Chemical Reaction Engineering 2 (Heterogeneous Reactors)
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Lecture 40
Fluidized Bed Reactor Models-Continued

Okay, so we will start now in the last class I told the story about how the models develop so I will draw now that figure and then we will again discuss a little bit quickly then we will go for fluidized bed bubbling fluidized bed model.

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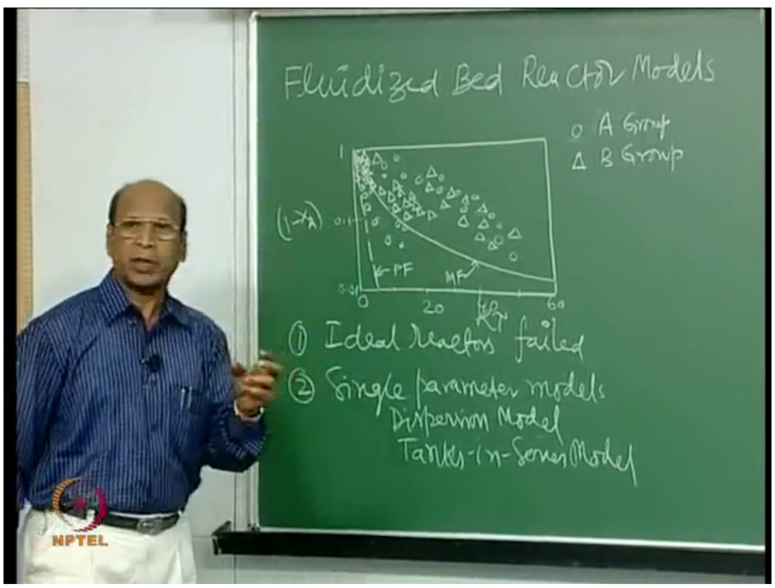

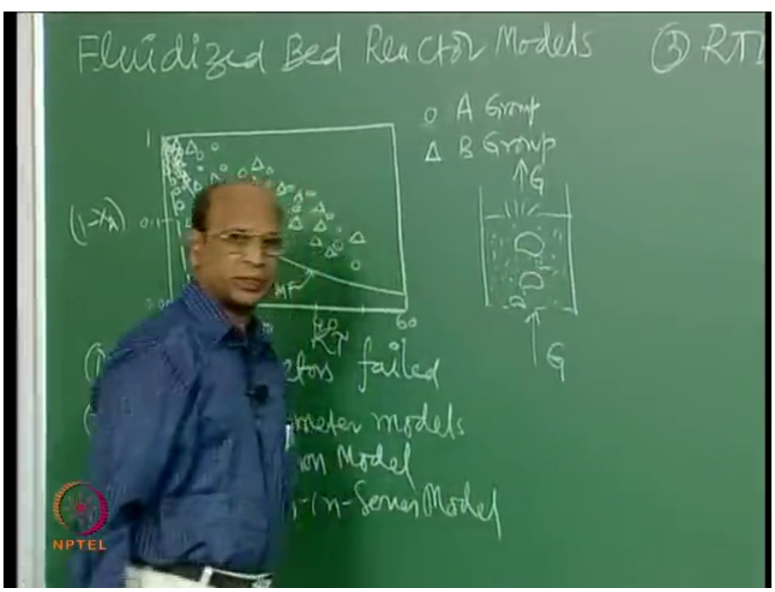

When we plot the conversion versus Damkohler number this is 1 minus xa k tau is the Damkohler number for first order reactions this will be 20, 40, 60 you have 0.01, 0.1 and 1 this is the straight line this is plug flow line this is mixed flow line and the points what we have, okay this is one category of particles and I also have another category triangles I am putting, okay.

So this is the kind of behavior and the circles are Geldart, okay A particles A group Geldart A group and the triangles are B group and some of them are A, B group also, okay A, B group means that border line between A and B. So under these conditions I think the researchers could not predict what is really happening in the fluidized bed because this is mixed flow, this is plug flow and many points are there away from mixed flow reactor.

So that means there is something serious things happening in the reactor if you look into the carefully into reactor what is really happening one should find out otherwise by simple models like mixed flow and plug flow they cannot predict the conversions, okay. So that means the first attempt like our ideal reactors failed that is 1 ideal reactors failed in the sense that you know they could not predict the conversion, right? So then logically the next one is single parameter models models like dispersion model and tanks in series model recycle model is not valid here because what is recycling there you know is not, right? So you should have an external recycle and again come back that is what is recycle model but here that is not that will not arise so it is only these two models have been predicted.

