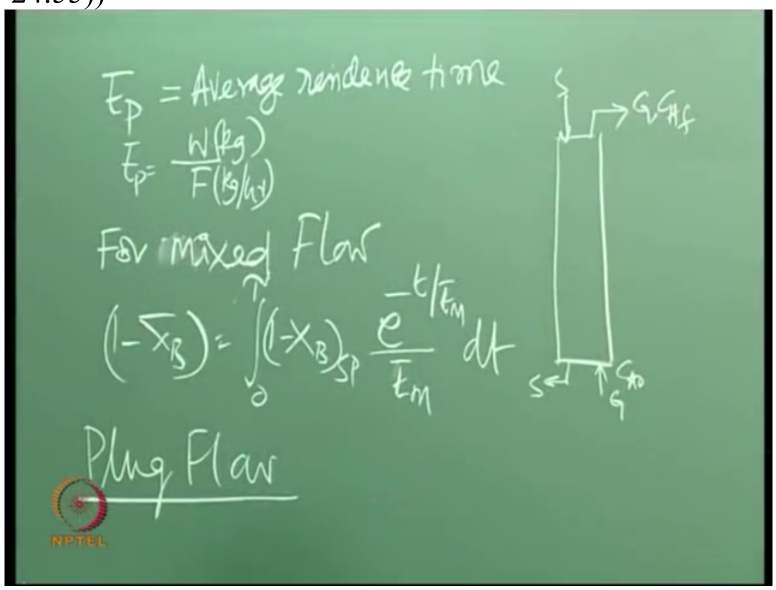

Otherwise, when I have a, okay, let me draw that, because, I think most of the time, I am doing an in the air. Yeah, if this is solid coming, solid going out. Yeah, this is gas. If there is change in gas constant concentration, initially, I may not here, I may have here Ca naught. Somewhere, this may be CAF final gas concentration, okay.

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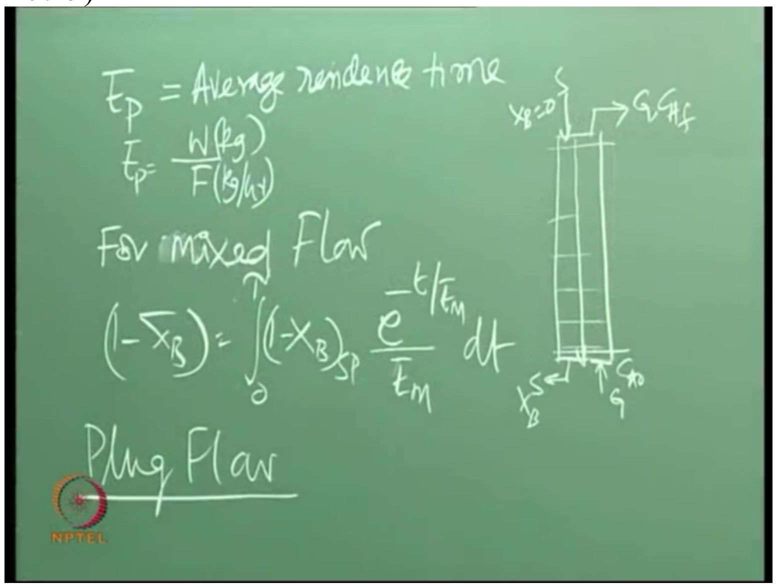

So, solids are of course here we have XB equal to zero, here, I have some XB. So, when the particles are slowly moving assuming that we have plug flow, as, I told you already if this particle will see a concentration of CAF, almost CAF, whereas, this particle we will see a concentration of Ca naught, okay.

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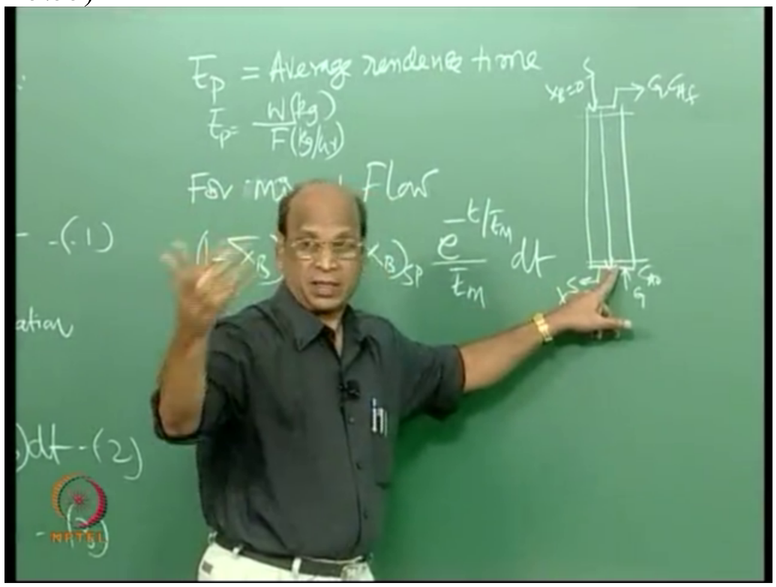

