Lec 4: Mechanism of Size Reduction

Hello everybody. Welcome to this massive open online course on solid fluid operations. So, today we will start second module. This is regarding that size reduction of the particle. In the previous lecture we have discussed the brief introduction on solid fluid operations and characteristics of solid fluid and also its importance. In this module we will start with the lecture on mechanism of size reduction.

So, in this lecture we will try to discuss about the importance of particle size reduction, mechanism of particle size reduction, fracture mechanism, power measurement and efficiency in size reduction. So, what is the importance of particle size reduction? Where that particle size reduction to be important? Where it will be used? Why I should reduce the size of the particle? So, whenever you are going to reduce the size that will require some energy, that energy will produce new surface area. That surface area is required for any physical or chemical processes. So, the size reduction will be based on a certain mechanism.

So, it may be used to create particles of a certain size and shape and also whenever you are going to reduce the size it will increase the surface area which will be available for chemical reaction or to liberate some valuable minerals that is held within the particles. It is an energy intensive process. You will see that in industry around 5 percent of all electricity used which will be utilized in size reduction. So, to obtain workable size, to obtain powders, to obtain specific shape and size, increase reactivity, permit separation of unwanted ingredients from the mixer. So, for those purposes the reduction of the size of the solid or materials is required.

Now, you will see that whenever you are going to reduce the size or you are reducing the size it will improve the uniformity of the mixing between solid and liquid or solid and solid you will get uniformity of the mixing for the reduced size particles. If the size of the particle is small, you will see that the flow of powder into dyes during the compression of tablet is very effective. So, in that case the production of the tablet and its compression you need to reduce the size of the particle. To repeat the effective drying, it is a physical process whenever drying operation will be there, there will be mass transfer or you can say that the transfer of the vapour or moisture from the solid particles to the atmosphere by evaporation. So, to repeat this effective drying you need to have more surface area through which that mass transfer will happen or drying or removal of moisture will happen.

So, if the size of the granules is small then the drying of granular mass will become rapid. Also, you will see that sometimes you need to improve the physical stability in suspensions and emulsions. So, rate of sedimentation you will see that it will decrease if the particles are of small and uniform in size. To facilitate rate of dissolution you need to increase the surface area. So, there dissolution of the substance can be increased by increasing more surface area.

So, to get this more surface area you need to reduce the size of the particle. Also, to improve the absorption rate or adsorption rate you will see that you will have better adsorption on the surface of the particles like if you want to adsorb carbon dioxide or other gaseous sulphur dioxide or hydrogen sulphide onto an activated carbon particles. You will see that if you have more surface area there will be an efficient adsorption for that operation. So, to improve adsorption rate smaller the particle the faster is the adsorption because of increase in surface area. So, to improve that adsorption process you need to have more surface area.

Similarly, if suppose this absorption happened, absorption and adsorption both are different. Absorption generally gaseous molecules will be transferred from the gaseous mixture to the liquid whereas adsorption is AD, adsorption is the gaseous molecule to be transferred from the gaseous mixture to the solid. So, that is adsorption. So, whichever is that you need to have more interfacial area interface between two phases either gas or solid or gas or liquid. So, to create more interfacial area to get the more solid gas or solid liquid interface you need to reduce the size of the particle.

Then some key properties of the solids which is to be known to designing a process or selecting an equipment in that case you have to reduce the size of the particle. You have to know what the size distribution in the feed whether it is in wider size distribution or narrow size distribution. Wider size distribution will give you the wide range of particle size, narrow size distribution will give you the almost uniform size of the particles. So, to get the better mixing or more dissolution or better reaction performance you need to have narrow size distribution of the feed. Different particle shape, density, elasticity, hardness, brittleness and free ability are also more important for the analysis of the performance whenever you are going to use this particle.

So, if you have different shape particles, different density particles its elasticity behaviour is different, hardness behaviour is different you will see that their applicability of that particles for that physical or chemical processes will be different. So, that is why to get uniform size, uniform shape you have to reduce the size of the particle. Again if you reduce the size of the particle you can increase the flowability sometimes cohesiveness will increase and adhesiveness will increase though it will be not suitable for any give better yield for that processes. So, in that case flowability can be increased which is very acceptable for transporting the materials from one point to another point. Whereas cohesiveness will not be sometimes acceptable or it will not be that suitable for that particular operation but in that case you have to optimize the size of the particle but you cannot use that bigger size or coarser size for that operation.

