Chemical Reaction Engineering 2 (Heterogeneous Reactors)
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Lecture-24.
Mass transfer correlations for various reactors.

Professor: Okay, yesterday we had been discussing about the effectiveness factor, right and of course we have derived, the derivation has come nicely and also we have plotted all the graph to discuss what is the effect of various parameters and all that. Okay, if you could have observed those derivations, there is one very important thing there, right, how do you define that observable, do you remember? What is the definition of observable, that is Carberry's number. Yah, you are seeing and telling no? Yet, but I think you do not remember at all. Okay, Rob by…?

Student: CB KG a.

Professor: KG a, yah, so everything depends on the measurement of Rob and also the measurement of KG, whether you measure experimentally or whether you use the correlations. So that is why I would like to say something about these mass transfer correlations, so under various conditions how do you, what kind of mass transfer correlations you get, okay. Most of the time, what correlation you know in masses were? Tell me one correlation? Some of these things we can… That is why you know the school education fortunately is always rememberable, right.

If you do not remember alpha, beta, I think you cannot do anything later on. But, somehow when you come to the college, I think nothing to be remembered. I do know, I mean I have been telling you all this, you know except Reynolds number you do not remember any other number. Okay. You tell me any correlation in chemical engineering, forget about must answer correlation, one correlation and you may say why so much interest you are telling about correlation. But only correlations, you have now used only for the design, you do not have complete analytical solutions or (())(2:13) equations to design something. Right, always you have only correlations.

You know no, Anurag, no? In which course you have used so many correlations?

Student: Mass transfer.

Professor: Heat transfer you have not used? Yah, and also your equipment design, I think if you have really designed, you could have never escaped correlation. So many correlations are there for final design, so that is why understanding fairy is different and finally when you are designing, you have to only go for correlations. So we will write some few correlations, just to make you aware of what kind of correlations you may get. 1st let us start with our industrial workhorse, particularly chemical industry workhorse, what is the equipment?

Student: (())(3:06).

Professor: Pump, heat exchangers, no any other? At least I am happy that you remember the equipment name. Yah? It is called the chemical industry workhorse, packet bed. If there is any choice of using a packet bed, 1st go for packet bed. What is the reason? Yah, why? Packet bed you do not have low pressure.

Student: Correlation.

Professor: Because correlations are avoidable, it cannot become workhorse… Workhorse, meaning what is the meaning of that? Very hard-working, all the time it works without any problem. So in packet bed there are no moving parts, okay, it is fixed packing. So this is one of the main reasons and also what is the equipment, you have a cylindrical tube, right, most of the time. But you do not go for square or rectangular cross-section and have 10 metres or 20 metres column, you will not have, why? Either square cross-section or rectangular cross-section.

All these fundamental questions you like asking why are you here, why I was want to only these parents, not someone else? So these are all basic questions where all of us can think, I will ever get answers. Okay, but here at least you will get answers if you probe deep, a little bit deep. Tell me?

Student: In square, the corners will be inaccessible.

Professor: For what?

Student: Packed and flow as well.

Professor: Packing I can always put.

Student: If it is big then it might not fit…

Professor: In fact when it is big, it fits very well. When it is big, it fits very well because the particle sizes are small, so happily they will go inside. If you have small diameter and then of course as you said rectangular…

Student: (())(5:08).

Professor: Yah, the flow is not uniform if you take rectangular or square cross-section. Because in the corners, in those corners, the flow is not uniform as in the Centre. Whereas if you have a circular cross-section like cylinder, you can expect almost uniform flow, except maybe near the walls where I can always, without walls you cannot do anything. So you should have walls but you should minimise that affect, that is why you go for bigger and bigger diameter. So that is why for packet bed, what type of mass transfer correlations, that is what 1st I want to tell you.

