Fluidization Engineering
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Lecture – 14
Bubbling Fluidization Part 2: Bubble Characteristics (Contd.)

Welcome to massive open online course on fluidization engineering, todays lecture will be on bubbling fluidization part two, here also the bubble characteristics in the bubbling fluidized bed will be discussed.

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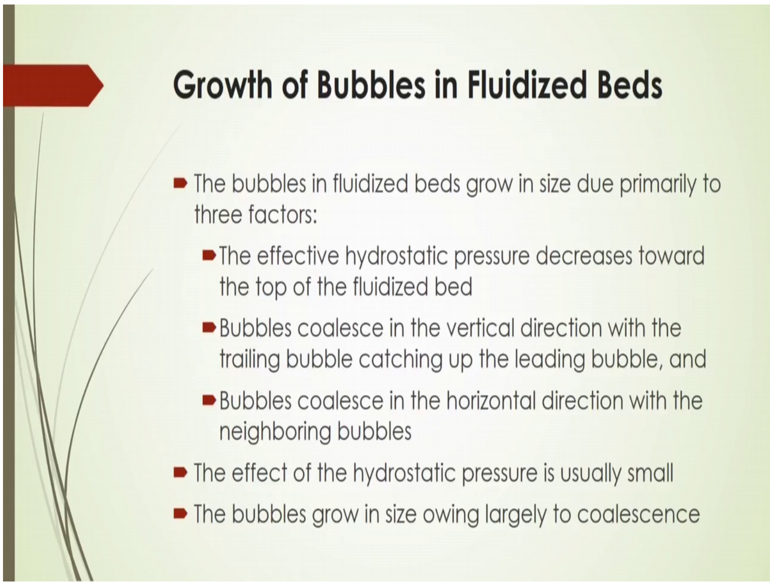

In this lecture, we will see that how that bubble is growth and also how bubbles are splitting into parts, and what will be the required mechanism for that in the bubbling fluidized bed will be trying to learn something about this. Now in this case, you see that the bubbles in fluidized beds that grow in size due to primarily to actually some several factors mainly three factors, we can observe in the happening of that growth of bubbles in the fluidized bed.

First is the effective hydrostatic pressure, which may effect on the growth of the bubble from the distributor in the fluidized bed, in that case the effective hydrostatic pressure decreases the bubble size toward the top of the fluidized bed. And bubble coalescence in the vertical direction with the training bubble that catching up in the leading bubble, and this mechanism because of certain that is distance to arrive to this leading bubble, then there will be catching up that bubble and then coalescence of this two bubbles will happen.

Now, in the horizontal direction you will see that bubble coalescence will be based on the neighboring bubbles and there of course, the side by side collisions of the bubbles in the horizontal cases. So, there also the bubble growth will be just colliding of two bubbles may be the horizontally by colliding to each other side by side whereas, in the vertical cases of course, one bubbles will be going upward followed by another one and then the tailing bubbles of course, the will catch up the will catch up that that that another bubbles vertically and making a bigger one so, that the bubble size will be increased from its initial diameter or size.

The effects of the hydrostatic pressure is usually small in this case and you will see that that higher pressure sometimes will reduce the size of the bubbles, and then coalescence may hindered because of some other fluid properties. And also at low pressures will see that there will be terminal velocity of course, will be higher than compare to the others then then catching up phenomena will be more intensive than higher pressure.

So, low pressure sometimes will enhance the coalescence phenomena and growth of the bubble. The bubbles grow in size owing largely to coalescence of course, because of the coalescence to bubbles will come to each other and making a bigger one. So, it is this is this is this is the called coalescence phenomena. So, by coalescence of course, two smaller bubbles may become bigger one.

So, from the bottom to top you will see there will be a trained of that coalescence phenomena in such way that, at the bottom the more number of bubbles will be coming to each other and colliding and making a coalescence and due to their (Refer Time: 04:48) and they will go up and then after a certain time at a certain distance, you will see there will be a bigger bubble formation at a certain location.

So, three factors mainly that effects on the bubble growth or bubble coalescence you can say that one is hydrostatic pressure another is that catching up of the bubbles trailing bubbles and then the colliding of this bubbles parallelly or you can say horizontally you can say the effect of hydrostatic pressure, in this case nearly small whereas, the bubbles grow in size owing largely to coalescence there.

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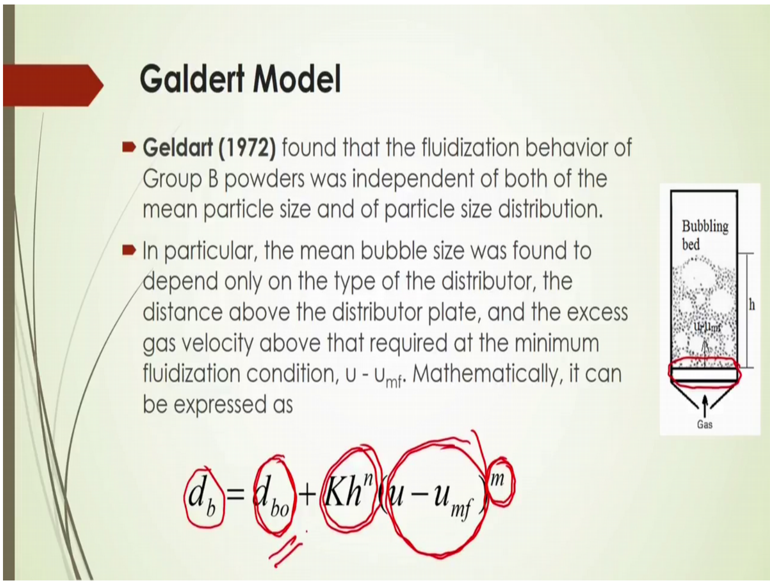

Now, there are different models available by which you can estimate, what should be the size of bubbles at a certain height of the fluidized bed. So, Geldart 1972 actually they have observed some phenomena of this bubble formation from its distributor, and they also done the experiment with the group B powders and in that case in that they reported that fluidization behavior of this group B powders was independent of the mean particles size and the particle size distribution.

So, particle size distribution is one of the important factor also there to characterize the fluidization behavior. In particular, it will see that the mean bubble size was found to depend only on the type of the distributor. So, there are various types of distributor that already we have discussed in earlier lectures that several different type of distributors they have different actually capability to distribute the gas of this first page of bubbles and also various distributor will give you the different sizes in bubbles.

Now, the distance above the distributor plate of course, that is very important to characterize the bubble size, at the very near to that distributor plate the bubble size is be very small whereas, above this distributor this size of the bubble will reduced, and there also the frequency of the bubbles will reduce frequency means number of bubbles they are formation.

Now due to that coalescence we will see the frequency of course, will be reduced because of the coalescence and this of course, formation of the bubbles depends on the gas velocity above the distributor of course, relative to that minimum fluidization velocity. Now Geldart 1972 they reported that the bubble size depends on this height of this fluidized bed from the distributor plate, and also the relative velocity of the gas or fluid that is maintained inside the bed.

Now this relative velocity is nothing but the, what should be the velocity of gas which is used for operation of the fluidized bed and what will be the minimum bubbling fluidization they are. So, u minus u m f there will be the, this is called the relative velocity here. So, this as per this equation here that as per this equation here given d b will be is equal to d b 0, d b 0 plus K into h to the power n and u minus u m f to the power m here.

These K n and m are coefficients that will be obtained from the experimental observation. Now this d b 0 is called the initial bubble diameter that is being produced from the distributor plate here in the fluidized bed. And K is the constant of course, this will characterize that how bubbles are actually moving from this distributor plate to the top of the fluidized bed, and it is depends on the, depends on the path of the bubble. And this n and m these are coefficient of course, this depends on different operating condition as well as the systems of the fluidized bed here.

Of course, it depends on the particle diameter of to this particle size and particle size distribution that will also effect on this bubble diameter. Now this m and n will be experimental obtained by changing this operating variables and also the system properties and by doing the experiment calculating the bubble diameter and the making this correlation of course, this d b 0 it is very difficult to calculate this initial bubble diameter from this distributor, but you can obtain this here, if you just feed this d b data in terms of this u minus u m f and h n, h then you will be getting them that from the profile as a intercept and this what is the coefficient here from those factors you will be able to find out what would the initial bubble diameter.

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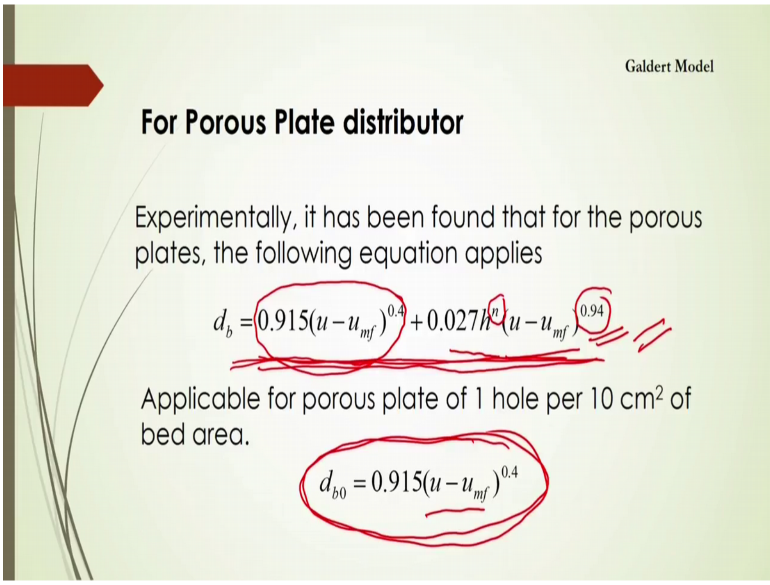

And the of course, this initial bubble diameter will be varying according to the flow velocity and also that depends on the type of distributor there. It is seen for porous plate distributor and that this d b will be is equal to here 0.915 into u minus u m f to the power 0.4 what does it means this actually this portion is nothing, but the initial bubble diameter.