So, you have to reduce up to a certain extent which is optimum in value. Then abrasiveness, stickiness, dust explosion characteristics are also important. You can reduce the size of the particles where you can get the you know optimum value which will give you the optimum stickiness, dust explosion and characteristics of that particle which will be useful for the assessment of the process. Then temperature sensitivity which will be more effective if you reduce the size of the particle and in that case degradation, stickiness and phase change will be effective for that particular reduced size. You will see that some property that you have to consider like corrosivity, that toxicity and composition, moisture oil and fat content in the particles, fibrous morphology, reactivity or release of gases, shock sensitivity and explosiveness, all those properties depends on the particle size.

So, you need to have that optimum size from the coarser size which can be used for a particular process analysis. Now, next question will come that what will be the mechanism by which we can get the reduction of the size of the particles. There are different mechanisms in this slide it is shown that there are basically four types of mechanisms are there. Those are compression like impact, attrition, shear. Other than those basic mechanisms you can use other different types of provisions or mechanism by which you can reduce the size like introduction of energy based on which you can reduce the size.

Those energy will come from thermal shock, explosive shattering and electro hydraulic forces. So, these are the mechanism by which you can reduce the size of the particle. Common mechanisms that we told that compression, impact, attrition, shear. What is compression? In that case you will see that particle disintegration or particle breakage will be happened by two rigid forces. Here in this slide it is shown that compression in the C, figure C, two rigid surface in between there will be a particle and this particle breakage will happen by introducing two forces by this two rigid surfaces.

Then impact particle breaks by a single rigid forces. Single rigid force there you will see in the picture you will see that in D here one rigid surface will be there and solid particles will be broken by a rigid force on the surface of this force that is created by the solid surface. And then attrition, attrition is basically what is that particle-particle interaction. Whenever high kinetic energy will be utilizing to moves the particles whether random direction or in a particular fashion you will see that due to that energy transport the particles will be interacting to each other. This is happened basically in the fluidized bed or other starting reactor where particle-particle interaction will be more high.

In that case because of that interaction particles may be reduced its size by breaking. So, breaking of particles by scraping between two surfaces that will be called attrition. Then shear, by shear you will see that particles will be produced in its lower size based on compression between two edges of the hard surfaces. It is shown here in this figure F in this case there will be a shear of these two surfaces. So, these are the some common mechanism by which you can reduce the size of the particles.

Other non-mechanical mechanism like thermal shock, explosive shattering and electro-hydraulic force by which you can reduce the size of the particles. Now, in this case let us have an example here how size can be reduced by crushing. Here in this figure it is shown that if a single lump of material is subjected to a sudden impact in a gap of two jaws in a certain mechanical provision it is called jaw crusher. You will see that it will generally breaks so as to yield a few relatively large particles and number of fine particles with relatively few particles which will be intermediate in size. What is the feed particles to be you know given here in this jaw crusher and what is the coming up of these fine particles, those particles may be in the intermediate range.

So, here we can say that if a single lump of material is subjected to a sudden impact it will generally break into a finer one and which will be with relatively few particles of intermediate size. Now, if the energy in the flow is increased the larger particles will be of a rather smaller size and more numerous whereas, the number of fine particles will be appreciably increased. So, we can say that if we reduce the size of the particles number of particles will be more whereas, the feed particles number will be less which will be broken into a finer ones give you more number of particles because of its reducing size. And also you will see that in case of impact mechanism for the size reduction kinetic energy of the particles is used to generate the degree of deformation that is required for the breakup of this particle. In this case you will see that a material is said to be brittle elastic if the deformation of the product is initially proportional to the applied stress.

So, you have to apply some stress on the particles by which that will be broken. Now if suppose the material is brittle elastic if the deformation of the product is initially proportional to the applied stress then you will see that the fracture of the particle will be happened suddenly. Now, initially you will see that in the linear range the particle deformation will be elastic and also reversible but as soon as higher stresses will be applied there the material will absorb that higher stress and the material strength is exceeded locally and attacks into a sudden under that stresses and cracks immediately which are to be triggered. So, in the linear range you can say that initially particle deformation will be elastic and reversible but whenever more stresses will be applied the material strength will be exceeded locally and cracks will be triggered. Now the cracks grow extremely fast and lead to the destruction of the particle based on which that particle will be broken into a finer ones.

So, you will see here how that fracture mechanism will be acting based on the applied stress here. You will see that particles are getting cracked after applying some stress. So, in this case some energy is required that energy required to effective size reduction and it will be related to the internal structure, internal structure of the material and the process will consist of two parts. In that case first of all that it will be opening up any smaller fissures which are already present in the material and then finally or second you can say it will form a new surface. So, first of all this energy which is required that of course to be effective to get this material into cracked just by two mechanism one will be opening up any small fissures initially which are already present in that case and then just by absorption of the energy it will become or it will give you new surfaces just by breaking up.

