Mechanical Unit Operations
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Lecture No. 16
Size Enlargement Equipment - 2

Welcome to the MOOCS course mechanical unit operations. The title of this particular lecture is size enlargement equipment number 2. In the previous lecture we have seen different size enlargement methods under each method what type of equipments are available which are extensively used in the current industries and then what are their capacity advantages etc. those kind of things we have seen and also we have seen equipment under tumbling granulator category that is drum and disk granulators we have seen. We have also seen their relative merits and demerits etc. those details we have seen in the previous lecture of size enlargement equipment.

This is the second lecture on the size enlargement equipment, here in this particular lecture we will be discussing a few details about the mixer granulator and then spray drying, prilling, pressure compaction etc., under those categories what kind of equipment are available what are their merits on what the applications they are more suitable those kind of details we are going to see in this particular lecture.

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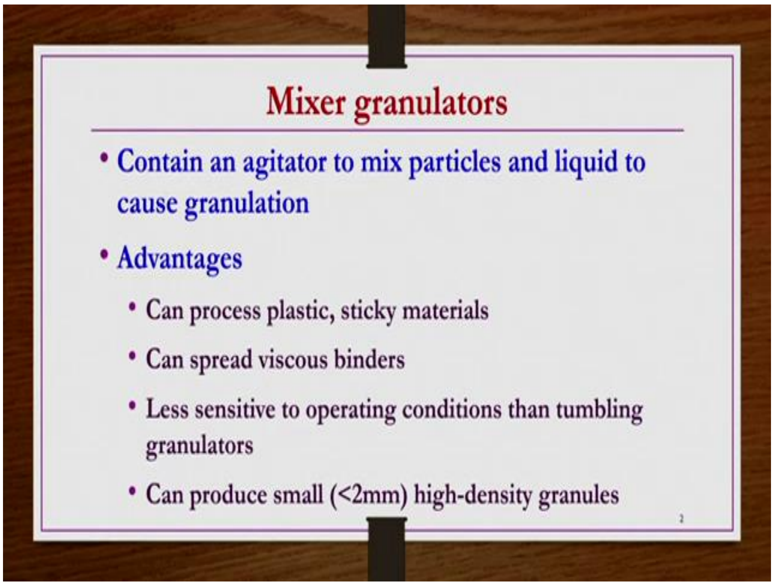

So let us start with mixer granulators in this lecture. In general, they contain an agitator to mix particles and liquid to cause a granulation whatever the binding liquid is there that and then the particles are taken in the kind of mixer and then agitation is caused, so that the mixing of the particles and then binding liquids will take place because of that one a kind of granulation will take place.

It has several advantages such as can process plastic and sticky materials which are in general little bit difficult in handling using the tumbling granulators but we can conveniently handle this kind of sticky materials and then plastic materials using the mixer granulators. Also the spreading of a viscous binders, in general liquid whatever the binders that we are using they are not very viscous in general. If they are viscous then the spreading is a kind of a problem.

So, that spreading of a viscous binder is not at all a problem in this mixer granulators they can conveniently easily even the viscous binders can spread easily so the granulation performance or degree of granulation can be better. And then the operating conditions are not very sensitive or the performance is not very sensitive to the operating conditions as we have seen like in a tumbling granulators the operating condition are to be properly manage so that to have a kind of proper granulation otherwise consolidation etc., may take place.

Those kind of details we have seen in tumbling granulators but however in this mixer granulators operating conditions are not very sensitive. So, consolidation etc., those kind of processes may not be very severe using this mixer granulators. And then they produce granules of size less than 2mm which are having high density. So, high density granules of appropriate size up to 2mm or less can be conveniently produced by this mixer granulators,