So even if you want to predict these two then this is the 0 mixing term, this is infinite mixing, this is 0 mixing plug flow. So all these models also should be somewhere in between, right? Because this is intermediate mixing these two models will give me something intermediate mixing like if dispersion number equal to 0 it is plug flow dispersion number equal to infinity it is mixed flow if I say take dispersion number equal to 0.01 for example you are towards mixed flow, sorry somewhere here not towards mixed flow but if you have dispersion number 0.00 3 zeros 1 or 4 zeros 1 then you are very close to plug flow otherwise it is not infinity means it is not really infinity even beyond dispersion number equal to 0.2, 0.4, 0.5 you are almost near mixed flow that is why he was telling no that one earlier.

So that means even these models if they are really valid all the data must be somewhere here but not away from this boundary, right? So then people tried this RTD models that is number 3 please remember even though we discussed these two under RTD models, right? Under RTD just to understand very easily under RTD even without RTD also I can derive this dispersion model and tanks and series model, right? You take 1 take, next tank, next tank what is going in the first tank and then that is coming to the second tank, second tank going to third tank everything is perfect mixing and when you go to dispersion model you take ideal plug flow over that you put that dispersion term, so that means that fixed law term effect diffusive if you take diffusivity multiplied by dou c by dou z term will come along with your convective term, okay. So I think this is what in packed beds also you have seen in packed beds we have so many terms if you are able to take only axial dispersion term and convective term and reaction term that equation can be solve I also gave the solution for first order reactions in the last class in the last semester.

So that is why it need not be categorized under RTD models you may be thinking no this fellow discussion last time these two under RTD models and now separately he has written these two as separate category and RTD models separate category. RTD models mainly the way we are discussing here is that it will take dead space into account, channeling into account, bypassing into account, channeling, bypassing we have you know slightly different meanings for that.

So all that taking into account RTD models have been tried but you know RTD means residence time distribution models, right? So when you look into the fluidized bed where the solid particles are catalysts and if you look into the bed a little bit more closely then we have the bubbles and we have the solids, right? If there are no bubbles, wonderful because I think you know every particle will be contacted by this gas then you can clearly try to find out whether you have what kind of mixing going on there whether it is single parameter model or ideal reactor this could have happened beautifully but without bubbles even fluidized bed cannot live because when you want to have a little bit of mixing for the solids then bubbles must form you cannot operate a exactly at minimum fluidized velocity then it will become most of the times as packed bed.

So when you go away from minimum fluidized velocity bubbles will form and particularly when you have large diameters in the industrial columns they go 20 times, 30 times, 40 times minimum fluidized velocity because they want to keep all the particles under fluidization conditions that is why that extra gas is definitely necessary what I am trying to say is that you can never avoid bubbles, right? So that is why in the RTD models when you take how the, okay I think I will draw here a simple fluidized bed I have drawn this many times but I think again I will draw this this is enough three bubbles these are the particles and one bubble maybe breaking here, okay.

So gas, gas this is the catalyst particles, right? So most of the gas is going in the form of bubbles whatever you have more than you know necessary for minimum fluidization velocity all the extra gas is going in the form of bubbles, right? So that gas will contact only the solids around this around the bubble, right? So around the bubble, around the bubble here that means the gas which is in the bubbles will see only small number of particles number wise.

So the residence time or the contacting time between these bubbles and the solids is very small, right? Because bubbles are moving up, whereas in the other we call emulsion phase the other phase and the gas is going but at a minimum fluidization velocity that contact is more but it is very low velocity and then there is sufficient contact. So that means in RTD if you remember the equation you know for first order reactions what is the equation for conversion using RTD model, first order, Abhinav (())(10:52), 1 minus xa equal to for first order reaction RTD using RTD that is all e4 minus k tau.

Student: (())(11:09).

Professor: Integral 0 to tau.

Student: 1 minus xa of single particles.

Professor: What is this tau? 1 minus (())(11:23) of single particle you are in non-catalytic reaction you are not in catalytic reaction I am asking in general for first order reactions what is RTD expression, see how many times I am right you know that is all only that semester remember afterwards no, okay I think Abhinav was telling something what is that integral and all that before integral what you have 1 minus xa let us take, okay.

