Chemical Reaction Engineering 2 (Heterogeneous Reactors)

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Lecture 15

Design Equation for MF of Solids with Elutriation, Mixture of Particles of different size, Uniform Gas Composition, SCM.

Yeah, in the last class, we have derived the equations for a design with elutriation, right, with elutriation. And the last equations were 9, 10 and 11, where we have 1 minus X, XB double bar is in terms of Tau Ri and t bar Ra, okay, t m bar Ra. Okay, now, we have now really find out whether the t bar i, how do you get it? Okay. Yeah, and unless you know that t bar i, you cannot calculate the conversions or given conversions you cannot calculate the volume of the reactor, okay.

So, these are the problems. And if you notice those equations 9, 10 and 11. Actually, those are more general equations where you can simplify to the other two conditions. What are the other two conditions for mixed flow? Yeah, constant size - single particles, okay. If Tau bar i equal to simply Tau, that means for all particles we have Tau same. And t bar i of t bar Ri is again t bar, then you will have the first equation coming, okay. Yeah, the first equation in the sense that is no first condition, where we have only mixed flow and uniform size particles. And if you take Tau Ri alone and t bar same as for all the particles then that condition becomes again the size distribution of particles but no elutriation.

With elutriation, when you take then this is a more general expression where that means, what I am trying to say is, even if you are worrying about the examination, you do not have to remember thrice, okay. It is the same equation what we have, right? But, elutriation you have to do some more work. To calculate what will be the Mean Residence Time for each particle. That is the only thing that is extra coming. So, that is why, because most of the time till someone points out you may not recognize that, the simplicity in the equations. So, that is why, I am just trying to point out.

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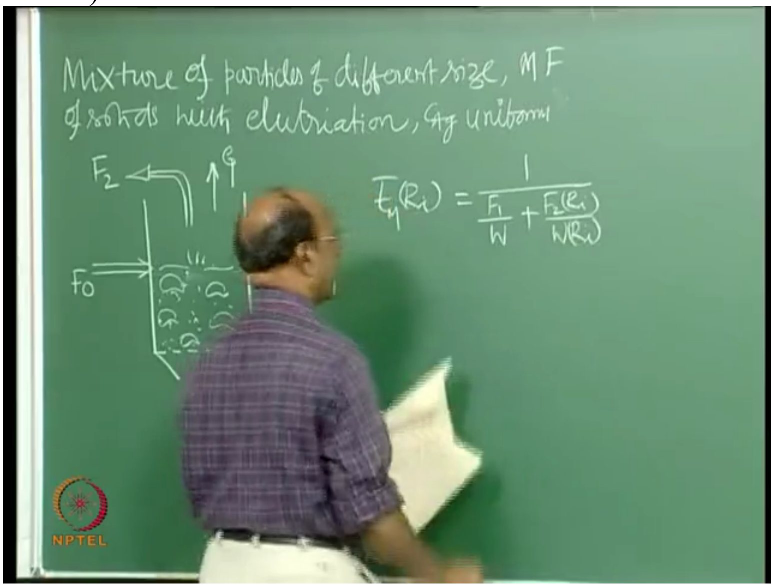

Okay, please take these equations 9, 10 and 11 cannot be used to predict the conversions, because t bar M of Ri is not known and this depends on F1 and F2 of equation 6. Let me write again equation 6 here for continuity t bar M of Ri equal to F1 W F2 of Ri W Ri. This is equation 6. Yeah, please take this also, t bar M Ri can be calculated from elutriation data from fluidized beds. Elutriation, itself is a separate research topic in gas-solid fluidization, okay.

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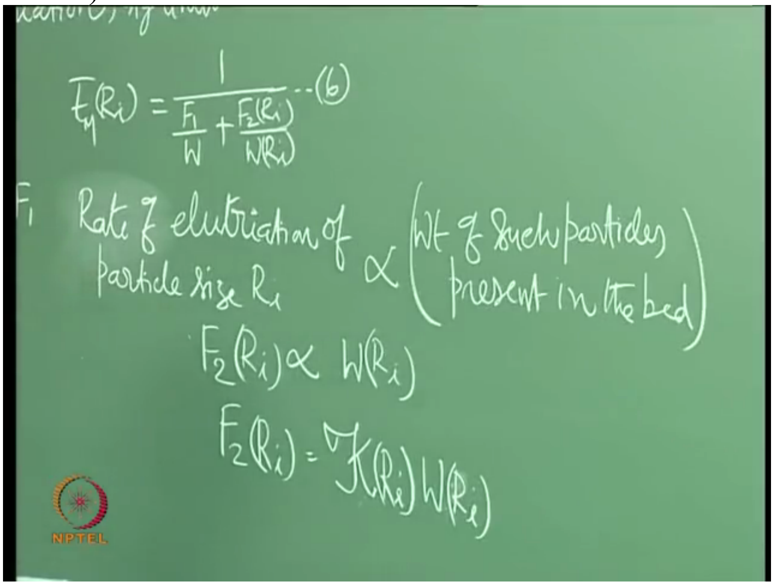