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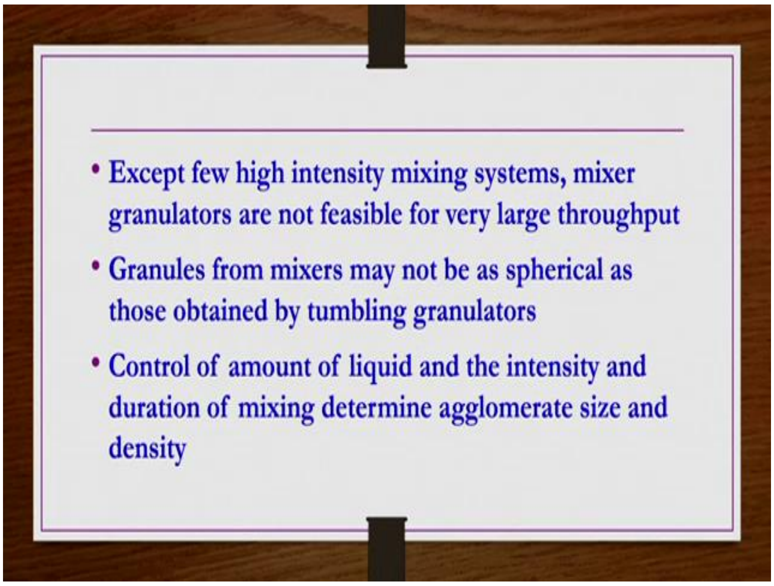

Coming to the throughput actually these mixer granulators are not good for a high throughput in general. The throughput is a kind of a medium moderate to low in general but however there are a few high intensity mixing systems where you can even achieve a kind of a high throughput as well but in general they are not suitable for a very large throughputs. Then the shape of the granules, the shape of the granules at we have seen by using tumbling granulators we get a very spherical granulators that is what we have already seen and discussed.

So, but such high degree of spherical granules are not possible to get by using this kind of a mixer granulators. So, granules from mixers or mixer granulators may not be as spherical as those obtained by tumbling granulators. Then the granulation performance using this mixer granulator or the granule size and then density of the granules can be controlled by the amount of the binding liquid that is being provided along with the intensity and then time of mixing. These three parameters are going to determine the agglomerate granule size and its density.

So, these three parameters the amount of the binding liquid then the intensity of the mixing and then time of the mixing is going to have a kind of a important role on the granule size as well as the density of the granules that has been obtained after the size enlargement by using this mixer granulators.

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Now, we see a few mixer granulators which are both low speed and high speed are there. So let us start with low speed mixer granulators, they are in general used for both batch and continuous applications that is their designs are available for both batch operations as well as the continuous operations. In general, these low speed mixers have a horizontal troughs in which rotates central shafts with attached mixing blades of bar rod or paddle etc. are main used actually.

So we will be going to see a kind of schematic also in the next slide how they are going to operate. In general, we have a kind of a horizontal trough which rotate with central shaft and then this whatever this shaft is the that is being attached to with some kind of mixing blades or knifes etc. the provided. So that the whatever the material is there that is being push through forward as well as to the center so that the both mixing and kneading kind of action can take efficiently.

So that is the general principle of this low speed horizontal mixers. Essentially these are kind of twin rotor mixers nothing but a just a twin rotor mixers. Then these vessels may be single or double trough design, so one can have either of the design but mostly people have a kind of double trough design. Then rotating blades carried forward the material and then bring it to the center to achieve a kind kneading and mixing action as the blades or the shafts rotates, so it is having the blades as it rotates so then material is carried forward from one direction to the other direction.

As well as while carrying forward from one direction to the other direction the material also moves through the center to the peripheral like that also, so that the mixing action takes place efficiently. However, because of their low throughput reasons in this kind of mixer granulators especially low speed mixer granulators are largely replaced by the tumbling granulators specially in metallurgical and fertilizer in the space. So, wherever the metallurgical and fertilizer applications whatever the previously I used the low speed mixer granulators are there, now a days they are being replaced by a kind of tumbling granulators because of the throughput concerns because you may not have a kind of high throughput using this mixer granulator. However, they are still used as a kind of premixing step for blending very different raw materials. Let us say if you have a kind of mixing you need to do and mixing has to be done between two very different type of materials.