So, this initial bubble diameter denoted by d b 0 is a function of here relative velocity of the gas, compare to the minimum fluidization velocity. And also it depends on this factor a is that is that a certain height and what should be the coefficient for m here m is equal to 0.94. And if you are changing this n is equal to one then of course, you will see there will be a bubble diameter at height is or n varying that depends on the physical properties of the system.

Now this correlations of course, here applicable or this correlations has been made by doing experiment, with the porous plate where the porous plate will be consisting or porous plate consist of one hole per 10 centimeter square area of the bed. So, based on this porous plate distributor, you can obtain you can calculate the bubble diameter at a certain height and at a certain gas velocity and also the initial bubble diameter of course, will be having from this correlations at a certain gas velocity there.

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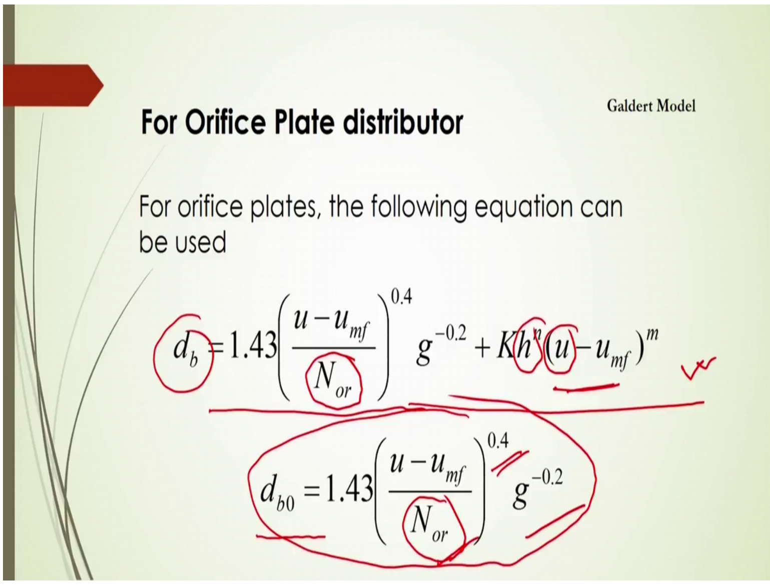

But for orifice plate distributor you will see this initial bubble diameter, that depends on the number of holes in the porous orifice plate distributor. So, in that case if number of holes increase you will see the bubble diameter will be initial bubble diameter will be less whereas, if you increase the gas velocity and fixing of fixed this orifice plate whole numbers then of course, there of course, there is a possibility of increase of bubble diameter there.

So, to get the less diameter bubble or less such diameter or you can say the smaller size bubble diameter from the distributor you have to increase the orifice hole number there that is denoted by N o r. So, d b o here the initial bubble diameter for this orifice plate distributor is again can be calculated from this correlations here say 1.43 into u minus u m f by N o r to the power 0.4 here into here g to the power minus 2.2. and then if you substitute this d b 0; that means, initial bubble diameter here in this equation then again you can calculate this d b at a certain height and at a certain gas velocity that is operated that governs the fluidized bed then what should be the bubble diameter inside the bed for this orifice plate distributor.

So, in this case of course, the you can get the smaller bubble size, if you use the plate distributor of large number of hole. And of course, if you increase the gas velocity there will be a possibility of this higher diameters. So, optimum condition will be there you have to design the distributor in such way that to get the smaller bubble size distribution for the more beneficial mass transfer operation you have to have a smaller diameter and smaller diameter and of course, to get the more interfacial area so that you can get mass transfer in this case. So, for getting more mass transfer area and getting more performance of this fluidized bed this orifice plate distributor with the large number of porous plate will be more suitable compare to the porous plate distributor there.

Mori and Wen in a 1975 they have developed another correlations to calculate or to predict the bubble diameter inside the bubbling fluidized bed. They have observed that the from the distributor there will be a chain of bubbles that is forms from this distributor to that to the top of the bubble here.

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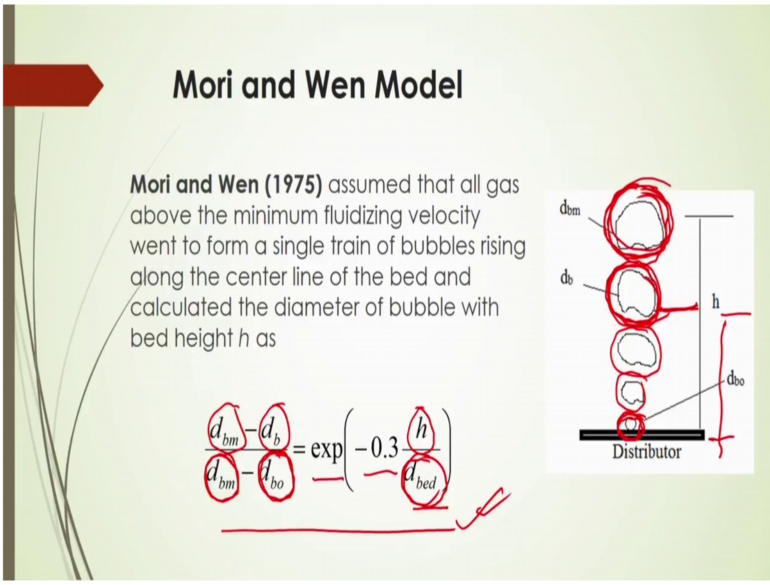

But at the distributor there will be very small bubble whereas, they are going up they are observing that relatively higher size bubbles are there. And at the top it is almost you will see there will be a maximum bubble diameter. So, here in this case two bubbles may be colliding vertically and then testing to each other or capturing each that is leading one to that trailing one, then an getting the coalescence and becoming bigger bubbles and at the top it will be moving there and then the maximum bubble size will be there. So, in that case Mori and Wen based on this actually happening they have develop this correlations here whatever shown here, and they have assumed that all the gas above the minimum fluidizing velocity went to form a single train of bubbles rising along with the center line of the bed and circulated sorry and that can be calculated the diameter of the bubble with the bed height h as per this correlation here.

So, what is this here d b m minus d b divided by d b m minus d b 0 that will be is equal to exponent of minus 0.3 into h by d bed here this d bed is the bed diameter and here d b m is the maximum bubble diameter and d b 0 is the initial bubble diameter.

So, you have to know the initial bubble diameter and also what should be the maximum bubble diameter, and once you know this maximum and minimum bubble diameter at a certain height here supposed here at a certain height here this is the maximum bubble diameter and this is the diameter of this height h and this is the maximum bubble diameter. So, what should be the size of this bubble that you can obtain from this equation.

Now you have here only you have to know what is the height here from the distributor, and also what will be the initial bubble diameter maximum bubble diameter just substitute here you will get the maximum value also you have to know the what would be the diameter of the bed. So, except this d b everything is known to you this is d bed d b 0 and d b m then you will be able to calculate what should be the bubble diameter at this particular height.

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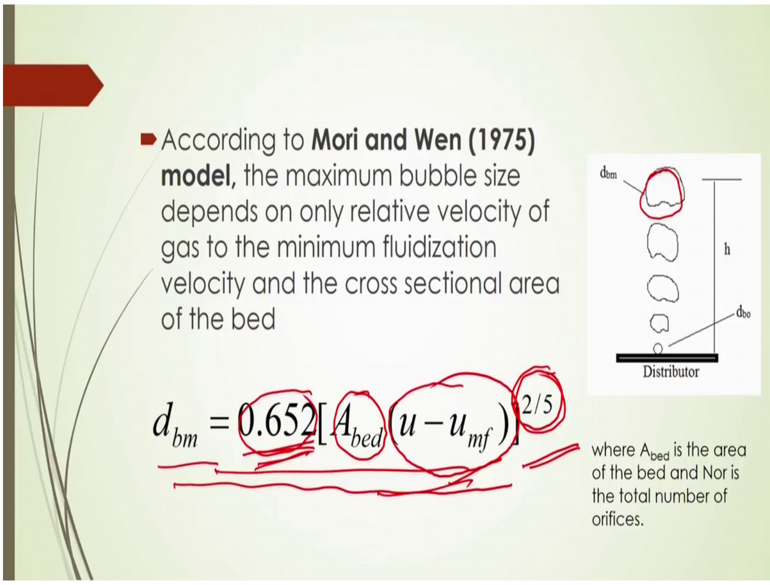

Now, according to this Mori and Wen 1975 model, the maximum bubble size depends on only this relative velocity of the gas to the minimum fluidization velocity, and also the cross sectional area of the bed. So, the d b m this maximum bubble diameter will be is equal to 0.652 into cross sectional area of the bed into it is this relative velocity of the gas to the minimum fluidization velocity that is to the power 2.5.