So, but, this particle has already been converted to certain value that depends on your design. What is the flow rate and how I use your reactor? That depends on that. So, that is why, at every point I have my CAG changing in your equation. So in every question for a single particle you have CAG that CAG is continuously changing with height. So that has to be integrated throughout that also has to be taken into the equation then integrate throughout from this point to this point. If it is XB equal to zero XB equal to some XB one orbital, okay, right?

So, that is the reason why we are not taking right now that complicated phenomena. It is only just, you know, conceptually only you can understand, but the rest is mathematics, okay. So, for simplicity, we are now saying that throughout a house Ca naught or CAG. So that every particle is exposed to the same environment. So, then it is only, I have to concentrate on solids. I do not have to worry about gas. That is correct, okay, solids. So, that is why, what we are doing now, okay.

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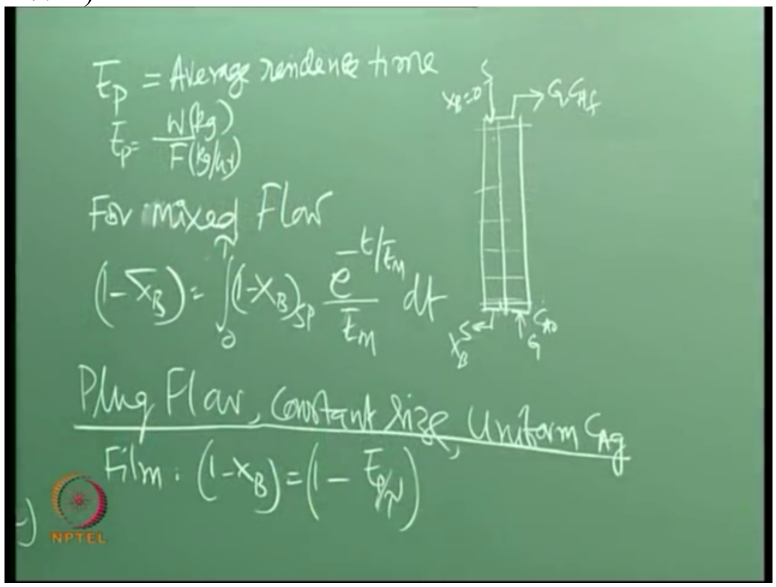

For plug flow you have again at the assumptions, I am telling plug flow, constant size, spherical particles only we are talking, okay. Constant size and uniformed CAG throughout the reaction. Yeah and here what we are discussing now is Shrinking Core Model is valid in all these models, Shrinking Core Model, okay. So, under these conditions, I have given you those equations, yeah, for film you please tell me, for film means film controlling that is what is the meaning, so, 1 minus XB equal to 1 minus t bar by t bar p, correct, no? Yeah.

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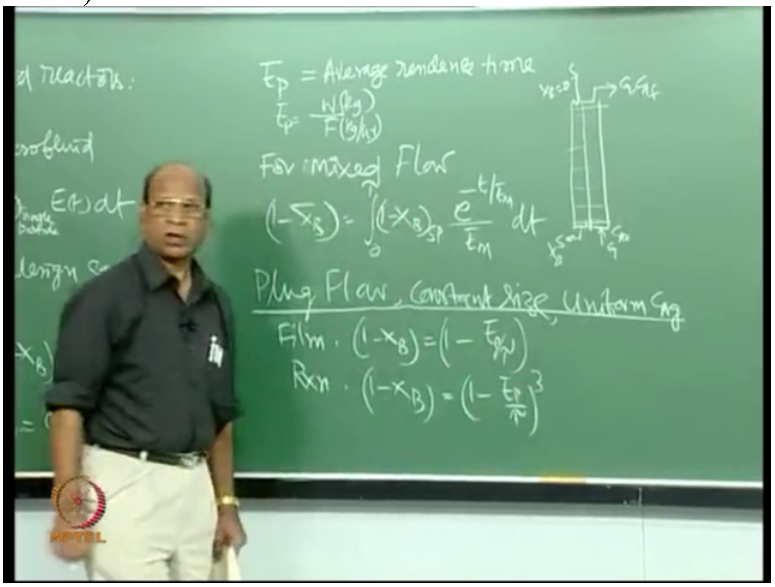

And for reaction control, what we will have for reaction control? You have to remember that exam is coming next week, okay. Reaction then we will write diffusion, because, diffusion is slightly complicated 1 minus XB equal to 1 minus t bar by Tau whole cubed it is there now. You see the equation whole cubed, right? Yeah, and for the other one, you cannot write so easily, you can only write in terms of t bar by Tau of equal to t bar p by Tau equal to 1 minus XB and all that. So, you have to solve that, okay.

