INDIAN INSTITUTE OF TECHNOLOGY ROORKEE

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NPTEL ONLINE CERTIFICATION COURSE

Unit Operations of Particulate Matter

Lec – 11
Fluidisation (Part -01)

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Welcome to the 3rd week of the course unit operation in particulate matter. This is the first lecture of week 3 and here we are covering topic fluidisation now this topic fluidisation will be covered in 2 lecture, lecture 1 and lecture2 in lecture1 what we will discuss we will define the fluidisation we will discuss different types of fluidisation and then characteristics of fluidisation will be discussed. Lecture 2 we will cover governing equations associated with the fluidisation process. So let us start the lecture1 of week 3 and here we will define the fluidisation.

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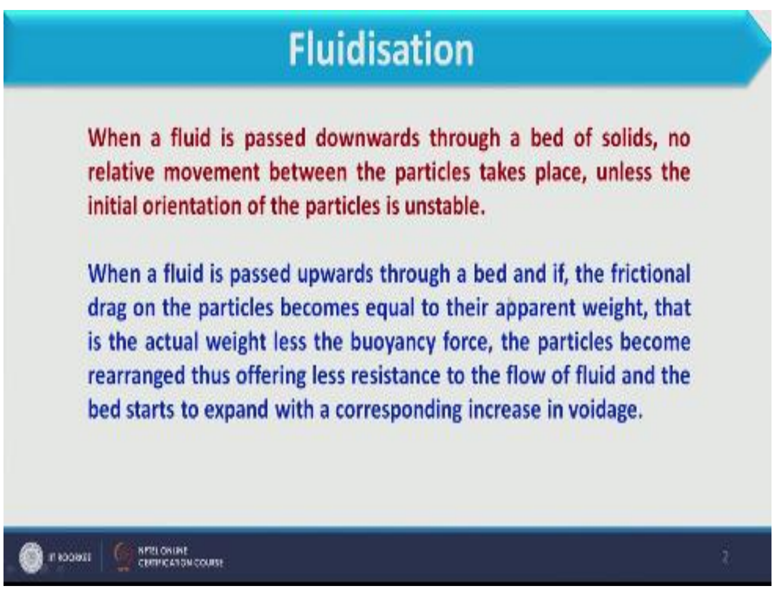

So what happens when a fluid is passed downwards through a bed of solids, no relative movement between particles takes place unless the initial orientation of particle is unstable. Now what is the meaning of this statement for example if I consider a column where particles are available where the column is filled with the particles now if the loss now if fluid enters from the top and most downward then what happens through when it will pass through the particle it will not disturb the movement of the particle until unless the orientation of the particle will be changed.

For example if I am having very needle kind of particle and if particle move particle initially associated like this so when fluid will pass through this it may be oriented it may be it may take position vertically so in that case if this type of orientation of different particle occur then the position then the bed the high of the bed may change but it is not significant, on the other hand what happens if the fluid moves upward initially we have discussed the movement of fluid through wards downward.

Now we will discuss what happens fluid moves upward through the bed of particles so when a fluid is passed upward through the bed and if the frictional drag on the particles become equal to their apparent weight what is apparent weight is the actual weight minus the buoyancy force. The particles becomes rearranged thus offering less resistance to flow of the liquid and the bed starts to expand with a corresponding increase in void age.

Now what happens when fluid moves from downward through the bed of particle it exert a drag force on the particle now if bad drag force will be equal to the apparent weight of the particle it means the weight of particle itself minus the buoyancy which is acting over this when this difference of this will be equal to drag force which is exerted by the fluid it will start it will leave it is position and start moving upward so at that point the height of the bed expands or height of the bed increases.

And when height of the bed increases the void age available between the particle that also increases.

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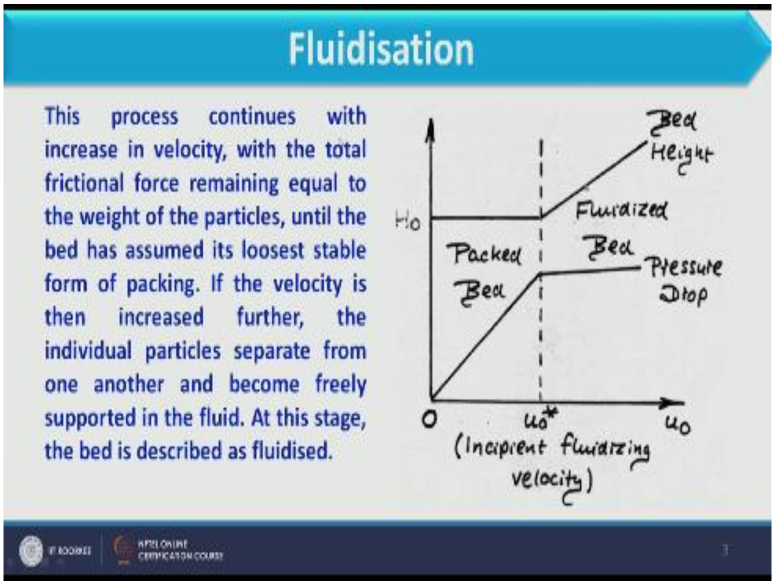

Further this process continues with the increase in velocity with the total frictional force remaining equal to weight of the particle until the bed as assumed it is loosets stable form of packing. So what happen further increase in velocity further allows particle to leave it is a stable state and go further moving state and when we further increase the velocity the individual particle separate from one another and becomes freely supported in the fluid.

