Fundamentals Of Particle And Fluid Solid Processing
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Lecture - 21
Fluidization

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Hello everyone. Welcome back to the another class of Fundamentals of Particle and Fluid Solid Processing. Today, we will see the fundamentals of fluidization that we started from our last class that was on the flow through packed bed and when there was some upward flow of fluid through a stack of particles we saw some fluidization the concept of fluidization we just introduced while solving one of the problems.

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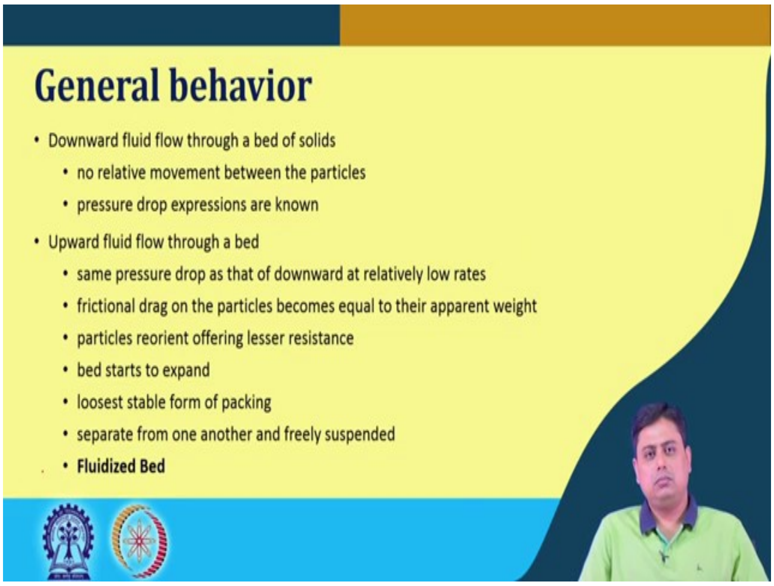

Now, the point here that when there is downward fluid flow through a bed of solids, this concept we have cleared pretty much, ok. Over the last week we have seen several expressions that how to calculate pressure drop through such scenario or flow system, when there is a downward flow through a solid bed or bed of solid particles, fine particles, irregular shaped particles.

So, basically they are at the bottom this bed was rested on a support and since there is a downward flow, if there is no vibration, and let say the particle orientation is firm, there was no loose contact between the particles, during this downward motion of the flow through such bed of solids there was no relative movement between the particles. If particles were loosely packed or oriented then they have could have been a motion of particles, but that quickly settles down.

Eventually, on a steady state case when there is a flow downward in a packed bed of particles there is no relative movement between the particles and we have now know that what are the pressure drop expressions, how to calculate those; be it a laminar condition, be a turbulent condition of the flow region.

Now, in case of upward fluid flow through this exactly same bed; if those solid particles are unrestrained on the top surface, like the problem we solved in the flow through packed bed section, when there was this particles are just stacked on a support porous support through which let say the gas or liquid is flowing upward then there is same pressure drop expression as of the downward fluid flow, but at relatively low flow rate that is valid.

As we increase the liquid flow rate or let say the gas flow rate or in general fluid flow rate the frictional drag on the particles becomes equal to their apparent weight and that is the condition the critical condition based on which we solved one problem in the last section.

So, as you will increase the fluid velocity there will be a point when the apparent weight of the bed or the solid particles, will be equal to that of the head loss of the frictional drag on the particles and in that scenario, ok, what will happen if you further increase the fluid flow rate, particle orientation will be rearranged, to offer the less resistance, it will reorient itself the particle movement will start and the bed will start to expand. So, particles will no longer be in contact with each other, ok.

Just before that scenario there will be the maximum void space that would be available for such particle orientation. Once there is no contact between the particles we say that the fluid or that the bed is now fluidized, ok.

So, just before that at the onset of fluidization we will have the loosest possible stable form of the packing which will have the maximum porosity or the voidage of the bed, ok; and after that with further increment in the fluid velocity, it will separate from one another and will be kind of freely suspended or supported by the fluid media, ok, and it will be carried with the fluid that is flowing upward. If that those bed of particles if it is un-resistant at the top surface. This phenomena is called the fluidization the fluidized state of the bed of this particle solid particles, ok.

So, this is the basic idea behind the fluidization, or the onset of fluidization, when fluidization occurs, why it occurs, ok. So, we will go into this phenomena now in deeper state. So, now, you can understand that this fluid state can be either liquid phase or the gas phase. Now, what would be the difference between that two system?