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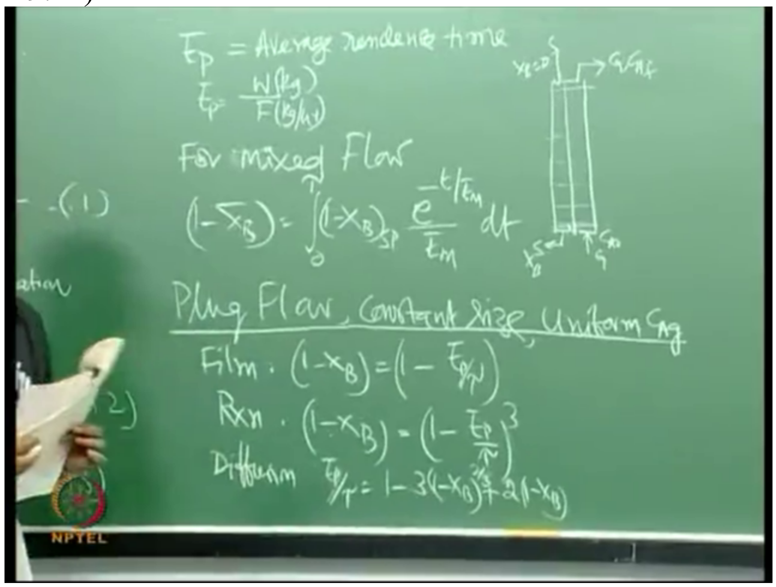

So for diffusion I will just write here, now, t bar p by Tau equal to, someone can tell that, 1 minus 3, 2 by 3 plus 2 into 1 minus XB, so, this is the equation. Yeah, in fact, now, if you have a reactor which is already operating that means you know t bar p, okay. Then you have to calculate XB means it is cubic equation for you, okay. But, the other one is easy, if you want to find out t bar p for 90 conversion very easy, okay. Substitute here 90 percent conversion and then you can calculate what is t bar p.

So these assumption we have plug flow of solids, constant size, uniform composition and uniform size particles also, all particle constant size does not mean that uniform particles size. I have only one size particle, constant size means I think that is understood, okay, good. So this is about plug flow for single particles that means constant size particles. Yeah, Rita? Yeah, good. I think, I thought, I asked you in when I was about to write, but, I think, I now forgotten but anyway. Yeah, you tell me, I think does that matter for plug flow? Even, if I put X bar p or X bar XB both are same, why?

Every particle will spend exactly same time that is why you want where there is average are single particle it is same. But, if you are still feeling comfortable you can write that, okay. And, nothing wrong even if you do not write also, but that you cannot write for mixed flow. Because every particle will have different conversion there what you see is the real average, okay, good. So, this is one aspect.

Now, yeah, if two steps are controlling then you have to write that t by Tau equal to all that thing, you know, in terms of XB 1 minus XB. Yeah, if three controlling same but solve for XB, yeah, 1 minus XB and then substitute here. Analytically, it may not be possible, so, that is why, you have to go sometimes the graphical integration or numerical integration or so, okay, good. I think the procedure is same, but easy for us to remember these equations. So, that is why, we are writing this good, okay. So, now, another thing is next thing what I like to tell is for plug flow I have constant size particle only, particle is not changing with the reaction the overall size. But, I have mixture of particles not single size. What do you do under those conditions?

