Chemical Reaction Engineering 2 (Heterogeneous Reactors)
Professor K. Krishnaiah
Department of Chemical Engineering.
Indian Institute of Technology Madras
Lecture 13
Design Equation for MF of Solids, Uniform Gas Composition, Const. Single Particle Size, Shrinking Core Model.

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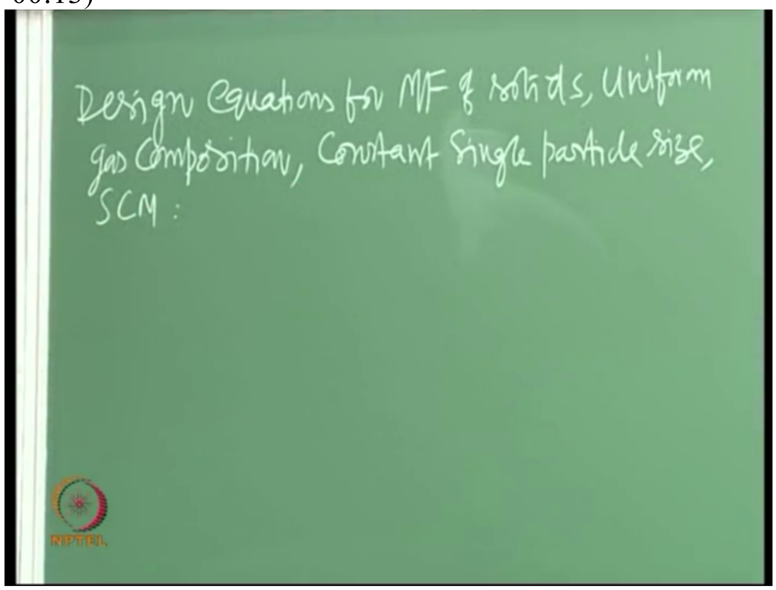

Okay, so design equations for MF of solids, okay. MF of solids still there are some more condition uniform gas throughout uniform gas composition. Yeah, any other condition constant particle size, okay. You can also add, here, constant single particle size and SCM, right, yeah, good. The design expression already you have derived, right. We have given the equation.

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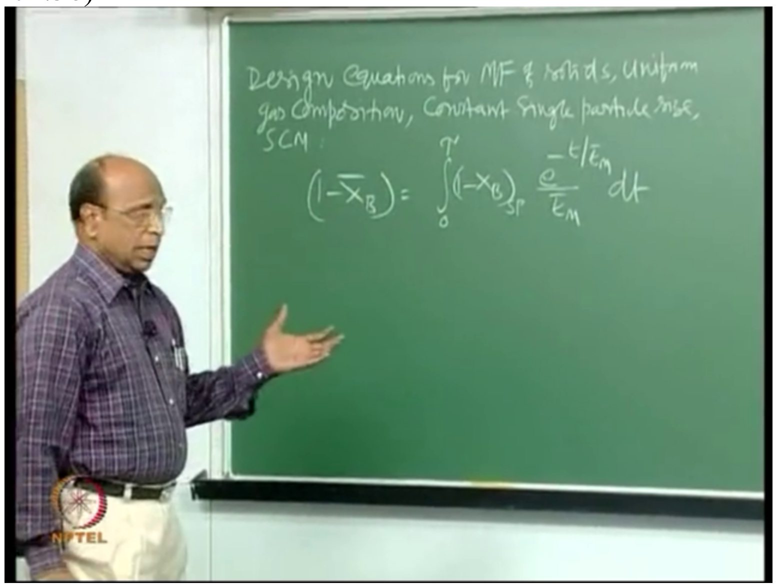

What is the equation? Tomorrow, examination 1 minus X bar B equal to 0 to Tau 1 minus XB single-particle, SP is single-particle, e power minus t by t bar m by t bar m dt. That is a design expression. And the general procedure is, if I have three steps controlling. We have that equation t by Tau equal to in terms of three resistances - very lengthy equation! So, that equation you have to take, but this t by Tau is a function of XB. You will have 1 minus XB to the power of 2 by 3 and also 1 by 3. All kinds of combinations of 1 minus XB is there.

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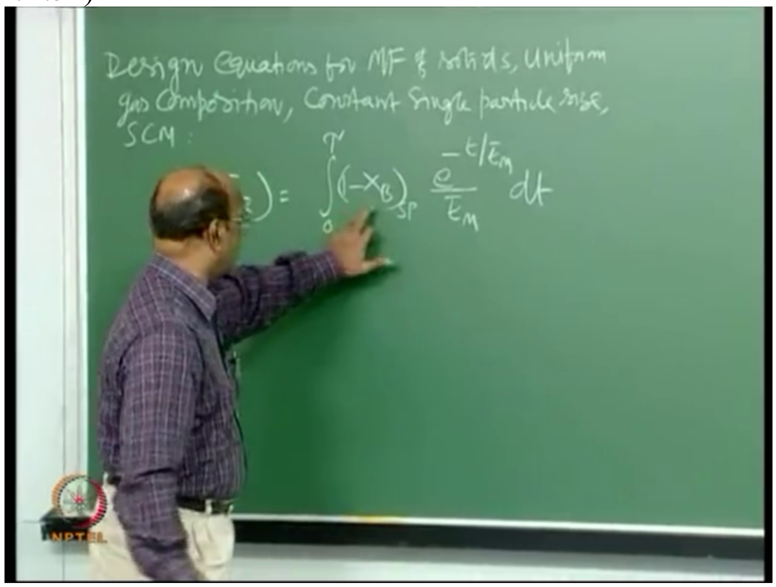

So, we have to solve for 1 minus XB and then substitute here for single-particle and then integrate that the general procedure. So to simplify to understand you know easily for example, if it is film controlling or reaction controlling or diffusion alone controlling. All three steps, single steps controlling, we will have the equations. And complicated things I will give it to you. So that, you can do in the, yeah, in the examination, okay. Simple things I took in the class, complicated things you have to do the exam. But that is an examination, say. It is always like that, you know, you tell in the class simple things and then allow you to expand your brain thinking.

How to exchange these situations to various complicated situations? In fact, true education is that, okay. And if you are not doing that, what you are doing is coaching. What is that give the problem and ask you to solve thousand times the same problem. So that your speed will go to zero to infinity, okay. Even before you see the question, you will answer. That is what is coaching centers do, no? But, I think in real education expansion of brain. So, that is why, examination always complicated problems. You have to extend what you have understood, you know, the knowledge, good.

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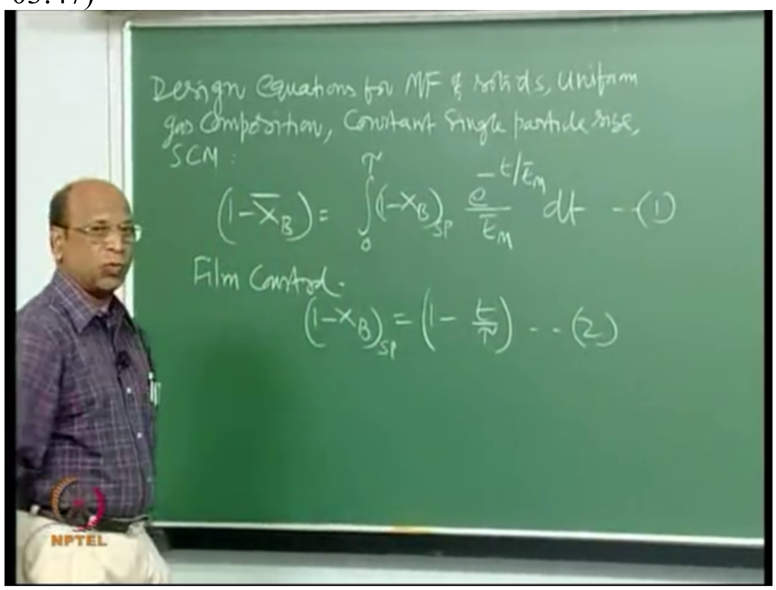

So, now, that is why simple things for me first, film control. If you have film control, you know, that the equation for 1 minus XB. What is the equation for film control, if I have only I mean in terms of 1 minus XB? 1 minus XB equal to, t bar Tau funda is, okay, that is okay. For now you have to write in this fashion for single particle, right. So, 1 minus t by Tau. That is the one. So, we have to substitute this equation 2 in equation 1.

Yeah, Prabhu, finally you got your assignment? Will do it today, because tomorrow is exam. But, did you see? You said that, email you could not get it and all that. Now, first of all you have to accept that you should be in the group. You already accepted that then why did you not get? All of you got it are not got?

Student 1: (())(04:58) joined later (())(04.58)

Student 2: Not in my (())(04.59)

Student 3: It is a group of (())(5:00)

So, because all other assignments, also, I will be sending only through this group. Otherwise, Rahul, I think you can do simply taking their actual IDs and then make as a group, I say. Why should we go to Google and take permission from them yes or no and all that and then finally put it. That is the best one. You have, you know, you are not using Smail, right? You use? So then give me Smail. I think you have all the roll numbers, if you add all the numbers that is your automatically Smail, right. Yeah, that is efficient is always better.

Google is difficult. You do not know, I think everyone has to accept first, if they do not accept they do not accept. Yeah, but, I prefer Smail instead of Google group. What is the advantage of Google group? This also, I can make it as a group. All these numbers together in one group made, so, I can. How many, everyone forwards, right. Your Smail, whatever you are using for that mainly a Smail is forward. You can also do that, okay, good.

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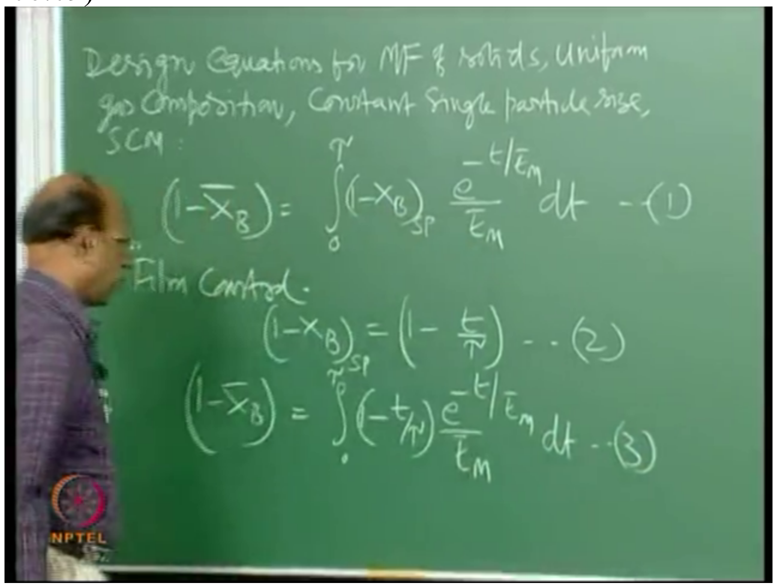

So, substituting equation 2 here. We have for single particle 0 to Tau and this one 1 minus t by Tau e power minus t by t bar m dt. So this is equation 3. And, I am going to write here, after integration you are going to get the final expression but if you write the same thing in the examination, I do not give you in marks, okay. Yeah, so it is not memory. You should also use that mathematics. So, that is why, please do not write that after integrating you are getting the 1, now, I am going to write after integrating, okay.