Next para you can write. In a steady state multi-particle fluidized bed for particles of size Ri the elutriation rate can be written as rate of elutriation, elutriation of particle size Ri is proportional to, I think, let me write here weight of such particles present in the bed or in other words F2 of Ri is proportional to W Ri, okay, or the proportionality constant, yeah, is K of Ri W Ri, where K is elutriation rate constant.

Student: Why is k dependent constant?

Professor: K is not dependent, K is proportionality constant. You have to find out that, depends on what particle size you are telling. In fact, this is nothing but first order reaction. The rate of reaction is directly proportional to the concentration of the particles in the bed, okay. And, the K is the proportionality constant and that is, it is not changing with this but it changes with for each particle, okay. The rate changes for each particle, right

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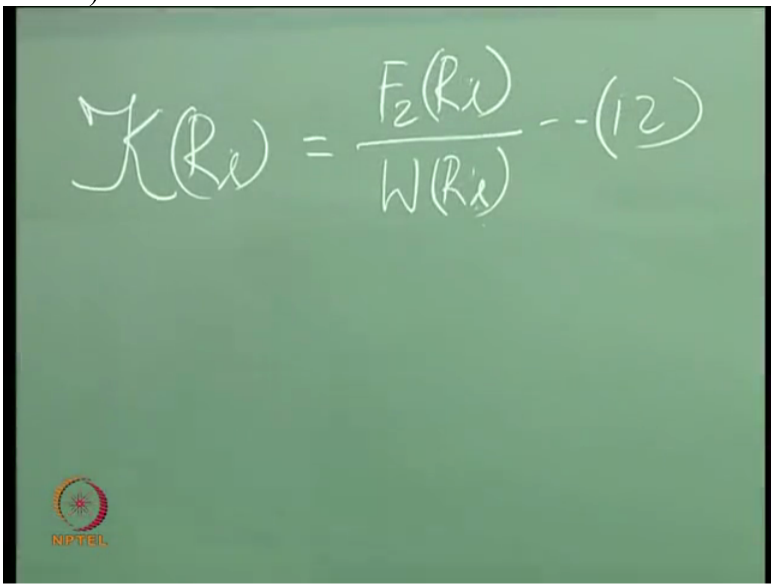

So, I will write here we will come back. Yeah, K of Ri is F2 of Ri divided by W of Ri, okay. So this is equation, last equation was 12, sorry, 11 this is 12. Okay, Nella, you understood, no? This is simply proportionality constant, it is like first order reaction, okay. So, more number of let us say 500 micron particles in the bed means, okay, more rate, okay, directly proportional to rate.

But this one as, I told you that, the fluidization in fluidization elutriation itself is a separate field. There are lot of research papers published on elutriation on different conditions for different particles, different flow rates all this and lot of correlations are available. Even, now, most of these correlations are not universal correlations that you know all put together, can i generate one particular correlation? No, because, I think still it is a difficult phenomena in a fluidized bed. Shekhar, you asked me something?

Student: Particles present in the bed, can we not relate it to the particle present in the feed? Would that few time not be more logical, because, unless, they are in the feed, they won't be in the bed.

Professor: No, See you have in the bed the particles are falling here, right? So, then here you have certain concentration of the particles. Here, there is no concentration. It is only simply flow rate. So many Kgs per hour, but, here, I have so many particles per unit volume of the bed, okay. You heard of holdup of the solids. Similarly, we can also express this holdup either in grams or you can also express the holdup in terms of fractions. You know, for example, we say that the voidage is of the packed bed. What is the voidage of the packed bed? Voidage of the packed, not volume of a packed bed. I think, you know, as chemical engineers you will be able to answer that very quickly

Student: Sir, empty space in the bed to the total volume of (())(08:26)

Professor: Yeah, I asked you that, what is the voidage in a packed bed. I am asking you a numerical value.

Student: 0.4 to 0.6

Professor: Yeah, when it is 0.4, when it is point 6. You cannot say point 4 to point six. If you have sufficient information, you could have questioned me what packing you are talking, okay. Yeah, so, that means, of course, you cannot even visualize what is a packet bed that is the simplest the system in a chemical engineering industry. Simplest! Okay. So if you have spherical particles, the voidage will be around 0.4. If you have some people use Raschig Rings, some people use Berl Saddles and all that. Then depending on even for reactors I am talking, okay. The catalyst can be made in terms of in the form of Raschig Rings. So, then it will it will be around 0.6. So that voidage is nothing but the fraction of volume which is vacant, okay.

