Fluidization Engineering
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Lecture - 23
Attrition in Fluidization Bed (Part 2)

Welcome to massive open online course on fluidization engineering. Today's lecture will be on extension of that attrition in fluidized bed that we have discussed in the previous lecture. So, in this lecture, we will be further on that attrition in fluidized bed. In this case, we will discuss the attrition rate based on the different models and like a breakage model excess velocity model, even surface reaction model there and also, what are the different factors that change that attrition rate and also how to minimize this attrition rate we will be discussed in this lecture.

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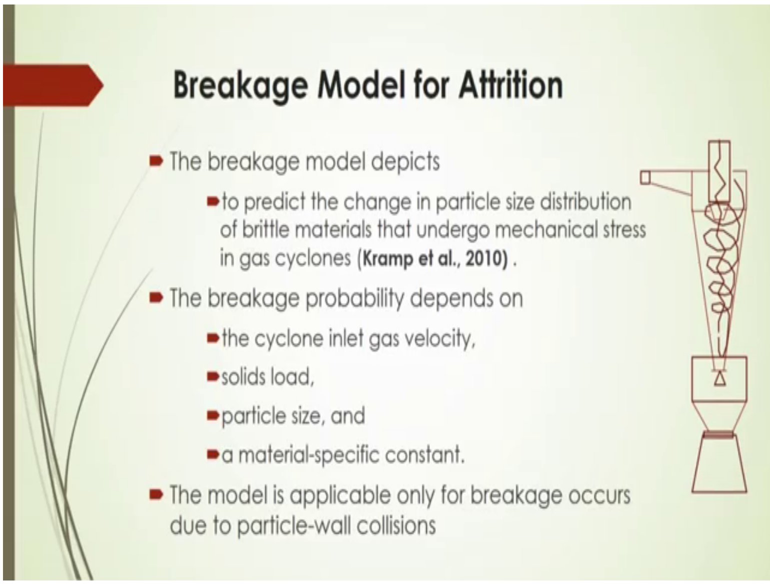

So, there are different models, actually, already we have discussed in our previous lecture, here some more models like here breakage model, let us discuss something about that breakage model for attrition. Now what does it actually mean that breakage model; now breakage model here, of course, the during that attrition the size of the particles will be reduced and what should be the particle size distribution of at different operating conditions if the different types of materials with different properties is being considered here.

And also this breakage model will be generally of extended to that cyclone separator also, there how excess velocity will be actually being take part in the attrition process and will be discussed by the excess velocity model there.

Now, the breakage model the depicts the prediction of change of that is a particle size distribution for brittle type materials and who are those materials actually undergo the mechanic mechanical stress in a gas cyclone. So, this model means derived by the Kramp et al 2010 here.

The breakage, here in this case, efficiency depends on the breakage probability and that breakage probability depends on the cyclone, inlet gas velocity, what will be the solids load and the particle size, also very interesting that it will be a material specific. So, that certain constants of that model to be maintains for that particular materials the model is applicable only for breakage where it occurs due to the particle wall collision here.

So, see in this slides that here one a cyclone separator, how this solid particles will generally move inside that a cyclone separator and then how due to this collision of these particles to the wall of the a cyclone separator there and then attrition is being happened, then inside the a cyclone separator not only the a cyclone separator, you will see that inside the fluidize bed also, there will be a wall and solid collisions there. So, this model can also be used for that analysis.

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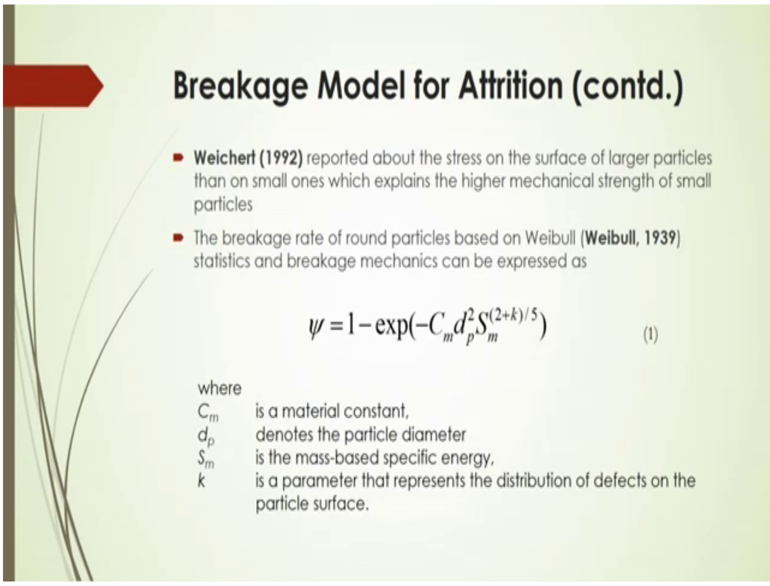

Now, Welchert 1992, actually stated that the stress on the surface of the large particles, then on small ones explains the higher mechanical strength of smaller particles and the breakage rate of round particles that based on the Weibull statistical analysis and breakage mechanics and that more rate because can be expressed based on that statistics and breakage mechanics by this equation 1.

In this case, you see that this breakage rate is denoted by psi which will be is equal to 1 minus exponent of minus C m into d p square into S m to the power 2 plus k divided by 5. Now, what is that C m here? C here, this C m is called a constant. This is called material constant. Already, we told that this model will be a specific material constant.

So, here this is the material constant this will be obtained by numerical simulation or from the experimental data and the d p denotes the particle diameter and S m is the mass based a specific energy. What will be the specific energy is consumed for that the collision of solid particles to the wall and k is a parameter that actually represent the distribution of defects on the particle surface. So, this k is nothing, but one constants will this may be actually change based on the particle of characteristics that is there any defects any suppose any crack, any other like irregularity of the particle, then what should the distribution of that that depends on those factor.

Now, based on the stress that act on the particles in the cyclone, the following relationship, you can see equation number 2 that psi i that will be is equal to 1 minus exponent of this C m d p squared u gc to the power 2 plus 2 by 5 into 1 minus 5 this relationship or the breakage rate for the particle of size dpi can be obtained.

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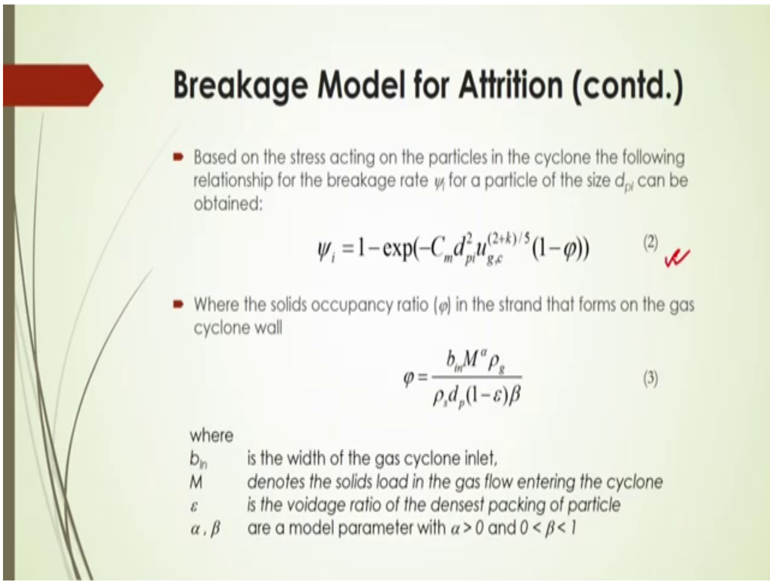

So, this is basically as per that Weichert model that these this breakage rate for particular class of particles, whether, it is coarser or finer that denoted by that class of the particles and it will be as i; the i means ith class here and the diameter of that particle in that particular classes it is denoted by d p i and for those class particles, what should be the stress and based on that is stress this breakage rate will be expressed as a psi i i for that class of particles here.

So, here again the C m is the of course, that material constants here d p i is the particle diameter of each ith class and u gc here u gc is the gas velocity at the cyclone separator and this very interesting that psi here phi is there. So, that phi is called that; what will be the volume of solids that occupy in the cyclone and where the solids occupancy ratio will be expressed by this phi in the strand that forms on the gas cyclone wall.

Now, this psi will be is equal to b m into m to the power some constants a and or alpha into rho g by rho S d p into 1 minus epsilon into beta here. So, this solid occupancy ratio in the strand is a function of gas density solid density particle size and the, and then you can see that it is a solid load in the gas flow entering the cyclone.

