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Unit operations of Particulate Matter

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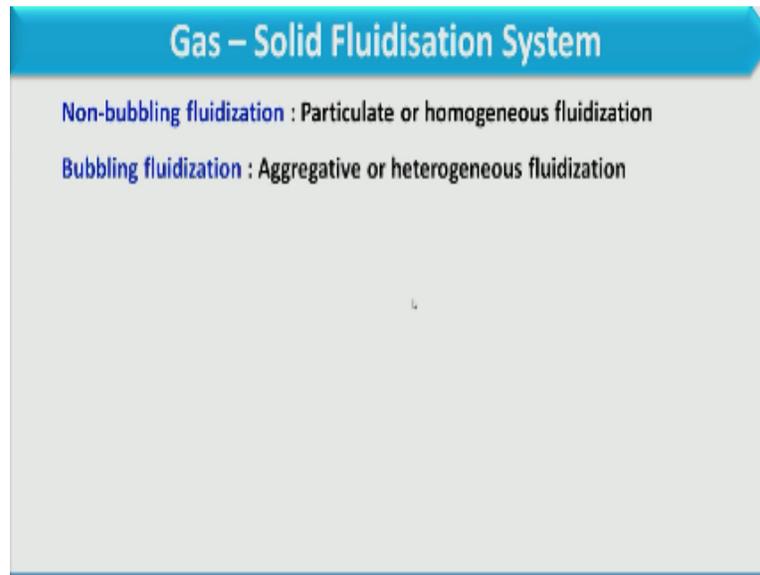
Gas Fluidisation (Part-01)

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Welcome to the fourth lecture of the week three and in the course of the unit of the operation of the particulate metal in this lecture we will discuss the gas fluidization and now here the lectures divided in to two part in the lecture two and lecture five, in the both lecture we will discuss gas fluidization however in the lecture four we will discuss the classification of the powders and how these powder behave in the fluidization environment that we will discuss where as the in the fifth lecture we will discuss the entertainment how the entertainment is counted in the fluidization process and then design the fluidizer and though a example we will disuses the application of fluidizer industry. So let start the fourth lecture fluidization here we are.

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And we discussing the non bobbling fluidization as well as bubbling fluidization you understand bubbling we have understand particulate homogeneous and the fluidization and the bubbling fluidization we called as aggregative and heterogeneous fluidization particular fluidization aggregative fluidization we have already discussed previously but here these two will be discussed ni the terms of the gas fluidization so the first we will discuss no bubbling fluidization which is nothing but he particulate fluidization and you understand the particulate fluidization is where the particle are in the uniformly distributed in the bed .

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Gas - Solid Fluidisation System

Non-bubbling fluidization : Particulate or homogeneous fluidization

Bubbling fluidization : Aggregative or heterogeneous fluidization

Non-bubbling fluidization

Although fine particles generally form fluidised beds more readily than coarse particles, surface-related forces tend to predominate with very fine particles. It is very difficult to fluidise some very fine particles as they tend to form large stable agglomerates that are almost entirely by-passed by the gas. In some extreme cases, particularly with small diameter beds, the whole of the particulate mass may be lifted as a solid 'piston'.

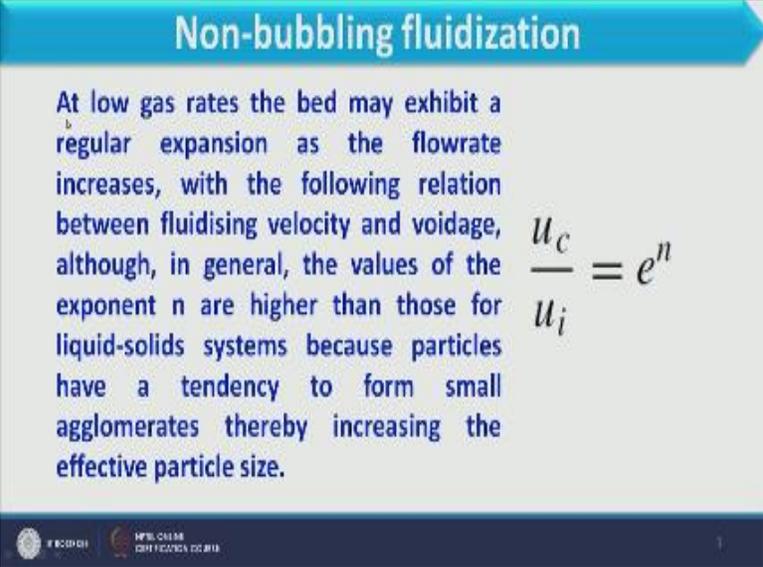
So let's start with the no bubbling fluidization although the fine particles are in the generally form and in the fluidized bed in the readily then the Coarse particles the surface related forces tend to the dominate with very fine particle although here you see though find in the fluids particle easily. in the comparison in to the course particle but has the same as far as fluidization is a concert in the because of the surface related forces are related in the fine particle .