Student: C by C not of batch reactor into uft dt.

Professor: Excellent, but not 0 to t, 0 to infinity, okay not tau, okay. So that is the equation what you have so that means this Ca by C not batch is for first order reaction, what is the equation for Ca by C not batch? e4 minus kt that k is the reaction constant so that constant will be different for the bubbles because the contact time is different and that constant will be different for the solids the other solids emulsion solids.

So that means you need two constants, one is a small constant which will take care of the bubble moment and then solid surrounding the bubble and the other one is emulsion where the k is slightly large so that is why how do you get this information from RTD models is becoming big problem, okay so then they stopped that idea the RTD models also cannot predict because this contact time the k value exactly we do not know because we need two k's, one k is for the solids which are surrounding the bubbles the other k is for the particles which are in the emulsion phase so emulsion phase is contacted by gas in a different way and actually this is a beautiful lesson for modeling also fluidized bed is a wonderful lesson for modeling, how do you look a little bit deeper and deeper and deeper and finally what do (())(13:20), okay.

So initially all of us start only with ideal reactors they field then afterwards next simple step is this step by step you go no, okay so next step is trying to find out whether single parameter models can able to you know can predict the conversions there also not then slightly more complicated RTD models, RTD models also we have problem because with k because we are not able to get two k's for this.

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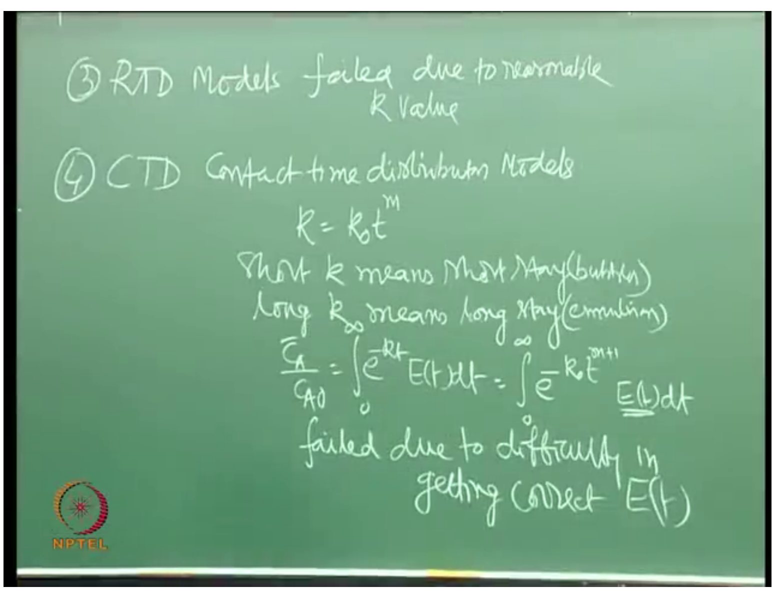

So that is why this same information same equation and same information but RTD models failed, okay that also I will write failed due to reasonable k value I hope you will understand, okay k value k means you know reaction rate constant value reasonable k value means whether it is a small constant or large constant depending on the contact, okay bubbles are the emulsion.

So then the same information someone started calling that as CTD models, heard of CTD models? RTD is residence time distribution, CTD is contact time distribution, okay so these are the new class of models which are used only for fluidized beds, okay actually that will be a good term even for us what is our contact time distribution, okay how many classes you come at least physical contact, okay mental contact I do not know unless we go to avatar and then put your pictale and my pictale together then only I will know mental contacting but otherwise physical contacting is only. So this is contact time distribution models, so here in the contact time distribution models they assume it is same thing as RTD only but I think you know only they I mean some researchers which I think you know at this present time you may not be interested in.

So what they have taken was that they have taken a k that is, okay k equal to k0 t to the power of m where m is the fitted parameter, okay depending on large contact or small contact, right? So this equation they have used with a meaning that short k means short stay in the bed that is bubbles long stay means short k means, okay short means short stay, large k means long stay. So you can now see this must be bubbles and around bubbles this must be emulsion, okay. So now you can see that you equation what you have just now told Ca bar by Ca not equal to 0 to infinity e power minus kt Et dt straight we have taken e power minus kt because it is first order we are talking about only first order, okay.

