Chemical Reaction Engineering 2 (Heterogeneous Reactors)
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Module no 01
Lecture no 36
Fluidized Bed Reactor Design Part I

(())(0:10) fluidized bed reactors. Take the definition. Fluidizaation is the technique in which fine solids are transformed into a fluid like state through contact by a fluid. Bracket, you can put either gas or liquid. So the phenomena, we will discuss through the diagrams.

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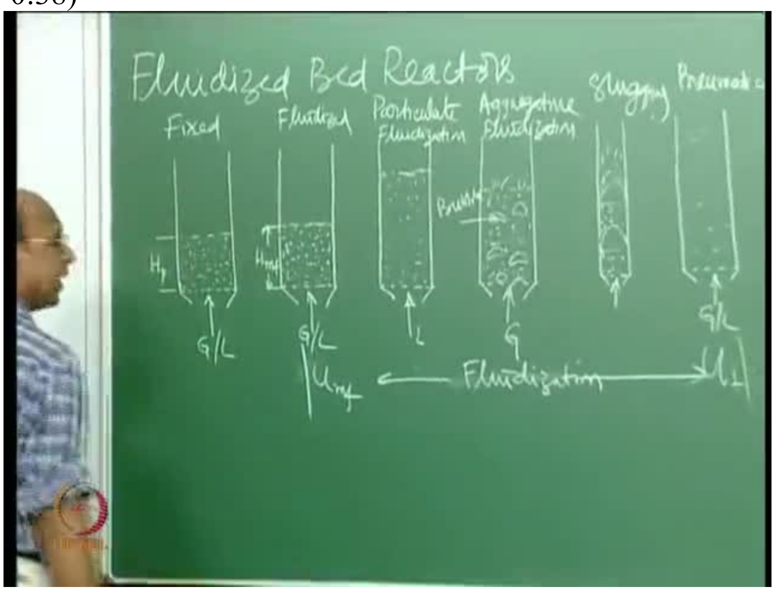


I will draw these Jack diagrams. Picture will be easy for you to understand. Gas or liquid. Then we have, this one we call it as HP packed bed height. Okay. You able to see? Okay. So this is HP, height of the packed bed and ya, at very low gas or liquid velocities, there is not sufficient energy in this phase, fluid phase where it can move the particles but on the other hand what it does is, it only tries to find out where is, wherever there is small interstecies.Ya, through that it will move and comes out. Okay. Nothing happens at that time. The bed remains as a bed and Jack of course depending on very low flow rates, one can also measure the pressure drops, that I will draw the graph later.

So at a particular point, this situation Jack this is fixed bed we can write. Fixed bed. Then same thing gas or liquid. When you have a this is the height, still you have the particles very close, just see here, just a little bit more height. This is HMF, height at minimum fluidization velocity. Okay, good. So this is okay ya, so as I told you, when you slowly increase either gas or liquid, nothing will happen at very lowvelocities, only the gas or liquid try to percolate through the pores and then when you go on increase very Jack very small increments, then the gas or liquid at one point of time, the drag force exerted by this fluid, either gas or liquid, will exactly balances the weight of the solids in the bed okay.

So drag, drag is a force, weight in thegravitational field is also a force. So when the both the forces are same, drag force balanced by the weight or weight balanced by the drag force, then you will have the particle moment later Jack Jack little bit,ya the particles move a little but still the bed is not expanding that much. The particles try to readjust themselves okay for a more easy, Jack in a relaxed manner. So then, it will try to move in that restricted place, a little bit you know like small vibrations, small movement of the solids.

So at a minimum fluidization velocity if you look at the bed, it is not exactly like Jack you know vigourously solids moving but definitely solids will readjust themselves but capable of moving even at that time but not to a great distances and the distance between each particle is also not that much. So that is the reason why you have, anyway this side, this side and this side, it cannot expand. It has to only expand in this direction. That is why, I put, this is packed bed,it is slightly less because of the readjustments.

Okay, just because of the readjustment a little bit more but all the time, we will take HP also equal to HMF at a minimum fluidization conditions okay. But here at this point of time if Iwant to test the characteristics of this bed, if I put a let us say an iron ball right,ya, at this Jack here after the weight is balanced by the drag force, if I put that steel ball then that will simply sink. Just for comparison, if you do the same thing here when the bed has not yet fluidized,that means it is still in packed condition, what will happen? It will simply stay at the top.

So that means the density difference has come and ya, not only that, in fact if you have the cork also, cork will just simply float exactly like it is in water. Not only that, you have, if you have a small hole here, then it flows like a fluid. So just at the time of minimum fluidization velocity, at the point of minimum fluidization velocity, try to have a hole here, sidewall, okay. Then it comes as a jet. It is exactly like, if you have water in a tank and then put a hole, then it comes as a jet.

And also, one more property, if I slightly tilted this, okay instead of putting vertically, if we slightly tilt it like this, so when you tilt with this, but still, your surface will be horizontal.