So what happens when all forces when forces at thing on the practice like weight of the particle itself and buoyancy force and drag force when the when drag force is equal to the apparent force of the particle what happens it will start leaving it is space now when we further increase the velocity it will loss it is stable condition and it will be carried by the fluid so in that case we can say that particle is supported by the fluid now the particle will be supported by the fluid it means it will leave it is space and moving with the fluid.

So at that position at that time when the particle moves what we call in this the particle is at fluidisation condition so that when the particle is stat moving with the liquid then we call this a fluidisation and that state is entirely different when the particle is at stable position, now if you see this graph this is drawn between height of the bed verses velocity now what happens as we have discussed that particle will remain at stable position till velocity will increase and that velocity will put the drag force and then when this drag force is equal to the apparent weight till the particle state particle will stay at stable condition.

So when velocity will increase you see in this graph when the velocity will increase we are absorbing on pressure drop and effect on bed height, now pressure drop increases you see in this graph shows the with the increment of velocity pressure drop increases till all forces become in at equilibrium all forces means drag force should be equal to weight a particle minus buoyancy force,

And when further increase in velocity when the particle will leave it is stable state at that time particle will state at that time particle will start moving with the fluid so bed will start expanding so here you see when we consider the bed height up to certain velocity the height of bed will remain as it still forces become equal and then it will start expanding so when it comes to fluidized state you see the bed height will keep on increasing and bed height will keep on increasing when we observe the pressure drop condition.

Pressure drop will increase but it will not increase significantly you see once all force becomes equal pressure drop will become almost constant so when we increase the velocity and when that velocity at appear where bed will start expanding all particle will be at fluidized condition we call that velocity as minimum fluidisation velocity or incipient fluidisation velocity this concept we will discuss in detail further. Now we will discuss few important facts about the fluidisation such as.

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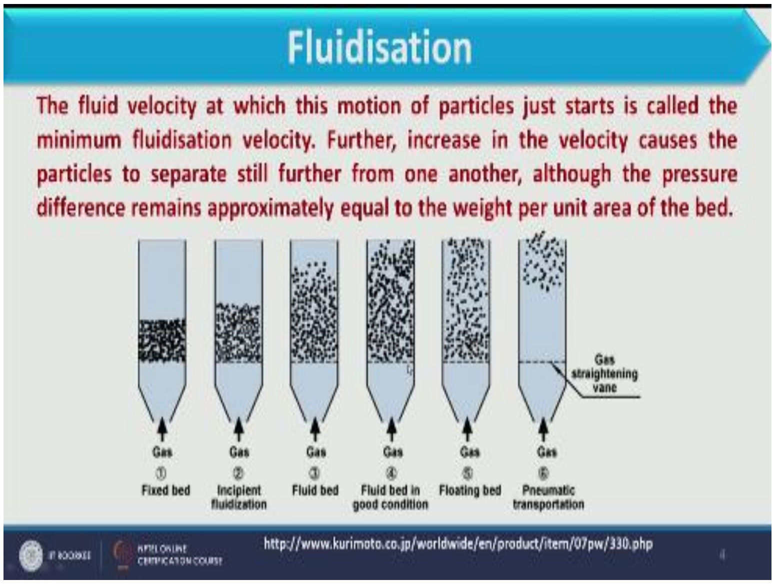

The fluid velocity at which this motion particles just starts is called minimum fluidisation velocity that we have already discussed in the last slide further increasing velocity causes the particles to separate still further from one another, so once we have we will achieve the minimum fluidisation condition where particle will coming into the fluidized state and further increase velocity will separate particle from each other.

Although the pressure difference remains approximately equal to weight per unit area of the bed so you see once fluidized condition is archived one and further we increase the velocity particle will start moving from each other and at that time the pressure drop in the bed remains almost constant. So you see this figure her there are different conditions where bed expression is shown in first condition when we are considering bed at static position when gas passes through it.

Till that point the bed will be at static position and it will have a minimum height it will have a constant height now when minimum fluidisation state occur at that time particle will start a moving with the fluid or we can say particle will be supported by the fluid and then the bed expansion occurs now if you see figure what happens over here we will further increase in velocity and all particle.

If you consider previous figure that is figure here few particles are joined together but in figure 3 all particles are moving separately and few very less particles are joining further increase in velocity in figure 4 we have absorbed that particle will move with fluid and it will be at more fluidized state and the bed expansion will keep on increasing in comparisons to figure 1, 2 and 3 so with this condition we call as fluid bed in good condition now when we increase the gas velocity further the particle will start floating with the liquid it means it will all particle will be hanging in the fluid so that we condition we can call as it is fluidize so that condition we call as particle are floating over the fluid.

So this figure 5 shows the floating bed further increase in velocity use you can see in figure 6 that particle left the bottom space bottom support where it was initially placed particle leave this space and start moving upward entirely so if this condition occurs in this condition we can say particle will be carried by the fluid and this particle condition we can this particular condition we call as pneumatic transport.

This is very important as far as chemical process is concerned when we have to carry the solid from one position to another position pneumatic transport is important in that case and which is done by fluidization when the fluidization reach to that level where fluid support the particle in such a way so that it flows with the particle, it is the particles are carried by the fluid itself that condition we can call as pneumatic transport, pneumatic transportation as shown in figure six.

