Lec 8: Mechanism of Size Enlargement

Hello everybody welcome to this massive open online course on solid-fluid operations. So, we are discussing about the module on size enlargement of the particle. In the previous lecture we were discussing about the importance of size enlargement and what are the basic components are required for the size enlargement we have discussed. Now, in this lecture we will try to understand what is the mechanism of size enlargement. In this lecture we will cover the rate process of the size enlargement, basically mechanism of that granulation process and also what is weight and dry granulation. We will see that agglomeration is one of the important process for this granulation process.

So, basically both are same you can say that agglomeration process and granulation process. So it is the formation of agglomerates or granules or aggregates you can say by sticking together of a smaller particle and granulation is agglomeration by agitation. There are several methods available for this granulation process like that compaction, extrusion, sintering, spray drying, prilling even that granulation process. So we will see in this slide it is shown that there are several methods which are following for this granulation, compaction, even prilling process, spray drying process, even sintering process, extrusion process are there.

And for granulation process you will see that there are basically two types of granulations are there, one is called dry granulation and another is called wet granulation. And the dry granulation you will see that there will be some dry mixing and then slug dislug condition and then compaction based on which that granules will be formed. Now whenever you are going to mix such dry condition you will see that there will be some shifting and mixing mechanism certain phenomena of that mixing to be followed and then finally you have to blend that molecules or particles to get it into a binding and then forming a granules. In between you will see that there will be certain slug and dislug conditions some granules will be sometimes it will be making a bigger one and then breaking into a finer one again and then coalescence and then breaking up. So these are all basically that slug, dislug condition based on that degree of mixing, degree of shifting, degree of milling of that operating condition even what is the optimum size of that product to be obtained based on which that slug, dislug condition should be controlled.

And then compaction is basically again that in this process you will see that depends on that shifting, mixing processes even if you are doing that compaction for that granulation process what is the mechanism of that compaction with either by rolling or some other compaction methods to be followed whether it can be milling or sizing and finally you have to do the blending. So slug, dislug and compaction both will be the same way that will be done and finally to be compaction to make that free load, dry free load granules there. So this is the dry granulation process whereas wet granulation process there may be two types it will be aqueous and some will be non-aqueous. So in that case again that aqueous non-aqueous cases there of course that mechanism will be like that some molecules will be shifting, mixing and then blending, drying, milling all those operations to be there. And in this case as per that restriction to the coarse level for UG only granulation process will be discussed and you will see that here in this picture to shown one schematic of granulation.

You will see that a typical agglomeration circuit utilized in the processing of pharmaceuticals that involves both granulation and compression techniques. So here you will see that initially that feed powders with ingredients that will be kept in a bin and from that bin it will be passed through that blender or mixer. So all the ingredients to be mixed here and before sending it to the granulator which is called that granulation equipment is that it will be pre-mixed with that binding fluid or other binding agents if it is required or you can say that there before sending it to that it will be halt in a bin so that if there is any controlling of that binding liquid or agent to be required that you can done here. And then you will see that in this granulator you have to mix here in this granulator by certain mechanism based on which that granulation or granules will be formed there. So with that binding liquid whenever that particles after blending or mixing it will be coming to that granulator then you will see that bigger size particles will be formed.

After that bigger size particles along with that smaller also particles will be coming or will be allowed to pass to the classifier where you will see that granule will be separated from that which are not actually converted into granule forms that will be separated. So based on this classifier action this granules will be separated and then it will be passed through again that granule bin and after that from that granule bin it will be passed through that tabulating press and where that desired size of the products will be obtained. Whereas other the components from the classifiers which are not actually formed as granule those will be recycled and before recycling it will be milled again because some granules will be formed so that it will be separated by that milling process or it will be broken up into milling equipment. So through this milling it will be passed through again to the feed powders. So here this is the simple schematic of the granulation process which is being used in pharmaceutical industry.

Now we are talking about first that mechanism of wet granulation, how that wet granulation being happened. Generally four key mechanisms contribute to size enlargement by this wet granulation process. These are generally you will see that wetting and nucleation stage, then growth stage and consolidation stage and attrition or break stage. So these four you will see that four stages generally followed to get that granules. So what are these actually steps and how that steps actually performed that depends on what are the size of the particles, what is the density of the particles, whether that particles will be at treated during that process or not, how that particles will be dispersed in that granulator, even what is the flowability characteristics of that granulator.