Then all large lumps of materials which will contains that cracks and size reduction occurs it will be a result of crack initiation and crack propagation. So this crack initiation and crack propagation will occurs above a certain critical parameter that is represented by f and that f can be defined by tau square A by y. Here it is shown in the slide that equation this F is equal to tau square A by y.

$$F = \frac{\tau^2 a}{Y}$$

What is that tau? Tau is basically that applied stress on that particle and A is the crack length as shown in the picture and y is the Young's modulus. So, in this case this critical parameter will show you whether these particles will be broken up into a finer ones or not.

So, at lower values of f elastic deformation occurs without fracture. So, in that case the particles will not be broken up into a two pieces or three pieces or more than that and the energy input is completely ineffective in that case for this achieving of that size reduction. So you have to give the effective energy on the particles so that this critical parameter value will be exceeded from its critical value. Now let us have this example what should be the critical parameter of a concrete material. For different materials this critical parameter will be different.

So, if you consider a concrete material you see that what should be that critical parameter beyond which the material lose its elastic deformation if the crack length is 10 centimeter. Stress is 100 kilo Pascal and Young's modulus is of 17 into 10 to the power 9 Pascal. So, in this case we can easily calculate what should be the critical parameter here in this case for concrete material. In this case crack length is given it is measured as 10 centimeter that means 0.1 meter and stress is here tau is 100 kilo Pascal it is also applied stress here given based on which that cracks happen and Young's modulus is what is that y it is 17 into 10 to the power 9 Pascal as per the material characteristics.

Now then what should be the critical parameter f that will be equal to tau square a by y that will be equal to tau is what is the values of tau this that it is given I think 100 kPa whole square then into 0.1 that is a value divided by y value 17 into 10 10 to the power 9. So, after calculation you will get this value as 0.06. So, this a value critical parameter is 0.

06. So, beyond this critical value this all the concrete whatever it is it will be cracked into a smaller pieces. So, this is your critical parameter that you have to know. Some Young's modulus values are given for different materials in the slide like for aluminum, beryllium, that copper, bone compact, cadmium, carbon nanotube, rhodium, silver, nickel, thorium, tin and zinc all those materials have their different   Young's modulus values. So, based on this Young's modulus values and the applied stress and from the experimental value of that crack lengths you will be able to find out what will be the critical parameter and based on which you will be able to assess whether that material will be broken up into a finer one or not. Then here some typical values you will see that whenever particles will be you know broken up into a finer one there will be a creation of surface area more surface area.

So, bigger particles will give you whatever surface area if you make into a finer one by reduction size reduction you will see that more surface area of the particle will be there. Now in that case you need some energy which is to be adsorbed on the surface. Now order of that magnitude of the surface fracture energy per unit surface area typically for the glass it will be 1 to 10 joule per meter square plastic 10 to the power 3 joule per meter square and metals it will be 10 to the power 3 to 10 to the power 5 joule per meter square. Now in the presence of a crack modifies the stress field in its immediate location that means from where that crack has started the increase in energy would be approximately proportional to the crack length and what is that distance from the crack tip. The stress field is proportional to square root of that A by L square root of A by L

$$Stress\ \ field\sqrt{(a/l)}$$

that means here we can say that the stress whatever applied that will be you know proportional to the square root of crack length and inversely proportional to the square root of distance from the crack tip.

So, the presence of a crack which will be modifies the stress field in its immediate location with the increase in energy which will be proportional to this stress field and this stress field again as a proportional to the square root of crack length and inversely proportional to the square root of distance from the crack tip. Now in this case you have to remember some important points that whenever particles will be storing some energy for its reduction of size the capacity of the particle for storing this energy is proportional to the volume of the particles that means proportional to the cube of the particle diameter and also you can say that the energy requirement for propagating geometrically similar cracks is proportional to the surface area and the energy available per unit crack area that is increases linearly with particle size. So, these three points that you have to remember. Now let us have an example, it is said that by what factor will the stress field change if the crack length increases by four times and the distance from the crack tip does not change. Here we know that whatever energy is required to have this crack or make this crack that will be proportional to the stress field and that stress field is proportional to root over a by L where a is the crack length and L is the distance from the crack tip.

Now initial stress applied as per problem that will be equal to K into root over a by L here K is the proportionality constant and final stress that will be then K into root over 4 a L that means crack length will be four times of that initial length whereas the distance from this crack tip will not be changed. So, in that case L will be remain same. So, it will be coming as 2 into K root over a by L. So, therefore the stress field change by two factors. So, this is simple problem by which you can easily understood what will be the energy required which is proportional to the stress field.