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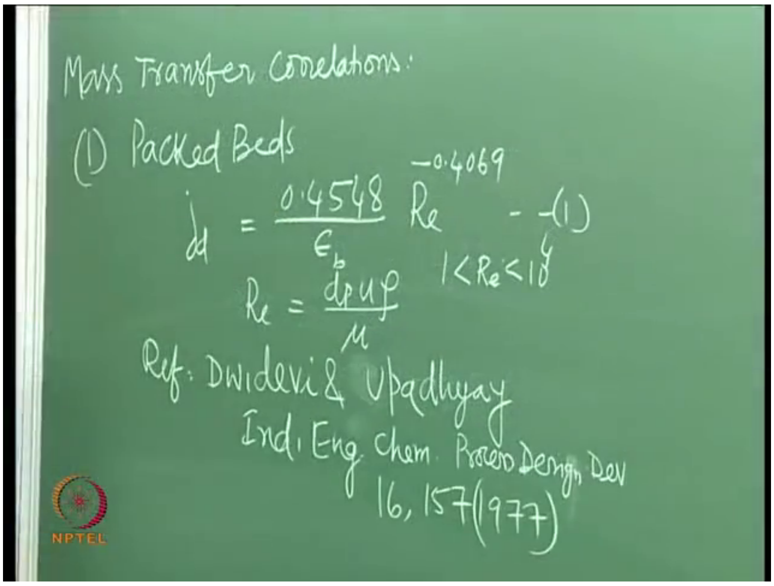

One is packet beds, the problem is I think you are happily reasoning and you may be understanding what I am saying now but I think next minute you are going to forget, that is my problem. That is why many times I also repeat, okay. It is not like that matrix move, where oracle tells okay, whatever we discussed, the moment you cross the door, everything you will forget, okay, you do not even remember that, we have a discussion and all that. But that is reversed, it is matrix, inverse matrix, you should remember everything. You should remember everything, whatever we discussed here, you can never forget.

Kalpana, did you see matrix movie? Why? I will not give you great unless you see that movie. You have to see that movie, it is a wonderful movie, not one-shot, 2 to 3 times you have to do. Kavya, did you see?

Student: No, I do not remember the name (())(6:45).

Professor: Oh, that means you have really seen the movie because after seeing the movie if you do not remember also, that is valid. Okay, but you know, beautiful concept that, after all that is what is inversion of the mind, how beautifully it was, the concept, simple concept. Where we do all the time, I mean philosophically I relate that in this way, you are just looking at me but your mind may not be with me, your mind maybe somewhere else. That is what matrix also says but that I think technically you put a rod here, connection and go somewhere wherever you want.

Right, yah but you may be looking at me but still yah mind maybe in Delhi, India gate or maybe Gateway of India or Qutub Minar or in Hyderabad Char Minar, so you may be thinking all about that, right. So but anyway, this concentration is not there, that is why I think I repeat so many times. I repeat some a times so that at least one point of time you will come to the real class. Will catch what I am trying to tell, okay. Packet beds, one of the correlations, there are many correlations for underwater I am going to discuss, in packet bed itself there at least you know 10 to 15 correlations but what is the very, I mean widely used, correlations, that is what only I am trying to give here.

We have JD, JD definition yesterday only we have seen, JD equal to 0.4548 by Epsilon B into Reynolds to the power of -0.4069, this is the correlation, where Reynolds number is given as dP u row by mu, this I do not have to explain. So this is equation number 1, okay and this is valid , this correlation is valid between Reynolds numbers 1 to 10 to the power of 4, Reynolds number 10 to the power of 4. That is a very large Reynolds number for packet bed. It is not, it is not like tubular flow, where 10 to the power of 4 also you may not get complete turbulence.

Whereas here in packet beds, when do you get turbulence, around 400, okay. And where do you get Reynolds, I mean laminar? Abhinav, any idea about packet bed? When do you get, till what Reynolds number you get laminar flow in packet bed? Absolutely no idea? Around 1, yah, not a bad guess but…

Student: 10.

Professor: Why 10? Because the log scale, 110, 100, like that, that is why you just guessing next one? Yah, around 100, you are taking transportation phenomena no? You do not have goes on transport phenomena? Okay, you completed already. So then it is there in that, packet bed. Then what did you… In transport phenomena?

Student: (())(10:18). Vector and tensors.

Professor: Okay, vector and tensors you have done, that means that early you have been shifted to mathematics department or what? Who taught you transfer phenomena? Prof natrajan would have covered all that, no.

Student: He did not cover only (())(10:38).