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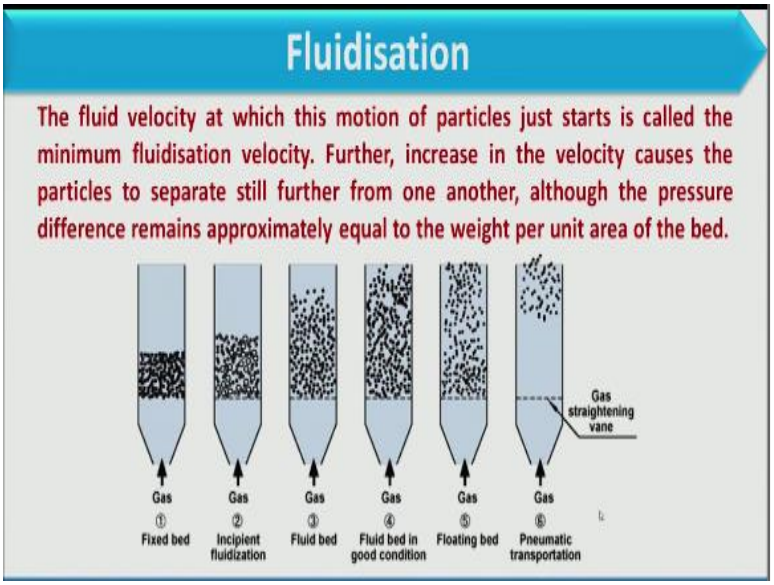

So here we have different conditions of fluidization if you want to study more you can go through this web link now we will discuss different types of fluidization what are the different types of fluidization, mainly it is categorized in two way first is the particulate fluidization and second is the aggregative fluidization, so what happens.

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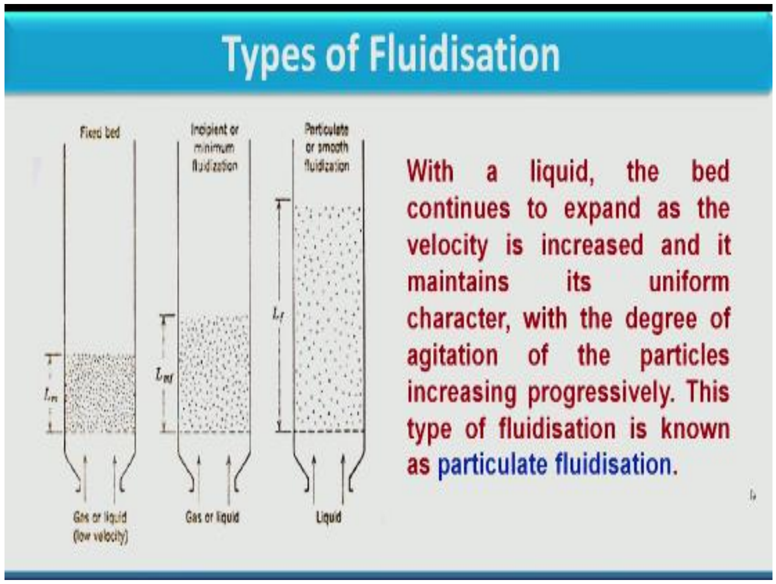

When you see this figure, in figure 1 when gas or liquid flows through the bed and when velocity is less so when velocity is less it will not start moving particle will be at static position itself, so the total height of the bed that should be denoted by Lm, that is the initial height of the bed now further increase in gas velocity when all when drag forces will be equal to the apparent force of the bed it will start expanding and when it will reach to the minimum fluidization condition.

It will flow it will carried by the fluid it will be supported by the fluid in other word so when that condition achieves we resemble that if that condition achieve we can call the height of bed at that condition is the height of bed at minimum fluidization condition and which is denoted by l_{mf} further when we increase the velocity, now if you see third figure here we have one consider only liquid phase.

In first and second phase we have considered liquid as well as gas but here in third position third figure we have only liquid, now once we increase the velocity of the liquid the particle becomes distributed uniformly through the bed if you see this here height of the bed increases significantly but in total height of the bed particle will be distributed uniformly, it means it is not like collection of some particle are more in some spaces and less in some spaces.

In this condition it is uniformly distributed, so when this condition achieves the height of the bed is referred as Lf and this particular condition is called as particulate or smooth fluidization. So you see when we increase the velocity of gas and liquid after sometime when fluidization will achieve after sometime when we consider when we increase the velocity of the liquid not the gas but the liquid the distribution of particle in total bed will be uniform and that condition we call as particulate fluidization.

It happens with the liquid only and what happens with the gas when we increase the velocity further that we will see in next slide, so you see what is particulate fluidization, particulate fluidization is when tickle are fluidized with the fluid but it will be uniformly distributed throughout the bed that is called as particulate fluidization. So with the liquid the bed continues to expand as the velocity is increased and it maintains its uniform character.

With the degree of agitation or the particles increasing progressively so particle movement will increase progressively but it will be uniformly distributed throughout the bed, so this type of fluidization is known as particulate fluidization, it usually happens with liquid it can happen with gas but at lower velocity.