Then the mixer granulators are found to be very efficient so, something like filter cake and then dry powder. One is the filter cake it is a kind of cake pastry kind of thing and then other one is a kind of a dry powder. These two are a kind of very different nature feed and then if you wanted to mix them together then this kind of mixer granulators are found to be kind of very efficient.

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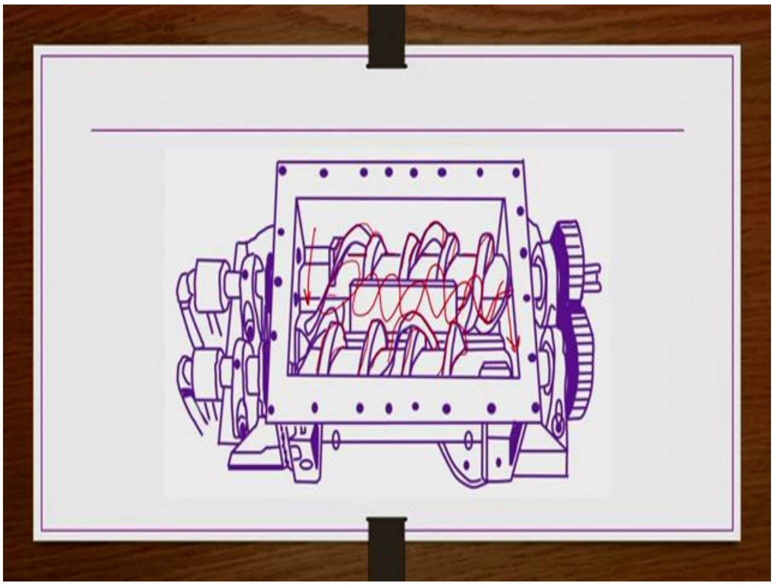

Now, we see a schematic of a typical low speed horizontal mixer granulators. So here we have a kind of shaft, this shaft there are actually two rotors 1 and 2 like this. So this shaft whatever is there on to this we have a kind of blades, so blades are something kind of this kind of blades etc. are provided. Something like this, so we can have a kind of this is a actually double trough design shown here so these blades are now like this material when let us say this is the this side is the material is coming in.

So, whatever the material comes in because it rotates in both of these are rotating, so then when rotates the blades, they carry forward this material like this. Like this they may take in this particular direction something like this, so it takes forward as well as it moves through the center so that in a kind of a efficient mixing can take place and then collected from the other end as a kind of product, this is the basic principle, very simple kind principle that is available but the problem with this kind of mixer granulator is the throughput is very less.

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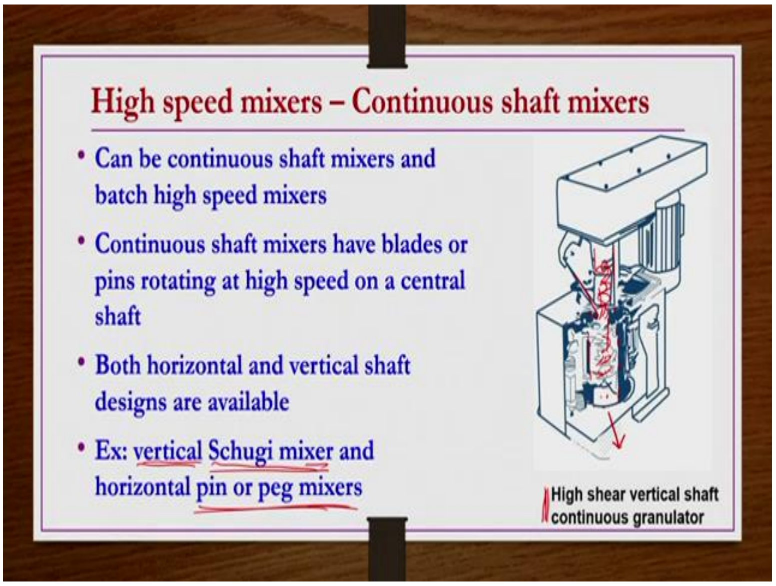

