Chemical Reaction Engineering 2 (Heterogeneous Reactors)
By Professor K. Krishnaiah
Department of Chemical Engineering
Indian Institute of Technology, Madras
Lecture 39
Fluidized Bed Reactor Design-Part 4

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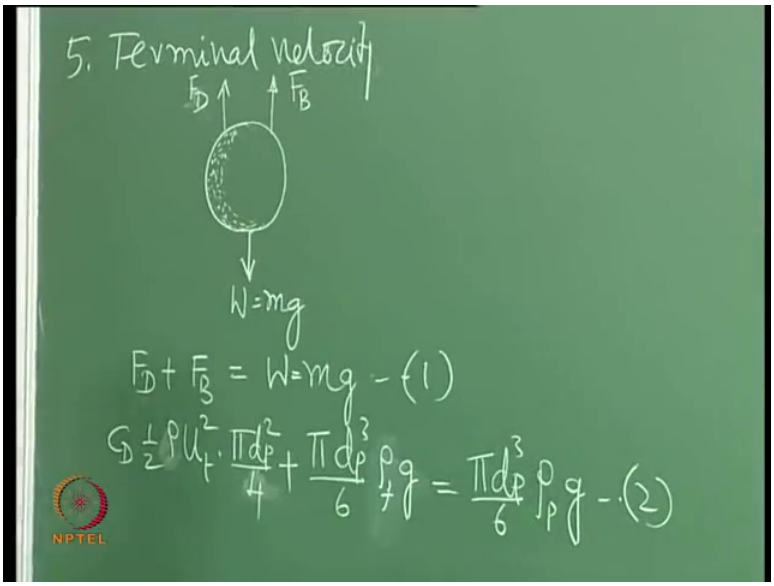

Okay I think we will start now in the last class in the last class we have talked about minimum fluidization velocity that is one parameter now we talk about terminal velocities because that also we should know that is parameter number 5 normally terminal velocity of single particles only we talk here so if you take one particle we have some kind of 3D effect I just want to put this, good this particle is just fall in through way fluid, right? Is a terminal velocity of single particle where you take the very big tube and then fluid is flowing through that and you drop the particle.

So what are the forces that are acting on this? So weight will be acting downwards which is mg and because it is coming down drag will be acting the opposite direction that is Fd and you also have another force buoyance Fb. So when all these three W and these two are balanced then you will get the terminal velocity where it will of course initially when you put you have acceleration and all that then it reaches terminal velocity from then onwards it constantly coming down, okay.

So we can derive this equation if we know all this terms and the balance is Fd drag force plus Fb buoyance should give you W mg, okay so that is the one and the drag force is nothing but you

have of rho ut square multiplied by the drag coefficient and the projected area, okay so all three so if I have that means drag force is directly proportional to the area, okay more the area more the drag force you know that is very simple one and then of course the kinetic energy.

So if I write that you will have Cd half rho ut square rho ut square into the projected area, projected area of this is is a circular area because is a spherical particle so I can write this one as pi dp square by 4 sorry 4 plus buoyance is the fluid displaced so that volume is dp cube 6 into rho into (())(3:51) rho f into g, right? Then this side we have mass into acceleration that you gravity this again dp cube 6 that is the volume rho p is the particle and then g is the that gravitational constant, okay so this is the one.

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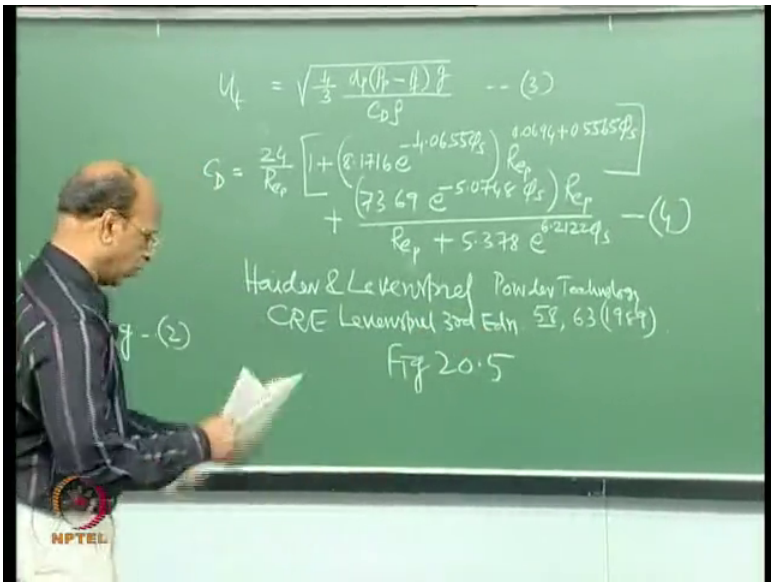