Then one of the important point or important topics here that power requirement and efficiency in size reduction. It is required anyway for reducing the size you need to have you need to apply some energy that energy to be absorbed on the solid surface and based on that based on that absorption of that energy the particles will be breaking up into a finer ones. Now how much energy will be required or what will be the energy for that reduction of that size that you need to calculate and also know. So, whenever stress is applied material are distorted and strained . Now in that case some work will be required to strain which is stored as a mechanical energy till the ultimate strength is reached.

So, you have to apply some stress that stress will give you the strain that means breaking up of the materials or that deformation of the materials that means strain you can calculate for that getting strain you have to do some work on that particles that work will be considered as energy mechanical energy. So, you have to keep that mechanical energy till the ultimate strength of the material will be recent. So, energy goes to increase in surface area and excess energy is liberated as heat. So, all the energy whatever to be supplied to the material will not be utilized for the breaking up some energy will be released as a heat. So, in that case you cannot say that 100 percent energy will be utilized for breaking up the material.

So, in that case there will be some efficiency size reduction efficiency. Now that size reduction can be done by crushing equipment or crusher you can say we will discuss in the next classes next lecture the different types of crushing and what are the crushing machine by which you can reduce the size of the particles. Now what will be the efficiency of that size reduction by that crushing mechanism? So, this can be basically defined by here what will be the surface energy that is created by size reduction mechanism divided by energy absorbed by the material. Now in this case it can be defined mathematically as Es into Asp minus Asf by Ws. What is that? Here surface energy created by size reduction mechanism that can be calculated by Es into Asp minus Asf.

$$\eta_c = \frac{\text{Surface energy created by size reduction mechanism}}{\text{Energy absorbed by the material}}$$

$$= \frac{e_s(a_{s,p} - a_{s,f})}{W_s}$$

Here Es is surface energy per unit area. What are the surface energy absorbed by the material per unit area? And then Asp specific surface area of the product P for here product and As is basically specific surface area that means what will be the surface area that is created per unit mass of the material. And then Asf what is the specific surface area for the feed particles per unit mass of the material. So, that is represented by Asf and then Ws is basically the energy absorbed by unit mass of the solid. So, one thing is that surface energy created by surface energy absorbed.

This is the very important point. So, what is the surface energy created that can be calculated by this here Es into Asp minus Asf and surface energy absorbed by the material as Ws. Now this As how you will calculate As? As is the what that is? As is basically the specific surface area either for product or feed. So, specific surface area is basically what is the surface area? Suppose one single particle a spherical particle or if it is not spherical then you have to consider equivalent spherical diameter. For that what would be the surface area? It will be pi Dp square and divided by its mass that will be specific surface area. What is the mass? First of all you have to calculate what will be the volume of that particle that means pi by 6 Dp cube then you have to multiply it by density of the solid.

Then you will get what will be the mass of the solid. So, the surface area divided by mass of the solid that will be called as specific surface area. Now energy absorbed by solid cannot be 100% we told. Whatever energy supplied by the shaft energy or mechanically that should not be utilized fully. This is due to the energy loss by conversion to heat energy. That means we can say that there is some mechanical energy of shaft energy for absorption by material to get its size reduction.

$$\text{Mechanical efficiency } (\eta_m) = \frac{\text{Energy absorbed by the material}}{\text{Energy input to the machine}} = \frac{W_s}{W}$$

That means some portion of the materials some fractional energy will be utilized to get the particle its size in reduction form. That means get its size reduction. What is that mechanical efficiency? That means what is the energy absorbed by the material? This is Ws and what is the energy supplied to the machine for this size reduction that is W. So, this mechanical efficiency will be basically Ws by W. So, we can write from this equation as W will be is equal to what? Ws by eta m.

$$W = \frac{W_s}{\eta_m} = \frac{e_s(a_{s,p} - a_{s,f})}{\eta_m \eta_c}$$

What is this eta m? Eta m basically mechanical efficiency. Now Ws we know that in the previous equation Ws is equal to what is that? E s Asp minus Asp by eta c by which you can calculate Ws. So we can write here Ws is as like this. This is your Ws and here eta m is the mechanical efficiency. So, from this equation number 4 you can easily calculate what will be the energy input to the machine and then what will be the power requirement? Power requirement is basically what will be the energy input to the machine into what will be the mass flow rate of the feed which will be processed for its size reduction.

$$P = W\dot{m} = \frac{e_s(a_{s,p} - a_{s,f})\dot{m}}{\eta_m \eta_c}$$

So that you can find it out. So, you have to just multiply by this mass flow rate with that energy input to the machine which will give you the power requirement. Now let us do an example for this. A machine is used to reduce the size of a unpolished limestone of 5 kg for 1 minute and of equivalent spherical size of 50 millimeter. After size reduction of the limestone by the machine it is found that average size of the particle is 5 millimeter.