Professor: He only uncovered many things? He only uncovered many things? Unfortunately what is happening with most of us, we are not able to identify what is required for the students in the B tech and M tech classes. But anyway, yah, so this is the one, it covers and the correlation was proposed by reference Dwivedi and Upadhyay, okay, these are the others and there is a journal called industrial engineering chemistry process design, process design, okay, design and development, that is the journal, process design and development. And this was volume 16 page number 157, 1977, this is how we normally read, one method of writing references.

1st one is volume number, every year they will have volume in journals, then 157 is the page number, sometimes we also write 157 to 165 page numbers, starting to ending and then this is the year, in this journal. And these 2 people from BHU, Banaras Hindu University, Upadhayay I think is still there or just about to retire or something. But they have done a wonderful work, this is Indian research, where we collect all the data and then try to analyse. Okay, so whatever data on packet beds has been available, so that data they have put, they have taken and then analysed and fixed in this format. Okay.

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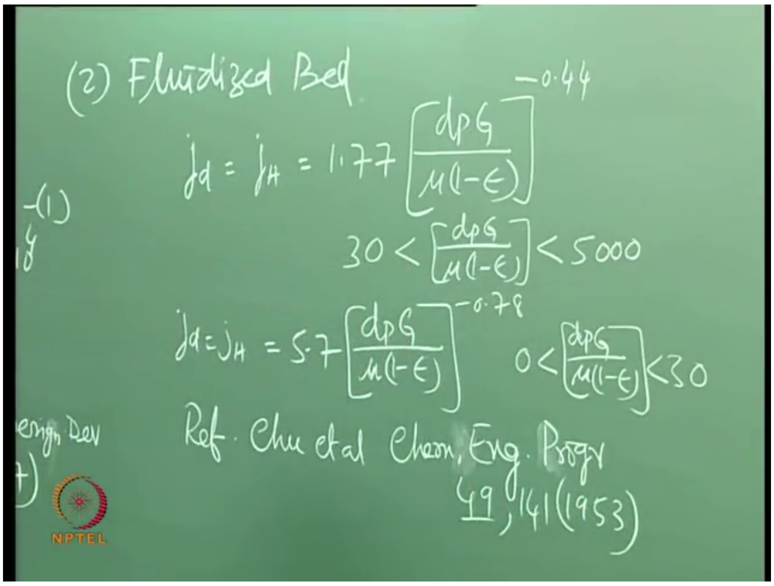

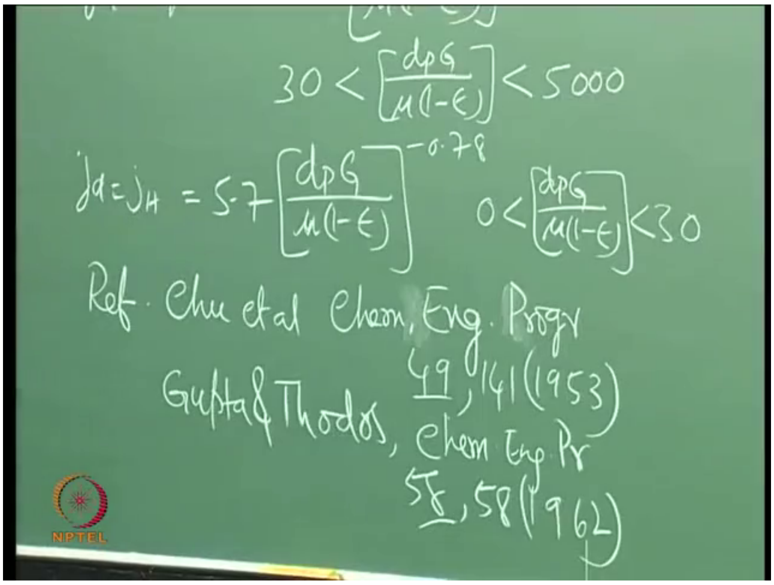

And mass transfer coefficient is there in the JD, definition. So what is Epsilon B, you could have guessed? Arhenius factor, okay, then I better write, Epsilon B is porosity of the packet bit. Okay, good, so this is one correlation, now I think you know the other one is the fluid bed, which is again very widely used. So for that the correlation is, I will write here, 2, fluidised bed, a correlation is little bit simple here, so JD and JH, heat transfer correlation also we can use the same thing. So 1.77 dp G by mu 1 minus Epsilon to the power of -0.44., This is valid, okay, this is valid between 0, less than BP G, BP G mu less than 5000. Okay. So that is 1.