So if I rearrange this for ut ut will be, okay I will write here ut is forth third dp rho p rho f into g by Cd into, okay so this is equation number 3, correct no? What happened? Nela something wrong? Okay. So if I know Cd then I can calculate ut for any condition, okay so again you have Stokes law regime and all that you know what is Cd for Stokes law regime all that will be there you can derive but I am going to give one shot all the birds died, okay.

So that is why Cd given by Levenspiel and some other person called Haider they gave Cd for all regimes together, okay. So idea is I have to calculate ut dp I know, rho p I know, rho f I know because I am using you know some fluid which I know, particle size I know, particle density I know so all that I know and g also you know and only Cd I do not know so for Cd if you get a

correlation this correlation by that I will give you later Cd equal to 24 by Rep where Rep is particle Reynolds number at terminal velocity, okay that u is ut but Rep we are writing to say that it is particle Reynolds number, okay.

This is 1 plus 8.1716e power minus purely empirical equation so that is why you will have all funny powers phi s this whole thing multiplied by Rep to the power of 0.0694 the power only this one 0.5565 phi s that is one term, okay then I have here I think I can write here plus this continuation plus I have 73.69 e power minus 5.0748 phi s into Rep whole thing divided by Rep plus 5.378 e power 6.2122 phi s this is the equation this is equation number 4, okay I do not know how do you remember this you have to remember, (())(8:32) thank you thank you this entire thing, good thank you this thing too, okay that is right thank you you know that correlation or just like that you guessed, 24 by okay so unless it is multiplied by that, true this is the one and I do not know how you are going to remember in the examination so I think this is the correlation which we have to use if I give a problem to calculate ut you have to use this correlation, okay.

So this is given by Haider and Levenspiel the same man Cre man this is powder technology that is the general name and you have volume 58 page number 63 1989, where you born at that time? No (())(9:51) most of you, okay good then it happened only in your zamana. So I think this is the correlation if you see the literature there will be hundreds of ut correlations but this is very well accepted one because so much effort has gone into it is only to take all the data that is available till now till then published they have put into one correlation, okay good.

So this is the equation and as usual for completely spherical particles you can reduce this equation to simple equation where phi s equal to 1 so this becomes a constant and also this also becomes a constant so this becomes a constant, this also becomes a constant it is a little bit simpler, okay good. So I think how many of you have Levenspiel book with you third edition? Wake him up I mean early morning I think you know how you are getting sleep is really surprising I say early morning you just got unless of course your early morning is 6 o clock 6 pm and this is the night time for you, okay I think you came from some other planet already in the US, okay so that is why practicing US timings sleep in the class room and be moving in the night in the hostels, that is all US I was asking you something what is that, Levenspiel book, Abhinav? You have the Levenspiel book with you? No no? Very good why unnecessarily wasting time for

chemical engineering or wasting money, okay how many you say how many (())(11:47) frankly I am not going to check your room do not really deceive yourself that is most important, okay you also have Prabhu.

Student: Sir e-books.

Professor: He has always something different answers I think my god must be he is from I think Pandora that planet avatar always as very good e-book you have, how did you get e-book?

Student: (())(12:16).

Professor: So anyone can download I will tell Levenspiel, okay and most of your books are I think misused because hard copy is easy to read and e-copy is easy to store, okay you cannot your open unless you want to cut and paste something if I give the assignment cut and paste and you can submit the assignment no that kind of thing. So in fact this same equation and also emf yesterday what we have discussed there is a graph there in the third edition I think all of you should have third edition you belong to third 3G generation 3G section, okay.

So that is why third edition I have first edition, second edition to because I think I have seen 1G, 2G now it will come to 3G, right? So in the third edition CRE Levenspiel in third edition what you have you know there is a figure 20.5 chapter 20 figure number 5 this figure in fact gives one dimensionless number that is equivalent to Archimedes number versus Umf ut and there are many other things also in that graph, okay I think that graph also I have brought here to show because you would have never seen this this graph, okay. If you know the x axis, x axis dp star this dp star is he has used some other dimensionless numbers so that will be Archimedes number Archimedes number all the information you know gdp cube rho f rho s minus rho f my mu square.