Whereas, that is not possible here in the packed bed condition. So that means what is that we have done already? We have spoiled it because I think it was very happy, stable, without moving. So then we made it as a fluid where it can easily move. Right? All the fluid properties, it acquired like density difference, something can sink and also something can float and when you change thedirection through any inclined position was still all fluids maintain horizontal surface, right? So same thing is there.

And if you put a small hole, then it will like it will come like a fluid, all the properties what we normally see for fluids are seen for the solids in the presence of another fluid. That is the reason why it is called fluidization okay. That means you are imparting fluid properties to the otherwise immobile solid particles okay. Tremendous advantages okay because of the sub the 1st fluidized bed was in Germany, (())(7:50), I do not know whether you have studied in chemical technology. Winkler Winkler, W I N K L E R, Winkler gas fire, that is one of the 1st applications of a fluidized bed.

The later applications came to your FCC, fluid (())(8:07). So from then onwards, unlimited uses of fluidized beds. But in the beginning is 1st the gas fire. I think that was 1921 1922, that time, I am not very sure exact. So the advantage of this fluidized bed is that now you can, if you want, you can easily transport the solids from one place to the other place and particularly, you know in chemical engineering, all the operations are multiphase and you should have better contact between these 2 phases. Now we have either solid or liquid or liquid-liquid, you know, two immersible liquids or gases-liquid, Jack you know you will have allcombinations of the phases in chemical engineering.

So our idea is how to have the best contact between these 2 phases. So that kind of excellent contact will come here if I have solid-phase and then either gas or liquid I am trying to use. Okay? Excellent contact. And theoretically speaking, if I look at the particles, in I in an ideal fluidized bed, each particle is simply suspended by the fluid. So that is why, like our fluid mechanics we always draw one beautiful circle as a particle, around that you will show very nice streamlines. Okay? So what is happening when I show the streamlines?

Whether it is heat transfer process, whether it is a mass transfer process, then beautifully,each particle is uniformly either taking Jack if it is a mass transfer, absorbing or if it is coming out from the leaching and all that, so beautifully comes out. Heat transfer also same thing. Heat is uniformly transported. And on the other hand, if you look at the packed bed of the same height, what happens?Packed bed is resting one above the other all the particles. Right? So that means always some contact area will go for the solids. That contact area is not available in the packed bed conditions okay?

Talking about the same particle size, right? And normally, we use the particles, very very small particles in a fluidized bed to take care of our surface area per unit volume advantage. That means when you are going for smaller and smaller size, you know surface area per unit volume equation is 6 by DP, diameter of the particle, surface area per unit volume. So when you are decreasing particle size, surface area will be tremendously increasing, okay? If you are going for 1 MM, then 0.1 MM, 0.01 MM, 0.01 MM is 100 microns right? Oh ya, 10microns.

Then go to one micron, then you will have tremendous surface area and we can use that kind of surface area also for the Jack for the solids so that we will get very high transport processes. Right? Good. So that is the one. Now till here we are almost in ideal conditions. This is fluidized but beyond that, if you increase, what will happen? Beyond that if I increase, let us 1^{st} say only I have liquid. Okay, the behaviour from here, the behaviourif I use liquid as the fluidizing medium or if I use gas as the fluidizing medium, the behaviour changes. That is why 1^{st} we are taking liquid.

If we take liquid and then go for example, Jack this point also I can say that I have EMF, the velocity corresponding to this minimum fluidization condition is EMF. So beyond this if I go and let us say I am using 2.5 times or 3 times EMF right, so then if I use that, then beautifully, this expands in the presence of liquid. Why I am telling beautifully is, the inter-particle distance between the okay.Ya, the inter-article distance in the bed is almost uniform when you have liquid and that is why we call this one as smooth fluidization or particulate fluidization.

Particulate fluidization. Right? It is very nice. To see one can easily predict also the length of the bed, how it is expanding and I can just imagine here, beyond minimum fluidization velocity, the drag force of course is just balancing. So beyond that, you are increasing velocity. So drag force will be definitely more. So when it is more what is happening? How it is transformed?The drag force is transformed in the form of expanding the bed okay. But if you take the pressure drop drop, I will come to the pressure drop later, atthis point onwards, you have the same pressure drop for the solids.

Weight is not changing, right? I mean weight is same, weight is not changing. So keeping the weight same and when you increase the drag force, okay by changing the liquid, Jack by changing the liquid velocity or gas velocity, so the pressure drop is not going to change. Only thing is, in the bed you will have different conditions coming. Right? So like that it in the particulate fluidization condition, the pressure drop will not change but the bed can be very smoothly varying. Now the same conservation if I show for gas, it is not so smooth. So you will have here a bed, these are the bubbles. So you will have small bubbles forming here, growing like this, you know we take spherical bubbles, they are not like that.

Ya, this is the bubble. Gas bubbles will form and these bubbles are not seen in the liquid, solid fluidization. Okay? And the reason for the bubbles, I think we do not know at exactly but we know how they form because whenever I have a perforated plate, and with a small perforation and the solids are just resting on that, the gas has to move through that. So when it is moving, it will try to push the solid slightly away from the, from its way. So when it is pushing, so then there will be a wall like thing just about the that area. So that wall, this wall is nothing but solids only.