So, similarly, here, the all the holdups, yeah. Then what we say is even in factory, because, I am telling you about packet bed, the reason is that packet repeat is the easiest one to imagine, right. So, when you have for example two phase system that is solid as catalyst and fluid is going through this packed bed that means always, I can look the look at the packet bed if I have spherical particles. I have 60 percent of the fluid and 40 percent of solids. No, there the otherwise, the other way. Yeah, 60 percent of solid and 40 percent of fluid. The fluid is within the voids, okay. Yeah, so, these are the volume fraction.

Similarly, here, I can have now volume fraction of the gas, okay, volume fraction of the solids but within that volume fraction of solids again I have, yeah, 500 distribution, 500 particles, 500 micron particles and maybe 1 mm particles or 100 micron particles all these things together inside the bed, okay. So that is why logically it will be the rate of reaction is proportional to the concentration of solids, okay. So, that is one of the simplest assumptions it is Empiricism. You assume that and then try to find out from the experiment whether what your assumption is right or wrong. Okay. And in many cases in fluidized bed, yes, it is approximately turning as directly proportional to the solids that are available in the bed. Not left, it is already in the bed, okay.

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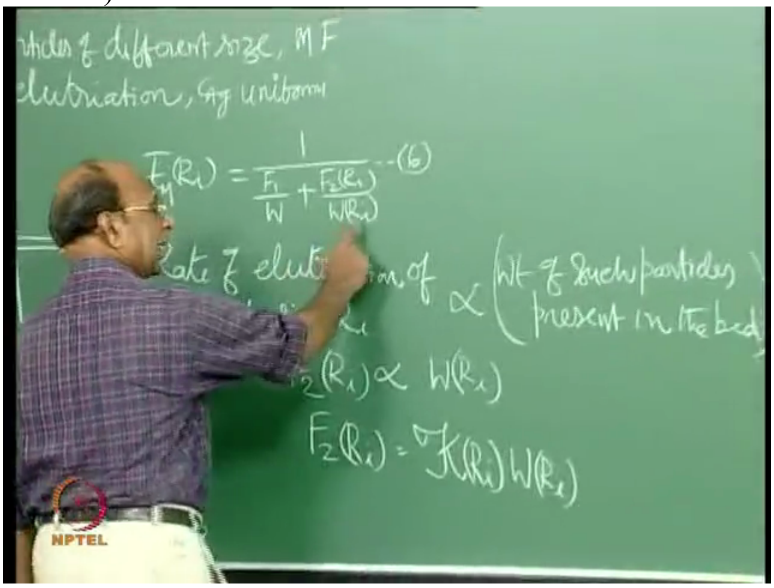

That is why that is the meaning of minus Ra equal to K into Ca. Ca is the concentration left at any time, right? Yeah, so that, this is similar to that time, this is the equation for elutriation constant. Now, if you observe that F2 RI by W Ri, did you get that term anywhere in your t bar i. Yeah, here you have. So, that means, if I can estimate my elutriation constant from the experiments, it is only experiments, no theory there. Theory, we have only for single particle, elutriation. That single particle what are the assumptions, when you are deriving that single particle terminal velocity, order no, are spherical and…

Student: Constant size

Professor: Okay, other than that, there are many assumptions, in fact. Have you know, any idea? You heard of terminal velocity, no? Prabhu?

Student: Sir, I think it is creeping flow.

Professor: Creeping flow, when you have creeping flow, what will happen? It only creeps. So, because there is no terminal velocity, you know. Even at (())() number one, if you have very fine particle it can fluidized, it can go away. Yeah, what are the assumptions when you for the derivation? Ok. Spherical particle and it is very-very kind, you know, wild imagination in when you are deriving, because it is one particle in infinite medium. Why? That is very important. Flow is, there is only one particle in an infinite medium. Why should, I assume that? Yeah, no interaction with the other particles and also no interaction with walls, okay, even if you have disturbance with the walls then your terminal velocity again the deviation is not valid, okay.

Yeah, but in reality when do you use in chemical engineering or factories only one particle? We can never use, okay. So, that is why, multi-particle systems are very-very complicated, that is the reason why we will have lot of empirical equation. That empiricism present day academicians, very young academicians are not really appreciating that it is good, but if you are breakaway this empiricism and then try to go for actual theory, analytical expressions wonderful! But in engineering not many systems are possible to you analyse like that. That is why, we are still living with empiricism. And even now you use heat transfer coefficients, mass transfer coefficients from those correlations, which have been developed in 40s, 50s, 30s, okay. But theory definitely help us to understand more and more the phenomena. What is really happening.