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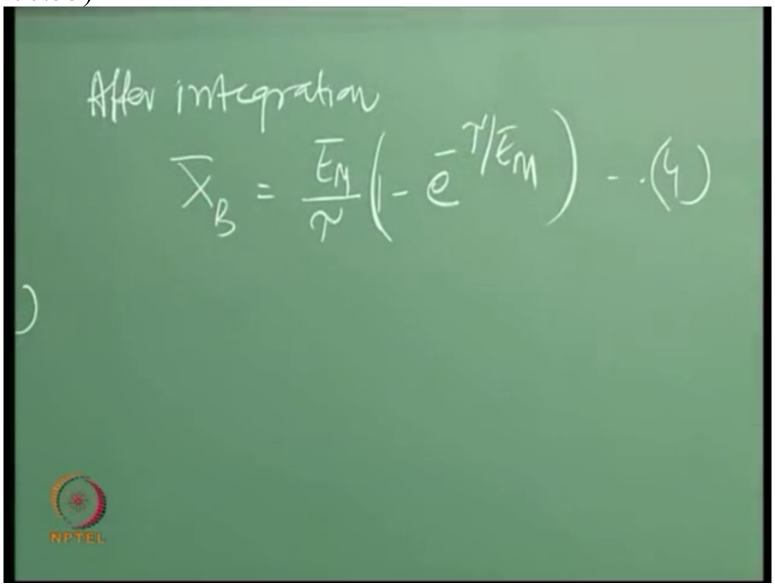

So after integration, yeah, integration by parts, you know, this is e. So after doing that what you get is X bar B equal to, you can also write in terms of 1 minus e power minus t by t bar m, where Tau is the single particle time required for complete conversion and t bar m is, yeah, you see this is the beautiful integration of kinetics and contacting, okay. Yeah, contacting comes through t bar m, okay. Yeah, and kinetics comes through Tau, okay, good.

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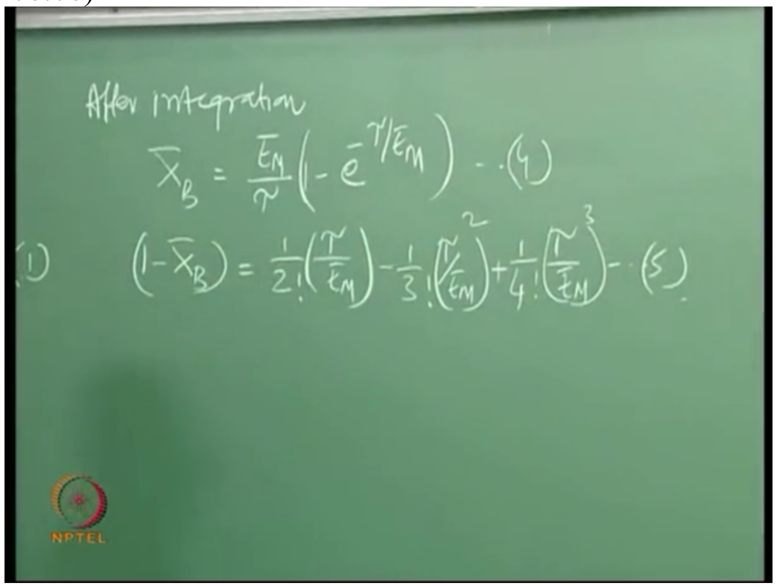

So, this is 4, so, practical engineers have also used these, this e power X, if you take e power minus X. You have some expansion, right. You power minus X equal to 1 minus X and X square factorial by 2 and all that it is, okay, X square by 2 factorial that expansion if you do and then write you will get again in terms of 1 minus X bar B equal to 2 factorial Tau by t bar m 1 by 3 factorial Tau by t bar m square again plus, alternatively, 1 by 4 factorial. Yeah, factorial Tau by t bar m whole cube minus now, etc. So, this is the equation, yeah, 5, yeah.

Generally, we can prefer this and this also sometimes can be used, you know, this is trial and error role you have to solve. In this case, of course, it is easy you can bring this side here. And, because, you know, either you have to find out either XB or t bar m, okay. So, given t bar m you find out X bar B, otherwise for a new reactor X bar B you have to assume, okay, 90 percent conversion for example or 99 percent conversion and then solve for t bar m, Tau comes through kinetics. Total time you should know, okay. So, that is why, it may trial and error problem. So this is good guess in the beginning and then you can refind, reach unit for exact answer. So that is what, what we do. So, this is for film control.

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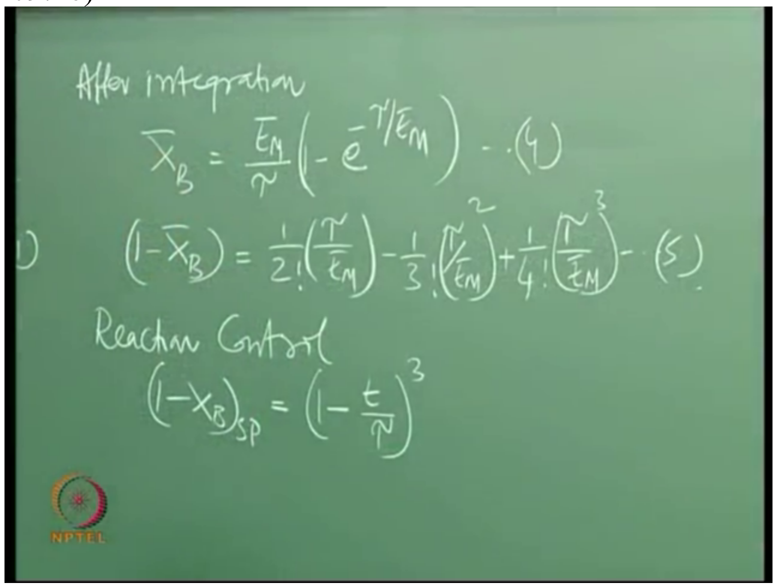

Next one is the reaction control. Diffusion is slightly combustion, so, that is why, reaction control we are going. This is again, you will get an analytical expression here. For reaction control, you have the equation for single particle XB SP, yeah, anyone remembers? 1 minus t by Tau, yeah, whole cube, okay. Yeah, if you see the actual equation in terms of t by Tau equal to 1 minus XB to the power of 1 by 3, okay. So that, you are writing in this fashion.

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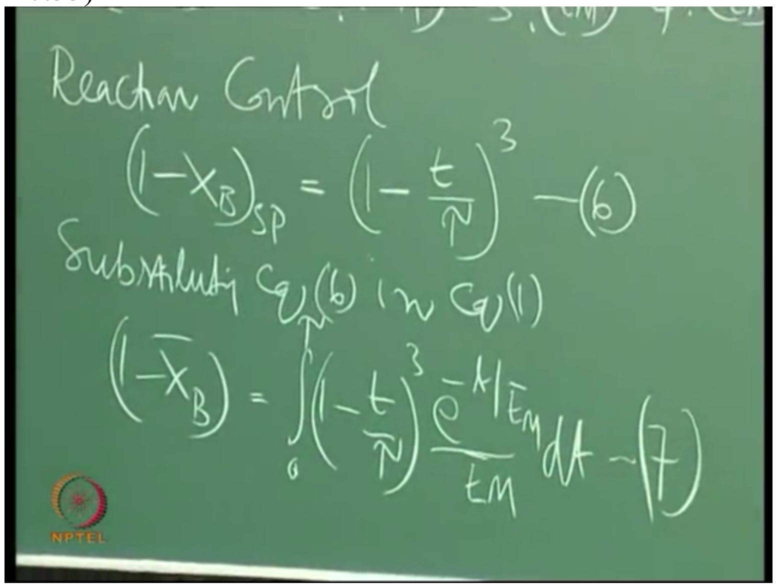

So, now, equation 6 is again substituted in equation 1. Substituting equation 6 in 1, let me write the equation 1 minus X bar B equal to 0 to Tau, for this one it is 1 minus t by Tau whole cube t bar m by t bar m dt. So, this is equation 7, good.

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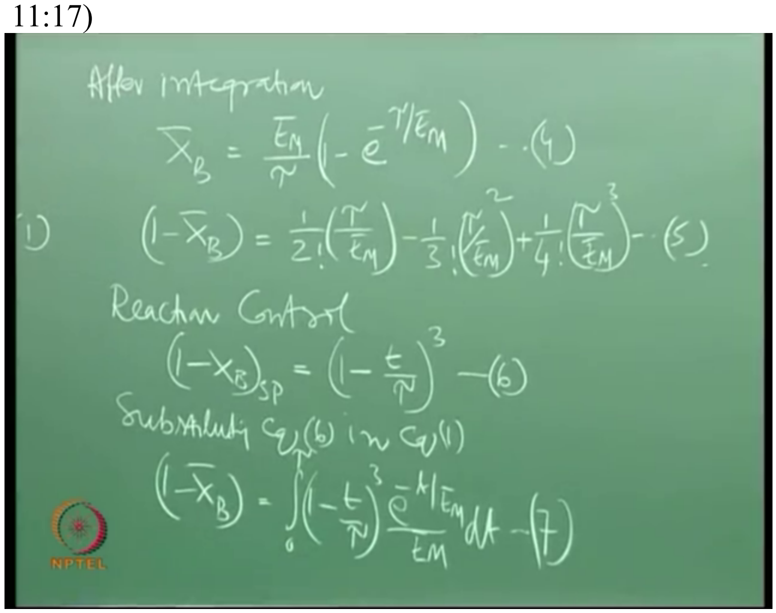

And this mathematical technique you have to learn. It comes through the recursion formula, because this is cubed and you have e power minus t here, ok. You know, this is constant. So that mathematical technique you how to show when I ask derive that corresponding equation, ok.

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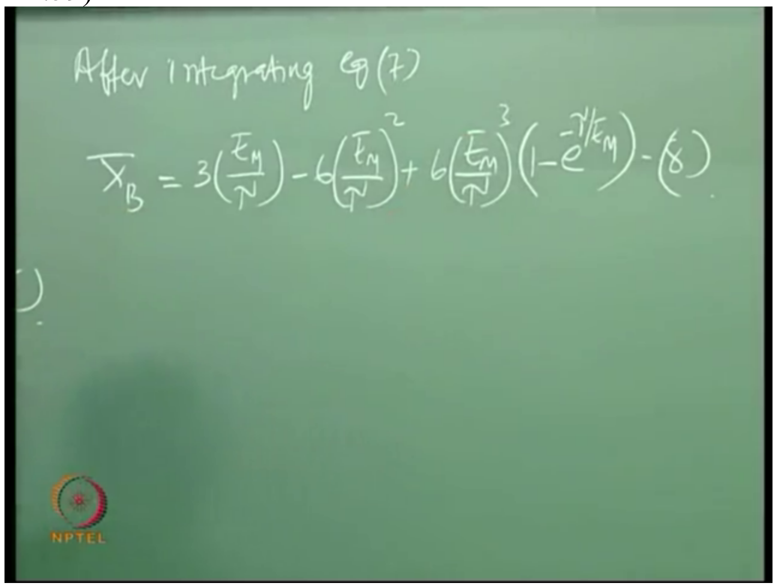

So, after, this is equation seven. Yeah, again after integrating equation 7 through that recursion formula, okay, brush-up, you know, you learnt mathematics only not to write the examination (()) (12:00) to use, okay. So, that is why, I think you have to brush up all those things here. Yeah, what we get is an analytical expression X bar B equal to, yeah, I do not know how do you remember, but you have to remember. Tau minus six t bar by Tau whole square plus six t bar m by Tau whole cube, yeah. And, here, we have 1 minus e power minus t bar m. So this is equation number 8.

You see, now, you have 3 t bar by Tau and next one is minus 6 t bar m by Tau square plus 6 t bar by Tau t bar cube and into that exponential term, right. This is truly difficult, if I give you t bar it is very easy for you to calculate. Simply, substitute t bar by Tau, because Tau through kinetics and you know. And then you can easily calculate X bar B, but for a new reactor it is hell. You have to solve this equation, okay.

