Fluidization Engineering
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Lecture – 11
Gas Distribution to Distributors

Welcome to massive open online course on fluidization engineering, today's lecture will be on gas distribution through distributor. So, what to learn to learn in this lecture that of course, you will learn what happens at the bottom of dense fluidized bed, and what are the different types of distributor are been used for distribution of gas for the fluidization and also how to design a gas distributor to be discussed in this lecture. Now you see there are different types of distributor through which gas is distributed inside the fluidized bed.

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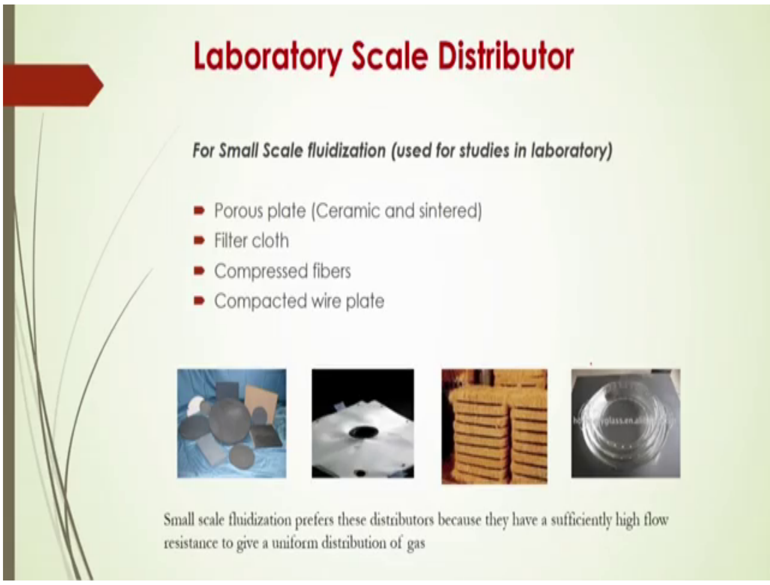

Of this first stage of bubbles for bubbling fluidized bed or gas distributed in particular bed also. So, gas distribution is the main important factor for fluidizing.

Now, you will see there are two types of gas distribution one is laboratory scale distributor and the industrial scale distributor. For small scale fluidization then early used for studies in studies in laboratory, there you will see several different type of distributors are available. One is porous plate that is made ceramic or sintered materials filter cloth compressed fiber and complicated wire plate type distributor.

Here see the figures in this figure, this is called porous plate and this is filter cloth type and this compressed fibers and compacted wire plate through this distributor you will see there will be a of course, force through which the gas should be distributed as a small bubbles from the distributor or fine bubbles at the distributor and beyond that this bubbles or gas which is distributed as a this first page of bubbles will be coalescence and it will be becoming bigger and then it will go off due to the buoyancy effect and at the top then it will be collapse and so, these are this laboratory scale distributor, there is a generally used for small scale see for studies and the small column or small diameter column there will be a fixation of this distributor and through this gas should be distributed.

Now small scale fluidization prefers this distributor because they have significantly high flow resistance to give a uniform distribution of gas.

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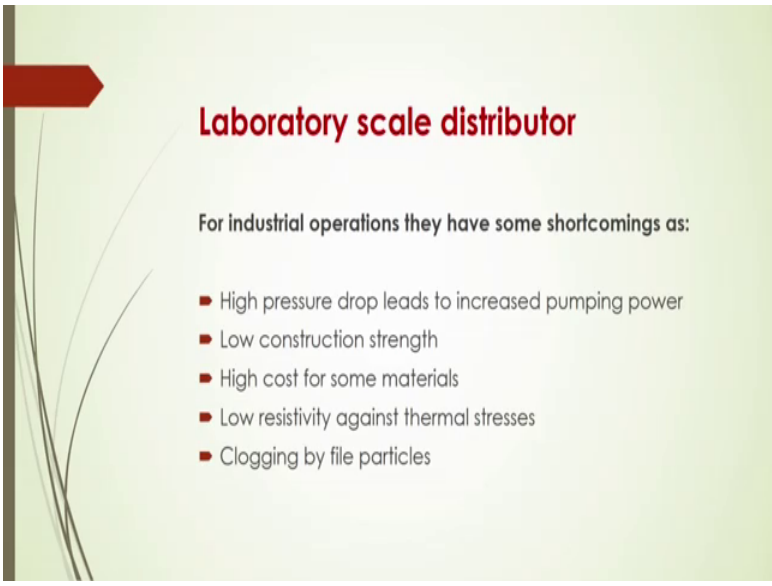

Now, laboratory scale distributor of course, you will see for industrial operations they have some shortcomings like high pressure drop may leads to increase the pumping power and low construction strength, and also high cost for say material and low resistivity against to thermal stresses, and clogging by file particles there is a possibility. So, for small scale you will see there will be a small up hole through which the particle also may deposited and because of which it is called the clogging of fine particles and distribution will be uneven fluid bed. So, that is why this laboratory scale distributor may not be suitable for industrial purpose.

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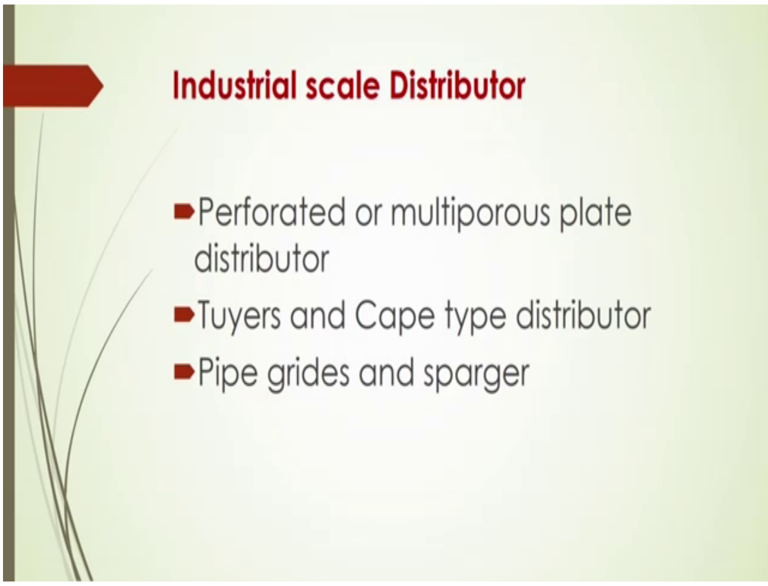

Now, what are those industrial scale distributor then we used for fluidized bed. Let us see again different types of industrial scale distributors are available, one is perforated or multiporous plate distributor. Some other that Tuyers or cape type distributor and some others are pipe grides and sparger. So, all those distributor have some advantage and some disadvantage of course, we will be discussing successively.

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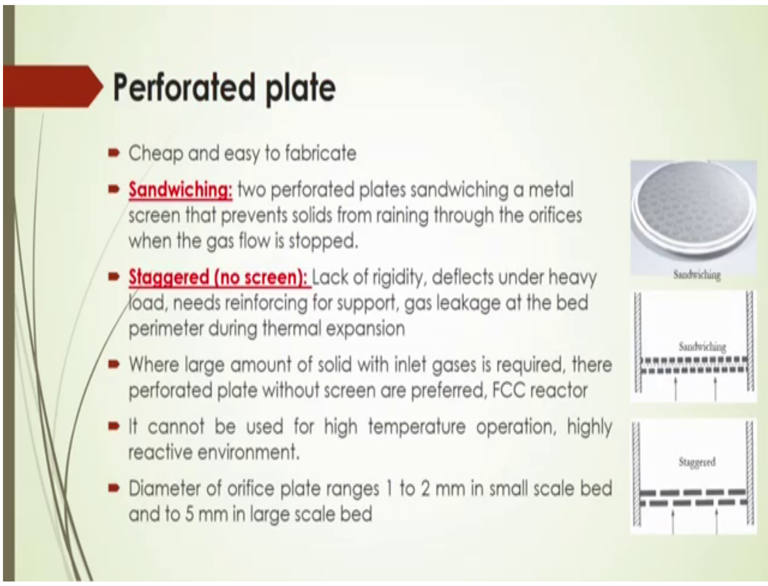

And here let us see, what is the characteristics of the perforated plate? So, this perforated plate see the figure here diagram or given here different types of perforated plates are also available commercially. So, these perforated plates are cheap and easy to fabricate, some perforated plates are sandwiching some perforated plates are staggered with screen and without screen.

So, sandwiching means here two perforated plates, sandwiching a metal screen that prevent solids from ranging through the orifices, when the gas flow stopped. So, this is actually what happened, this plates sandwiches a metal screen like bright here, that prevents solids in this case advantages that, by sandwiching this perforated plate you can prevent the solids deposition inside the bed and you can get the even distribution also in industrial scale. And staggered without screen you will see some disadvantages are in this case lack of rigidity of course, they are it deflects under heavy load.