So, that is why, these empirical equations we have to use from the experimental data and then if you are able to substitute that equation 12 in 6. Equation 12, if you are able to substitute in 6. Then we have t bar m of Ri equal to 1 by F1 W plus elutriation constant. Yeah, this equation is 13, yeah, nice. Ok. But, still I am able to substitute for Kri from correlations available in the literature for this term, right. Yeah, for example for 100 micron particles, 500 micron particles, 800 micron particles we can substitute.

But, still I don’t know, what is F1? So F1, F2, if I know, we can calculate and then still, you know, so, that is why, what we have to do further is that, these are all of course this equation is already known to you.

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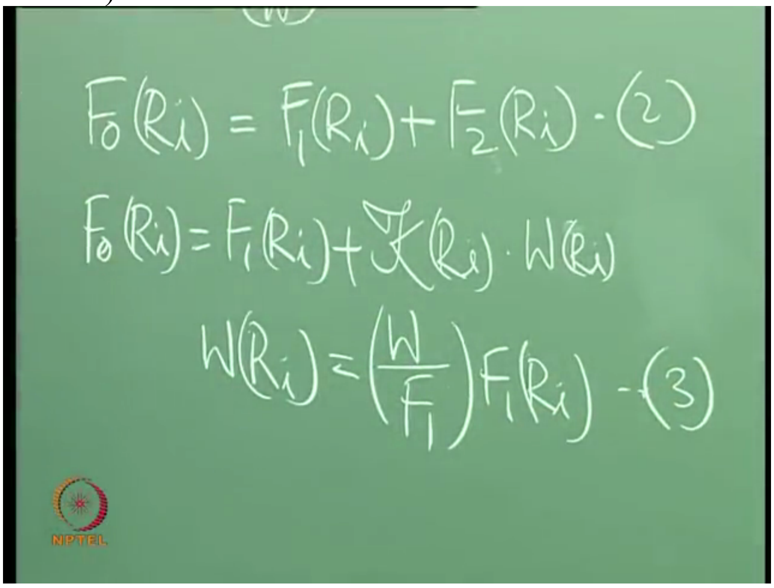

Let us take this equation which has been already written F of Ri plus F2 of Ri. What is this equation number? What was that equation number? 2, okay. Yeah, so, now, I will substitute here equation 12 here for F2. So, F of Ri equal to F1 Ri. For F2, if I am substituting equation 12 then this will be K of Ri into W of Ri. This is equation, there is no equation, I think at the end I will give that. Yeah, so this W of Ri also can be written in terms of we have another equation. You can check this equation W of Ri can be written as W by F1 in to, correct, F1 of Ri. This is equation number 3 (())(16:38) us slightly different. That is all. Because W of Ri also, I do not know so that's why I just would like to substitute this one in terms of W and F1. So that, I will have F1 everywhere then we can try to find out what is happening, okay. You can estimate what is F1.

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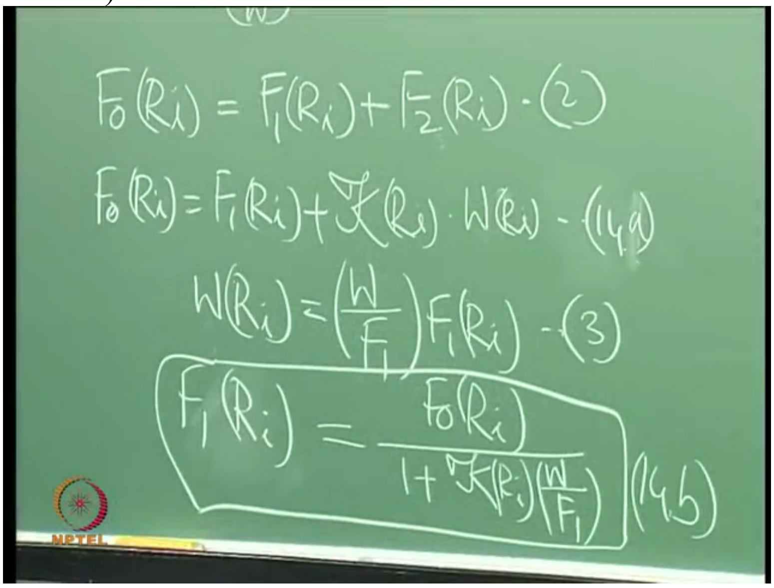

So, that is why, substituting equation 3 in above, okay. That equation, yeah, write there, I am not writing that, at least you have to write that, you know, substituting equation 3 in 14, what you get and rearranging, I am just jumping the steps and rearranging. What we get is f naught F1 of Ri equal to F naught of Ri divided by 1 plus K of Ri to W by F1. Can you please check this? This equation, right. Very simple only. So this is equation number, yeah, I will write here instead of that 14a and I will write here 14b, ok, that's good now. Yes. So, now, this one is F1 of one particle size. So if I want to get total F1, I should take the summation of all that, okay. F1, for example again, I am telling F1 Sigma, if I say you will immediately confuse. So, I have to say that, this is F1 for 100 micron particles may be 500 micron particles and 800 micron particles, if you have that distribution, okay.