So, b i n is the width of the gas cyclone inlet and m denotes the solid load in the gas flow entering the cyclone and C is the voidage, you can say here, C is the voidage, sorry C; not C, this is epsilon, epsilon is the voidage ratio of the of the density packing of the particle and alpha and beta are the para model parameters here and generally alpha should be greater than 0 and beta should be within the range of 0 to 1.

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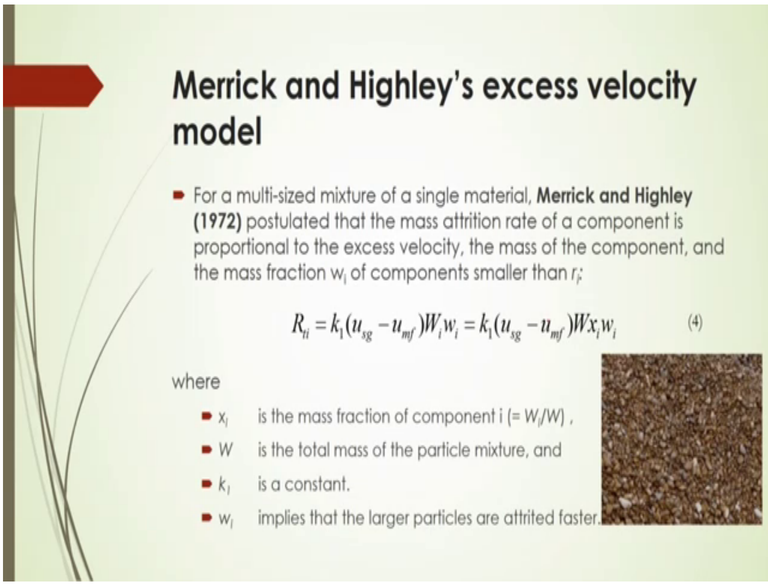

Now, another model is the given by Merrick and Highley's 1972 their model basically based on the excess velocity and they have used to analyze their model, a multi sized mixture of a single material and based on that multi sized mixture of a single material, they actually proposed that the mass attrition rate of a component is a proportional to the the excess velocity and the mass of the component and the mass fraction w i of components a smaller than smaller than R i, then it can be expressed as like R i that will be is equal to or R ti.

That will be is equal to k 1 into x s velocity from the minimum fluidization velocity into w i into small w i here, this x i is nothing, but here is the mass fraction of component i that is w i by W. So, this R ti can be again expressed as this k 1 into u sg minus f into W into x i into w i as per equation number 4 and capital W is the total mass of particle mixer and k one is a constant which will be obtained from the experimental results and a w i that implies that the larger particles are attrited faster here

So, this what should be that amount of larger particles the that are attrited faster and then a fraction will be xi there for that a specific class of particles fan.

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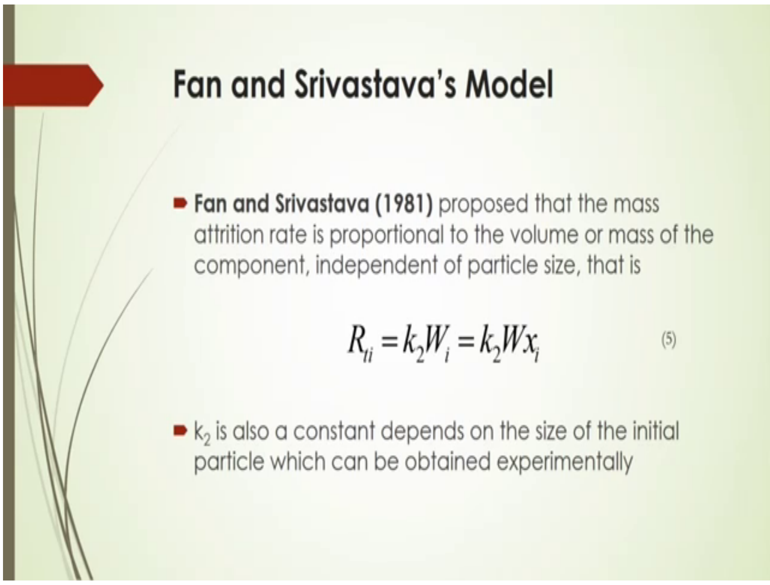

And Srivastava's model; as per their model, they proposed that the mass attrition rate should be proportional to the volume or mass of the component which will be independent of particle size.

So, it is very interesting that somewhere is the model is the considering that it will be the based on the particle size somewhere it is not that independent of the particle size, whereas, it will be proportion to the volume or mass of the component.

So, as per the fan and Srivastava's model, ok, if we are not considering the particle size there, then simply R ti that is attrition rate for that particular size of particles, it will be proportional to that w i. W i means the you can say that volume or mass; component mass component of that part class i and this you can modify this model there the it is it may not be that exactly to will be the power 1 here , but here somewhere maybe it will be varying as per your experimental data and it varies system to system also.

So, it will be better to express this model not directly related to that volume or mass of the component, you can express in the power law model by that here and if you are expressing that w i, you can simple express also by the mass fraction here for that particular class i we have this rate constant or you can say that proportionality constant is also constant that depends on the size of the initial particle which can be obtained experimentally.

So, here very interesting that though the model is independent of particle size, but you have to consider you have to find out this proportionality constant, just by changing the particle initial particle size, if you are changing that initial particle size, maybe, this attrition rate will be changing. So, if you are only consider ring one that is initial size particles they need to for that particular class of particles it will give you the attrition rate.

So, basically this is for a single class, particles here and another model is called arenas model.

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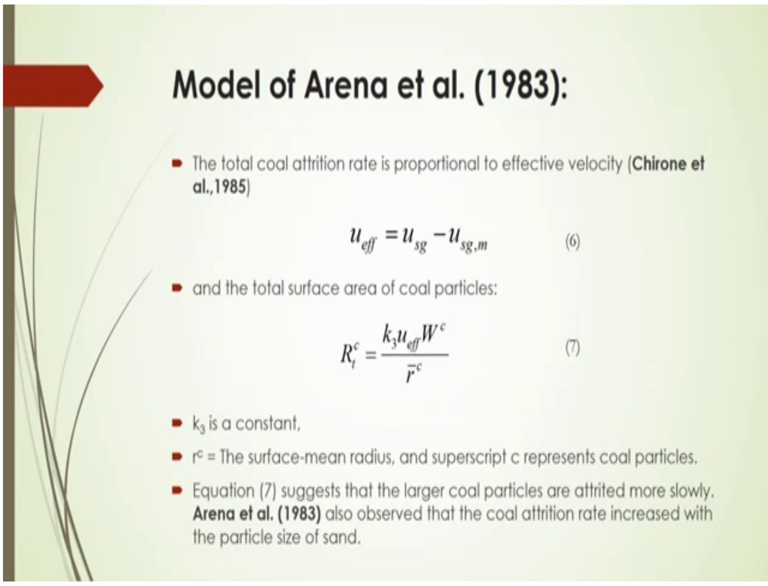

Here the total coal attrition rate there actually they have done this experiment with the coal particle. So, they have expressed into that the total coal attrition rate should be proportional to the effective velocity, there, what should that what should be the effective velocity; that were effective velocity should be what should be the relative velocity of the gas or fluid to its minimum velocity for its minimum fluidization.

Now, that effective velocity; so, as per this model that total surface area of the coal particles, then will be changing. So, that change of that total surface area of coal particles can be represented at R t c, here c for coal. So, it will be it will be proportional to that mass or you can say load of particles which is in the fluidized bed and also effective velocity and it is inversely proportional to the surface mean radius and that surface mean radius of that particular substances or you can say, here as per their experiment, it will be as per coal particles there.

So, simple that we can get here the total surface area will be changed because of the attrition and based on that this they have expressed this attrition rate change of attrition or attrition rate as R t c or you can say inversely or indirectly, you can say that rate of total surface area change of that particles. So, this R t c will be is equal to k 3 ua effective W to the W c and R c here this k 3 is a constant which is to be actually obtained by the experimental results.

Now, equation 7; this actually suggests that the larger coal particles can attrited more slowly more slowly, but earlier model that they have stated the that that larger particles may attrited attired more fastly, but here Arena et al also observed that the coal attrition rate increase to the particle size of sand. So, here the very interesting that larger coal particles or larger particles may increase the attrition rate there because of that high impact of the particle on that other particle there because of their weight.

