Mechanical Unit Operations
Professor Nanda Kishore
Department of Chemical Engineering
Indian Institute of Technology Guwahati
Lecture 15 - Size Enlargement Equipment

Welcome to the MOOCS course Mechanical Unit Operations. The title of this particular lecture is size enlargement equipment. So we have already seen the requirement of size enlargement, why should we go for a size enlargement of the particles. Fine particles we have seen that they are very difficult to handle and then they are very difficult to convey from one level to the other level, one of that reason and another reason is that they are also having kind of health hazards to the people working around or handling this kind of particles. So there are other issues are also associated with the fine particles.

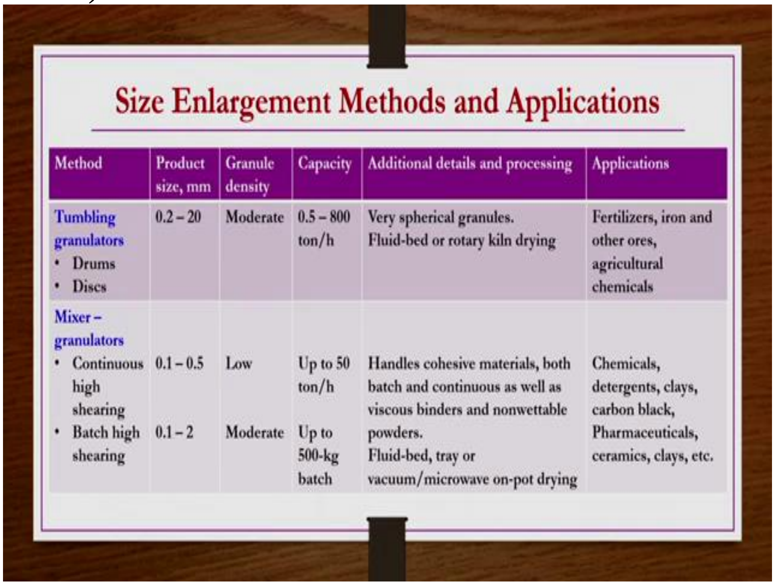
Considering all those reasons, what it has been decided rather having glidance, et cetera which may allow the flowing of the particles, even fine particles also comfortably, so it is better to optimize the particle size so that you know you do not need additional glidance et cetera and then you can handle these fine particles comfortably. So then in this consequent, we have also realized the importance of the size enlargement.

So we have seen the methods of size enlargements or how the size enlargement takes place, like something like you know agitative agglomeration which is also known as the granulation or granulation is the process where agglomeration of the particles takes place and then size enlargement, because of that one size enlargement takes place due to the agitative action imposed by external forces, something like that, okay. So other process that we have seen, like sintering is also one kind of a size enlargement process or method and then we have also seen that pressure compaction is also a kind of one of the size enlargement method.

We have also seen the kinetics, the different processes associated with these fine particles when they are combined with fluid or when they are flowing along with a fluid or bulk fluid is flowing carrying this fine particle, then what kind of processes are available? That perikinetic, orthokinetic processes, et cetera we have already seen. So now this particular lecture, before going into the details of the equipment under each size enlargement method, we will be you know seeing the listing out those kind of equipment, what are the different types of equipments available for size enlargement and what are their capacity, applications, et cetera.

Then we will be discussing the working procedure of some of these size enlargement equipments using their schematics. That is what we are going to see now in this particular lecture.

(Refer Slide Time: 3:01)



Size Enlargement Methods and Applications

Method	Product size, mm	Granule density	Capacity	Additional details and processing	Applications
Tumbling granulators • Drums • Discs	0.2 – 20	Moderate	0.5 – 800 ton/h	Very spherical granules. Fluid-bed or rotary kiln drying	Fertilizers, iron and other ores, agricultural chemicals
Mixer – granulators • Continuous high shearing • Batch high shearing	0.1 – 0.5 0.1 – 2	Low Moderate	Up to 50 ton/h Up to 500-kg batch	Handles cohesive materials, both batch and continuous as well as viscous binders and nonwettable powders. Fluid-bed, tray or vacuum/microwave on-pot drying	Chemicals, detergents, clays, carbon black, Pharmaceuticals, ceramics, clays, etc.

So tumbling granulators. Tumbling granulators by name the granulators, granulators in the sense size enlargement or agglomeration is taking place because of the agitative actions, some kind of agitation is imposed. That agitation here is taking place because of the tumbling of vessel in which the agglomeration is taking place. So that is the reason they are known as the tumbling granulators. We have 2 different types of methods available or the designs available under this tumbling granulators. So one is the drum granulator, another one is the disc granulator.

They are good enough to produce product size between 0.2 to 20 mm. Product size here in the sense the enlarged product, whatever the enlarged size particle is there, after size enlargement whatever the particle size is there, that is you know product size. So enlarged particles now in this context we are referring it as a kind of product, okay it is not a kind of some product of a reaction. Product here in the sense whatever the enlarged size of the particle is there you know that is the product size. So size enlargement is a process.

So size enlarged particles are now product. So these tumbling granulators are good enough to producing you know granulators or granules of size 0.2 to 20 mm, the granule density or density of the agglomerated particles or granule is in general moderate. The tumbling granulator having the advantage of high capacity, they can handle up to 800 ton per hour as well and then the granules after the size enlargement whatever the granules that you get, they are very spherical in nature by using this you know tumbling granulator.

So whatever the granules that we get by tumbling granulators, they are very spherical in the nature. Then after the granulation or size enlargement this particle in general has to be dried, that is also a kind of requirement. So the drying of these granules in general done by the fluid bed or rotary kiln drying. Application of this tumbling granulators in general we find in fertilizers, iron and other ores, agricultural chemical processing, et cetera. So in this production of fertilizers, iron, other ores, agricultural chemicals, somewhere we need to have a kind of you know enlargement of the particles.

So enlargement of such kind of you know products in general one can use these tumbling granulators. The next method of size enlargement equipment is you know mixer granulators. So they are also granulators, that is the agglomeration is taking place by agitative action. So these mixer granulators can be of 2 types; continuous high shearing or batch high shearing equipment. Continuous high shearing mixer granulators in general produce the products of size 0.1 to 0.5 mm whereas the batch high shearing mixer granulators can produce product size up to 2 mm, that is 0.1 to 2 mm.

The density in general low if you apply the continuous high shearing mixer granulator. If you apply the batch high shearing granulator, then the granule density in general moderate. The capacity wise continuous high shearing mixer granulator can handle 50 tons per hour whereas the batch high shearing mixer granulators in general can handle 500 kg batch up to that capacity they can handle. So these mixer granulators in general handles cohesive materials, both batch and continuous as well as the viscous binders and non-wettable powders. For all these categories they are suitable.

Whereas coming to the subsequent drying processing, fluid bed, tray or vacuum, microwave, on pot drying methodologies can be applied. These mixer granulators, in general we find you know applications in production of several chemicals, detergents, clays, carbon black, pharmaceuticals, ceramics, clays, et cetera. So mostly the pharmaceuticals, ceramics, clays in general, batch high shearing mixer granulators are used.