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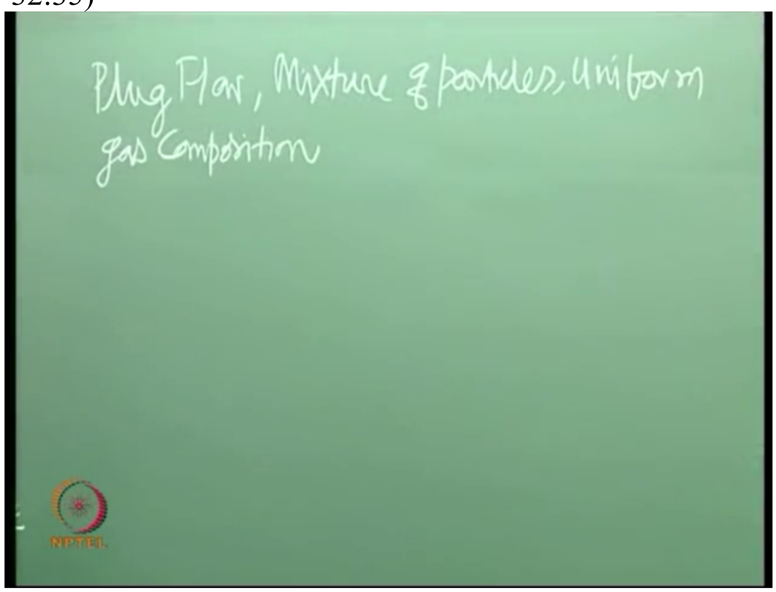

So, I have plug flow, plug flow of solids, mixture of particles, uniform gas, okay, uniform gas composition, mixture of particles but constant size again you know even if the mixture of particles, if I take 1 mm particles, 1 mm, 5 mm, 10 mm three size are there. But, 1 mm will remain as 1 mm till reaction is completed. 5, 10 mm - 10 mm, 5 mm - 5 mm, I think that constant size is maintained. But, now, I have instead of one size, one size 1 mm on a 1 mm, I have 1 mm, 5 mm, 10 mm mixture of particles, okay. So, what do you do under these conditions?

We have to simply average the contribution of each particle fraction, okay. I am sending continuously let us say 100 kgs per hour out of this 100 kgs per hour, maybe, 30 kgs are 1 mm particles. Another, 30 may be 5 mm particles and another 40 percent is, you know 10 mm particles, okay. So, now, I know the fraction 30 percent, 30 percent, 40 percent. So, now, we have average, weighted average of this particular contributions, okay. From each size. So, that is what, what we do, okay, good.

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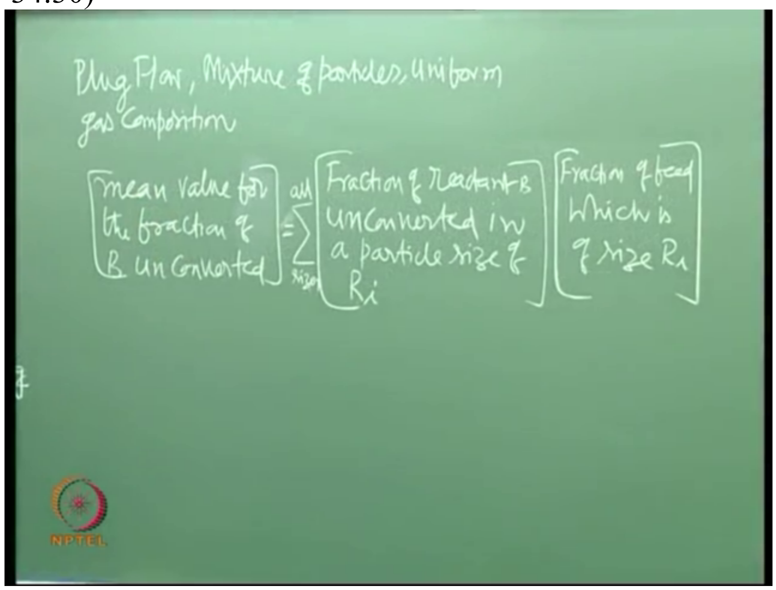

Under those conditions what we can write the equation is mean value of, I will write the, this is more realistic condition. So, mean value for the fraction of B unconverted, this is the one equal to fraction of reactant B unconverted in a particle size of Ri. The Ri may be 1 mm or a may be 5 mm, 10 mm. This is the one, okay. So, I have another term here fraction of feed, which is in fraction of feed, which is of size Ri. And finally you have to all sizes summation that, okay. So, number 7 got.