So it is very difficult in the fluidized some very fine particles hills they tend to form large stable aggregates are almost entirely passed by the gas here what happens we are considering very small particles due to the surface particle in the forces and they join the other particles and prepare the abbre grace particle, so will be in the larger in the gas of the fluid makes it do die it pipe pass these particles

So that is the article in the very fine particles in some extreme cases particularly with some meter beds the whole of the particular mass will be lifted as a solid piston so here we are considering very fine particles sane this situation is occurs instead of the fluidizing it fluidizing a single particle or the fluidizing or the particles the group of the particles what happens the all find join

together and when it is fluidized the whole section is fluidized once. So that will be lifted as the piston.

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Non-bubbling fluidization

At low gas rates the bed may exhibit a regular expansion as the flowrate increases, with the following relation between fluidising velocity and voidage, although, in general, the values of the exponent n are higher than those for liquid-solids systems because particles have a tendency to form small agglomerates thereby increasing the effective particle size.

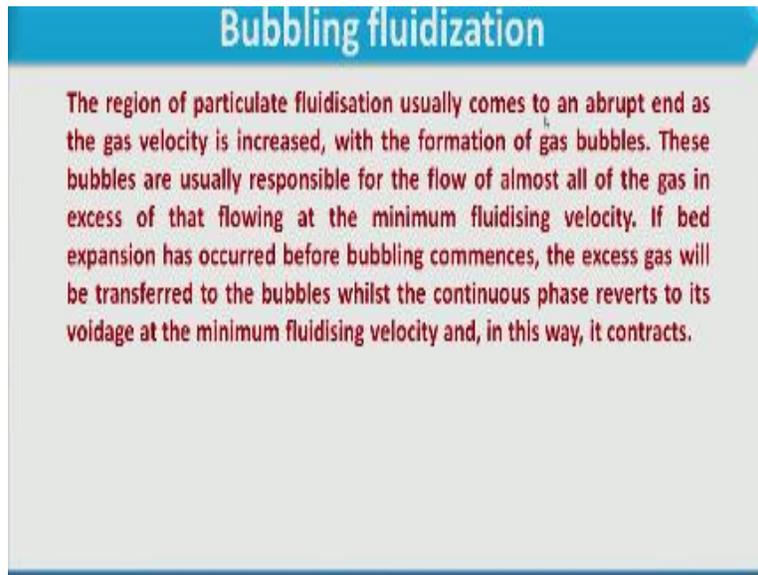
$$\frac{u_c}{u_i} = e^n$$

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At the low gas rates the bed may exhibit the regular expansion as the flow rate increases with the following relation between fluidising velocity and the voidage regular expansion will be observed with the dealing with the gas in the velocity increases the n the speaks about the voidage will be related to the velocity and in the generate the following expansion and in the end you see the expression here we have the expression and the N are higher those for the liquid solids system.

Because the solid system will exhibit the agglomerates thereby increasing the effective particle size .so here you see when we have we are dealing with at the flow rate in the non uniform in that can correlate in the voidage of that but in the n value to be in the liquid fluidization now we are discussed own the region particulate fluidization.

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As the gas velocity has been increased, so in the bubbling fluidization what happens bubbles form inside the bed and form particulate fluidization comes to the end these which are formed as the particulate fluidization are usually responsible for the flow of almost all of the velocity.

