Fluidization Engineering
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Lecture – 20
Entrainment Characteristics (Part 2): Fast fluidization condition

Ah welcome to massive open online course on fluidization engineering. today's lecture will be on entrainment characteristics, part two, basically, it will be on fast fluidization condition. So, we have already discussed about that entrainment mechanism in the churn turbulent, even for a particulate system in bubbling fluidize bed system, and also how these solid particles is entrained by the bubble by capturing the solid particle to its bottom part; that is in wake region and then busting into the surface and ejecting the solid particles to the freeboard.

So, there is a certain mechanism that by which this entrainment of solid is being happened. So, that has already been discussed in previous lecture on that. Again, this entrainment characteristics is being continued here in this lecture 20 and this entrainment characteristics will be only for the condition of fast fluidization system. Now, what is that fast fluidization? Of course, you know that.

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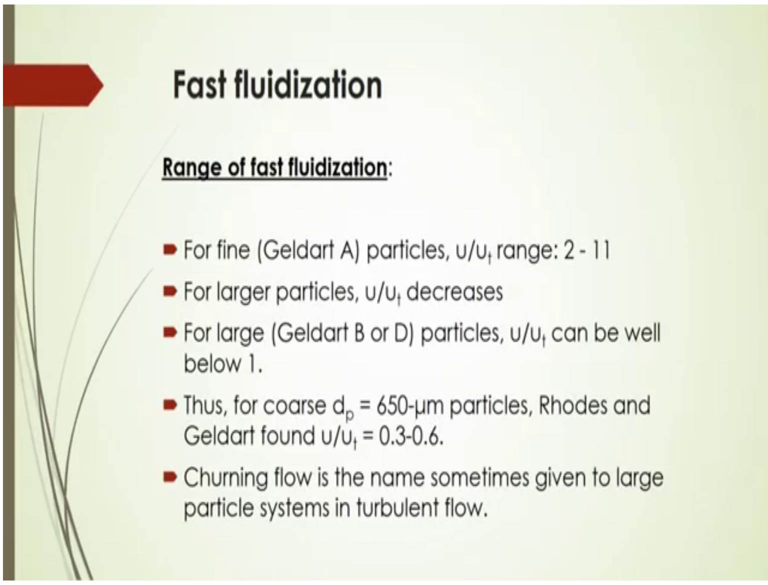

That there will be certain range of operating condition by which you can get the fast fluidization. Already, we have discussed at the very beginning of the courses regarding the flow pattern of the fluidization system and they are we have discussed to the range and the operating condition of different flow pattern like particulate system bubbling fluidized bed, bubbling fluidized bed slag fluidized bed and fast fluidization and the churn turbulent churn turbulent fluidization.

So, in that case, we have seen that generally fast fluidization occurs for the fine particle of type Geldart A where the gas velocity or fluid velocity relative to the terminal velocity will be a certain range and it is observed that this ratio of this fluid velocity to the terminal velocity of the solid particles will be ranging within 2 to 11 and in that case of you will see that fast fluidization phenomena will decreases if you are using on the large particles there.

Fast fluidization only occurs for fine particles, but this characteristics can be obtained, but in decreasing manner for larger particles for large Geldart B or D type particles, of course, you I think, you will obtain that the ratio of a fluid velocity to the terminal velocity should be less than well below one thus for a coarse particle. If particle diameter is 6 650 micrometer and it is above in that case, Rhodes and Geldart found that the ratio of the fluid velocity to the terminal velocity will be within the range of 0.3 to 0.6.

And churning flow is the name sometimes that given to large particle system in turbulent flow. So, fast fluidization case within this operating region or operating condition how the entrainment characteristics happens will be actually continued here for fast fluidization also you will see some characteristics that has already been discussed.

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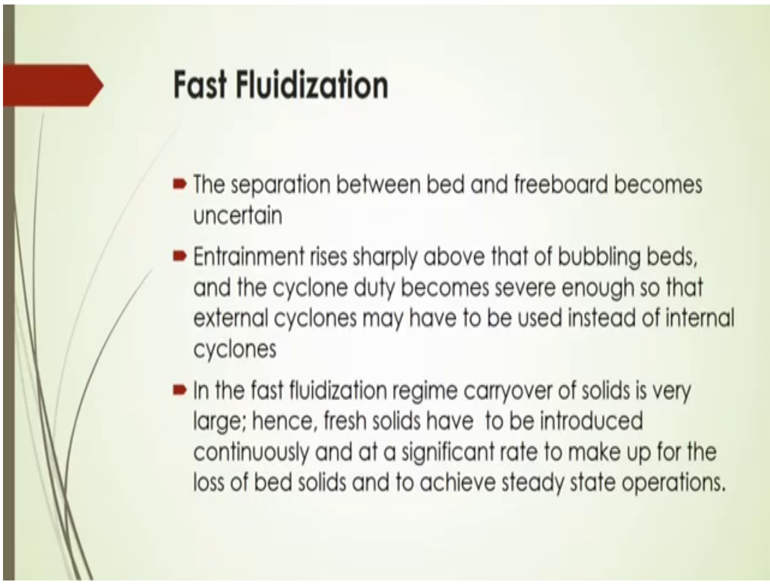

Still, we are discussing here some extend of that this case the separation between that bed and the freeboard becomes uncertain, but for this regular that is particulate system or bubbling fluidized bed system that the bed and freeboard region should be actually defined at a certain condition and in that case, transport disagreement height is main factor for which the phenomena of the entrainment actually depends on.

Now, in the case of fast fluidization, you not get that particular actually separation mark between the bed and the freeboard high because the high turbulence is there in fast fluidization and for this you will not exactly estimate, the demarcation between that bed and freeboard entrainment and this case, you will see rises sharply above that of bubbling beds, you will see before going to entrainment, of course, there will be a bubbling condition and whenever bubbles will be busting at the surface of this freeboard and the bubbling bed region, then there will be ejection of the solid particles by which the entrainment occurs.

And in this fast fluidization case, you will see the ejection will be so fast, ejection will be so forcely that the entrainment rises sharply and above that bubbling beds and the cyclone duty becomes severe enough so that the external cyclones may have to be used instead of internal cyclones there so, in this case because of that entrainment for reusing that solid particle which in which is coming out by the entrainment characteristics that

that to be reused by separating it from the gaseous medium or from the outlet by some mechanical device that is called cyclone separator.

Now, if in this case, fast fluidization case you cannot use the, a cyclone separator, they are internally because here the flow is so fast that is so turbulence than that cyclone duty would be severe, they are enough so, that that you need to have some external cyclones instead of internal cyclones. So, in the fast fluidization regimes, you will see that carryover of the solid is very large. hence the fresh solids have to be introduced continuously and at a significant rate to make up to the loss of bed solids and to achieve steady state operations.

So, this is very important point that of course, this in this fast fluidization case, since the fluid velocity is very high relative to the terminal velocity, the carryover of the solid is of course, the amount of that to carryover solids is so high that sometimes fresh solids have to be actually supplied for making up the flow consistency even the conservation of the mass and their for significant rate at a significant rate for the loss of beds because of these entrainment and to achieve the steady state operations in the fast fluidization system.