And for JD equal to JH, 5.77 DPG mu 1 minus Epsilon, -0.78, so this is valid between okay, 0, sorry, this is 30, the above one is 30, this is 0, less than, less than 30, good. There are 2 references for this, reference Chu etal, etal means some more are there, I do not have other names Chu etal, the journal is chemical dot engineering dot progress, there is a journal called chemical engineering progress, I do know whether you seen or not. Chemical engineering progress, so this is 49 volume, I also underlined that, 49 volume, 141 page number, 1953. Most of you, why most of you, all of you were not there at that time, 1953.

Yah, and also another person, maybe this one correspondingly is Gupta and Thodos, this is also chemical engineering progress, chemical engineering progress, 58 page number, 1962, so these are the references. Okay, by the way what is that in that group, does that have a name, DPG by mu, 1 minus Epsilon. You, this also a Reynolds number sometimes based on wideness of the bed, okay, wideness of the bed. So that is what is there. I think G is, what are the units of G? Yah, mask flux inside., Good, right. So that is one and then now, I do not use these other conventional ones and also you have moving bed, you have rotary quills, for all those things, okay.

So that is why you have to just look, I mean 2 very widely used equipment we have taken and just given. Just to have an idea what kind of correlation we are talking about when you are talking about KG a, okay. And there are some novel types of reactors, for example monolith. Yesterday only suddenly I got the idea you know, I now give MS Project based on 2, the catalytic converters. I can take them, even though they are used or unused new ones, I give a mu project on finding out hydrodynamic through that. I do not think any published literature is there on hydrodynamics through monolith auto, what is that automotive catalysts, monolith.

It is very nice, you know if they will have a diameter of 4 inches or So and length will be thick inches or 8 inches and that is simply inserted in the exhaust pipe of cord. Okay, so when the gases after the combustion coming out through the exhaust pipe, they have to travel through this particular monolith. So it is a catalytic reaction, so when the gases are passing through the monolith, then you will have the catalytic conversion, that means CO going to CO2 and you have many hydrocarbons normally converted into hydrogen and CO2, okay. Yah, I mean, non-harmful products which you can simply put into the atmosphere.

But you see the entire thing is one reactor, that means diameter 4 inches and length is 6 inches, okay. It is a wonderful idea but I think hydrodynamics, vary the dead space or example, whether it is really possible or not, I do not think many people would have done it. Okay, so because I have drawn yesterday the picture, okay, as a cylindrical and then you have lots of slots, yah, each slot is a plugged flow. That is what is your resumption but really we do not know whether that is plugged flow or not. So that is why we have to check in the laboratory whether religion they plugged flow. You have to conduct the RTD test which is not that easy because the residence time of the gases through 6 inch tube or 6 inch length monolith is very very small, maybe less than seconds.

So if everything is automated, you can beautifully find out whether there is this plugged flow and what will be the pressure drop. You know the pressure drop, I do not know whether you seen, nowadays movies I think they do not show. Old movies when you see black-and-white movies, if you do not want your opponent to start the car, you take some kind of lemon or you and then just stop the exhaust, so the outlet gases cannot come, so the engine will not start because the pressure is not developing. So, okay, so that is a kind of thing. So why I am telling you, what you are doing by putting this lemon or some other obsession, you are creating pressure drop, okay, very high pressure drop.

So similarly if the monolith is there inside, beyond certain pressure, pressure drop, then definitely you may have less combustion exchange. Oil may be injecting but still it is not burn. So that is why is there optimal pressure drop across that. I mean all these things they would have done in the research time, like you know all the Ford company or all other Benz companies, would have done, but it is secret for them, they will not… But only Academicians, we do not have any secrets, all things we talk, okay. So that is why that kind of information is really wonderful information, okay, anyway, good.