Solids only, just forming like this. So when it is just pushing it up, then they form that wall and the wall cannot break because just after that also, you have lot of solids. See, it is not breaking. So the entire bed almost in the small void there, it will try to push it up. And beyond here, at the top because there are no further solids there, then it has to break. And when it is breaking, then all the solids, till then it is just moving like this okay.Ya, just moving and then when the bubble breaks there, all the solids now cannot be supported by anything.

There is nothing to be supported. So they simply fall. When they are falling, they come to the bed. That is how you have good mixing in gas-solid fluidizer beds because of this bubble formation.And the bubbles are not there at the minimum fluidization velocity. That is why, at this point, whatever gas you have all the gas you use only to support the solids but here, when I have that you know 2.5 times or 3 times as I told you, the gas velocity, then that extra gas beyond what you use it for minimum fluidization velocity, extra gas beyond minimum fluidization velocity, that goes in the form of gas.

So that is why, many researchers have accepted that if I am sending U as the velocity and the velocity at minimum fluidization is UMF, so U minus UMF multiplied by cross-sectional area is the volume of gas that is in the bubbles. Correct no? U is the actual gas, let us say 10 litres okay. I mean velocity wise and now directly I can tell volumetric flow rate wise. And I need only 2 litres per hour or 2 litres per minute as the gas required for minimum fluidization velocity. So that extra 8 litres per minute is the gas that is going in the form of bubbles okay?

It is not exact measurement but I think this is very difficult contacting pattern for gas solid right? So that is why, it is not exact. Many people say that no nono, some other gas is going this way, that way, still fighting is going on but still majority of the gas the form of bubbles and the our imagination that there is no other way togo for the bubbles. Okay? I mean for the gas to go. So that is either it has to support the solids and go, otherwise it has to go as bubbles. Right? So that is the reason why you have here a kind of aggregative fluidization where it is not uniform.

Because why it is not uniform? Where the bubbles form, where the bubbles break, you cannot say it. In fact when you have this situation, you can do that experiment in your house also, take a water, put in some vessel, and then bubble it, just look from the top. Can you find out at what point bubble gum and then what point bubble breaks? You cannot. Same thing happening. So that is why some people say that it is also boiling solids. We do not see the bubble, we see the only the you know the empty space in the solid.

The empty space in solid is seen as the bubble, okay and people have photograph. I will also show you that photograph later okay. Some photographs have been taken and I think people thought that you know there are definitely bubbles. Okay, it is what, that is why many people still have lots of doubt.Ya, gas liquid, one can see. That is what no normal things, those are all low hanging fruits what we say. Okay, when you are able to imagine, when you are able to see very clearly okay, so then the description of that,understanding of that is much easier.

But something beyond our mind, if you are not able to see and then you have to imagine, okay.so that is why a measurement is required where you because you are not able to see that. Of course you can see that when you have a gross column but I think you know that voids and all that definitely can be seen. But to be still perfect and measure it and then find out what kind of bubbles we are getting, why they are coming, under what conditions, like for example, that they also depends on your velocity, that also depends on particle size, okay, particle density, all kinds of things will come, how the bubbles forming right? Good.

So that is why this is not no more smooth fluidization, this is called aggregative fluidization. Aggregative. So essentially what we have to remember here is that till minimum fluidization velocity, whether you have gas or liquid does not matter because both are going to behave sameway and then beyond that when you are using liquid fluidization, liquid solid where liquid solid applications also after biochemical engineering, there are many. For example, wastewater is one of the applications, liquid solid systems inusing fluidized beds. Okay.

Of course leaching, you know one method of extracting the ores is leaching. So if you want to take fromcopper from copper ore, you take copper ore and then fluidize with sulphuric acid for example, you will get copper sulphate and again copper sulphate you take it to electrochemical cells and then sulphursofor separately, cu separately, you can deposit, right?ya, cu. So then you get one of the purest forms. That is how zinc and copper and all kinds of things they do but that is the leaching operation where fluidized bed can be used.

Why fluidised bed is very good? There is that you can have small particles, number 1. In packed but, you cannot have that kind of particles and number 2, surface area is more. So then, the rate of leaching will be very high and on the other hand, every particle will be uniformly fluidised particularly when you have liquid system. Then on the whole, each and every particle is uniformly leached out. You know that can be used for leaching each and every particle. So like that, there are many examples which we can give andliquid solid and there is not many exacting things in liquid solid because everything we know what is going to happen there, correct no?

Because there are no bubbles. Whereas here, many many exacting things. Because 1st of all I do not know how to measure the bubble perfectly and the people who have measured the bubbles are only two-dimensional bubbles what they measured. Three-dimensional bubbles they could not measure. They only estimate by some technique okay. By sending light for example or by sending some not laser, not NMR also, this one, radioactivity, some signals they send from this to that side.