Say you have liquid solid system and the gas solid system, so two state of fluidization can happen, gas solid fluidization liquid solid fluidization, ok; and what would be the difference between these two; is there any difference?

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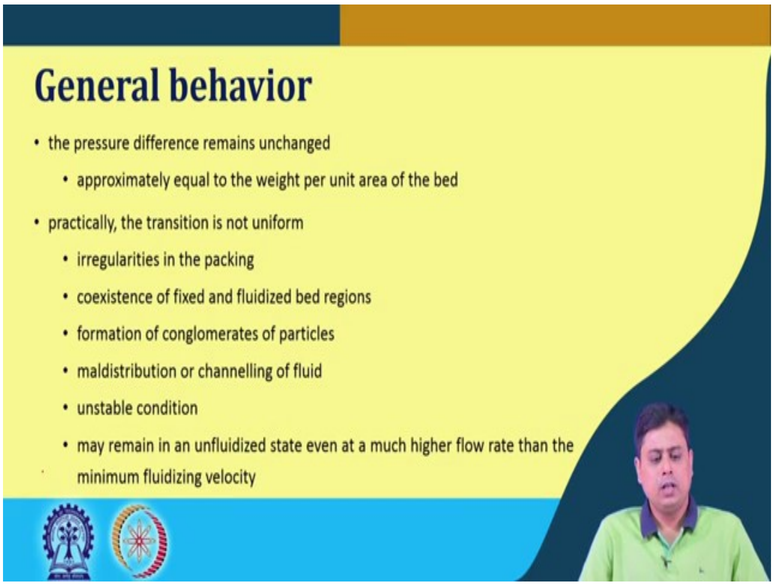

The point is this pressure difference, ok. Now, here the before we go into this gas and liquid differentiation, the point is that pressure difference at this fluidization state would remain unchanged because that was the problem that we mentioned that after this state when the particle reorients itself and it now suspended with the fluid media, ok.

There is a range until which there is no change in the pressure drop or the pressure difference again, it remains unchanged, because until the point the fluid velocity is so high or becomes higher than this weight of the bed per unit area. So, this pressure difference remains almost unchanged until this imbalance is introduced by increasing further fluid velocity.

So, basically a fixed bed is behaving now as a fluidized bed, so that means, there is a transition between the fluid fixed bed, and the fluidized bed the fixed bed with upward motion of fluid and the fluidized bed there is a transition. Now, this transition, practically is not this the kind is of smooth or uniform, ok, because there are several irregularities, specially with the packings, ok.

Because the packings that are practically used are not of I mean mono sized sphere, ok, it is of different shape, different sizes, there is a size distribution, fine. So, there are irregularities in the packing which this shape and size differences leads to the coexistence of fixed bed as well as the fluidized bed. These two beds inside a particular operating region.

And top of that there due to the surface properties of this solid particles and its nature there can be a chance of formation of conglomerates of particles. This aggregates are not what ideally it should have been there. Now, once it forms the flow pattern inside the fluidized bed or in that region changes, there are chunks of let us say the solid particles, agglomeration of solid particles, if that happens then the flow behaviour changes, so that means, it is this transition is not this much smooth that we have ideally expected.

This introduction of this agglomerates aggregates, actually also leads to the maldistribution or channelling of the fluid that is flowing upward because this fluid always try to go through the path where there are less resistances of flow, ok.

So, it would not pass through where there are minimum voidage, it will try to go through the maximum voidage spaces and if this voidage distribution is not uniform that leads to the channeling or the maldistribution of the fluid, and that again creates or combines the whole problem to another complicated level and this condition of the bed becomes unstable because you can understand now there are few chunks here and there inside the bed, ok.

There is maldistribution of the part of the fluid that is flowing, so some portion of the fluid is suspending some particle and in some portion some particles are not suspended, ok. So, it may remain in un-fluidized state even at much higher flow rate than the minimum fluidizing velocity.

So, this transition is not what we have we had expected that the all particles will be fluidized at a particular or a single fluidized minimum fluidization velocity, and it will be uniformly distributed or homogeneously distributed or homogeneous media, ok; because there are several complicacies involved in this operation.

Practically, there are different shapes and the size ranges of particles that are used, and they have their different surface properties, they tries to stick to one another, forms conglomerates, ok, and then the channeling of this fluid that flows upward that takes place, that leads to a further complicacy in this whole operation.