Also it depends on voidage inside the granulator, also some other operating variables that how that binding liquids will be mixed with that powders either by drop wise or then if it is drop wise then how that drop will be penetrating on the bed of that granular beds and then what is the mechanism or how you can calculate how much penetration will happen and what is the degree of penetration and that depends on what, all those phenomena to be considered there. And also you will see that this granulation process, this four stages or five stages there whatever final stage you can say that depends on that requirement of the design of that granules. So these are four basic stages that will be considered for that wet granulation process. Now first stage is that wetting and nucleation stage, in this stage you will see that voids between particles, you will see that here particles are there, between particles there will be a voidage. Now that voidage will be replaced by liquid which is added as a liquid drop, that liquid drop will be basically that binding agent liquid.

So here this whatever voidage will be there in between particles that will be filled up with the bonding liquids or binding solvent, you can say that will be supplied as a drop wise or spray. Now wetting is governed by the surface tension basically of the liquid and contact angle with the particles. So whenever binding liquid that will be added to that particles, you will see that this wetting of these particles by that binding agent will change that their inter-particle interaction and that inter-particle interaction will be governed by the surface tension of the liquid and also contact angle with the particles. So in this case here you will see that nucleation is also one important stage here. In this case this nucleation basically applied to the initial coalescence and growth of the primary particles in the immediate vicinity of the larger wetting drops.

So whenever wetting drops will be falls into that powdered surface, you will see that immediately there will be some growth of the particles just by binding that particles with that binding solvent. So this is called that initial growth or nucleation stage and then you will see that there will be a certain rate at which that wetting should be followed in that wetting and nucleation stage. Now actually the rate at which that wetting occurs is important in granulation which is known as Washburn equation by which you can calculate what will be the rate of that wetting that you can calculate. So this basically depends on that how much penetration happens or that is binding liquids how much it will be penetrated inside the particular bed. So that will give you that rate at which that granulation occurs.

So basically you will see that whenever drop will be hold onto the surface of that particulate bed you will see that immediately that solvent or binding agent or liquid it will be spread over the surface of this particulate bed and during that spreading how much it will be spreaded that will be represented by Z that is called penetration distance of the liquid into the powder and this penetration depth or penetration distance will be changing with respect to time of with respect to time gradually that it will be this particulate bed will be wetted by that binding liquid. So, in that case, gradually that distance will be increasing. So what will be the rate of increasing that penetration distance with respect to time that is basically the rate at which that granulation occurs. So dZ by dt we can express this change of that penetration distance with respect to time and this depends on what that Rp.

Here the equation(s)

$$\frac{dz}{dt} = \frac{R_p \gamma \cos cos\, \theta}{4 \mu z}$$

Or

$$z = \sqrt{\frac{R_p \gamma \cos cos\, \theta}{2 \mu z} t}$$

Rp is basically what the average pore radius what is the average pore radius inside that particle in the particulate bed.

The average pore radius is actually function of packing density as well as size distribution of the powder. That pore radius depend on how it will be distributed that is particles in the particulate bed will be distributed as well as packing density. So more packing density it will give you the less pores and also accordingly what would be the average size that can be calculated and gamma. Gamma is here basically the surface tension of the liquid and then cos theta, cos theta that will be the what is the contact angle to gamma cos theta will give you that surface tension there in that particular direction of the penetration and then here also it depends on that viscosity of the liquid and also the distance of that penetration. So here this the change of that penetration distance with respect to time that can be represented by dZ by dt and it will be you know defined by this as per this equation of Washburn equation.

So it will be Rp gamma cos theta by 4 mu Z or after integration you can express this equation as Z will be is equal to root over Rp gamma cos theta by 2 mu Z into t. t is the time here time for that penetration get up to a certain distance. Now you will see that there are several stages of this wetting. Initially you will see that the drop will be allowed to fall into that surface of the powder bed here like this and then whenever one drop will be falls into the powder bed and then subsequently another drop will come into that initial drop and it will coalesce and then it will become a bigger size of the droplet and then you will see that it will be spread over the powder bed and then you will see that after this that gradual spreading drops on the powder surface you will see that that binding liquid will be entering into that whole bed of this powder just as a channeling and it is actually passing through that pores of that powder materials that means gap between the particles in the powder bed. So binder will dispersed by wetting and capillary penetration there and then after that this binder will be dispersed also by the mixing process there.