Nowadays I think people trying to use what is called TEM, transmission electro,ya, so that kind of sophisticated methods are now coming to measure okay. And that to measure, it is a 3, when you have a three-dimensional column, you will have some bubbles here, backside also you have some bubbles, this side also you have some bubbles, this side also you have some bubbles. Which side you measure? Whatever side you focus, that is not uniformly reproduced all the time. Okay? So that is why they take from various sides and then average the bubble size. Bubble size is one of the most difficult parameters which we have to estimate properly and that itself is distorting point for all our calculations.

So that is the reason why it is very difficult woman gas solid fluidization. Okay? Good. And because it is very difficult, there are challenging things. If it is very simple, I think you know there is no problem at all because there is, the phenomena is so complicated, there is a reason why I told you that you have many exacting things in gas solid fluidised bed. Okay. Then next one if you have let us say I have done the same thing here beyond this minimum fluidisation velocity in a small, this kind of column. Okay?

Very narrow column if you take, narrow cross section more then what you see is this bubbles occupy the entire cross-section and then somewhere here, they break because of instability okay.ya. So these are the please remember, you have when it is going up, near the walls, you will not have that much drag, because the velocity will take 0 you know, near the wall. So the solids will be slipping near the wall. Somewhere it will go up and then because of some instability, it will go to almost to the top okay, if there is no disturbance.

But somewhere if we have disturbance means many many chaotic conditions. That is why you know I do know whether you thought of there is what is called chaotic theory. For each and everything, there is chaos in this world, in this universe, not only world. So that is why, if it may be with us very very small fluctuation or very very large fluctuation. Large fluctuation means we feel, small fluctuation means we do not even notice them. But everything can be analysed in terms of only this kind of fluctuations right? So chaotic theory. That means system is not stable, it is chaotic.

But people see that there is an order in thein the chaotic environment. There is still an order. You know if you go to Mount Road and if you stand there for some time, first-time it looks very chaotic. I do not know why people are going this side, car is going this side,I think bullock carts maybe going that side and all that. You observe that lets say 1 week, you will find a pattern. How? How do you find a pattern? The same 18 B bus will come all the time. Okay? Really, 23C will go there. So if you are able to look efficiently there, you see some pattern coming.

Maybe there is some bench cup, the same bench cup that fellow's office maybe somewhere there nearer. Okay. So always you know when you patiently observe, you will find a pattern. So that is what. You know, order out of chaos I do not know whether there is a wonderful book which I could not complete in last 20 years, I think I told you. Am hmm, James Glake is chaos. That is a beautiful to read. The other book is thatElia Prigogine. Heard of him? Prigogine, P R I G O G I N E. He is a Noble laureate and chemistry. He wrote this book, order out of chaos okay. Actually he wrote that in French and someone translated into English. Horrible translation because that is why I think nothing moves there.

There is no flow in that book. Oh my God. How many years I have that book? I am not able to still complete but there are wonderful information about thermodynamics, about biological systems, all order and how do you see sorry, all chaos, how do you see order out of that? James Glake is beautiful book. Once you start, like novel you can read okay but the other book is very very difficult where tremendous amount of information is there. So that is why here also because of those fluctuations, somewhere because of instability, the slugs will break and then all the particles will come down.

When they are coming down, again you know some of the bubbles also maybe broken and that is why some of the fluidisation researchers thought that let me take becauseyou see how human mind works because to break the problem into simpler problem, so is it difficult?jack is it easy to have thousand bubbles and then try to characterise thousand bubbles or one bubble and then try to characterise one bubble?so that is why what they did was let me take small diameter column okay, let me create slugs and let me understand how the slug because there is only slug (()) (27:25).

Correct no? So that is why. But most of the time what happens is, when you have this kind of thing, it is too much aggregative fluidisation and this is a big void. Most of the time in the bed if you see there will be only 20 percent at 10 percent solids. The rest is onlyjack gas bubble. One bubble that means one bubble here, another bubble there, another bubble there, may be 5-6 bubbles will occupy but that bubble is very slug, you know very lengthy bubble and occupying the entire cross-section. So it is not allowing solids to have many solids.

So that is why they try to break it. Particularly Australians, there are few who are trying to do that. And this is called slugging bed.Ya, there are many things here. You know, this aggregative Jack as I told you and you have more and more knowledge, you also try to look more read more narrowly between velocities okay. Between aggregation and then if I go slightly more than that what we care what we call as turbulent bed. Okay, the difference between aggregative and turbulent is the bubbles are slowly trying to dissolve. Okay dissolve what?

Dissolve to go for pneumatic, pneumatic conveying, that means when around terminal velocity, the bubbles may disappear, solids may try to go out. Okay. So another concept is I think definitely you would have heard of circulating fluidised beds. No? Not heard? I told thousand times I say in the last semester also.Anand Kumar looks as if it is a new word for him, Latin or Greek. You have not heard? Do not remember, okay ha haAnell?

Student1.(())(29:08)

Professor1.Ya. So you allow the entertainment and then bring the solids again continuously and circulate them. What is the advantage? Because now I do not bubbles, I can clearly find out what is going, what is happening at least in the bed. But what is the Jack drawback? Drawback maybe that the amount of solids in the bed maybe small. So normally it happens around 15 percent solids, 20 percent solids. Whereas here, I have 50 percent solids and also 60 percent solids okay. 60 percent is more, around 50 percent. Because normally packed bed will have how much about percentage (())(29:48)? Packed beds will have what percentage of solids, normal packing,spherical particles?