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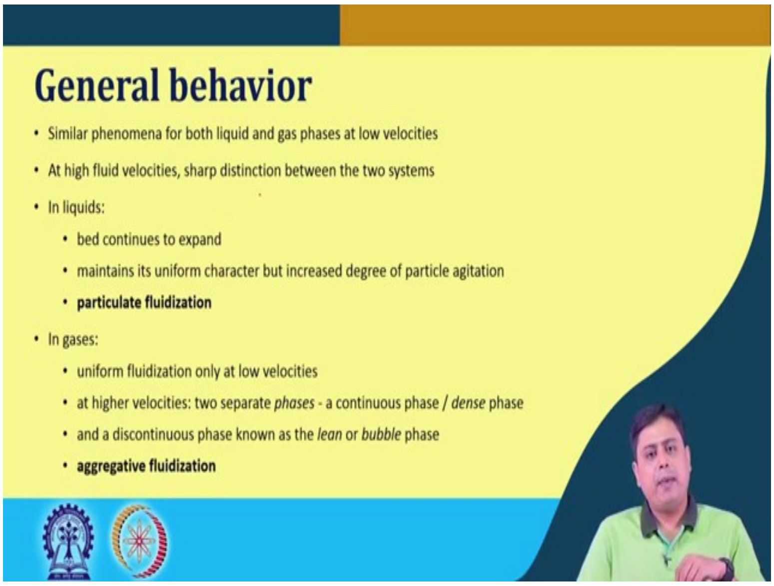

So, now, coming back to this gas liquid difference that the liquid solid fluidization and gas solid fluidized bed, ok. What are the difference between these two systems? Ok. One they are similar in nature, ok, but at low velocities, at very low velocities both the beds behaves in a similar way, but at higher fluid velocity there is a sharp distinction between the two systems. In liquid case what happens?

As you increase the liquid velocity bed continues to expand, it maintains in uniform character, but with a higher degree of particle agitation inside the media. This is called the particulate fluidization, ok.

So, particulate fluidization relates to the liquid solid fluidization system and here you can appreciate one scenario that in liquid flow solid fluidization you require lesser minimum fluidization velocity to suspend the particles. You remember the apparent weight of the system that is its actual weight minus the buoyancy force. So, in liquid solid case there will be a lower value requirement for the minimum fluidization case.

In gaseous system, uniform fluidization happens only at a very low velocities, at higher velocity two separate phases basically we can identify, one we say the continuous phase or the dense phase the other we say the lean or the bubble phase, the gas the discontinuous phase, ok; and as you increase the fluid velocity or the gas velocity this agitation in the particles is much higher than what could have been in the liquid phase, ok. In gas phase such fluidization is called the aggregative fluidization.

So, in liquid solid system we have particulate fluidization, in gas liquid system we have aggregative fluidization, fine.

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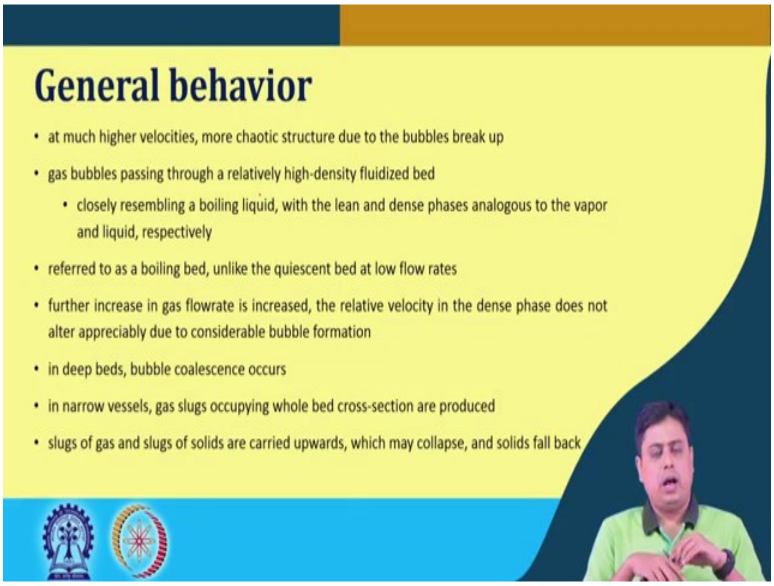

Now, at much higher velocities, in gas solid fluidization more chaotic structure appears due to the bubble, the gas bubble that is there or that forms inside the bed that breaks up and that creates a more chaotic motion of the particles. So, when the gas bubble basically flows through a relatively high density fluidized bed, ok, we find an analogy of such flow phenomena with a boiling liquid, where this lean and the dense phases you can relate that to the vapor and the liquid phases, respectively.