(Refer Slide Time: 7:07)

Method	Product size, mm	Granule density	Capacity	Additional details and processing	Applications
Fluidized granulators • Fluid beds • Spouted beds • Wurster coaters	0.1 – 1	Low (agglomerated) Moderate (layered)	100 – 900 kg batch 50 ton/h continuous	Flexible, relatively easy to scale, difficult for nonwettable powders and viscous binders, good for coating applications. Same vessel drying, air handling requirements	Continuous: fertilizers, inorganic salts, food, detergents Batch: nuclear wastes, agricultural chemicals, pharmaceuticals
Centrifugal granulators	0.3 – 3	Moderate to high	Up to 200-kg batch	Powder-layering and coating applications. Fluid-bed or same pot drying	Pharmaceuticals, agricultural chemicals

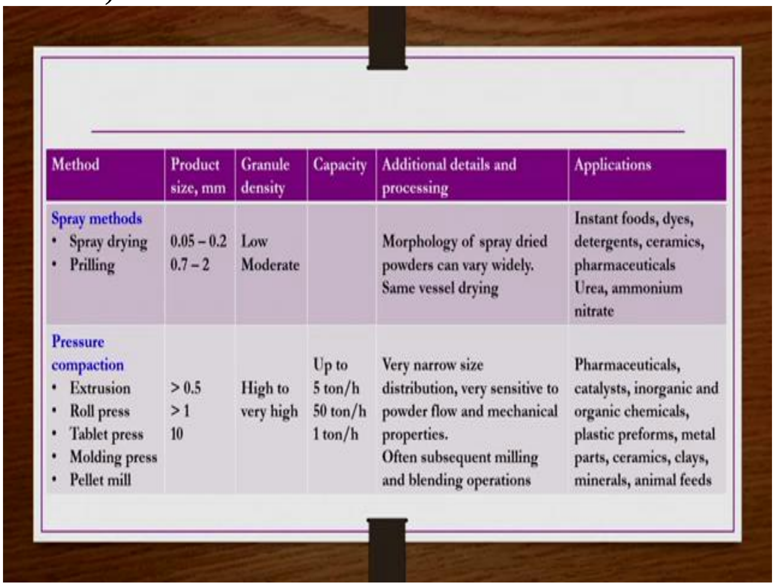
The next method of you know size enlargement is fluidized granulators. So fluidized granulators under the fluidized granulators, we have 3 different types of methods available. One is the fluid bed, another one is the spouted bed and then third one is the wurster coaters. So they are not only for size enlargement, these fluidized granulators are also used for a coating or layering kind of applications. And these fluidized granulators in general good for producing product of size 0.1 to 1 mm and then their granule density is in general low if they are used for the granulation or agglomeration. And whereas their density may be moderate if they are used for a layering or coating kind of applications.

The capacity in general batch wise, they can handle 100 to 900 kg whereas in a continuous mode, they can handle 50 tons per hour. These fluidized granulators in general flexible and relatively easy to scale. However, they are difficult for handling non-wettable powders and viscous binders. They are good for coating applications and then the required drying or air requirements, et cetera can be handled in the same vessel. Such kind of fluidized granulators, we find applications in you know continuous mode if you are operating them, fertilizers, inorganic salts, food, detergents, et cetera.

In their processing, we may be using this fluidized granulator. At the same fluidized bed granulator in the batch mode in general used for the nuclear waste, agricultural, chemicals, pharmaceuticals. Next method of size enlargement is the centrifugal granulators. So here also, they are granulators because the agglomeration is taking place by agitation. Agitative action is causing a kind of agglomeration, granule formation. So and then here in the under the case of centrifugal granulators, centrifugation forces are the kind of ones which are providing required agitation. Right?

And these granulators, centrifugal granulators are good for producing product size between 0.3 and 3 mm. Granule density in general moderate to high, the capacity is up to 200 kg per batch. They are in general used for powder layering and coating applications. The drying requirement, fluid bed or same pot drying can be done. The chemicals or where we in general find the application of these kind of centrifugal granulators are in general for production of some pharmaceuticals, chemicals or agricultural chemicals, et cetera. There we in general find these applications of these centrifugal granulators.

(Refer Slide Time: 10:00)



Method	Product size, mm	Granule density	Capacity	Additional details and processing	Applications
Spray methods • Spray drying • Prilling	0.05 – 0.2 0.7 – 2	Low Moderate		Morphology of spray dried powders can vary widely. Same vessel drying	Instant foods, dyes, detergents, ceramics, pharmaceuticals Urea, ammonium nitrate
Pressure compaction • Extrusion • Roll press • Tablet press • Molding press • Pellet mill	> 0.5 > 1 10	High to very high	Up to 5 ton/h 50 ton/h 1 ton/h	Very narrow size distribution, very sensitive to powder flow and mechanical properties. Often subsequent milling and blending operations	Pharmaceuticals, catalysts, inorganic and organic chemicals, plastic preforms, metal parts, ceramics, clays, minerals, animal feeds

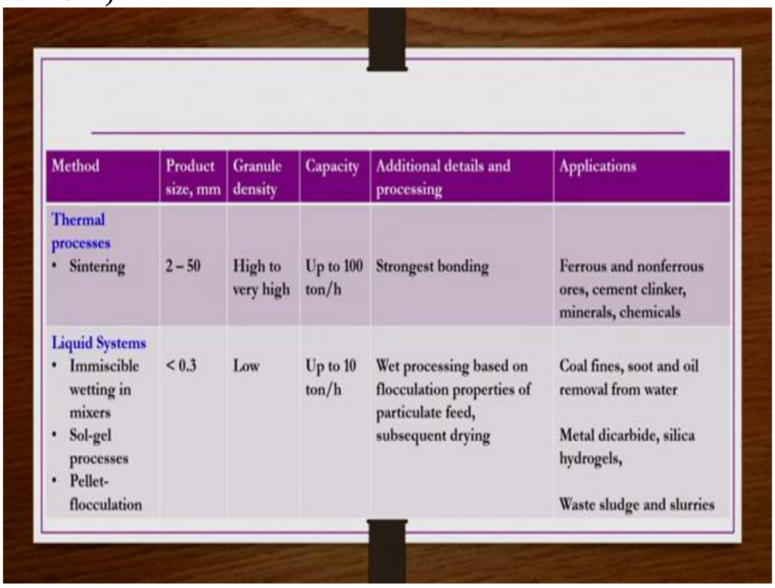
The next method of size enlargement is the spraying method. Under the spraying methods, we have spray drying and then prilling as well. Product size distribution by spray drying is between 0.5 to 0.2 mm. Whereas the prilling, the size distribution or the product size distribution in general 0.72 to 2 mm. Under the spray drying or by using spray drying, one can obtain low granule density but by using the prilling, the moderate density granules are in general obtained. Morphology of spray dried powders can vary widely and then in general same vessel can be used for the drying of these granules as well.

Coming to the applications, spray drying methods is in general used for instant products, something like instant foods, dyes, detergents, ceramics, pharmaceuticals. Whereas prilling methods in general used for urea and ammonium nitrate plants. The next method of size enlargement is the pressure compaction. There in general you know several types of pressure compaction is possible. Extrusion, roll press, tablet press, molding press, pellet mill. The product size by extrusion is in general more than 0.5 mm whereas the roll press produces the products of size greater than 1 mm, tablet press in general of size 10 mm. Right?

The density of the granules that are produced by pressure compaction is in general high to very high. Whereas the extrusion can handle the capacity up to 5 tons per hour whereas the roll press, 50 tons per hour and the other hand, the tablets or tablet press 1 ton per hour is their capacity. Because tablets, et cetera these kind of things are you know specified amount of materials, specified sizes are there after compaction, pressure compaction you know the product whatever you get, so in general you get very narrow product size because they are very spaced.

The compaction devices are very specified in size. So whatever the material comes in there and then get compressed and form as a kind of tablet or bricketing kind of things are there. So they are very specific in size. Very narrow size distribution one can get and they are very sensitive to powder flow and mechanical properties. Then often subsequent milling and blending operations are required under this kind of pressure compaction process. Applications: pharmaceuticals, catalysts, inorganic and organic chemicals production, plastic reforms, metal parts, ceramics, clays, minerals, animal feeds are some of the kind of applications where we can find the usage of such kind of pressure compaction.