So rho f and mu are the fluid properties rho p dp are the properties of and g is the property of this planet, okay so all the things you know so you have that information you can easily calculate and then read what is Umf or what is Ut, okay instead of solving but anyway this is not allowed in the examination you have to use this equation to calculate if Ut is asked and who knows tomorrow there maybe surprise test asking this, okay I know how to pain you and you also know how to pain me because I think you come here and sleep that pains me, okay and you do not do

any work that pains me and also immediately before even class started (())(14:55), okay and no one tells sir (())(14:58), okay.

So all this things you know you also pain me in equal direction or reversible reactions, okay good. Anyway so this is the one which is a very good figure where he has nicely beautifully put that and he has also given in this figure what are the possible ranges of operation what we have done you know normal fluidization, fast fluidization, pneumatic conveying all that regimes are given wonderful graph, okay but I think you know assumption is that you are interested that is why I am telling I think you think that I am a mad man, right? So generally this fellow talk something I think you know which we come here and happily sleep that is enough for me, okay.

So that is the kind of attitude if you have what you learn I say what anyone can learn, no one can learn anything so this is the problem yesterday we had one and a half two hours discussion about JEE, okay and non-other than the DST chief I think you know next next to minister he is in the scientific thing Doctor Ramaswamy he came and spent so much time and I was thinking that why the hell in our country we should have I think I believe movo very strongly, you know who is movo? You know, you do not know Shiv Kumar movo, who is movo? Chinese something what is that Chinese animal or Chinese Horse or Chinese dog or what, Chinese man, Chinese student Chinese food noodles we know that we know very well.

Movo once he came to the power he found that many people are not concentrated in academic institutions so then he closed all the acedamic institutions and then said that you know you have to go and produce wheat, that is all send (())(16:56), okay so I mean some people say no no the entire academic intellectuality gone and all that but I feel that it is more practical because if someone is not interested why should be spent time on that, okay.

So I mean yesterday so much discussion about this JEE how to improve, how to increase the interest in the students, where is the interest I say once the JEE is passed and once any entrance examination is passed you think that life is settled, okay any entrance examination it may be T CET, K CET, T CET, F CET, M CET many sets you know everything there is SET only, okay once that examination is over then life is settled because you do not have to do anything and what do you do in the school, all there is no school for you anyway is only coaching centers what you have seen, okay.

So I think that beautiful life of school gone, now he wants to bring that back that school education to some extent, that is why I think board they want to have some 40 percent marks that school mark in fact we had that excellent time we had really excellent life and we were students no one use to tell that you read or do not read that is all very happily while going also I mean I have to walk nearly 7 kilometers every day to go to school another 7 kilometers to come back. So on the way all happy walking, happy running, happy playing and all that, okay and then you come here and then there is no power anyway by the time you come it will be 6 o clock or so eat food and then until sleep most of the time, okay but (())(18:29) one year examinations and all that not for every day 10 tests like coaching center, okay 10 or 24 test because every hour a test in coaching center, okay every hour a test (())(18:41) finally I think you do not know what to write at the end, okay.

So everything tick tick technology, technology has become ticknology totally beautifully converted technology has been ticknology now. So that is why in Hyderabad I do not know whether I told you I think I told you last semester also this thing maybe Abhinav all this people maybe knowing this at least they will come to know about this, in Hyderabad you know Hyderabad 50 percent of the Hyderabad in the US every family, every hut, every building, every story buildings all these people I think in any place you take there is one person who has gone to US from Hyderabad.

So I think that person stayed there for 5 years or so he came back here to marry, okay because I think after finishing B. Tech or something he went there after coming back and then he saw 4 girls and he does not know how to choose, right? So then father knows his you know strength and weakness or anything so then father what he said is okay first girl A, second girl B, third girl C, fourth girl D then he knows to tick fourth D till then he does not know how to tick, how to choose so that is how we have converted all our younger generation to technology to ticknology that is what I have been telling ticknology, okay.