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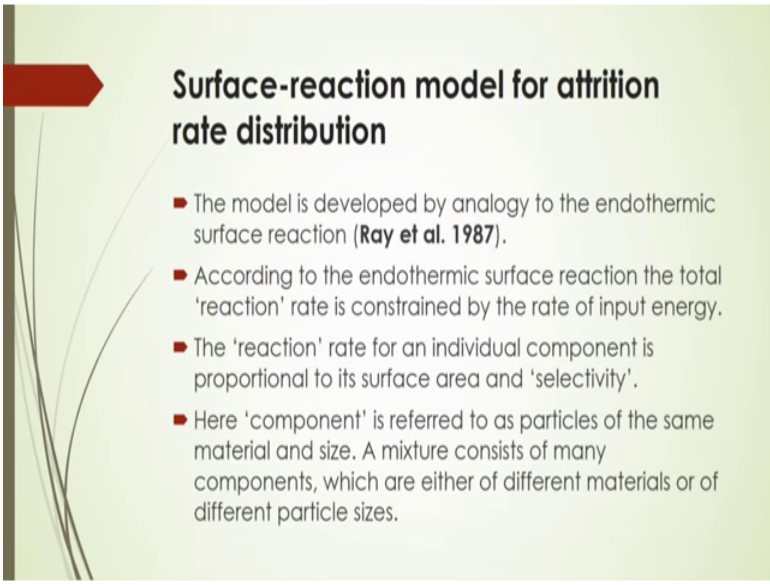

Now, surface reaction model for attrition rate distribution, the model, this actually developed by the analogy to the endothermic surface reaction which is given by Ray et al 1987. Now according to their model, they actually considered that there is some endothermic surface reaction a surface reaction and according to that reaction the total reaction rate is constituted by the rate of input energy.

Now, what will be the energy consumption for that total reaction, there the reaction rate for an individual component is proportional to the surface area and selectivity and also one energy. Now the component here, it will be referred to as particles of the same material and size here, it is not that multi sized particles or multi component materials are there.

So, same size of particles and same materials should be there and a mixer that consists of many component which are either of different materials or different particle size also can be actually assisted by this model, here basically, they have developed the model based on the same material and size and single component.

Now, a mixer also you can consider to assess these attrition rate based on their a knowledge because she had the energy consumption for the a mixer; that you can also calculate and also for individual component that the reaction rate, you can calculate; that will be proportional to the surface area of that individual component and also, what should be the selectivity.

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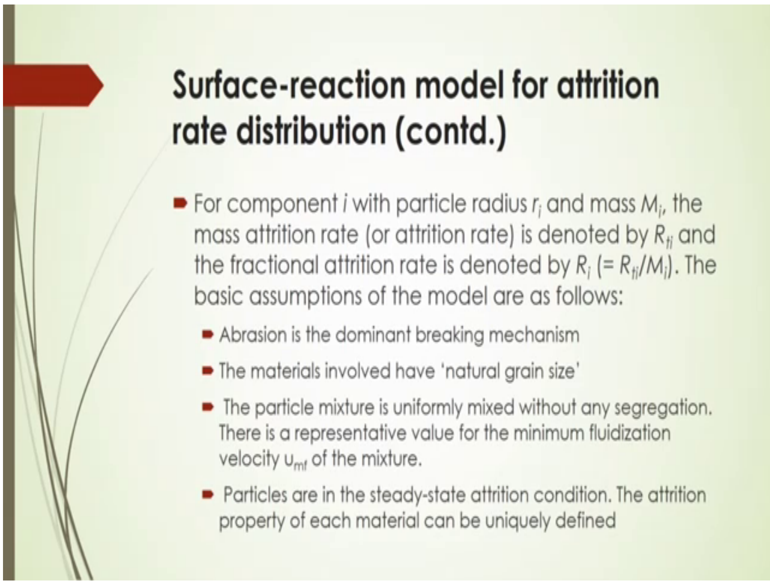

Now, for component i with particle radius suppose r i and if you take that masses M i, the mass attrition rate or you can simply represent as attrition rate which will be denoted by R t i and the fractional attrition rate which will be denoted by what should be the R i for that individual component and it will be defined by that rti for that particular size material divided by it is what is that load of that parti of that particular size material.

So, it will be the factional attrition rate that is R t i by M i the basic assumption of the model are as follows, it is as that abrasion, here, they have considered that the dominant breaking mechanism and the materials involved have natural grain size, they have considered here, they also assumed that the particle mixer is uniformly mixed without any segregation and there should be a representative value for the minimum fluidization velocity of U mf of that mixer and particles should be in the steady state attrition condition and the attrition property of each material should be uniquely defined there.

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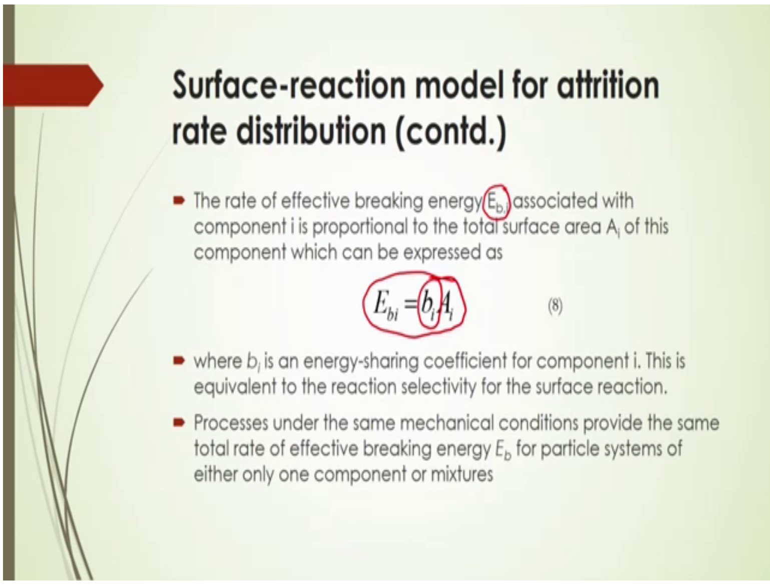

So, these are the basic assumptions for their model the and also, they considered that the rate of effective breaking energy that E b i denoted by E b i here associated with the component i and this should be proportional to the total surface area A i of this component and this can be expressed as this E b i that will be is equal to b i into A i in this case, this b i is called the proportionality constant and this will be referred to as energy sharing coefficient for component i and this is generally equivalent to the reaction selectivity for the surface reaction.

Now, process under the same mechanical conditions; if you are using the same mechanical condition, then total rate of effective breaking energy should be same for the particle system of either only one component or mixer there ; so, here very interesting that because of that surface reaction what should be the rate of effective breaking energy and that you can calculate based on their that is surface area generated for that particular component, it is actually we will see that the energy sharing coefficient, if it is large, they are then more energy to be required for smaller surface area and also you will see that if suppose larger surface area is produced for the same energy, then this energy sharing coefficient should be small there.

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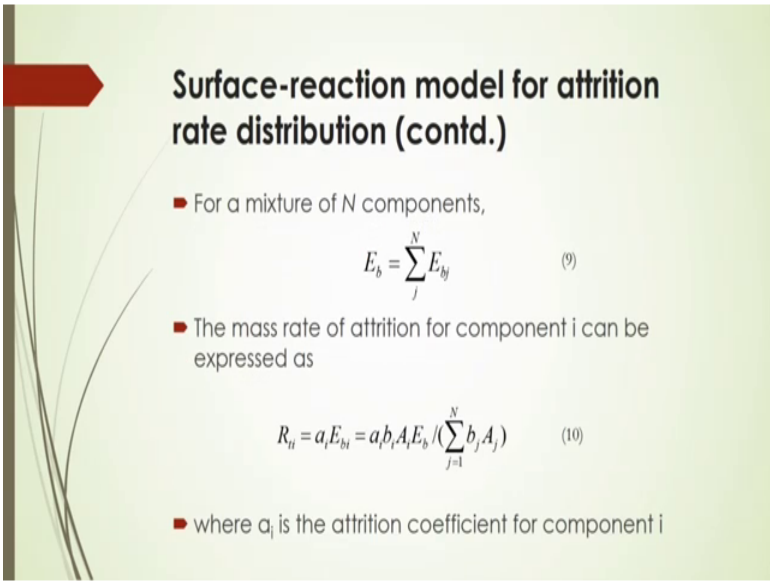

Also for a mixer of n components, what should be that energy breaking energy effective breaking energy associate with the component for that i and for that mixer.

Now, for a mixer of suppose n components are there, then the energy breaking energy you can say that E b should be is equal to the energy which is associated for the individual component of that material and the mass rate of attrition for component i can be expressed as this R t i that will be is equal to A i into E b i.