Now you will have of course, earlier that discussed how to obtain this maximum bubble diameter by photographic method if you use the highest speed camera as well as the microscopic camera there you will observe that what should be the exactly size of this bubble diameter after analyzing it by suitable software of image analyze, is then you will be able to calculate what should be the maximum bubble diameter there.

So, once you know that maximum bubble diameter with respect to different operating conditions, then if you make with this correlations with the experimental results you will get this type of coefficient of 0.6 0.2 and 2 by 5. Of course, this coefficients may be different from different experimental results, may be that depends on the system to system of course.

So, you can get the idea to calculate the maximum bubble size from this correlations also from your experimental data you can also make one correlations this way so, that you can predict your maximum bubble diameter. So, this may be there the error will be may be some extent that ten percent or fifteen percent that can be expectable, but if you try to make the correlations in this way you will be able to do in your experiment.

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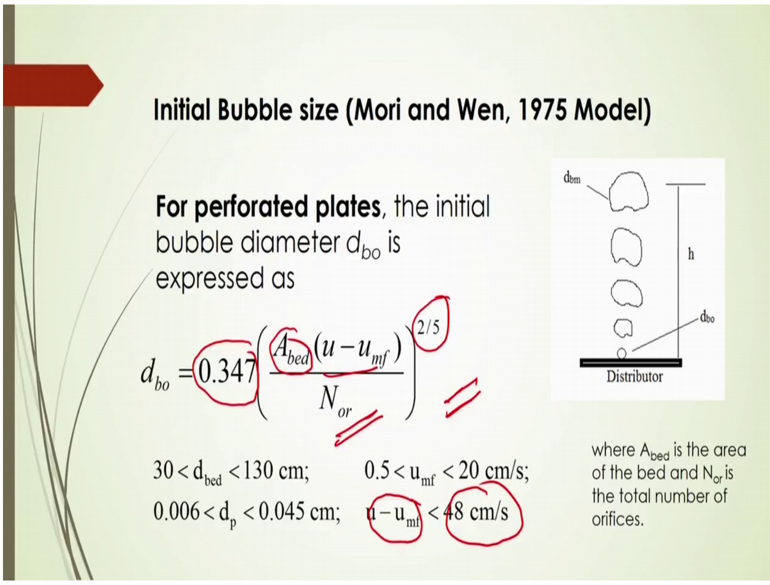

Now, initial bubble size as per this Mori and Wen model, the for perforated plates they measured this initial bubble size and the initial bubble diameter from their experimental data they have correlated to predict this initial bubble diameter as this and they told that this initial bubble diameter depends on the number of what is that orifices and also the bed diameter and the relative velocity of the gas with the minimum fluidization velocity.

So, again here you can also make this type of correlations just from your experiment, otherwise you can directly use this correlation to calculate the minimum bubble size from the distributor here. So, these correlations of course, all correlations whatever will be made from the experimental data, will be validated within a certain range of operating conditions.

So, these correlations is valid here it is seen that this bed diameter will be within the range of 30 to 130 centimeter and minimum fluidization velocity should be within the range of 0.5 to 20 centimeter per second. Whereas, this particle size of course, it has of course, the immense effect on that bubble initial bubble size, then this correlations of course, this validated within the particle size of 0.00 meter to 0.045 centimeter. So, 0.006 to 0.045 centimeter. And of course, this relative velocity u minus m f should be within the less than 48 centimeter per second. So, within these operating conditions you can use this correlations to predict or to calculate the initial bubble diameter for the perforated plate distributor.

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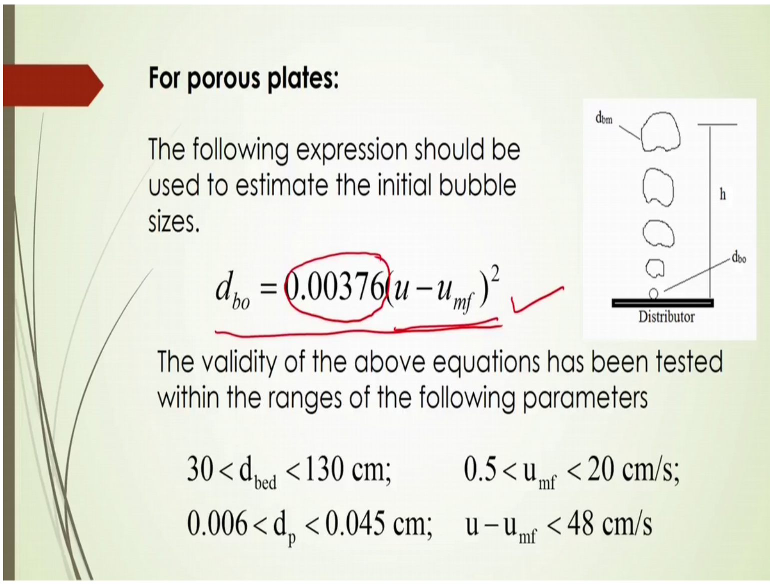

For porous plate distributor again they have developed one correlations here they have seen that this initial bubble diameter directly related to the relative velocity now they have seen that this this initial bubble diameter is the proportional to the square of the relative velocity, and this proportional constant is 0.00376. So, this flowing expression can also be used to calculate the initial bubble diameter.

Now this again correlation will be validated within a certain range, in that case this correlations is valid if the bed diameter is within the range of 30 to 130 centimeter and this minimum fluidization velocity will be within the range of 0.5 to 20 centimeter per second of course, within the same particle diameter range and operating variables operating parameter like the gas velocity will be within the range of this u m f plus 48 centimeter per second here as per equation.

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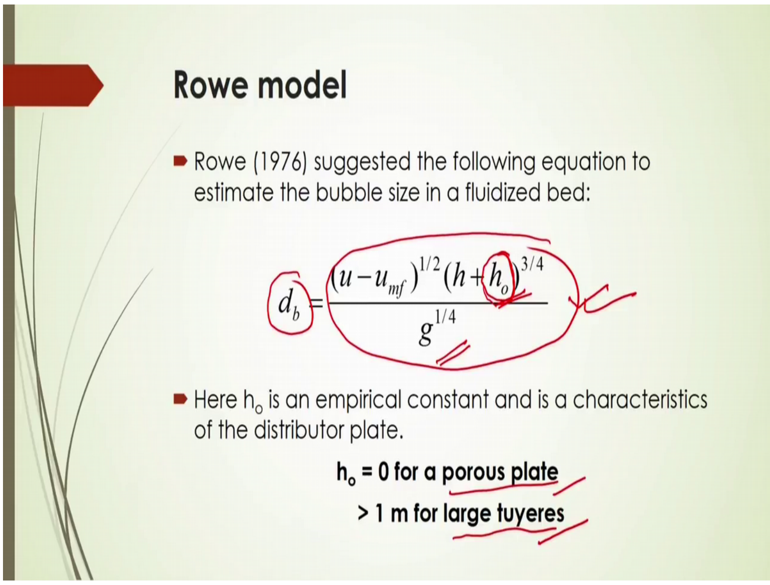

Now, Rowe et al, Rowe of course, 1976 he also suggested the following equation to estimate the bubble size in the fluidized bed. They have obtained that this bubble size is a function of this relative velocity as well as height and the gravitational acceleration, here one important parameter is empirical constant here h 0 is inserted her based on this correlations here d b is equal to u minus u m f to the power half into h plus h 0 to the power three by five here this h 0 is the one empirical constant and it is characterized based on that what is that distributor.

And it is seen that this h 0 this empirical constant you will be 0 for a porous plate distributor and it should be greater than one meter for large tuyeres types distributor. So, this bubble diameter you can obtain or you can predict or you can calculate only if is produced from this porous plate and large tuyeres then you can say what should be the bubble diameter at a certain height.

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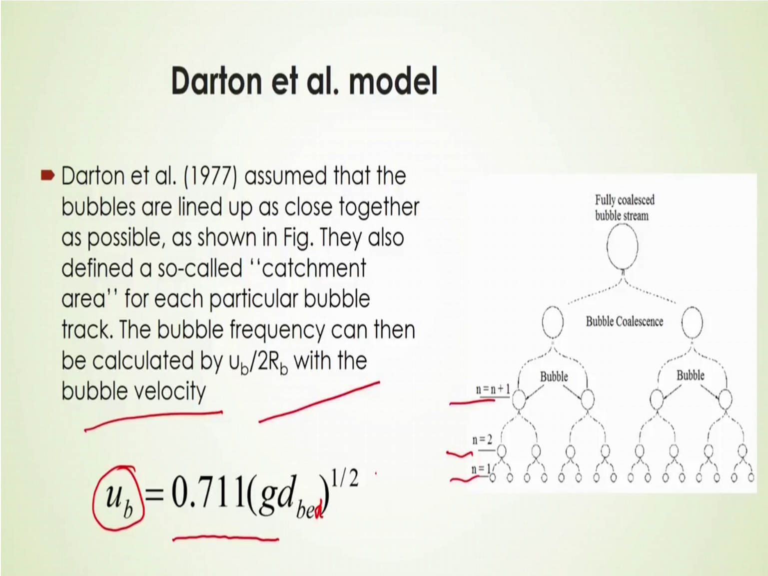

Darton et al 1977 they have also given another mechanism and also that mechanism to grow the bubble and also what should be the frequency of that bubbles, how many bubbles are formed forming in the fluidized bed, based on that they have actually suggested different correlations to calculate the bubble size.