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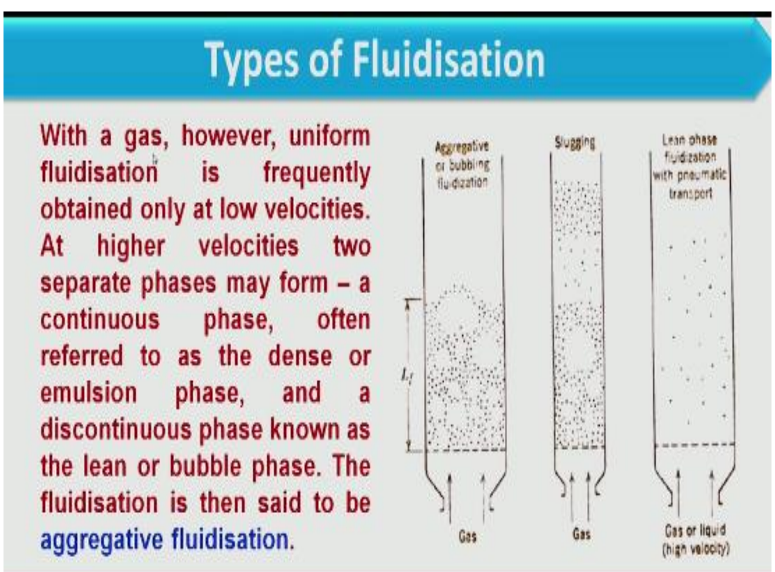

Further if you see this figure in the first figure we have movement of gas so what happens over here when we this happens after minimum fluidization condition achieved after that when we increase the velocity of gas what happens the bubbles are formed inside the bed so particle will not be uniformly distributed but these are placed some more the bunch of particle is placed and some one position.

And in some position there will not be any particle because of availability of the bubbles, so you see here more when this bubble is formed why this bubble is formed because it consumes the excess air with it, so when the bubble will keep on moving upward because gas is continuously entering into this the size of bubble will also keep on increasing as you can see from this figure. So when this condition is achieved that bubbles will, are formed inside the bed.

This condition we can call as aggregative or bubbling fluidization. It usually happens with the gases with liquid the particles are uniformly spaced but in gas we have aggregative fluidization. Now when we increase the velocity further what happens that some particles needs the total bed and start moving with the gas and after sometime they fall down it will not be carried by the gas continuously.

But for some time the larger you can say the larger bubble when bubble size is increased almost equal to the diameter of the column, if that size of bubble is achieved then the particle few particles are carried away from the reset of particle of the bed and some gap is observed as you can see over here but after sometime they goes they fall down, so if this condition achieve along with bubbles when space is created where particles are not available.

And particles are available above that space this condition we can call as slugging and you can see you can observe in figure 3 that gas or liquid high velocity when we have so we can further pneumatic transport, pneumatic transport is basically occur when we are considering gas as a fluid not the liquid. But in that condition particles will be suspended in the gas and that it will help to carry the particle from one place to another place.

So all these condition will occur with the gas and transportation will also carried out with the liquid and that we call as hydraulic transportation not then pneumatic, so you see aggregative or bubbling fluidization occurs with the gas and particulate fluidization occur with the liquid. So here the fact with just we have discussed that with the gas however uniform fluidization is frequently obtained only at low velocities as we have already discussed.

At high velocities two separate phase may form a continuous phase or we also call it a dense emulsion phase as you can observe that these particles are collecting over here so these are making the dense phase or the continuous phase and another phase is the phase created by the bubbles, so that we call as the lean phase so the fluidization is then said to be aggregative fluidization. So here we have discussed two types of fluidization.

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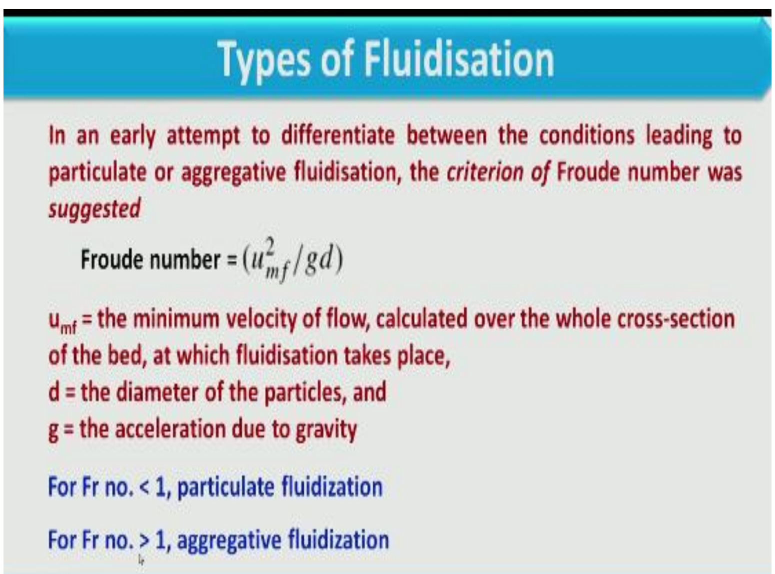

In an earlier attempt to differentiate between condition leading to particulate or aggregative fluidization so here you see we have discussed two type of fluidization the particulate fluidization and aggregative fluidization now what happens that what was the condition through which we can define that this is the particulate fluidization and this is the aggregative fluidization to define this condition we have one dimension less number and that we call as Froude number.

So you see the Froude number we define this is defined as u_{mf}^2 /gd now what is u_{mf}, is the minimum fluidization velocity or the minimum velocity of flow calculated over the whole cross sectional area of the bed at which fluidization takes place, so this is nothing but the minimum fluidization velocity diameter of the particle is denoted by D and G is gravity acceleration so considering these Froude number.