So, once you have to know that what should be the E b i for their surface creation and then once you know the E b i; that means, energy breaking energy required for that individual particles and if you sum up for the whole mixer, then you will get the total effective breaking energy there and then what should be the mass of attrition for that component i, it can be represented by this and substitution of these, then you can directly get what should be the total energy required for the effective breaking of that material.

In this case, you will see that one coefficient is coming A i here, this A i is the attrition coefficient for component i. So, mass attrition rate for the component i can be expressed in terms of that total energy or you can say the total energy can be calculated based on the energy that is required for that individual component.

Now, it is very difficult to actually calculate or experimentally estimate the energy required for individual component, though you can calculate from their surface energy , but it will be better to know, what should be the total energy required. So, once you know that total energy required for that breaking and if you know the individual surface energy after breaking and then the coefficient and b i for that from those portion you can calculate what should be the a mass rate of attrition for component i.

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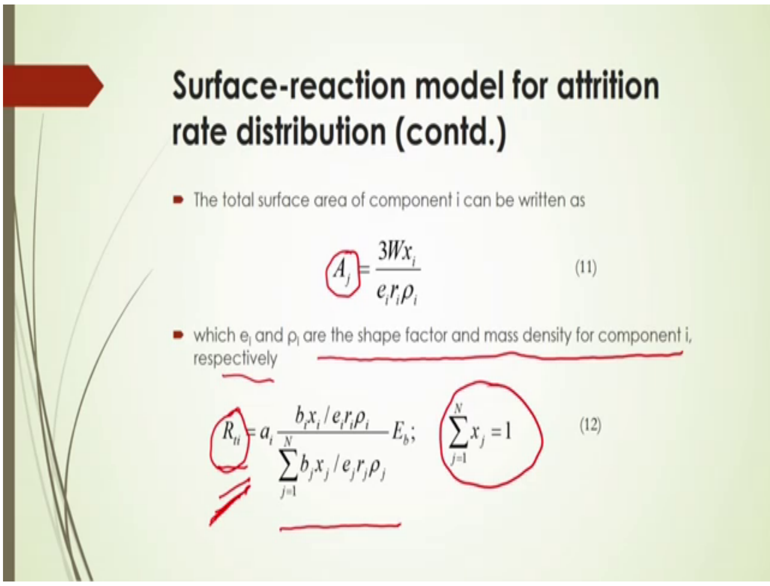

Now, the total surface area of the component i can be written as this A j, here total surface area of component i that is formed after attrition that will be is equal to what that W x i divided by e i r i rho i what is that e i? E i is the e i and rho i are the shape factor and mass density of the component i respectively.

Now, all this; then if you substitute this a, a j in equation 10 here, then you will see what should be the mass rate of attrition for that individual component the substitution of this A j that will be is equal to this and here summation of xj that is for j j class materials a fraction mass fraction should be is equal to 1 and then this mass attrition rate for that individual component i, it will be represented by the what should be the fraction of j comp j at fraction and what should be that j density and what should be the size of that j classes and what the energy required for the j classes and also what should be the coefficient for this j classes that individual, you have to individual for individual component after getting the surface area you can of course, calculate, what should be the energy.

Now, you will see that very interesting that energy required for that there will be several component. Now after stimulation, you have to just or you just solving this non-linear equation for coefficient b i b j and ei r i rj after that; you will be able to express this individual component mass rate of attrition by equation 12.

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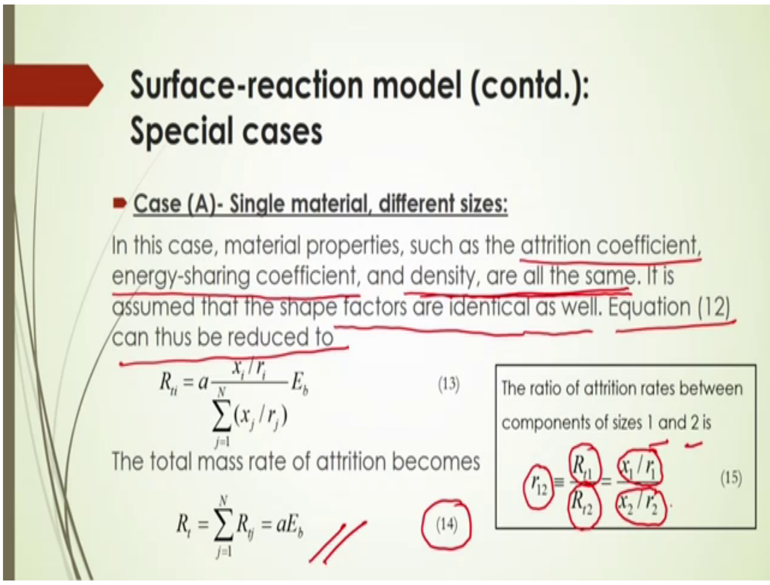

Now, for special cases, let us see the single material for different sizes. Now, in this case, material properties such as the attrition coefficient energy sharing coefficient and density are all same here. So, material properties, you have to take the material where attrition coefficient energy sharing coefficient that is b and then density for all for those material that will be same. So, it is assumed that the shape factors are identical as well also.

So, equation 12 can thus be reduced to this very simple way that this if this sharing coefficient of same, then A will be 1 value and x i by r i and j is equal to 1 to n x j r j into E b. Now the total mass rate of attrition, then becomes this will be is equal to simple A into total energy for effective breaking of that particles.

And then this is represented by equation fourteen and the ratio of attrition rates between components of size 1 and 2, then r 1 2 to be actually considered here that will be is equal r t 1 rate mass rate of component mass rate of attrition of component 1 and mass rate of attrition for component 2, what should be the ratio that will be represented by r small r 1 2 and it will be simple that x 1 by r 1 by x 2 by r 2; what is that; x 1 is the mass fraction of that component 1 and r 1 is the that is size of that component 1 and x 2 is the mass component of component 2 and then r 2 is the size of that component 2 there.

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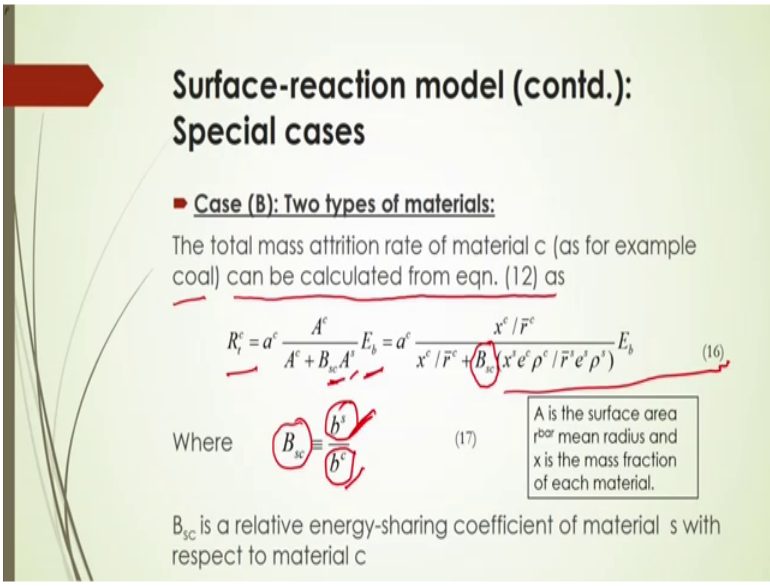

Now, surface reaction model; if we used for two types of materials suppose there is a mixture of coal and sand.

So, in that case, the total mass attrition rate of material c material cc as for example, coal can be calculated from equation 12 here that will the R t c that will be is equal to A c, here A c by A c plus B sc in to as s for sands c for coal here and then what should be the total energy required now? Then it will be is equal to sc into xc by rc by xc by rc plus B sc. B sc is the constants for that sand and coal mixer here x sec ec rho into rho to the power c by rs.

This by this equation number 16, you can calculate the coefficient the total mass attrition rate of comp component c that is for coal and where B sc will be defined as B s by B c here B s means here what is that energy sharing coefficient is called for sand and energy coefficient by for c that is for coal. So, A; A is the surface area r bar here mean radius and x is the mass fraction of its material and bs is the relative energy sharing coefficient of material s with respect to material c here.

So, from this relation, you will be able to calculate what should be the total mass attrition rate for that is for coal, here if there is a mixture of coal and sand based on the parameter of the other material of sand. Now if x c is very small or you can say A c is much smaller than A as.