Now they have assumed that the bubbles are lined up as close together as possible as per this figure, and they also defined a so, called it is called catchment area and catchment area for each particular bubble track this is the particular bubble track here, and the bubble frequency can then be calculated by this bubble rise velocity upon the diameter of the bubble. And diameter of the yeah bubble and with the bubble velocity here, this bubble velocity will be is equal to 0.11 into g d bed to the power half here.

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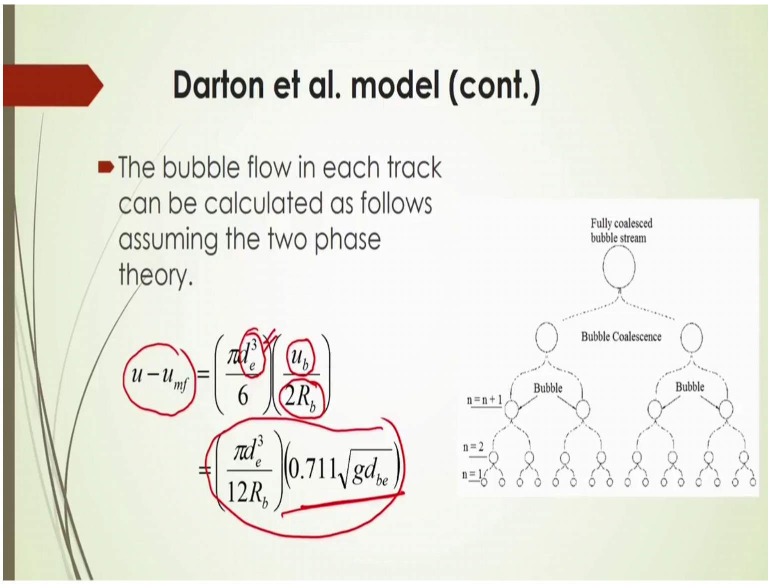

So, based on that the bubble flow in each track, they have suggested how to calculate there and according to their model then this bubble flow that is u minus u m f, that is called relative flow of the bubble can be calculated from this two phase theory as per this correlations here, this will be is equal to pi d e to cube by 6 into u b by 2 R b here. Whereas, d e is called equivalent bubble diameter, because here this equivalent bubble diameter is that that all bubbles may not be the same in size and also same in shape.

So, in that case you have to calculate from the equivalent bubble diameter. And what should be the bubble rise velocity that has been given earlier in this bubble rise velocity can be calculated by this correlation and here this R b, 2 R b is the bubble diameter here. And then from this you just directly substitute the bubble rise velocity here then you can calculate what should be the relative velocity of the flow of bubble inside the bed.

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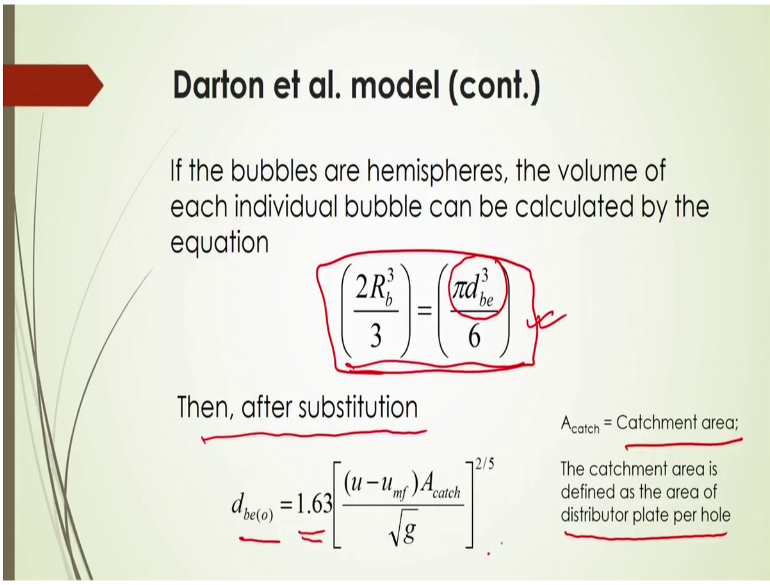

And if the bubbles are hemispheres, the bubble of each individual bubble can be calculated by the equation here. So, all bubbles may not be spherical some bubbles will be what is the hemisphere. So, in that this hemisphere 2 R b cube by 3 is equal to pi d b cube by 6 this will be satisfied, here in this case to calculate the equivalent bubbles diameter just by considering that that spherical bubble here.

And then after substitution that d b e 0 that means, initial bubble diameter equivalent bubble diameter can be calculated from this correlations here will be 1.63 into u minus u m f into A catch by root over g to the power 2 by 5; what is A catch is v called catchment area, the catchment area what is that catchment area? Catchment area is defined as the area of distributor plate per hole; that means, area of distributor plate per hole what how many area is occupied that is catchment area. So, once you know that catchment area and the relative flow of the bubble, then what should be the initial bubble diameter you can calculate from this correlation.

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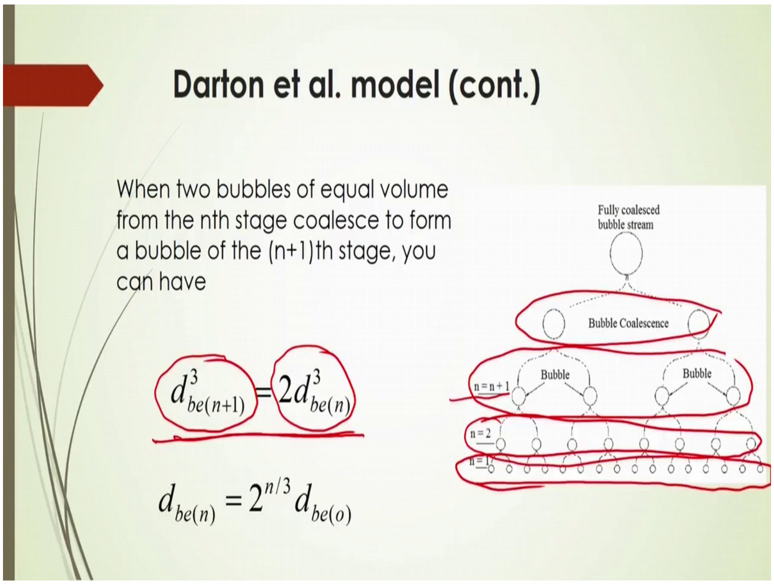

And when the there are two bubbles of equal volume they are coming to each other and from the nth stage they are coming, there is nth stage they are coming, then how they will be collapsing and how they will be coalescence to each other to form a bubble of size a particular size in the plus n plus 1 stage, they are then you can say that that will be the here this at this stage, this n is equal to n plus 1 stage this equivalent bubble diameter will be is equal to cube root of this 2 into d b e to the power n here.

So, from this relationship you will be able to calculate, what should be the equivalent bubble diameter at a certain stage. So, if you consider the stage that initial stage from this distributor n is equal to 1, and then in the next stage n is equal to 2 what should be the bubble size? And then nth plus one what should be the bubble size here. So, from this different stages how this bubbles will be growing up to the top, based on this stages you will be able to find out from this correlation. So, this will give you that what should be the equivalent biometer bubble diameter at a; at nth stage here according to their model.

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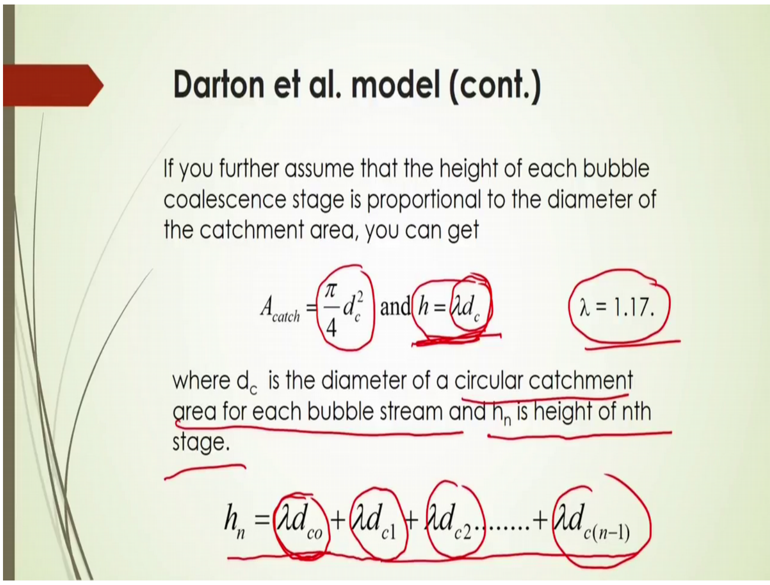

And if you further assume that the height of each bubble coalescence stage is proportional to the diameter of the catchment area you can get this what should be the catchment area here this will be considered as pi by 4 into d c square; that means, here cross sectional area of the column to be considered, and also h there should be considered as at a certain height that will be some factor multiplied by d c here. This is the column diameter, where d c is the diameter of the circular catchment area for each bubbles stream and h n is the height of nth stage.

So, at nth stage height at a certain height then what should be that, this h that should be multiplied by lambda. Now what is that lambda factor? That lambda factor is nothing, but here that lambda factor generally considered according to their model based on their experimental data they suggested that lambda should be is equal to 1.17. That means, h at the h that is 1.17 times of that catchment diameter or area, then you can obtain what should be that h value. And at that h value at that certain stage what should be the actually bubble diameter that can obtain from this relationship here.