So like that I think you know unless that ABCD is there you cannot do anything you go to your mess and if it is you know idli dosa and upma and all that you do not know what to take if that fellow writes A, B, C, D tick and then take that is the kind of life we have here now on this planet particularly in India, okay. So then what is the interest for you? Absolutely there is no interest no I mean like a mad fellow I will be talking here very enthusiastically thinking that, oh

my god entire thing is fluidization the whole universe again is you know only fluidization, so that kind of thing I will say but you come here and then happily sleep, okay

And then otherwise you go to your own matrix searching for Neo and searching for rather what is your name in a movie you have seen no, trinity good he woke up now he is in the matrix so he knows trinity he is inside the matrix trinity or a old person like me, what is his name? Morpheus and I think the names also a very good names you know switch, switch is one person's name you know switch connection so like that it is very wonderful movie I say, okay good.

So this is about terminal velocity the next point is in fact you know terminal velocity also there is lot of information and when we tell about this particular thing completely we are in a ideal world where is one particle when do you use one particle in chemical engineering, you never use except on the board, okay even if you go to lab also I think you will have number of particles but in reality you will have again some other thing which is called transportation velocity and all that I think that will come later when you really take a fluidize bed course, okay but I think here it is only an indication for us that what is the maximum velocity that maybe possible for fluidization that is why we need this parameter, okay.

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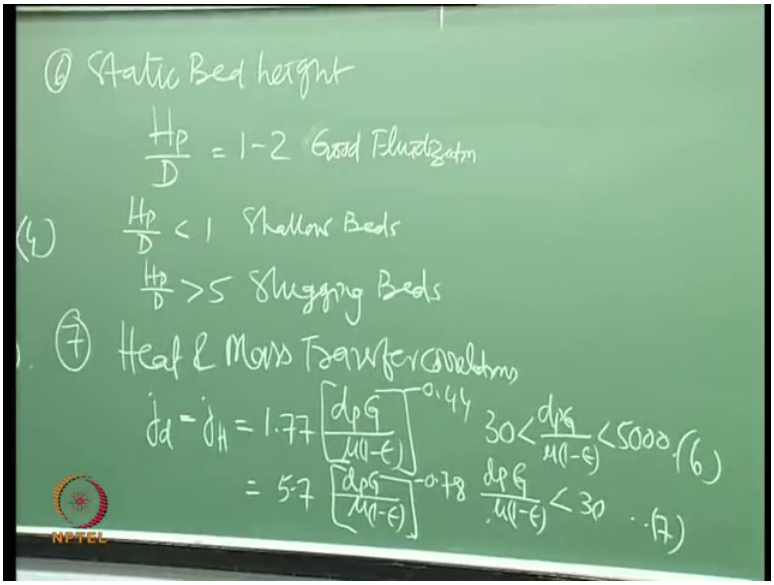

The next one is bed height, right? Or you do not know static bed height, what is the static bed height we use what is the number, 6 static bed height, okay see every time I will tell what I have been telling in all the time to you is only to make you again temporarily come back to the class that is why I tell that you know you do not have interest and all that so that at least, okay this fellow is telling at least 10 minute let me concentrate, so that is the reason otherwise you know you may think that you know this fellow is pessimistic always talks like that, no whenever it is trying to go away from the track slightly applying some force to bring it back to the track that is why I do not know any other force except telling this if you have any other information tell me I will use that technique, okay how to bring you to the class, so otherwise I do not know I think that is why every time I will point out the moment I think that you are not concentrating, okay.

So that is the reason, Prabhu any comments he will give a wonderful comment, no comment but itself is wonderful, okay. So usually Hp by D static bed height, okay is normally 1 to 2 best fluidization or good fluidization you do not say best good fluidization, okay best fluidization means all the particles should be very very spherical and all the particles should be exactly same size all these that we do not get normally so that is why, okay this is good fluidization what do you mean by good fluidization if someone asks you what do you mean by good fluidization, what do you say Kaviya? When do you say you have good fluidization? What is the meaning of that you are only telling the other you know opposite quality you are telling so that you know if everyone is lousy I am very good, okay that kind of thing not that I mean Abhinav that means

good contact between not mixing, mixing also you have without good contact also because you know when you have bubbles and all that.