Now, there are you see different modes to run a fast fluidized circulation systems like mode 1, mode 2, mode 3, mode 4, here in this case, mode 1 means here you have to keep a constant inventory of the solids.

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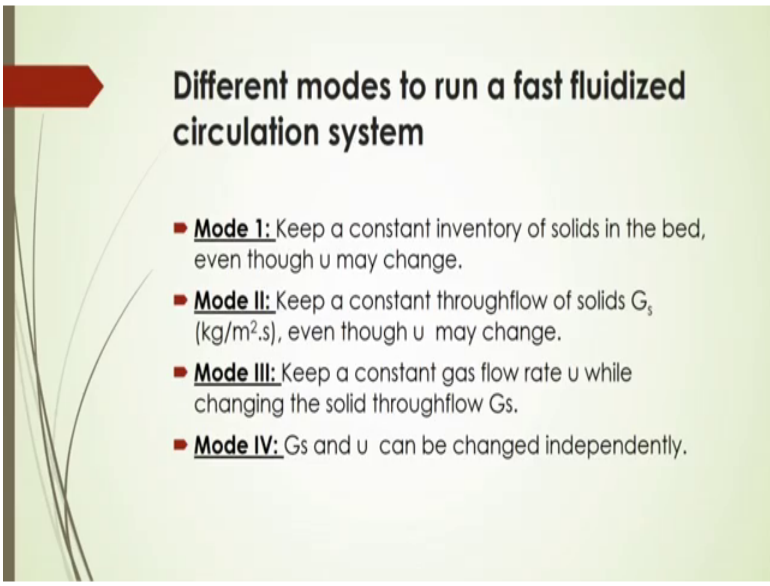

In the bed, even though you or may change; that means, here if there is velocity of the fluid change of course, you have to keep the inventory of the solids constants in the bed.

And as a mode 2, you have to keep the throughflow of solids constant that is denoted by Gs here Gs, then even though your fluid velocity may change and mode 3. In this case, you have to keep the gas flow rate are constants while changing the solid throughflow, there in the bed and mode 4 in this case ; that means, solid inventory or you can say solid flow rate and the fluid flow rate both can be changed independently there as a mode 4.

So, there are several mode of operations by which you can run the fast fluidize circulation system. So, once you have to keep the inventory of solids constant one you have to keep the constant of the throughflow of the solid even you can keep the flow of gas constant by changing gas solid flow rate and also you can independently change the Gs; that means, solid inventory or you can say the solid throughflow and the gas velocity they are or fluid velocity, they are in the bed, you will see because of the entrainment inside the bed by either of this mode.

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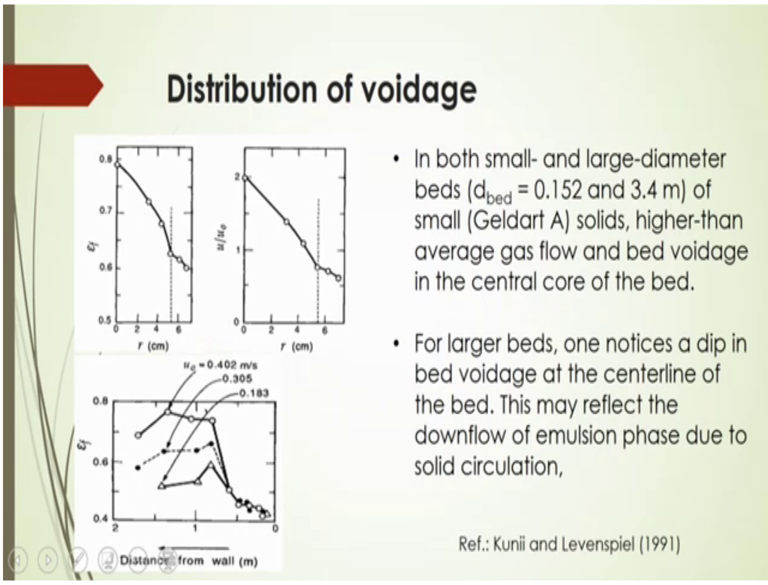

You will see there will be a certain distribution of the voidage inside the bed.

And this voidage may not be the same as whatever, it is in case of bubbling fluidized bed in this case, I think there will be more viodage compared to the bubbling fluidized beds and both small and large diameter beds, you will see, if the bed diameter is a 15.2

centimeter and 34 centimeter of small particles of type a higher than average gas flow and bed voidage in the central core of the bed is being observed and for larger beds; one notice says a dip in bed voidage of at the centerline of the bed, this may affect the downflow of the emulsion phase due to the solid circulation.

So, this case that you will see in this fast fluidization system for small and large diameter beds, you will see for the small solids, you will get the higher gas flow rate which will be higher than the average gas flow rate and the bed voidage also will be higher in the central core of the bed and for larger beds one, of course, you can get that the at the centerline of the bed, there will be a dip in bed voidage, this may reflect the downflow of emulsion phases due to solid circulation.

So, here in this figure, you will see that at the central region the maximum voidage absorb in the fluidized bed here. So, this is 0 R 0 means at the central region and 0.8 is the maximum voidage of fluid here and add up I think that adjusting to the wall of the bed, they are the height will be laser and related to the central zone.

Similarly, gas flow rate; that means, flow pattern the average gas flow rate at the centerline, it will be also higher than the average value and here distance from the wall, you will see that of course, that it will be a increasing like this this is the pattern here, but at the wall, it will see, there will be a 0 voidage of course,. So, this this pattern will give you that what will be the distribution of the voidage inside the bed of course, this distribution of voidage other the same pattern will change just by changing the fluid velocity inside the bed.

So, for higher velocity you will get the higher voidage inside the bed and for lower velocity will get the lower, of course, the for first fluidization a bed condition here of course.

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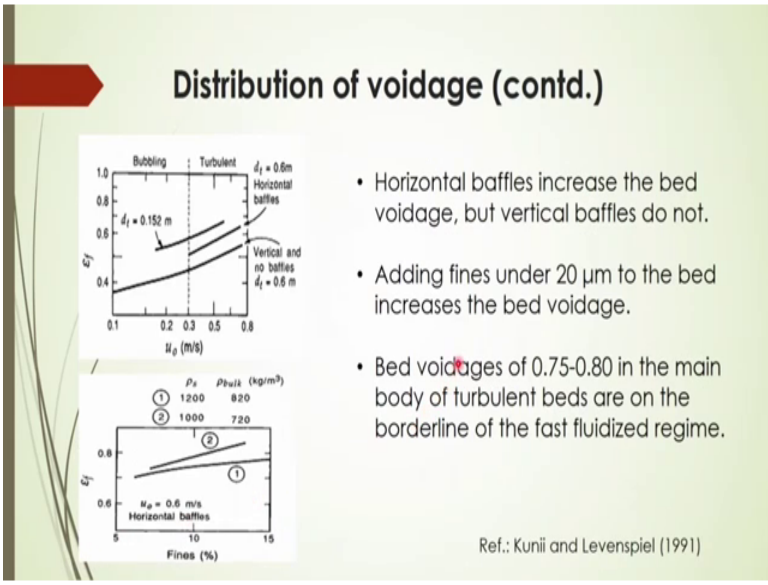

The you will see that other factors of that distribution of voidage, if you add some baffles in the bed; that means, a there will some internal provisions you are making to just change the effective area of the flow of fluid then in that case you will see there will be a change of voidage there.