Now this here h n at a certain nth stage what should be the n here that will be is equal to lambda d c 0; that means, for the initially what should be that bubble diameter, and then what should be that catchment diameter initially that d c 0 and then what is lambda d c 1, d c 2 lambda d c n minus one that catchment area of the bubbles there at the nth stage of course, you have to calculate that what should be the h n there based on this value.

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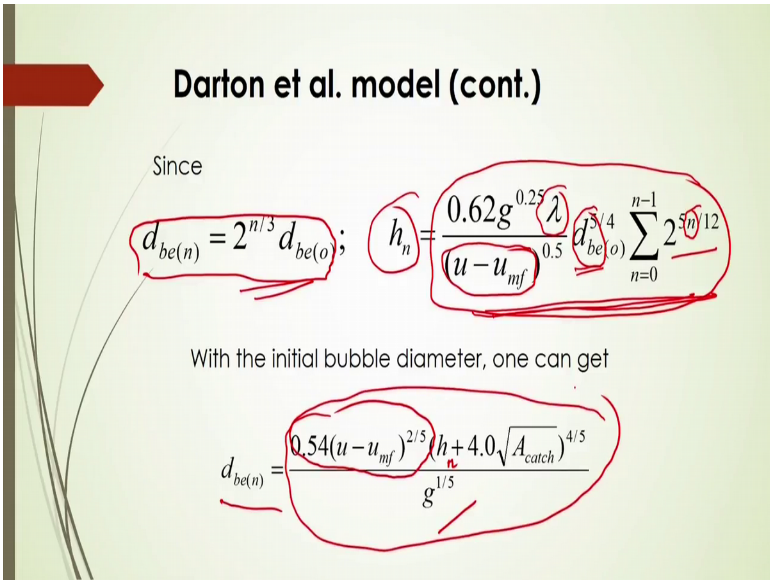

Now, since this d b n that will be is equal to this here as per this at nth stage what should be the equivalent bubble diameter that can be obtained from this correlation then what should be the h n value, then you can obtain by this relationship that will be is equal to 0.62 into g to the power 0.25 into lambda, divided by u minus u m f to the power 0.5 and d b e that means, equivalent bubble diameter to the power point 5 by 4 initially what is that and summation of that n is equal to 0 to n minus 1, that is nth stage up to that 2 to the power 5 n by 12.

So, here this h n depends on this flow velocity of this bubble as well as the diameter equivalent bubble diameter, and also the number of stages there. So, in that case how to calculate this h n you can of course will be obtained from this now lambda should be is equal to 1.17. Now with this equation of h n if you once you calculate this h n, then what should be the bubble diameter at that particular nth stage you can calculate here by this 0.54 into u minus u m f into h plus. Here h should be h n here or of course, this is very simple that h n means at a certain height of the bubble fluidized bed, then h n plus 4.0 into root over catchment area to the power 4 by 5 by g to the power 1 by 5. So, from this correlations you can obtain what should be the equivalently bubble diameter.

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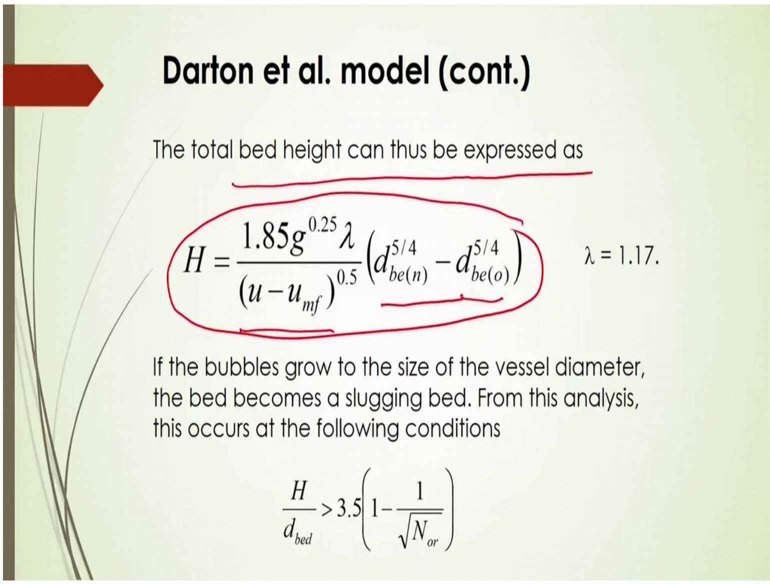

And then what should be the total bed height then as per that. Suppose there is from the beginning to that certain height, the all bubbles will be coalescing to a single bubble. So, based on that what should be the total height of the bed, based on this that is the coalescence of this bubbles, the total bed height then can then be expressed as here H will be is equal to 1.85 g to the power 0.25 into lambda by this here into d b e nth stage to the power 5 by 4 minus d b e at the initial stage to the power 5 by 4, and then from this what should be the total height of the bed you can calculate here.

Now if the bubbles grow to the size of the vessel diameter, the bed becomes a slugging bed, from this analysis this occurs at the flowing conditions here you can say H by d bed; if it is greater than 3.5 into 1 minus o1 by root over N o r, you can say that there will be a formation of this bubble in such way that the bubble size will be of almost equals to the vessel diameter, and in that case the beds will behave like a slugging bed.

Zenz 1977 they have proposed another model to calculate the bubble diameter here. So, they have assumed that bubble growth in the fluidized bed that resembles the we known that is Fibonacci series that has given by Zenz 1978 and proposed the following equation to bubble growth here.

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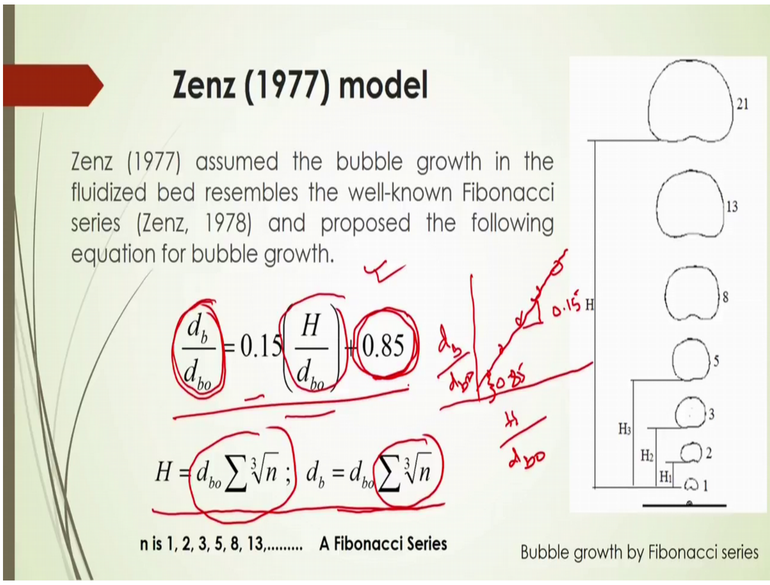

In this case this ratio of the bubble diameter at a certain height to the initial bubble diameter that will be is equal to 0.15 into H by d b 0 plus 0.85. So, this 0.85 is nothing, but this intersect here intersect; that means, if you are getting this d b by d b 0 from your experiment at a certain height, then what should be the just simple just fitting the experimental data here like this here if it is suppose d b by here d b by d b 0 and here h by d b 0, if you have the data from the experiment like this then you can get this type of straight line, where this intercept will give you 0.85 whereas, this slops will give you the value of one point 0.15.

So, from this experimental data you will be able to find out what should be the bubble diameter at a certain height there. Whereas, this height can be calculated as per that Fibonacci series also that here this H will be is equal to d b 0 into summation of root over n and d b will be is equal to d b 0 into n b r, this summation of cube root over n b r. So, in this case of course, this n her you see that Fibonacci series 1, 2, 3, 5, 8 and 13 they are and respective height that denoted by H 1, H 2, H 3 then you will be able to total height by summation of this here. So, based on this bubble growth by Fibonacci series Zenz 1977 they have developed this correlation to obtain the bubble size here. So, these correlations also can be used to calculate what should be the bubble diameter of a certain height.

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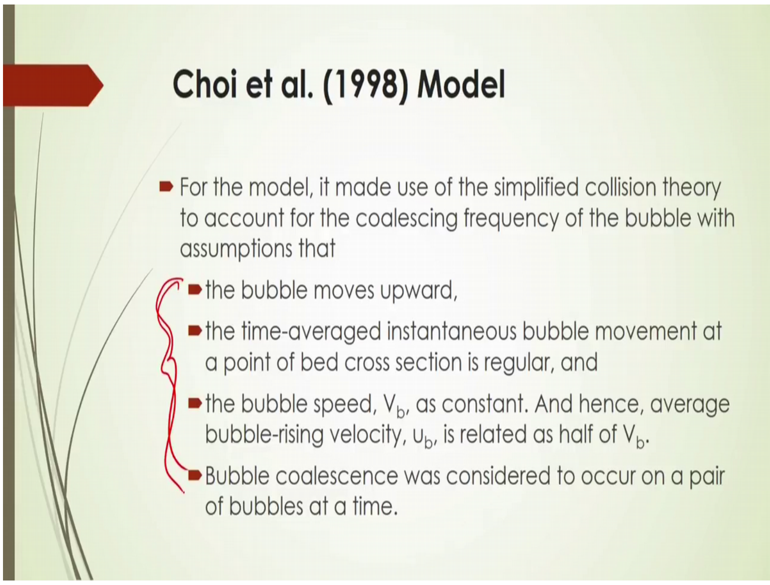

Choi et al 1998 let us that model for the that is for the bubble size based on the collision theory, and they have developed this model and they have stated that the bubble moves upward and the time averaged instantaneous bubbles movement at a point a bed cross section is regular, and the bubble speed V b as a constant here and hence average bubble rising velocity U b is related as half of the bubble speed. And bubble coalescence was considered to occur on a pair of bubbles at a time. So, based on these assumptions they have actually made one simplified collision theory, based on this analyzes based on this mechanism or assumption and they have stated different way to calculate the bubble frequency.