So you will see that initially whenever drop will be coming on to the surface of that powder bed it will be spreading over the surface and then the dispersion of that binding liquid will be done by mechanical mixing. So stages of wetting for fine powder compared to the drop size it is shown here. Again you will see that drop penetration at a moving powder bed this is happened when there will be a gap between two particles and then binding agents will be spreading inside that gap of that particles as a simply capillary flow. So liquid flows through a narrow pores here it is shown. Now whenever drops will fall here that will be spreading over the powder surface so there you will see that powder compaction will be happened and here spreading of drops you will see that and then drops and getting penetration inside that powder bed at a certain flow rate that is V and then penetration of particles into the fluid happens like this here with respect to time and also sometimes you will see that during that penetration some chemical proving of powder will happen you will see that some chemicals will be attached to that powder surface or particle surface and it will be sticked on that you particles as a molecule here and there will be making a layer over the surface of that you know particles that will be making a bridge that is called liquid bridge formation of liquid bridge by just probing of that chemical into the particle surface.

And then you will see that whenever a drop of certain known volume let it be Vd is when placed onto a small powder bed with certain porosity let it be epsilon V and the time taken for the drop to completely sink into the powder bed then you will be able to find out what would be the penetration time for that known volume of binding liquid to be supplied there. So in that case Tp can be obtained by this correlation okay which is given by you know Hapgood et al., 2003.

Here the equation

$$t_p = 1.35\frac{V_d^{2/3}\mu}{\varepsilon_b^2 R_p \gamma Cos\theta}$$

Here you will see that it depends on that Vd that means known volume of that drop and also the porosity bed porosity and the average particle size and also surface tension and contact angle of the liquid with the solid particle. And here this Rp can be calculated that depends on porosity itself and also sauter mean particle diameter.

Here the equation

$$R_p = \frac{\varphi d_{32}}{3}\left(\frac{\varepsilon}{1-\varepsilon}\right)$$

I think we have discussed that what is particle diameter it is basically volume to surface ratio mean particle diameter that we have discussed earlier also how to calculate the Sauter mean bubble diameter or Sauter mean particle diameter there.

So it depends on that this Sauter mean particle diameter and also porosity of the bed. If there are not uniform particle size then you have to consider what will be the you know sphericity of that particle. That sphericity of the particle of course you can calculate if it is in different shape so according to that shape you can calculate what is the sphericity as per definition that is given earlier. Now some important point that you have to remember in this case. You can improve this wetting if it gives a narrower granular size distribution and improved product quality through better control over the granulation process okay.

So here this wetting or nucleation stage improved wetting is desirable as it gives a narrower granular size distribution and then improved product quality through a better control over the granulation process. Also this rate of wetting you will see that depends on that viscosity, surface tension even you will see that contact angle in even you will see that size of the pores within the powder. Now the rate of this wetting it will increase with reducing viscosity, it may increase with surface tension with increasing surface tension, it may increase by minimizing that contact angle and also it can be increased by increasing the size of pores that within the powder. And small particles give small pores and large particles give of course that large pores and also this wider particle size distribution will give rise to smaller pores. Large pores ensure a high rate of liquid penetration but give rise to a lower extent of wetting.

So this is very important point here that large pores you cannot be suitably considered for getting that better wetting. Then drop controlled nucleation, this is the second of controlling phenomena where that you can control that nucleation stage. Now in this case there will be some phenomena or some condition based on which you can control this nucleation regime. There will be certain ideal stage to have this condition. Now in this case each droplet should land on the powder without touching other droplets and sink quickly into the powder to form a new nucleus granule.

This is the ideal statement based on which that you can have this condition of that drop controlled nucleation regime. So here always that drop when whatever it will be allowed to wet that surface of that powder bed it should be individually without interacting each other. That means droplet will not interact with each other and also you can say that whenever it will be touched onto the surface of the powder or bed powder surface you will see immediately it should sink into the powder so that that new nucleus immediately will form. So this is the case so these ideal conditions are called the drop controlled nucleation regime and it occurs generally at low penetration time and low dimensionless spray flux that is denoted by Sai_a and this Sai_a that is called spray flux, can be calculated by this equation given by Lister et al.

Here the equation

$$\psi_a = \frac{3Q}{2v_s w_s d_d}$$

to try to understand that spray flux depends on what? It depends on that solution flow rate that is Q, it depends on the powder velocity in the spray zone, it depends on the width of the spray and also d_d that means average drop diameter which is falling onto the surface of the powder bed. At low spray flux if it is very less than 1 then you will see that drop footprints will not overlap and each drop will form a separate nucleus granule. So this is one of the important that as low as possible this spray flux to be controlled so that you can have separate nucleus granule. At high spray flux if it is more than 1 then there will significant overlap of drops that will heat the powder bed and that is not actually suitable for that operation.