To calculate what is t bar m and for that unless you have practice, you are always going to complaining the examinations, Sir, time is not enough. Yeah, if your velocity of writing is zero. You need an infinite time, I said. Infinite time we cannot give for examination, okay. So, that is why, you practice, practice, practice. That is why, assignments are given, good.

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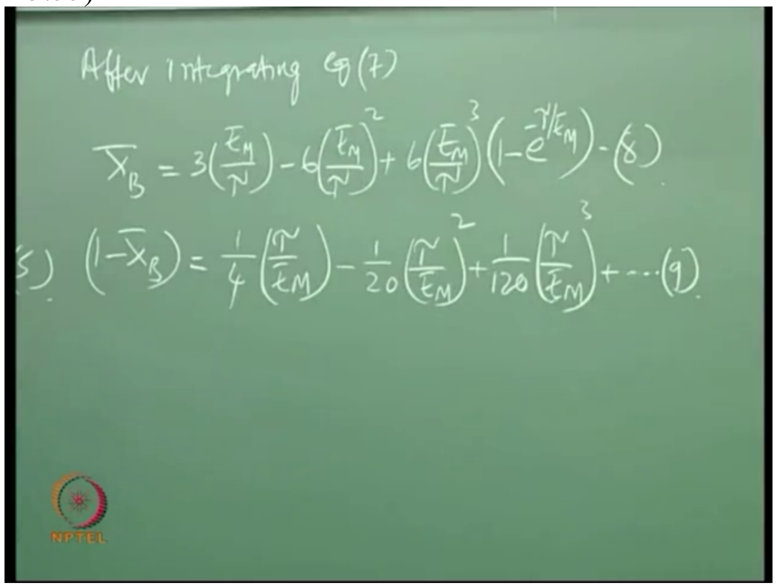

So, again, we can expand this and then write this in a more easy manner for solving the problem as engineers. So, we have in series 1 minus X bar B 1 by 4 Tau by t bar m minus 1 by 20 Tau by t bar m square plus 1 by 120 Tau by t bar m whole cube, etc. So this is equation number 9. So, that is the another case, okay.

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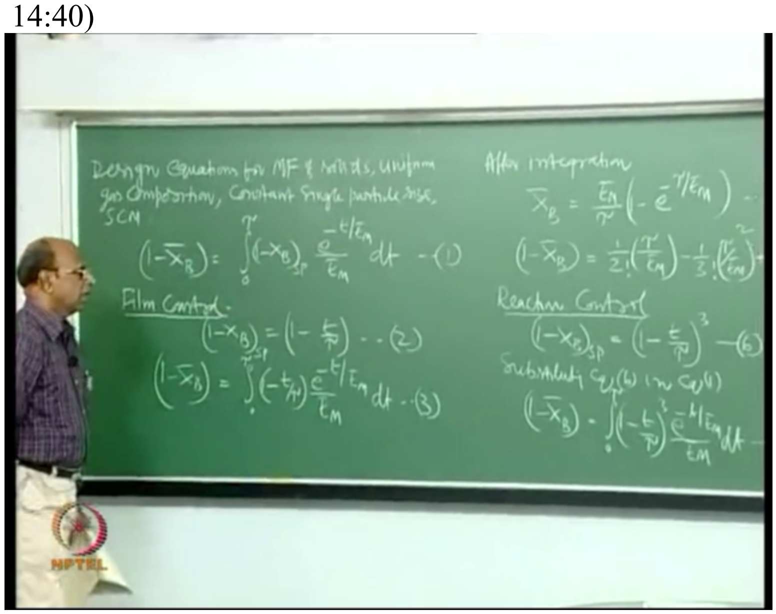

Let me underline this, so that, you will see differences, alright.

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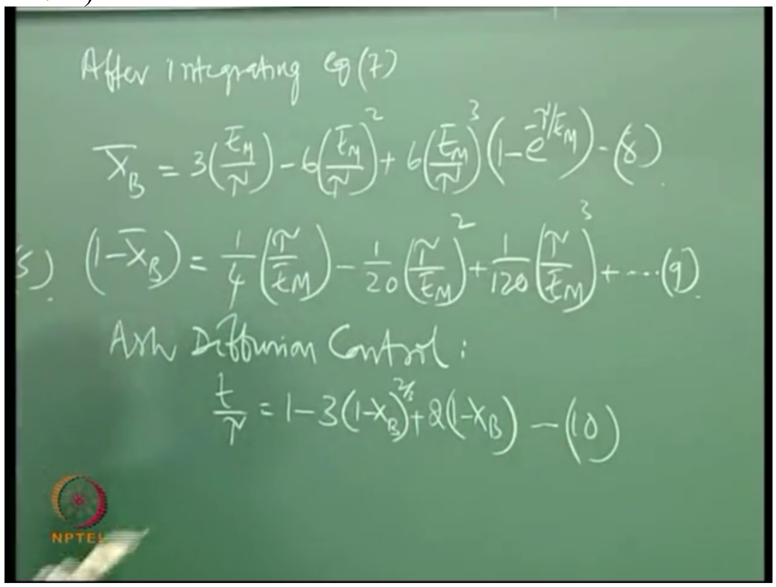

Yeah, next one is diffusion control, ash diffusion control. Yeah, what is equation for ash diffusion control? Yeah, I write tell me, t by Tau equal to 1 minus, 1 minus 3 into, yeah, right, 3 into 1 minus XB 2 by 3 plus, yeah. This is for single particle, right, that the equation number 10.

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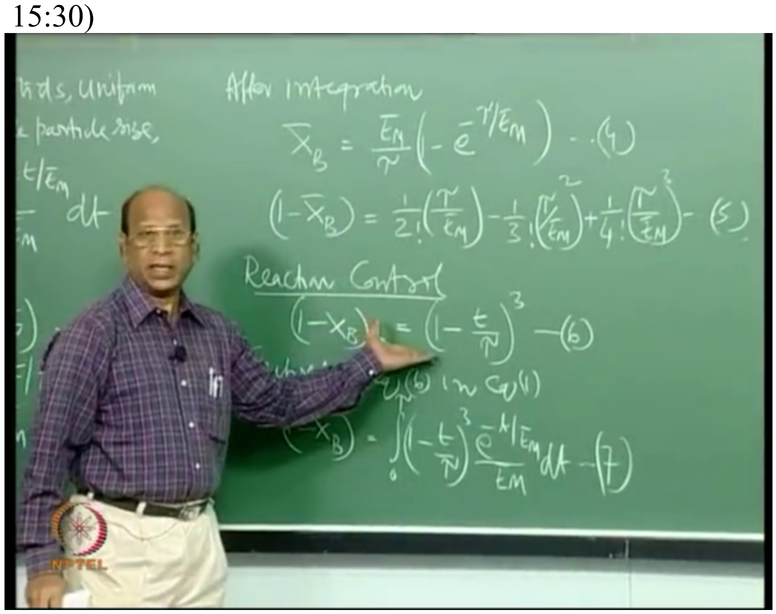

This, I cannot write so easily the way we have written here, okay. Yeah, I am doing that many times.

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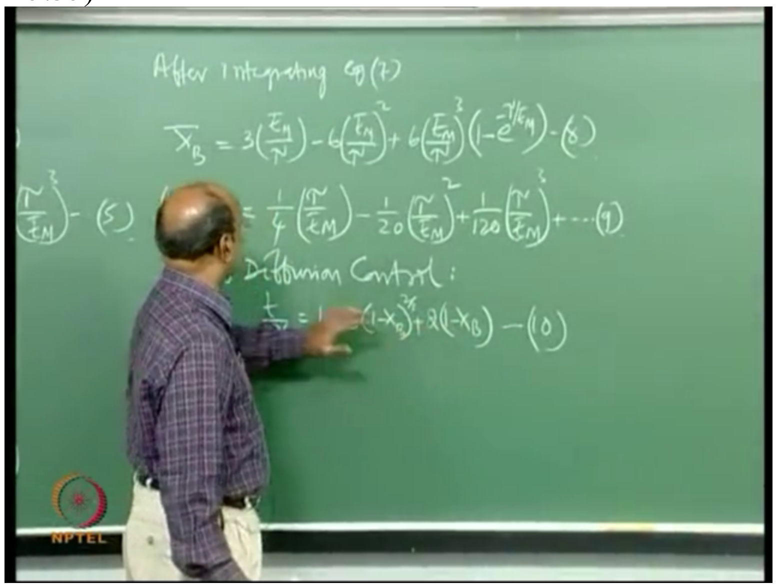

So you have to solve for this 1 minus XB and then substitute equation 1. And then you have to get the final solution. So that is not the easy one. So, that is why, people have already expanded that in, you know, some comment on series solution.

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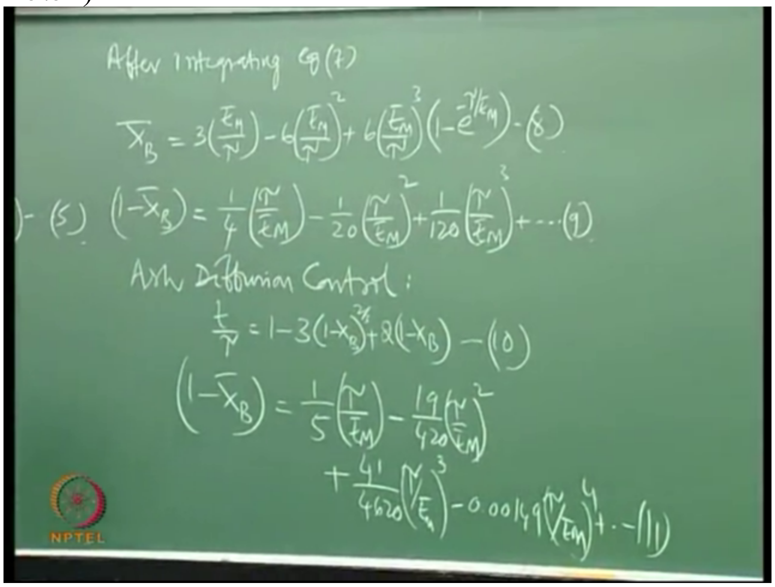

Then we have the solution for ash diffusion control as 1 minus X bar B equal to 1 by 5 Tau by t bar m minus is going on, okay. 19 by 420 Tau by t bar m whole square across that, ok, plus, I will it write here, 41 by 4620 Tau by t bar m whole cubed that is plus. Then we also have another term minus for 0.00149 Tau by t bar m to the power of still some more. Able to see? This is equation number 11. Only thing you have to pray is that, you know, you should never be diffusion control, okay,

But, unfortunately, most of the time it is the diffusion control. Why? Why most of the time it is diffusion control? There are thumb rules, you know, to remember very easily, why? Because, most of these gas-solid non-catalytic reactions takes place at very high temperature. So reaction will be generally very-very fast, because, I really see equation. Then, whenever, you have the product as ash, where you know structure is porous than outside film is always negligible.

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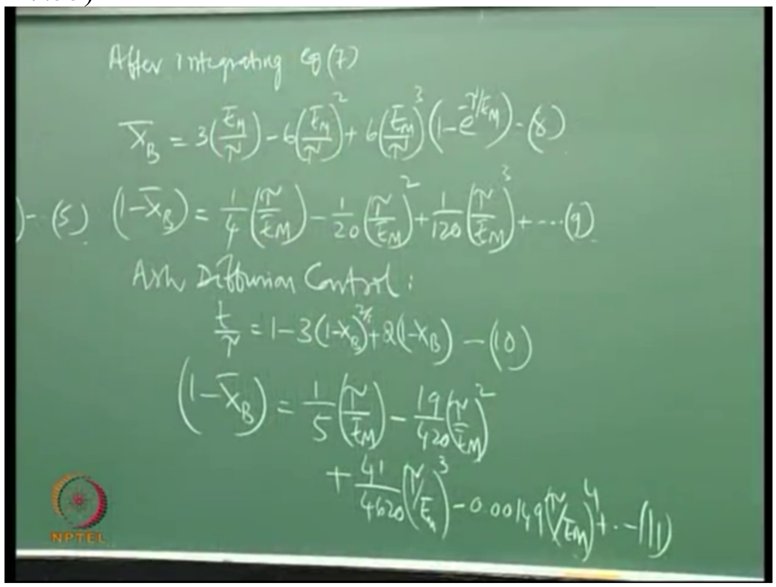

So, that is why, most of the time this is equation we have to remember. Not for the examination I am talking. I am talking about in general, examination I can give you any control, okay. So, this is how you have to solve this problem. And then you have to remember all this.