Student1. 40 percent.

Professor1.Kavya?

Student1. 85 percent.

Professor1. How can you have 80 percent (())(30:02) in packed bed?) Packed bed has also porosity.

Student1.(())(30:07)

Professor1. Which one is 60 you are talking?voidageor solids? I have asked you solids.

Student1.Voidage.

Professor1.Voidage is 60 percent.Abhinav?Anurag?

Student1. Sir, solid (())(30:23).

Professor1. Call it?

Student1. Solid solid.

Professor1. Oh, Solid. What did you say before that?

Student1. 40 to 50 percent.

Professor1. 40 to 50 percent. Why 40 to 50 percent? You see packed beds, under what conditions it will be 40, under what conditions it will be 50?Renita?(())(30:40) will give nice answer. (())(30:42) what?

Student1.(())(30:45)

Professor1. Ahh, 5 percent increase. 65 percent solids. Why 65 percent?

Student1. Sir because(())(30:53)

Professor1. Told you know. Beautiful. That is the reason I ask you. At the end, you are the final answer. Okay.ya, always averaging things. Okay I think like Buddha's thing, take the middle path. If you take extreme path, you have to unnecessarily work hard. Take the middle path, happy, no problem. No one can push with that corner, no one can push you this corner. Walk. Okay, Buddha's fundamental thing it seems take the middle path always in your life. Do not be an extremist. That is the idea. Okay.ya, you tell me why 40 and why 50? 65 is not correct. 45 or?

See, material science, they derive and then show it also as a, if you have ideal spherical particles, how much fraction you get.Haan?

Student1. Shape.

Professor1. Size it will not depend if you have spherical particle.

Student1. Shape.

Professor1. Shape is spherical I am telling no.ya, spherical spherical. Exactly, there is around, you know 0.32 or something you get. Structure if you take, that isvoidage I am talking.Voidage is around 32 and you have 60 percent solids okay. In packed bed, because they are not 100 percent spherical most of the time, we can take around 40 percent voidage and 60 percent solids. If I take 100 litres, I will have 60 litres of solid and 40 litres ofvoidage. Okay. So that is what.Ya. So Jack that is why now the operations depend on what regime you operate. Like for example, next one is, we have pneumatic conveying.

Here again it is same. Either gas or liquid. Again, you come back to the original to the same. Okay, so when you go to thepneumatic conveying, you have only a few solids, that is pneumatic regime. So that means solids are, we say pneumatic regime but I think you know hydraulic hydraulic regime also we will say where the transportation of solids are occurring because of water okay, liquid. So this is pneumatic again but does not matter whether you have liquid or solid, you will have this. So what are the basic conditions here?

Basic conditions for fluidisation 1st of all, it should be vertical. You should take a vertical column okay and then put a distributor plateand then the distributor design also is one of the very very important crucial factors and then slowly increase the velocity such that the entire bed is supported by the drag force of the fluid and beyond that if you increase, then if you have a liquid system, it nicely expands. Nicely expands means, anywhere fluidisation and the inter- particle distance is uniform throughout the bed, et cetera.

And if you take the same condition, that means 2.5 emf or 3 emf and then conduct the same thing with gas, right, so the gas will have aggregative fluidisation where the gas goes in the form of bubbles. So that creates aggregations and that also creates good mixing. In fact, you will not have that kind of good mixing here. You will have here very good mixing for solids. That is why, (())(34:31) says that you know that phthalic anhydride is the plant where chemical engineering is designed.

It seems any Chief engineer designingphthalic anhydrideplant okay if you ask them to sit on the plant just before start-up, it seems he says that very few Chief engineers would have left in the world because definitely something will happen and explode, Chief engineerwill be converted to some other mass okay.ya, baby apparatus, anything can happen. So that is the reason. So for that to control that kind of heat you know that is generated, this condition is the best condition. Okay. This is what also what they do you know, circulating fluidised bed. Before circulating fluidised bed, there was fluidised bed combusters.

I do not know whether you have heard of them or not. These are not you know myth, they are reality where they are working in thermal power plants. What they do is, they take very big sized fluidised beds,fluidized coal continuouslyfeed the coal.Ya, I have told here that only but continuously also, we can do that experiment. Nothing will change okay if you are maintaining the same bed and all that. So coal particles will be continuously fed and burning, combustion is taking place. Now you put inside, heat exchangers, cooling (())(36:00). They are not actually cooling.

Water, water pipes, water tubes. So then water will get evaporated to steam, that steam will come out, you know, after getting (())(36:11) , then that is attached to your steam turbine. The turbine is attached to a generator. From there, you will get AC and all that. Okay Ya really. So that is one of fluidised beds you know when compared to other beds, this is very easy because particularly what happened was when people started thinking about environmental pollution, if we have SO_2, S as the one of the constituents in the coal, that will become SO_2.