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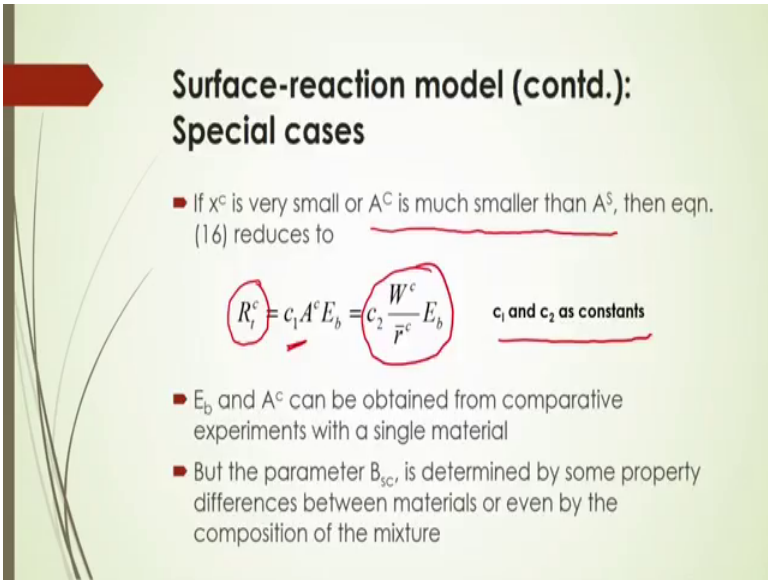

So, in that case, this equation 16; equation 16 will reduce to here this R t c that will be is equal to here c 2 into w c by r bar c into E b here c 1 and c 2 are here constants and this E b and sc can be obtained from that comparative experiments with a single material, but the parameter B sc which will be determined by some property difference between the material and a by the composition of the mixture.

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Now, what are the different factors that affect the attrition rate we have discussed the different models that is surface reaction model and what is that breakage model and also excess velocity model and by which you can analyze the mass attrition rate of the material, even if the material the single material is being used or if you are using the mixture of materials there. So, now if we know that that attrition from the experiment let us see what are the different factor that effects the on that attrition read.

So, effect of particle structure is one important factor that how this particle structure will be affecting on the attrition rate and it is seen that the state of materials like whether the material is a single crystal or other forms like amorphous structure or in the agglomerate that will affect the attrition rate and it is seen that spray dried materials or spray dried crystal are allergitic allergic to attrition; that means, it will not actually attrited mass if there is a crystals there.

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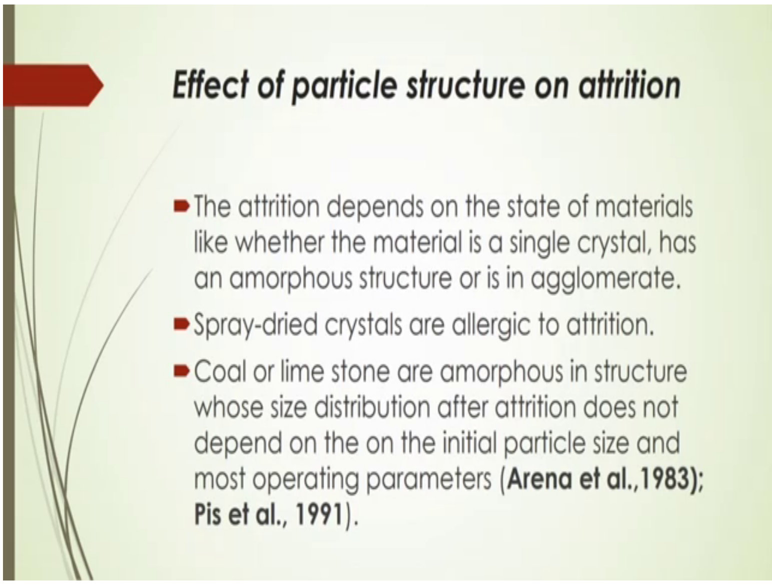

And coal or limestone are amorphous in structure and it is seen that it is the size distribution of after attrition that does not actually change significantly on the initial particle size and also most operating parameters it is seen that there will be no or change of that amorphous structure of coal to be attributed into smaller sizes, the pretreatment and preparation of the background of the particles that also effect on attrition, it is seen that the higher and the longer forgoing stress of the solid particles by pretreatment that will results easier to attrite the solid particles.

The breakdown of the weakest agglomerates during the drying of crystals particle is an example in this case. The degradation tendency of salt samples depends on their pretreatment route that is the stated by Ghadiri et al, 1994.

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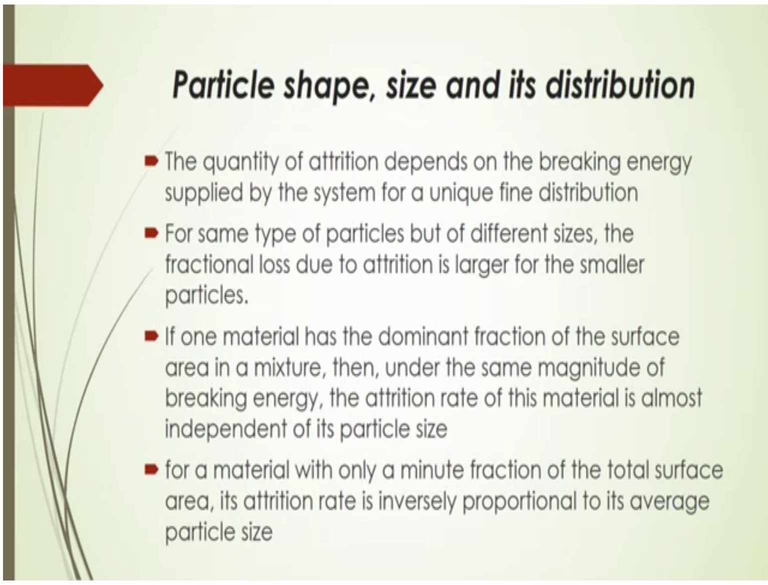

It is seen that the particle shape size and its distribution has a significant role on the on the on the degree of attrition and this degree of attrition that depends on the breaking energy that supplied by the system for a unique fine distribution and for same type of particles , but if it has a different size then you will see that fractional loss due to the attrition will be more than the smaller particles and if one material has the dominant fraction of the surface area in a mixture, then you can say the same magnitude of the breaking energy will take part to the attribution rate and it will be almost independent of the particle size.

And for the material if the fraction is very small of the total surface area then its attrition rate will be inversely proportional to the average particle size and it is seen that that the irregular or angular particles are deposited to have their corners that knocked off in collisions.

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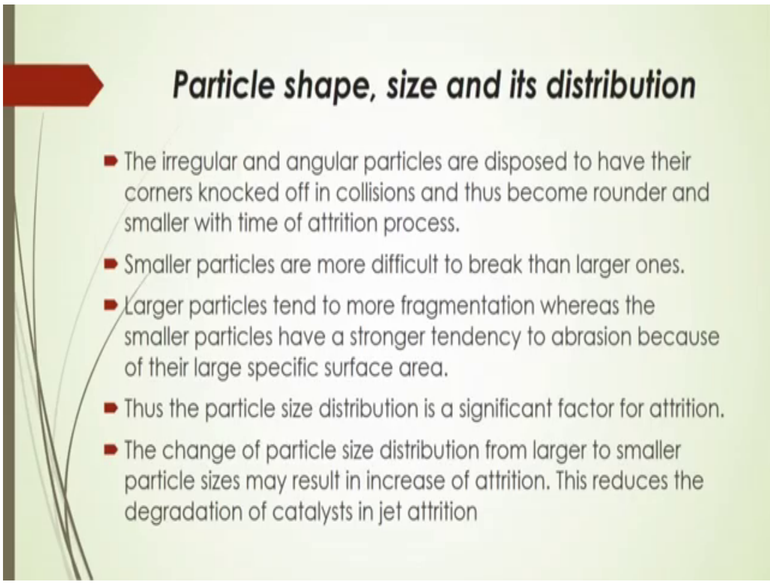

And hence by it will become rounder sometimes and a smaller with time of attrition process.

And smaller particles are more difficult to break than larger ones and larger particles tend to more fragmentation, whereas, the smaller particles have a stronger tendency to abrasion because of the large specific surface area and it is seen that that particle size distribution is a significant factor in this attrition and the change of particle size distribution from larger to the smaller particle size; that means, whether it is wider or that narrow that will results in increased of attrition. So, this reduced the degradation of the catalysts in jet attrition.

So, the particle shape whether this how whether, it is regular or angular or irregular that is that will govern that attrition rate and also larger particles it is seen that will have more tendency to get more degree of attrition and also the change in particle size distribution may change the attrition rate.

Now, effect the process condition effect of process now what should be the gas velocity what should be the solid velocity.