The reduction efficiency was calculated as 0.85. Now you have to find out what is the energy absorbed by the material per kg of the limestone when its mechanical efficiency will be of the machine 0.90 and also the surface energy per unit area of the limestone at unpolished condition is 0.250 joule per meter square. So, you have to find out what is the energy absorbed by the material per kg of the limestone. So, how to solve this problem? In this case you need to have what will be the energy absorbed by the material.

So energy absorbed by the material is Ws. To calculate the Ws you need to know that energy what is that energy absorbed by the material that means surface energy per unit area of the limestone that you need to know and also specific surface area for the product and feed and then what is that crushing efficiency. So, first of all we have to calculate ASP. What is that ASP? ASP the specific surface area for the product. So, it will be that pi Dp square that is surface area for the product p for product here and Dp here particle diameter divided by the mass of the particle here mass of the particle pi by 6 Dp square here it will be Dp cube into rho s.

$$a_s = \frac{\pi d_p^2}{(\pi / 6) d_p^3 \rho_s}$$

So, this will be your what is that mass of the particles. Now what is the value is given this is pi Dp square if Dp square and Dp cube then it will be cancelled only Dp will be there. So, it will be only 6 by Dp then divided by rho s. So, it will be 6 by Dp is 0.005 because the product size it is given as 5 millimetres so it will be 0.005 and then into 2709 is the density of the solid particle. So it is coming as 0.443 metre square per kg. Similarly for the feed ASF, ASF will be is equal to pi Dp square F divided by pi by 6 Dp F cube into rho s.

So, it will be again coming as 6 by 0.05 this is 0.05 is basically the equivalent spherical size of the feed particle which is given as 50 millimetre. So, it will be converting into metre like 0.

05 yeah 50 millimetre then it will be 0.05 metre. So, here it will be 6 by 0.05 into 2709 so it will come as 0.0443 metre square per kg. Now after substitution of this ASP and ASF here as 0.443 and 0.

0443 and also what will be the surface energy per unit area as 0.250 it is given and then substituting the crushing efficiency which is given as 0.85 in the problem then after simplification we can get 0.117 joule per kg. Then you have to calculate what will be the power requirement to run the machine if the mechanical efficiency of the machine is given 0.90. So, P you have to calculate P power requirement which is W into m dot what is the W? W is W s by eta m W s that you can calculate or you have already calculated it is 0.117 joule per kg then this is here you have to substitute and then eta m is given 0.90 here it is given 0.90 mechanical efficiency and then what will be the mass flow rate it is given I think it is given 5 kg per 1 minute so you have to convert it to kg per second so 5 by 60 so ultimately it is coming 0.011 watt. So, in this way you can calculate what will be the power requirement to break the materials from its feed size to the product size at a particular rate of feed. So, I think you understood this problem and how to calculate the power and energy requirement for reduction of the size. We will also discuss regarding this size reduction there will be other theory to calculate the size reduction based on the feed size and product size that will be discussed in the separate lecture soon. So, I think you understood this one and then also another problem here what is the power requirement if the energy absorbed by the material is 2000 kilojoule if efficiency is 0.7 and the mass flow rate is 10 kg per hour. Here also exactly the same then energy absorbed by material it is given 2000 kilojoule efficiency mechanical efficiency it is given 0.7 mass flow rate of the material it is m dot will be 10 kg per hour energy input to the machine that means W is equal to Ws by time this is basically 2000 by 0.7 then it will come 2857.14 kilojoule and then power requirement will be is equal to P that will be W into m dot so this will be as 2857.14 into 10 by 3600 here 10 by 3600 because this is given as 10 kg per hour it will be 10 kg per second so that is why you have to divide it by 3600.

So finally it is coming as 7.94 kilowatt so in this way you can calculate what will be the power requirement for reducing the size of the material. So, I think you understood is the mechanism of the size reduction and what is the power requirement how to calculate it, what is the absorption, what is the mechanical efficiency and what is the crushing efficiency, what is the surface area produced for that particle size reduction. So it will be very useful for you also calculating for the further lecture whatever problem it will be discussed it will be required so I think you have understood this size reduction mechanism here in this lecture. We will be discussing more about that size reduction in the next lecture we will try to understand the machines for size reduction, what are the different machines will be used for the size reduction and what are those machines how they are working and what are the capacities for that machines for the size reduction. So thank you have a good day. .