So uniform fluidization and also good contact between solids and gas that means each and every particle must have very good contact with the fluid, okay either gas or liquid that is what what we mean by good fluidization, okay but when you have Hp by D less than 1 you have what is called shallow beds, so in the shallow beds generally you will not have good contact because there is no time for contacting because you take only 10 particles height, okay if you have 1 mm particles 1 mm is very large for fluidization but easy visualization that is why I am telling 1 mm so 10 mm bed height you put even though diameter is 1 meter those are shallow beds 1 meter diameter also if you have only 10 particle height or 20 particles height then that is very very shallow bed, okay under some circumstances shallow beds are preferred if you avoid bubbling because there is no time for gas to bubble bubble to grow, okay.

So that is why shallow beds are used some time particularly for drying it is also can be used beautifully drying, okay and they call this fluidized bed plug flow dryers you know fluidized bed we know that it is a mixed flow how can you have plug flow not in gases solids are, how can you make this mixed flow as plug flow? It is shallow but I think, how can it be plug flow because I think even then they are bubbling you know I mean they are mixing you increase the length, okay and then put the solids here this is just a plate with perforations maybe with slight angle for flow, okay even you do not need slight angle but better to have if you want better flow otherwise even if you put horizontally also you are feeding here all the time and it maybe 2 meters length, right? Straight channel and bottom you have the perforated plate and uniformly you distribute throughout the channel hot air and the beds solids are put in one corner.

So those particles will slowly dry there and then start moving so till there of course there may not be any flow there once you starts moving then from there continuously it comes out and then you can collect the solids there and the length is designed for how much drying you require, maybe you know end moisture maybe 1 percent, 2 percent, 5 percent, 10 percent depending on your requirement but drawback here is that you cannot use 50 percent, 60 percent moisture it is a tertiary treatment for tertiary drying technique that means first you may if it is completely pressed what do you do you cannot use any column except tray, tray type dryers, okay then once it is dried for some time then you will have some moisture where the particles are not sticking

but a little bit flow able so at that point of time you switch over to this and if that is not sufficient then you use some other drying technique there are so many drying techniques, okay.

So then the final one when you want have only one percent and all that fluidized beds are excellent particularly plug flow dryers, what is the advantage of plug flow dryers? Because each and every particle again will have exactly same moisture content in fact you use this nylon and all that no shirts for polymer drying particularly when they want to make this rayon and all that you know the for making this cloth they first make the polymer granules and they have to be very accurately dried that means each and every particle should have exactly same moisture content it seems if this moisture content is slightly different in some particles, okay in some other particles whether low or high then the thread will not come properly it seems, okay so that will not come properly so that is the reason why they use this plug flow dryers for polymer drying you want to use that one for textiles, so many advantages, okay good.

So this is the one that is all what we, I think another one is of course if Hp by D greater than 5 what do you get? That means you have not seen at all you just look what I have told to (()) (29:07) one narrow column and then slightly more thing it is slugging that means the entire bed is occupying the bubbles occupying the entire cross sectional of the bed slugging that means if the initial static bed height itself if you have 5 and then of course generally you know when we say this condition slugging means you know narrow construction narrow cross section then you get the slugging, okay I means what I said was true I say I think all of you are Gajini's only I do not know when you remember maybe I think that Gajini at least will after 15 minutes he remembers something but here I think there is no remembrance at all maybe just examination before before the examination you may remember, okay good.

So that is static bed height and the last one is 7, (())(30:04) you have heat and mass transfer correlations all this things we require before we start the rector models so that is why here you have again correlation so there cannot discuss much unless how do you develop this correlations when you go we can discuss but we do not have that much time but simply we accept these things because they are already available and those who are interested anyway they can definitely go and then read all these information how do you develop this.

jd equal to jh equal to to save the students I think they have given nice correlation for both one, okay this is dpG mu into 1 minus epsilon whole to the power of minus 0.44 that is 1 this is also equal to 5.7 same number dpG mu by 1 minus epsilon this is to the power of minus 0.78 and the condition is this is less than 5000 and this is dpG by mu into 1 minus epsilon less than 30, so what is that I have equation number 4 I think here we do not have to give this equation number this is 6 this is 7, okay Renita do you remember what is that number called, dpG by is it dimensionless? Reynolds question Reynolds? No, answer why that (())(32:23) what are the units of that? What is dp, what is G? What are the units of mass flow rate?

Student: Kg per second.