In the expansion as occurred before the bubbling commences the excess has been transferred to the bubbles continuous in the reverse to its which act as a minimum fluidizing and in this way interact here we are dealing with the bubbling fluidization how the bubbles are formed when we are having the fluids bubble and the velocity increase then after the achieving the minimum velocity if the gas the best the higher in that instead of the expansion of the bed.

That the gas is accumulated as bubble and that bubble will not increase in the moving from in the bottom of the bed from the higher side and the continuous face particles are available that comes down so that section is that sections where particles are available it contracts whereas the other section have for me of other section has different heat bubbles.

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Bubbling fluidization

The region of particulate fluidisation usually comes to an abrupt end as the gas velocity is increased, with the formation of gas bubbles. These bubbles are usually responsible for the flow of almost all of the gas in excess of that flowing at the minimum fluidising velocity. If bed expansion has occurred before bubbling commences, the excess gas will be transferred to the bubbles whilst the continuous phase reverts to its voidage at the minimum fluidising velocity and, in this way, it contracts.

Particulate fluidisation stops, aggregative fluidisation starts

The upper limit of gas velocity for particulate expansion is termed as the minimum bubbling velocity, u_{mb} .

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So the main point is particulate fluidization stops aggregative fluidization starts, so in gas case in the case of gas fluidization what happens at low flow rate particulate fluidization proceeds where as when velocity increases it converts into the aggregative fluidization and the formation of bubbles occur when we are having excess air in the bed, so upper limit of gas velocity for particulate expansion is termed as minimum bubbling velocity. Here we have understood that once particulate fluidization will occur and after that aggregative fluidization will occur.

And therefore we can say that bubble fluidization bubble formation is occurring in aggregative fluidization and therefore we can say the minimum velocity of gas where bubble will be formed that will be the highest velocity where particulate fluidization occurs.

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Classification of Powders

Geldart (1973) classified powders into four groups according to their fluidization properties at ambient conditions. The Geldart Classification of Powders is now used widely in all fields of powder technology.

Group A powders - when fluidized by air at ambient conditions, give a region of non-bubbling fluidization beginning at U_{mf} , followed by bubbling fluidization as fluidizing velocity increases.

Group B powders - give only bubbling fluidization under ambient conditions.

Group C powders - very fine, cohesive powders which are incapable of fluidization in the strict sense.

Group D powders - are large particles that are distinguished by their ability to produce deep spouting beds

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And in this slide we will classify different powders, now why we are classifying because each powder has different tendency different particle size so how these powder behave with the fluidize environment how these powder behave in fluidization environment that we have to observe, so the ease with which a powder can be fluidized by a gas is highly depended on the property of particles in general fine, low density particles fluidized more evenly than large dense one provided that they are not so small that they make agglomerates.

So here we have different powder and each powder has different category because it has different property and they behave differently during fluidization for example spherical particle fluidized easily in this respect long needle shape particles are most difficult to fluidize so particles of mixed sizes will usually fluidize more evenly then those of uniform sizes, so here we should also understand that it depends on the shape of the particle like when a spherical we are spherical particle we are considering.

It will fluidize easily where as if it is needle type or a stripe type particle it will not full it will not fluidized easily and when we are considering mixture of particles where different shapes are

available, so that can be that those particle will be fluidized evenly in comparison to uniform particle.

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Classification of Powders

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Group B powders - give only bubbling fluidization under ambient conditions.

Group C powders - very fine, cohesive powders which are incapable of fluidization in the strict sense.

Group D powders - are large particles that are distinguished by their ability to produce deep spouting beds

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So now we will discuss the classification of powders Geldart classified powders into four groups according to their fluidization property at ambient condition, Geldart classification of powders is use widely in all fields f powder technology so here we have four group, group a powder when fluidized by air at ambient condition give a region of non bubbling fluidization beginning at u_{mf} , now what is u_{mf} is minimum fluidizing velocity so the powder falling in group a that shows particulate fluidization when minimum fluidization condition.