And horizontal baffle in that case increase the bed voidage, but vertical bubbles vertical baffles that do not. So, adding fines under 20 micrometer of size of particles to the bed that may increase the bed voidage here and bed voidage of 75 percent to 85 percent in the main body of the turbulent beds can be obtained on the borderline of the fast fluidization regime.

So, this is the voidage distribution, it is important because it is related to that entrainment characteristic. So, they are; so, they are what is that you will see in this figure the voidage will increase with the velocity of the fluid and in case of horizontal bubbles baffles, it will be higher than the verticals one. So, vertical and no baffles you will get for bed diameter of 0.6 meter, this is the trend of that velocity profile which is increasing with the increasing gas velocity whereas, for a lower diameter of the bed it, you can get more voidage they are even if you are using that baffles or not.

So, that case, if you are using the same gas velocity and the different diameter you will get, of course, higher entrainment higher voidage, even if you are using same diameter and if you are using horizontal baffles and the vertical bubbles horizontal baffles will give you the more voidage, they are for a particular gas velocity or fluid velocity and this are voidage of could change with the solid concentration inside the bed and that case you will see if you increase the fines they are in the bed you get the more voidage and also this more voidage will decreases will decreases, if you are using a more densed particles and also the bulk density of the fluid medium inside the bed increases, then you may get the lower voidage inside the bed because of the viscous effect of the solid particles, there as an emulsion which is being used there that may change the voidage inside the bed.

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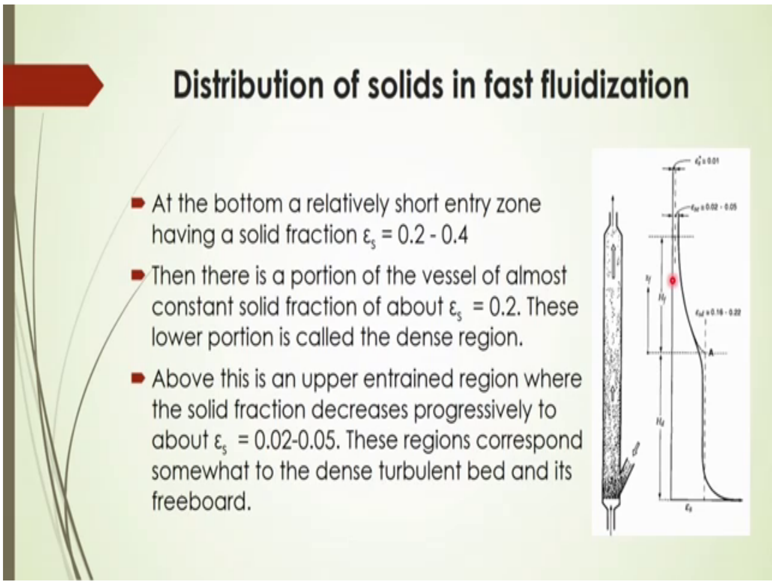

And also you will see that distribution of solids in the first fluidized bed and that case this distribution of solids will get into the results for the entrainment characteristics inside the bed. Now at the bottom, you will see a relatively short entry zone having a solid fraction of 0.2 to 0.4 here and then there is a portion of the vessel of almost constant solid fraction as shown in the figure of about this solid fraction of around twenty percent there.

And then this lower portion is called the denser region and above these and upper entrained region higher the solid fraction decreases progressively to about solid volume fraction of about 0.02 to 0.05 and this region of course, the signify somewhat to the denser turbulence in the bed and its freeboard. So, they are of course, you will see certain range of volume fraction of the solids that based on that volume fraction of the solids, you can classify whether it will be the bottom region and how it will be the entrainment characteristics happens.

So, they are and there is a portion of the vessel of almost there constant solid fraction of about twenty percent and this lower portion is will be called as that this will be called as that a denser region and above this denser region. You may get that the void fraction of very drastically reducing to the 0.0 to the 0.05 there. So, these are the profile that has been given this is given exactly as far; what the model we have discussed in the previous lecture according to that this profile will come only thing different is that the flow velocity when also what is that the height of the bed is they are and the what is that there will be the solid fraction that effect on that.

So, here exactly in the denser region as per are the constant solid fraction will be there, whereas, in the freeboard region this freeboard region here the solid fraction will be decreasing exponentially like this here.

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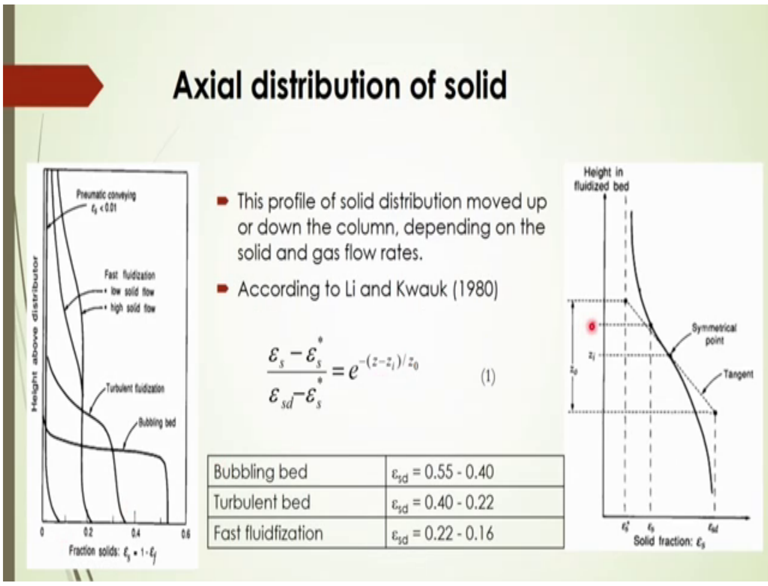

And of course, this axial distribution of the solids that you can experimentally observe from your that is solid distribution data, in this case, you will see the profile of solid distribution that moved up or down the column that depending on the solid and gas flow rates.

According to Lli and Kwauk 1980; they have developed or proposed one correlations based on their experimental data and they obtained their the solid distribution inside the bed like this here and they represented as epsilon s minus epsilon s star by epsilon sd minus epsilon s star that will be is equal to E to the power minus z minus zi by z 0.

So, this way you can calculate what should be the solid distribution inside the bed, of course, what is that z? Z is at any position at any point of this curve, here you just locate here and then what is that zi? Zi is the here what is symmetrical point here based on this Es star and the E sd here and then what is the intersection point, it will be is equal to zi and what is z 0? Z 0 is nothing, but that here that in this case that what is the E sd; that means, the solid distribution for this dense zone here and if you extend it and then where this the tangent line just joining to this zi intersect and from which you will get this z 0 up to these points.