(Refer Slide Time: 12:48)



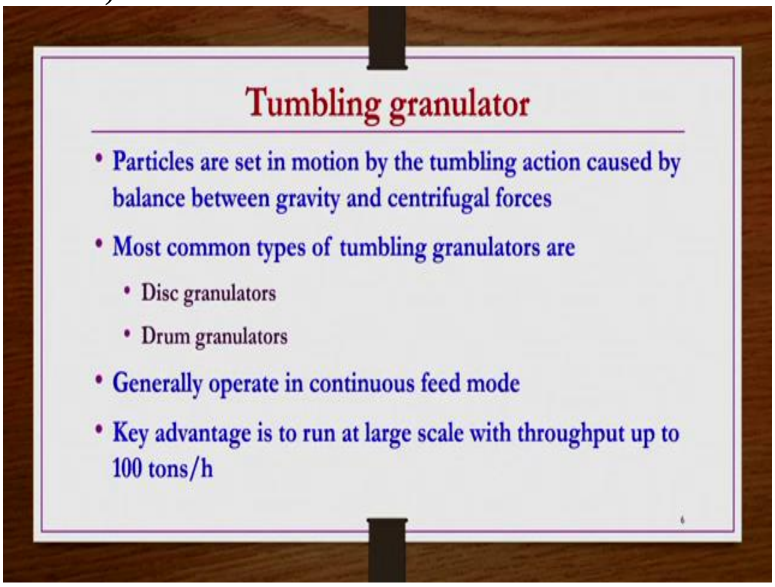
Method	Product size, mm	Granule density	Capacity	Additional details and processing	Applications
Thermal processes • Sintering	2 – 50	High to very high	Up to 100 ton/h	Strongest bonding	Ferrous and nonferrous ores, cement clinker, minerals, chemicals
Liquid Systems • Immiscible wetting in mixers • Sol-gel processes • Pellet-flocculation	< 0.3	Low	Up to 10 ton/h	Wet processing based on flocculation properties of particulate feed, subsequent drying	Coal fines, soot and oil removal from water Metal dicarbide, silica hydrogels, Waste sludge and slurries

Then next method of size enlargement is sintering which is a kind of thermal processes. The product size in general 2 to 50 mm, granule density in general high to very high. They can handle the capacity up to 100 tons per hour and then strongest bonding is the one of the primary feature of this sintering processes. Applications, in general we find in ferrous, nonferrous ores, cement clinkers, minerals and chemicals productions, et cetera. The last method of size enlargement is liquid systems where immiscible wetting in mixers or Sol gel processes, pellet flocculation are kind of a some type of you know size enlargement methods coming under liquid systems.

They produce the product less than 0.3 mm in general, granule density is low and then capacity is up to 10 ton per hour. The wet processing based on flocculation properties of particulate feeds, subsequent drying is taking place in general. The applications, we find by using these systems in coal fines, soot and oil removal from water, metal dicarbides, silica, hydrogels, waste sludge and slurries, et cetera. And processing from this kind of materials, we often may need some kind of liquid systems where this kind of size enlargement processes or methods are involved.

Now these are the size enlargement methods. Now we one by one we see some more details of our working process of this equipment.

(Refer Slide Time: 14:16)

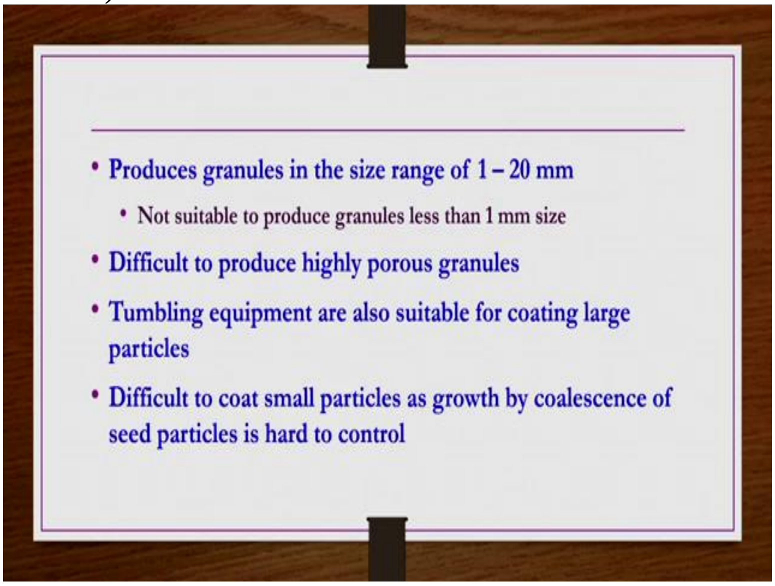


Let us start with tumbling granulators. In tumbling granulators particles are set in motion by the tumbling action caused by balance between the gravity and then centrifugal forces. So there will be a kind of vessel which will be rotating actually and which will be rotating. So when they are rotating, there will be a kind of some amount of centrifugal force and under the rotation the particles move up, so then after moving to the top they may fall down. Same as in ball mills or something like that. So their size reduction is taking place here, you know some additional binders are added together so that the fine particles are being granulated.

So both are centrifugal and then gravity forces may be acting. So accordingly, the optimum speed should be used. So those details we are going to see now. So in general, in this kind of tumbling granulator, this is what happens. The fine particles are set in motion by the tumbling action caused by balance between gravity and centrifugal forces. And most common types of tumbling granulators are two; disc granulators and drum granulators. Generally, they operate in continuous feed mode.

The most important advantage of this tumbling granulator that you know they can handle large scale, I mean they can run at large scale with throughput up to 100 tons per hour even more as well.

(Refer Slide Time: 15:35)

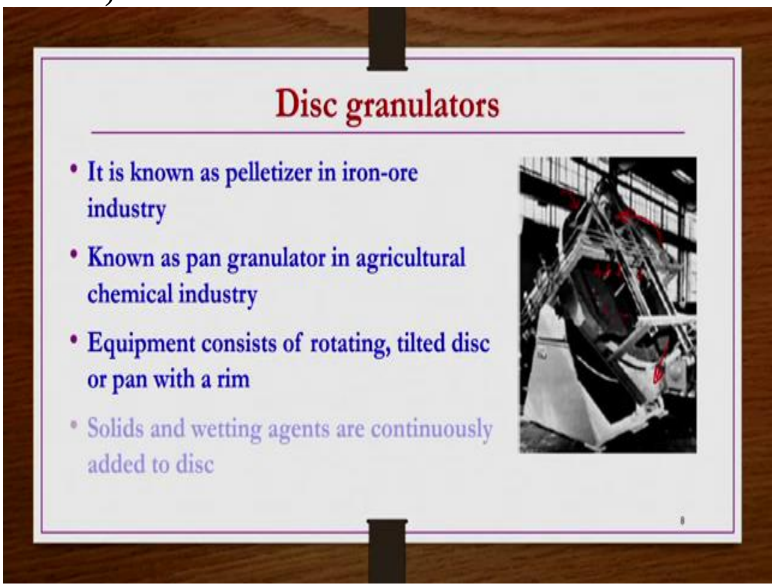


Further, they produces granules in the size range of 1 to 20 mm in general and they are not suitable for producing granules less than 1 mm size because there is no control of granulation process in general in this kind of tumbling granulators. They are very difficult to produce highly porous granules because in this continuous process or batch process, this spray drying of some solutions or binders would be done. So these you know, when these particles coming together because when they come in contact with the binders you know this whatever the interstitial spaces between the particles are there, those particles in general they occupy thoroughly, efficiently by these binding materials.

So because of that one, the porous structure, getting porous structure is a bit difficult by using these tumbling granulators. The tumbling equipment are also suitable for coating of large particles. First of all, they are not suitable for producing small sized particles from fines. They are suitable for producing larger size particles like up to 20 mm something like that. And in addition to that, they are also used for coating such large particles. However, as I already mentioned, first of all, they are not suitable for producing the smaller size particles and then it is not possible or very difficult to coat such small sized particles.