We can say that when Froude number is less than 1 the particulate fluidization occur and when Froude number > 1 aggregative fluidization occur, so based on this Froude number we can identify what type of fluidization is occurring in the process. Now we have another criteria to see whether the fluidization is particulate or aggregative another so we have another method another approach so that we can say that this is the particulate fluidization and this is aggregative fluidization and the approach is.

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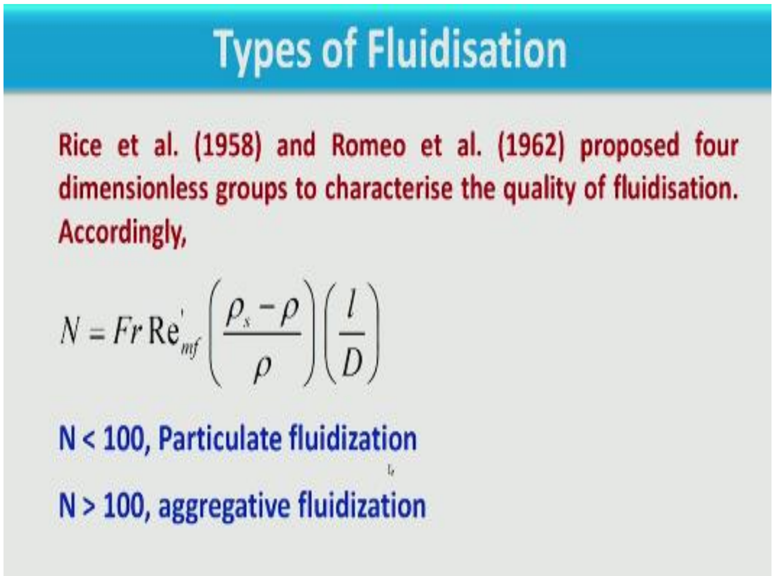

Rice et al. (1958) and Romeo et al. (1962) proposed four dimension less groups to characterize the quality of fluidization, now according to them the dimension less number they have proposed as N which is equal to the Froude number this is first dimension less number the Reynolds number at minimum fluidization condition that is second dimensionless group and here you see the density ration of solid and fluid and then we have the ratio of height of the bed.

And diameter of the column so you see this is another dimensionless group this is another dimensionless group so total four dimensionless group has been defined and collectively it is called as dimensionless number N so you see how we calculate the Froude number that we have seen in the last slide Reynolds number at minimum fluidization condition how we will calculate this that you will calculate the velocity where fluidization will occur.

And considering that velocity we can calculate Reynolds number the densities and height of the bed as well as diameter all factors so we can calculate so we can obtain value of N so when N < 100 aggregative fluidization will occurred. So you see when we have increased in number the possibility of aggregative fluidization increase.

Similarly the factor observed in last method which is given a through the froud number one need so when we see the value of the froud number or value of the Reynold number all this has fluidization velocity in numerator. So what happens when we increase the velocity aggregative fluidization may occur.

So that aggregative fluidization velocity can be observed then we increase the velocity so in that we can by considering the froud number as well as the value of N we can distinguish between particular as well as aggregative fluidization however when you have observed then also we can see.

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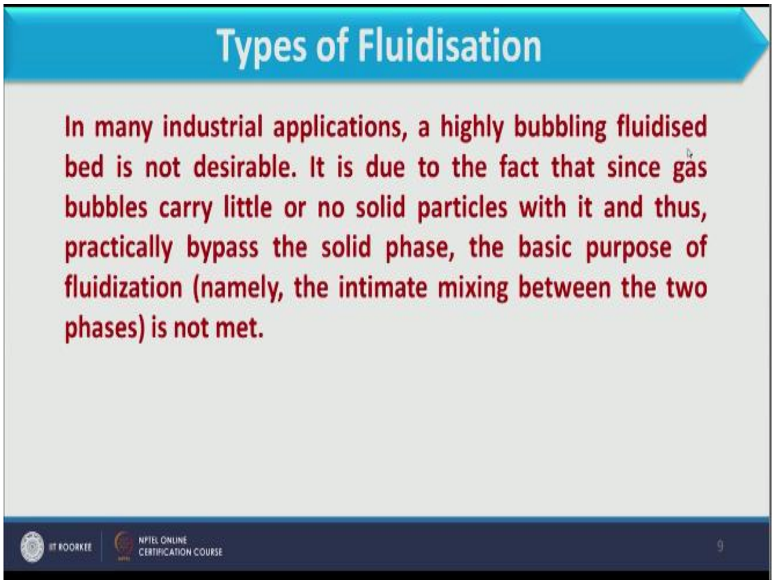

Now in many industrial applications a highly bubbling fluidized bed is not desirable. It is due to the fact that since gas bubbles carry little or no solid particles with it and thus practically bypass the solid phase, the basic purpose of fluidization is not met. So what happens we usually do not consider or do not desire for bubbling fluidization or aggregative fluidization because in that case the gas which has passed through the bed.

It will bypass the solid it means when the solid is available over here it will bypass this solid so that this solid will not come into the fluidization state and therefore fluidization will not met now what why we do the fluidization for example if I am having mixture of two different particles so what we have to do if we want to create uniform mixtures of these two particles then it should be fluidized properly.