So, as per this diagram, you can see how the z 0 and zi will be calculated, once you know these zi and z 0 and if you substitute here for a particular operating condition, you will be able to calculate, what should be the solid distribution at that particular location here now for bubbling beds you will see these C sd; that means, the concentration of the solid for this dense region will be within the range of 0.55 to 0.40 here, whereas, for turbulent bed it will be 0.40 to 0.22, it will be lesser or as this fast fluidization case, it will be very less here, it will be 0.22 to 0.16.

So, as per these are bubbling to fast fluidization, you will see that the dense region will be a coming down there because of the solid concentration will be decreasing there. So, this case you will see that once you know the C sd; that means, dense region solid concentration and the carrying capacity amount of this solid concentration that will be epsilon s star that already been discussed earlier also the what is this epsilon s star here at this location at an infinite length you will see there will be constant dilutions of the solid particles here which is coming out that would be fixed here.

So, that would be represented by epsilon s star. So, once you know this epsilon s star and the epsilon s d and also by the quantity of interactions of zi and what slope or tangent and what is the intersection point of these and these then you will get the exact amount of solid concentration at this particular z height. So, this is the profile by which you can say how axial distribution of the solids actually happening inside the different type of beds.

So, for the bubbling beds, you will see the nature in this figure the nature of this entrainment profile here and also, what is the turbulent fluidization this is the nature here and this is for pneumatic or conveying or fast fluidization case you will see this is the a profile. So, in this case you will see that the height above the distributor the dense region will be higher and then this is the dense region and this portion is the dense region for this. So, this is and this is for the a bubbling bed the dense region is so high relative to that other bubbling condition other fluidization pattern.

So, so, this is the trend of that is the entrainment characteristic of the solid and by which you can get the profile of this a solid distribution inside the bed.

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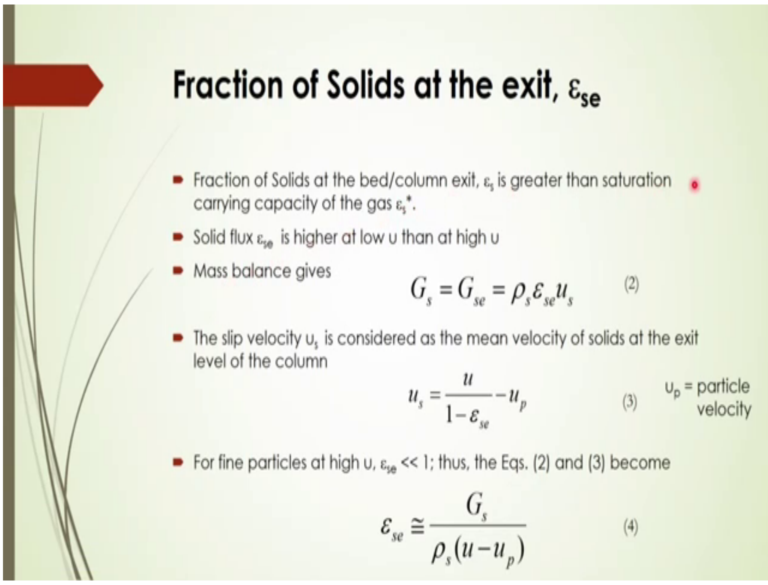

And the fraction of solids at the exit that is epsilon se how to calculate that epsilon se and what should be the value for that if you know that exit concentration then what should be the makeup and also circulation rate that can be obtained by these.

So, fraction of solids at the bed or column exits, you can say epsilon is greater than the saturation carrying capacity of the gas that is epsilon s star and solid flux of that is epsilon se at the exit is higher at low fluid velocity, then at higher fluid velocity and as per this mass balance gives this equation number 2 here Gs that will be is equal to G se that will be rho s into epsilon se into e s epsilon that is epsilon se into us.

So, here the slip velocity us is considered as the mean velocity of the solids at the exit level of the column now this us should be calculated as u by 1 minus epsilon se minus up u is the fluid velocities as a superficial fluid velocity, if you divided by 1 minus epsilon se, it will be is equal to actual fluid velocity inside the bed and if you subtract the particle velocity from this absolute fluid velocity, then you will get the slip velocity here up is the particle velocity and for the fine particles at high gas velocity where you will see that exit solid concentration will be very very less to be; if it is less than less than equals to 1; thus the equation here 2 and 3, you will yields the epsilon se; that means, solid concentration at the exit, it will be by the mass balance equation will be approximately equals to Gs, this is called solid flux divided by rho s into u minus u p.

So, by this equation 4, you will be able to calculate what should be the fraction of solids at the exit epsilon as epsilon se.

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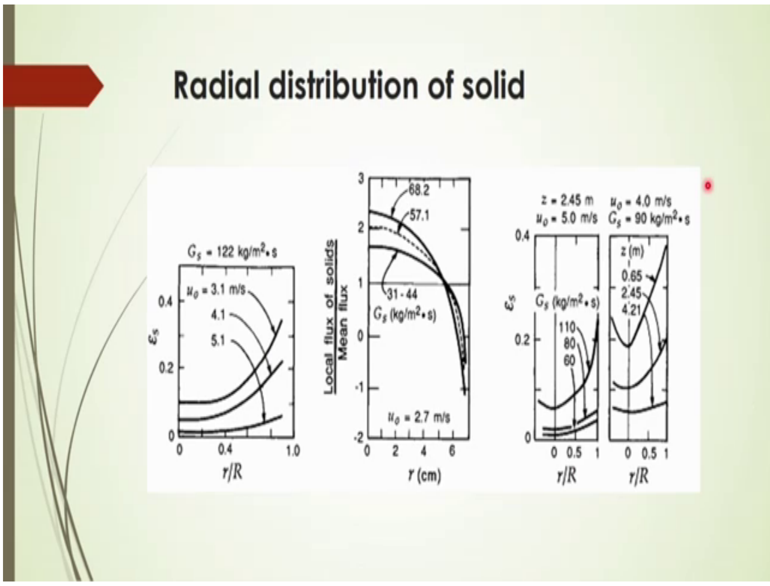

So, this is the case, but if you are good as bed is the or diameter is too high, then in that case, you have to know what should be the radial distribution of the solids because they are in the side the bed, they are may be internal fluid circulation will be in such way that solid will be distributed not only in the actually, it will be radially also distributed and because of which this entrainment a radial entrainment, it will give you the a change of radial distribution of the solids inside the bed.

And as for this figure that is given by Kunii and Levenspiel in their books that they are that the solid distribution radially, you will see if you just go from the center to the wall, you will see there will be a change of solid distribution and at the center, there will be higher solid fraction relative to the what is that center region.

So, relative to the center region that will be wall region, there will be here, this solid fraction here this is as per this, but here local flux of solids that is mean flux, if you are getting that according to our; if you increase the radius of the diameter of the bed, then it will be coming decreases and whereas, in this case this epsilon under solid fraction here by this graph you can see how this solid fraction will be changing as per this radial distance here.