Then high speed mixers, they are also possible both continuous and then the batch mode. So, let us start with the continuous shaft mixers, these high speed mixers can be continuous shaft mixers or they can be a batch high speed mixers. So we will see both of them few details, so continuous shaft mixers have blades or pins rotating at high speed on a central shaft, both horizontal and vertical shaft designs are in general available within this continuous shaft mixers both in continuous as well as the batch shaft mixers two categories and within each category again we can have a kind of horizontal and vertical shaft designs are possible.

So we are going to see some of them, let us say Schugi mixer is kind of one of the famous mixer used in industries so that can have a kind of vertical configurations or vertical shaft design, and then there are a kind of pins or peg mixers kind of things are there. They can be a kind of a horizontal shafts designs. So let us say high shear vertical shaft continuous granulator if you see an example, it is a kind of a Schugi mixer that we are going to have here.

So here let us say this is a kind of container here, so in this container whatever the material is a that is being taken here, so this material may come continuously from here, something like that and then they may be collected from the bottom as a kind of product, mean that this is not a kind of schematic it is a kind of cross section cut, this section we have of a kind of this Schugi mixer is shown here.

So in this what we have, we have the kind of vertical shaft something like this, so then there is a motor connected to this, this rotates when it rotates a like this, so a kind of mixing take place here, so whatever the solids you have and then binding liquid and that you have they undergo kind of very high shear why because very high shear because here the rotations in general very high.

So, because of the high rotational speed a kind of very high shear is generated and because of that high shearing, high mixing takes place here, in the case of I know continuous shaft vertical granulators so that is going to have a kind of in fact kind of performance final granulation degree.

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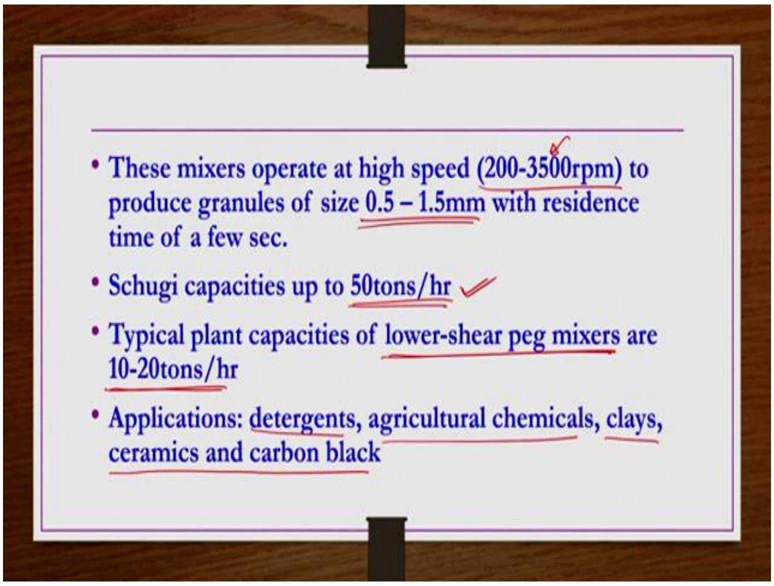

So, these mixers operate in general as I said at high speed 200 to 3500 rpm. So, in the control state you can operate it at lower speed also but, in general they are operated at the upper end, so more than 2000 rpm or something like that and then they produce granules between.0.5 to 1.5mm within a few seconds of residence time within a few seconds of residence time. In general, the tumbling granulators also otherwise low speed mixer granulator that we have seen their residence time is in general in minutes 5 to 10 minutes or something like that.

But, because of the high shearing in this continuous shaft granulators the mixing takes place within a few seconds at however you cannot have a kind of larger size particles because that high shearing that may, because of the high shearing some amount of attrition may also takes place, so that will not allow the particle to grow bigger and bigger or consolidation to take place. So, that is the reason the particle size may be have only up to 0.5 to 1.5mm only.