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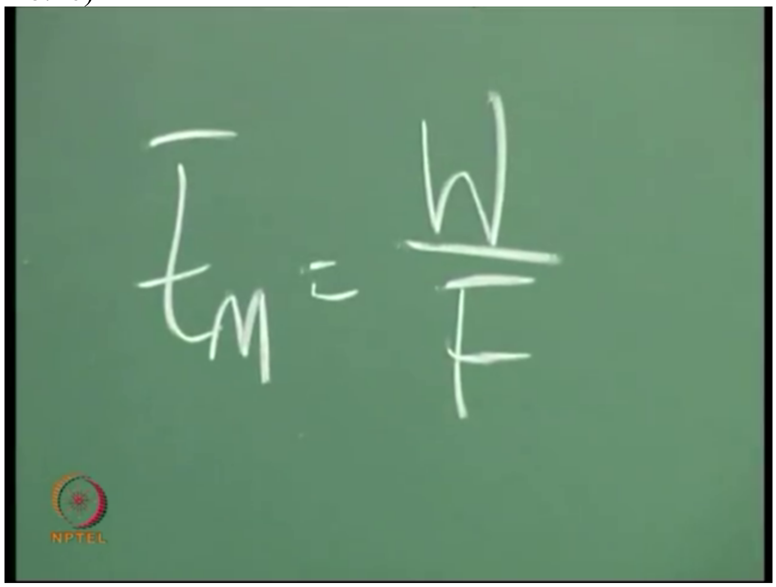

And, again as usual I am giving you. If I give you t bar m that is a for existing reactor. Where you know already t bar m is nothing but W by F. Where W is the holdup of solids inside the reactor and F is mass flow rate of the solids, okay. Normally, it is in homogeneous system it is volume by volumetric flow rate but here we go for mass. Yeah, weight by mass flow rate of solids, okay, good.

So, if already have the reactor t bar m I know then I can calculate X bar B which is easy but to design a new reactor you have to assume whether you are going for 99 percent conversion, 99.9 percent conversion and then solve this equation for t bar m, good, okay. So, because, you have exam tomorrow, let us do so not to problem. So that, you will have at least some experience of being a problem. I know this may be the first and last time you do the problems. So that, I think, I will tell you some problems one plug flow reactor other one is mixture flow reactor we will take, okay.

For plug flow reactor, please, take the problem statement, I will just dictate. Now, you remember plug flow, for plug flow, the single particle equations like equation 2, equation 6 and equation 10. All of them are straight. Straight forward you will get it. The only thing is t is replaced by t bar p, okay. So that, mean residence time of solids within the plug flow reactor. So, that is all. And depending on which one is control you have to substitute that. And, I also told you that we may have distribution of particles that we have done. If you have simply distribution take the average, weighted average, right. So, that is why, we will do one problem. Because, the other problem is simple single sized particles.

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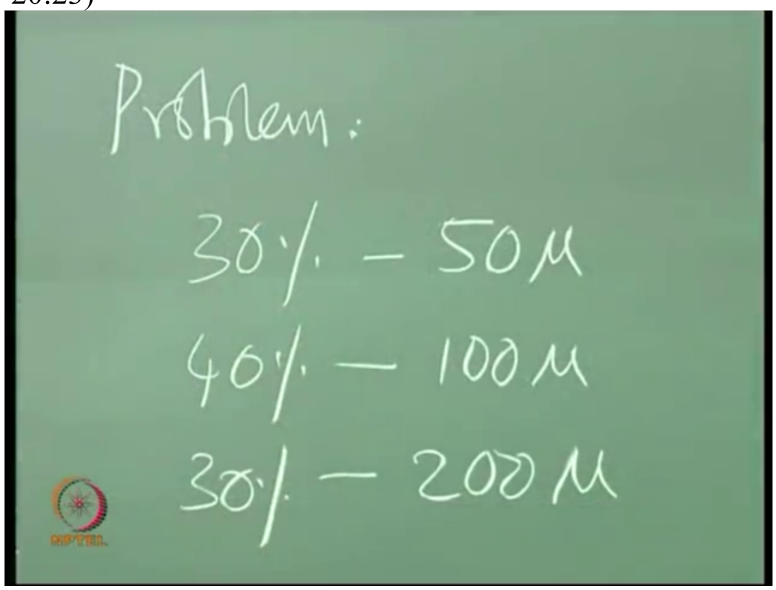

We will take for plug flow distribution of particles, right. That one is it okay, please take this problem. A feed consisting of 30 percent of 50 micron radius particles, 40 percent of hundred micron particles-micron radius, okay, hundred micron radius particles and 30 percent of 200 micron radius particles used to be fed, continuously, in a thin layer onto a moving grate cross current, okay, to a flow of reactant gas, okay. For the planned operating conditions the time required for complete conversion is 5, 10 and 20 minutes for the three sizes of the particles.

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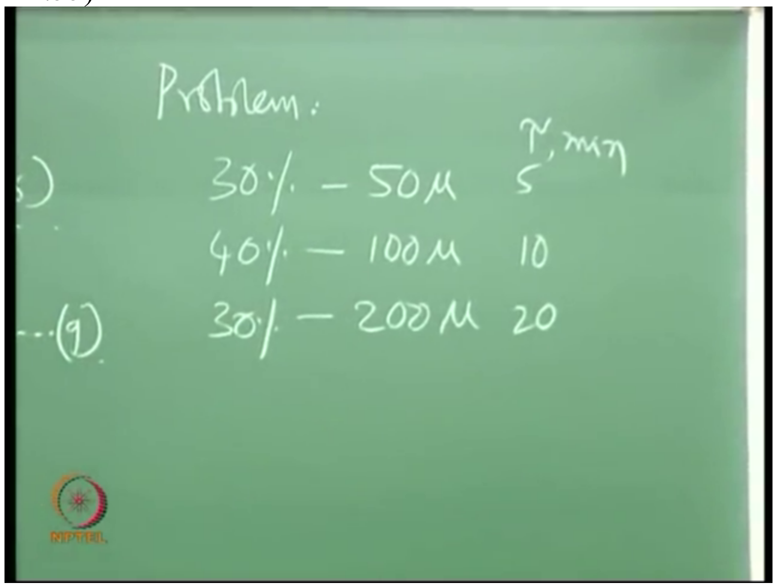

That means, here, I have Tau minutes 5, 10, 20 for three size of particles, okay. Find the conversion of solids for a residence time of 8 minutes in the reactor - very nice problem! So t bar p is 8 minutes, yeah, Tau are given, Tau for 50, Tau for 100, Tau for 200.

Please try, you have the calculators, no? You have to bring calculators every day, because surprise tests, anytime, I can give. Whatever, now, no calculator, read the problem is there anything missing? Which is not specifically given. Yeah, How do you find out which one is reactor? Which one is controlling? (())(22:59) reaction control. Why do you say the reaction control?

Student: (())(23:05)

Professor: Tau is directly proportional to R, yeah. But, now, you have cross the LKg, because, the other one when you are talking about three controls, Tau was also proportional to R for film also. But, later you graduated, when you are talking about changing size particle, okay. First, if the particle is becoming smaller and smaller, okay. So, that means, if you take very small particle, constant size then the exponent may be different. So, that is why, for film control the exponent changes from 1.5 to okay, so, that is why, the logical conclusion here is reaction control. How can you say that?

Student: Feed is fed in a controlled manner.

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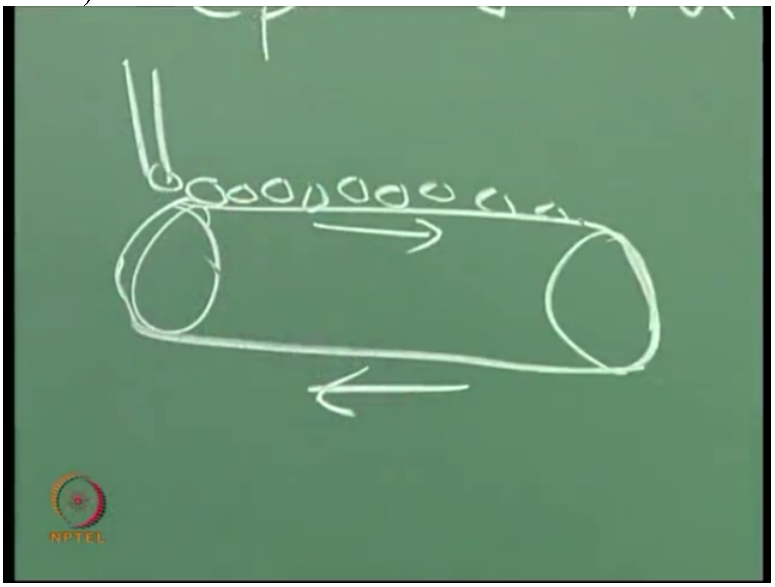

Professor: Yeah, Feed is fed in a control manner. This is moving-grate, in fact, okay. So, this is moving-grate, where, so, here only you are feeding. Of course, the depth I have not shown you. So, this is this is moving- grate comes out. So, I told you know this is wonderful example for plug flow because every particle definitely will spend exactly same time here. In normal flow when you have fluids that is not possible, but solid this is one of the excellent examples, okay. Yeah, so, this is what, but, (())12(24:29) how could you say that, when I put on the moving-grate, how can you say that, it is reaction control?

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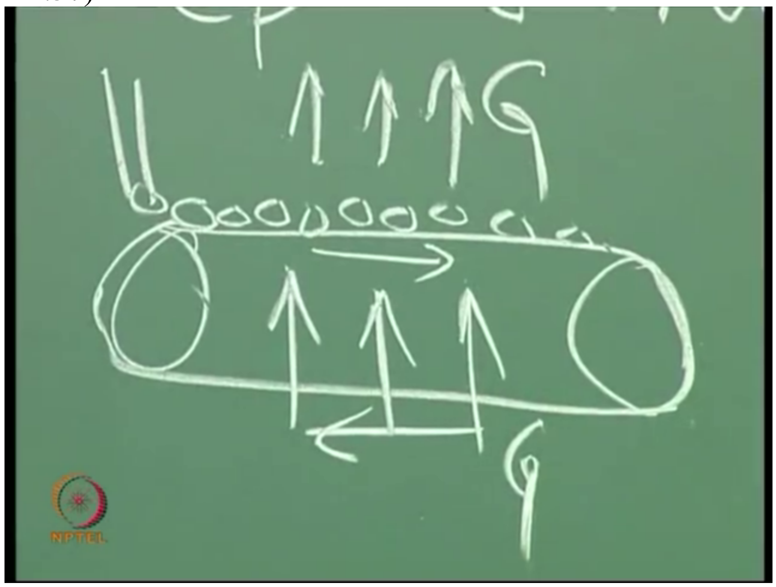

And, yeah, gas is moving cross current to this. Yeah, so what? Even then how do you conclude that it is the reaction control, you cannot say, okay. Thin means what? You are putting thin, so what? It can be film controlling, it can be diffusion controlling, ash diffusion control or it can be reaction control also, that we will not tell you anything. Unless, I say that, I have infinity velocity one will go. Which one you will go? Infinity gas velocity, film control you will not be there, because the film thickness is so small that may not be contributing.