SO2 will come from the chimneys. That is dangerous. Okay. That is even spoiling TajMahal okay,sulphur, falling on TajMahal. Because how sulphur is falling on TajMahal?Ya, where is acid there?

Student1. Madura refineries.

Professor1. Madura refineries.Madura refineries. Refineries also will you know desulphurisation there is one step. So the sulphur has to be removed. If you are not able to contain that only inside the reactors or inside the process equipment when it comes out, then this acid rain will fall and unfortunately,Shahjahan used calcium carbonate which is a reactive material, it is not inert. If he had used granite, nothing will happen whatever you do okay.Ya, granite also will slowly dissolve, you know, some other things.

Ya, so this CA calcium carbonate reacts with H2 SO 4 forming calcium sulphate. So after some time, you will have calcium sulphateTajMahal okay. So even know if you go on layer by layer if you see, probably already 1st one or two mm or 3 mm, 4 mm would have gone. Okay? So that is the problem. So at that time, what they thought was that the sulphur can be contained and also NOX is a problem, all these things are problems now in pollution. So with temperature control, you can control NOX, you can control SO2 and all that. And another beautiful advantage in fluidised bed that to remove sulphur dioxide is, you do not allow that one to go to chimney.

What you do is, when you are sending when you are sending coal continuously, you also send along with coal, calcium carbonate. Calcium carbonate,TajMahal only. You make powderTajMahal and then put it inside. What will happen? Because at that temperature, calcium carbonate going to calcium oxide is very very fast. It is a non-catalytic reaction which we already discussed.Haan?Haan, type C reaction, CAO. CAO will form one, that is instantaneous. What do you call that? Calcination. Calcination step is instantaneous.

Then that becomes CAO. CAO is highly reactive and you have in the coal,sulphur. Fromsulphur will react with oxygen in this because combustion, you have to send oxygen anyway. So sulphur dioxide will form, CAO plus SO2 plus half O2 will give you CASO4. CASO4 is now solid. It is not going to TajMahal now. It is only at the bottom you will collect and try to use CASO4 for something okay. CASO4 is nothing but gypsum no.ya, so Haan?Haan, then that depends on you know hydration and all that. Okay so anyway, that can be used.

That is the reason why they were only trying to convert the problem, gaseous pollution into solid pollution because if you are not able to use this calcium sulphate, that is gypsum then that is a waste again. Again you have to dump somewhere. When you dump it again, because calcium sulphide is a unstable compound, calcium sulphate is stable and sometimes, calcium sulphide will be there in this conversion. It is not 100 percent converted to calcium sulphate. So that will leach out and then sulphur again will go into water and all that.

We are doing a wonderful job as chemical engineers, polluting the entire world okay that is what is our great contribution. Other things are great there but this also one of the greatest contributors now.Haan?

Student1.(())(40:21)

Professor1.Ya, unless you prevent, you know you have to prevent. That is why only we have green chemical engineering, green chemistry, all that. You have to do it okay.ya, so that is why please show some interest in chemical engineering. Okay. All of you I say. All of you. Whereas interest in chemical engineering? I say, if you have real interest in chemical engineering, you cannot ask for only marks. You will ask for a project, Sir, I want to do this, I want to do this,I want to do this. How many projects are there? How many things are there? Are you asking anything?

You are not asking anything. No, now you have, you play everything. You take tennis bat where it is manufactured by nano carbons, you know carbon tubes.Ya, and then you play very well and with carbon,nano carbons also I think some dresses, many things are made and you do not know who has made it and then you only playJack tennis and then throw the tennis bat away. Where is the pride for you, I made it as chemical engineers? You made it, okay. Even use car very happily, driving or running or in all that but you never feel that it is running because of petrol which you manufacture.

Where is the pride for you? There is no pride. Why there is no pride? Because you are not involved, very simple. My logic is very simple. If you are involved, you cannot stopped staying that.Everytime you see that, oh petrol, chemical engineering. Okay. So anything like that? Cement, building, whenever I see building, ah beautiful, chemical engineering. No, really. Even computers. Computer science people think they are doing so many wonderful things. They can only do provided you give the floppy disk for them.

Student1.(())(42:11)

Professor1.Ya, hardware,ya materials. Okay,this CDs and all that manufactured by us will still you do not even know that, you are not proud of it. Okay. So that is why history is very important. What earlier people have done, what you are going to do. So that is why, that is why you are not involved. I think happy, okay whether it comes in the examination or not. That is all. That is the sole motto from joining date 1 to finally tell you get in the sack building, that degree certificate called in theconvocation, degree certificate, that useless paper. Right? Thatwill be useless if you do not know anything in that field.

Really useless, okay. So but anyway, these things I am repeating so many times but in your mind all the subroutines are going on thinking that this idiot is talking all the times, anything. Okay? ya, is matrix no so you are in your own matrix calling me that this fellow tells only this, nothing else. Okay, good.Ya, this is pneumatic conveying and now, the fluidization ya beyond somewhere here, you have if I take that as UT, terminal velocity, your fluidisation range is from here to here. That is why as I have been telling you all the time, you know you have the float, not flow, what is that? Flow regimes. Even here, we have a flow regime.