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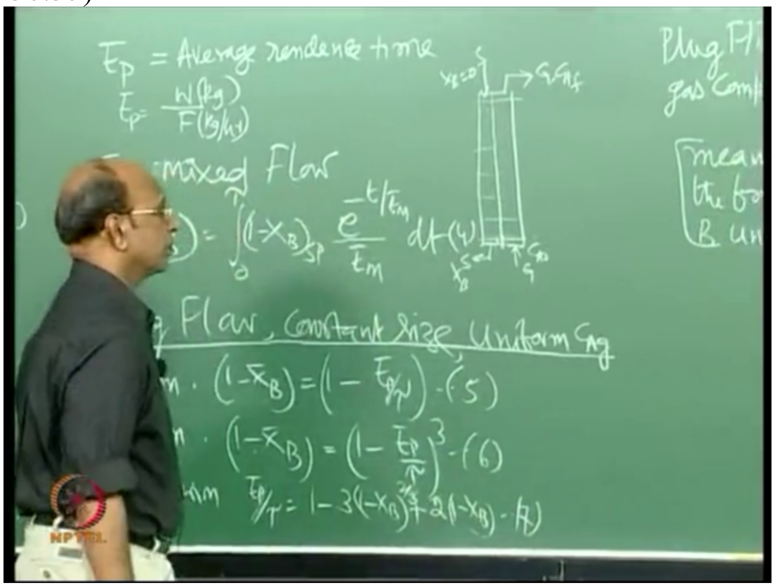

So this is 4, 5, 6, 7, okay.

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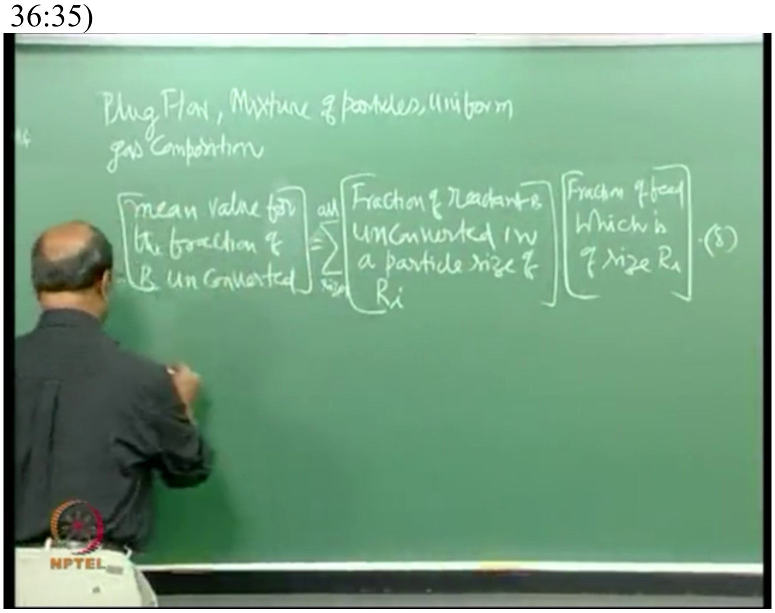

So this can be 8

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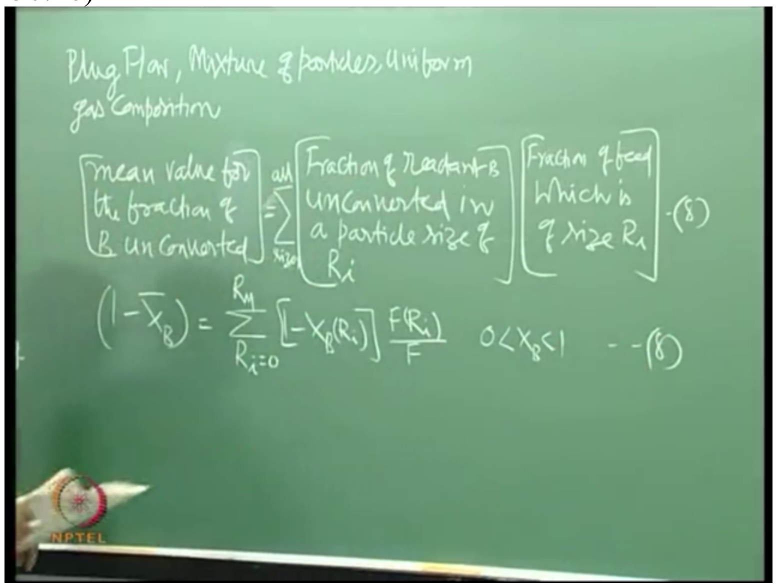

So, if I write this sigma of Ri equal to 0 to RM very appraise the total flow rate. Of course, sometimes, this will be more than one, sometimes it will come. So, that is why, that limitation must be given there, so this is equation number 8. I hope you understood, no? This X bar of Ri, this is the conversion which you got for 1 mm particle, okay, or 5 mm particle or 10 mm particle and this one is F of Ri is the flow rate of 1 mm particles. I told you we have a hundred kgs per hour, so, 30 percent of that means, 30 kgs per hour off you know, 1 mm particles.30 k is per hour of 5 mm particles, 40 k is per hour of 10 mm particles. So that is what the meaning, okay.