So, needs in that case reinforcing for support gas leakage, at the bed perimeter during thermal expansion. So, these are the some characteristics of this staggered this these are staggered perforated plate without screen here see staggered, see this holes are unevenly distributed through holes this gas are flowing through this force for orifices. Where large amount of solid with inlet gases is required that case perforated plate without this screen are generally preferred like in FCC reactor, this type of perforated plates are being used. It cannot be this perforated plate cannot be used for high temperature operation and also it cannot be used for highly reactive environment.

So, in that case high temperature may be rigidity of this materials will be withheld and that is why you will see this high temperature it will not be a suitable may be broken may be attrition will be there because of this sudden drop of pressure there. And of course, diameter of the orifice plate generally ranges from 1 to 2 millimeter in small scale bed and to five millimeter in large scale bed.

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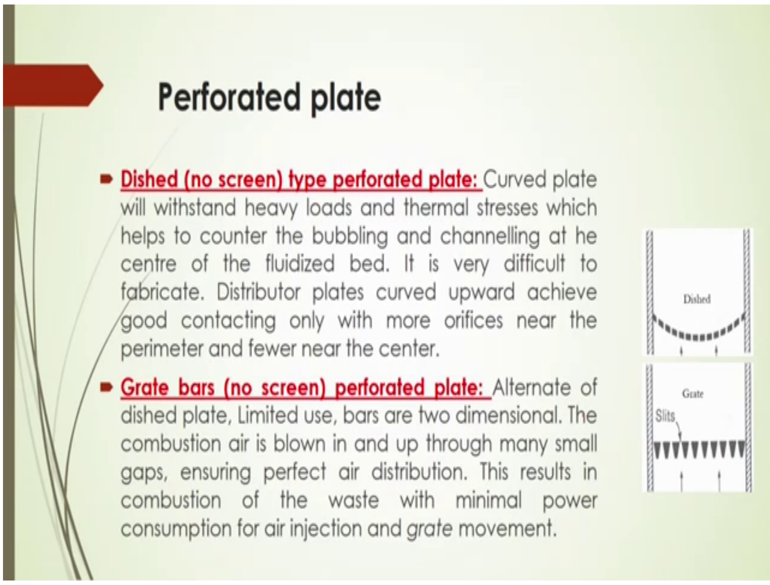

And other different type of perforated plates like dished type perforated plate; in this case it will be curve shape this curve shape dished perforated plate. In this case this type of perforated plate withstand heavy loads and thermal stresses, which helps to counter the bubbling and channeling at the center of the fluidized bed.

And it also it is very difficult to fabricate in this case this is the disadvantage it is very difficult to fabricate, in this case distributor plates curved upward to achieve good contacting only with more orifices near the perimeter and fewer near the center. Another type is called grate bars; it is also there will be no screen this type of perforated plate actually alternate this dished type plate. These are the limited in use and bars are two dimensional generally preferred the combustion air is blown in and up through this many small gaps, which ensures the perfect air distribution. So, this is results in combustion of the waste with minimal power consumption for air injection and grate movement.

So, this type of bars the grate bars we will see in this diagram this type of grate bars, they are generally used for many small scale and limited use where perfect air distributions are required within a small scale operation and also for the minimal power consumption for air distribution or gas distribution inside the bed. So, for this purpose this type of grate bars are being used.

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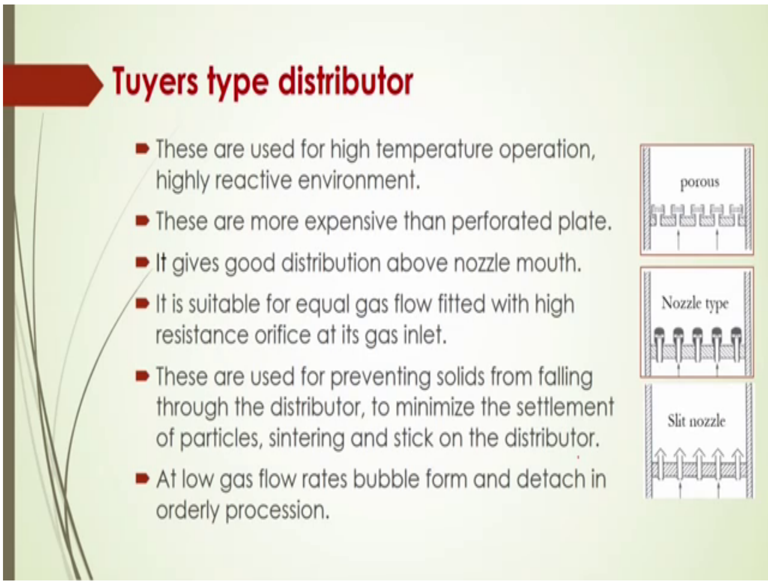

Another type is called Tuyer type distributor, these are generally used for high temperature operation and it is also it is suitable for highly reactive environment. These are more expensive for operation than perforated plate, it gives good distribution above the nozzle mouth and also it is suitable for equal gas flow through the distributor, and also if there is high resistance orifice are been used for this type of Tuyers, then you can evenly distribute the gas inside the bed.

And there are used for prevailing solids also from falling through the distributor to minimize the settlement of particles, and sintering and stick on the distributor also is one important factor to get this highly resistive distributor of this type of distributor. At low gas flow rates it generally bubbles form and detach in orderly procession in this type of tuyers. So, this tuyers type distributor it will be very must preferred for low gas flow rate where bubbles are formed, and when this bubbles detach in orderly processions are required for getting different flow regimes of the bubble fluidized bed.

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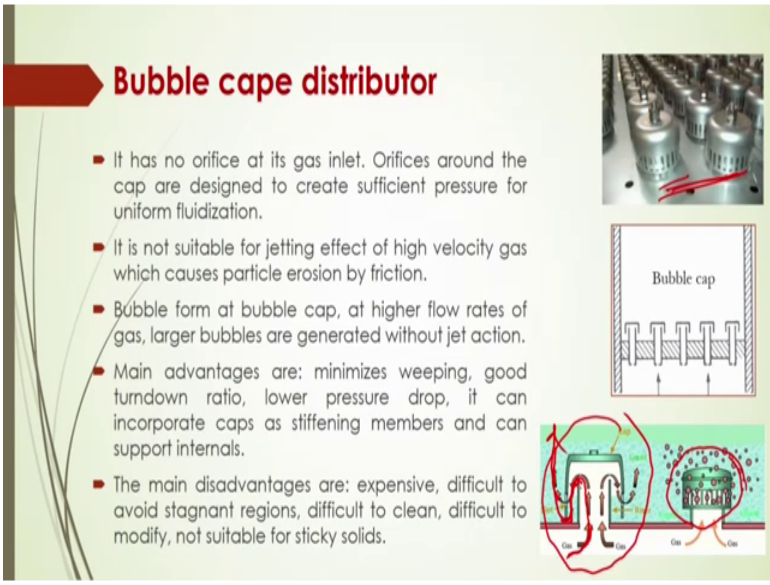

And bubble cape distributor is another important, which are widely used in industry for fluidizing of different multiple system, and in this case of course, there will be no orifice at gas inlet and orifice around the cap are generally designed to create sufficient pressure for uniform fluidization. And it is not suitable actually for jetting effect somewhere some fluidized bed the jet fluidized bed is also some particular operation it is suitable, but it is not suitable for jetting effect of this type of bubble cap distributor because there high velocity gas which causes particle erosion by friction inside the bed.

And bubble form bubble form at the bubble cap at higher flow rates of gas and larger bubbles are generated without jet action in this type of bubble cap. See this figure here how this bubble cap distributor are being given this is the actual this bubble cap distributor, and this is the bubble cap and if you are see the flow from the bottom of this distributor how gas is coming out and then, it will be just inverting and horizontal it will passing and then bubble will be coming out like this.

So, this type of. So, there will be actually window type here this cap. So, is cap there will be say window here through window the bubbles or gas will be horizontally coming out and making a bubble like this. So, the main advantage of this type of bubble cap distributor is that it minimizes the weeping and good turndown ratio lower pressure drop, it can incorporate caps as stiffening members and I can support internals also.

The main disadvantage is that is the expensive of course, the difficult to avoid stagnant regions some stagnant regions will form. So, it is difficult to actually control that stagnant region and difficult to clean of course, difficult to modify not suitable for the particle size the size is less than 30 microns or various sticky solid particles you cannot use this type of bubble cap distributor for fluidization.