But, you know, that is a lousy assumption. If I have infinity velocity, solids will not be there. They will be fluidized, they will go to some other solar system, okay. So, that is why, that is also you cannot say, only from data you have to see. Tau is proportional to R. Yeah, we have another one for film control. I have given you some data. I do not know, whether, you are there on that day or if you have film control the exponent falls. It will change from 1.5 to 2. There is also one of my favorite problems, I can ask that also, proved that, for film control, if for small particles and large particles. So that the exponent changes.

Student: How can we get that from the problem statement?

Professor: But, already, you should have that knowledge. Because for film control, we have shown that from mathematical equations, derivations. Derivations we have derived for small particles, large particles. I did it for in you know exponent n.

Student: We just want a small particle and large particle. Here, we do not really have a particular transitions as in particular numerical value which has whatever (())(26:22)

Professor: That is excellent expansion of the brain, good. That is nice, if we do that, but, we are not going to that complicated where in transition between this particle to that particle. If you are able to do that, you will get 100 percent marks.

Student: But, there would be a number. Generally, as at least in order of size. So like mm, 1 mm particle would be considered or….

Professor: But, how do you find out? That you tell me!

Student: (())(26:45) I am asking you. Otherwise…

Professor: I have already told that, I say. That order also, how do you find?

Student: We can draw the graph and see. As in, we need 3-4 data points.

Professor: What is the starting point (())(26:59) What are the equations we have used for small particles and large particles? Film controlling, you heard of Frossling equation or (())(27:12) I have told that already, yeah. That is why, you have to continuously come to the classes not alternatively. You are sine waves, okay. Yeah, up-class, down, no-class, up-class, okay. And, the regular period, one class attend, next class do not attend, another class attend. By the by, if you do not get that 85 percent attendance, I am going to send this information to Ram Moorthy, Dean AC, okay.

So, I think definitely you have to follow, I mean, the continuity is a subject, continuity must be there. (())(27:46) mass correlation, you remember? (())(27:49) correlation, what is that? 2 plus something. That something also, you have remember in the examination. Now, we can say something, okay. From there you can find out, whether, 2 is dominant and compared to the other term. You know, for small particles Reynolds number can be neglected. Based on that, you can really find out what is the transition range and all that.

But, these are the simple problems for your exercise understanding. Straightforward R is proportional to Tau or Tau is proportional to R. That is what I say film control, if you have film control the exponent will change from 1.5 to 2 for small particles and large particles. So that, kind of situation is not here, okay. So, that is why, read my notes, even if you do not come to the class takes notes from someone and then read. Large particles 1, no-no, 1 to 1.5, correct, yeah, I am sorry, I was telling 1.5 to, it will change from 0.5 to, I have given also that one that notes. I do not have. Yeah, done it? No one has done it. So, much time 0.9352. Ravikumar, you have done it? 0.966 is not correct. How did you do? We should have three terms there for three contributions.

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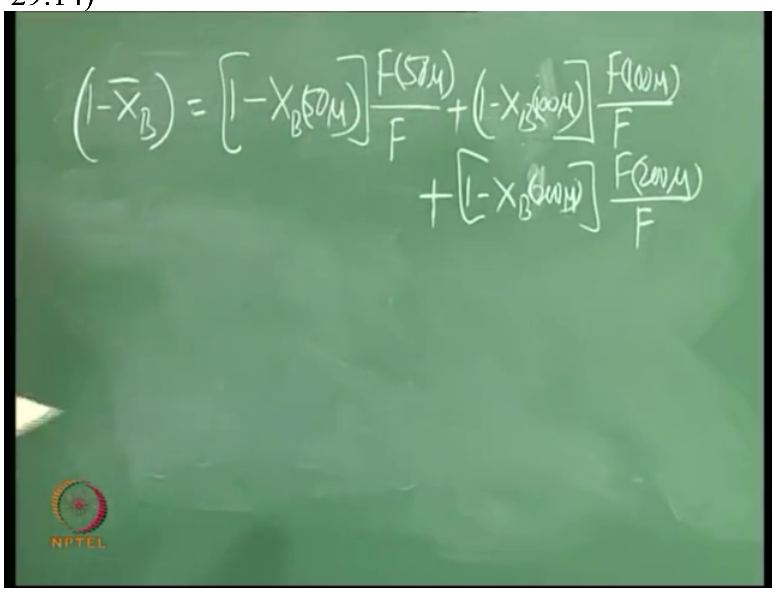

So, I will write the general expression. I think, I will go that side 1 minus X bar B equal to - we have one minus XB for 50 micron particles into F of 50 micron particles by F plus 100 micron particles again F of 100 microns by F. I think I have to write here only. So, 1 minus XB of 200 micron particles. Yeah, that is the equation, okay.

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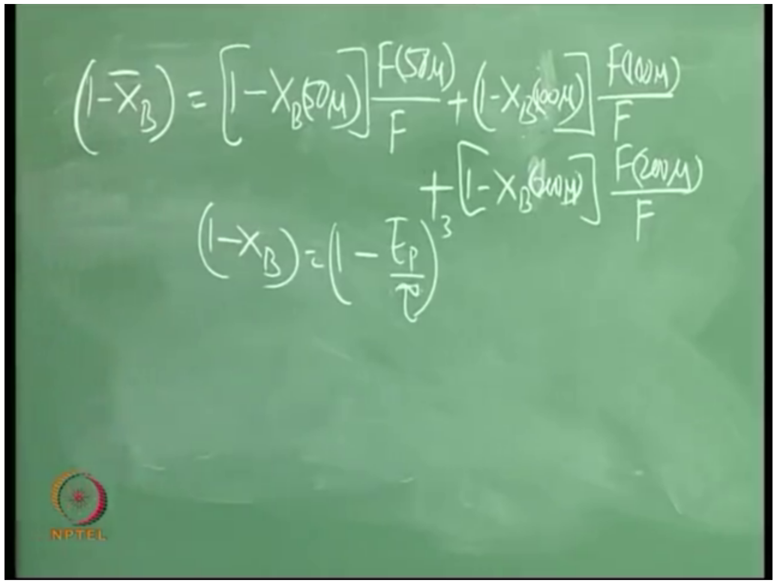

Yeah and 1 minus XB of each general expression is for plug flow 1 minus, yeah, Tau whole cube, right. So, you have to substitute this for each, you know, t bar p. You know, Tau for each particle, three terms and F by F naught is 30 percent, 40 percent another 30 percent for, yeah, different three sizes. Yeah, how much you got? Please, remember there is a condition that, if a particle has Tau less than t bar p, so, that will not contribute to those terms, okay. And to check, if you substitute that and calculate you will get some illogical answer. Conversion coming more than one. Yeah, exactly! Conversion coming more than one is illogical. You know, you cannot have conversion 120 percent or 200 percent, okay. What Shekhar? You will get correctly 93.2.

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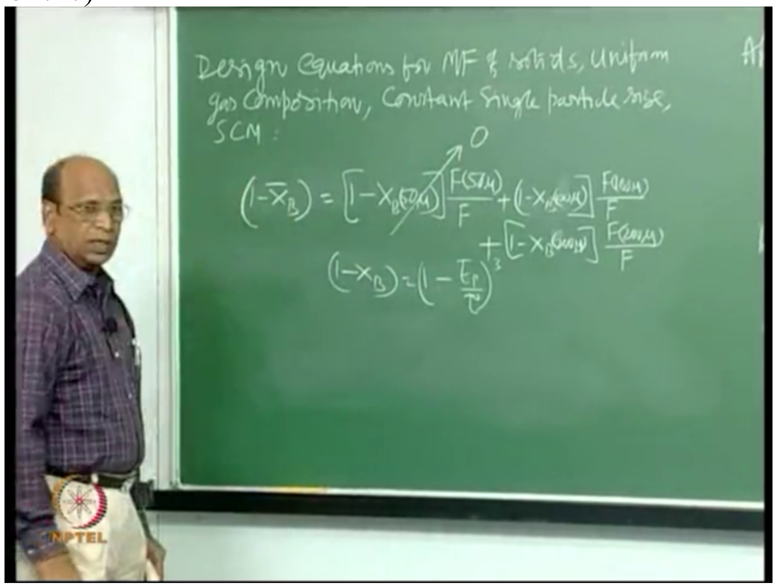

See, actually, this term will not be there. Yeah, that term will not be there.

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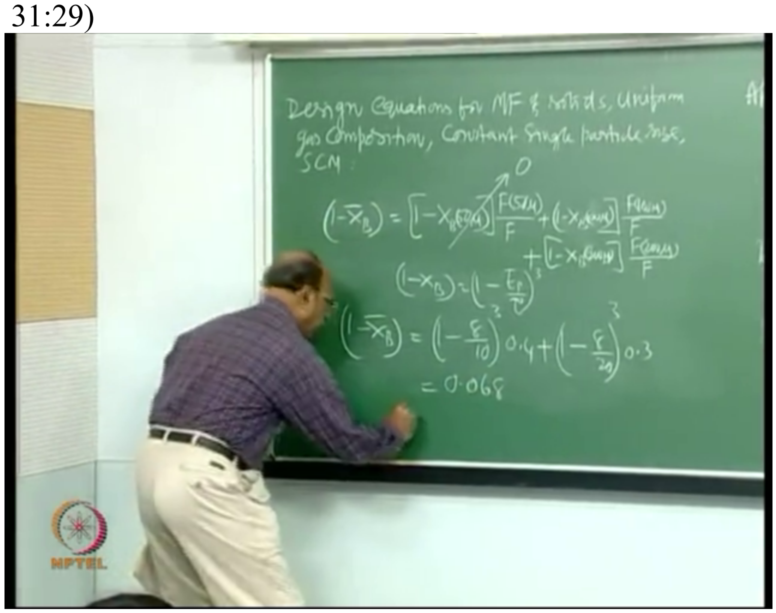

So then I think you know, for the 1 minus X bar B equal to 1 minus 8 by 10 whole cubed into 0.4 plus 1 minus 8 by 20 whole cubed into 0.3. This would, yeah, this how much it comes with tell me?

Student: 0.068

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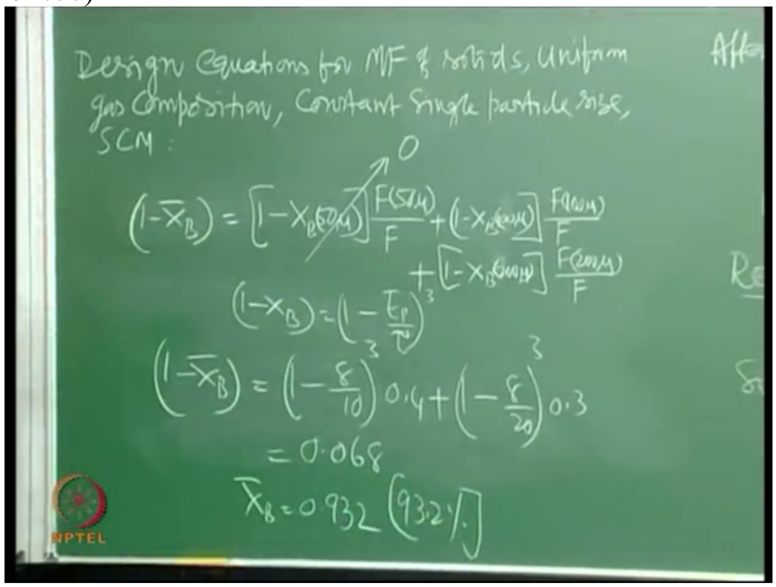

Professor: This one 0.068. So, X bar B will be 0.932 or 93.2 percent. Yeah, that is the answer. Good. Shall we take another another problem quickly? Yeah, we have to do this because in examination for you tomorrow, okay. This is fine, now, Prabhu, able to get it? Yeah, simple only, I say. For you simple if you concentrate it is not difficult at all.