So difficult to coat small particles as growth by coalescence of seed particles is hard to control in tumbling granulators. In tumbling granulators controlling the consolidation process, coalescence and then granule formation and then consolidation of those granules is very difficult to control in general, that is the reason the product size that we get from this tumbling granulators is in general very large, up to 20 mm. 20 mm is a kind of you know large size, considered under large size particles.

(Refer Slide Time: 17:38)

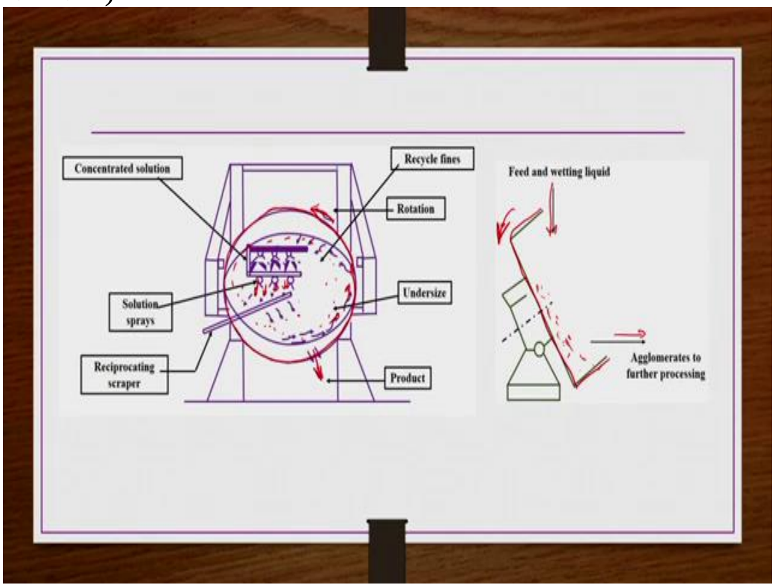


So now we start with the disc granulators. So one of industrial disc granulator is shown here. So here, this disc this circular disc whatever is there, that in general rotates onto which you know the particles are coming from here somewhere and then these are the kind of, from here some amount of liquids or binders are in general sprayed. So these particles whatever are coming here, so they will be mixed with this solution and then this rotates in a kind of direction like this, the granulator or disc granulator rotates in this direction. So the mixing of these particles and then binding solutions takes place.

And larger particles are in general taken as a product from somewhere here, whereas the undersized particles, now undersized particles are not the products. They are kind of a rejected material. So they will be sent back into the process after recycling so that you know they will be further granulated. So this is a general kind of process but this disc granulators we will be seeing the schematic of the same thing once again in the next slide. Right? These disc granulators have been given different names in different industries. Let us say it is known as the pelletizer in iron ore industry.

Whereas in agricultural chemical industry, it is known as the pan granulator. Equipment in general consists of rotating, tilted disc or pan with a rim. Whereas the solids and wetting agents are continuously fed or added to disc and then granulated products are taken continuously from the bottom of the disc.

(Refer Slide Time: 19:16)



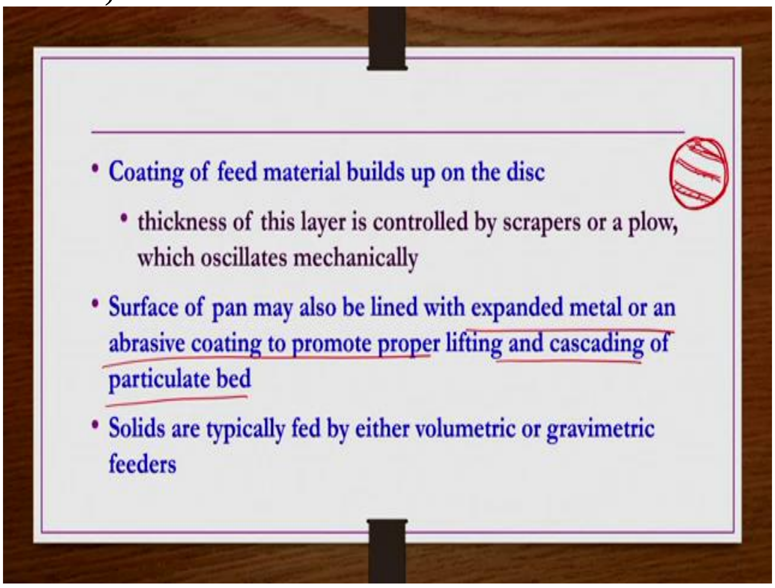
So schematic if you have, so let us say as the disc that I was mentioning, you know in the previous slide whatever the industrial scale or disc granulator is shown, that has been redrawn for our kind of clarity here. So there is a kind of disc kind of thing is there, so which will be rotating in this particular direction like this, okay. So there is a kind of concentrated solution chamber is there or bins or continuous are there at the top. So they can spray the solutions continuously. Right?

So the particles are also coming continuously here. Right? So these particles whatever are there, continuously fed particles you know they mix with the kind of you know solutions or binders that we have been used. Once the particles of sufficiently large size are there, product size are there, you know they can be taken as a kind of product from here at the bottom. Whereas the undersized particles or rejected particles, they will be taken to the recycles and then from the recycle bins, they will be again added to the process and then this process continues until the desired degree of size enlargement taking place.

So there is a kind of scrapper which controls the, which is useful in controlling the size of the granulator as well as you know whatever the solution being added. So those controlling can be done or the size classification can be done by this reciprocating scrapper which is moving mechanically. Now the frontal view of the same equipment if you see, so this is a kind of disc here we are having. The feed and then the wetting liquid is coming continuously here. So here this disc rotates something like this and this let us say in this direction, it may rotate the other direction also.

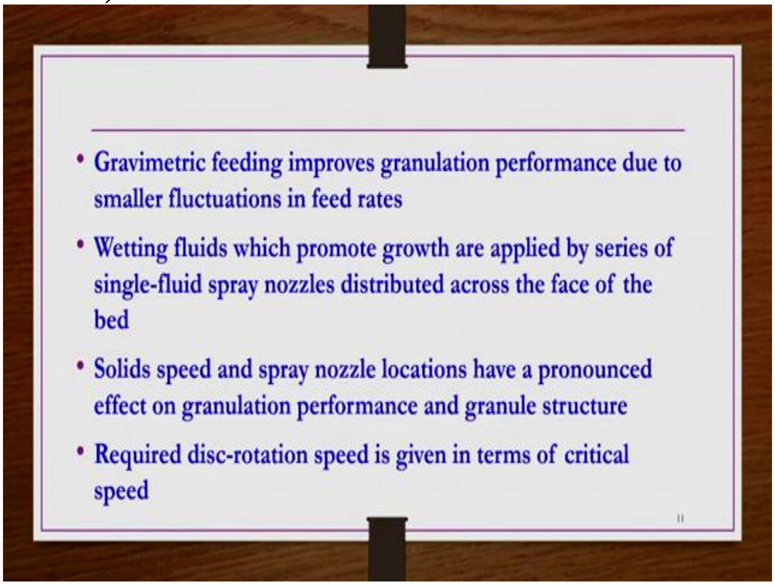
So when it rotates, then whatever the feed in the sense, small size particles, right? So they will be mixed with the binders and then as a kind of enlargement will take place and then agglomerated or enlarged particles will be collected from here for the further processing if at all required or if it is last stage then they will be collected as a kind of product. In general, they are taken to the further processing because they have to be dried as well. So this is what about the disc granulator.