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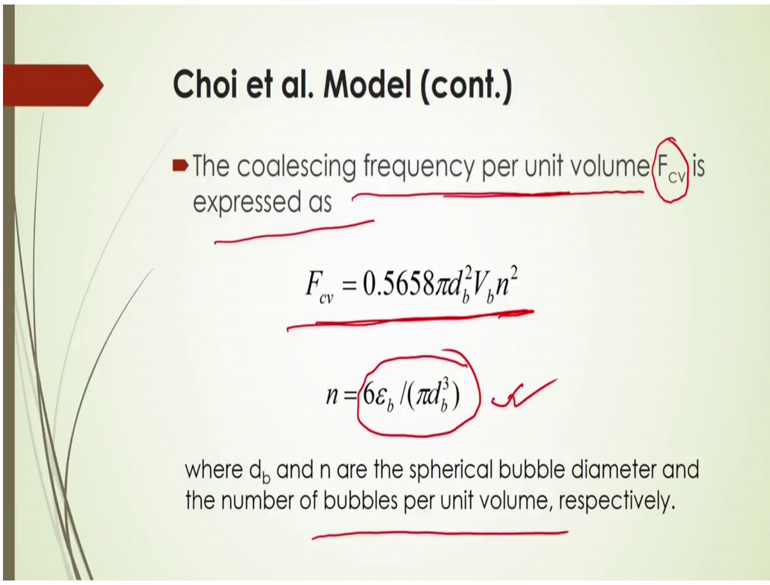

And the bubble coalescence frequency as per that is per unit volume, that is denoted by F c v is calculated in this way by this correlations F c v that will be 0.5658 into pi d b square into V b into n square here. This n is nothing, but number of bubbles how many number of bubbles are forming inside the bed, that can be obtained from the bubble diameter and as well as the what should be the bubble volume fraction inside the bed. If you know the bubble volume fraction inside the bed and if you know the bubble volume, that is 1 by 6 into pi d b cube then just bubble volume fraction divided by the total volume of the bubble that is the bubble volume bubble volume, then you will get the number of bubbles forms here.

If you know the number of bubbles there of course, what should be the frequency of the coalescence; that means, what is the probability, what would be the, that is how many times that bubbles can coalescence inside the bed per unit volume of the fluidized bed that can be obtained from this. So, this frequency depends on the bubble size as well as the how many number of bubbles are forms inside the bed and so, you have to know what should be the bubble speed there. So, here this d b and n are the spherical bubble diameter and the number of bubbles per unit, volume that should be calculated and based on that you will be able to calculate what will be the coalescence frequency per unit volume.

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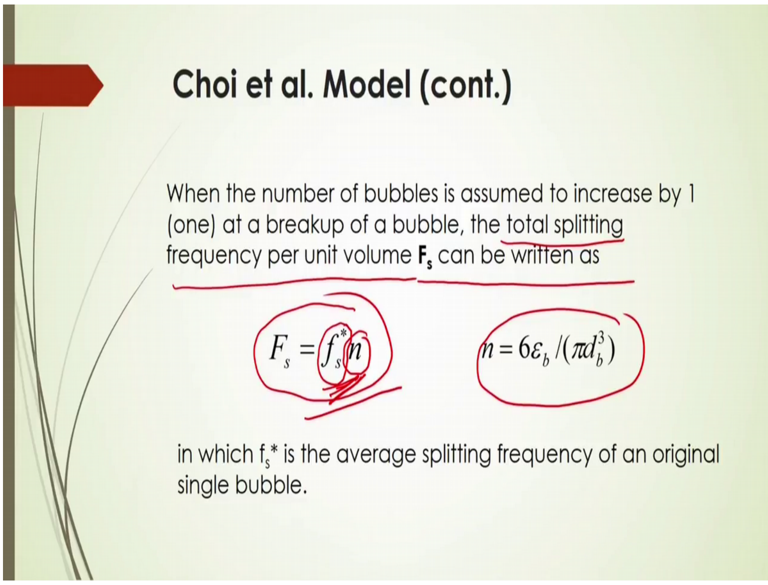

Once you know this coalescence frequency of course, you have to know when the number of bubbles is assumed to increase by 1 at a breakup of bubble, there is a possibility to breakup also their bubble then total splitting frequency per unit volume also to be calculated. So, total splitting frequency per unit volume F s can also can be calculated from this here, now this F s will be is equal to f s star into n, here n will be is equal to again that what would be the number of bubbles formed here.

So, here splitting frequency per unit volume f s is equal to this this f s star is the average splitting frequency of an original single bubble here, this is the original single bubble. If you split you have the splitting frequency for the single bubble then you have to multiply by the n number of bubbles then total you will see that splitting frequency per unit volume inside the bed will be is equal to f s star into n.

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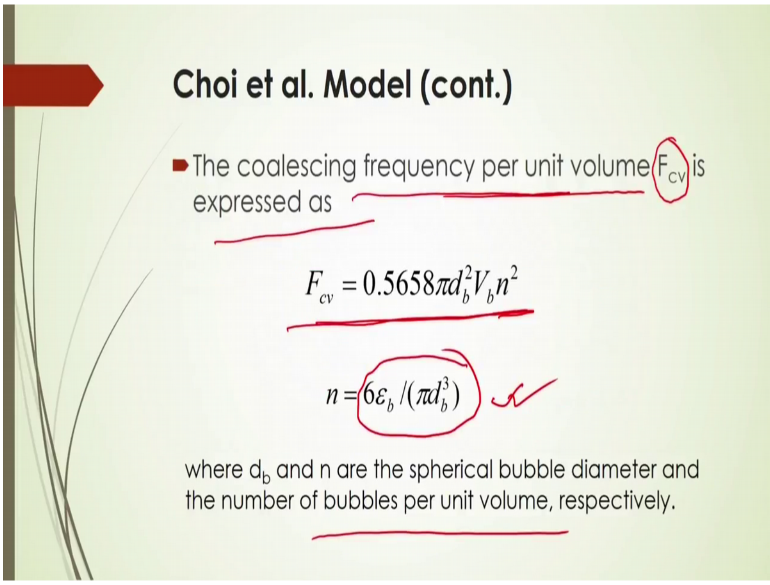

Now, we know that then coalescence frequency and the splitting frequency. So, once you know the coalescence and splitting both will be there then of course, the effective then what should be the effective manner by which that you can get the effective bubble number, because one may be that bubble may be will be splitting as well as coalescence once it is splitting then two bubbles again make coalescence. So, what should be the effective actually number of bubbles will come.

Now, the variation of then number of flow rate n f number flow rate that is number flow rate; that means, how many numbers are produced by unit time; that means, here number flow rate n f of the bubbles across the bed cross section with respect to height h above the distributor is then calculated here in this way. So, this is d N by d h will be representing by that is number flow rate of bubbles, and that depends on what is that depends on cross sectional area of the bed and the bubble speed and then what is that bubble volume fraction inside the bed, and bubble diameter and what will be the bubble splitting frequency for single bubble.

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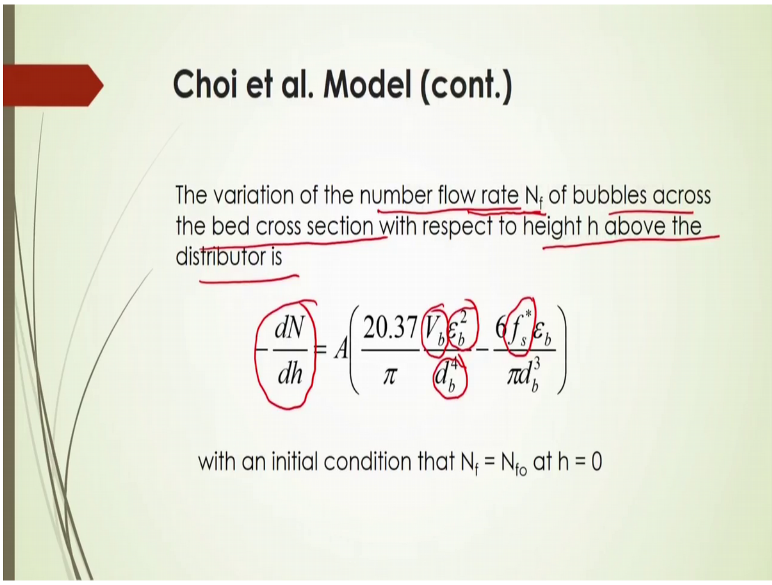

So, once you know this then from this correlation, we will be able to find out what should be the rate of number of bubbles formation there inside the bed. Now if you consider that initially as an initial condition that N f will be is equal to N f 0 that h is equal to 0.