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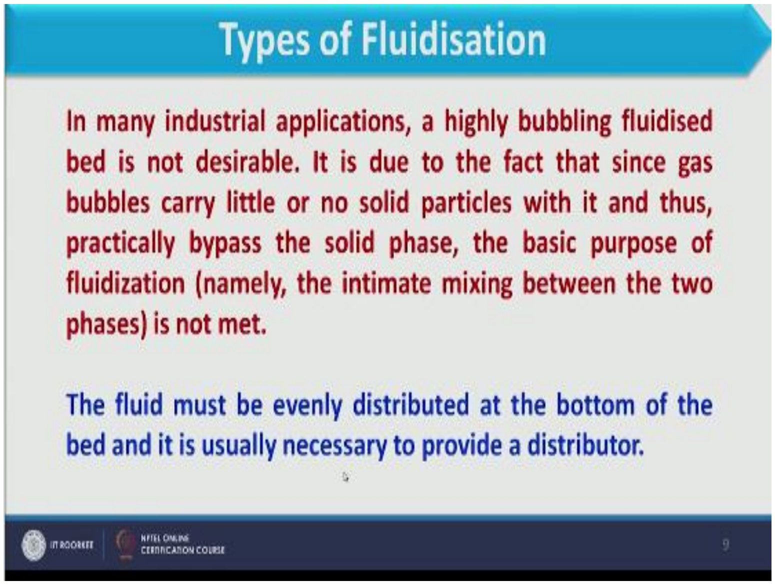

But cannot be achieve the bubbling fluidization and that's why bubbling fluidization is undesirable in the industry cases. So the fluid must be evenly distributed at the bottom of the bed and it is usually necessary to provide a distributor. So what happens for uniform, movement of through the bed the fluid should passed through the bed not from one portion itself.

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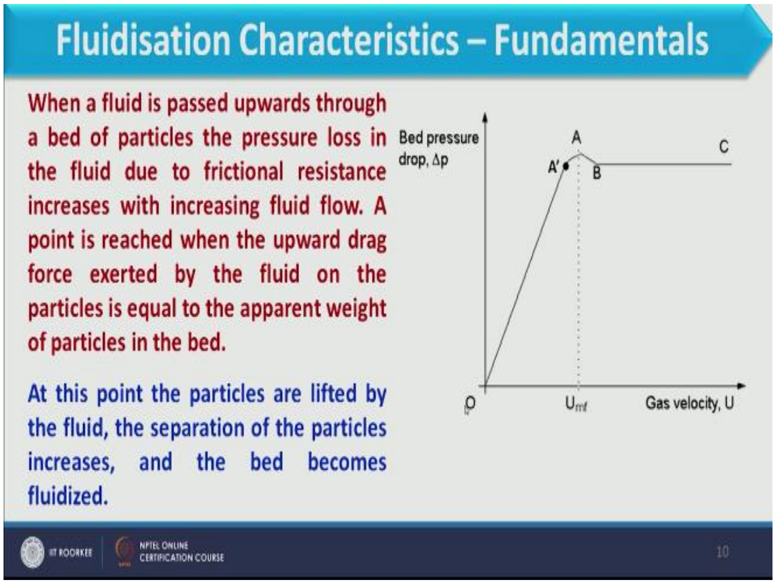

So for proper distribution is for proper distribution of fluid we provide distributor plate at the bottom over which bed space so distributor is important necessary in fluidized bed. Now here we will discuss the fluidization characteristics that is fundamental of fluidization if you consider this curve here we have bed pressure drop verses gas velocity.

So what happens when a fluid is passed appeared through the bed of particles the pressure loss in the fluid due to frictional resistance increases with increasing fluid flow. A point is reached when the upward drag force exerted by the fluid or by the fluid on the particles is equal to the apparent weight of particles in the bed.

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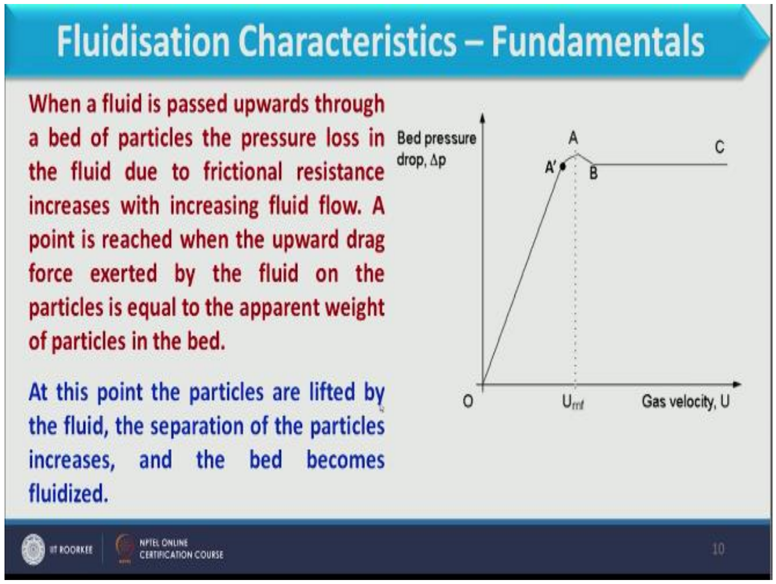

So when this condition is achieved particles it will be start may be in the position in the bed and bed will start expanding at this point the particles are lifted by the fluid, the separation of the particle occurs and further increase in the velocity the separation of the particles increases and the bed becomes fluidized.

So you see what happens when you considered the fluidization has we have already discussed previously when lack forces will be equal to the apparent force by the particles will start and leaving when it is space and then the separation of the particles from each other occurs and that condition the bed becomes fluidized.