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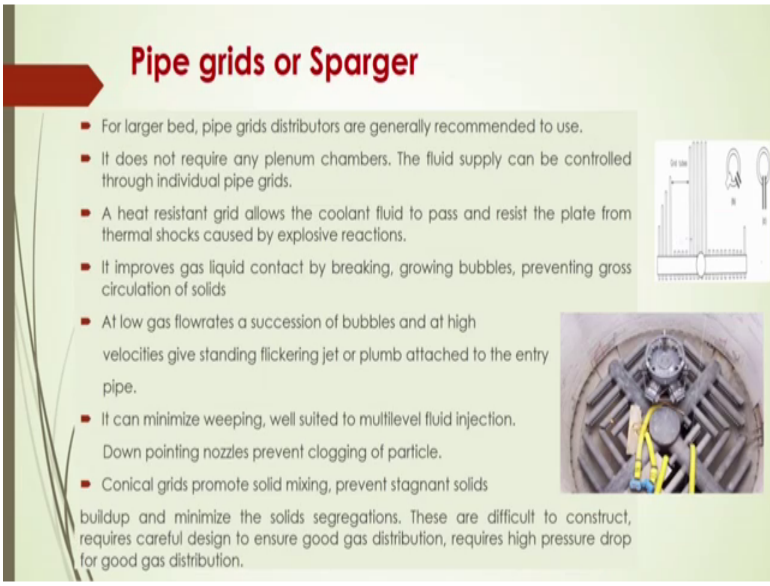

And another is called pipe grids or sparger. In this case if the picture here this is the one pipe through the pipe gas is coming and also in each saw pipe of this here, there will be a force and through which this bubbles are coming and gas is coming and permits a bubbles and it will be distributed inside the bed.

So, for larger bed this pipe grid distributor are generally recommended to use, and it does not require any plenum chamber generally for others distributor this plenum should be designed and it will be actually attached from the bottom and there should be a gap to just enhance this or equally distribution of the gas without disturbing through this nozzle of this gas distribution and then it does not require any plenum chamber of course, the fluid supply can be controlled to the individual pipe grid.

So, in this case fluid will be supplied for this fluid or gas here gas or liquid will be supplied through individual pipe grids. So, a heat resistance grid here of course, you can design and through which this gas distribution will be there.

So, it allow sometimes the coolant fluid to pass and resist to the plate, from thermal shocks which is caused by explosive reactions. So, for this heat resistance grid of course, should be designed and also install in the bed. And this type of distributor of course, improves the gas liquid contact by breaking the bubbles or breaking the draw plates or breaking the liquid gas and liquid by making the interface between the gas and liquid and also growing bubbles also preventing, you can say if there is any gross circulation of the solid inside the bed that in this type of distributor will prevent.

And at low gas flow rates it is seen that from this type of distributor is succession a bubbles and at high velocities, gives standing flickering jet or plumb attached to the entry pipe they are. So, it can minimize weeping and well suited to multi level fluid injection possible. And also sometimes this type of beads will give you the down pointing nozzles prohibition which made prevent the logging of the particle and conical grids promote solid mixing, even prevent stagnant solids.

So, these are actually different forms of this pipe grid distributor which have some advantage and disadvantage. So, in this case buildup and minimize the solid segregation these are difficult to construct, and requires careful design to ensure good gas distribution requires high pressure drop for good gas distribution also. So, though these pipe grids are have some disadvantage of higher pressure and this and also careful design also solid segregation buildup. So, in that case careful design should be considered for this type of, it has several advantages compared to the other and it can use industrially.

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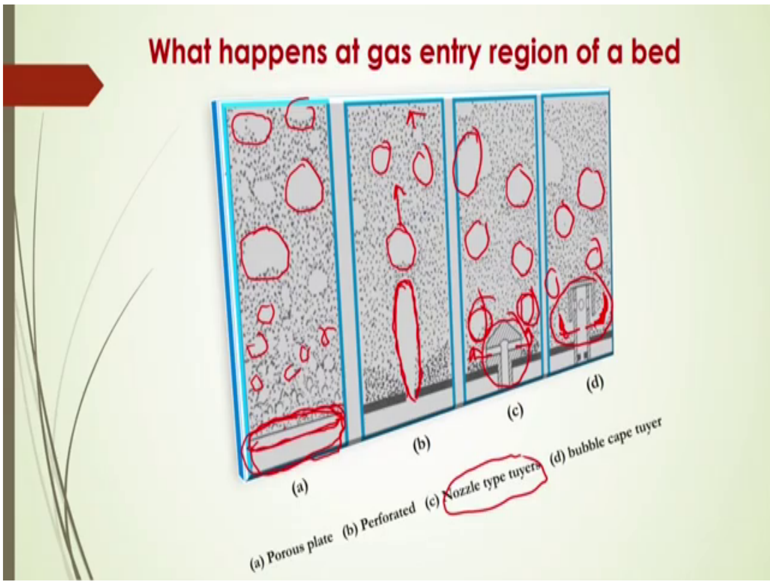

Now, what happens at gas entry region of a bed? So, here gas entry region means to the distributor what happens. So, in this in this case how actually gas is actually distributed through the different distributor? Here see a this is one type of this called porous plate this is porous plate here. So, this is plenum. So, this through the porous plate here how gas is distributed as it phosphate a bubble, at the distributor you will see by entry region the bubbles are forming very small in size and after that whenever it will be going up this bubbles will try to coalescence to each other and becoming a bigger bubble here.

And after that due to their higher buoyancy it will go up, and at the top it will be dissolved whereas, in the perforated plate you will see jet type of jet will be forming gas jet will be forming like this is long jet and after a certain time after a certain pressure and the velocity you will see this jet will be breaking at its top and making individual bubbles, and then this bubbles will go up and at the top it will dissolve sometime this bubbles also make coalescence, and also it may breakup also due to some internal energy distribution there, and also higher kinetic energy supplied by this gas velocity of fluid velocity there.

And here this nozzle type tuyers this is this one nozzle type tuyers, in this case you are see horizontally gas will be making jet and from which the gas will be forming, and then this gas will be moving up and then it will be dissolved at the top.

So, how at this region see this is smaller bubble will be formed. And whenever it will going up it will become bigger due to their coalescence and bubble cap tuyer in this case here again this horizontal jet will be forming and from which there will be bubble formation. So, at the region of this there will be a smaller bubbles and may be the bubbles will be elongated and as jet form and it may not be the spherical one ah.

So, after certain height, it may become its spherical one because of the critical wave number where the criteria to become this non uniform surface to become a uniform curve shape and forming at the spherical bubble. So, this happened at the gas entry region of the bed from this distributor.

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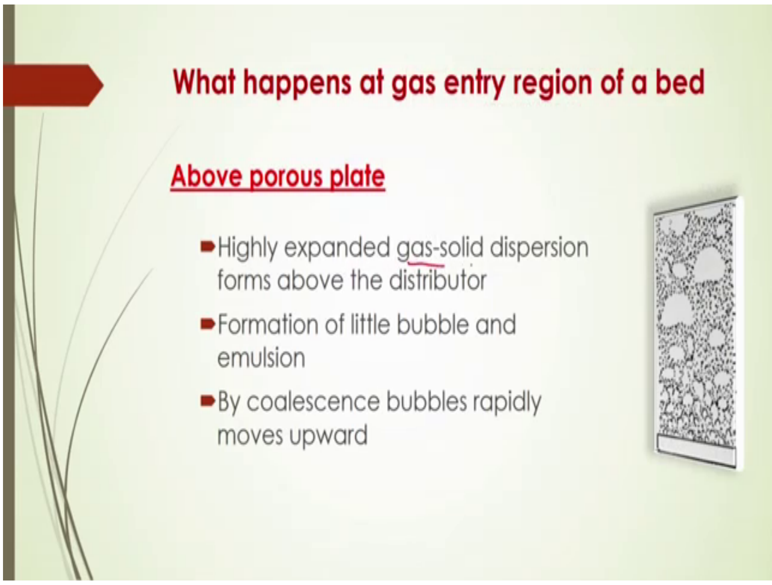

Now, what happens at gas entry region of a bed above porous plate? It is seen that highly expanded gas solid dispersion forms above the distributor, and also formation of little bubble and emulsion it is seen whenever gas is distributed from the porous plate and at its region of this distributor. By coalescence bubbles rapidly move upward due to their higher bounce above also perforated plate here.

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It is seen that there will be jet formation particles are seen to settle on the flat surfaces between flat surfaces between orifices to form. A dead zone the dead zone shrinks with increasing gas velocity, increasing particle size, increasing orifice size and decreased spacing of orifices and at high enough orifice flow rates and it is seen that large enough article size these dead zones are completely eliminated. So, at high flow rate this dead zone may be eliminated. So, above single orifice you will see that bubble rise velocity exceeds its linear growth rate.