So which also can be written as 0 to infinity e power minus k0 t to the power of m plus 1 Et dt, okay this is straight forward, correct no? We are substituted for this k here k0 k0 into t to the power so then what they are trying to do is that you have now 1 minus xa and you try to fit this m so that you will get there are two now, okay m plus 1 so there are 2 now so the m you adjust such that your x is described by or you know predicted by this equation but they found another problem, what is the problem? Problem now is how do you get Et you know this one (())(18:00) distribution function, how do you normally get Et? You have done the experiment no RTD experiments? Concentration versus time and then get area under the curve, okay then divide each concentration by that that area you get Et and Et dt will give you the fraction of material which stayed between time t and t plus delta t so that is the definition we know but the problem in fluidized bed is there also what when you are doing fortunate you are doing with the liquid, right?

So then once it comes out you put in the outlet a probe or try to collect the sample and then analyze you will use probe or collected samples, no I think in our labs what is happening Prabhu? You remember.

Student: (())(18:58).

Professor: Collected only and tritated, okay but any others have used some probes and all that in (())(19:06) university we use probes, here you are now trying to change you have already changed, okay but you changed it but is it used for B. Tech.

Student: Sir next semester it will be used.

Professor: Next time okay. So that is the one I think that was a simple one which you have been doing also long time back and I do not know what has happened in between I think the tracer use is (())(19:30) I mean NaCL, okay good. So then what the important assumption there is once the liquid crosses the probe it cannot go back inside it is only once through floor.

So that means the tracer which ever what you have worth collecting once it crosses your that measuring port it cannot go again inside, if it goes then it is hell you do not know how to characterize and another peculate things are there for RTD always we talk about only one inlet one outlet the theory will be very complicated the moment you have entry not required only single entry but multiple outputs also you will have problem if you have multi inputs and multi output then it will have much more problem that is why that no one uses this multi things but anyway that is logical for chemical engineering because I think reactor will have only one inlet and one outlet or you should have two outlets, okay I mean in general all the time.

So that is the reason why that is a good point but here what is happening is when the bubbles you put the probe here somewhere or you may put probe here at the center or you may put some 4, 5 across the that cross section but what happens is when the bubbles go they are talking the solids with that go to the top and then come back because they just go here break and then solids will come not only that I will also give you that figure now this explanation that explanation also will vary. Normally the gas will try to find a shortcut through the bubbles because resistance is less no solids, right? There maybe few one or two solids, okay which they form but most of the time because the resistance is less gas will try to bypass through the bubbles but when the bubble is moving much faster what happens is it is not allowing the gas to bypass but on the other hand the gas will try to recirculate here like this when it is moving faster you know like circulations when you stand near in the mount road for a bus assuming that it is midnight you know 12 o clock because there is no traffic and it is going very fast, okay.

Otherwise here I think more than 5 kilometers an hour no one can move no right now if you go so there you cannot see this effect when the car or bus is moving very fast behind that you will definitely see some kind of low pressure you yourself will feel like this when it is going very fast like trains going and then you are standing on the platform. So that kind of thing also will happen here so actually that is a kind of bringing back that air which is very near to the surface, okay this has been proved by Davidson and all those people theoretically also that I will give you sometime later.

So this gas will go break and again try to come back, that means once it crosses the probe there it is not leaving the bed but again coming back you already found out what is the its residence time but again the same fellow is again coming back if you take a pocket of this gas so that is why you are not able to actually find out what is that you know what is the meaning of actual Et what is the definition of Et again fraction of materials staying between time t plus delta t but which delta t you take now because the fellow is going out and then again coming in going out coming in.

So that was the reason why people said that CTD models, RTD models both failed because this is RTD information, right? This is nothing but RTD information so then this also failed because of the E curve failed due to difficulty in getting correct Et (())(23:43) distribution function. See earlier it was the k problem in RTD models but here there also it is the same problem but only we are trying to tell here you know because we solved one problem but this problem we have forgotten in the beginning this problem there also it exists even in RTD here also it exists, right?

RTD models failed because not only that k value because of e value also, okay but anyway here we are specifically telling that it is due to incorrect Et which you are measuring and without measuring you cannot have any equation for this kind of complicated systems, okay then people get that what is now we have to do, right? So what is we can do now all simple operations failed, what is the next one? Next one people really thought that okay now let me go and see what is really happening, okay till there it is imagination, okay some bubbles are there bubbles are going, right?