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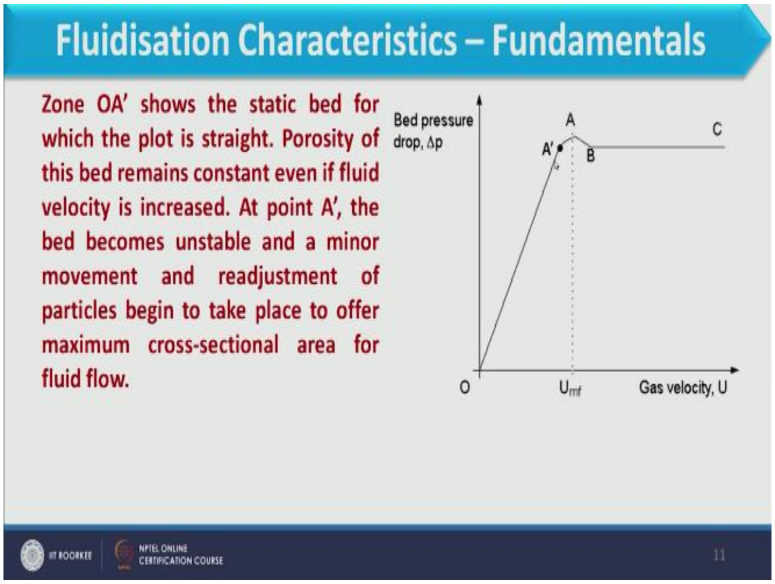

So we have to discuss the nature more carefully the nature of this graph more carefully so what happens you should increase the gas velocity pressure drop increases. A pressure drop increases still all forces become equal so when we consider this graph and when we observe the zone OA' this line or this zone shows the static bed of particles for which plot is straight.

You see you have mistrotic bed considering it means the bed is not coming into the fluidized state so porosity of this bed remains constant even if fluid velocity is increased because still al forces become equal then it will come into the expansion state and till that the voltage or the porosity of the particle porosity of the bed becomes uniform, or becomes constant.

Further at point A' the bed becomes unstable and a minor movement and readjustment of particles begin to take place to offer maximum cross-sectional area for fluid flow now what happens in A' when the particle start leaving the space so instead of uniform voltage the voltage increases and it may happen that the fluid may be passed through the complete cross of sectional area of the bed.

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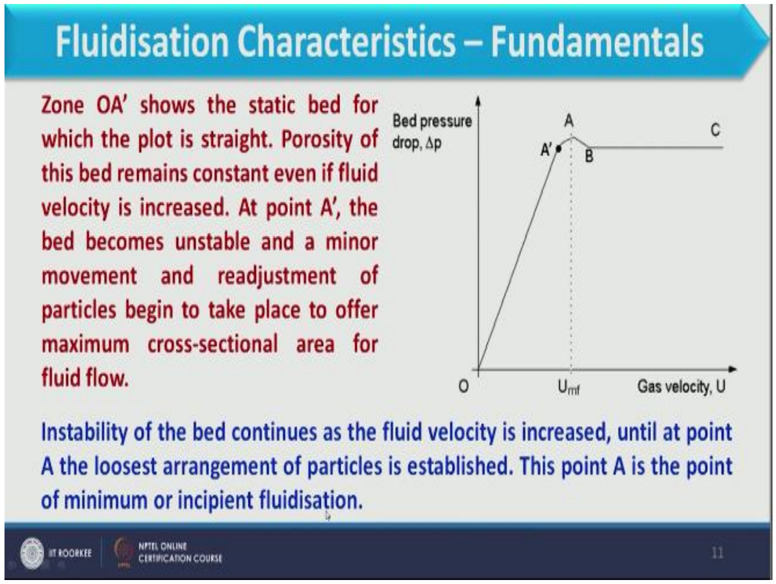

So instability of the bed continues as the fluid velocity is increased until at point A the loosest arrangement of particles is established. So you see at point A the particle may start losing its arrangement and at point A the bed becomes fluidized or this is the condition where minimum fluidization this condition we can called as minimum fluidization condition.

Now from point A the bed begins to expand with increasing fluid velocities since the porosity of the bed increases. So at point B you see the point B is enable over here at point B fluidization is complete and all particles which is Re motion. So at point A Particles will start moving or loses the particle start losing its arrangement and fluidization is starts over here.

At point B the complete bed is at fluidized condition so beyond point B further increases in velocity can be obtained by relatively slight increase in pressure drop so here you see from point B when we increases the velocity all forces is equal over up to all forces become equal on the particle.

And then further increase in the velocity the pressure drop will not be observed over here because drag force is always may be equal to the weight of apparent weight of the particle so from B to C slight increase in pressure drop is observed that is very less.