So that is the equation, that means you do not have to use any new equation you have to only just take the weighted average of all these contributions, right. So, otherwise, the same equations are useful if it is a reaction control or if it is film control or if it is the diffusion control same equations are useful, good, okay.

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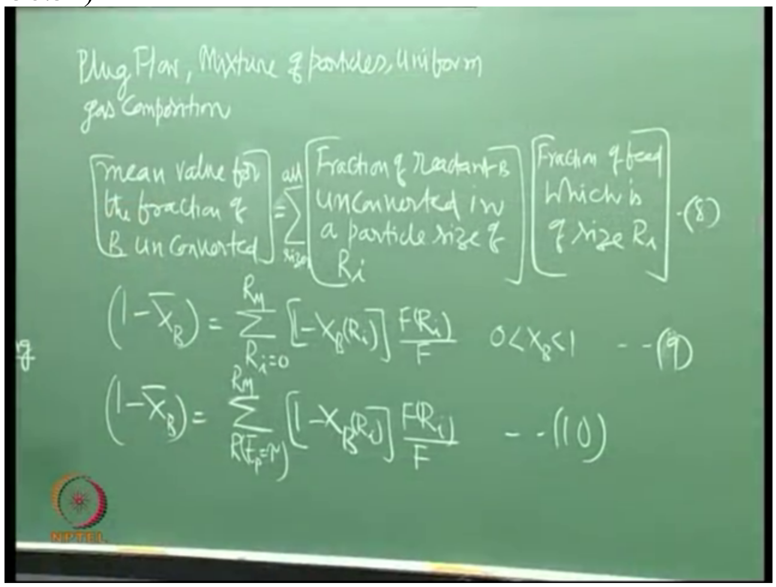

So to more realistically manipulate this equation we can write this lower limit as 1 minus X bar B Sigma of RM that is maximum size and, actually, I do not have to take the contributions from this particular size or less than that size into 1 minus XB of Ri, okay. Yeah. I do not know whether you understood these are not. This is 9, this is 10.

So, what is the meaning of that t bar Tau you know, is a plug flow reactor then imagine that you know we have our beautiful plug flow reactor is conveyer-belt, right. So, you put on this conveyor belt 1 mm particles, 5 mm particles, 10 mm particles, okay, good. And for 1 mm particles Tau is 3 minutes, okay, and t bar p is 5 minutes. Not able to follow, because, for each small particle individual particle you have Tau, Tau is the total time required for that particle to completely get converted.

So, 1 mm particle just as an example he is getting converted in 3 minutes and 5 mm particles may be getting in converted in 6 minutes and 10 mm particles are getting converted in may be 12 minutes, okay, 3-6-12 minutes, okay. I am just giving some values but you are residence time that you provided for plug flow in plug flow is 3 minutes as I said, 5 minutes, okay. Then what will happen to the contribution of 1 mm particles completely converted, so, what will happen 1 minus XB of that? That is what is the meaning of that. So, take only those particles which are above your t bar p. That is all, okay.

So, you can take that into account and then only try to design but that is the meaning of this particular equation, good. So, I think the examples we will do it later but the next one is the mixed flow reactor. Mixed flow reactor, also, exactly the same thing we do. What is that? What are the equations for 1 minus, yeah, here, okay,

Renita, X bar B is okay? Yeah, in fact, if I put this X bar B, I have to put their double. Yeah, so, that is why, we remove X bar B here. That is your convention, okay. If you are comfortable with X bar B, where still I will average, Sir, no problem. Because, every particle is giving, okay, Convertion 90, 90, 90, 90, 90, 90, 90, 90 divided by 1000 is again 90 only, okay, not 90 divided by thousand the corresponding ones, yeah. So, then if you still feel that no, no, I will just put again only that bar it is okay.

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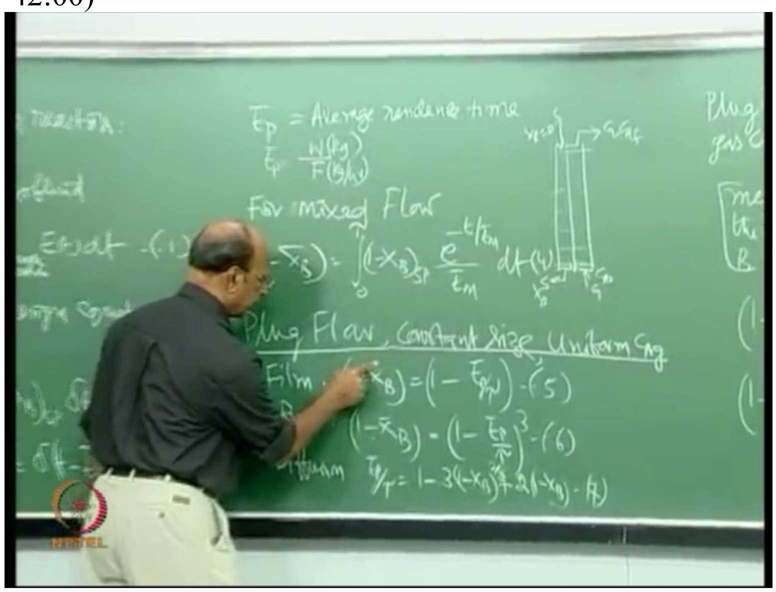