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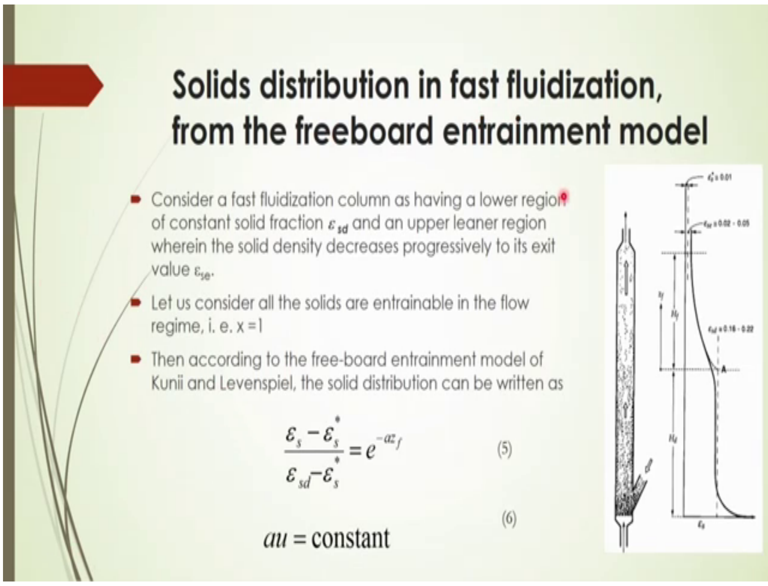

And solid distribution in the fast fluidization from the freeboard entrainment model let us see how this solid distribution can be expressed by the entrainment model now just first consider a first fluidization column which have a lower region of constant solid fraction that is generated by epsilon sd and upper linear region where the solid density decreases the progressively to its exit value epsilon se.

Now, let us consider all the solids are entrainable in the flow regime; that means, here the all the solid fractions like x is equal to one if you are considering that x is the solid fraction which are being entrainable. Now if all the particles are entrainable, then x will be is equal to 1, then according to the freeboard entertainment model that has already been discussed in the previous lectures that has given by the Kunii and Levenspiel, the solid distribution can be written as this epsilon s minus epsilon s star divided by epsilon sd minus epsilon star that will be is equal to e to the power minus a into zf.

Now, this a is called decay constant this decay constant will be depending on the velocity of the fluid. Now this you will see that this decay constants will be inversely proportional to the fluid velocity. So, from that truth you can express that a into u that would be is equal to constant. So, based on these entrainment model, you can obtain what should be the solid fraction at a certain height of the freeboard. So, this is zf or a shape you can say from this location you are considering that zf and this will be your total freeboard height.

So, at this outlet what should be the solid fraction you just substitute the capital F instead of zf here or at a certain location what should be the value of epsilon s that you can calculate from this equation 5.

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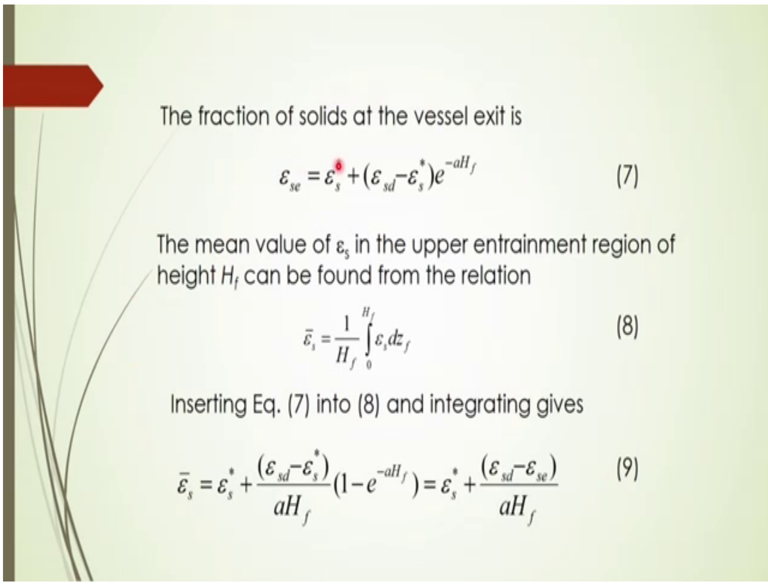

Now, the fraction of solids at the vessel exit just you just substitute the value of zf value of zf here as F capital is a, then you will get the solid fraction at the vessel exit, the mean value of epsilon s in the upper entrainment region; that means, in the freeboard height of Hf can be found from the relation here this epsilon s bar here as that will be linked average you can say that is 1 by Hf 0 to Hf epsilon sd zf.

So, if you integrate this epsilon s within the height of that is freeboard height and if you divide it by the total height of the freeboard, then you can get average or mean value of the solid a fraction in the freeboard height now inserting this equation number seven you know that this is the exit concentration or exit solid fraction just by substituting this zf into Hf and if you substitute this exit that is solid fraction here in equation that is given in earlier that here in this case that then epsilon s bar that will be is equal to here this epsilon sd minus epsilon s star by a Hf into one minus e into Hf, just after substitution inserting equation and integrating gives you will get this epsilon s star plus then epsilon Hd minus epsilon se by a Hf here.

So, this in this case, then you just substitute this value, you will get this average solid fraction they are inside the bed.

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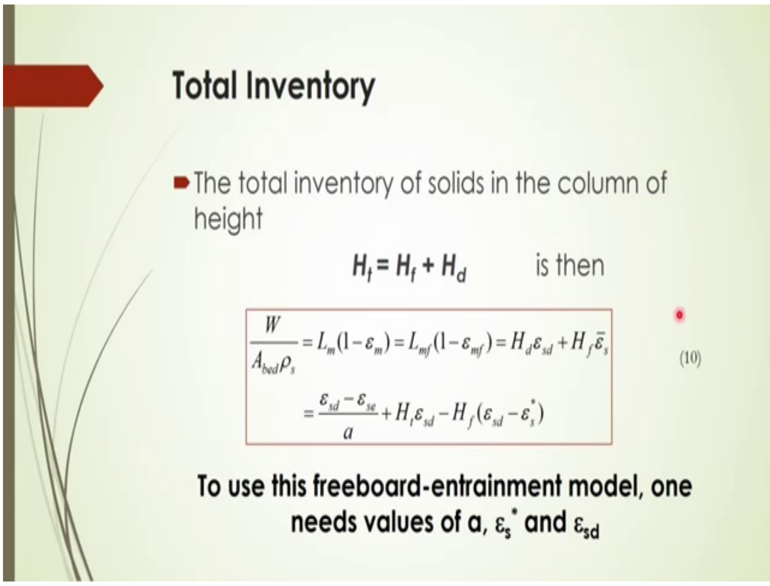

And then total inventory how to calculate then total inventory here. Now total inventory of the solids in the column of height that will be is equal to Ht that is equal to Hf plus Hd, then Ht is the total height of the bed and Hf is the freeboard height and Hd is the dense region height of the dense region here.

So, according to this height of the bed total height of the bed, what should be the total inventory here? Now, total inventory if you are considering the W; the W by A bed rho s will be is equal to that as per that mass balance that will be is equal to; that means, mass of the solids, then if you multiply it, L m into 1 minus epsilon mf into a bed into rho s, then you can get this W here. So, it will be is equal to nothing, but L mf into 1 minus epsilon mf or Hd epsilon Hd plus Hf into epsilon s bar; that means, mean solid fraction here.