And wetting of powder is by spray drops and number of nuclei how much nuclei will be formed and what will be say spray flux value, what is the fraction of that powder surface actually will be wetted by that spray drops that also can be calculated by Hapgood et al. principle. So as per that Hapgood et al. principle at a given spray flux value the fraction of the powder surface that is wetted by spray drops as it passes beneath the spray zone is given by f wetted that will be equal to 1 minus exponent of minus Sai_a.

Here the equation

$$f_{wet} = 1 - \exp exp\left(- \psi_{a} \right)$$

Here this Sai_a is basically the spray flux and the fraction of nuclei how many number of nuclei to be formed and what is the fraction of that total nuclei formed by that n number of drops can be calculated by using again given by Hapgood et al. 2004 as per this equation.

Here the equation(s)

$$f_{n} = \exp exp\left(- 4\psi_{a} \right)\left[\frac{\left(4\psi_{a}\right)^{n-1}}{(n-1)!} \right]$$

So here f_n that means here the fraction of nuclei that is formed by that n drops that can be calculated by this equation this is also depends on that spray flux and here n, n is basically the number of drops and Sai_a is called the spray flux and then nucleation regime map that is also important to know because how that the time of penetration will be depending on that spray flux and based on which you can say that different stages or regimes that you can have during that wetting and nucleation and based on which you can control also whether it is intermediate or drop controlled region or mechanical dispersion regime or there will be no actually change of distribution it is required and also sometimes it is required to have that narrower nuclei size distribution in that case where at what time of that penetration to be allowed or what will be the spray flux to be followed or that allowed. Also sometimes you will see that whenever binding liquid will be spreading over that powder bed there will be formation of cake which may reduce the pores inside the bed and they may hinder the penetration of that binding liquid there. So, in that case in which cases or what will be the spray flux that means spray flow rate and also what will be the time of that penetration from which you can easily interpret. So, here in this picture it is shown that that TP versus?a that means time of penetration versus spray flux. There are different regions you will see that drop controlled region, caking region, narrower nuclear size distribution region, intermediate region and no change in distribution even mechanical dispersion regime.

So, all those regimes depends on that Sai_a value and t_p. For a particular suppose you need to control that operation as a drop controlled region at this point. So, you have to have that spray flux as this value and accordingly what will be the time of penetration that you can have. So, combination of this time of spray flux then you can say that your operation will be controlled by drop. So, here this called drop controlled region.

So, three you will see that nucleation regimes can be defined here drop controlled, shear controlled and intermediate zone. Shear controlled basically the mechanical dispersion where it happens so it is called shear controlled and also intermediate between these two drop controlled and shear controlled regime. Drop controlled nucleation occurs when one drop forms one nucleus and should occur when there is both. Like this here low spray flux if you are considering here low spray flux, the spray density is low and relatively few drops will be overlapping. And for fast penetration time suppose here your penetration time will be very high so in that case the drop must penetrate completely into the powder bed before it touches either other drops on the powder surface or new drops arriving from the spray.

And also if either criterion is not made the powder mixing and shear characteristics will dominate as mechanical dispersion regime. So, here in this case other than this mechanical dispersion regime you have to follow these two conditions. So, beyond this condition all will be as a mechanical dispersion regime. So, in the case of mechanical dispersion regime you will see that liquid binder can only be dispersed by powder, shear and agitation there. There will be no other drop controlled or intermediate control of that dispersion.

And then granule consolidation stage here depends on that granule density and also you will see that whether that packing of that bed will be very closer or not that is very important. So, in this stage the granule density will be increased and that will be caused by closer packing of primary particles. It determines the porosity and density of the final granules. The granule porosity epsilon and the liquid level denoted by W that means concentration you can say control the granule saturation that is defined by S here which is the fraction of pore space that will be filled by the liquid. So, that saturation will be defined by W rho S into 1 minus epsilon by rho L epsilon.

Here the equation

$$S = \frac{w\rho_s(1-\varepsilon)}{\rho_l \varepsilon}$$

where W is called that liquid level and rho S is basically the solid density and epsilon is the porosity of the bed and rho L is the liquid density of that binding agent.