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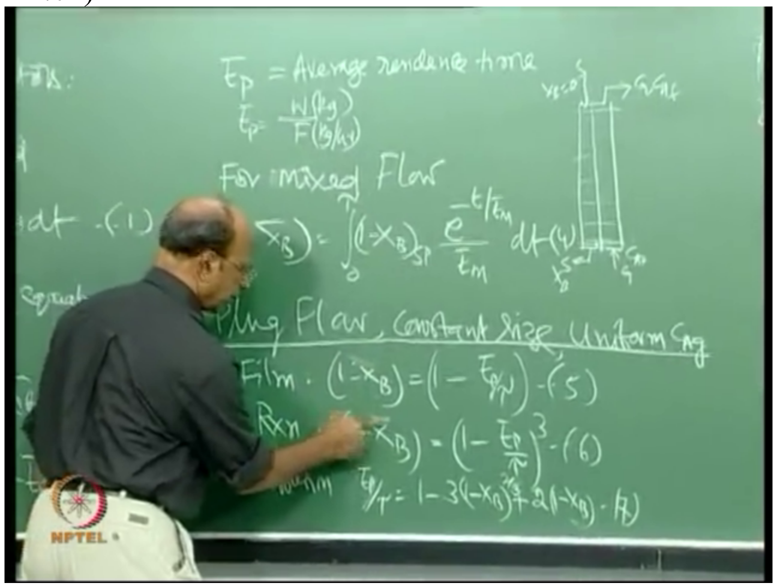

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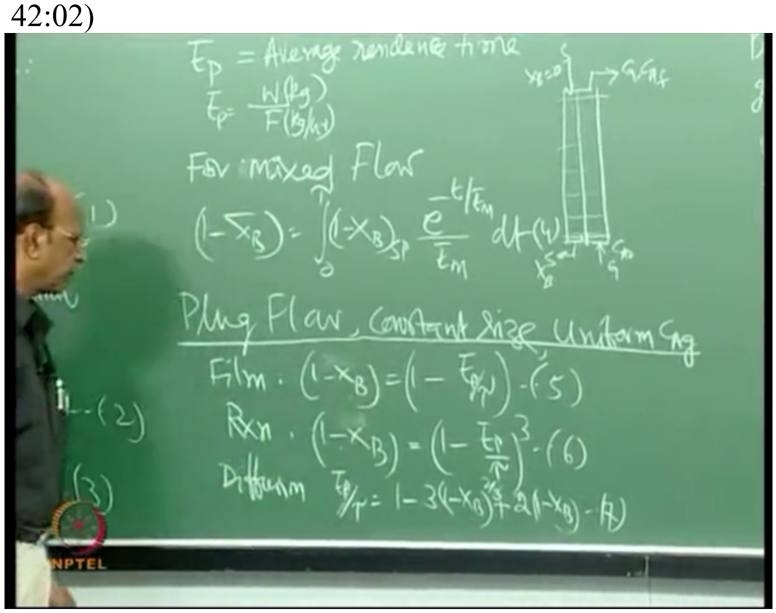

When you put bar here, you have to put double bar here. That average again you are taking here, okay. So, that is why will remove here, okay, for single particle.

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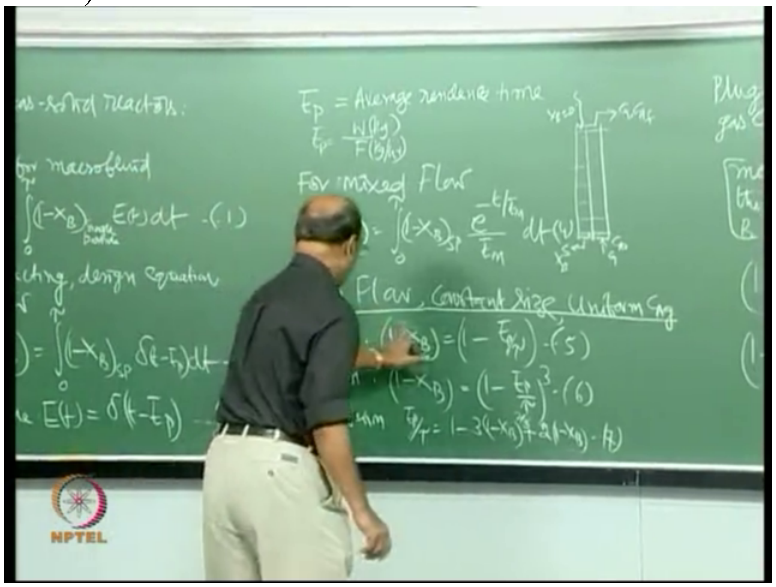