Beyond this no one can operate that as a fluidisation bed. And beyond this also, no one can operate ya till here.ya. So beyond this also beyond this also no one can use that as a fluidisation bed because it is not simply fluidizing. So that is the range of fluidisation. But in between, you have so many operations like you know, this is normal conventional fluidised bed. Then we have slightly turbulent or aggregative fluidised bed. Then you have here in between, I have not shown you, circulating fluidised bed. All that depends on how much solids you have in the bed.

Right? Aggregative fluidisation and turbulent fluidisation and normal fluidisation, you will have 60 percent solids, 50 percent solids,40 percent solids, till aggregative and also turbulent. Beyond turbulent, the Jack the particle starts coming out. So at that time, it, you will have around 20 percent if you are able to operate around 20 percent, then you have circulating fluidisation bed. Beyond that, if you go to only 3 percent solids, 3 percent pneumatic conveying, normally we get that. So then you will have pneumatic conveying and beyond that, no operation is feasible.

So all these things are there. Okay. Good. I know none of you will write all these things because why? Ata Anurag? I do not know, you do not write. Yes, correct because you think that this is simply waste of paper, waste of pen, okay. Why should I write? Because it may come or it may not come in the examination. Till then is my duty. After my duty is over, that is all. Who wants this? Throw the particles and books and then go and join somewhere. What a great great generation we have I say?

No respect for what we do. What we are supposed to do, not what we do. What we are supposed to do. Okay. All of you, I am not only talking about them. Okay? They may throw this that book 10 kilometres away, you may throw 1 kilometre away. That is all the difference. Okay, that is all. That is why, it hurts us you know most of the time because when we are excited and then telling, you sit there like a statue. Probably statues would have reacted okay. Real statue if you take and then put there and then talk 40 hours, probably it will have some kind of movement and there. But here, you have movement, become finally statues.

Okay, good.Ya,So now if you want to understand this fluidised beds, we need some parameters.Ya, I think anyway, before that I think we will have the advantages and disadvantages. What are the advantages in using the fluidised beds?Ya.

Student1.(())(46:38)

Professor1. Okay, good control of solids. That is one. Then?

Student1. Excellent…

Professor1. Excellent heat and mass transfer transport processes. Inside that, okay. So heat and mass transfer rates are very high in the bed. That is one. And controlled flow of solids. And number 3 is isothermal conditions which prevent hotspots. Isothermal conditions which prevents ya due torigourous mixing of solids. What are the disadvantages? Because I think you know whatever you do, definitely there will be some particle particlecollision, some powder will always generate. Right? So due to attrition that there is a disadvantage.

That is called attrition. Due to attrition of solids, because we are talking about this one as a reactor, so the catalyst may go out of the due to attrition of solidsthe weight of catalyst may decrease in the bed. That will come, which pressure drop is more. Okay, then? What is the otherdisadvantage? Attrition is one where you lose solids. Right?yaya.Anurag, any other? Whypressure drop is what do you say?

Student1. Sir to overcome the force of forces through the solid also.

Professor1. In packet bed, what is happening? In fact, packet bed gives youmore pressure drop then fluidised bed. So that is why, pressure drop is not a problem because if you are using the same velocities okay, like 2.5 minimum fluidisation velocity, like that. The pressure drop in the packet bed will be much more than fluidised bed. Pressure drop is not the disadvantage. So there is anything else?

Student1.(())(48:41)

Professor1.Haan radial velocity is emf and UT. Beyond that, you cannot go.Haan, particle diameter.

Student1.(())(48:52)

Professor1.Ya.

Student1.And then after a certain point of time when you have to (())(48:58)…

Professor1.Ya but that is not a disadvantage. That is only a pausible operational regime okay. There is not a disadvantage because no one would like to have autumns to be fluidised.

Student1. (())(49:11)

Professor1. Sometimes it will help also. To get smooth fluidisation, they take slightly coarse particle, add fine particles. So then it seems, you will get better fluidisation. So this is always counterintuitive. And you get kicked when you have counterintuitive things.Automatically what you imagine in your mind and what is happening is same, there is no kick no?Haan?

Student1. (())(49:46)

Professor1. Why?

Student1. Because the solid (())(49:49)

Professor1. Because of solid?

Student1. Because of the injection of the solid.

Professor1.Ya, if you are taking that one as a catalytic reactor, catalyst isthe solid particle right? Where is the purity coming? Because reaction occurs in the particle, inside the particle or outside the particle and the catalyst and then anyway, product will diffuse out and then comes out. What you are talking about, the particles coming with the gas, those we have we are masters of that. What do you use? Cyclones. Not one. Ten. Also can use depending on particle size that is coming so you can use one, 1st cyclone, 2nd cyclone, 3rd cycle, 4, 5 cyclones also people use.

And beyond that also, if you are not able to take from the cyclones, then what is it that you use? Filters block. Electrostatic precipitators.ESP plants. Very common, okay. So all those things are there. All those things are there. Unfortunately, you are not putting your mind to assimilate your knowledge. I think definitely professors would have told you in particle technology and all that. Here question advantage, disadvantage what you are trying to tell? Actually when you have a deactivating catalyst,fluidised bed is excellent.