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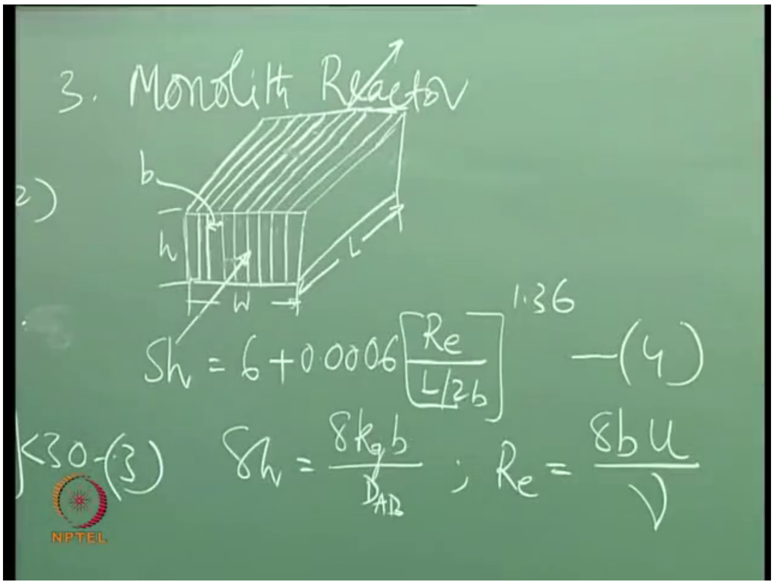

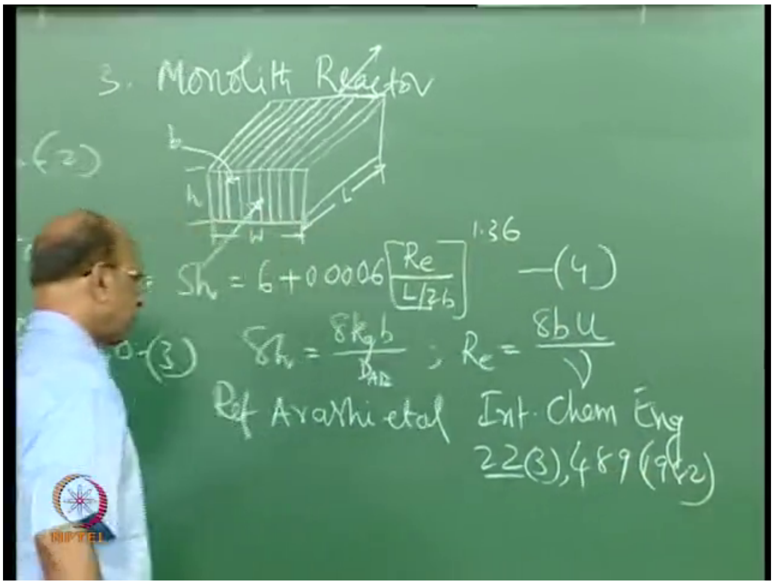

So now we are going to have one monolith reactor, where this monolith is given something like this, you have plates like this, then it is extending in this direction, yah. So you have to also draw, yah, yah. So till here, looks like a monolithic, good. The flow is parallel in this direction and then coming out, good, that is monolith. And each slot is like a (())(22:15) flow, if slot. And there is a plate here where both sides the catalyst is coated, decide on that side, both sides. So then gases going in this will react here, here, here, here, that is what what we call as hydraulic diameter.

Correct no, wherever it is weighted, good, so all the things will come there and the correlation for this is, for this Sherwood number equal to 6+, okay, let me also give the dimensions here, so this one, this is the height H, this is W and this is the length of course, yah, that is the length. So, yah, I also say that this is the width, that is B, width of this slot, yah. So the correlation is 6 plus 0.0006, how many zeros, 3 zeros 6 Reynolds by L by 2b, all thing to the power of 1.36. Where of course, all the meanings are there, we have B and all that, but let me check this one also, Sherwood is defined as 8 KG b DA B, that is the definition of Sherwood.

And the Reynolds definition is 8 BU is the velocity buy nu, yah, I think I lost the equation, that is equation 1, 2, 3, this is 4. Yah, so this is given by some Arashi reference, Arashi et al, I hope you know what is et al, I also wrote here et al. et al means? Yah, plus some more. And when do you write et al normally?

Student: (())(24:44).

Professor: How many?

Student: More than 3.