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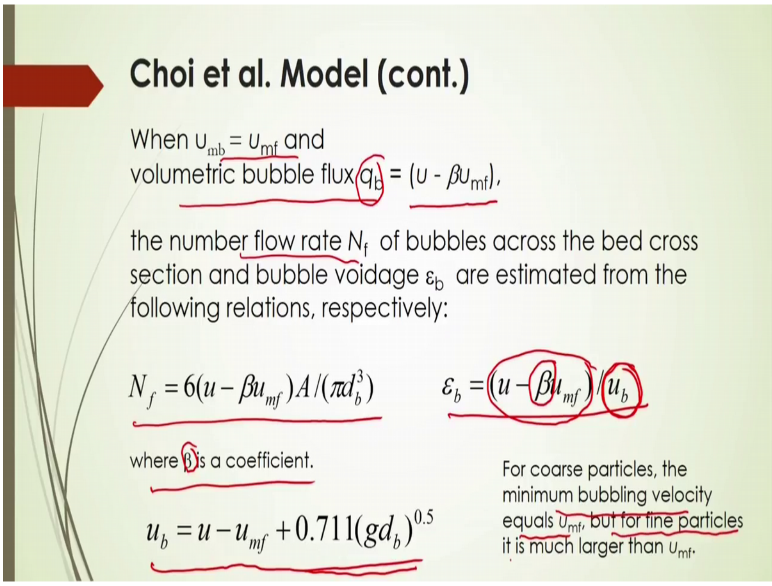

And also if you are considering that bubble rise velocity as u m b is equal to u m f and the volumetric flux that is q b will be is equal to U into U minus beta into U m f. Then the number flow rate N f of the bubbles across the bed cross section and bubble voidage epsilon b then can be calculated from this equations. Here N f will be is equal to 6 into u minus beta u m f into A divided by pi d b cube whereas, this bubble volume fraction that depends on the velocity of the gas and also what will be the bubble rise velocity there.

So, this will be is equal to u minus beta into u m f, u m f is the minimum fluidizing velocity and also u b is the bubble rise velocity where here, in this case beta is one coefficient this coefficient of course, depends on the experimental data actual condition in actual condition, what should be the bubble actually flux volumetric bubble flux inside the bed that depends on this particle size and distribution also what would be the system used there. So, that depends. So, this beta factor also depends on the operating condition.

Now, this u generally it is seen that this beta is equal to 1 in many cases. So, almost equals to 1 so, what would be the bubble rise velocity will be is equal to u minus u m f plus 0.11, 0.711 into g d b to the power 0.5. And for coarse particles the minimum bubbling velocity equals the u m f, but for the fine particles it is much larger than u m f. So, this beta of course, depends on the bubbles particle size also for coarse of particle it will be different than finer particles.

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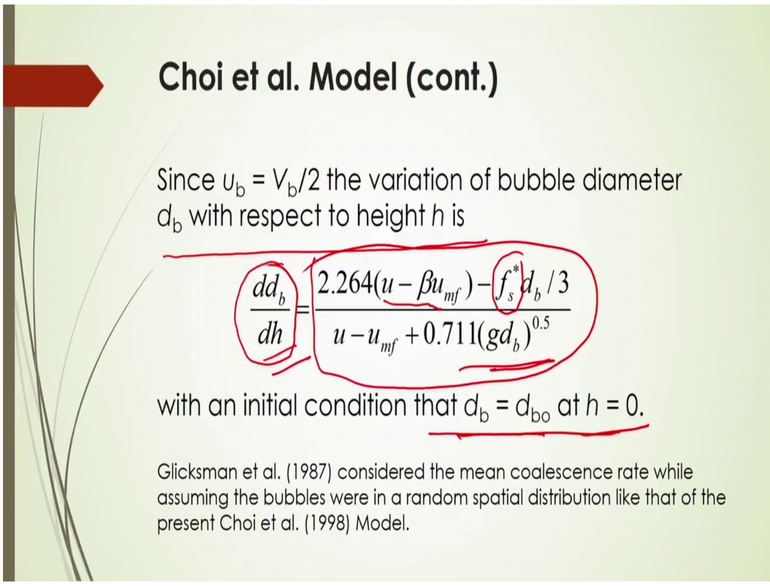

And of course, if this bubble rise velocity is equal to V b by 2, the variation of bubble diameter d b with respect to height h will be equals to then d b d b by d h that will be is equal to how actually the bubble diameter respect to height will be changing then you can calculate from this correlation here. This will be equals to 2.264 into u minus u minus beta u m f, then that depends on this also this bubble frequency splitting frequency and also bubble rise velocity there.

With an initial condition that d b is equal to d b 0 and h is equal to h i; that means, here h 0. So, with this initial condition if you integrate this you will be having the, what should be the bubble diameter with respect to height. Now Glickman et al 1987 considered the mean coalescence rate, while assuming the bubbles were in a random spatial distribution spatial distribution like that of the present Choi et al model here.

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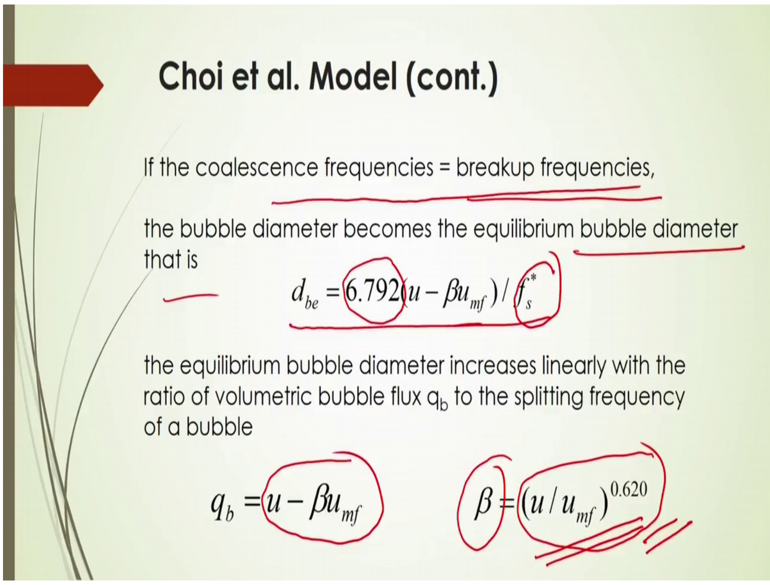

Now, if the coalescence frequencies is equal to bubble frequencies; both the same then the bubble diameter becomes the equilibrium bubble diameter. So, that will be equilibrium bubble diameter then will be obtained from this the equilibrium of this frequencies and coalescence and breakup frequencies. So, this will be is equal to 6.792 into u minus beta into u m f by f s star.

The equilibrium bubble diameter increases linearly with the ration of volumetric bubble flux to the splitting frequency of a bubble. So, this bubble flux q b can be obtain from this u minus beta into u beta times of what is that minimum fluidization velocity, where beta can be calculated here u minus u m f to the power 0.620. So, here this depends on particle size because that particle size will give the minimum fluidization velocity. So, from that minimum fluidization velocity what should be the beta factor, what will be the ratio of this u by u m f and from which you will be able to calculate this beta here.

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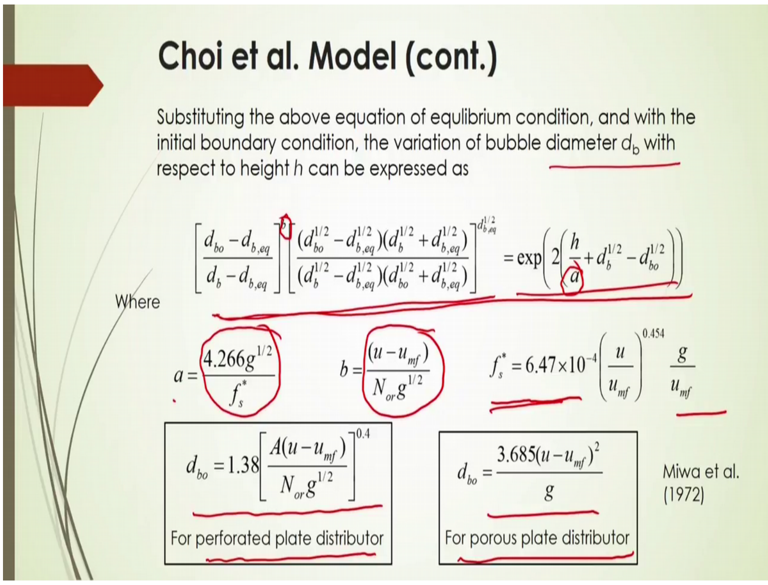

And substituting this above equation of equilibrium condition and with the initial boundary condition the variation of bubble diameter d b with respect to height, h can then be expressed as by this equation this here. So, from this equation you will be able to calculate, what should be the bubble diameter at its equilibrium condition; that means, where bubble coalescence and bubble breakups of its frequency will be same. So, in that case from this relationship you will be able to calculate the bubble diameter at its equilibrium condition.

Where some coefficient here a and b are there. So, this a and b value will be obtained from the experimental condition, and then here this a to be calculated here and b to be here in this way and this b here. So, f dot s start that will be is equal to here from this correlation you can obtain what will be the value for this f s star. And then d b 0 can be calculated if you are using perforated plate distributor, and if you are using porous plate distributor d b 0 can be calculated from this. So, once you know this a b and what is that f star and then d b 0, then you can calculate what should be the bubble size at equilibrium condition there.