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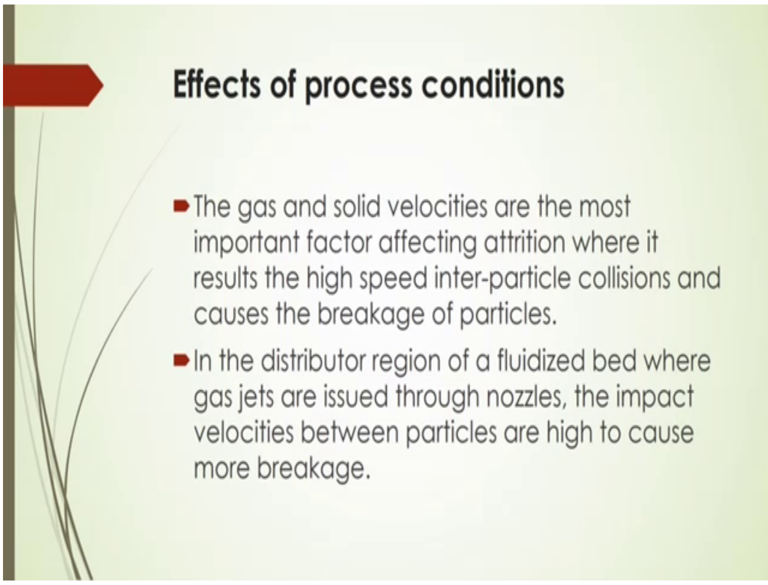

That also effect the attrition degree of attrition. Now in this case, you will see that higher speed maybe higher speed of the gas or higher velocity of the solid and gas may speed up the inter particle collisions and also the collision with the walls that may cause the more breakage of the particles into finer one.

And generally, it is seen that that distributed resign region that high kinetic energy distribution will be there in the fluidized bed higher gas jets or issued through the nozzle and the impact of the gas velocities between the particles impact of the velocities between the particles or high to cause more breakage there.

So, that it is why the gas velocity or solid velocity is a predominant role for the attrition of the solid particles to become its finer solid one.

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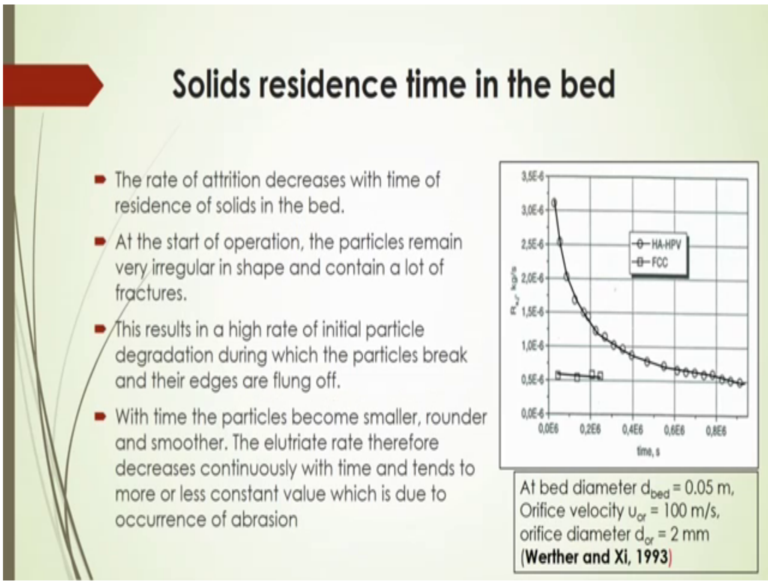

And another important factor is solids residence time in the bed how long these solids will be residing inside the bed, if contact time of collision or residence time of the solids for getting this collision is more than more attrition can be expected.

So, rate of attrition will be decreases with the time of residence solids in the bed, if if it is not residing for a longer time there and at and for high fluidization case, it is seen that the residence time of the fine particles is the less and that is why, the attrition rate will be raised, list in the free board region, whereas, in the distributed region, it will be high initially because of that high kinetic energy and at the start of the operation the particles remain very irregular in shape and the condition ha a containing lot of fractures there.

And this results in a high rate of initial particle degradation during which you can say that particles break and they are edges are turn off there and also, of course, that the with the time the particles become smaller and rounder and smoother because of that higher residence time there and the attrition rate therefore, will be decreasing continuously with the fine and tend to more or less a constant value which is due to the occurrence of that abrasion there.

So, abrasion may occur if the more finer particles will be there. So, it will tends to abrasion if the solid residence time of the will be there more because they are you know that finer more finer particles will be there because of that breaking or attrition and once the there is a becoming more finer particles all almost maybe 80 percent of the particles will become more finer, then we will see, there will be a mechanism of attrition as the occurrence to the aberration and then coming down of that attrition rate there.

So, with respect to time, it is seen that then this attrition rate will gradually decreasing here as soon in figure also Werther and Xi, 1993, they have shown this trend at the bed diameter of 0.05 meter and the orifice velocity of hundred meter per second, whereas, its diameter will be 2 millimeter. So, as per they are it is very actually easy to explain that ok, how, why actually that this attrition rate will be decreasing with respect to time because of that continuously that is along with the time or with respect to time these more finer particles will be forming and then there will be a abrasion tendency of the attrition rate.

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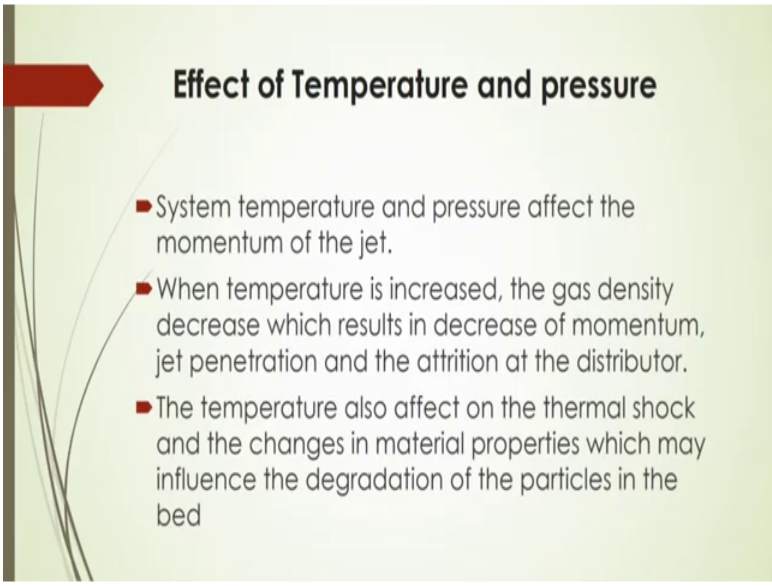

Now, another important factor is called temperature and pressure, now system temperature and pressure that will affect the momentum of the jet, of course, you will see the high pressure will give you the more attrition and then accordingly, if you increase the temperature, the material properties will change and there may be the fracture of the materials will easily happen. So, at higher temperature may be the attrition will increase.

So, when temperature is increased, the gas density decrease who which results in decrease of momentum jet penetration and the attrition of the distributor is the distributor, but sometimes this will this will actually contradicting because of that that higher temperature the material properties will change and then the brittle materials can easily be actually converting to the finer particles or reduction size reduction will be there and high at higher temperature.

So, because of who is that their attrition will be higher, but at the same times maybe the gas density will decrease and which results in degrees of momentum jet penetration and because of who is these attrition at the distributor will decrease. So, there will be a what is that a contradictory option, but you have to what should be that; then effective attrition rate there and the temperature also affect the thermal shock that is what we what I actually told that the temperature affect the thermal shock and the changes in material properties which may influence the degradation of the particles in the bed and that is why the attrition rate will change.

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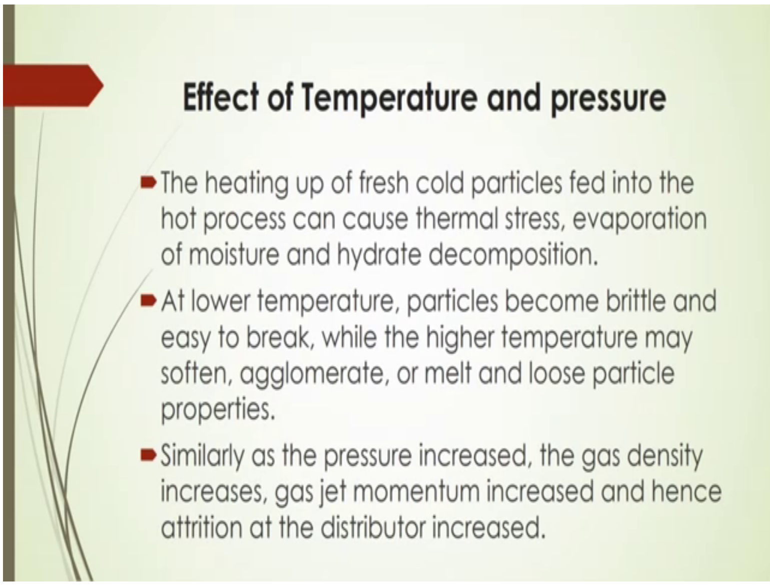

And the heating up of a fresh cold particles, you will see that is fed into the hot process can cause thermal stress. Now evaporation of moisture and the hydrate decomposition that is why the material properties physical properties will automatically change, there at lower temperature particles become brittle and easy to break while the higher temperature may soften agglomerate or melt and lose the particle properties.