Then its capacity is moderate 50 tons per hour. Then typical plant capacities of lower shear peg mixers that we have not seen the schematic so, they are even smaller capacity 10 to 20 tons/hour whereas the vertical shaft continuous granulator that we have seen in the previous slide, so that had up to 50 tons/hour kind of a capacity whereas the other lower shear peg mixers are having only 10 to 20 tons/hour capacity.

The applications we find these kind of continuous shaft and low shear granulators we find their applications in several industries where we produce detergents, agricultural chemicals, clays, ceramics and then carbon blacks are processed. So, these are the few applications that where we can see we can find application of these high shear continuous shaft granulators.

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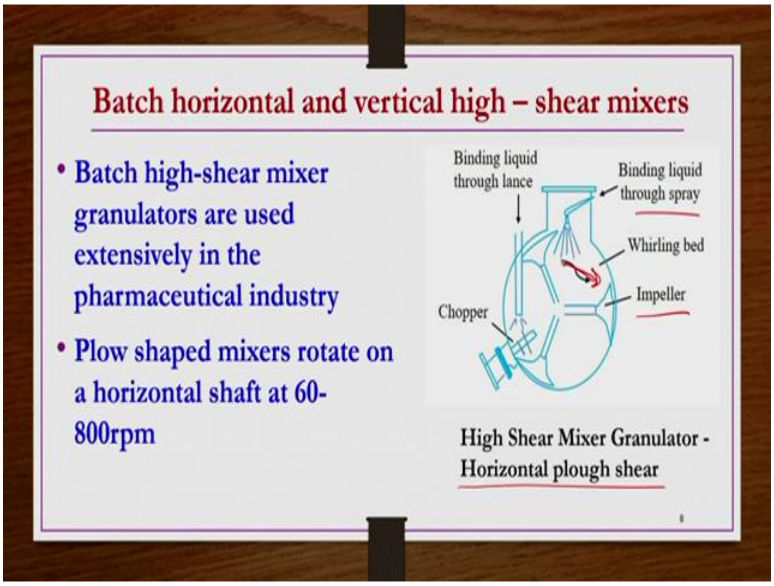

So now, we see batch high shear mixers or batch high shear granulators. So here we see both the horizontal and then vertical configurations. So, batch high shear mixer granulators are used extensively in pharmaceutical industries. In general plow shaped mixers rotate on a horizontal shaft at 60 to 800 rpm. So it is schematically if you see here, high shear mixer granulators horizontal plow shear, so here we have a container on which, it is a kind of batch more so, we have a container where we can take the liquid, binding liquid through two different sections if you want to spray you can take from here, otherwise you want to take the binding liquid through lance so that comes here.

So, inside this equipment there is a kind of a impeller so that impeller rotates because it is having a kind of a rotational you know provision inside. So, we are showing only a kind of (()) (15:23) a kind of thing. So that when it is rotates and then whatever the feed that you have taken along with the binding liquid that undergoes a kind of a continuous mixing under high shear, high shear because of that high shear mixing the granulation takes place so, this here also the process seems to be very simple of course this equipment we are not getting into the design concept.

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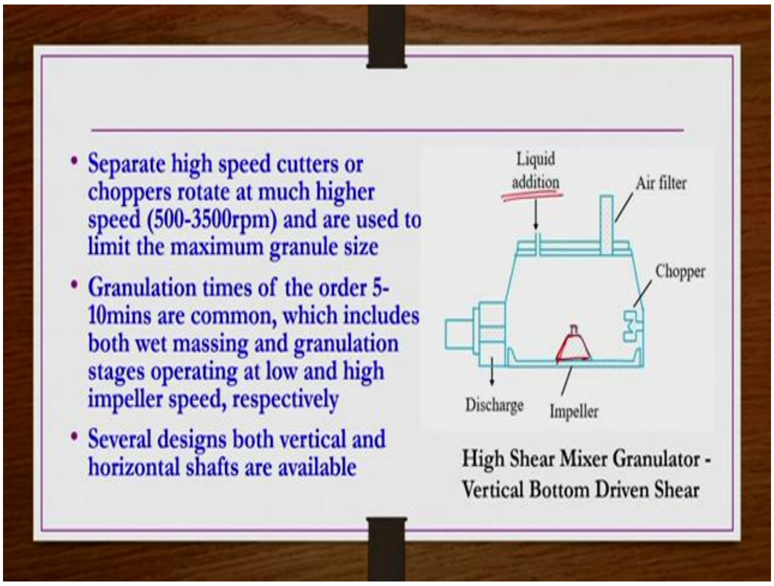