Professor: Kg per, you put kg per second and then try to get dimensionless number, mass flux, okay mass flux, okay we call also mass velocity sometimes but it is mass flux so kg meter square per second this is one of another sum question which I asked in Phd interviews and all that give two or three different forms of Reynolds number it is not always u rho dp by mu this is also another one, what is the other form? There is another one, dp that is (())(33:27) numerator what do you have? dp by mu du, du my mu, okay so where mu is (())(33:42) at least know that there are different forms, okay good.

So this is the correlation what we have where of course here you see wide edge is the one which has been used, right? These are empirical correlations very very old correlations but if you see the literature again you will have lots of correlations available for and of course jd definition do you remember kg by mu 2 by 3 very good excellent, okay jd equal to k by u or kg by u Smith number to the power of 2 by 3, okay good.

Can you also tell me in terms of another dimensionless numbers jd not j by u not (())(34:37) you also have actually that same thing k by u or kg by u smith number to the power of 2 by 3 can be also written in terms of Sherwood number, Reynolds number and Smith number do that exercise you will know that I do not want to write there Sherwood number, Reynolds number and Smith number again of course that is the original definition jd equal to in terms of dimensionless number all dimensionless numbers, okay the problem there is why we cannot have kg by u kg will have some other units you may have some other units but when you make as a

dimensionless number group of dimensionless number then you do not have to really worry, so that is why originally old people have done that, okay good so that is the one good.

So now all the parameters are over there are many correlations available, okay so but still these are the some I know again here you are very nice students no you never ask questions so I have to ask questions and I have to also answer, okay when I say this jd equal to jh mass transfer or heat transfer you never told me where is this mass transfer going sir from which place to which place, sir this transfer should be from one to the other no which one is transferring what we have here gas phase or if we have fluid phase and solid phase this is mainly for gas solid fluidization that you have to note down somewhere because for liquid solid applications are so less most of the information is given in the literature only for gas solid fluidization, okay.

So that is why this one if I have particles from particles to if hot particles are there you want to cool them then you send cold air so then some of the heat that is there in the particles is taken by the gas, gas will go, okay. So similarly if you want to heat the solids then you have to use drying you know like not drying, sorry heating hot air you take, right? And then send fluidize cold particles they will get heated out so those particles maybe used somewhere else in the process, okay so these are the things what we have and of course as I told you this fluidized beds can also be used as combustors whole combustors where they use you know power generation, power generation they use coal combustors fluidized bed used as the combustors where coal is fluidized and burnt if you go for beyond 650 degrees or 700 degree centigrade it catches fire if you have sufficient oxygen so then it burns and you have to extract that heat to extract that heat you put inside cooling coils with water so that water will become steam then steam will go through steam turbines steam turbines will be attached to generator and generator will give us AC DC whatever this lights and all that, okay.

So there the heat transfer is from solids to because coal particles are burning and there at high temperature and you have the coal liquid and water going inside so the heat transfer is from solids to pipes the tubes where you have water. So finally it has to cross tubes and then reach water and water will get steam water will become steam, okay so those are the things.

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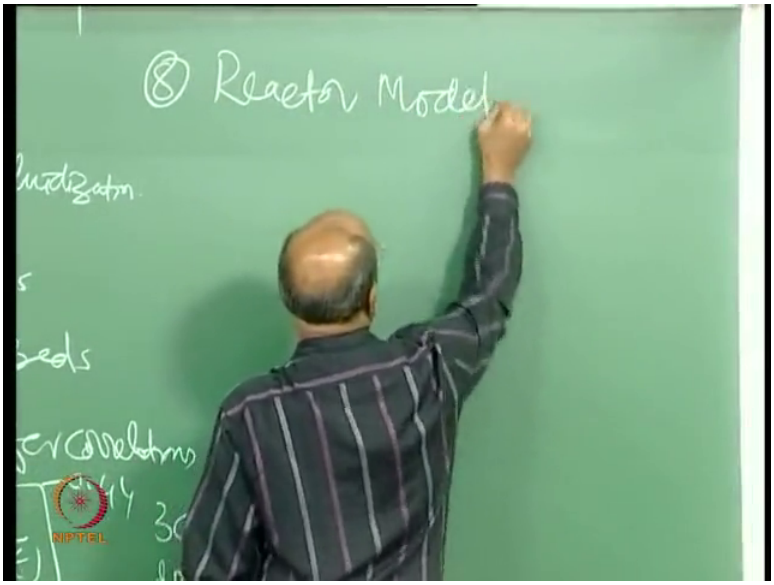

So now we have to go for reactor models that is 8 reactor models that means fluidized bed rector models, okay I think I will tell you the story I think you know quickly so that next class I think we will have because if I draw that figure it may take some time, okay so that is why you do not have that time no, the story here is that in the reactor models what they did was they have taken the conversion available in the literature for first order reactions, okay and they have even taken the same first order reaction one particular reaction and then collected data from someone you know publishing from India someone maybe from Germany, someone from Japan or UK, US all the data they have plotted same reaction same catalyst same temperature.