The saturation here you will see that increases as the porosity decreases and once the saturation exceeds 100 percent you will see that you have to see that further consolidation pulses there and that consolidation will give you that liquid push to the granule surface which make that surface wet and also you can say that surface wetness that will cause the dramatic change in granule growth rates. So, very important here you have to control this saturation. So, the saturation of course will increases as the porosity decreases. Now whether we are going to increase the saturation beyond 100 percent or not. So, that also to be understood well sometimes if you are having that exceeded that 100 percent saturation you will see that there would be a kinetic energy transfer because of that flow of that fluid over the surface of that particles and they are immediately to be wet that surface of the particle and also that there will be change of that you know granule growth rates.

So, as much as possible that the saturation region should be near about 100 so that that will be as optimum value. growth stage due to we will see agitation and dispersion of kinetic energy that we are talking about that granules coalescence by collision and you will see that create an increased surface area by bonding. Now as granules grow so do the internal forces trying to pull the granule apart and it is only possible to predict a critical maximum size of the granule beyond which that coalescence is not possible during that collision. So, this is one of the important point that you have to remember that during that growth of that granules you will see that internal forces trying to pull the granule apart. Now if it is allowed to apart that particle then you will granule will not form.

So, they are sometimes that some critical maximum size of the granules to be maintained so that internal forces will be acting over the particles or between the particles so that the apartness of that granules will not happen. That means here you are going to that control the coalescence or collision between the particles. So, in this case there will be certain parameter based on which that you can say whether this coalescence will occur or not. The parameter which determines whether coalescence will occur is a Stokes number which is defined by this equation here rho V D by 16 mu where rho is the granule density.

Here the equation(s)

$$St = \frac{\rho V d}{16\mu}$$

here V is the approach velocity of that particles or granules you will see that D is the diameter of the granules and mu is the viscosity of the liquid which is used as a binder. The Stokes number is a measure of the ratio of collisional kinetic energy to the energy dissipated through viscous dissipation.

So, you have to control that internal forces or collision or coalescence based on this Stokes number. So, for this for coalescence to occur the Stokes number must be less than a critical value of that Stokes number which is represented by that St star how to calculate that critical Stokes number beyond which that you can control that your coalescence. So, here this St star that will be the 1 plus 1 by E into ln H by hA.

Here the equation

$$St^{*} = \left(1 + \frac{1}{e}\right) \ln ln \left(\frac{h}{h_a}\right)$$

what is this E is basically the coefficient of restitution for the collision. This coefficient will give you that whether collision will be happened or about to happen and then h, h is basically the thickness of coated powder of each granule. If suppose any granule is produced just by binding liquid making the layer over that granule surface by that binding liquid now what is the thickness of that coated layer of H is granule that you have to measure and then hA is basically the measure of surface roughness of the granule whatever granule will form what will be the surface roughness that is.

So, this critical Stokes number can be calculated by this equation. Now, you will see that based on this criterion three regimes of granule growth are identified for batch systems with relatively low agitation intensity. So, here you will see that you have to widely or wisely you can say that select that velocity of that spray that means spray flux that you have to consider in such a way that based on that you have to calculate what will the Stokes number. Now, if this Stokes number is coming beyond this critical Stokes number then there will be mechanically agitation. There will be mechanical agitation and these are the non inertial inertial and coating regimes will be there if that Stokes number will be less than this critical Stokes number.

Once the average Stokes number for the powder mass in the granules is comparable with the critical value granule growth is balanced by breakage and growth continuous by coating of primary particles onto the existing granules. Then another stage it is called granule deformation. In case of in high agitation intensity systems one cannot ignore the granule deformation there. Two types of granule behavior that occur depending on granule deformation you will see that one will be called steady growth behavior another will be called induction behavior. In steady growth behavior you will see that it occurs when the granule size increase is roughly proportional to granule penetration time.

And also induction behavior the induction growth occurs when there is a long period during which no increase in size occurs. Here some stages of this mechanism of granule coalescence for low and high deformability systems is shown here. Now you will see that here two colliding granules will be there approaching to each other and then you will see that they will colliding to each other and making high value of deformation at contact and then here it will be rebound then some coalescence then rebound and then coalescence. There are different stages which happen continuously inside the granulator. So mechanism of granule coalescence for low and high deformity system here you will see that rebound occurs for average granule size that will be greater than the critical granule size that is K.