Will be achieved and further bubbling fluidization occur when velocity increases group b powder give only bubbling fluidization condition under ambient conditions, so you see here we have group a where bubbling as well as non bubbling fluidization both will occur whereas in group b only bubbling fluidization occur under ambient condition group c powders these are very fine cohesive powders which are in capable of fluidization in a strict sense so you see when we are considering group a it has initially non bubbling fluidization then bubbling fluidization group d it

is started with bubbling fluidization group c it is very difficult to fluidize the powder which are falling group c, now we have group d powder.

These is are large particles that are distinguished by their ability to produce deep spouting bed so group d powder as a tendency to prepare to made this spouting bed now what is a spouting bed that we will discuss in subsequent slides, now as far as classification of powder is concern here we have four groups and now we will see the effect of parameter on behavior of these powders.

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Geldart's Classification of Powders				
GROUP →	GROUP C	GROUP A	GROUP B	GROUP D
Most obvious characteristic	Cohesive difficult to fluidize	Ideal for fluidization Exhibits range of non-bubbling fluidization	Starts bubbling at U_{mf}	Coarse solids
Typical solids	Flour, Cement	Cracking catalyst	Building Sand	Gravel, Coffee beans
PROPERTY ▼				
Bed Expansion	Low because of channelling	High	Moderate	Low
De-aeration rate	Initially fast, then exponential	Slow, linear	fast	Fast
Bubble Properties	No bubbles - only channels	Bubbles split and coalesce Maximum bubble size	No limit to size	No limit to size
Solids Mixing	Very low	High	Moderate	Low
Gas Backmixing	Very low	High	Moderate	Low
Spouting	No	No	Only in shallow	Yes, even in deep beds

Here we have Geldart classification of powders group c a b and d here you see the first point is most obvious characteristic what is the most obvious characteristics of these powder group c if we are considering these are cohesive and very difficult to fluidize group a ideal for fluidization exhibits range of non bubbling fluidization, so group a has initially non bubbling fluidization then bubbling fluidization when we are considering group b it has bubbling fluidization but that will be started at minimum fluidization velocity.

And that will be started once minimum fluidization condition will be achieved and further group d these are course solid, so particles size are large in group d and similarly we have other

properties for example if we consider bed expansion group c low because of channeling so what happens when we consider group c powder because these are very difficult to fluidize so gas which is use to fluidize these powder that passes the powder without fluidizing it so that forms a channel inside the bed.

Group a that is ideal for fluidization so obviously bed expansion would be higher in that case group b as it is having bubbling a condition bubbling fluidization occurs over here so bed expansion is not that much high it is moderate whereas in group d where we are consider in large particle and a spouting bed are formed their bed expansion is very low. So similarly other parameters you can study for these four groups of powder.

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Gas fluidization-Minimum bubbling velocity

The superficial gas velocity at which bubbles first appear is known as the minimum bubbling velocity U_{mb} . Abrahamsen and Geldart (1980) correlated the maximum values of U_{mb} with gas and particle properties using the following correlation:

$$U_{mb} = 2.07 \exp(0.716 F) (x_p \rho_g)^{0.06} / \mu^{0.347} \quad x_p = \text{mean sieve size of a powder; m}$$

Where, F is the mass fraction of powder less than 45 μm .

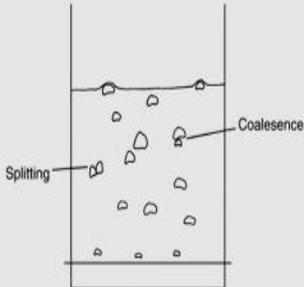
Now how we can calculate the minimum bubbling velocity for different condition so the superficial gas velocity at which bubbles first appear is known as minimum bubbling velocity. Abrahamsen and Geldart correlated the maximum value of U_{mb} with gas and particle property using the following correlation where U_{mb} that is minimum bubbling velocity is equal to 2.07 exponential 0.716 f x $x_p \rho_g^{0.06} / \mu^{0.347}$.

Now in this expression x_p is mean sieve size of the powder we have to first carry out the particle size analysis we should first carry out the particles analysis to know what is the mean size available in powder and in this expression f is the mass fraction of powder less than 45 mm so what is that f here we have different sizes of particle ion the powder and the fraction of particles which are lesser than 45mm that we have to consider as f so considering this expression we can calculate minimum bubbling velocity.