So let us really focus on the phenomenon that is happening in the bed that is what I have been telling all the time in my classes that the phenomenon, physical phenomenon is much more important than the mathematics if you understand that then automatically mathematics will fall in inline, right? So here a little bit deeper they wanted look into, right? That little bit deeper what they thought was it is same thing bubbles are there and then emulsion particles are there now they thought that, okay now let me separate all the gas in as one compartment all the solids are in another compartment and some gas is going through this gas compartment some gas is going through this emulsion you know solid compartment both of them are coming and then meeting there but for the reaction to take place there must be some transfer of this reactant from the bubble to solid you see the physics is very simple if you are able to understand the gas is moving in the bubble but there is concentration gradient in the bubble, right? Naturally because reactant maximum in here only in the bubble so it moves to the emulsion because of the concentration gradient diffusion, right?

So then there is some transfer of gas from bubble to the emulsion. So imagination is now is let me take bubble as one compartment, okay.

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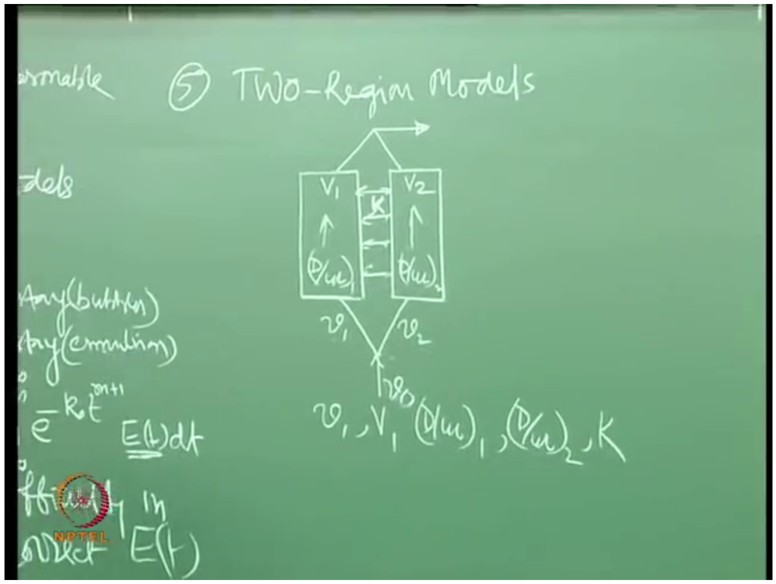

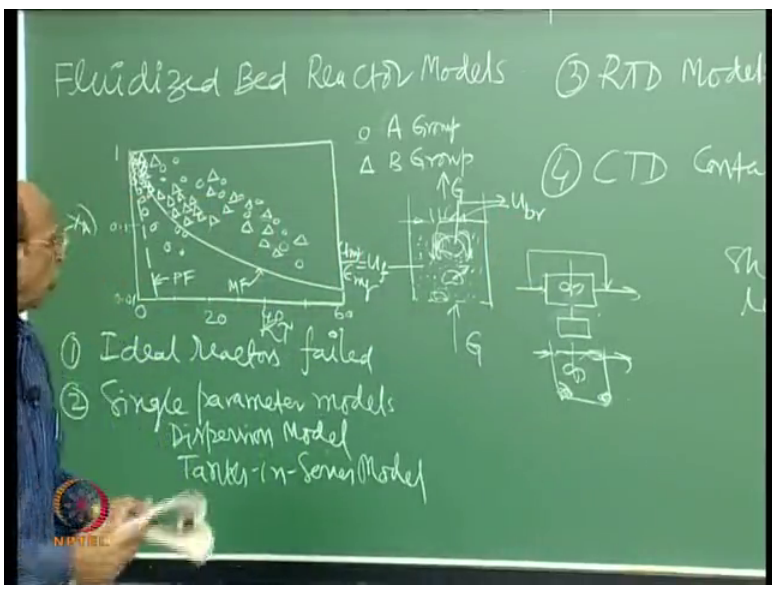

So that is that is called two phased two region model two regions or two phase also sometimes called but two regions that means bubble region and also solids is region. So imagination is we have this is bubble region, this is solid region so you have the amount of gas this is v in u not of v not volumetric flow rate if you take this will be v not. So then anyway it has to come because what you see is at the outlet at the outlet again you know you are not seeing these two separately it is only your imagination that is why model is always our imagination, right?