That means K is basically the deformability. And here granule structure resulting from a low and high deformity system here this is for low and this is for high deformity system. Then growth regime all types of granule growth can be described using the saturation and deformation Stokes number and the granule growth regimes map. Here it is shown that there is a granule growth regime map and it actually basically give you that idea of that increasing deformation number based on that maximum saturation condition. So this the Stokes number at this deformation condition will be defined by this equation where UC will be is equal to representative collision velocity in the granulator and rho g is called the average granule density and yd is the dynamic yield stress of the granule. And this deformation Stokes number that will presented based on that maximum saturation condition which is defined as W rho s into 1 minus epsilon min by rho L epsilon min.

Here the equation

$$St_{def} = \rho_g U_c^2/(2Y_d)$$

So based on this condition of that deformation number and saturation we are having different flow regimes. Some will be dry free powder flowing and then there will be crumb, there will be slurry and steady growth, there will be rapid growth, there will be induction, there will be nucleation only. So based on that at low saturation condition you will see that and also for low deformation Stokes number you can have this nucleation only. Whereas you will see that for maximum saturation that means here you will see that at higher saturation condition that induction can be obtained based on that lower value of Stokes number. And in this case the lower deformation Stokes number will decrease that induction at high saturation.

Then the granule breakage stage, the breakage also called that fragmentation is the fracture of a granule to form two or more pieces. Here attrition also called erosion is the reduction in size of a granule by loss of primary particles from its surface. In practice you will see that breakage may be controlled by altering the granule properties such as by increasing the fracture toughness, by increasing resistance to attrition, by making changes to the process example like reduce agitation intensity like this. And so these are all about that weight granulation process. So there are several that stages are there mainly that four stages are you know described here in details that so you have to know this mechanism of that granulation process.

Now how that dry granulation occurs that also in a nutshell can be explained here. The process of dry granulation actually depends on the inter-particle bond formation, granule bond formation you will see that characterized in different stages which usually occur in the following order like particle rearrangement, particle deformation, particle fragmentation, particle bonding and then finally plastic and elastic deformation. Here there are different stages of this dry granulation is shown here. One is the rearrangement here then deformation will occur and then fragmentation will be happened and then bonding just coming to that each other there will be intermolecular action based on that Van der Waals force that will be bonding, creating and then plastic deformation will be happened and based on which there will be a fragmentation. You will see that particle rearrangement generally occurs initially as powder particles begin filling that void spaces by either air or some other fluid.

Generally air being used so air begins to leave the powder blends interstitial spaces and particles begin to move closer together and then particle deformation occurs as compression forces are increased and this deformation you will see that increases the points of contact between particles where bonding occurs and described as a particle deformation. And then particle will be fragmented into a finer one in that fragmentation stage there you will see that this occurs at increased compression force levels there in the mixer. And at this stage particle fracturing you will see that creates multiple new surface sites and you will see that additional contact points will be creating and also there will be a potential bonding sites will create during this fragmentation. After that this particle bonding will occur when plastic deformation and fragmentation occur. It is generally accepted that bonding takes place at the molecular level and that is due to the effect of Van der Waal force that told earlier.

And then final stage elastic and plastic deformations you will see that when powder granules undergo an applied force or stress or stress force is released from the granules. In this case you will see that a deformation will actually not totally recover after the stress is released which is called the plastic deformation. Whereas the granules attempt to return to their original shape or form which will be described by the elastic deformation. So, elastic and plastic deformations can occur there simultaneously but one effect of course will be predominance to the others.

So, one effect of course will be dominates to the other. So, here this elastic and plastic deformation both will be happening because of that applied stress that is released from the granules or applied to the granules. Here one curve is given that stress versus strain there. So, what is the limit of that elastic deformation and that plastic deformation that depends on that critical value of that applied stress. So, I think you understood here some extent of that mechanism of that granulation process. There are two process one is wet granulation another is dry granulation and for wet granulation we learn there are several stages like that growth and nucleation stage even then there will be consolidation stage and then breaking stage like this and also for dry granulation there are also several stages that you have learned some will be that collision and then you will see that fragmentation and then elastic and plastic deformation.

So, by this two mechanism generally this all the granulation process either wet or dry depends on. Also other several factors for this granulation process efficiency will be depending on like what is the size of that particles, what type of bonding liquid you are using whether it is high viscous or not whether surface tension will be less or higher even what is the contact angle between that a liquid and particle surface all those factors will give you that efficiency of the granulation process. So, thank you for your attention. Next lecture will be on based on basic equipment for the granulation. Thank you have a nice day. .