So, there are separate high speed cutters or choppers rotate at much higher speed between 500 to 3500 rpm and are used to limit the maximum granule size because of high shearing obviously you cannot expect to have a kind of a larger granule size so specially if you do not want very large granule size so, then it is better to go for these kind of equipment, if you want to have a kind of a larger granule, if you your requirement is okay to have a kind of a granule size between 2 to 20mm such wider range, then it is better to go for a kind of a tumbling granulators.

Granulation times of the order of 5 to 10 minutes are common and this kind of a batch of operations which includes wet massing and granulation stages operating at low and high impeller speed respectively. This time whatever 5 to 10 minutes is the that includes for all the operations like wetting of the feed material that has been taken by using the spray nozzles by using the binders through the spray nozzles etc. and then granulation all those processes completes in 5 to 10 minutes.

And of course there are several designs both vertical and horizontal shafts are available, so the previous figure we have seen the kind of a horizontal plow shear mixer, now we take vertical bottom driven shear, high shear mixer granulators vertical bottom driven shear, so here the only thing that we have a kind of container through which, to which the liquid is being added and there is air filter, chopper is also there in order to control the size of the granules and there is a discharge.

So here, what we said impeller is at the bottom, is at the bottom and then, this rotates in a kind of vertical direction so, vertical but so rotation, that rotation or the shearing whatever is being induced by their rotation that is at the bottom and it is in the vertical direction. A similar kind of this is one can have the impeller one can have on the top and then that is still kind of vertical shearing only but, the rotation whatever the rotation that is driven and all that the top so, that way also it possible that is what as mentioned previous slide there are several designs are available we have taken only two designs.

So where high shear mixer granulator both horizontal and then vertical driven shear we have seen, so like that one can as per the requirement one can choose this kind of designs are even modify the designs as per their requirements.

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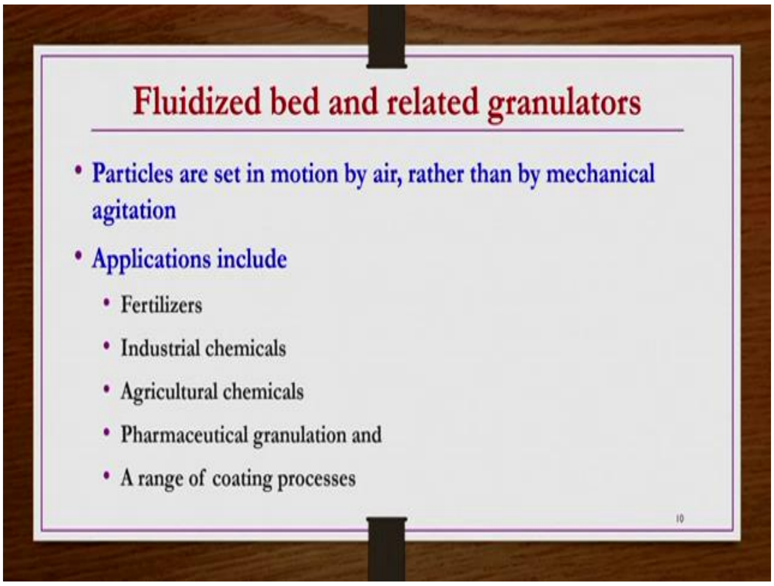

Then fluidized bed and related granulators is the other type of a granulators that we have seen so we see some details about then now, here in this kind of fluidized bed, the fluid bed granulators, the particles are set in motion by air rather than by using any kind of mechanical agitations, till now whether the tumbling granulators or the mechanical or the mixer granulator the agitation is being crossed because of the some kind of mechanical agitations, mechanical mills so the granulation is a kind of a agitation, the agglomeration because of the agitative action.