Professor: More than 2. When you have more than 2, this question I am asking till many Ph.D. scholars when they come to me for the synopsis meeting, okay. I think after 5 years also, some of them, at least maybe 20, I will not say 20 but 15 percent, at least they do not know when to write et al. Okay, even for one writer they, 1 also the right et al, okay, because safe no, no problem. I think that was a, one of the oldest movies, remember all these things, because I have also passion for movies. So when the mu bridegroom and bride when they are entering the house, they want to, you know you have to enter only with the right leg no, you put your right leg 1st before entering.

I do not know what is the sanctity, right leg if you do not have or left leg you do not have, you cannot walk anyway. So I think you know people say that right leg is better than left leg, okay, but do not know, all these things, okay, we do not know, all these things are unnecessary things, necessarily defined parameters which really troubles us, this kind of left legs footing, right leg footing and all that. So you have to put the right leg, so the bridegroom does not know which is right leg, which is left leg. So the father tells her to put 2 legs, one will be red, one will be left, citing that is a very good suggestion.

So like that we also has here et al, okay, yah. So this Arashi et al where you have international chemical engineering is the journal. These abbreviations also you should know as chemical engineers. So volume 23 and sometimes we write in the brackets, that means issue. The issue means, every month they will have an issue, so then totally you will have 12 in a year, okay, good. So 22, this 3 means maybe March, okay, then you have what, 489 page number, this is 1982, so that is the correlation, the use, yah. You see here I have given a different correlation for RE, see here it is different, straightforward which you can see, correct no, Dp. And here we use mass flow rate or mass flux and here we have used kinematic viscosity. Okay, that means mu by rho or rho by mu directly combined here.

So that is why this is one of my favourite questions in asking students when they come for interview, tell me Reynolds number in the different ways. Okay, yah this is one of the thing, symbolising the essay. And also of course this B the distance, we saying the definition of Sherwood number or Reynolds number, it is not always D, and the characteristic length, okay. So the characters decline for the packet bed is particle diameter but not the tube diameter. Even fluidised bed, take the particle diameter rather than tube diameter, even in moving but it is particle diameter, why?

A very simple tube we will take diameter completely, diameter of the tube, matrix or here, here only, physically you are here but mentally I am asking.

Student: Yes.

Professor: Yah, why, you understood the question what I am asking? Reynolds number if you have that you, empty tube flow, then we will see you take the tube diameter. But in packet bed you take particle, fluidised bed you take particle, moving but you take particle. Why not tube, because that is also a tube?

Student: (())(28:27).

Professor: Yah, all the phenomena is taking place around the particle. That is why the characteristic length will be the particle rather than the tube, okay. So that is why, I mean these things many people will not repeat, will not say but I think if you know all that, that is happy, if you know that simple simple things, they are important for us. In fact it is most of the times simple thing which give you happiness, complicated things always give you problems, okay. Okay, good, so that is why we say that before marriage I was very happy, after marriage there is no unhappiness, that means there is a complicated thing, simple thing is no marriage, so this is a kind of…

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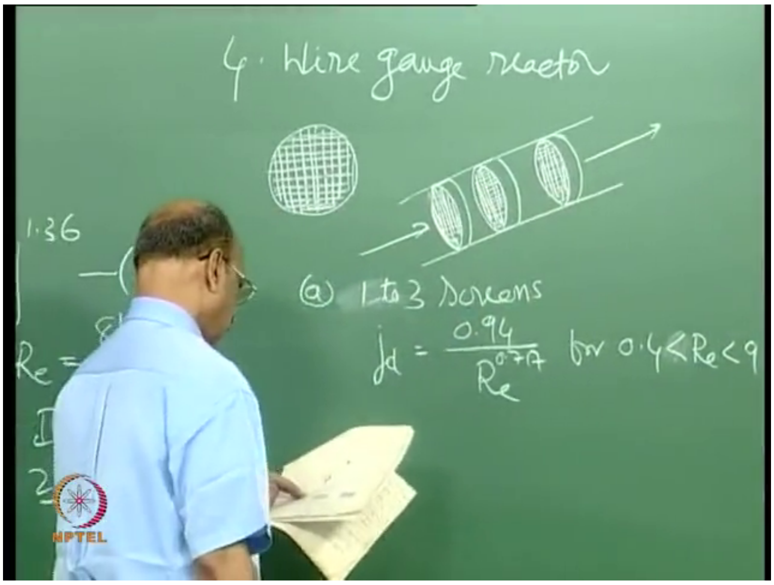