So, as if some boiling of liquid is happening or the gas bubble, it forms and breaks and creates chaotic motion inside that is gas solid fluidization and this we refer to as the boiling bed, unlike that we happens in the case of very at a low flow rate there is a stagnant bed and some gaseous phases is flowing through the bed, ok. There is a common question bed at low flow rates, but at very high flow rate this bed will behave as if this is a boiling bed.

And further increase in gas flow rate what will happen? The relative velocity of the dense phase does not appreciably change, due to maximum of this gas is contributing towards the bubble formation or maximum portion of this fluid is now contributing towards the bubble formation and its breaking and participating in such phenomena, ok. In deep beds; that means, when there is the fluidization bed depth is quite sufficient or higher or longer this bubble coalescence also occurs and in case of narrow vessel or shallow bed gas slugs that occupies across whole cross section of the bed and such formations are frequent in case of narrow vessel or shallow bed and what happens?

The slugs of gas, and slugs of liquids, solids, both are carried upward, and this may collapse that leads to fall back of the solids at the bottom of the bed for the downwards scenario. So, the recirculation of the solid particles are very prominent in such cases.

So, the point being is that at higher velocity, we have bubbling phenomena in gas solid fluidization, and this we typically referred to as a boiling bed finding an analogy of boiling a pool of liquid and high flow rate through a bed of solid particles during fluidization, ok.

In this boiling bed, if we further increase our flow rate we do not see much difference in this relative velocity of this densed phase because most of the gas phase are now creating this bubbles and its coalescence happens in a deep bed and in shallow bed or narrow vessel, gas slugs, occupying this whole cross sections are formed and this gas slugs solid particles, again gas slugs solid particles these actually flows upward and which basically collapses. There are chances of such collapse and so, the solid particles fall back again at the with that downward motion.

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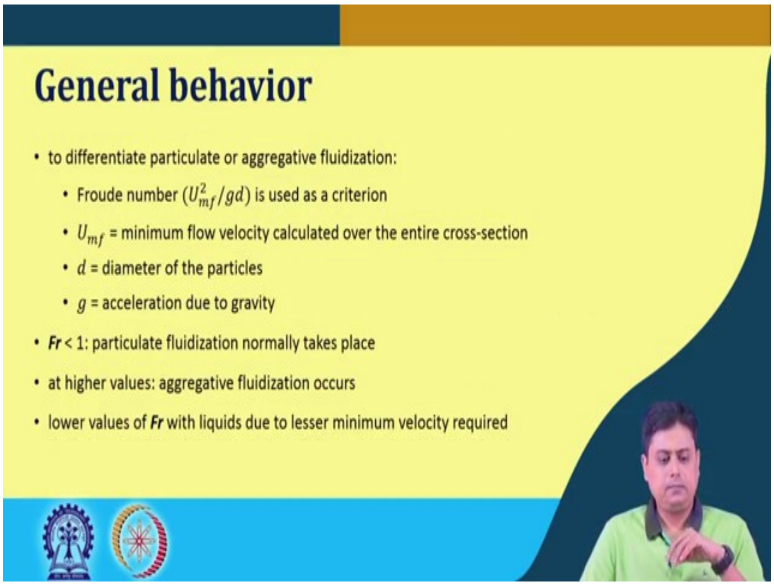

Now, to differentiate between this particulate and aggregative fluidization several researchers have come up with some proposition and one of them is the definition of Froude number to use that has a criteria, where the Froude number is basically U_{mf}^2/gd.

d is the diameter of the particle, g is the acceleration due to gravity.

So, this Froude number if it is lesser than 1, typically this particulate fluidization takes place and it higher value aggregative fluidization occurs. Now, this formation why this is formed and when this is formed this is now, nowadays pretty much can be predictably which can say that sufficient. In fact, more than sufficient research has been done on this area, and there is now clear cut distinction or for the prediction of this regime that where or when the particulate fluidization will happen and when aggregative fluidization will happen this can predictably be mentioned.

And now, you can understand that the rational behind this Froude number less than 1, because in the case of liquid as we require this U_{mf} at a lesser value this condition is typically satisfied in the liquid phase very quickly.