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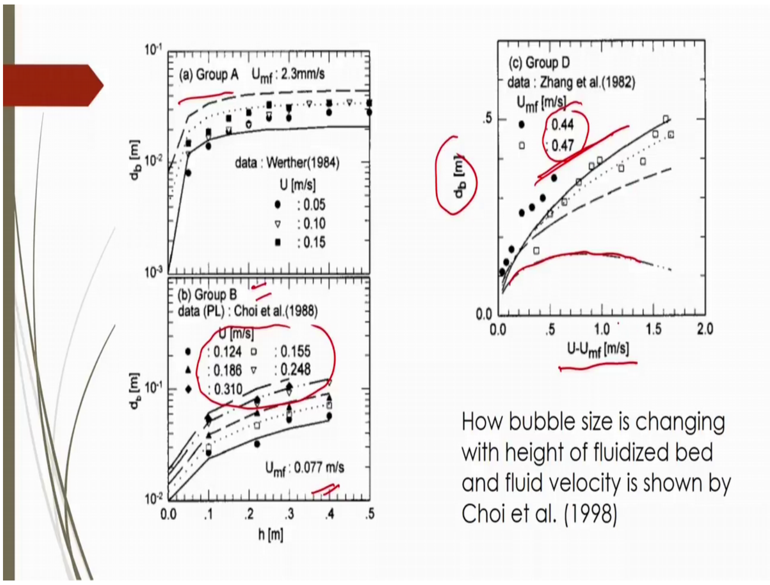

Now, from this graph we can observe that how bubble size is changing with height of fluidized bed and the velocity that is shown by Choi et al. In this case see here bubble size is increasing and then it will be coming almost constant here with respect to different gas velocity, and at minimum fluidization velocity as 2.3 millimeter per second for group a particle. Whereas, here in this case for group B particle here, it will be reducing at certain velocity here because this minimum fluidization velocity will be less than this earlier minimum fluidization velocity there. And also the size of the particles will be different from them and group B here of course, the size of the particle will be more higher then this b and a.

So, in that case the more minimum fluidization velocity is required because of that you will get the different value of beta and from which the coalescence and the splitting frequency will be different according to this function of this u m f. Now how then d b will be changing here. So, this is the profile from which you can calculate, what should be the bubble diameter at particular operating variables here.

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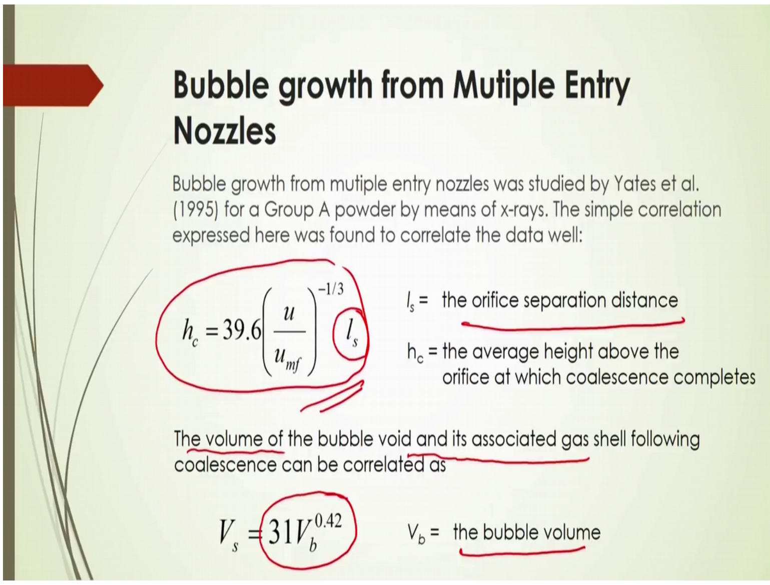

Now, if there is a bubble is producing from the multiple entry nozzles, then in that case bubble growth from the multiple entry nozzles, depends on different other parameters here like that like what should be the orifice separation distance, what should be the average height above the orifice at which coalescence totally completes, and then volume of the bubble void and its associated gas shell that following coalescence that can be correlated as this.

So, here this h c is nothing, but what that of the what will be the bubble growth here, here average height above which that orifice at their coalescence will be complete that you can calculate from this; where this l s is nothing, but the orifice separation distance, orifice separation distance means here. So, what will be the hole and what will be the distance between two holes there. So, here the and of course, this in that case what should be the volume of bubble void there inside the bed that will be is equal to 31 times of V b to the power 0.42, V b is the bubble volume here. So, from this from the multiple entry nozzles, that the complete coalescence at a certain height that can be calculated from this correlation.

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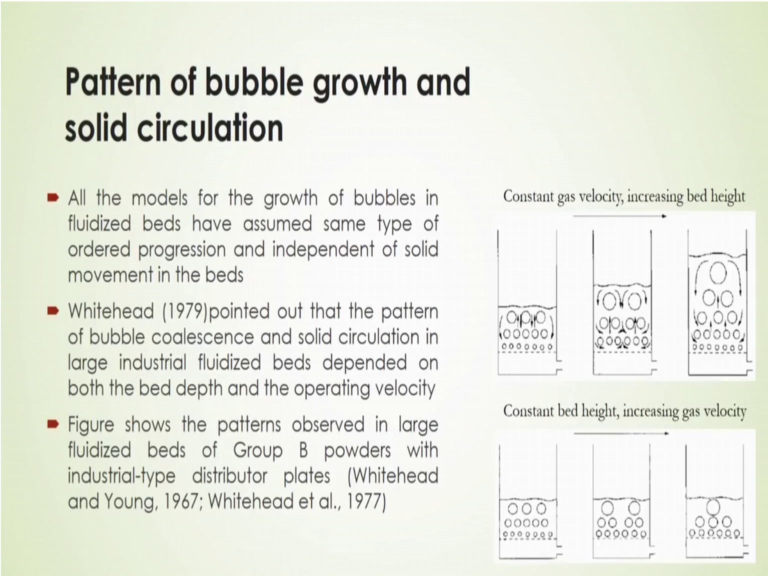

And then pattern of bubble growth and solid circulation that can be obtained from this here phenomena. So, in this case you will see that all the models for the growth of bubbles in a fluidized bed, have assumed the same type of ordered progression and independent of solid movement in the beds whereas, whitehead 1979 pointed out that the pattern of bubble coalescence and solid circulation in large industrial fluidized bed depend on both the bed depth and the operating variable. And also the figure shows that patterns observed in the large fluidized bed of group b particle with industrial type distributor plates.

In this case you will see what the large diameter there will be a possibility of that getting the circulation of the fluid velocity and because of which the coalescence phenomena will be something different. There will be a inter circulation shell formation inside the bed and because of which that coalescence and the breakup will be distinct; and then for uniform actually flow velocity that means, here for you will see fully developed flow. If there is no circulation inside the bed, then you will see there will be a easily obtained the equilibriums stages and from which at a certain height, when that equilibrium condition and the coalescence happens that you can obtain from this correlation.

So, this is the pattern how actually this circulation shell inside the bed, and how bubbles are getting interacted to each other. So, it depends on the diameter of the bed of course. If you are having more diameter of the; that means, larger diameter of the bed you are having that sums to get the more circulations shell formation inside the bed and the energy distribution across the cross section will be different and because of which there will be a splitting phenomena difference splitting phenomena will be there, and the number frequency of the bubbles will be higher there. And of course, if bubble if bed diameter is less there will be a formation of slag and because there of which that slagging phenomena will be there number of frequency of the bubbles will be less and so, because of that, that the proof pattern inside the bed that will governs the how the growth of the bubble inside the bed will happen.

So, next lecture will be again will be discussing what should be the bubble growth coalescence and breakup inside the bed in case of three phase system; that means gas liquid solid system. In this case whatever discussed here only for gas solid system, but in the next class will be or next lecture this, what should be the phenomena that will be discussed for gas liquid solid system.

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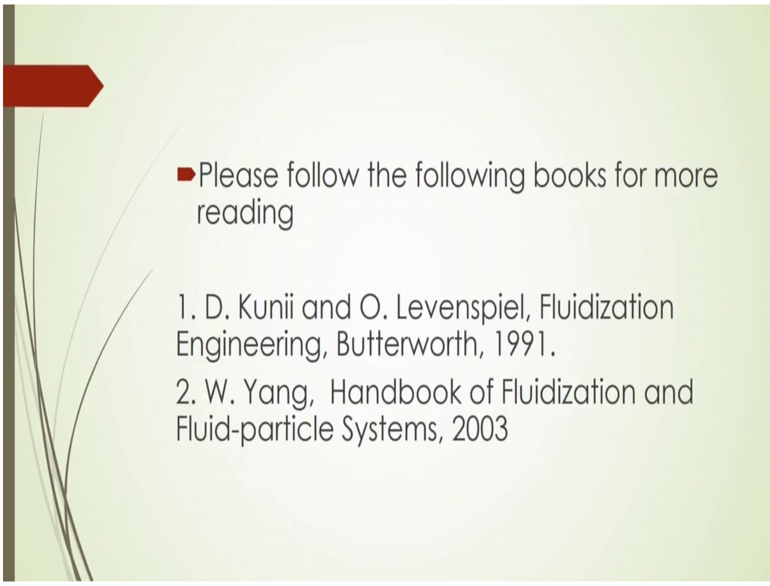

So, that is for all, today you can get more information from this two references here Kunii and Levenspiel fluidization engineering, and also yang that is handbook of fluidization and fluid particle systems so.

Thank you.