So, here Hf into mean solid fraction, it will give you the weight of the solids at the freeboard height and this is Hd into epsilon Hd, it will give you the weight of the solids at this dense region. So, after substitution of epsilon sd and epsilon s bar, here you will get this equation finally, as equation 10, in this case, what should be the total inventory for the fast fluidization system in this case you can calculate.

Now, to use this freeboard entrainment model one have to know the value of; that means, decay constant and saturation carrying capacity value and the solid fraction at the dense region. So, three parameters of course, you have to know then what should the total inventory and what should be the value of solid fraction at a particular height of the fast fluidized bed.

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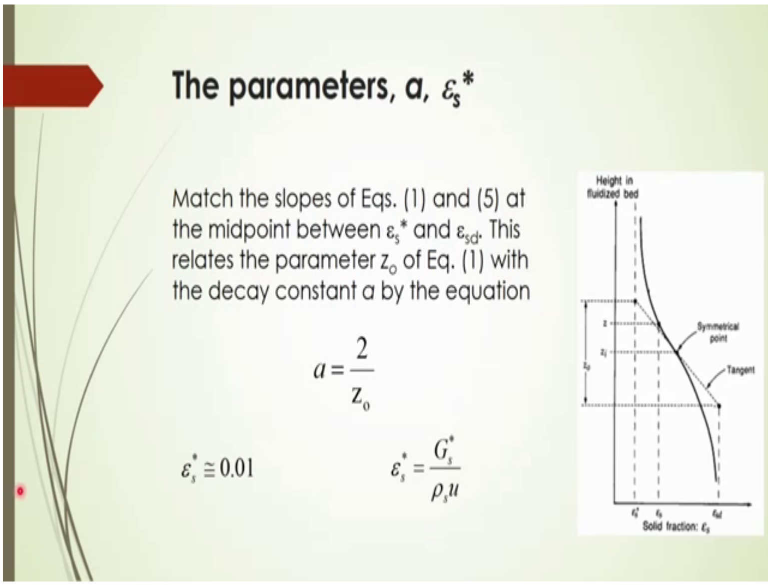

And then the parameter how to calculate this parameter than a and carrying a saturation capacity here.

Now, if you match the slopes of equation one that; earlier have we have shown and 5 at the midpoint between epsilon s star and epsilon sd, this relates the parameters z 0 of equation 1 that earlier we have given to the decay constant a by the equation here, a will be is equal to 2 by z 0 that you can obtain by the by experimental here. So, this is from this 2 by z 0, you have to find out what should be the value of z 0 here this height total height; that means, at zi ah; that means, here symmetrical point here and where the symmetrical line that is tangent that this point will intersect this here. So, that will be you that will be giving you total height here at z 0.

Now, epsilon s star generally is considered for first at 0.01 and epsilon s star general represented as Gs star by rho su. Now, you have to know if you collect the solid amount there and if you represented that saturated amount of solids which is coming out at Gs star, it will be is equal to some solid flux represent and if you divide it by rho s into fluid velocity density of the solid and the fluid velocity, then you will get this epsilon s star, generally, it is a very small amount then it is a generally 0.01 for different of flow pattern of flow regimes, you will get different value of this saturated carrying capacity amount here of solid.

And after substitution of this es star and decay constant and then you will get the final value for the that is total inventory inside the bed.

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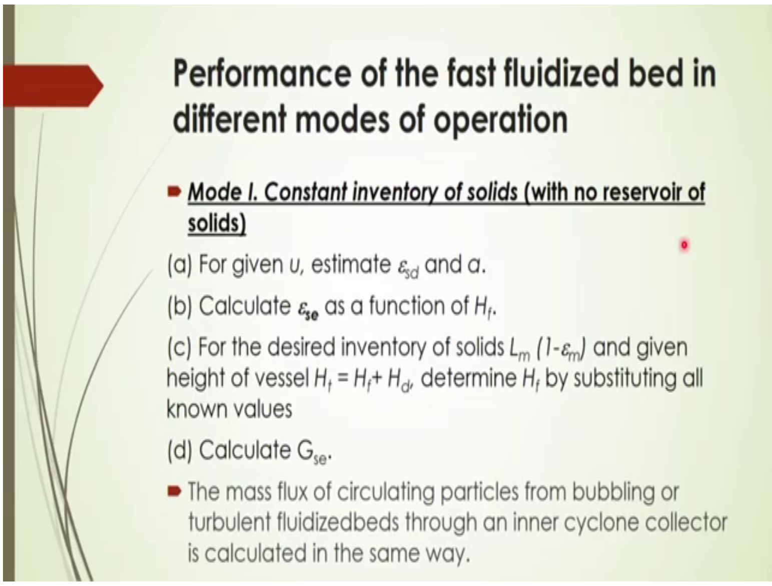

Now performance of the fast fluidized bed in different modes of operation so, how to actually calculate the performance of the fluidized bed with different mode of that solid inventory now sometimes this has mode 1, you can say constant inventory of the solids that there we know reservoir of the solids there. So, for a given fluid velocity first you have to estimate the epsilon sd and the decay constant and then calculate the epsilon se; that means, exit solid fraction as a function of freeboard height for the desired inventory of the solids; that means, L m into 1 minus epsilon m and given height of the vessel as a total height that will be is equal to freeboard height and dense region height as a summation that will determine the Hf by substituting all known values there.

After that you have to calculate the exit value of the that is solid flux, then the mass flux of the circulating particles that is coming out from the bed the other by bubbling or turbulent fluidized bed through an inner cyclone collector is calculated in the same way that you can calculate what would be the amount of that the solid flux is coming out from the fast fluidized bed.

So, so, you can calculate the performance of fluidized bed by just calculating in this way systematic way and here like this.

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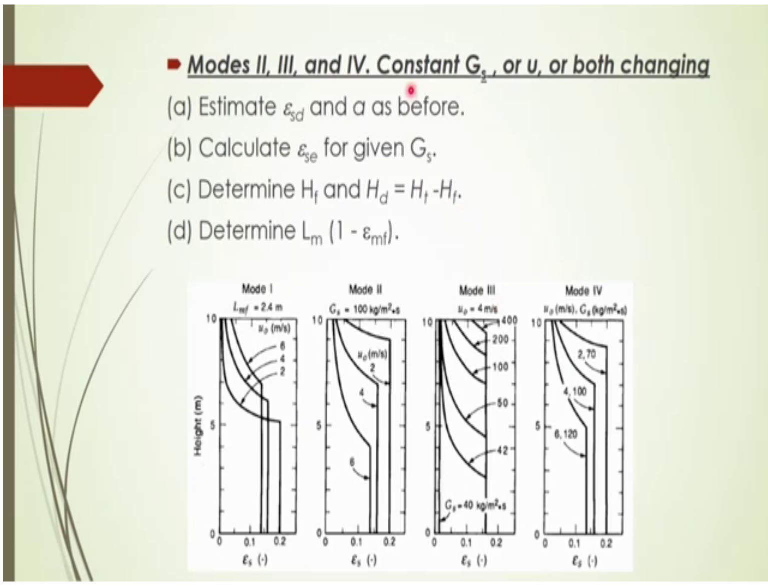

And then model 2, model 3 and model 4 in that case constant inventory; that means, constant solid flux or you can say constant fluid velocity or you can both change that Gs and u there. So, in that case, you have to estimate the again the solid fraction at the dense region and the decay constant as before and after that you have to calculate the exit solid fraction for a given solid flux and then you have to determine what will be the height of freeboard and the dense from the truth of that Hd is equal to Ht minus Hf.