(Refer Slide Time: 21:39)



So what happens here? Whatever the coating of feed material is there that builds up on the disc. Thickness of this layer is controlled by the scrapers or a plow which oscillates mechanically. Surfaces of pan may also be lined with expanded metal or an abrasive coating to promote proper lifting and cascading of particulate bed. So on the pan, we have in general so let us say this is the pan, so there will be a kind of a metal lining or kind of cascading kind of things are available or provided so that you know this proper to coat the proper lifting and then cascading of the particulate bed, et cetera that is possible or that would be enhanced because of this cascading metal lines. Solids are typically fed by either volumetric or gravimetric feeders. So both way they are possible.

(Refer Slide Time: 22:39)



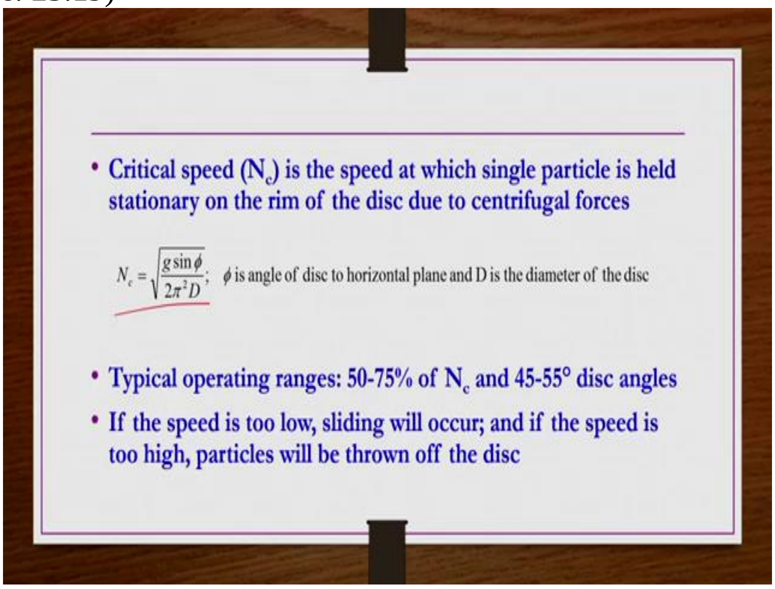
However, the gravimetric feeding improves the granulation performance due to smaller fluctuations in feed rates. Wetting fluids which promote growth are applied by series of single fluid spray nozzles distributed across the face of the bed. And then solids speed, at what speed solids are entering and then location of spray nozzle locations, they are going to have a kind of a significant pronounced effect on granulation performance and granule structure because the feed should not be coming at a very slow rate so that the most of the binder is you know large amount of binder or solution is coming and then when they are mixing a kind of slurry is taking place rather than kind of a granulation is taking place. So that should not be there.

Similarly, solid should not come in at very fast rate. Otherwise without being granulated, particles may be leaving from the container, et cetera. And in spray nozzle location also, it should be such a way that most of the spray is coming into the contact with the incoming feed materials to the maximum possible level. So that is the reason, the speed at which solids entering and then location of the spray nozzle used for the spraying this binding material, et cetera, both of them are going to have a kind of very strong effect on the granulation performance and then granule structure that are being produced after the process.

Required disc rotation speed is given in terms of critical speed in general. There is a kind of critical speed for rotating this disc because if the speed is you know the rotation speed of disc if it is very small, what happens? The particles may be sliding over. Right? If the rotational speed of the disc is very very large, then maybe particle thrown out of the disc. So both of them are not required. So that is the reason, there should be a kind of a critical speed for rotation for this disc granulators. The disc should be rotate below that critical speed only.

So how do you get that critical speed of that particular process in general? When you equate the forces on the disc granulator, because of the centrifugation and because of the gravity whatever 2 forces are there, if you equate them and then simplify those equations then you can get a kind of equation for the speed of the granulator. So that speed of the granulator, rotational speed of the granulator is known as the kind of critical speed. So that is the speed at which the centrifugal force is balanced by the gravity force.

(Refer Slide Time: 25:19)

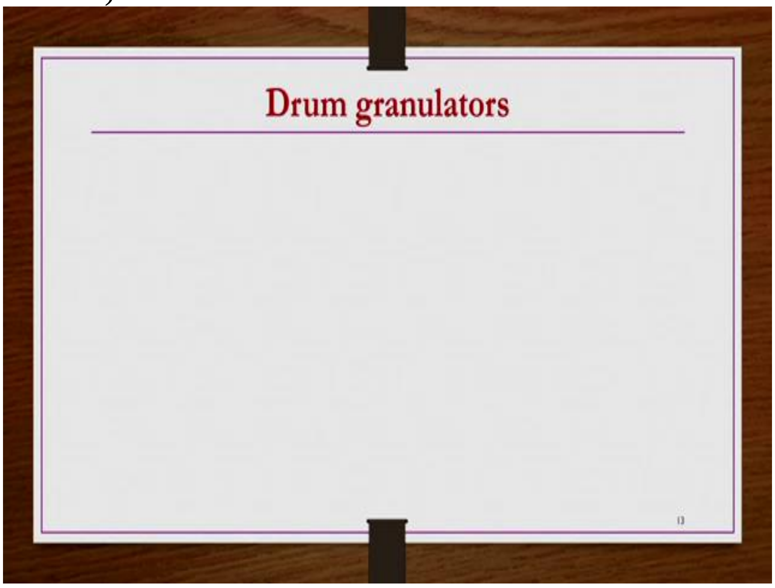


And then that equation we can see here. $N_c = \sqrt{\frac{g sin\emptyset}{2\pi^2 D}}$ where π is angle of disc horizontal to the plane because we know this, these disc granulators are in general not on flat, so they are making some kind of angle when they are you know mounted on a horizontal surface that what at what angle they are mounted, that is you know known as the that angle of disc to horizontal plane and D is nothing but the diameter of the disc. So in general, typical operating ranges for disc granulators is 50 to 75% of critical speed and the disc angle should not be more than 45 to 50º.

If the speed is too low, as I mentioned, sliding of the particle will occur and then if the speed is too high, then particles will be thrown off the disc in general as well as I already mentioned. So that is the reason we need to have a kind of proper speed or critical speed, so that should not be too smaller than the requirement, that should not be too larger than that critical speed. Otherwise you know, if that is too smaller than the critical speed, what will happen? The particles may slide over, okay, sliding of the particles may take place.

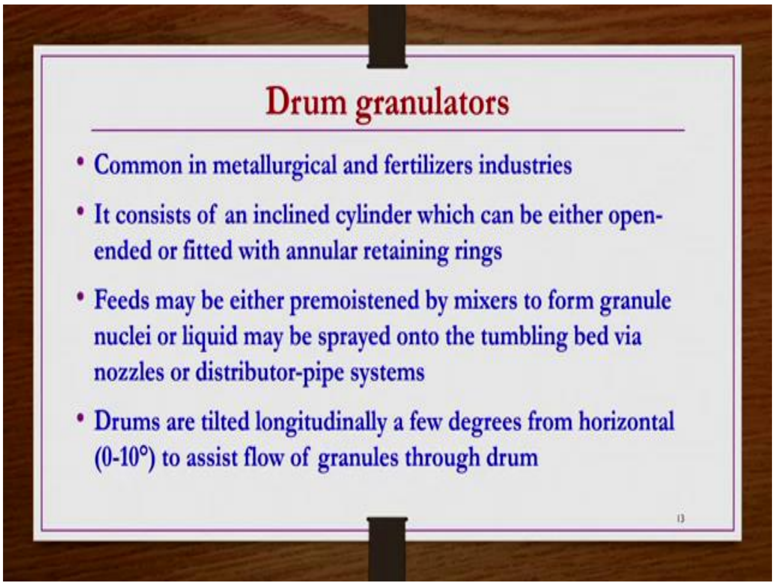
If the speed is larger than the critical speed, then centrifugal forces may strong dominating and then particles may be thrown out of the disc. So both of them are not required. They are not good for the efficient operation of such kind of processes.