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Gas fluidization-Minimum bubbling velocity

In Group A powders when $U_{mb} > U_{mf}$ bubbles are constantly splitting and coalescing. This makes smooth fluidization.



Through splitting and coalescence, bubbles achieve a maximum stable size, effectively independent of gas velocity or vessel size.

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Now what happens in group a, group a powders where $U_{mb} > U_{mf}$ group a powder what this powder what is this powder this is ideal for fluidization and in this case minimum bubbling velocity should be greater than minimum fluidizing velocity and at this condition bubbles are constantly splitting and coalescence this makes smooth fluidization so if you see this figure here we have splitting of bubble and few and these bubbles are joining so coalescence will occur over here so splitting and coalescence occur simultaneously in this bed.

So through a splitting and coalescence bubbles achieve a maximum stable size effectively independent of gas velocity or vessel size. So when bubble are formed these are continuously broken as well as joined other bubbles to make larger bubble. So this happen in group A.

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So you see in this slide I have shown two video in video one if you see this video here we have non bubbling expansion of fluidized bed of group a particle here we have non bubbling expansion of a fluidized bed of group a powder now if you absorb this video what happens the bed is continuously moving it means all particles are continuously moving in this and the uniformity we can easily absorbed over here.

Whereas when we are considering this video where bubbly fluidization occur of group a powder here you see bubbles are formed and when we absorb this bubble size will keep on increasing when it is moving from bottom to top, so in this way the bubble bypass the solid and fluidization will not occur properly.

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Gas fluidization-Minimum bubbling velocity

In Group 'B' $U_{mb} = U_{mf}$, bubbles continue to grow in size, never achieving a maximum size. This makes for rather poor quality fluidization since there are large pressure fluctuations.

It shows the continual increase in size of bubbles in a two-dimensional fluidized bed of a Group B powder. Bubbles increase in size with distance from the distributor and with increasing gas velocity. Bubble size is limited only by the vessel size.



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And when we consider group B as we know that in group b only bubbly fluidization occur so when minimum bubbling velocity is equal to minimum fluidization velocity bubbles continue to grow in size never achieving a maximum size this makes for rather poor quality fluidization since there are large pressure fluctuation. So what happens when you absorb this video here though granules are there but when gas enters in to this it enters in the form of bubble?

Now when the gas enters in to this it forms bubble and these bubble will keep on increasing it size till it move from bottom to top and at the top eruption of bubble occur and due to this it carry some solid particle but it will be again fall down in the bed as you can absorb here. So this video shows the continual increase in size of bubble in a two dimensional fluidize bed of a group powder, bubbles increase in size with distance from the distributor and will increasing gas velocity.

Bubble size is limited only by the vessel size so bubble size will be dependent on the diameter of Colum it cannot be larger so it is only dependent on the Colum diameter.

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Gas fluidization-Minimum bubbling velocity

In Group C powders the inter-particle forces are large compared with the inertial forces on the particles. As a result, true fluidization does not occur.

Bubbles, as such, do not appear; instead the gas flow forms channels through the powder.



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Now when we consider group C powder we have discussed that in group C powder fluidization is very difficult to achieve and that we can easily absorb through this slide, now in this slide I have shown this video so what happens in this video when gas starts passing it you see there is no fluidization occurring the particle will not start moving however after some time the block of particle will move upward through the gas, so gas will carry not a single particle nor a number of particles but the bulk of particles or we can say it will start it will let the powder move in the form of a piston and then it breaks down and then after some time.

Channeling occurs inside this, so what happens so in group C powder the inter-related particle forces are large compared to inertial forces on the particle and as a result true fluidization does not occur. So that is a tendency with group C powder particles that the inter-related forces are very high so these are connected to each other very tightly and therefore it is very difficult to fluidize a bubble as such does not appear instead the gas flow forms channels through the powder as we have already discussed.

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Gas fluidization – Slugging

When the size of the bubbles is greater than about one-third of the diameter of the equipment their rise velocity is controlled by the equipment and they become slugs of gas. Slugging is attended by large pressure fluctuations and so it is generally avoided in large units since it can cause vibration to the plant.