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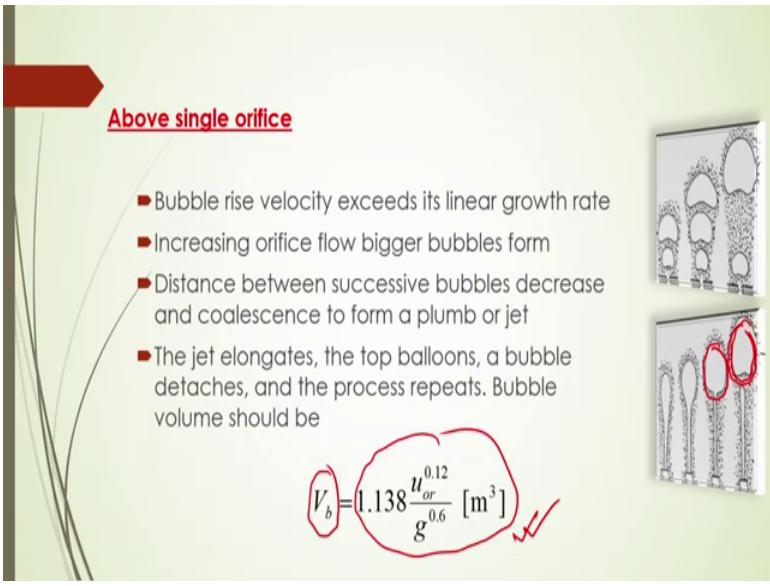

And increasing orifice flow bigger bubbles form. Distance between successive bubble decrease and coalescence to form a plump or jet. The jet elongates the top balloons a bubble detaches here this bubble here in this balloon you can say here bubbles will detaches and the process is repeated and bubble volume will be then bubble will then will go up and move with a certain velocity, and it will be dissolved.

Now what will be the volumes of bubbles that form from this jet? So, this bubble volume will be calculated by this equation here, this is V b will be represented by this bubble volume, then it will be is equal to 1.138 into u or to the power 0.12 u or means what was the velocity at this orifice of this distributor to the power 0.12 and g to the power 0.6. So, by this equation? You can calculate what should be the volume of bubbles that it has first it has from this jet through the single orifice.

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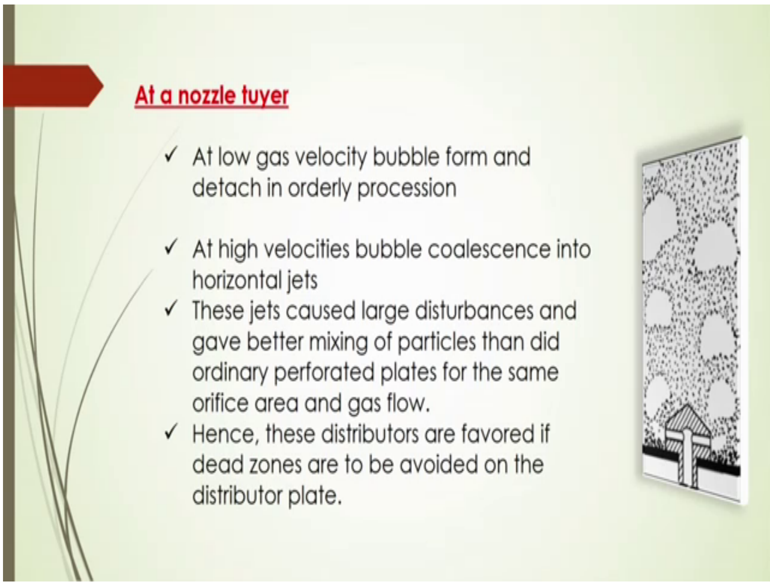

At a nozzle tuyer it is seen that, at low gas velocity bubbles form and detach in orderly procession like this here in this figure. At high velocities bubble coalescence into horizontal jets, these jets caused large disturbances and gave better mixing of particles and did ordinary perforated plates for the same orifice area and gas flow rate. Hence in this case these distributor are favored if dead zones are to be avoided on the distributor plate.

Now at a bubble cap tuyer it is seen that bubble form at bubble cap at higher flow rate of gas which is larger and at low gas flow rate the bubbles are formed will be generally small in size, and that case higher flow rate also it is seen that without making any jet this bubbles may form. And also in this case the advantage is that it may prevent from the falling through the distributor of the solids.

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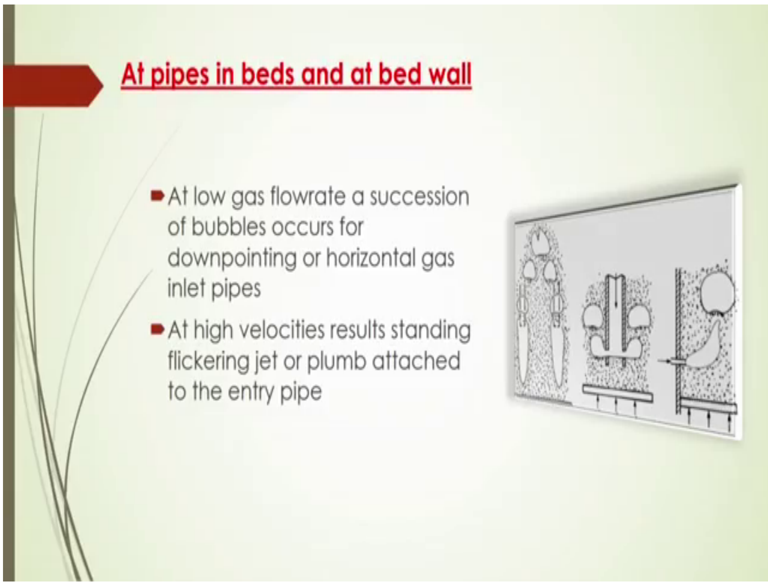

And then at pipes in beds and at bed wall this is at low gas flow rate a succession of bubbles occurs for down pointing or horizontal gas inlet pipes .At high velocities result standing flickering jet or plumb attached to the entry pipe like this in this figure and gas jets in fluidized bed. How gas jet is formed in this fluidized bed from the distributor.

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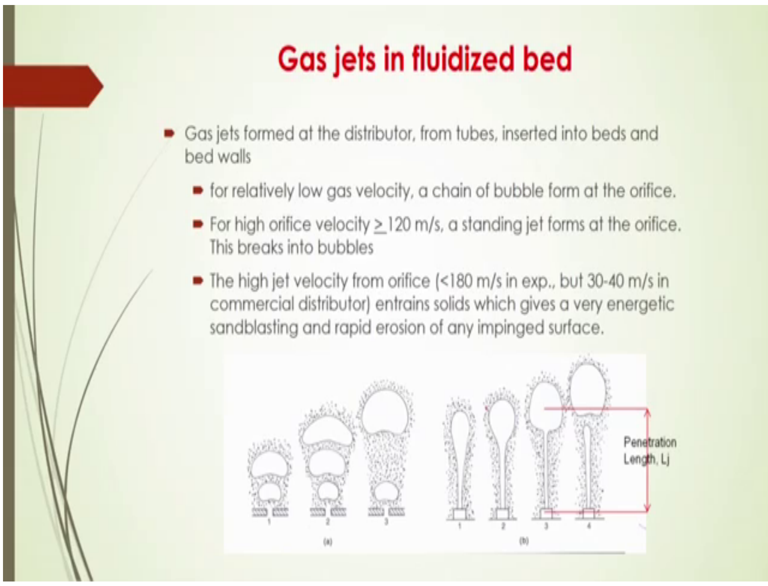

Now, gas jets forms at the distributor that that forms, tubes from tubes inserted into beds and bed walls. For relatively low gas velocity a chain of bubble form at the orifice. For high orifice velocity if its velocity is greater than 120 meter per second, it is seen that a standing jet forms at the orifice and this breaks into bubbles. At high jet velocity from orifice, but not greater than 180 meter per second in generally in experiment and, but 30 to 40 meter per second in commercial distributor, it is seen that that entrains solids which gives very energetic stand blasting and rapid erosion of any impinged surface.

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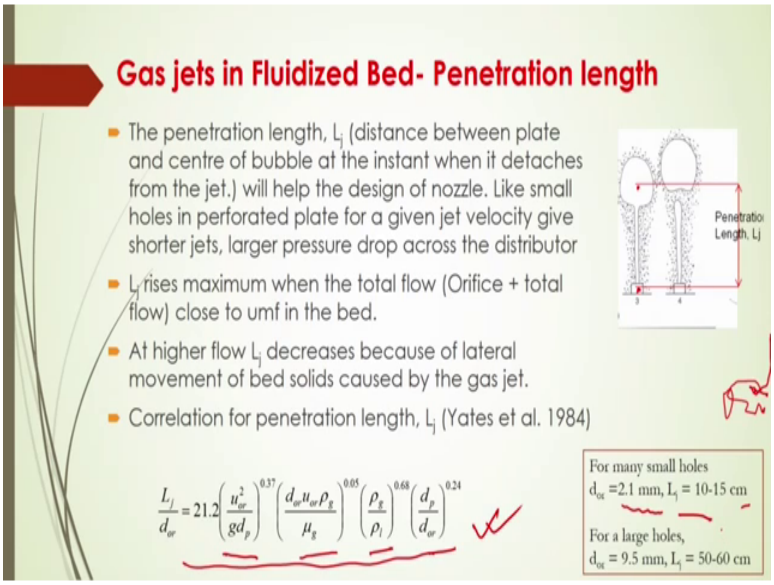

Gas jets in fluidize bed now penetration, penetration length what is that penetration length? The penetration length here what is that penetration length see in this figure, the from this gas jet at the top there will be permission of bubbles, and what is the center of this bubbles and from the entry point of this gas from the distributor, and this distance is called penetration length.