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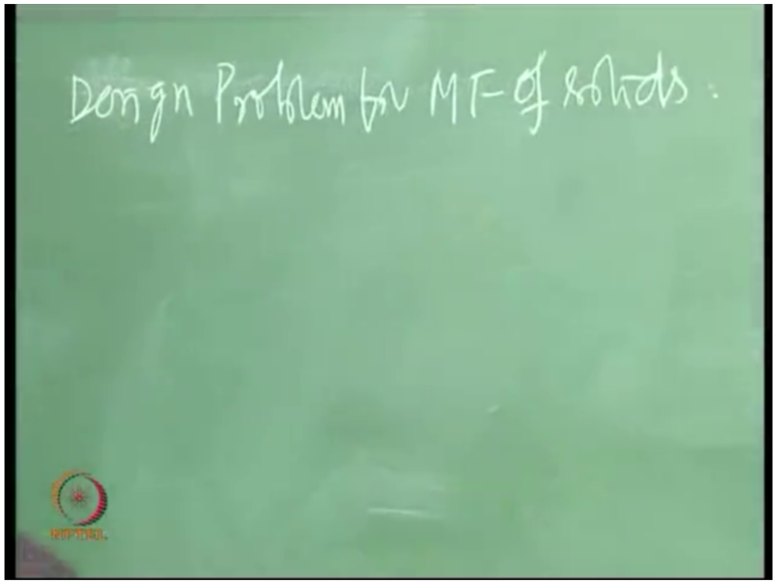

Okay, let us do for mixed flow reactor, another problem for mixed flow reactor, okay. Please take this. Yeah, a stream of solid particles are equal to 1 mm radius is equal to 1 mm passes through a bench scale fluidized bed reactor. The solids react with gas to give you a solid product according to SCM Shrinking Core Model slash Reaction Control. So, it is straightaway given here. It is Shrinking Core Model, Reaction control as follows, okay. The solids react with gas to give you a solid product according to Shrinking Core Model SCM, Reaction control as follows.

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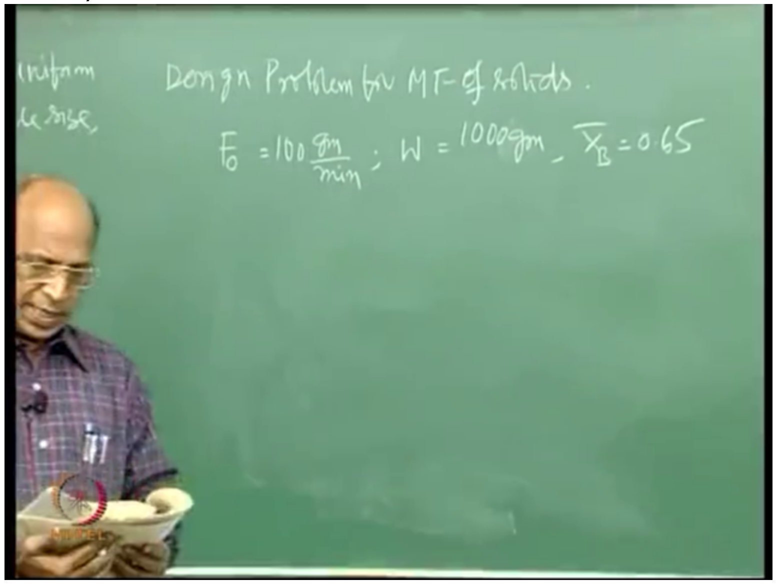

So that as follows is F naught equal to 100 grams per minute that is 1 W holdup, one more 0 and X bar p equal to 0.65, okay. This data given for the bench scale laboratory reactor. So, next one assume uniform gas composition throughout the reactor.

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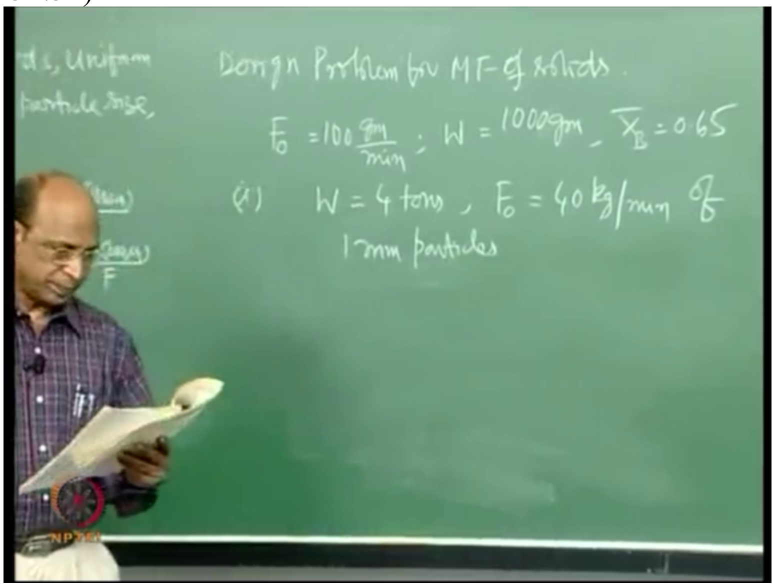

Then one calculate the expected conversion in a commercial sized fluidized bed reactor of 4 tons. That means W equal to 4 tons, 4 tons treating 40 kgs. F naught equal to 40 kg per minute of 1 mm particles. Yeah, that is one, okay. You have to calculate the expected conversion of this 1 mm particle in the actual industrial reactor, where I have 4 tons of holdup and 40 kg per minute we are processing, okay. That is the input to the reactor, good.

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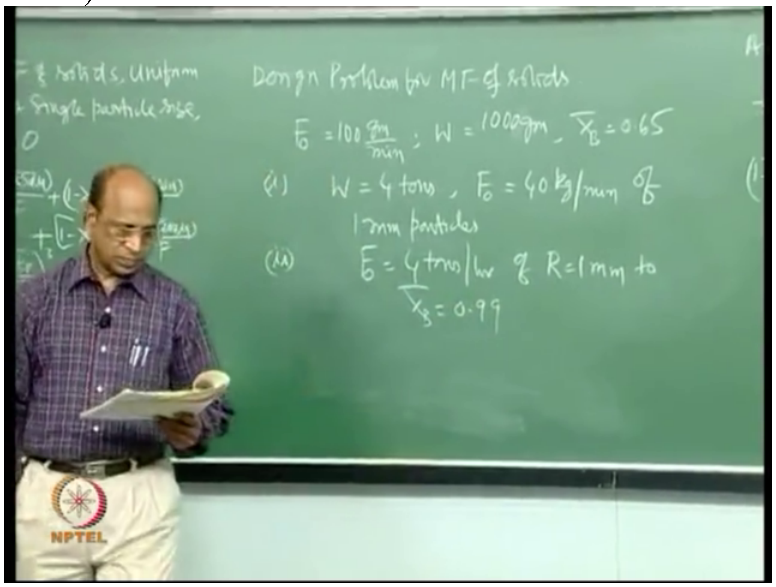

Number two, find the size of a single sized fluidized bed reactor needed to treat 4 tons per hour. That means, here, F naught is given 4 tons per hour of R equal to 1 mm particles again same particles, 1 mm particles to 99 percent conversion. So, X bar B. This is a nice problem covering all that, you know, like you have a fluidized by the laboratory reactor. These what normally we do for any new process. We develop a small reactor in the laboratory and then try to find out what is happening in that and then extend that data to large-scale systems, okay. Yeah, so in the first data is given to you to find out team is given tm is given, tm is a 1000 tons by, sorry, 1000 grams by 100 grams per minute. So, Tau you will know. And this only single size particle, no problem. Reaction control everything is clear. That means Tau you have to calculate from this data.

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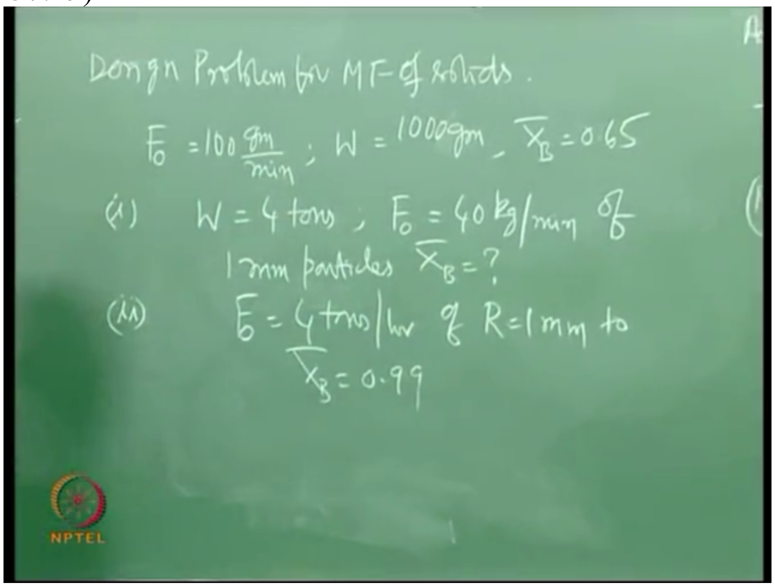

And in the first this industrial problem it is asked to calculate expected conversion XB equal to, X bar B equal to how much?

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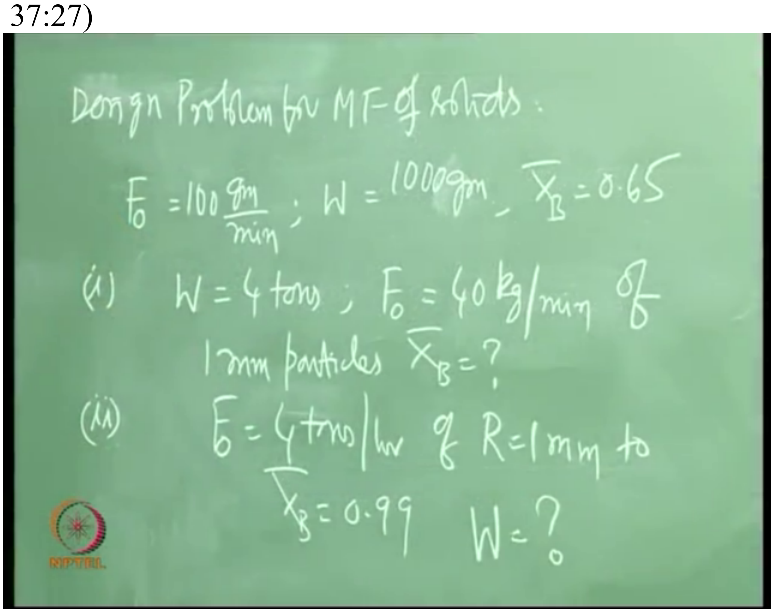

Here, W equal to how much? Yeah, t bar b is given there t bar m, t bar m is given here. Because, it is again, no, no! t bar m is not given here. Only, Tau you know. XB is given here. X bar B is given here. So, you have to find out t bar m. We will do that and you see from the laboratory reactor, you have to use this equation or this equation to calculate t bar m by Tau, t bar m is given anyway here and then calculate Tau, okay.