(Refer Slide Time: 26:55)



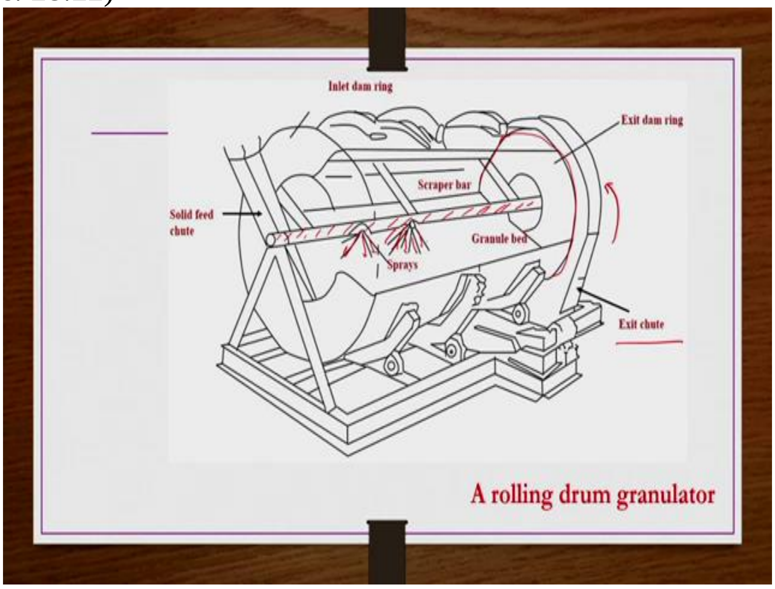
Next one are the drum granulators. The mechanism, physics is almost similar to whatever we have the disc granulator. But here, the difference primarily is that we have a kind of cylindrical vessel. There in the disc granulator, we have a disc, rotating disc onto which the feed and wetting fluid is coming. Now here we have a cylindrical drum kind of thing in which the feed material as well as the binding solutions are fed according to the required flow rates et cetera and then the cylindrical drum is rotating so that the granulation takes place.

(Refer Slide Time: 27:38)



So we will see some details of these drum granulators as well now. They are very common in metallurgical and fertilizers industries. It consists of an inclined cylinder which can be either open ended or fitted with annular retaining rings. There are different rings are possible. We will be seeing that schematic. So that will enhance the degree of granulation in general. Feeds may be either pre-moistened or premixed by the you know binding material by which we are going to form the granule nuclei or liquid may be sprayed onto the tumbling bed via nozzles or distributor pipe system. Drums are tilted longitudinally a few degrees from horizontal, 0º to 10º to assist flow of granules through drum in general.

(Refer Slide Time: 28:22)



So a schematic of a rolling drum granulator is shown here. So we can see, so this is a kind of a cylindrical drum. So two ends of this cylindrical drum is shown here, something like this.

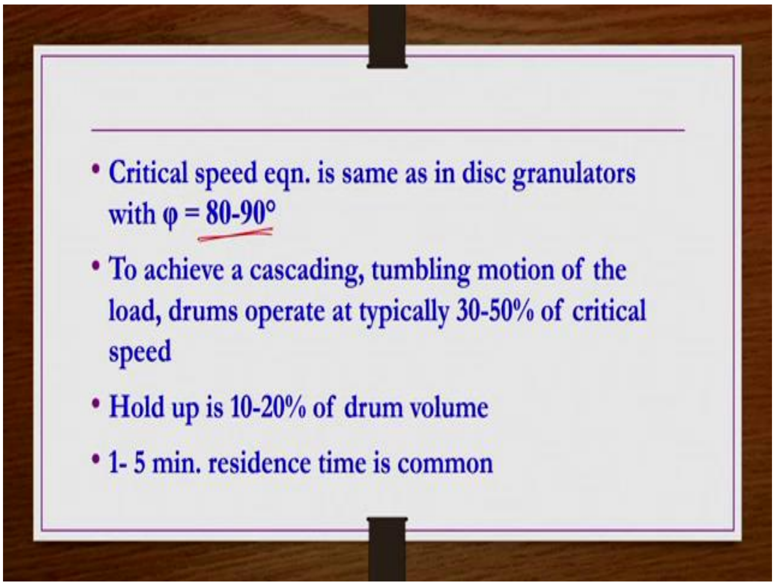
They are connected some you know like this. So they are having their kind of rings, whatever the internal rings they have mentioned. So they are kind of rings are also possible.

So the material comes through here, so the material, solid feed comes through the shoot from here and then there is a distributor pipe system through which this liquid is being sprayed or the liquid or the binder which is used for agglomeration here, so they are sprayed here through this distribution pipes like this. So you know when the particles comes here and then interact with the sprays and then this rotates, this rotates this drums rotates in either of the direction it is possible. Let us say that rotates in this particular direction, then you know mixing of these binders and then fine particles will take place and then these fine particles will form a kind of nuclei granules, so these granule nuclei further coalesce and then form a kind of a bigger sized particles.

That process takes place inside the drum. When this drum rotates drum is already having the feed, solid feed that is coming continuously and then binding solution is continuously sprayed onto that particle. So they are mixed and then kind of a granule, required granules are formed inside the cylinder. So these small particles are inside this cylinder, they are kind of rings are available, or kind of fractionators are available. So the particles you know moves from one level to the other level and then whatever the particles, the product are there, they are taken from this exit chutes here.

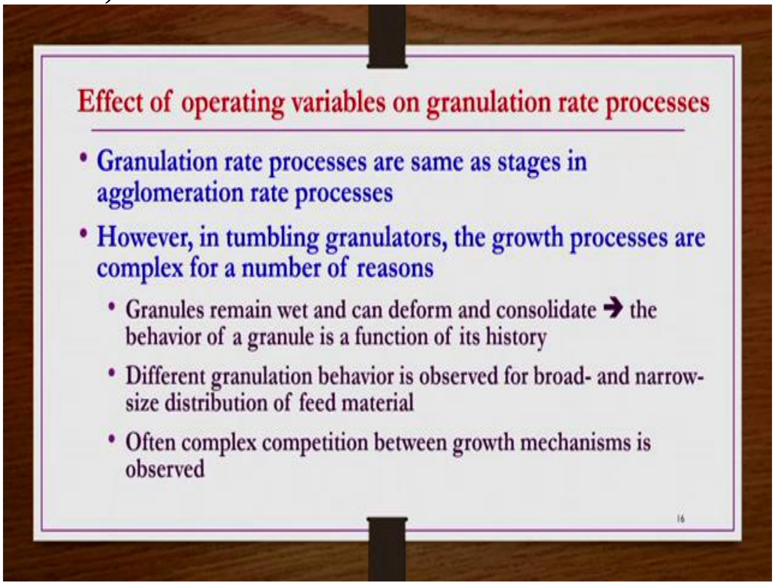
Whereas this particular you know whatever shown here, this is known as a kind of exit dam ring. Like that, several rings are there in between. So this is in general the way how the rolling drum granulator operates. The working principle, working process looks similar but its design and all that is going to be properly managed in order to have a proper granulation. So in this drum granulators, there is also a kind of scrapper bar which is going to control the granulation process or the amount of liquid coming and then amount of the solid feed that is you know those kind of things are being used, controlled by the scrapper bar.

(Refer Slide Time: 31:07)



So critical speed equation for this drum granulator is exactly same as the disc granulator but Ø should be between 80 to 90 because they are slightly inclined or longitudinally oriented slightly from the horizontal. So that slide degree is only up to 10º only. So that is the reason pi has to be 80 to 90 degrees. And then to achieve a cascading, tumbling motion of the load drums operate typically 30 to 50% of the critical speed. Whereas the hold-up is up to 10 to 20 percent of the drum volume. And then 1 to 5 minutes residence time is common and sufficient in general in order to fulfil a kind of a granulation operation in drum granulators.