So model becomes reality when you have mathematical description for all these things inside the bed, right? So that is why again I will make you to understand you know when you go for your RTD models we have drawn for CSTR with dead space and bypass, what did you do? You have done this is the active zone, okay this is the dead zone this is entering here this is leaving here and then this is dead zone this is bypass zone but what is this actually, actually I have a CSTR which is entering which is coming this maybe dead zone here it maybe bypass.

So now you see our imagination is all these volume has put as dead space all the other active volume is put as active space and now whatever is going very quickly short circuiting very quickly going out bypassing so very quickly coming out that is shown like that because it is practically not spending time anytime inside the system so this is the imagination. So if I am able to write this and this and this what are the equations how much is entering how much is leaving and if I am able to solve what is happening inside this mixture if I am able to solve and then I have an equation that equation is finally matched with my actual conversion here this is the reactor. So if this is matching with this model then I think that, yeah I have now bypass, I have dead space and so much bypass so much dead space is there inside that is the why the conversion is so much that is what is the imagination.

So similarly here also the same imagination all the gas in one region all the solids are one region then we have the cross flow all these, okay. So now this v not will split into v1 and v2 we do not know how much, okay. So then these volumes also we do not know exactly so that is why we also just float as v1 and v2 capital V1 volume of gas region volume of solids region, okay good then this cross flow we will call as K that means how many volumes of gas that is going into the into this, okay so that cross flow also we will take. Then in this region there is a flow, right? So all the gas region there is a flow all the solids region there is a flow for gas, right?

So in this region we will say that we have dispersion number D by ul one here you have dispersion number du by ul two there are many models you can say now this is equal to number of tanks so I may take 10 tanks here 3 tanks there for gas, so D by l is almost equivalent to number of tanks, right? Each D by ul value can be also converted nicely in terms of number of tanks, okay. So that is why you have now how many parameters you have now? v1, v2 is now both not the parameters I can take v1 one of them that means v0 equal to v1 plus v2 then I will know the other parameter then capital V1 another parameter the total volume I know, right?

So v1 plus v2 is again total volume total fluidized bed, okay good that is the one then this D by ul one and D by ul two this we cannot have I cannot subtract one from the other K and we also have another one because I told you experimentally it was seen that even in the bubble phase there are some amount of solid particles inside the bubbles also few solid particles are there. So that is why what we call is that you know you have some amount of this is m1 small m1, okay small m1 is amount of solids or fraction of solids let us say so if I have totally 10 kgs in the bed so how many kgs maybe 200 grams or 500 grams in the bubble phase that is also another parameter the remaining will be automatically in emulsion phase, right? Because total amount I am taking in the beginning, how may parameters are there? 6 parameters, so this 6 parameter model this is also called sometimes 6 parameter model.

So this 6 parameter model beautifully fitted the data excellent particularly this models where used for you know this which company is that it is FCC reactors FCC reactors like mobile company all these companies I have used this model in the industry and found that it is a beautiful fit they will find out exactly what is the conversion that is coming because this FCC is nothing but a fluidized bed cracker, right? Fluid catalytic cracker even though it is fast fluidized bed inside you have only fluidization that is going on. So that is why they tried this model but it was so beautiful people where very happy but when they got the parameters what is v1, v2, v3 it is beautiful operation successful patient very very happily died, okay.

So what is the problem they are getting for this v1 as minus 10, okay is there any meaning for volumetric flow rate to be minus 10 or even this v1 they are getting as maybe minus 20, okay. So that means even the physical values which are not supposed to have any negative values they are able to that means they are able to fit the data that is why most of you also will do that when you are doing your project you go to the mathematics to such an extent you do not know what you are doing, okay then you do not know what is the physical meaning of those particular parameters you know here there is a meaning you think you know this v1 cannot be negative at all first of all even D by ul cannot be negative your cross flow cannot be negative but they are getting some 3, 4 parameters negative and another 3 parameters the remaining 3 parameters positive but beautifully the experimental data fitting.

So that is why they thought that, yes we cannot now understand fluidized bed so they closed the books went home, okay. So could not do anything so then the problem started that you know when all this things are going on in the universities we do not have any other work no except thinking no really that thinking is very important we are not also not thinking anything now even if you think it will be something nonsense no sense there, okay. So those people in Cambridge university there was a person called Davidson he started thinking no one is able to think what is really happening in fluidized bed let me just very wildly imagine that these bubbles are just like bubbles in the liquid where you have the clear boundary and all that, okay.