And here this penetration length actually the distance between plate and center of bubble at the instant, when it detaches from the jet. Which will help the design of nozzle like small holes in perforated plate for a given jet velocity give shorter jets. Larger pressure drop across the distributor in this case it happens L j rises maximum when the total flow or orifice plus total flow here close to minimum fluidization velocity in the bed. At lower flow rate L j increases whereas, at higher flow rate L j decreases, because of lateral movement of bed solids caused by the gas jet.

Now you can calculate this what should be the jet length or penetration length here from a correlation that is proposed by Yates et al meant 1984 which is depending on the orifice velocity, when particle diameter even what should be the density of the fluid ah.

So, from those variables Yates et al 9984 they have developed on correlation which you can calculate this penetration length. The correlations is like this they have considered that the ratio of L j to the d o r as a penetration ratio, this penetration ratio is a function of this dimension length groups here Froude number, Reynolds number, even ratio of gas to liquid density and ratio of particle to orifice diameter.

So, from this correlation you can calculate what should be the penetration length inside the bed at the region of distributor when the gas is distributed from the distributor of the orifice type of nozzle type distributor. In this case many for small holes you will see d o r generally 0.1 2.1 millimeter, it is seen that this jet length or you can say penetration length L j will be 10 to 15 centimeter. Whereas, for larger holes of orifice where this orifice diameter is 9.5 millimeter. It is seen that to this penetration length will be within the range of 50 to 60 centimeter.

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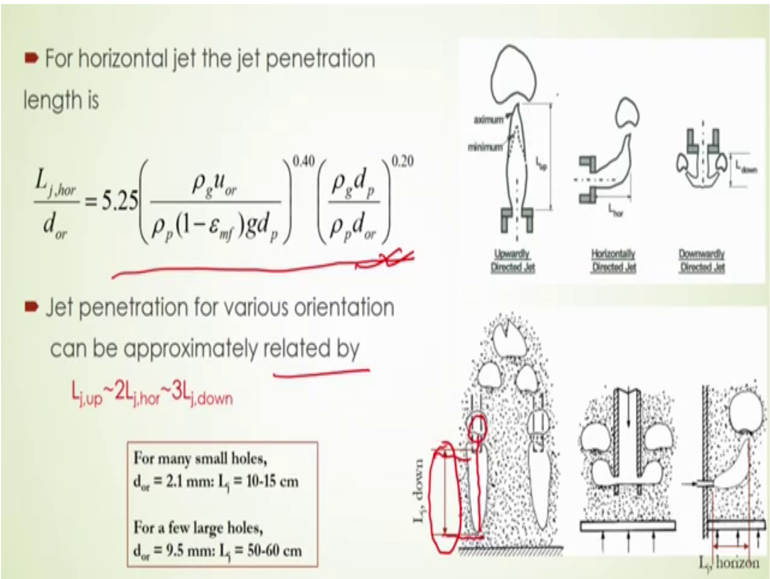

For horizontal jet the jet penetration length can be calculated from this relationship here, again this depends on this particle density minimum fluidization velocity even orifice velocity is there. So, from this correlation you can calculate what should be the penetration length if it is horizontally moving. So, and also there is a rough relationship for this jet penetration for various orientation, which can be approximately related by this L j up that will be caused to 2 L j horizontal approximately three into downward jet length.

That means, her the upward jet length penetration length upward penetration length it will be two times of horizontal penetration length whereas, it will be three times of downward penetration length. For many small holes it is seen that, this type of penetration length can be obtained by just doing the experiment to the orifice diameter of 2.1 millimeter, you can get this jet penetration length will be 10 to 15 centimeter in a range. So, here this diagram you are seen this sometimes these nozzles will give you the downward jet and this length is called L j down. So, this if you three times of L j down will give you the upward that is penetration length L upward.

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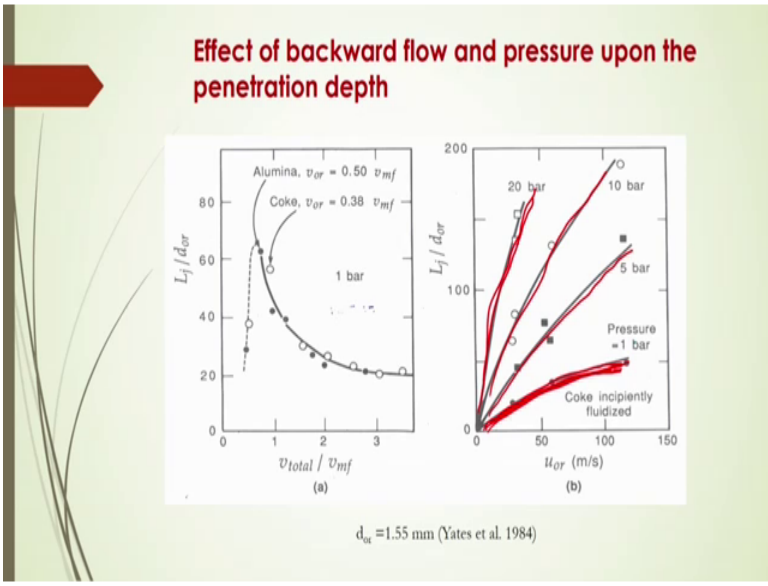

Now, effect of backward flow and pressure upon the penetration length; what is that? You will see that this jet penetration length it will be decreasing exponentially decreasing with total flowrate of the gas and also this penetration length it will of course, change with it will decrease if you if you decrease your pressure there. For high pressure this penetration length will be higher. So, here in this diagram if you see this how this penetration length will change with respect to orifice velocity, this orifice velocity if increase the orifice velocity this jet length will increase. Whereas, at higher pressure at higher pressure you will see this L j also increase. So, this pressure this pressure effect will be there. So, higher pressure will may produce the higher penetration depth or penetration length.

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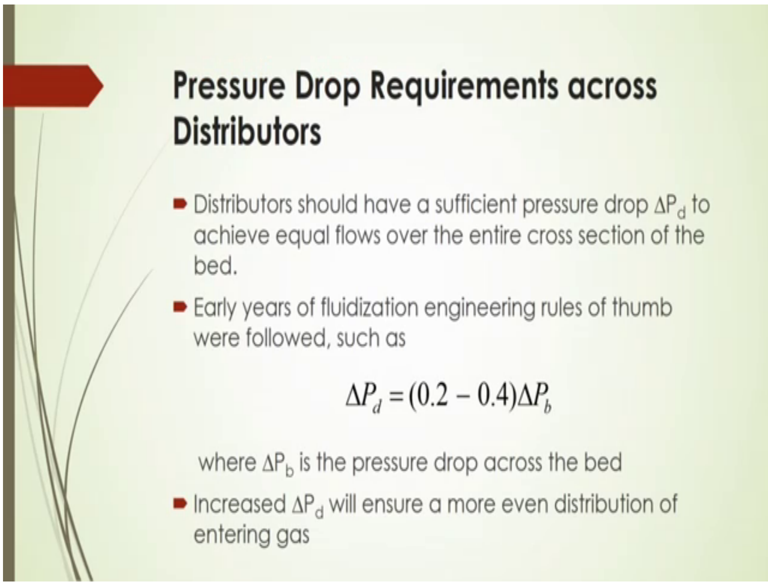

Now, what should be the pressure drop requirements across the distributors to get the uniform distribution of the gas through the distributor? And for this design of this distributor of course, you have to know the pressure drop requirements. This pressure drop of course, sufficient pressure drop should be there to achieve equal flows over the entire cross section of the bed.

So, early years of fluidization engineering rules of thumbs were followed to design this distributor such as that they have consider or at that time this distributive pressure for the design should be actually considered within the range of 0.2 to 0.4 times of the bed pressure. Where delta P b is called pressure drop across the bed and delta P d is the pressure drop across this distributor. So, distributor pressure should have 20 to 40 percent of the bed pressure to get this to get this equals flow for the entire cross section of the bed. So, increased distributor pressure will ensure a more even distributor of the entering gas.