Similarly, as the pressure increased, you will see the gas density increases gas jet momentum increased and hence attrition at the distribution increased. So, pressure increased means density increased attrition increased, whereas, temperature increase gas density decreased attrition decreases. So, at a certain temperature and pressure, what should be the effective attrition rate that you have to consider as per model, you have to consider the pressure as well as temperature effect, there is there any chemical reaction or humidity effect on the attrition rate ye chemical reaction may result that is fractural stresses within the particle by extending the reacting surface between gas and solid.

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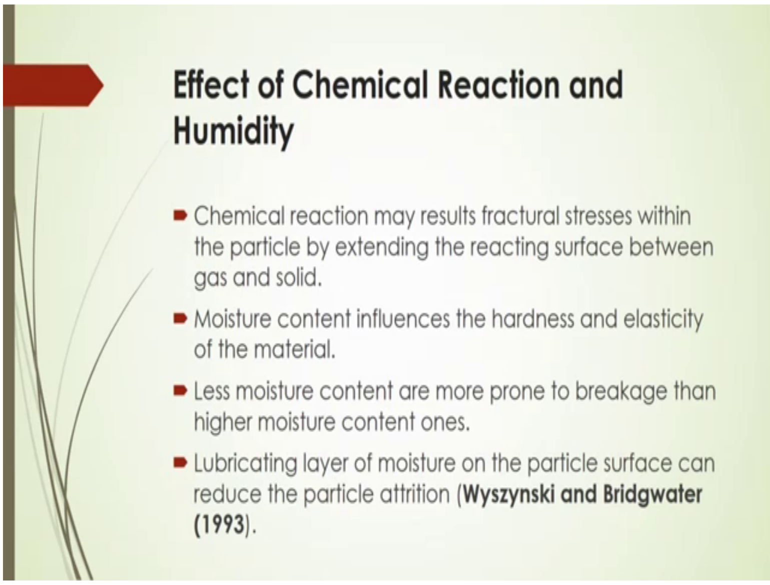

And moisture content sometimes influences the hardness and the elasticity of the material which may hinder the attrition rate, less moisture content are more prone to breakage, then higher moisture content, of course, there if there is a more moisture intact in to the solids, then the what is that impact of the particle particular collision; that will be more smooth there. So, there will be no that is surface will be more smoother and because of which that the attrition rate will be less and no lubricating layer of the moisture on the particle surface can reduce the particle attrition that is y.

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Now, of course, the during the operation of the fluidized bed, there will be a certain extent of attrition because of different or different variables effect of different variables that we have seen, there will be reaction, there will be a some surface properties of the material, there may be a some other gas velocity or fluid velocity or particle size distribution, there are lot of there are lot of actually factors that affect the attrition rate.

Now, to get some minimum attrition in the fluidized bed, sometime, it is required for that better reaction and, but better a conversion of that process so, so, you have to minimize the attrition. Now effects of that various attrition sources are kept as minimum as possible because the lack of attrition resistance is often a measure of course, that hinders the commercialization of fluidized bed for the particular processes.

Now, the attrition can be minimized by proper material selection, by proper design of distributor, by reducing the conveying velocity, in case of attrition in pneumatic conveying. So, there are several option there, of course, all those options they have some pros and cons, and maximum cases, it is seen that that general distributor are design in such a way that you can get the minimum attrition because most part of the attrition happens in the higher kinetic energy in the distributor zone the brakab breakup of that particles in that particular region.

So, you have to design in such a way that there should be minimum a collision of the particles in the distributor regime region. So, in that case, maybe there will be a certain provision. So, we will be discussing in this case, you will see that the.

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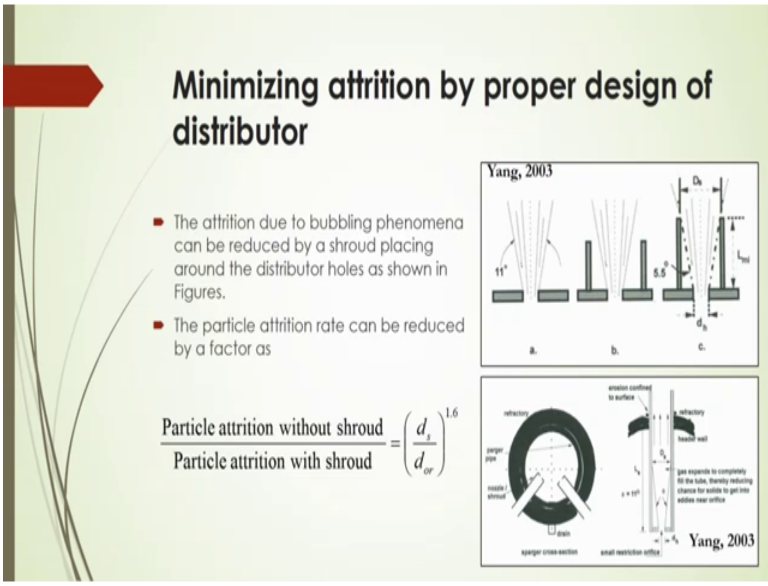

You can designed the distributor by just making a provision of that shroud there.

So, in that case, the attrition due to the bubbling phenomena can be reduced by a shroud the here, this is called a shroud this shroud surrounding this, what is that nozzle here. So, making a shrouds that reduced the attrition there and this around the distributor holes this shrouds will be given and then the particle attrition rate can then be reduced by this factor of this would provision in such a way that this you can you can estimate that particle attrition without shroud by this consideration, this particle attrition without shroud by particle attrition with shroud that will be depending on that; what should be the diameter of that shrouds, you are using here ds and what will be the d orifice there and what will be the ratio that is ds by d or to the power 1.6.

So, particle attrition without shroud that will be is equal to what ds by d or to the power 1.6 into particle attrition with shroud. So, particle attrition with shrouds then you can calculate from this relationship first of all you have to calculate what should be the particle attrition without shroud that is known and then if you substitute, if you if you if you make the prohibition or design in such a way that if you are reading that shroud then what should be the a particle attrition of course, it would be reduced by this expression.

So, here it is shown in the picture that a how shroud should be placed or design and based on this fluidization operation.

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Another important that you have to choose the material a properly so, that the attrition should be less and you have to choose the material in such a way that, that material properties will not be changing significantly with the pressure and temperature.

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So, in that case, you have to use those materials let us see some example here the in the combustion of solid fuels the particle degradation due to the attrition enlarges the reacting surface and thus increases the reactivity of the fuel and also sometimes that is being commonly used approach for the importing attrition resistance that is to add generally 30 to 50 percent of the colloidal silica to the catalyst precursor before spray drying and , but the excess amount of silica may affect both the catalyst activity and selectivity.

So, you have to you say, you have to sometimes make the solid particles by what is that coating with some other materials also. So, you have to coat the materials in such a way that your selectivity or combustion or what is a function of that particles catalyst particles that are being used for particular processes that will not be must hampered.

So, generally that importing attrition resistance; generally 30 to 50 percent of colloidal silica to the catalyst precursor are generally used before that spray drying. So, that the minimum effect on the catalyst activity and selectivity there may be a significant selectivity loss for vanadium phosphate catalyst to the selective oxidation of butane to maleic anhydrate that is stated by Contractor et al 1989.

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And encapsulation of the active catalyst like vanadium phosphate in a porous silica shell should be suitable to impair the catalyst attrition as per Bridle et al, 1999 and also it is seen that small scale slugging bed may reduce the attrition rate of zeolites by addition of small amount of fine solids that is called lubricants, if you use lubricants, there may be attrition rate should be a less because of surfaces smoothness the fine lubricants reduce attrition by protective coating that facilitates the sliding up the particles against each other and this, of course, will be hindered because of that that is surface smoothness.