(Refer Slide Time: 32:07)



Now effect of operating variables on granulation rate processes, especially for this tumbling granulators, et cetera, that we are going to see now here. So in general, this granulation rate processes are same as stages in agglomeration rate processes that we have already discussed. However in tumbling granulators, the growth processes are complex for a number of reasons. Why they are complex? We see a few of the reasons. First of all, granules remain wet and then they can deform and consolidate. So what does it mean?

The behavior of a granule is a function of its history. So whether it is weight or deformed or consolidating, or you know how much it has been weight, all those kind of things are going to show a kind of influence on the final you know granulation process. Then different granulation behavior is observed for broader and narrower size distribution of the feed material. If the feed material is having very narrow size distribution, then different granulation behavior is seen. If the feed distribution is having very wide size distribution, then the granulation behavior is found to be very different from the other case of narrow feed size distribution.

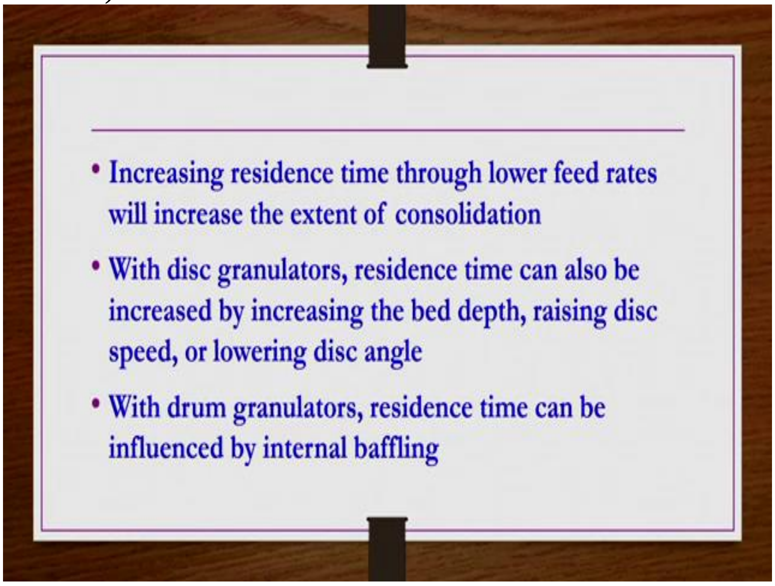
So this is another reason. And then often, growth mechanism competes, actually often complex competition between growth mechanisms have been observed. So that is the other reason. So because of these reasons, you know the growth processes are found to be a kind of a complex especially in this kind of tumbling granulators, that is disc and drum granulators.

(Refer Slide Time: 33:44)

Next, consolidation of granules, so consolidation of granules in tumbling granulators directly determines the granule density and porosity. Because there is no in situ drying to stop the consolidation process, here you know when we use the drum or disc granulator, the subsequent drying process in general has to be taken care by some other fluid bed or rotary kiln dryer kind of things one has to use. Because in situ drying of these granules is not possible in tumbling granulators because of that one consolidation process continues and it is very difficult to control. So that is the reason granules consolidate over extended times.

Further increasing size, speed and angle of drum and discs will further increase the rate of consolidation. So if you plan to have a kind of bigger sized equipment in order to, you can have a kind of larger capacity material, then it is also possible that by having such big equipments, you may be increasing the consolidation process. And then similarly, speed also if you go more than 50% of the critical speed, then again the consolidation may be severe problem and then angle of drum also you cannot have a larger angle drums, they should be you know up to 10 degrees from the horizontal. Otherwise, again consolidation will increase.

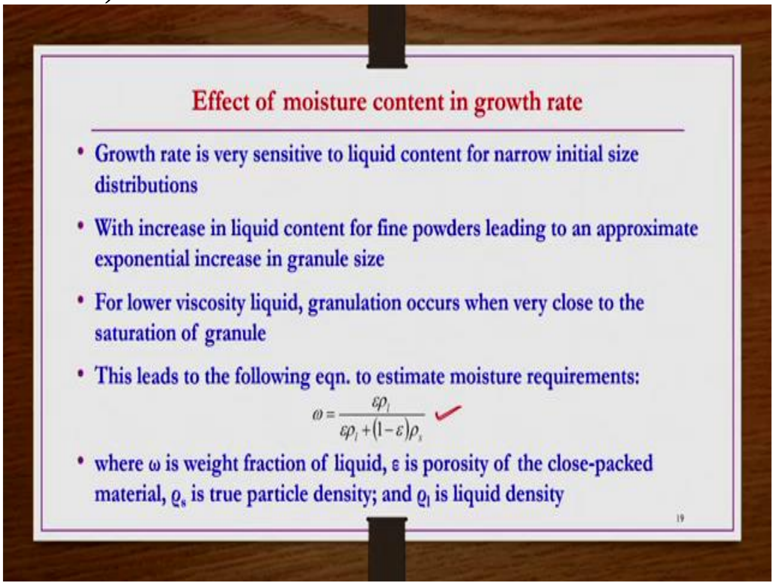
(Refer Slide Time: 35:17)



Further increasing time through lower feed rates will increase the extent of consolidation and then in the case of disc granulators, residence time can also be increased by increasing the bed depth, raising disc speed or lowering the disc angle. In the case of drum granulators, residence time can be influenced by the internal baffling. Internal baffling or baffles we can have like in general we have a kind of in mixers or the you know continuous mixing equipment where the reaction may also take place. So we in general what we do, in order to enhance the mixing we have a kind of baffles.

So such kind of baffles may be arranged inside the drum granulator. So when you have these baffles in the drum granulators, the residence time will again be increased.

(Refer Slide Time: 36:15)



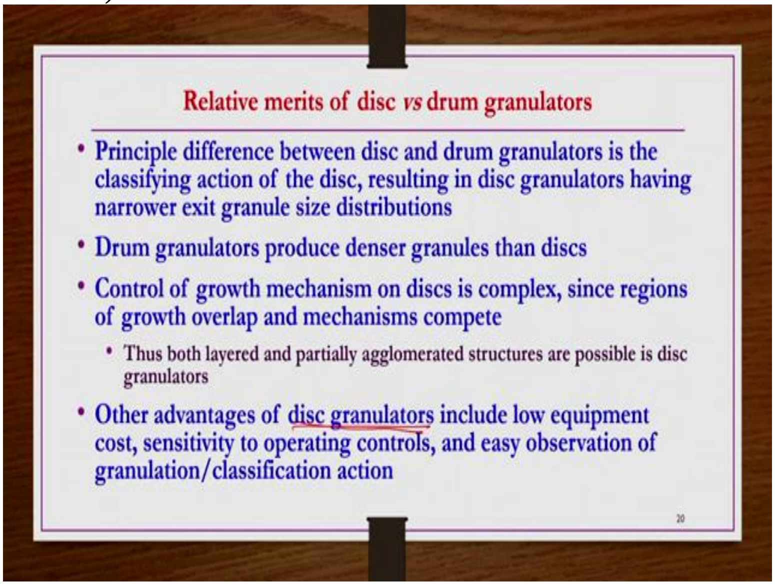
Next is effect of moisture content in growth rate. How much liquid should you give for a given fraction of material, solid material? So that is you know or for a given liquid density and for a given solid density, how much liquid should you use for a given operation or the granulation process is also a kind of a very important factor. So we will see first what are the effect of this moisture content and then we try to build up an equation for that moisture content. Growth rate or the size enlargement rate is in general very sensitive to liquid content for narrow initial size distributions.