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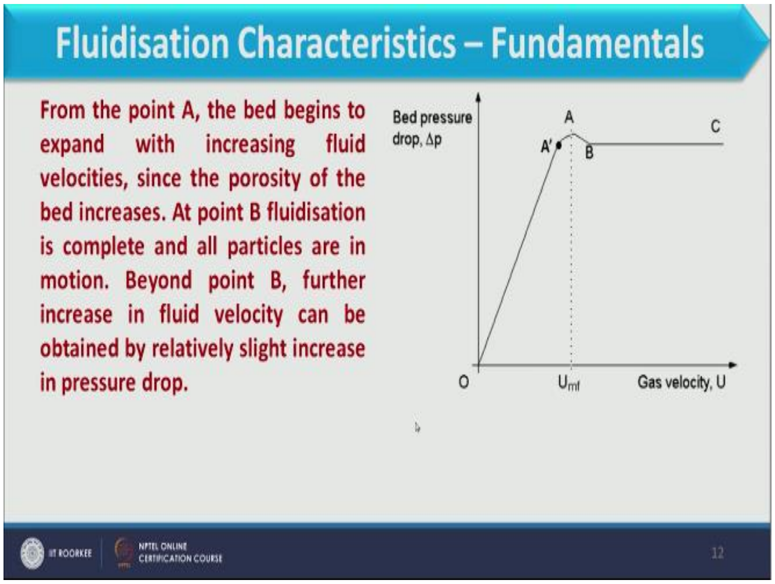

So it requires to overcome the increase in friction losses of the column consequently pressure drop remains essentially constant with increase in fluid velocity from point B and C so this is the whole pressure for the as well as the fluid velocity and we can observe from this we can draw this graph with the experimental data.

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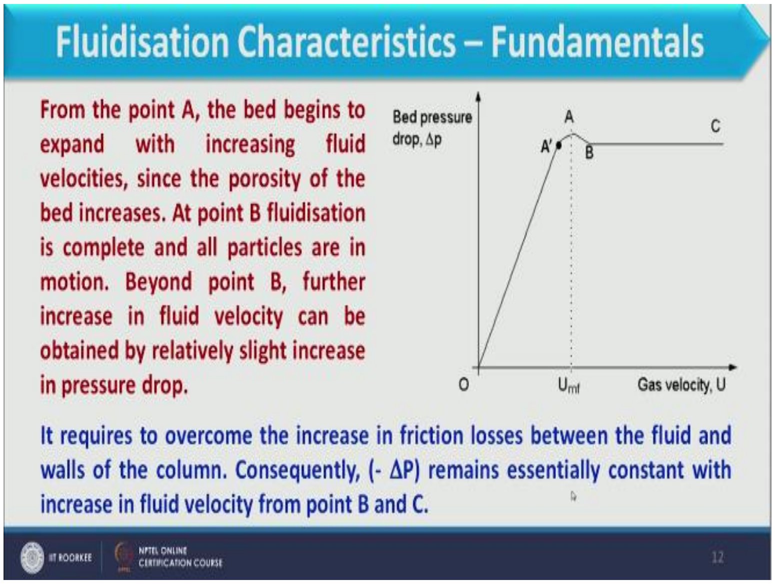

And then we can calculate what is the minimum fluidization velocity that experimentally so the force balance across the fluidized bed dictates that the fluid pressure los across the bed of particles is equal to the apparent weight of the particles per unit area of the bed. So total balance when we want to do should be like this pressure drop equal to weight of the particles – buoyancy force on particles and that should be divide by bed cross sectional area.

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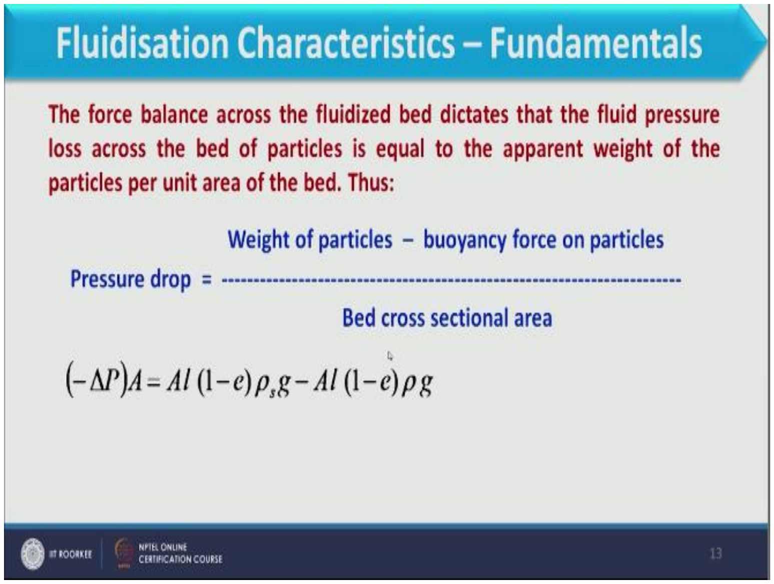

So when we are putting values over here you see pressure drop is (-Δp)A=A(1-e)p g-Al(1-E)p g what is Al is total volume of the A is cross sectional re and l is the height of the bed so thi is the volume of the bed 1-e is fluid section so Al-e is the total volume of the solid in the bed and e can multiplied by this row it will give the mass of the solid into g.

So that would be the weight of the particle and similarly we can define the force of the particle this is the volume of the bed 1-e that is the volume of the solid and that we have multiplied with the row that should be of fluid. Now if you consider the line you see it will consider the line fluid weight gas of the particle therefore here we have with the C mass as that of the particle.

So here we have the volume of the solid into row that should be a mass of the fluid into g and further half of solving further simplifying this equation we can have pressure drop during fluidization condition is equal to l-e p-p*g. so here we have discussed the fundamental characteristics of fluidization we have define the fluidization we have discussed different type of fluidization so we have stopping this lecture 1 over here we will continue the fluidization in lecture 2 so it’s all enough. Thank you.

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