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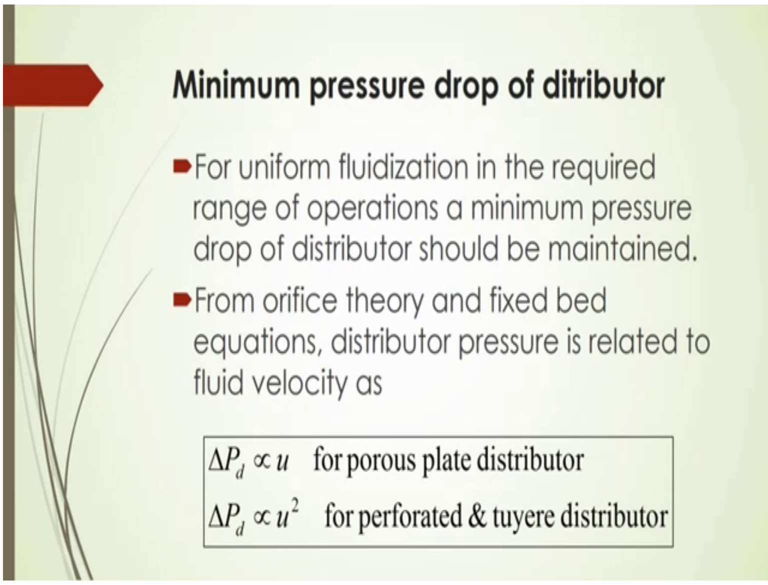

Minimum pressure drop of the distributor. For uniform fluidization in the required range of operations minimum pressure drop of distributor should be maintained and from orifice theory and fixed bed equations, the distributor pressure is related to fluid velocity which can be represented as this delta P d is proportional to u, for porous plate distributor whereas, this delta P d; that means, this distributor pressure will be proportional to the square of the square of the gas velocity, that for perforated tuyers type distributor.

And for stable operation of course, some criteria to be maintained for design there, and several investigators from their experiments they have developed, they have suggested different criteria for pressure drop of distributor as a function of bed pressure drop for the stable operation.

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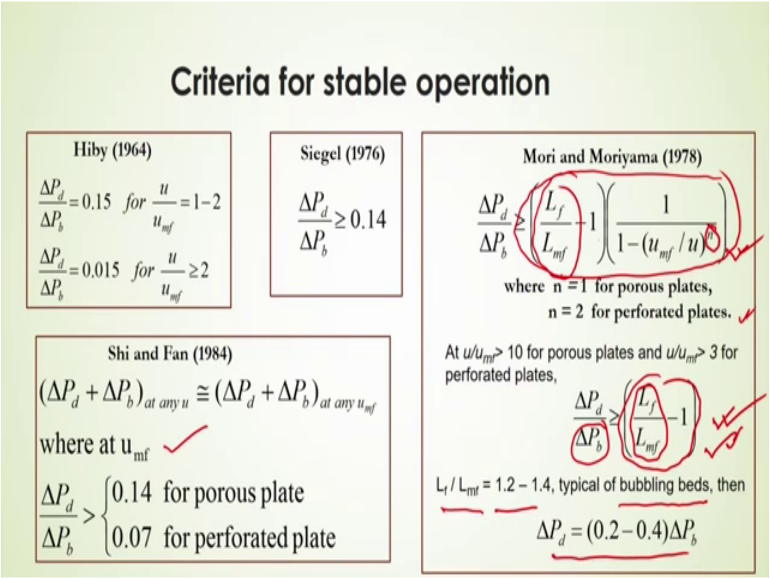

Now, as per Hiby 1964, this distributor pressure should be 15 percent of the bed pressure whereas, in this case this criteria should be of course, within the range of range of ratio of actual gas velocity to the minimum velocity will be 1 to 2. And another important that if suppose the ratio of gas velocity to the minimum velocity is greater than equals to then, you have to use the distributor pressure you have to consider the distributor pressure or you have to consider the distributor pressure for design it should be actually 0.01 5 times of bed pressure; that means, here 0.1 5percent of this bed pressure. So, at higher gas velocity you have to consider the lower bed pressure their lower distributor pressure whereas, for higher gas velocity below two ratio of this u 2 u m you have to consider the higher distributor pressure.

Siegel 1976 he has proposed one criteria that the distributor pressure should be greater than 14 percent of the bed pressure. And Mori and Moriyama 1978 they have developed one criteria for stable operation of the fluidized bed for the for the distribution of the gas by designing the distributor, in such way that they have considered they have suggested that this distributor pressure should be is greater than this some factor of the bed pressure that factor is nothing, but the factor is nothing, but L f by L m f minus 1 into 1 by 1 minus U m f by u to the power of n here this is the; that means, this criteria is depending on the what should be the height of the fluidized bed and what should be the minimum fluidization height also what should be the minimum fluidization velocity and gas velocity.

Now in this equation you will see there is one coefficient n, n is equal to one should be used for porous plates whereas, n should be 2 for perforated plates. At if gas velocity is 10 times of is greater than 10 times of minimum fluidization velocity for porous plates, and also if it is greater than if it is greater than three times of minimum fluidization for perforated plate, you have to consider this distributed pressure drop as this equation.

So, here delta P d by delta b should be is greater than equals to L f by L m f minus one into delta P b. So, this factor in this case only you have to do what should be the height of the fluidized bed, and what should be the minimum height of the that minimum condition..

So, if you know this from which you can calculate what should be distributed pressure inside the bed. And this if this ratio of fluidized height to the minimum fluidization height, if it is within the range of 1.2 to 1.4 typical of bubbling beds, then you can say this distributed pressure should be within the range of 20 to 40 percent of the total bed pressure; whereas, Shi and Fan 1984 they have proposed other criteria, they have proposed that if the summation of this distributor pressure and bed pressure at any fluid velocity should be approximately will be equals to the summation of this two pressure drop, at any minimum fluidization condition. Where at minimum fluidization condition this P d by P b; that means, ratio of distributed pressure to the ratio of to the bed pressure should be is greater than 0.14 for porous plate and it should be greater than 0.07 for perforated plate.

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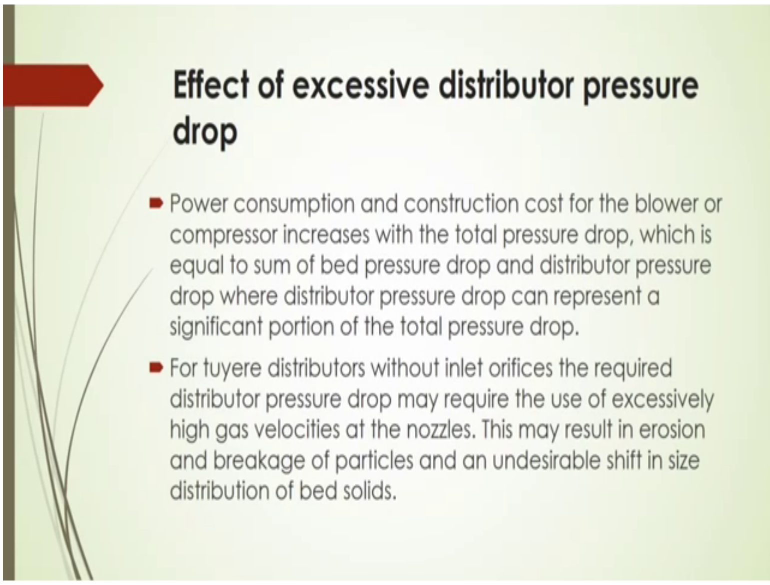

Now, what will happen if there is excessive distributor pressure inside the bed, then what should be the effect for that. Of course, there will be a effect for power consumption since this case power consumption construction cost will be higher for blower or compressor, that will increase with the total pressure drop here if you increase the total pressure of course, this increase power consumption will increase which is equal to the sum of bed pressure drop and the distributor pressure drop. Now where distributor pressure drop can represent a significant portion of the total pressure drop? Now, for tuyers distributor without inlet orifices.

So, the required distributor pressure may require the use of excessively high gas velocities at the nozzles. This may result in erosion and breakage of particles and undesirable shift in size distribution of bed solids. Now important factor is that inside the bed how this phases will be actually mixing that also depends on this distribution of the phases through the distributor. Now bed of fine solids you will see generally for FCC catalyst say well designed distributor act as a stirrer which sometimes promotes the mixing of a solids and keeping bed well fluidized inside the bed.