And then determine the; what will be the, this amount of solid they are L m into 1 minus epsilon multiplied into cross sectional into density of the H. So, you just determine it and then after that you just calculate what should be the freeboard height there. So, from these this mode 1, mode 2, mode 3, mode 4, in that way just you just L mf is equal to two point four a meter and Gs is equal to 100 kg per meter square second and here at a constant gas velocity of 4 meter per second and mode 4 constant gas velocity and solid flux how, then this solid fraction can be changing. So, here that different mode how this changes occurred.

So, ultimately you can say that that this epsilon s; that means, solid fraction inside the fluidized bed that depends on the that will minimum height of the fluidized bed the solid flux here and the fluid velocity and both the solid flux and fluid velocity even the type of fluid particles and other operating conditions there and so, this is very important. So, this is the example is given by Kunii and Levenspiel, how to get the solid fraction and how it look likes that for this for different mode of operations, how it will be there.

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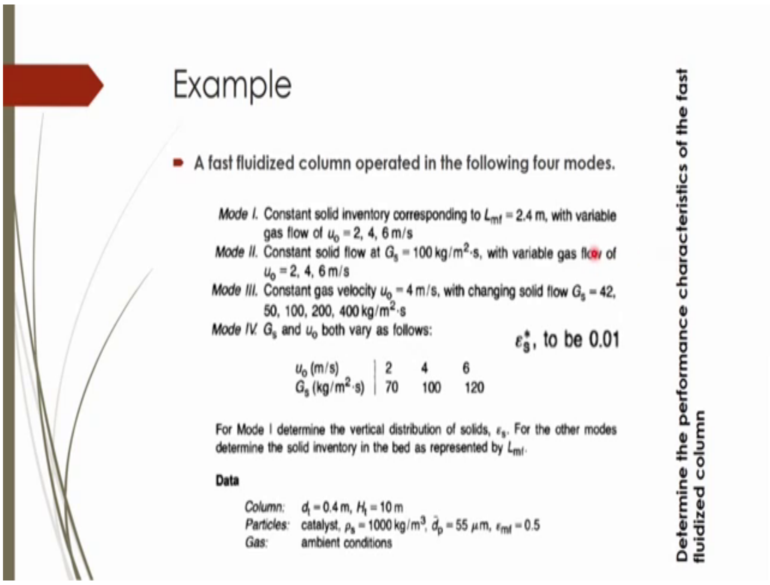

Now, let us see an example here to calculate this at different mode that the solid fraction they are. So, in this case a fast fluidized column operated in the following 4 modes, let us see mode 1 is constant solid inventory corresponding to minimum fluidized height is two point four meter with variable gas flow of u 0 is equal to 2, 4 and 6 meter per second where as in mode 2 constant solid flow at solid flux of 100 kg per meter square second with variable gas flow of velocity 2, 4 and 6 meter per second; mode 3 in that case, gas velocity should be should be constant at 4 meter per second, whereas, you have to change the solid flow ah; that means, Gs that will be 42, 50, 100, 200 and 400 kg per meter square second.

And as the mode 4 mode 4, you can say you can vary both of these Gs and u 0 as per table here u 0 and Gs that is gas velocity and the solid flux here if u 0 is equal to 2, then solid flux would be 70, then 406, 120, 120 and for all cases, you can consider that the saturated carrying capacity is solid fraction will be is equal to 0.01 and for mode 1 determine the vertical distribution of the solids epsilon is for the other modes determine the solid inventory in the bed as represented by this minimum fluidizing height.

So, column diameter is given you that forty centimeter and height, it is given 10 meter whereas, particles of the catalyst particles here density is 1000 kg per meter cube and particle diameter is 55 micrometer and minimum voidage in the fluidized bed will be is equal to 50 percent and gas condition is ambient condition there. So, determine the performance characteristics of the fast fluidized bed based on this operating condition.

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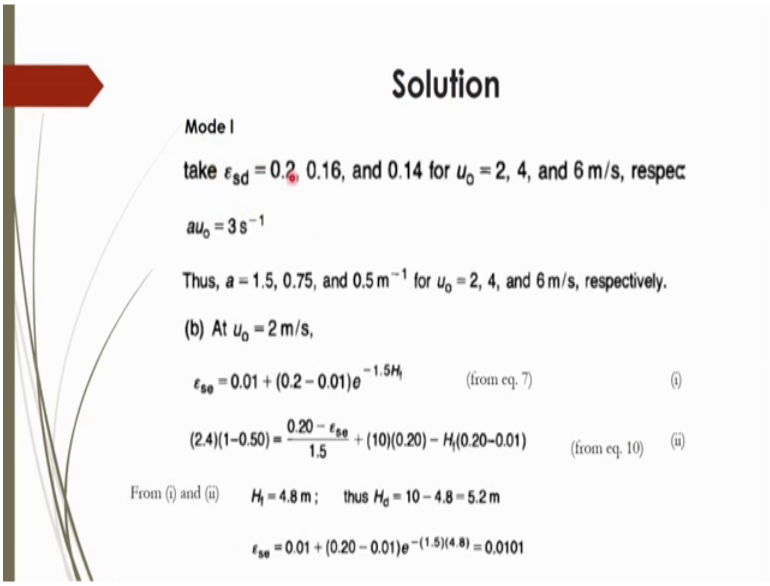

Now, mode 1 first of all you have to calculate the epsilon sd that is take this epsilon sd is equal to 0.2, 0.16 and 0.14 for gas velocity, 2, 4 and 6 meter per cell respectively and then calculate a from this a into u 0 is equal to 3, thus a will be is equal to 1.5, 0.75 and 0.5 meter inverse for u 0 u for different gas velocity, in this case respectively and for gas velocity is equal to 2 meter per second, you just calculate the exit solid fraction from the equation 7 here.

And and then just substitute the all known value here on in this case you will see that unknown value is Hf; that means, freeboard height now, but freeboard height you have to calculate here freeboard height, but what is that freeboard height is equal to be 4.8 meter because here you will see total height is given there and dense height is given. So, there what should be the freeboard height there and otherwise if you know that a total height and dense height there, then you have to solve this non-linear equation for freeboard height.

And after obtaining this freeboard height of 4.8 meter, then you substitute here in equation 7, then you will get what would be the exit concentration of this solid in the bed. Now here see equation 1 and 2 here in this case, this equation, if you substitute the parameters here just are knowing unknown parameter is a sf and epsilon se here in this case question from equation 10 you are substituting all parameters here under the sf and epsilon s is unknown.

So, solving these two equations you can get this sf also and Hd, they are from this total height. So, once you know this sf, then you substitute here in the equation seven again for this exit solid fraction.