But, when you talk about mixted flow reactor definitely you will have one bar here.

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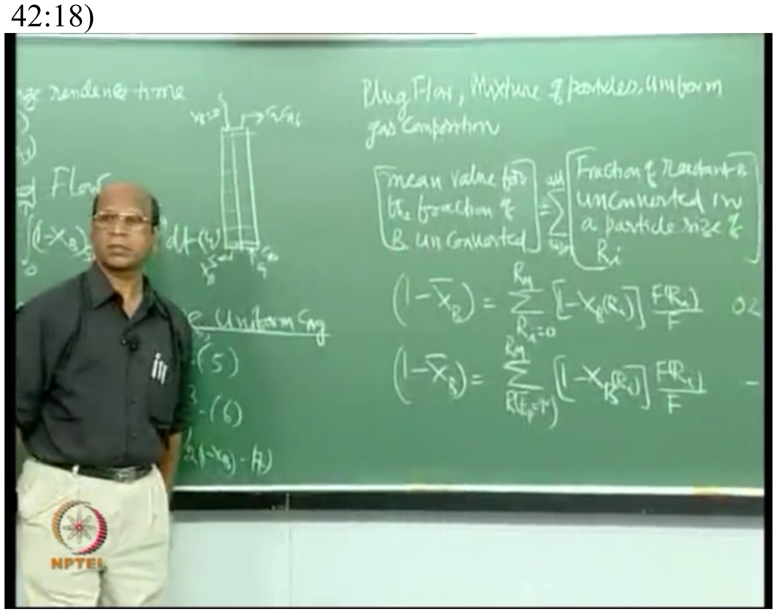

And, definitely, you will have double bar there too, okay. So, Mixed flow also what we do is, mixed flow is not this simple. Mixed flow is very-very complicated.

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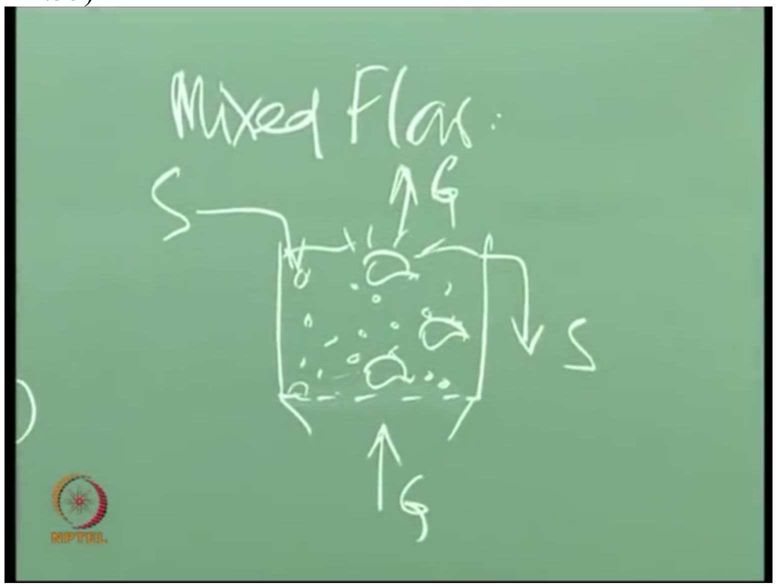

Again what is conceptually happening, I have the mixed flow like a fluidized bed and continuously mixed flow we have, okay. That is the distributor, this is the gas. We have the solid particles to start with uniform first then we have the bubbles and all that here bubble breaking small bubble. Okay. So, solids continuously coming, gas continuously going, yeah, okay.

Yeah, so, when particles are continuously coming and continuously going some particles may come in a very short time, because of mixing we know that very well. So, even at time zero plus you will have some particles coming out, so, in that there is no concentration almost and those particles which are staying more time 100 percent conversion. All that average only, I see at the outlet as conversion. So, that is why, there because of the Residence Time Distribution, you have to take that into account and derive the equation that we will do in the next class.