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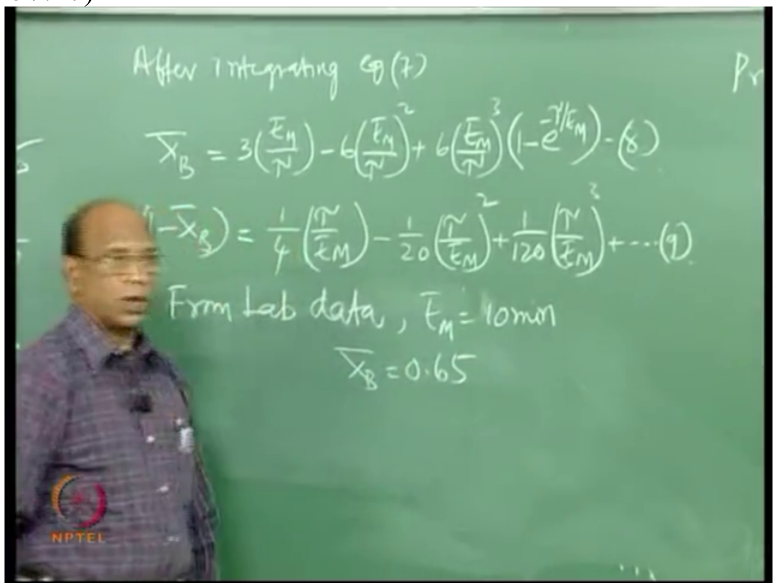

So, from Equation 8 by trial and error or this you can start and then put it here by trial and error and then you have to find out, right. Yeah, so, from laboratory data bench scale or lab data. Yeah, lab data, what is this t bar m equal to 10 minutes, right. X bar B is 0.65.

Student: Sir, if we are solving with the equation that you are expanded using trial and error till what term should be take...

Professor: That depends on the magnitude of Tau by t bar m. Because, if Tau by t bar m is very small. So, cube will not contribute that much. Yeah, so that, you have to decide for each problem, when you have this idea.

Student: But we do not know Tau, here, as in what is a (())(39:18) what do we start with?

Professor: Save that is eight, equation eight. That is a analytical formula closed form solution. So, you have to start. That is why, mathematical methods in chemical engineering you learn. You know, so, all that is only to use here. You all the time, you don't have to have your computers. You can also use brain. Tau is?

Student: 18.89

Professor: Yeah, approximately 20. Okay, 19.88, I got by trial and error. Decreases on how many terms they have taken another, okay. Yeah, you have to do that, good.

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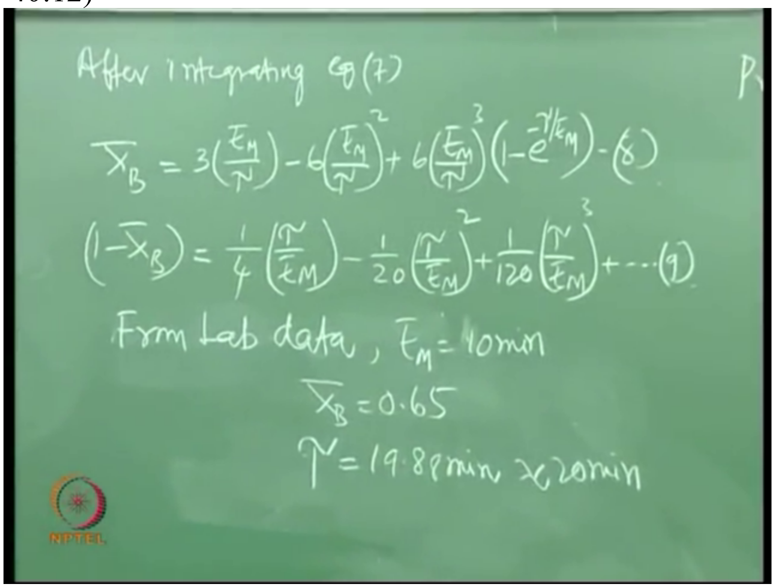

Yeah, so from this first part what you get Tau is 19.88 minutes or approximately 20 minutes engineering, good. By Trial and error method. There are many methods, no? I think, you can guess a value and then what is that next one whatever you get what is that notice have some method, yeah, correct. So, with two or three or three times also, if you do you will converge to one value like that, okay, good.

Yeah, so then the other one you know this bit if you want to find out. Again you have to use the same equation, but what is known there? Tau is known to me. Because same particles that is not going to change, okay. Then t bar m is known to me because t bar m for the first case is 4000 divided by 40. That will give me t bar m. Tau is known, t bar m is known.

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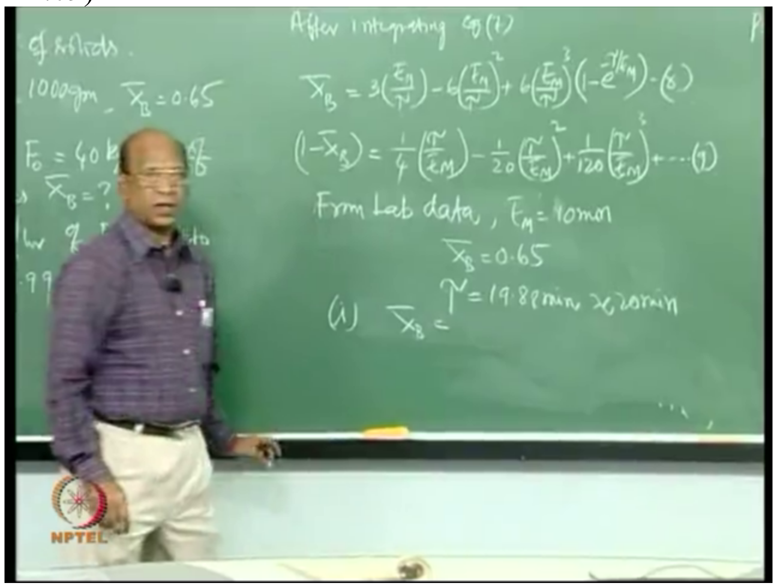

So, for first bit, here, this is easy. I think everyone likes that, t bar m, yeah, can someone tell the term, Sir? By the way, what is t bar by Tau? t bar by Tau how much? t bar m bar by Tau. 100 by 20. 19.88 if you take almost 5, t bar by Tau I am asking? 5, yeah, of course when you are substituting there you have to substitute reverse. Here it is, okay, t bar by Tau, correctly. How much? What is the answer there X bar B? Any other answer?

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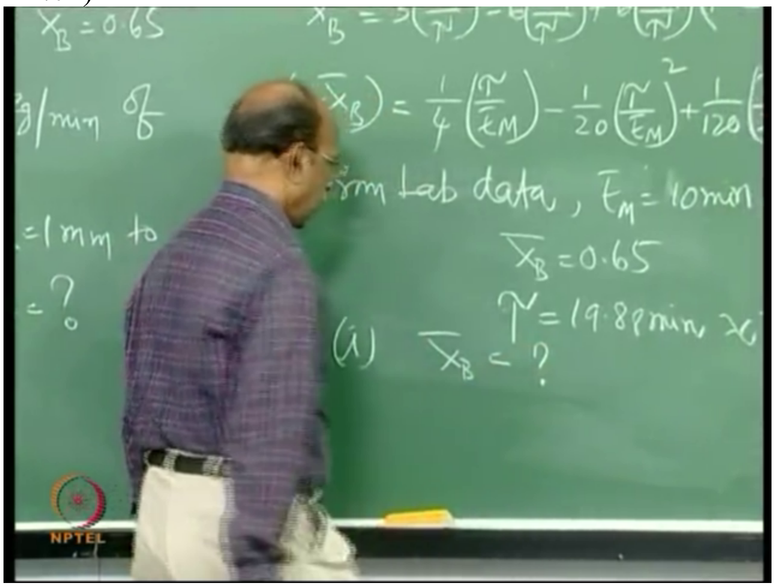

May be seeing me, you may think that I will give only always difficult problem. Rachit, got it? No calculator, why? If I have given you surprise test what would you have done? Exact! They also got 0.952, 95 percent, 95.22 percent, okay.

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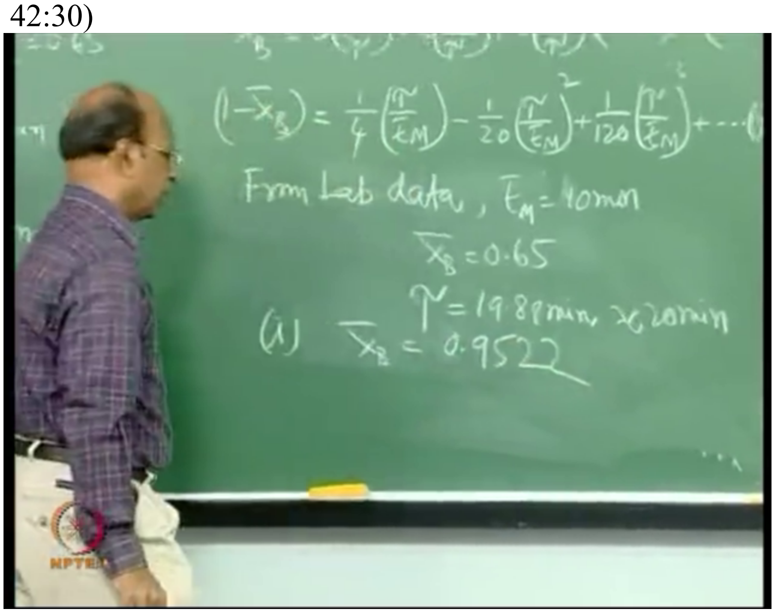

So X bar equal to 0.9522, good.

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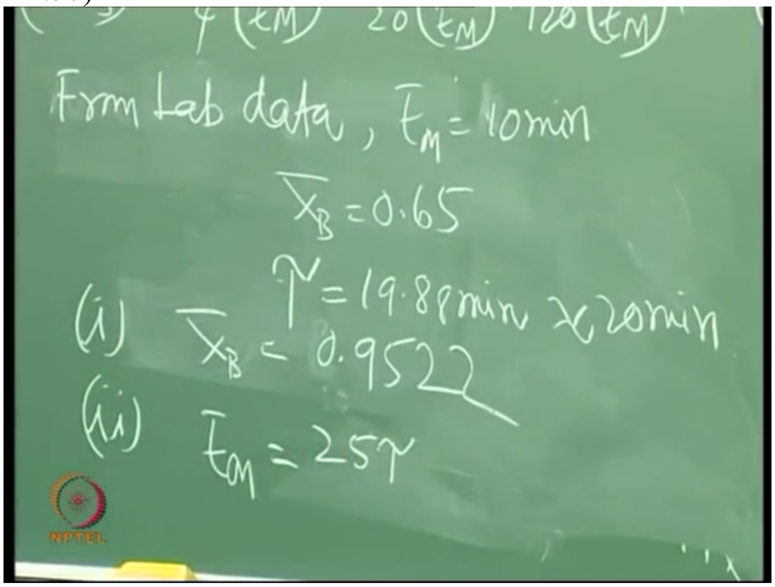

So the other one because you do not have time, now, to check all these. The other one is calculating W. To calculate W first you should solve this equation for t bar M, okay. Because Tau is known, X bar B is given. So X bar B is how much? 0.99. So you have to solve again the same formula only one formula. That is all. Now, you have to calculate t bar m, if you calculate t bar m that will be that you check that, I think, t bar m is approximately, anyone did it, no? 25 Tau. Yeah, around 25.