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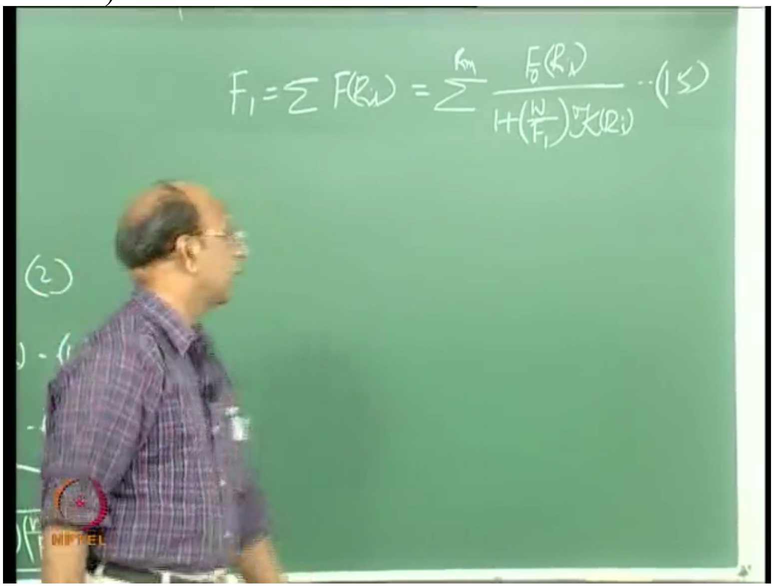

So, I can write F1 equal to Sigma of F of Ri which is also equal to all particles. F of Ri F nought Ri 1 plus W by F1, Yeah, so this is the one. This is equation number 15. What our procedure is, now, using that equation we have to solve your F1. F1 is present on both sides, no! Okay. So, that means you have to guess a value calculate this and that must be equal to your guest value. And the data what you get is F naught Ra, do you know? Yeah, that is the feed, so you know. And W hold up will be given for a already existing reactor. It should be given, otherwise, you have to calculate W for a given conversion, okay, one of them, okay. So and now F1, I do not know? KRi, you know? It is empirical correlation.

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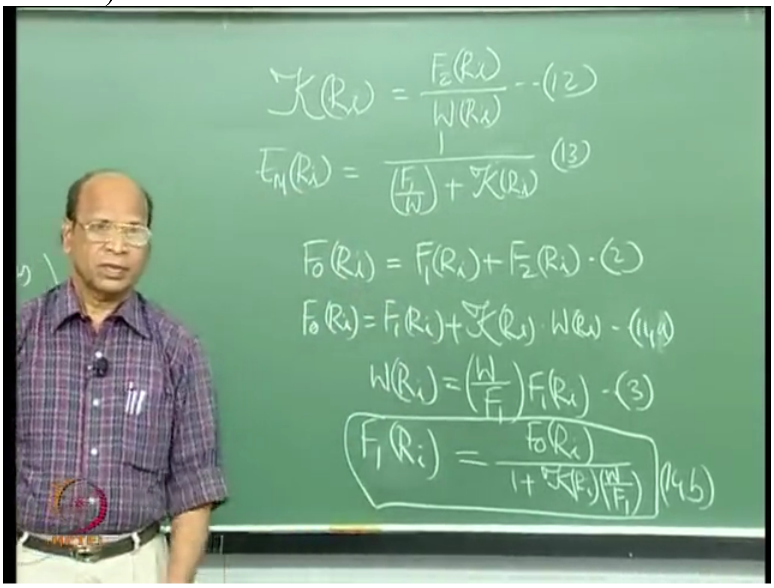

So, you know, in this equation, everything except you have F1. So you guess F1 and then LHS must be equal to RHS under those conditions you just stop. And when both are same then you will have that F1. So using that F1 what do you do? You have to calculate t bar of, yeah, of a particular size. So then I know W, I know F1, I know KRi, I can calculate. And from this I will go to now equations 9, 10 and 11, correct, yeah. Yeah, what are the things we have in equation 9, 10, 11. What are the parameters you do not know? That is all only two, okay. Do you know Tau?

Student 1: Do not know

Student 2: We don’t know.