And now let me take some properties which are not exactly liquid properties but something away from liquid properties representing fluidized bed and then let me simulate he simulated when you simulated he got wonderful information, I think he also would have jumped up and down, okay when he first saw that results. So what is happening is when he simulated when the gas is moving in the form of bubbles depending on the velocity of the bubble that is bubble rise velocity he did it for single bubble assuming that everything is minimum fluidization velocity beautiful no disturbance at all, okay only one bubble is allowed to move how it is going, so then he simulated all these stream lines gas flow and also solid flow around this bubbles he found wonderful information he found that when gas is moving up depending on the velocity the first thing what he found was that the gas is bypassing through the bubbles that means the gas is taking bubbles as a short circuit like I mean we are famous for that for any work we will try to have short circuits no see if you want to get visa or not visa passport we know what is the short circuit you go to someone give 1000 rupees he will give you passport that is the short circuit, okay.

So the gas also knows because I thin entire nature maybe like that only getting doing short circuits only, so this gas also is trying to go through the bubbles, right? But when the velocity of bubble is increasing slowing from low value to high value, okay so then that velocity comparison is, here I have what is called uf that is the gas velocity in the emulsion phase uf and which is nothing but this uf is nothing but umf divided by epsilon mf because we our assumption is that the emulsion is at minimum fluidization velocity.

So minimum fluidization wide edge if I take that will be the true velocity in the through the emulsion that is what is uf and here we call this one as, okay this one as ubr velocity of a single bubble. So when ubr is smaller than uf when ubr is smaller than uf, what should happen or okay when ubr equal to 0 stationary bubble when it is stationary bubble very happily gas is bypassing through that, right?

So when it is started moving a little bit then you know when even then it was till it reaches uf equal to ubr it started bypassing but beyond that at ub equal to ur and just beyond that even a small value beyond that then the gas is not allowed to bypass it is going through bubbles but again coming back the circulations, okay and when he simulated for very very high values of ubr that is what you know bubbling fluidized bed 30 times, 40 times, 100 times umf is 1 meter per second and ubr is 100 1 meter I said no 1 meter per second this one is 100 meters per second ubr is 100 meters per second under those conditions most of the gas is only recirculating within the bubble, see the beauty recirculation is taking place only within in the bubbles that means it is not at all allowing any gas to contact solids then where is the conversion, okay.

That was the beautiful reason why you get these points, correct no? Because you have solids but there is no reaction because there is no gas which is going and contacting there and the amount of gas that is going through the solids at a minimum fluidization velocity it is almost very very very small that is why you do not get much conversion in the emulsion unless this gas goes to emulsion, that was beautiful.

So then that is one finding where they found that when the gas velocity is varying in typical industrial reactors it will be 40, 50, 100 times umf you know the ubr. So then they found that under these conditions definitely we will have less conversion then this and that is one side about the bubble behavior then some other person he also told that you know it is not of course he assumed you know very very beautiful circular bubble but you know as it is most of the time we will try to draw only like this bubbles, right? All the time we are trying to draw like this, okay this is the bubble and here we have what is called wake it is like atom bomb also atom bomb also shape when it is exploding behind you have the low vacuum low pressure region so that also sucks all the gas from surrounding that will go there, like that it also does and along with that when it is sucking it also sucks the solids, okay it also sucks the solids.

So that means that in the wake there are some solids, right? And when the bubble is moving continuously during his simulation he found that for every bubble there is a definite thickness of cloud that means the cloud is moving along with the bubble cloud will have certain thickness that means, okay actually this is the cloud, right? Cloud means more particles but this entire thing is moving whereas other place the emulsion is, okay staying there, right? So finding out the cloud thickness and also finding it has got the wakes and wakes also have some solid material then gave some more beautiful imagination for us the two phase region what we have here, yes we have bubbles inside bubbles we have some small fraction of solids excellent, now all these remaining solids are not in the emulsion but some of them are in the cloud and also wake that means definitely you will get more conversion, right?