Now, mixture of different types of particles in the bed sometimes lead to reduce the attrition; attrition of one component can reduced can be reduced by the decrease of surface in relation to the entire material surface in the bed like coal combustion process with the three components of coal, ash and limestone.

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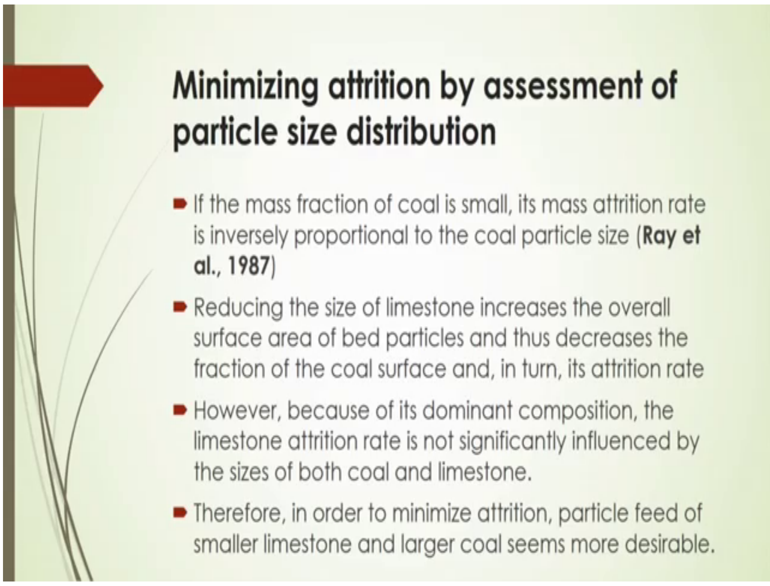

Sometimes you can minimize that attrition by assessment of particle size distribution if the mass fraction of the coal is small then the mass attrition rate is inversely proportional to the coal particle size. So, mass attrition rate, if it is inversely proportional to the particle size; that means, here if your size is less then your attrition rate will be higher. So, you have to use the particle initial particle size after certain size label. So, that there will be a minimum attrition rate, but again if you suppose are not used a particle size in a smaller than surface area will be less.

So, you proportional of particle surface area will be less finer particle surface area will be more. So, to get the more reaction perform the, our mass transfer, then you need two more surface area. So, you have to use the particle size wisely. So, that that you will get the optimum surface area and with the optimum attrition rate and reducing the size of the limestone that increases the overall structure area of the bed particles and thus, decreases the fraction of the coal structure and in turn its attrition rate.

However, you can say that the dominant composition may be may be significantly influence the attrition rate there and therefore, in order to minimize the attrition, a particle speed of smaller limestone and larger coal seems to be more desirable, in that case and if you reduce the convening velocity, there may be attrition rate should be less.

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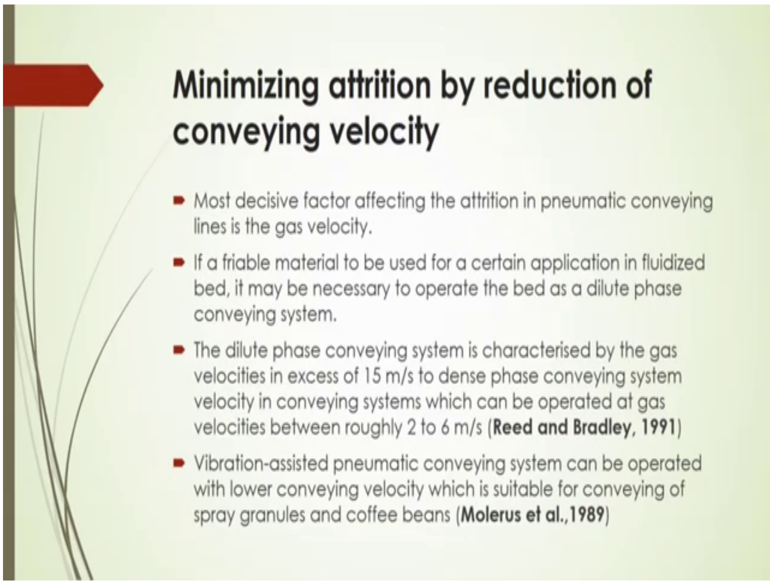

So, most decisive factor affecting the attrition in a pneumatic conveying lines is the gas velocity if a friable material to be used for a certain applicable or application in fluidized bed, then it is necessary to operate the bed as a dilute phase conveying system and the dilute phase convene system is generally characterized by the gas velocity, in excess of fifteen meter per second and to the dense based conveying system velocity in conveying system which can be operated at gas velocity between roughly 2 to 6 meter per second as stated by Reed and Bradley 1991.

Sometimes, the vibration assisted pneumatic conveying system are operated with a lower conveying velocity to get the less attrition rate there.

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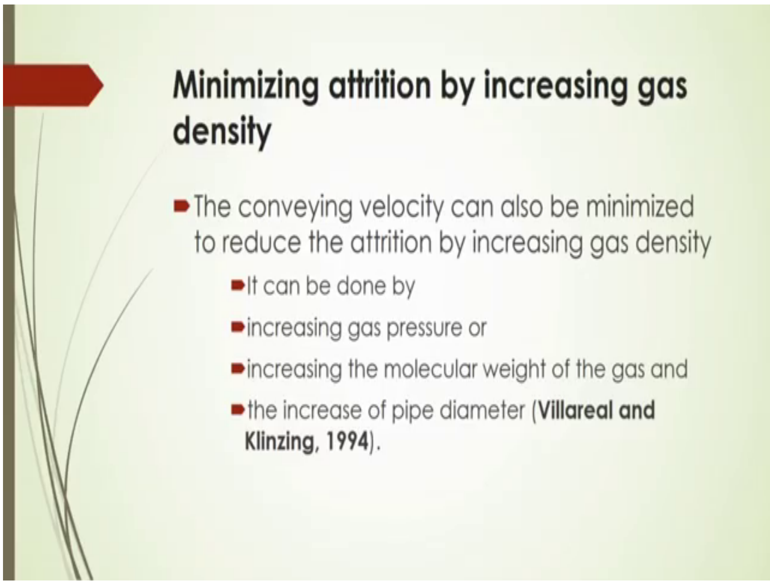

And if you increase that gas density; what will happen? Sometimes, it will minimize the attrition rate because they are gas density, it will of course, give the energy reduction and increase the gas pressure, who is increase the molecular weight of the gas and increase the pipe diameter which will effectively together will minimize this attrition rate; that is divide given by a Villareal and Klinzing, 1994 in their experiment.

So, so, we have discussed that, different operating conditions by which you can minimize the attrition rate there and pipeline routing and bend design also important one for that changing the attrition says rate.

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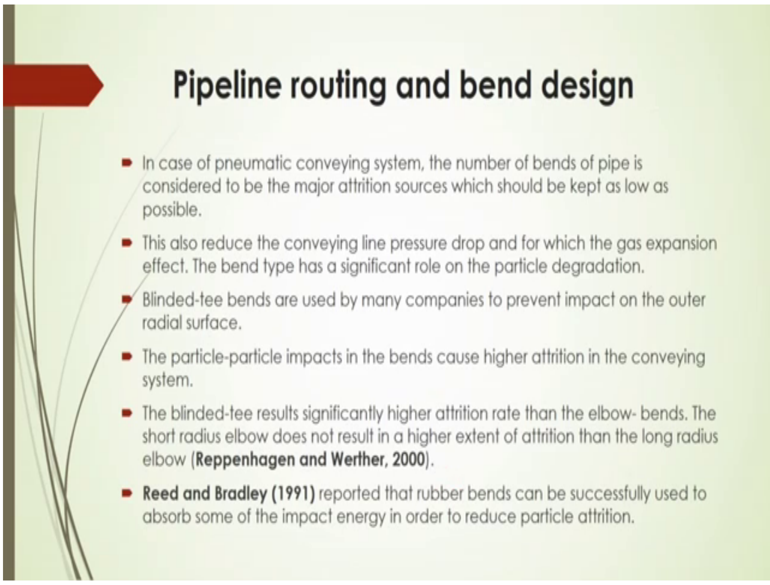

The in case of pneumatic conveying system; the number of bends of pipe is considered to be the measure attrition source which should be kept as low as possible there.

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So, more reading, you can follow these references given here, I think by this lecture, I think, you have learned something about that what would be the attrition degree of attrition by different models by excess velocity models by breakage model by surface reaction model and what are the different factors that effect on the attrition and how it can be minimized by changing different operating conditions there. Next part, we will be again discussing different aspects of that fluidization so.

Thank you.