Professor: Who said, we don’t know? Abhinav, you said that, no? Swami you said that? You said, ok. Yeah, you don't know Tau? What is Tau ?

Student 1: Filter the particle are over…

Professor: Tau?

Student 2: Time required to 100 percent, sir…

Student: Tau is to give a conversional (())(21:27)

Professor: Tau is for your single particle, where from kinetic already you get that. Tau is for single particle, okay. Single particle kinetic already you know, whether it is following shrinking core model, film control or diffusion control or ash control. That is why, you have those equation already, so Tau is already known to you, right? And t bar m, you are calculating for given size, if you had know what is F1 and what is W and what is KRi. So then you can substitute these two and calculate X bar, okay, good.

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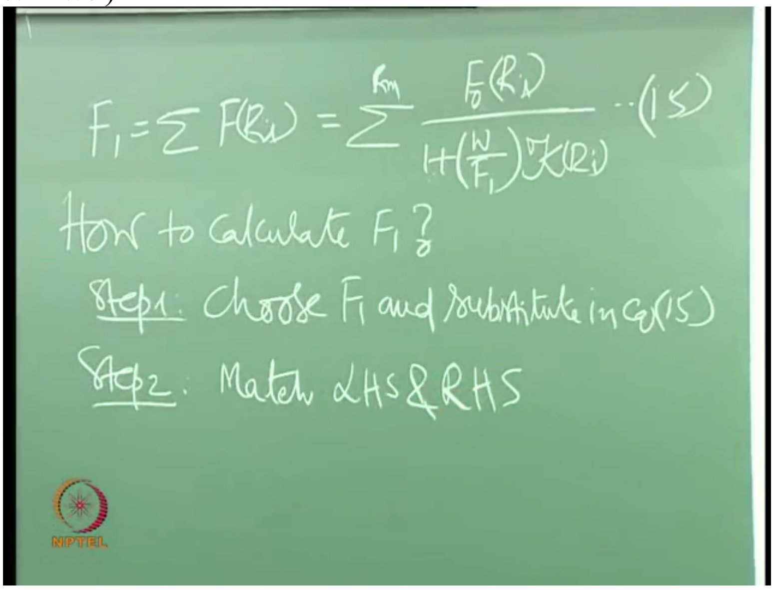

Yeah, so, that is why, what we do here is how to calculate F1? Step one is very simple only, you will laugh at the end. Choose F1 that is guess, okay. Guess F1 value and substitute in 15. In equation 15. Yeah, and step two is match LHS and RHS. If it is not then again you have to guess another value and again do that till you get both are equal. And then of course, you can calculate the, yeah, you can carry, you can choose that F1. From that F1 you go to 13, okay. I think probably you have to write that, I think there is one problem which I have given like this in the assignment which you have given stars, you have put, no, at the end. Somewhere, elutriation and all that also is given.

So they think you please try that, they are very beautiful problems. Particularly, non-catalytic reaction design is wonderful design. It is very-very good and in fact, I don't have much time, you know, because, I now have to go to catalytic reactions from there you have to go to a catalytic reactor design. And then you have to go to fluidized bed reactor design, then you have to go to slurry reactor. So, I am not able to take some more complicated cases like you know, even of course, factory bed we know is a system is equivalent to your plug flow, okay.

Yeah, So, but, I think it is beautifully, you know, it is a transient problem, I can put for example the non-catalytic reaction the iron ore in packed bed and then send hydrogen, but I can give those problems as an analytical thinking problem. No, really, if you are able to solve that that will be beautiful. What I may be asking is that, I have a packed bed, batch solids, iron ore and then I send hydrogen. Draw the concentration profiles of gas as well as solids. Solids means XB, okay. And Xa or Ca.

How the concentration changes in the bed, if it is co current and it can be counter current, okay. So the particles are reacting with the time that is the transient phase, it is not steady phase. Whereas gas is in continuous phase, steady flow, but the both the profiles you should be able to draw, okay. That gives beautiful analytical thinking, I tell you. Beautiful analytical means unless, you understand the whole packed bed and then the phenomena that is going on inside the packet bed you cannot draw.

I think, I have been telling you last semester, also I have been telling you, the simplest problem which you can imagine is, okay. I have put a iron ore ball spherical maybe 5 centimetres or 2 inches or 5 inches or 6 inches ball in a furnace. Where, I have the hydrogen continuously filled up, okay. So now can you draw the temperature initially when it is just, because the reaction has to have sufficient temperature? So, I just took the ball and then put inside the furnace has 500 degree centigrade, let us say the furnace has 500 degree centigrade. Then how the first of all temperature profiles are changing inside the particle? Once it attains 500 degrees then the reaction may start. After reaction starting, how again the concentration profiles are changing? That means, of course, we are assuming the hydrogen is constant throughout that is not a problem. But around that you may have film, right?