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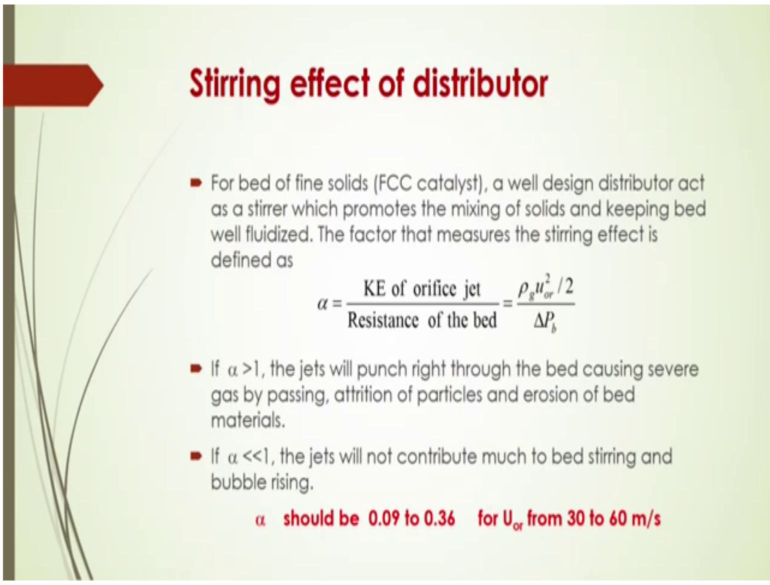

ah The factor that measures this stirring effect is defined as which is denoted by alpha which is nothing, but the ratio of kinetic energy of the orifice jet the resistance of the bed. This kinetic energy of the orifice jet is given a half of row g U o r square U o r is nothing, but the orifice velocity and resistance of the bed will be represented by the pressure drop of the bed.

Now, if alpha is greater than this factor is greater than 1, we can say this jets will punch right through the bed which cause severe gas by passing and which will make attrition of the particles inside the bed, and also the erosion of the bed materials. So, this alpha should not be is greater than 1 for the beta design and for beta operation of the fluidized bed.

If alpha is less than less than equals to one even suppose if kinetic energy orifice jet is very less compared to the resistance of the jet, then also the jets will not contribute must to the bed mixing bed phase mixing and also bubble rising inside the bed. That case it will also not be suitable if your this factor alpha is very much less than 1. So, there should be some optimize factor from which you can say that there will be a good distribution of the phase inside the bed, well mixing inside the bed.

So, the distributor should be design in such way that, you alpha this factor or you can say the ratio of the kinetic energy of the jet of the distributor and the bed resistance should be within a certain region. Now what is that? This should be of course, will be 0 to 1 it is also not good, but it is seen that the good design will give you this alpha value of within the range of 0.09 to 0.36 for orifice velocity from 30 to 60 meter per second.

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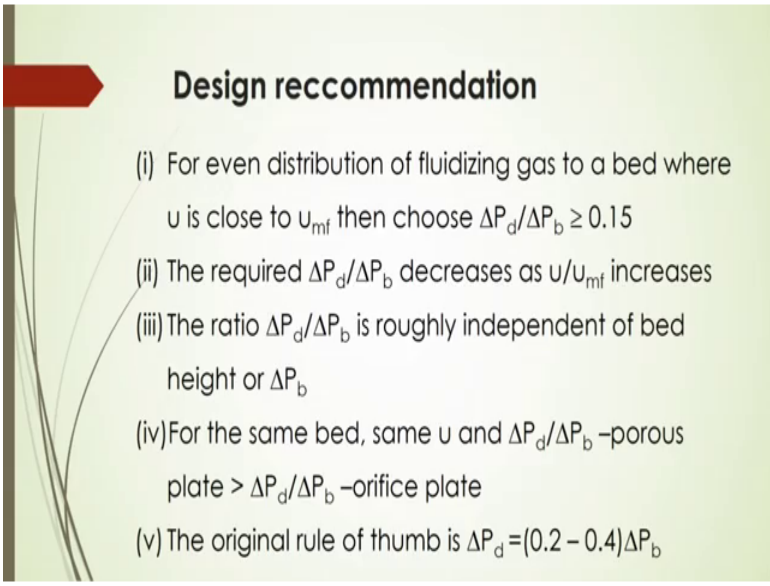

Now, what should be the design recommendation for then even get for this well mixing inside the bed of this gas liquid solid phases. For even distribution of the fluidizing gas to a bed where U is close to U m f; that means, the gas velocity were just maintaining at this minimum fluidization condition, then you have to choose that the ratio of this distributor pressure to the bed pressure should be is greater than 0.15; that means, here you have to take this distributor pressure which will be greater than 15 percent of the bed pressure drop.

The require this ratio this is delta P d by delta P b decreases as when your increasing this velocity of the fluid inside the bed and this ratio is roughly independent of the bed height or you can say the bed pressure for the same bed. And for same velocity and the ratio of this distributor pressure to the bed pressure for the porous plate should be is greater than the ratio of this distributor pressure to the bed pressure of orifice plate. Now this is things, but you have to use this thumb rule of pressure drop for this for its design, as a 0.2 to 0.4 times of bed pressure drop.

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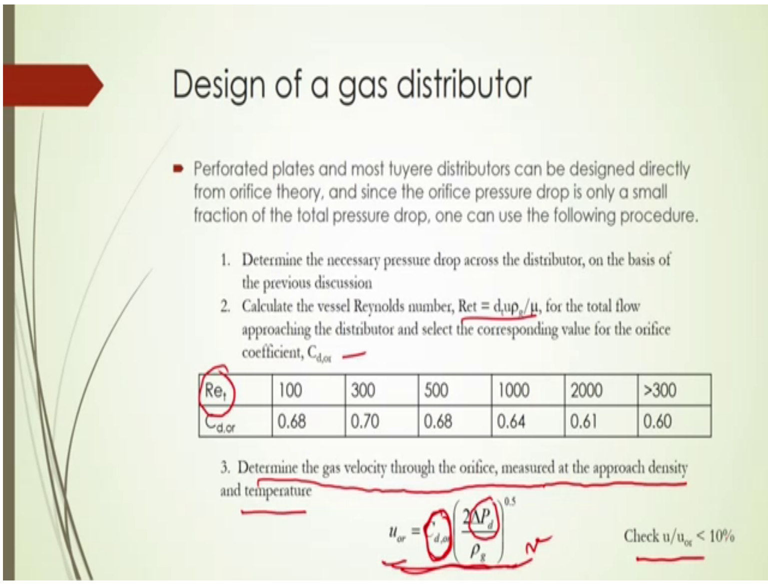

Now, design of a gas distributor, now how to design this gas let us see some step by step procedure here, let us see here perforated plates and most tuyer distributors can be designed directly from orifice theory and since the orifice pressure drop is only a small fraction of the total pressure drop, one can use this following procedure here.

First you have to determine the necessary pressure drop across the distributor on the basis of that the previous discussion, what should be the criteria for the distributor pressure to choose. Then calculate the vessel Reynolds number like R e t, this R e t will be defined as the Reynolds number based on this tube diameter or you can say column diameter for the total flow, which approaching the distributor and select the corresponding value of the orifice coefficient like this.

So, this orifice coefficient actually this orifice coefficient depends on this Reynolds number, this will be required to calculate the orifice velocity inside the distributor here. So, determine the then gas velocity through the orifice after getting this orifice coefficient measured at the approach density and temperature on pressure. So, you can calculate this orifice velocity from this correlation.

So, whenever you are getting the C d from this Reynolds number relationship you have to substitute this C d o r and then calculate U o r after substitution of this distributor pressure, and then what should be the u o r? After that you have to check if this U by U r whatever you are choosing that gas velocity to be operated fluidization. So, then that that velocity should be less than 10 percent of that U o r.

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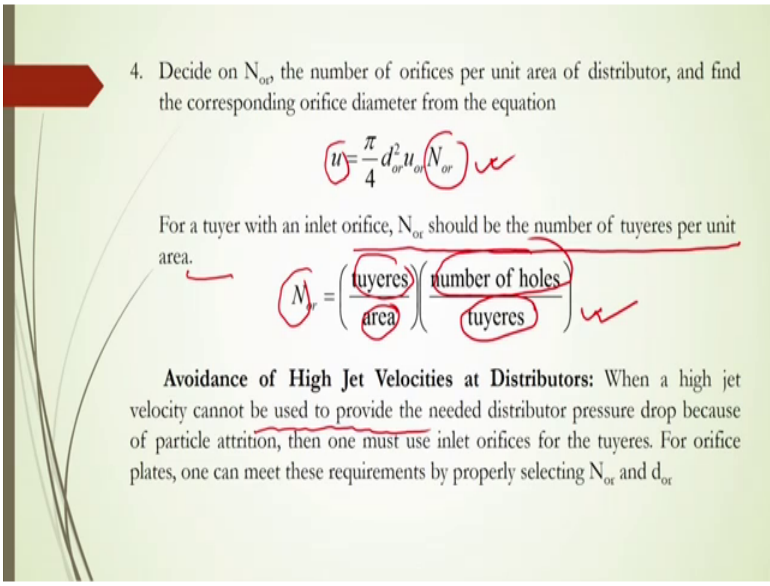

After that you have to decide how many holes of the orifice per unit area of the distributor to be maintained, and you have to find out the corresponding orifice diameter from the equation given here. For a tuyer with an inlet orifice N o r should be number of tuyers per unit area, should be calculated from this. This N word designed as what is the tuyers per unit area and number of holes for unit tuyers.

So, once you know this number of holes, then you have to substitute this here and then what should be the u again you have to check what will be the u or u r, whether it is the same with your considering of the gas velocity at which you are going to operate the fluidized bed or not..