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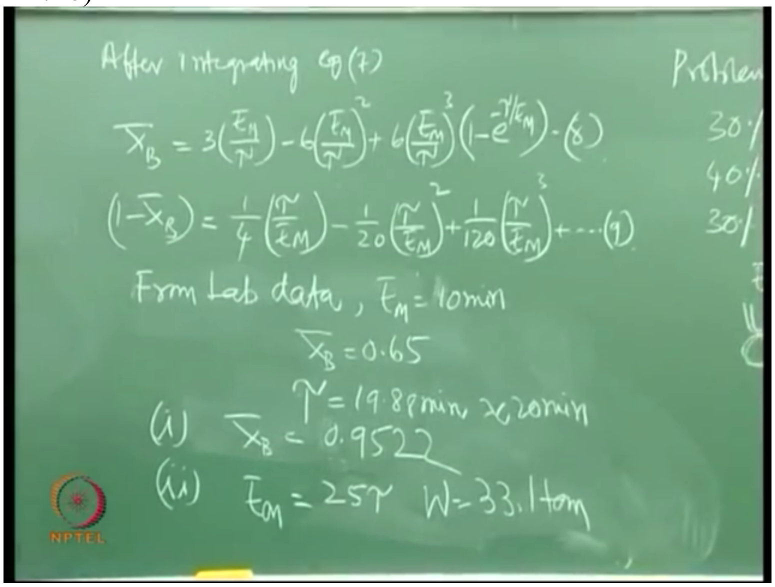

So, now, you know t bar, yeah, okay, what is W? If you take that answer. Calculate again, 25 Tau means 25 into 20, right, 500. Yes, 33.1 ton term method in a very slightly this way that way, okay. So, W equal to here 33.1 tons, okay.

And, now, you can imagine how do you put these 33.1 ton in the reactor? It is a fluidized bed. So, I told you know that example all our Indian movies end with a, yeah, what is that marriage, okay. All the problem starts later. So, here, also exactly same thing after calculating W all the problem start. How do you I put that? Is it one particle one above the other where it can go to Mars or Moon somewhere. Yeah, or is it in this direction any infinite diameter and then you know you will have one layer or less than one layer. How do you really choose it?

This no one talks, generally, most of us will only say that find the volume or find the hold up. Then how do you how do you really put that in the reactor? So that shall we wait till fluidized bed reactor design is done, okay. There are some thumb rules, what is the diameter and what will be the height of the bed diameter? Generally L by D people take 1 to 2, why? Pressure drop is one criteria, but, I think, you know, not that one. No, what is the idea? What is the assumption for fluidization? Perfect mixing. So to maintain, if you put one kilometer height and then you know perfect mixing I cannot expect.

So, similarly, I put one kilometer diameter and then again fluidize I may not expect again perfect mixing. So, that is why, L by D equal to 2. Even though industries they may go to 3-4, also, because, they do not bother approximation. Because in the same area they are able to accommodate more number of area is important there, no? So, that is why, sometimes 4-5 also they go but 4-5 you will not get definitely good mixing, because our assumption entire thing is based on perfect mixing. So, when you are designing in the reactor the final fluidized bed reactor in the industry that also should have perfect mixing of solids. When you do not have your assumptions are wrong.

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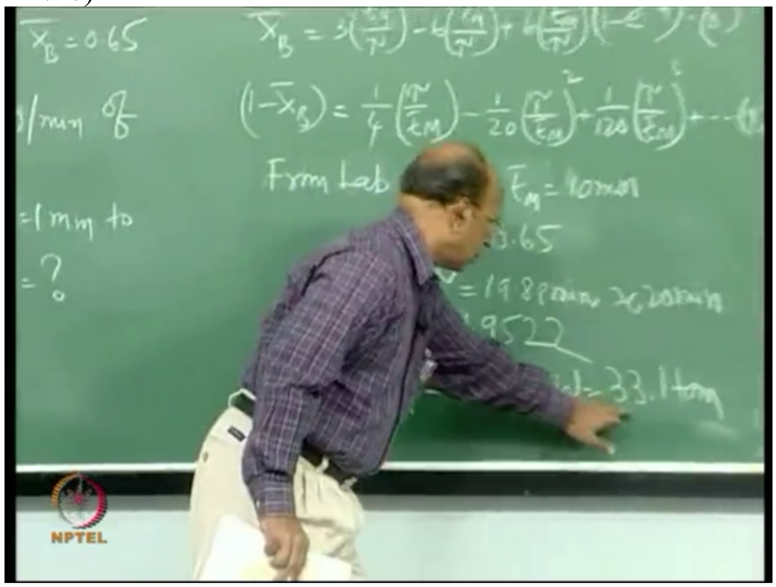

You will not get exactly the same conversions or you need more than this if the assumption of perfect mixing is wrong. You may need 40 tons engine of 33 tons, okay. So those things I think we will discuss when fluidized bed is designed.

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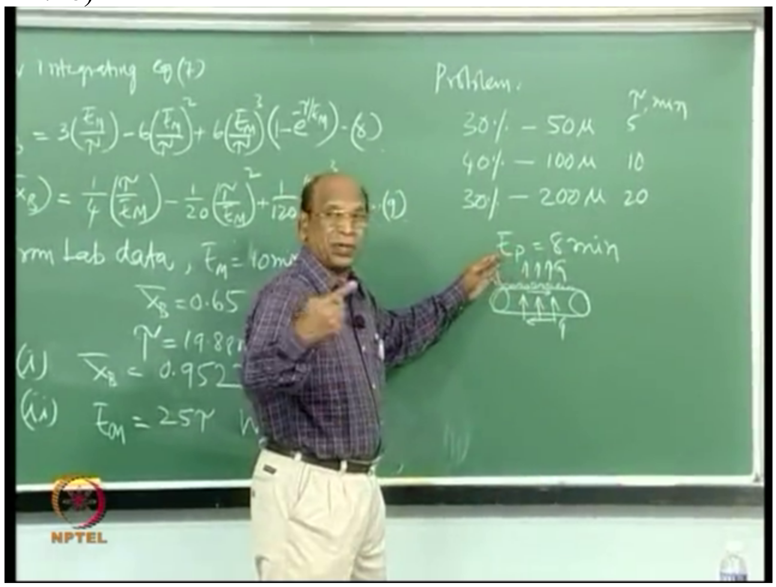

But this is how like, for example even in this is one, here, if the problem is the reverse I asked. You know in the plug flow reactor design, if I ask you the reverse question that means t bar p is given here. But, now, I will ask you to calculate t bar p and you have to calculate conversion, sorry, given conversion calculate t bar p, right. So t bar p you got 8 minutes. Now, I tell you that, okay, let us use Rotary Kiln, Rotary Kiln also is a plug flow reactor, right. What is the Rotary Kiln?

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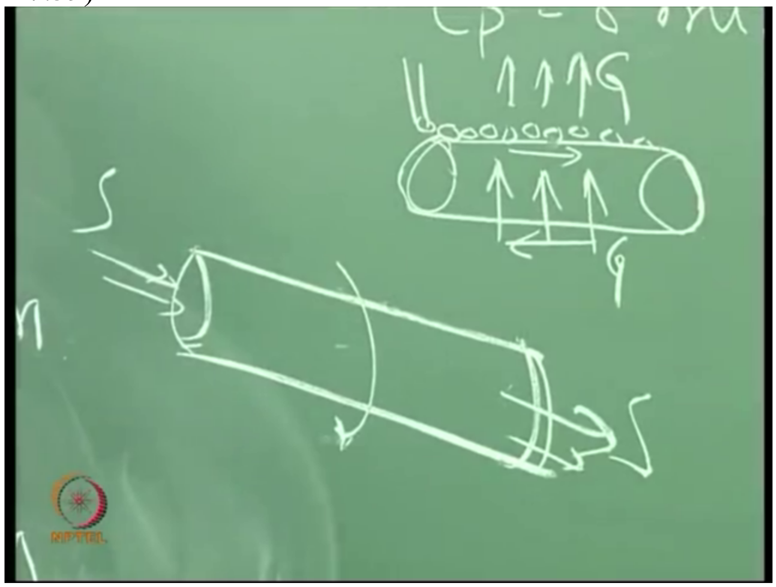

You have a cylindrical tube moving slowly like this, okay. So it will rotate, slowly it will be rotating. Feed here solids will come out. Of course, we are talking about large amount of gas, so either you can send this way or this way to maintain that uniform composition of gas throughout the reactor, okay. So then, yeah, I think listen to this is, with this is very important Rotary Kiln design, right. So that 33 tons for example, if I have that 33 tons and that 33 tons also I have to accommodate here. How do you accommodate? What is the length I have to take? What is the diameter you have to take? And you know holdup in a Rotary Kiln, how much free volume is given for the particles to move? Because it has to rotate like this go-up and the particles will be taken to the top and then they fall, okay.

So to give that, that is a good guess. Less than 10 percent will have hold up, 90 percent is free volume 6 7 and you know the rotation, have you know? RPM, very high. This I think one of my problems must be there in your plant design. I know that problems you have 60-70 problems. This Rotary Kiln design also should be there one of my problem at the time which I have, (()) (49:13) You have go to critical speed and all the totally (())(49:18) How much below? It is actually 5 rpm, 4 rpm, 6 rpm like that very-very low slow, very-very slow.

Particles slowly go-up, if you are almost going to critical speed what will happen I am just example, as an example, so, solids will go and stick to the walls. And all gas will go through the center, so, bypassing you also provide the residence time. So, that is why, length will come in the residence time and you know angle, how much angle do you think it will be? 30 is too, large. It is again 3-4 degrees to provide, you know, maximum residence time. 30 is very slant everything will come out so quickly. Yeah, so, you know all these things, you know, very-very simple things what we think. That is why, I told you my example, you know, that marriage our movies end with marriage but after so many problems are there.

Starting with you know, where to go on buying vegetables after marriage, before that both will go happily, okay. So like that here also every everything is a problem. How do you fix them? How do you rotate them? Even this also. So, what should be the diameter of this wheel? Okay. And the distance length and width all these things are problems. They should not be, if you have mechanical vibrations particle may go forward, particle may go, yeah, and also this way you cannot expect again ideal plug flow. We have to be close to our ideal assumptions, right. So that is the challenging for engineer. You assume something, how would you maintain the same thing in industry with the same assumptions? Same conditions like ideal plug flow, same conditions like ideal mixture flow. Beauty! Chemical Engineering is beautiful! Because only chemical engineers deal with so many types of equipment not others, because every process is different for us.

If you take sulfuric acid, the same sulfuric acid things you cannot use for nitric acid. You may say both are acid, Sir, “I can use?” You can never use. And even if you have the both the process nitric acid and sulphuric both process together also you can never use it for hydrochloric acid. That is that independent work. That is independent, these are independent. So, that is why, every time for every flow chart, you should have a different kind of equipment where beautifully everything is that is why Chemical Engineering curriculum, I think a subject is so beautifully designed, okay. Everything comes under mechanical operations or you know that other unit operations, correct, no? Any kind of equipment we can put that because the basic phenomena is same but you can use different take kind of equipment.

So, that is why, simply heat transfer, mass Transfer, momentum transfer and CRE if you read, you know, most of the things, of course, thermodynamics is God, you cannot cross beyond that. Cross control is the final control and process calculations will give you what is entering, what is leaving, you know, energy balance, material balance and all that. Really, I know chemical engineering, you know, the subjects everything, anything that is what you know only two ideal reactors. Any kind of reactor you bring, I can divide, I can tell you whether it is either plug flow or mixed flow. What a wonderful assumption! Or Assumptions!

So, that is why, chemical engineering that design of curriculum and it is really great. I do not know you may not like it, most of you when I say this, because you say that management is great. Because, thirty-thousand, thirty-lakhs, forty- lakhs after MBA. What is your 1.2 crores? That is what people see there. But, the beauty in subject I say that is very-very beautiful. Chemical engineering is wonderful, okay. Anyway this is my passion, but, it may not be your passion at all, okay. Thank you.