So, now, you have to draw the concentration profile of the gas and also concentration profile of the solid. Concentration profile means XB conversion profile. So these are wonderful problems, I think you know instead of going to Google and then searching all non-sense things. You can just sit down in your room, if you don't have anything just they take a pen and paper, okay. Now, let me draw the concentration profiles in each distillation column or in a heat exchanger or for example in your pipe, okay. Velocity profiles then the simplest one.

Yeah, so, if you are able to think about that then it's really I mean, you know, that only shows that your passion in your chosen field. I know, you may be laughing at me. This fellow does not have any work. So, that is why, he is telling all the time. Yeah, and I am not able to change their faces, I think B-Tech faces still now. I think you know they are stunned. I absolutely, I think maybe stones may smile sometime, but, I think no. I do not know, what is happening in our B-Tech system? My god! They have that skepticism all through that you know looking at the teacher that this idiot will be talking something and we will be just sitting and then doing whatever we want.

Prabhu, how did you develop that? Not you personally, I am talking in general. Now, because, I want to learn that, I want to know why people are so skeptical about any subject. Mechanical engineers complying the same way, civil engineers complying the same way. Of course, chemical engineering you know, yeah.

So any system, I think you know computer same certainly are supposed to be very good, okay. And the computer science and what is that other one the electrical and electronics. Now, they are also become stones and we are not talking about hundred percent. There may be always four or five out of hundred. That is nothing, statistically zero, correct. No, I mean, when, I have 100 people in the class, 90 people of ninety five people are just heckling at me and only five people are listening, I do not even see them. I don't even see them. You know, that is one drop of a good water in a washing. How do, I see that good water? Where I have to go and take? Okay.

Yeah, this is what I think. Why? Have you know? What is the reason? And it pains me a lot. And, on there, most of you also, I don't only blame them. So don not laugh. You are also like that, okay. You are also like that from the, you know, but you are not getting these exams, some other exams you are writing, okay. So I do not know except school education beyond that we are not learning anything, I can guarantee that. Even if you are learning that will be delta X, but you see you have passion, definitely, those people are learning. Now, Prabhu, got

90.99999, I don't know, how many 9 you have there, okay. Why? Because, his passion is not engineering. His passion is something else. No, like that many, they can do wonderful work after getting something, you should put your heart and soul into that particular field. So, that is why, whatever you get I think you should be able to put your heart and soul and then do it. Because, I don not get something, I cannot go to every day and then drink.

So, what is the use by the way, okay. Yeah, so then what is the use, I say. You have come here with a purpose. And I think, I can tell you 70-80 percent of these two faculty members are really enthusiastic to tell you something. Because, all this enthusiasm was killed by the, by seeing the faces where, you know, stone faces or wooden faces, okay. Yeah, so, I think that life in this face is totally go out the moment, they enter the class. And then of course when the class is over very happy, just go on, shout, laughing, right? The reason is that everywhere, every minute, every second you are guided by someone or other. Either your brother, either your sister or mother or father. Nowadays, I think these idiotic cell phones are there. So the moment they think that you are not doing what they want, they will send SMS do this.

So that is why every field and every field has thrills in that particular field, but only thing is you are not able to see. And. Sometimes, as teachers we are not able to exert you also that is also there. But, nowadays, I think, you know, I feel it is 50-50. But that 50-50, you know, if it is 60-50, 60 percent for students and 40 percent of faculty. When it is going beyond that, then you know the enthusiastic people also will die. Enthusiasm of the faculty members also is killed. I told, you know, 5 people people may be listening. 95 people may be sleeping, mentally, ok. So, then you cannot, you cannot talk to, I think you know, that is very easy to talk to empty chairs rather than people sitting and not listening to you. Really, that is easy for us.

Once you have the, you know, forced marriage, this is only forced marriage, because you may not like chemical engineering in the beginning, ok. But once you came to Chemical Engineering, you are supposed to love that again, otherwise, you only feel very bad. You feel very bad at the end, if someone asking you are a chemical engineer, do you know this? You may not show, because we are all actors from, you know, birth to death we have only act in between. Only two stages where you don't act is before birth after death, ok. Because, my God, I think we have a degree but we are not able to answer this man.

Like simple question, like, in our village some people usually ask me, “What do you do as a Chemical Engineer?” We do not know. Because no one told us. So then only vaguely used to tell that, no, no, we make medicines, ok. So, we make fertilizers, we make cement that kind of thing. They are very polite, I think, you know, they have not asked that, how do you make cement? Ok. So, if they asked, how do you make cement, gone. Because, chemical technology course a long time forgot, okay. So that is why, yeah, Shekhar!