Haan it is very good. You can take out the particles like water okay and then feed continuously. Always you know, you can maintain some amount of fresh catalyst inside the bed. It is not fresh actually. Mixed and fresh.Ya. Regenerator you can use like if you are using like FCC. Okay, take out all the solids, take the regenerator and then send it back. There is another one because this oh okay. So this fluidised bed is equivalent to CSTR orplug flow reactor. Solids are in perfect mixing condition. Is it disadvantage or advantage for reaction?

That is one of the disadvantages. Why? Because concentration gradient is not much. So what do you do? What do you do to overcome that?

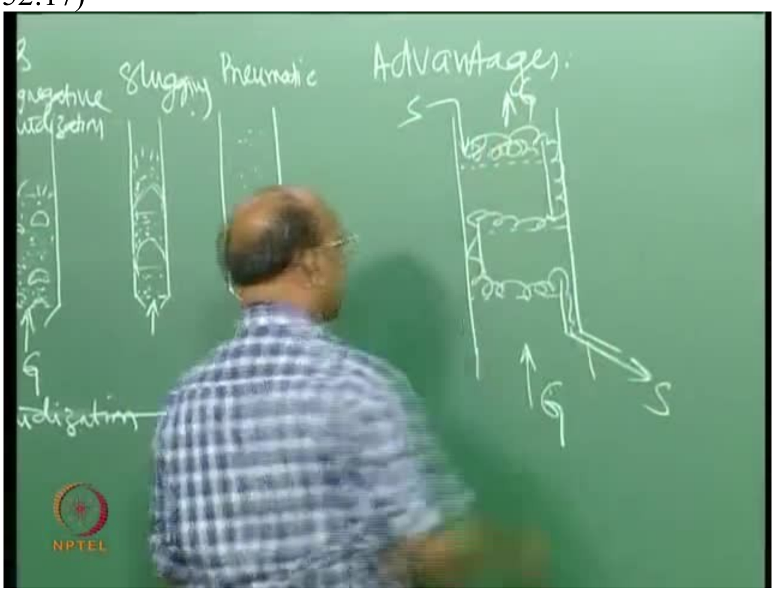
Student1.(())(52:01)

Professor1. What do you do if you want to go towards plug flow? You are using only mixing flows?

Student1.(())(52:07)

Professor1. That is all. So people use 2 or 3 fluidised beds okay. You know how beautifully they use that.

(Refer Slide Time:52:17)



They use like this. This is one down comer or, another down comer, another down comer. If you are using only 3, this fellow comes out. So this is gas, these are solids, coming out. Solid, solid, gas, gas. This is just CSTR1, CSTR2 are mixed flow reactor 1, MFR1, MFR2, MFR3. It is just one above the other. You need not put one above the other. You can also put parallely. One here, next one, next one, a loss of gravity because it is like a fluid. So it comes from one bed to the other bed if you are maintaining certain gravity you know certain level. So automatically it comes.

So that is why, if you want to know, you have to write there,nonuniform residence type. You know, when you have a mixed flow, you have nonuniform residence time for the solid phase. Okay? That is the disadvantage. Why it is disadvantage? Because if I take coal combustion for example, right, solids are in perfect mixing condition. Because of mixing, some particles will come out very quickly. And practically, the combustion in thatthe particle is almost and there may be another particle which is overburnt and then only ash is left.

On the other hand, if you take exactly our jack plug flow reactor, each and every particle would exactly burn depending on the time which you have given, maybe 10 minutes or maybe 10 seconds or whatever. So that is why you get uniform combustion there. But here also, you will get uniform combustion but at low level. At low level because you have at any time, coal must be large amount will have to put to compare with the to compare with the ideal plug flow reactor. Correct no? That is why in fact, for a given conversion, why CSTR will be bigger and plug flow reactor will be smaller is the residence time distribution problem.

One easy example which you can remember is coal combustion. Okay? So certain amount I am burning in a plug flow reactor but if I want to get the same conversion in mixed flow, I have to necessarily use larger bed because the total amount of solids, some converted, some unconverted, all that must compensate the ideal plug flow reactor where all solids are uniformly burnt. So that is why, you will have bigger size for mixed flow and smaller size for plug flow for a given conversion okay. So that is why,ya, so this is one of the disadvantages. And there is another disadvantage, you know at attrition we told, okay that is one.

That is with respect to particles but with respect to walls of the reactor, you have attrition. Okay? Or erosion, I do not say attrition. Erosion of the walls and after some time, wall may disappear, shrinking core model.Ya, wall thickness keep on decreasing because of like shrinking core and finally disappearing. Wall will disappear because always you knowthe solids are moving at a very high velocity, it will erode,erosion explains. So slightly you may lose some of the material of the wall and thickness will be smaller. If it is high-pressure all that, it may burst after some time. That is another disadvantage. Okay. So I think this is fine. And next class, tomorrow morning, 1st class, we will now try to find out what are the parameters used.