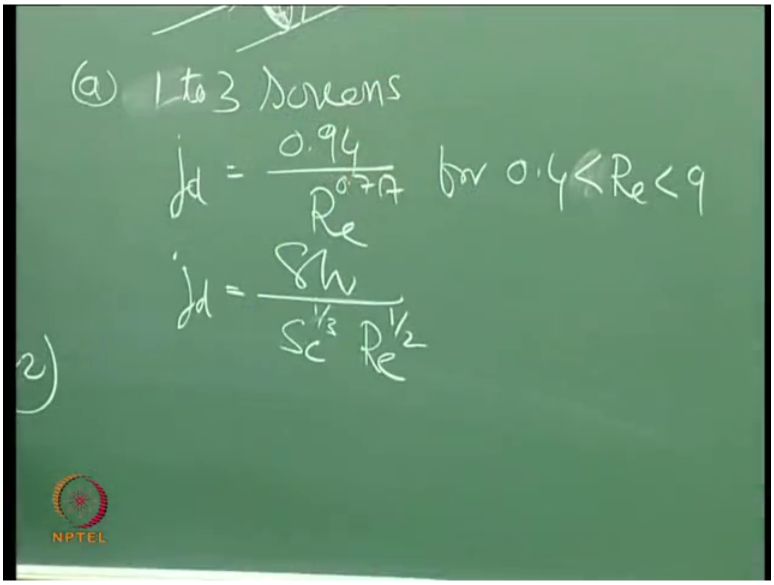

Okay, so this is another one equation, then we have another example wire gauze, wire gauze reactor. This I have been telling you many times, wire gauze, wire gauze and all that, okay, good. So if you look at one wire gauze, you will have something like this, almost, okay, this is the plan, if you put that did not look at that, that will be looking like this. And these wire gauzes are normally put in a reactor and that reactor, just to show you how that can be, yah you have class no, which class, not Ravi no? Ravi means you should avoid me in the beginning itself. Yah, okay.

This is one sieve, I mean one sieve, this is another, looking like sieve, yah. So there is another one here, yah the flow is looking sieve kept in the tube, not looking, no? Sphere, okay. So the flow is in this direction, what problem? You, you see, good. Yah, but cream biscuit cannot be used but here only sieves one have to use, yah, it is like a cream biscuit, when you are happy, good, yah good. When I have this kind of flow, then, again you may have, you may have to put sometimes 3, sometimes 5, sometimes 10, it is not always 5, 10, like that, but any number whatever is required for the design.

So these, okay, these are the wires which are woven in the form of sieve and those are the sieves which we will just keep their and you can see now if I have for one, 2, 3 screens in this correlation, if I have 1, 2, okay, I think I will dash, 1, 2, 3 screens. You will have JD equal to 0.94 divided by its Reynolds to the power of 0.717, so this is valid for 0.4 less than Reynolds number less than 9. Of course JD definition again you know, it is not actually the other definition what we have given, JD definition, JD definition in terms of dimensionless numbers do you remember? Too much to ask, okay, let me write that at least once.

JD equal to Sherwood number, by, there are 2 numbers here, Schmidt number, Reynolds number. So this is one 3rd and this will be half, that is what the actual definition. Always remember, you know whatever correlation we have for mass transfer, you should have something to take care of hydrodynamics, something to take care properties. Properties of the fluids you go, you get . What is that Rachit?

Student: 0.7A.

Professor: 0.717. Okay, this is 0.717, yah. This is what what you remember. Always you know take care of properties which number we use? Reynolds number you cannot take property… Schmidt number. To take care of the hydrodynamics or flow around the particle or inside, that is Reynolds number, so these 2 are must. Even for heat transport that is but the only thing is Schmidt number is replaced by Prandlt number. So that is why you have something connected, okay. Good, so this is the one, then of course where Reynolds number is defined here as, use everytime you to define Reynolds number depending on your convenience.