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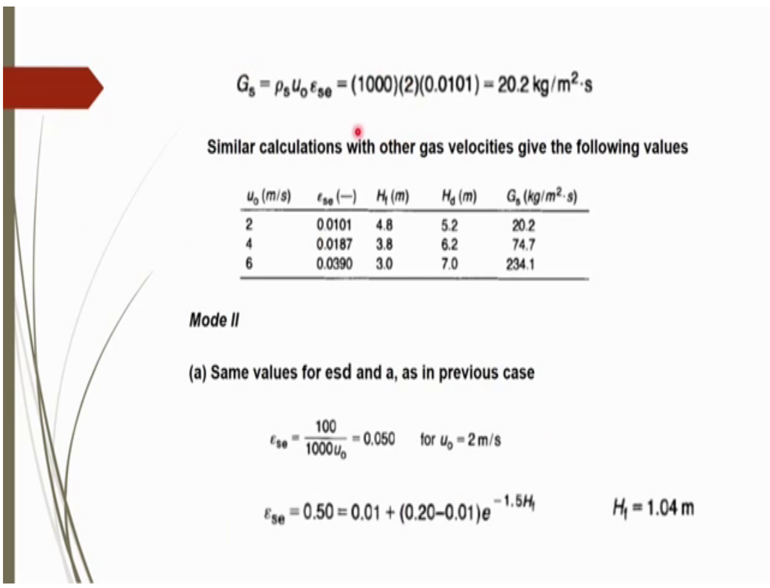

Once you know this of exit solid fraction you know already the solid density and the gas velocity then you will get the solid flux in the bed here. So, for different gas velocity and different exit solid fraction and different height of the freeboard and dense height, then you can get the respective solid fraction at different condition as mode 2 similarly mode 2, you have to calculate the same value of epsilon sd and a as in the previous case as in previous case, then what should be the exit solid fraction and what should be the solid fraction from the equation seven once you know that you will be able to calculate would be the freeboard height they are they are.

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$$L_{mf}(1-0.5)=\frac{0.20-0.050}{1.5}+(10)(0.20)-(1.04)(0.20-0.01)$$

$$L_{mf}=3.8\ \text{m}$$

Similar calculations for other gas velocities give the following values

u_0 (m/s)	ε_{se} (—)	H_f (m)	H_d (m)	L_{mf} (m)
2	0.050	1.0	9.0	3.8
4	0.025	3.1	6.9	2.6
6	0.0167	5.9	4.1	1.9

Mode III

(a) At $u_0 = 4\ \text{m/s}$ we have $a = 0.75\ \text{m}^{-1}$ and $\varepsilon_{sd} = 0.16$.

$$\varepsilon_{se}=\frac{1000}{(1000)(4)}=0.025$$

$$0.025 = 0.01 + (0.16-0.01)e^{-0.75H_f} \qquad H_f = 3.07\ \text{m}$$

Similarly, this L mf should be calculated from this equation given here and then at different gas velocity and different dense height of course, you will be able to calculate what would be the minimum fluidizing height there as a mode 3 at a certain gas velocity, it is given at 4 meter per second then a should be is equal to 0.75 and the dense a solid fraction is equal to 16 percent, if you substitute this value, what should be the exit solid fraction there, once you know the exit solid fraction and then from equation seven you will be able to calculate the what should be the freeboard height there.

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$$L_{mf}(1-0.5) = \frac{0.16-0.025}{0.75} + (10)(0.16) - (3.07)(0.16-0.01)$$

- $L_{mf} = 2.64$ m

Similar calculations with other solid circulation rates give the following values

G_s $(kg/m^2 \cdot s)$	ε_{se} (—)	H_f (m)	L_{mf} (m)
42	0.0105	7.6	1.3
50	0.0125	5.5	2.0
100	0.025	3.1	2.6
200	0.050	1.8	3.0
400	0.100	0.68	3.2

Mode IV

Calculations similar to those of Mode III give the following values:

u_o (m/s)	G_s $(kg/m^2 \cdot s)$	ε_{se} (—)	H_f (m)	L_{mf} (m)
2	70	0.035	1.35	3.7
4	100	0.025	3.1	2.6
6	120	0.020	5.1	1.95

And then you will be able to calculate what should be the dense side of course, it is given and then what should be the minimum fluidizing height there L mf.

Similar calculations with other solid, solid circulation rates given as follows, here you just calculate as per that the equation wisely given in that is equation one to 10 there. So, you will get this Gs Hf and L mf and then mode 4 again the calculation would be similar to those of mode 3 which is given the following values here as after calculation. So, you just you have to use the equation whatever given in the slides then only enough the to calculate this phenomena.

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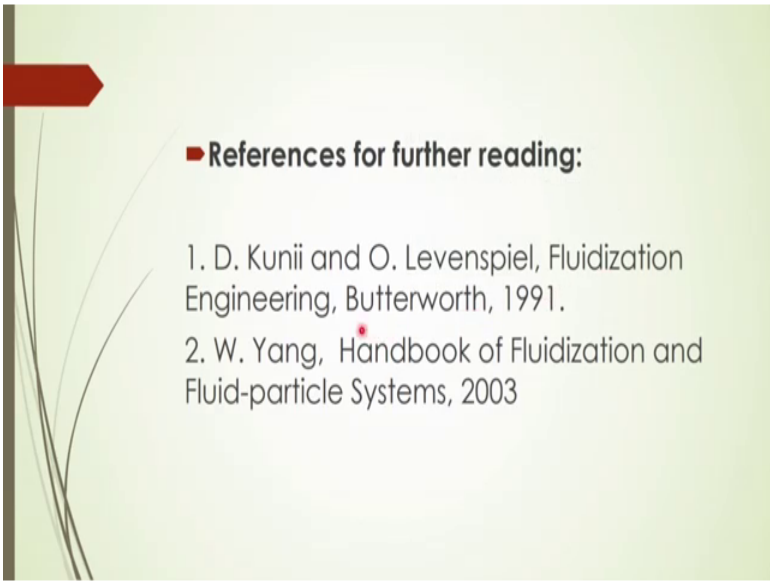

Now, for further reading you can follow this Kunii Levenspiel that fluidization it takes to kind the yang that is handbook of fluidization and fluid particle system and other references given in this book also here. So, in this lecture, what we have learned that in the what should be the fast fluidization condition and how the solid fraction is changing because of this entrainment characteristics, whatever mechanism discussed in the previous lecture, based on squeeze as per this entrainment model in solid fraction, how to calculate and what should be the freeboard height, once you know that exit a solid fraction.

And what should be the average the solid fraction inside the bed and also how to calculate the solid inventory inside the bed for the fast fluidization condition and based on this solid fraction distribution, this solid fraction distribution depends on different parameters operating condition like fluid velocity even the diameter of the column even the what is that if there is there any internal there or not and other solid load also is there.

So, based on who is this solid fraction distribution in the bed now this will be very helpful to actually calculate the performance of the fluidized bed whether it is in the reaction mode or not that of course, will be helpful we will discuss later on also more about these they are how these entrainment characteristics when solid fraction will be helpful to calculate the performance of the fluidized bed in different operating condition with a different flow pattern of the fluidized bed so.

Thank you for this lecture ok.