So when they plotted there in that graph the points are throughout the graph like our cricket field, okay throughout the graph you have the points that means there is no particular trend there is no particular trend for the behavior of conversion what they plotted was conversion versus for first order reaction what is the natural number that comes as a x axis for batch rector normally you use time (())(39:43) what is (())(39:44) for first order k tau where k is the reaction rate constant and tau is space time, okay.

So k tau versus x when they plotted they entire graph as different you know the all the particles and the same you know for the same reaction, same catalyst for the same conditions then they have also drawn theoretically what is plug flow line on that theoretically what is mixed flow line on that because we know only first two reactors ideal reactors what we have, right? So when they

theoretically they could draw those lines these are experimental points so they found that the conversion is even much less than mixed flow reactor now we know that in the extremes one is infinite mixing another one is 0 mixing 0 mixing for n greater than 0 reaction will give me always higher conversion for a given volume, okay and whereas mixed flow is the worst it will give the least conversion for a given volume.

So now I think fluidized bed is behaving much worse than that much worse than worst reactor so then they thought that what is really happening because you cannot no one expected that you know this much conversion low conversions you will get in a fluidized bed because, what is your assumption? Our assumption is that fluidized bed is equivalent to mixed flow contacting wise, so then what is natural tendency for anyone to try whenever you want to model you have done the experimental work what you how you start your data analysis is that whatever you know first the ideal reactors first that you check if you found out if you find what is the conversion for various (())(41:42) numbers you just try to put that in the form of either mixed flow reactor or plug flow reactor because those are ideal reactors if they are not properly able to predict this conversion experimental conversion, then what do you do? You will go for what are called one parameter models, what are one parameter models? Axial dispersion model, (())(42:07), what is that one more so many times I have drawn this last time in the I think here also once I think probably I would have written recycle model, recycle also recycle infinity what reactor mixed flow recycle 0 plug flow reactor.

So all the extremes are covered with axial dispersion and also n number of tanks you know when m equal to infinity you will have plug flow n equal to 1 you have mixed flow dispersion number equal to 0 plug flow dispersion number equal to infinity you have mixed flow. That means anywhere in between mixing also you can now try to imagine this is perfect mixing this is 0 mixing some intermediate mixing can be imagine with this 1 parameter model with r recycle with dispersion number and with tanks in series, okay they tried that when they tried that also did not worked then what is the next logical one compartments models, okay it is not just axial dispersion that is coming now let me imagine that I have axial dispersion plus channeling, dead space all these.

So even when they put this compartment models assuming more parameters like dead space for solids or dead space for gas, channeling for gas all that combinations these are all called RTD

models, okay residence time distributions models where you have studied in the I think even would have definitely studied you have done RTD no residence time distribution definitely in that Preeti would have told you Preeti only taught you, right? Definitely she would have told this she is also very much (())(43:47).

So all compartment models you try to use and those compartment models also did not work, that means all these models are not able to predict what is the conversion that is coming out and particularly when you go for 1 inch diameter then you go to 2 inch diameter, okay totally different conversions, right? Or otherwise you change the particle size totally different conversion same condition same but instead of using 10 micron particles you may use 101 100 micron particles then again changes, okay.

So even distributer plate you change the distributor plate perforated plate or instead of perforated plate you may have now porous plate you change that again conversion changes this has become a big mystery what you really do to understand what is going on in the fluidized bed, okay. So I think that we will discuss in the next class what is really going on in the fluidized bed, okay suspense like our serials in the correct time you know but you never bother anyway whether it is suspense or no suspense it is same for you, okay but you know what happens next time I mean in the next class only I will be excited but you will not be you will be sitting there I want some dead space here so that is there, okay again you know that is very interesting how they have done it I think really wonderful models they have developed and how much thinking has gone into that you will know when I explain that how they really developed fluidized bed models, okay good you have to run, okay thank you.