Student: Sir, interest is the subject comes from two aspects one is understanding, the second is visualization. Both go always hand-in-hand. Unless you have visualization, you cannot understand the subject. When you say, fluidized bed on the board it is very difficult to visualize what a fluidized bed is, unless and until someone is - from physically seen it. You say elutriation, elutriation is easy to understand as a word, but not as a concept when unless you do experiments on your own, unless you see the setup it is very difficult to visualize.

Professor: But, I think, you have simplified things. But, you know, cannot you imagine a particle just going out of the bed? I think, you know, see if you are not able to even imagine that, I think absolutely, we do not have any imagination.

Student: It is not that, Sir. From the first day itself, if you are asking the person to visualize the single particle. He may not be able to visualize some. Everyone has their own speed, Sir. If someone from day one, you start that person to visualize that, he may not be visualize that and after a few point if he is still not able to visualize. Somewhere, it will shatter his confidence also that, I am not visually able to visualize such a simple thing. How will I visualize the bigger things? Which are coming my ways

Professor: Bigger things will no one ask you to visualize because very difficult, you know, for example 3-dimensional diagrams is very-very difficult to understand. We are not going to that level of visualization. It is simple, you know, particles floating in water you cannot visualize. Particles floating in air you cannot visualize, okay. And then one particle are, you know, few particles just going out. Because every day you are also seeing. I think, when you have lot of wind don't you see particles just flying off, dust and all that, okay. That is what is elutriation. And that is why, why I give you so many simple examples, so that your visualization is simple. Simple examples for all my complicated problems.

I will try to tell, you know, particularly in my teaching, I do all that all the time like plug flow. No one can visualize so easily. Then why should I tell Tirupati queue. So, even Ttirupati queue which I cannot visualize means what can I do. And not only Tirupati queue, okay. You would have gone, too many people may would have not gone to Tirupati, okay. But, I have told you even road traffic, okay. Every car going exactly at same speed, every vehicle moving exactly same speed and I told you also another example, you know, conveyor belt. So many examples if I gave you, also if you are not able to visualize. No sorry, Sir, you have to show me how the molecule is moving inside the tube.

Student: Sir, I am talking about general subject point of view.

Professor: Yeah, that is why, as a teacher we give you very simple examples, where you are capable of visualizing. I don't know, if I think in every class also any teacher will try to tell some examples, I say. I mean any class examples are part of the teaching. So, that is why, so many examples, I bring movies, I bring so many things to use. So that, you know, what you know. Because, I think the one simplest definition of teaching is taking student from known to unknown, ok. Traffic is known to you, ok. So, I am taking from traffic to unknown, the plug flow reactor. So like that many examples which I give.

Student: Plug flow we have visualized during Saarang and all.

Professor: Plug flow where did you visualize? Saarang. Well, in mixed flow, you should have visualized.

Student: Saarang queue

Professor: Queue, yeah, exactly! That is before entering pro-shows that is true. And mixed flow where you see? Inside that, yeah. So then you see very simple. You never forget mixed flow. That means a guy can be anywhere inside OAT. Any instant of time. So, that is what is mixed flow. So that is the kind of simple examples we give so that you can easily imagine.

Student: Sometime we like a bypass like, we are entering and we are…

Professor: Jumping, Jumping wall. Yeah, you see, Anand Kumar, visualization expanded. Very, good. So, like that only, slowly you have to - because all the disease with the student is that, if they are not getting marks, they think, you know, they do not like the subject. And marks and liking subject is totally different, ok. But, anyways, nice, I think I could talked to you. This one, I think, it is bothering me a lot, really bothering me a lot. I think, as you told, may be 95 people are not listening to me means, I would, definitely would have exaggerated

But I can add only another 10, that is all, 15.

This is what, what we observe in a particularly hundred classes. Because, earlier, I used to be teaching only B-Tech classes. I think I really enjoyed those classes. Wonderful student! Out of 30 may be just 1 or 2 students were not attentive. That's all. But others, I think, you can get other 28 students beautifully attentive all the time. I am not exaggerating out of 30 at that time because even though they don't like it, there are also people who have been pushed by parents even at that time. But once they have taken, they were doing that minimum thing. But, now, even that minimum things are not there. That is why, Dean Ac has always again plug flow queue for the people coming. Sir, I have completed only two credits this semester. So how many semesters I will take to complete? You will take hundred semesters. Yeah, because two hundred of credits they have to finish, approximately on 165, of course. Yeah, so like that, okay. Anyway, I think I will stop here. Tomorrow, we will do multistage fluidized bed, you know tanks in series model using the same thing, okay. You run now.