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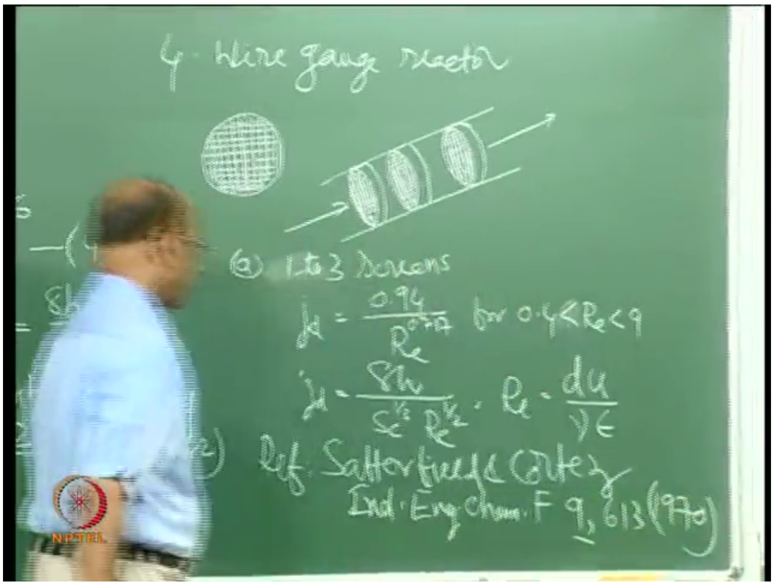

This is mu into Epsilon, Epsilon is the widage of the sieve, Epsilon is the widage of the sieve or porosity of the sieves. Epsilon is the porosity, it is the same, widage or porosity we are using. Okay. So that is Z1, and okay, if I have 5 screens, if you have 5 screens, this is B, 1 to 5 screens, same thing am containing bits, 4 wire gauzes. Then you have something called alpha JD equal to 0.664 Reynolds by alpha to the power of 0.57 and for Reynolds number 3 to 107, where alpha equal to 1 minus n into T whole square, where n equal to mesh size in number, mesh size in number of wires, number of wires per square inch,, very good, inch square, that is n.

And D is diameter of the wire, yah. I mean this also has been done by you know few people like I will tell you, one, one difference I will give you, one of the oldest professors was in MIT reference Satterfield, Satterfield was excellent in mass transfer, mass transfer through heterogeneous systems, and Cortez. Yah, so this one is industrial engineering chemistry fundamentals, yes. Industry engineering fundamentals, engineering chemistry fundamentals, 9 is the volume number, the number is 613 and year is 1970. Okay, one reference just I would like to give you, okay, good. So these are the kinds of references or correlations what we have and you see this one and this one is in 70s, 80s and 90s.

So that means the original thinking of you know packet beds conventional systems are slowly being replaced by nonconventional systems like these, monolith reactors, these wire gauzes and all that. That is our chemical engineering evolves, okay, but originally packet beds and fluidised bed, variously, 50s, 40s and also 60s. 70s, 80s and all that, mu thinking, so this is what I thought I will tell you, but still it is only the tip of the iceberg, right.

So we have so many other systems, so many other systems, the measures I would like to give here is that whenever you are going for nonconventional chemical reactors or nonchemical, nonconventional chemical engineering Systems in terms of equipment, then you have to find out from everytime you have to do research and then find out the masses of professions, heat transfer coefficients, hydrodynamics, hydrodynamics means what do you find out? The velocity that are possible, flooding that is, you know, when can that can occur? If it is movement of the solids, then you also find out when the particles fluidised or when the particles go away, all this information you have to find out through research. That is why still we are surviving, okay.

So something mu, something mu, something mu equipment, something mu correlation, something mu theory if it is possible. So all multiphase systems, are now taking multiphase systems? That also you have taken already? Okay, you do not have at all, that is only for dual degree, yah. I mean entire chemical engineering is only multiphase systems and when you go to multiphase systems, even 2 phases, then mostly the theory cannot be understood so easily. So that is why we go to (())(40:12), okay. So with this I think the external mass transfer thing is over in terms of effectiveness factors and also we have to correlation because all that analysis is depending on these correlations.

Why, because KG is very important or KL or whatever. Mass transfer coefficient is very important in defining that observable, okay. So that is the reason why you to spend some time to let you know what kind of correlations you may be having. At least you may not remember but at least later also in your life when sometimes come, I think you have to say that yah, we know this kind of correlation, someone I have seen. So that is the main reason why we have done this, so I think this is fine, okay. Good, thank you.