You will have more solids near the bubbles there are so many bubbles like that so when the bubble is carrying with a cloud and then the wake then you will have slightly definitely more conversion, why we are not able to tell anything in this thing is we do not know depending on the velocities where we whether we are having no cloud at all cloud thickness will reduce to all most 0 if you have ubr is very very high bubble rise velocity very very high, okay. So that is why sometime here and some bubbles maybe slower and you know this group B and group A particles that we have discussed some group A particles behave differently, group B particles behave differently you know you will get exploding bubbles, fast bubbles, very slow bubbles all these things will come all that we had never we never had any idea earlier.

So that is why all the data that means some people may be operating in very fast bubble region, right? Some people may be operating with Geldart B group and some people may be operating with C group all that data when you put what else you get only this one cricket field only you get, correct no throughout spread particularly after 20 overs or 10 overs now, now 20, 20 no otherwise 50 overs I think one day cricket you will have after 10 overs I think they will spread this is after ten overs spreading so everywhere you will see the people running here and there.

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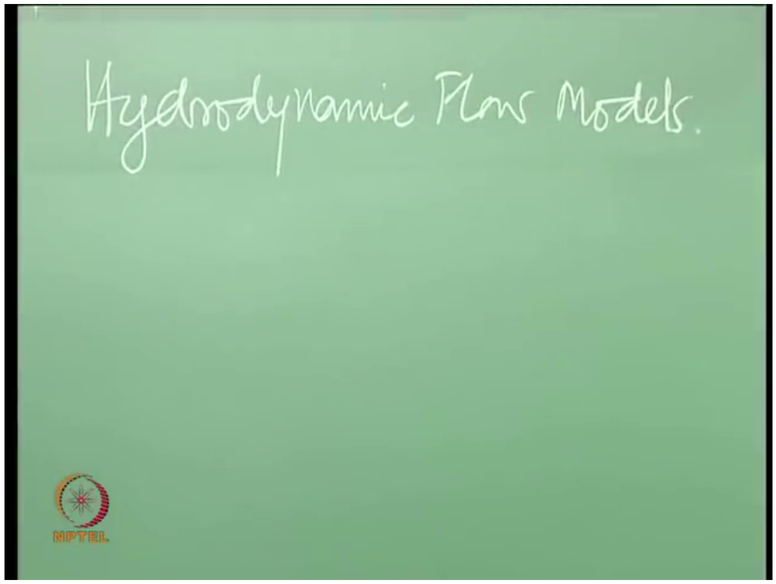

So that is the reason why we are not able to predict that beautifully, good? So what they try to do later was let us look into the hydrodynamics and these are called the hydrodynamic models hydrodynamic flow models I thought I will start that, okay that means what is the meaning Prabhu hydrodynamics means what, lives up to expectation all the time, okay so that is English meaning you are telling what you understand.

Student: Sir how the fluid (())(43:13).

Professor: Good, right? Common sense only hydro the how the phases are moving within the system if you have any equipment and if you are able to find out how the phases are moving whether of course simplest thing is whether they are moving in plug flow or mixed flow and all that, okay and hydrodynamics means not only just flow what we see under hydrodynamics is the actual flows, right? And also the hold ups, what do you mean by holdup? Prabhu heard of it? Would have not heard, Lalita? What is hold up?

Student: Sir space occupied by the bed.

Professor: Space occupied by bed by what?

Student: (())(44:01).

Professor: Why only liquid why you are always liking liquid, hydrophilic hydrophobic, solid why solid? (())(44:15) for all the phases what is the fraction of a particular phases occupying the system the reactor or any equipment, okay. So all those parameters in fact not only that even the flow regimes under what conditions you will operate like for example fluidized bed can never be operated beyond terminal velocity and also before packed bed you know that is minimum fluidization velocity, so that is the flow regime for that.

So under hydrodynamics you will get flow regimes and velocities and you know umf for example ut all that these are all and then you will also get the holdups and also the pressure drops, what is the pressure drop? Okay, when you are sending so much gas or liquid or both what will be the pressure drops all this will come under pressure drop and this hydrodynamic flow models will give me information about all that but in this particular case they mainly concentrated on the bubble flow, right? Okay, I think I have to close here you have to run, okay.

So then I think this again I have to bring I have brought this things anyway but if I give this you may not bring tomorrow, right? So I think I will bring tomorrow and then give it to you. So the entire fluidized bed reactor design is in one page here, okay this I will tell you in the next class, okay thank you.