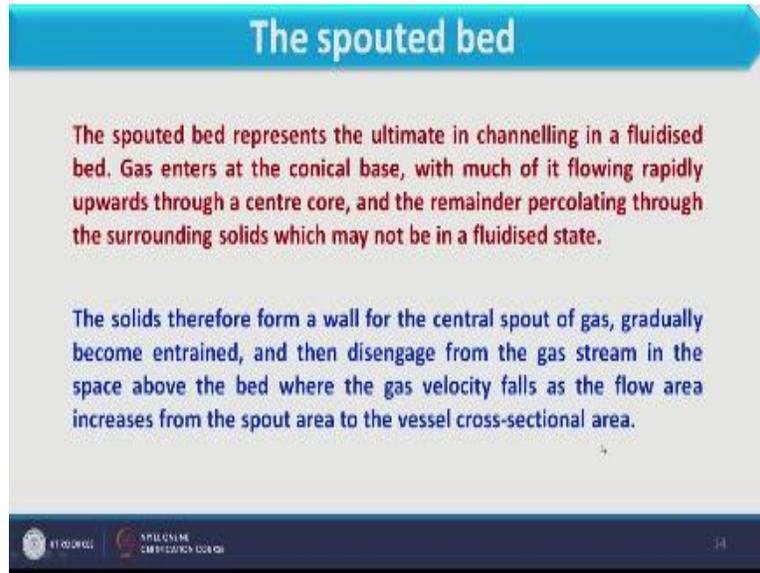
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Now there is another problem with gas fluidization that it has the problem of slugging, what is slugging? When the size of the bubbles is greater than about one third of the diameter of the equipment their rise velocity is controlled by the equipment and they become slugs of gas. So if you see this video here what happens gamers are there, due to formation of bubbles, instead of movement of particles the bulk of particle move together and if you see size of bubbles is equal to the diameter of column, and then after sometime it falls back, so this is nothing but slugging.

So slugging is attended by large pressure fluctuations and so it is generally avoided in large units since it can cause vibration to the plant and similarly you can absolve slugging in this video. Now here we have spouted bed, as we have discussed that the powder falling in group d behave as a spouted bed. Now what is the spouted bed?

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The spouted bed represents the ultimate in channeling in a fluidized bed. Gas enters at the conical base with much of it flowing rapidly upwards through a centre code, and the remainder percolating through the surrounding solids which may not be in a fluidized state. So what happens in spouted bed, when the gas enters into this it form a channel in between and the particles which are falling in this channel, they rises and then they fall to other side.

However the particle which is not falling in the path of gas they remain as it is, so this way the spout forms the fluidized bed. The solids therefore forms a wall for the central spout of gas, gradually become entrained , and then disengage from the gas stream in the space above the bed where the gas velocity falls as the flow area increases from the spout area to the vessel cross – sectional area. So what happens when we are considering spouting the gas velocity, gas passes through a channel in between, so when the channel of a small diameter velocity will increase?

However when it reach to upper level of the bed it come across the larger diameter of the column and then velocity decreases suddenly and then, therefore it carries the particle they fall suddenly to the bed.

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The spouted bed

The spouted bed fluidisers are used as efficient dryers for drying seeds such as rice and wheat from high moisture content (MC; 20–25%wb) to medium MC (\approx 18%wb).



So you can absorb the spouting bed in this video, where the gas passes over here, where the gas passes from the bottom and it forms the channel, so you see other particle which is not falling in the path of gas, they will maintain the uniform height of the bed. So you see particles which are available in channel they rise and then they fall because, when the gas reaches at the point it come across larger perception area and therefore its velocity will decrease suddenly and the particles fall.

So spouted bed fluidizers are used as efficient dryers for drying seed such as rice and wheat from high moisture content that is 20 to 25% to medium moisture content that is 18%. So in this lecture 4 we have discussed different types of powder, different types of conditions which are occurring in these powders and here we are stopping this lecture, we will continue gas fluidization in next lecture, so that is all for now thank you.

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