As I said, in the liquid solid fluidization you require a lesser magnitude of minimum fluidization velocity than the gas solid fluidization, and then this Froude number less than 1, can be achieved easily than the gas solid fluidization and that is why we related this particulate fluidization with the liquid solid and aggregate fluidization with the gas solid systems, fine.

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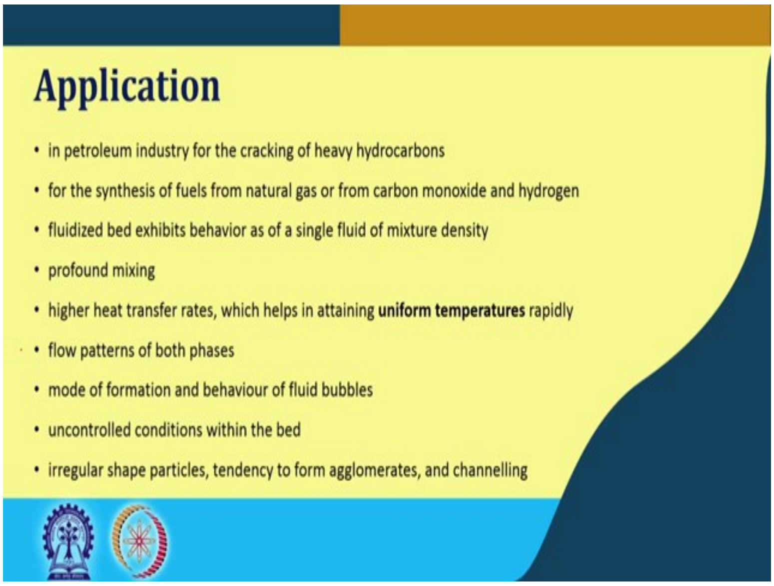

So, now, why we should go in to this in detail because there are several and extensive application of this fluidized bed. Particularly, it is mentioned about the that in petroleum industry for cracking of heavy hydrocarbons it is frequently used for synthesis of fuels from natural gas or from carbon monoxide and hydrogen.

These are extensively used. This fluidized bed when used, it basically exhibits a behaviour as if there is a single phase flow that has a density equals to the mixture density. There are solid and liquid or let us say a gas solid and gas phase, both has its own density.

Now, you can find out what is the mixture density. The point or the model typically has been developed for the fluidized bed earlier, considering that fluidized bed has this mixture density and behaving as if a single phase system. This fluidized bed, helps in achieving vigorous mixing between the phases or profound mixing can happen in a fluidized bed.

We can have higher heat transfer rate, which helps in attaining uniform temperatures very rapidly or very quickly inside the bed and that leads to the uniformity of temperature inside the bed which is very essential in several applications, that you have a sudden and uniform temperature throughout the bed and that is one of the biggest advantage of fluidization of the fluidized bed over the packed bed, the control of this uniformity of temperature, ok.

But to use fluidization or fluidized bed, we need to know the flow pattern of both the phases, ok. We need to know the mode of formation and behaviour of fluid bubbles because these are particularly relevant for the gas liquid system, and it becomes more and more prominent with the higher gas velocity because in several applications you need higher throughput that can be achieved by the higher flow rate of the gaseous phase and also the dense, high density fluidized bed.

So, a single operation, ok, let say a single application for what you are applying this fluidized bed ideally what should have been that there will be a reproducibility of the result, irrespective of place and I mean for a particular condition. But it has been seen that for a particular application, let say pertaining to this heat transfer several researchers have come up with a different results and that leads to its extensive research even till now that this irregularity of a particular applications and different result, ok. This comes from uncontrolled condition within the bed, and that actually stems from irregular shape of the particle, their surface property, their orientation and the non-uniformity of fluid distribution at the inlet, which propagates along the bed.

So, such things complicates the whole problem and the condition within the bed becomes uncontrolled, that leads to the different results for a similar applications and in several cases it has been seen that the reproducibilities of the results are lost, it is not there, fine.

So, I will stop here today. In the next class we will see that what are the pressure drop expressions, how the pressure drop varies in this case although we have seen very sketchily in the previous section, that how pressure drop and the pressure gradient varies in the fluidized bed as well as we will see some details of different types of a flow regime inside the fluidization fluidized bed when it happens for the gas liquid for the gas solid or the liquid solid systems.

Till then, thank you for your kind attention.