With increase in liquid content for fine powders leading to an approximate exponential increase in granule size may take place. For lower viscosity liquid granulation occurs when very close to the saturation of the granule. This leads to the following equation to estimate the moisture requirement. ω is equals to epsilon $\frac{\epsilon\rho_l}{\epsilon\rho_l+(1-\varepsilon)\rho_S}$where ω is the weight fraction of the liquid, ρ_l is the liquid density, ρ_S is the particle density whereas epsilon is the porosity of the closed, packed material.

What is the porosity? That is the interstitial spaces whatever is there of the packed material before the granulation, so that is you know epsilon. So how much? Let us say you have the you know 100 kg of the feed material and then let us say you have the moderately viscous liquid whose density rho L is 1000 kg/m^3 and then true density of the fine particles that you are going to agglomerate, that let us say it is having 1600 kg/m^3 and then when initially when this particle is taken inside the granulating equipment, the porosity of that material or volume fraction of the interstitial space is epsilon, then using this equation, you can know what fraction of you know liquid should you use.

If this comes out to be let us say 0.2, that means 20% of liquid should be used based on the whatever the initial solids that you have taken. If you take more than that one, it may be a kind of a low slurry kind of thing material may form and then granulation may not take place. If you take very smaller than this quantity of the liquid, then again the proper granulation may not take place and then only partial granulation may take place. So that is the reason, the effect of moisture content is also going to have a kind of very strong role on the size enlargement growth rate. Now we see some relative merits and demerits of disc versus drum granulators.

(Refer Slide Time: 39:14)

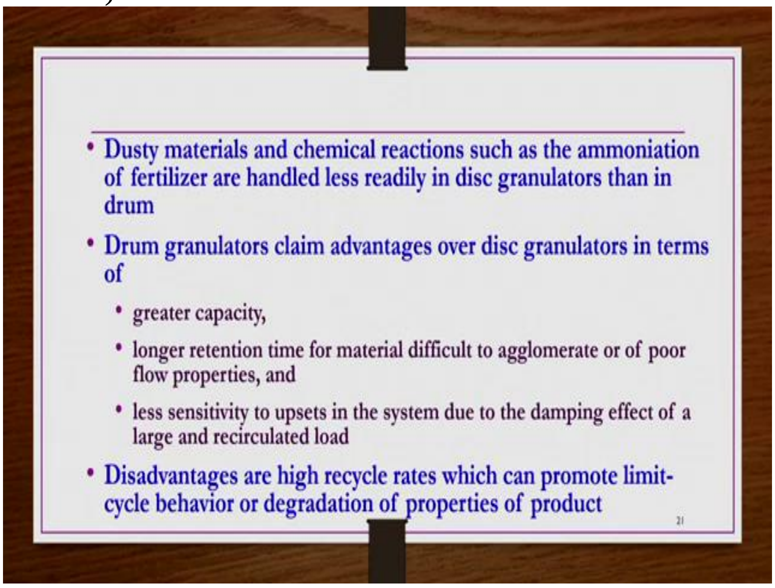


The principle difference between disk and drum granulators is the classifying action of the disc. The classifying action disc granulators are having a kind of classifying action that we have already seen. So because of that one, you know you can control the kind of narrow size distribution of the particle. That is products size distribution you can manage to very close particle size distribution. So because of this classifying action of the disc, one can get the disc granulators having narrower exit granule size distributions.

However, on the other hand, drum granulators produce denser granules than the discs. Control of growth mechanism on disc is very complex because regions of growth overlap and mechanisms in general compete each other. So because of that one, finding out the you know or controlling the growth mechanism on disc granulator is very difficult which we have already seen. So because of these regions of growth overlap and mechanisms competing each other, so both layered and then partially agglomerated structures are possible in disc granulators.

Rather than having a kind of proper complete granules you may get layering of the particles or partially agglomerated structures you may get. However, disc granulator is having several advantages which include that it is a low equipment cost. The equipment cost is very low and sensitivity to operating is under control. One can easily control and then easy observation of granulation and classification action. So one easily observe the granulation process as well as the classification process so that you know if anything goes wrong, one can make a kind of a necessary remedy or a necessary action immediately one can take.

(Refer Slide Time: 41:14)



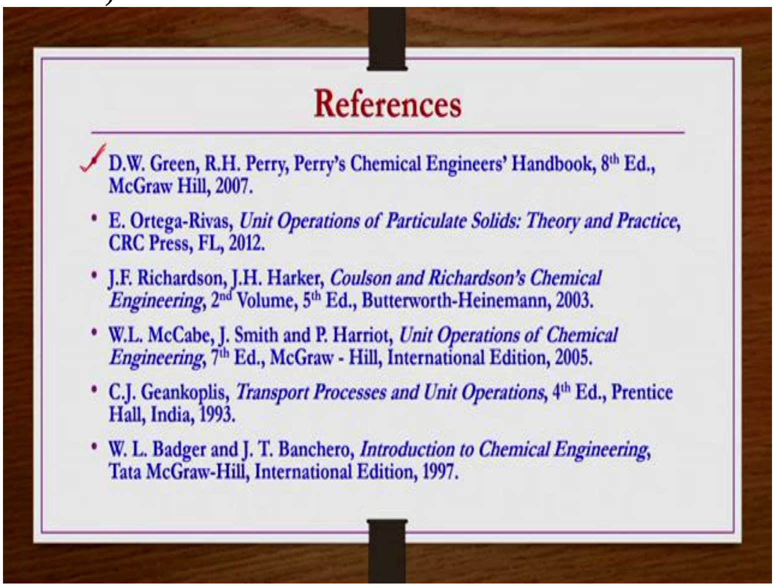
Dusty materials and chemical reactions such as the ammoniation of fertilizer are handled less readily in the disc granulators which is a kind of a disadvantage because in general, these disc granulators may not be completely closed in general. They may be sometimes open also. So because of that reason, so dusty materials and then chemical reactions like you know in fertilizers industries whatever takes place, where granulation is also kind of important process, it is not advisable to use these disc granulators. In such cases, it is better to use drum granulators.

Drum granulators having several advantages over disc granulators. Something like you know the capacity is very high in the case of drum granulators and then longer retention time for material difficult to agglomerate. It is not necessary that you know when we mix the material, binding liquid and then fine particles or feed you just mix and then rotate the drum. So then granule will take place. It is not like that. Some materials are in general very tough, very difficult to agglomerate.

So under such conditions, you need to have a kind of longer residence time of this feed material as well as the binding material. So that agglomeration properly takes place. So that, that can be easily done using the drum granulators or sometimes overflow properties are there, so then also for such kind of materials also, this drum granulators are better. And then materials less sensitivity to upsets in the system due to damping effect of a large and recirculated load that is the other advantage.

However, drum granulator is also having some kind of disadvantages such as high recycle rates which can promote limit cycle behavior or degradation of properties of product may take place because of this. So these are the kind of some disadvantage of drum granulator. So, both of them are having some kind of advantages or disadvantages. So based on the applications or requirement, you know one has to make a kind of a selection whether should one go for a disc granulator or should go for a drum granulator. So blindly one cannot go for any type of a granulator.

(Refer Slide Time: 43:39)



Finally, the references, the entire lecture indeed has been prepared from this reference book, Perry’s Chemical Engineer’s Handbook by Green and Perry. However, some details may also be find in this other book, Unit Operations Of Particulate Solids: Theory And Practice by Ortega and Rivas. Other reference books are Coulson and Richardson’s Chemical

Engineering series, 2nd Volume by Richardson and Harker. Then Unit Operations of Chemical Engineering by McCabe, Smith and Harriot, that can also be a good reference. And then Transport Processes and Unit Operations by Geankoplis. Finally, Introduction to Chemical Engineering by Badger and Banchero can also be a kind of good reference book for the lecture that has been you know presented, today's lecture. Thank you.