Now very interesting point that you have to note down that avoidance of high jet velocities at distributor; when a high jet velocity cannot be used to provide the needed distributor pressure drop, because of particle attrition then one must use inlet orifices for the tuyers for orifice plates one can meet these requirements by properly selecting this N o r and d o r.

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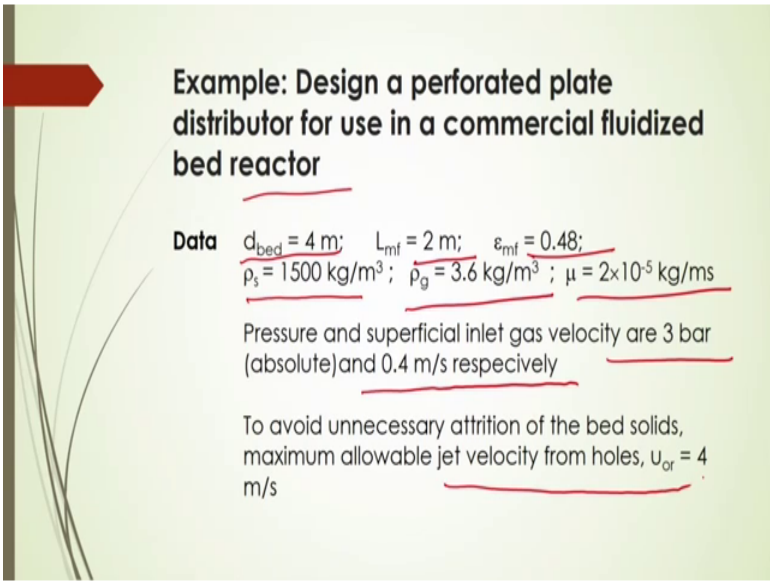

Let us see one example here like design of a perforated plate distributor for use in a commercial fluidized bed reactor. Now it is given that bed diameter is given minimum height of the fluidization is given, minimum porous it is given, density of the solid which is being used for that distributor is given to you, what will be the density of the gas is being used, what is the viscosity.

Now pressure and superficial inlet gas velocity are at 3 bar and 0.4 meter per second to be actually considered. To avoid unnecessary attrition of the bed solids maximum allowable jet velocity to be considered here U o r is equal to 4 meter per second.

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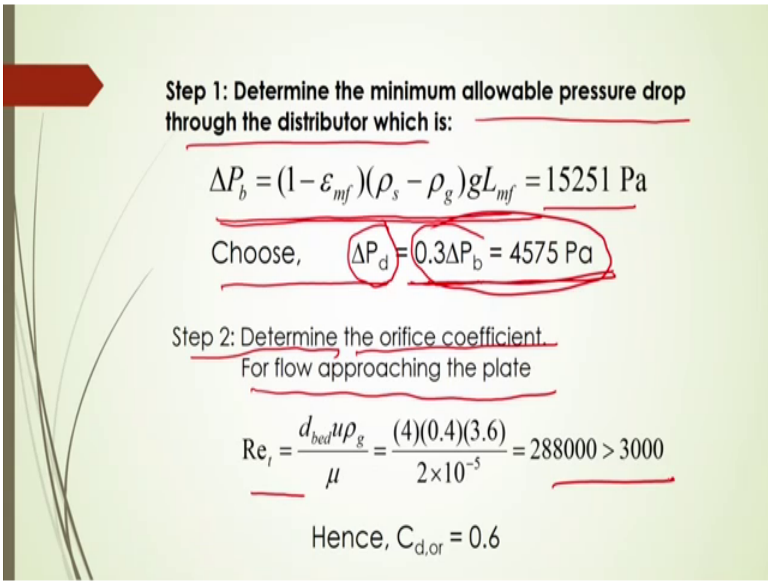

So, as per that procedure step 1 you have to determine what will be the minimum allowable pressure drop through the distributor, which can be calculated from this equation what should be the bed pressure here. This will be is equal to this thus after substitution of the data and then choose, what should be the delta P d. As per recommendation it should be 30 percent average of that 0.1 to 0.23.

So, it will be 0.3 here as per this recommendation, you can just see what should be the distributor pressure to be maintained. And then after that you have to determine the orifice coefficient from this Reynolds number relationship, if you Reynolds number is like this then you can calculate from this table that what should be the orifice coefficient is there.

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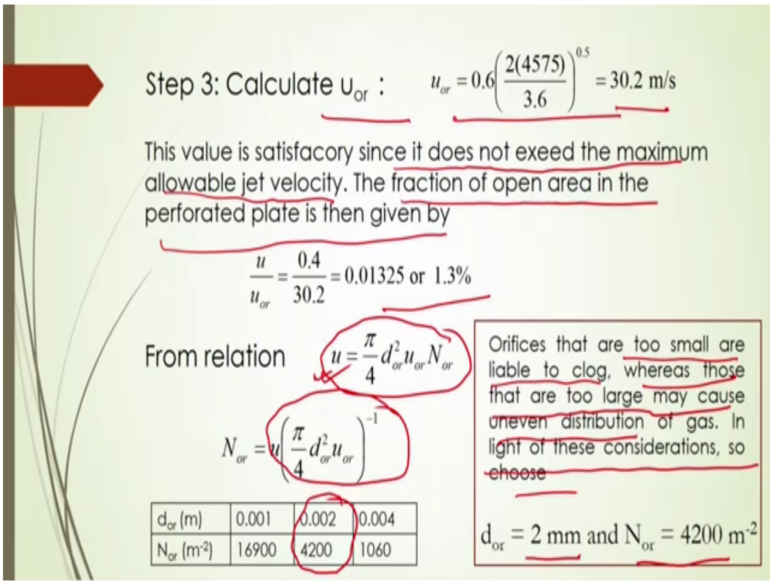

d_{or} (m)	0.001	0.002	0.004
N_{or} (m^{-2})	16900	4200	1060

After that calculate U o r by that equation and then you are getting this and this value is satisfactory since it does not exceed the maximum allowable jet velocity, the fraction of open area in the perforated plate then given by this u by U o r from this 1.3 percent. So, from this equation of this you have to then find out what should be the number of orifice holes to be maintained here.

So, N o r can be calculated from this here form just simplifying this equation or rearrangement of this equation here. So, if you just change this N o r you will get U o r at different or U o r if you are changing then you will get corresponding N o r value from this equation. Now what should be the optimize value orifice that are too small are liable to clog. So, you cannot use that whereas, those that are too large, may cause uneven distribution that also not suitable of gas. So, in light of this consideration you have to choose wisely that which one will be the best option.

So, you have to in this case you are just select this d o r as 2 millimeter or 0.002 meter whereas, this N o r will be 4200. As per this condition whatever check that U o r should be less than is equal to what is that? There is a option that should be less than 10 percent of U o r. So, this will be the criteria from which you have to calculate and the calculate the number of orifice hole.

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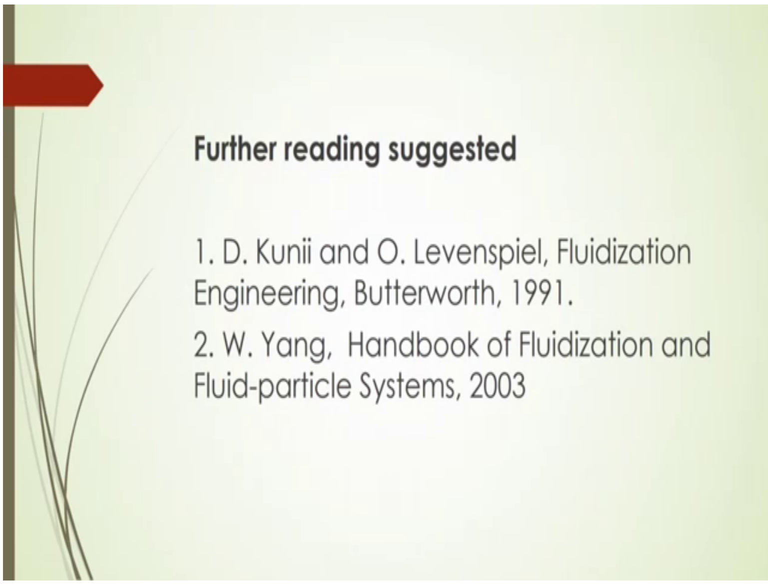

So, for further reading, you can go through this text book of Kunni and Levenspiel fluidization engineering and also you can consult with the books with that written by this Yang handbook of fluidization and fluid particle systems. So, you can use these books and for further reading and you get more details of design aspect.

So, I think this lecture this how actually what are the different types of distributor, how this distributor will be designed, thus some preliminary idea has given and it will be very helpful for you for design aspect also. So, thank you for this lecture next lecture will be discussing with some other characteristics of the fluidized bed.

Thank you.