So then we call them granulator and then those agitative action till now, whether it is tumbling bed or mixer granulator so those have been caused because of using some kind of a mechanical means. Now in the fluid bed granulators, the required the particle motion whatever it is required that is being done by using a kind of a dehumidified air or air mixed with nitrogen as per the application something like that.

They have a several applications which include like in fertilizers, some they are used in fertilizer industries and then several types of industrial chemicals and number of industrial chemicals productions so their also be used this fluid bed granulators, agricultural chemicals productions also be used a fluid bed granulators, for the size enlargement of agricultural chemicals likewise a pharmaceuticals also if you want to do a kind of a granulation of pharmaceutical then also this fluid bed granulators are in general used.

And then also they are used for the coating purposes also not only just for the size enlargement or the not only just agglomeration or granulation they are also used for the kind of a coating of a few fine particles.

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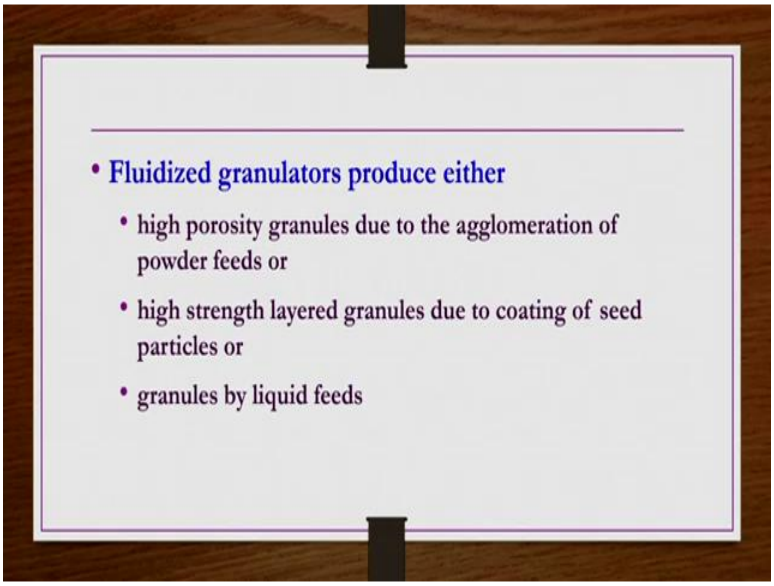

Further these fluidized granulators produced either high porosity granules due to the agglomeration of powder feeds and then high strength layered granules due to coating of seed particles and then granules by liquid feeds. High porosity granules you in general get because these particles are set in motion by the air so, whatever the liquid is spraying liquid is coming in interacting with the particles so, we are going to see this schematic in the next slide any way.

So, the particles mixing with the liquid so, whatever the interstitial spaces are there between the particles that are being occupied by the binding liquid in general in tumbling granulators so, there you don't get porous granules in general but, here in this kind of a fluid bed granulation now, particles are set in motion by the air so, whatever the interstitial spaces is there, that is now being completely covered by the binding liquid because these particles are in motion and in the kind of very random motion, you cannot define a kind of a particular motion specially fluid bed is under kind of turbulent conditions.

So because of that one the particles size will also be less or though enlargements will be taken place but, still the particles size would be less than 1.5 mm or something like that, so that is the reason if you want to have a kind of a high porosity granules then it is better to go for fluid bed granulators if you want to have a low porosity or almost without any porous structure granules if you want produce by size enlargement then, better to go by tumbling granulators.

Similarly, the strength if you are using the fluid bed granulators then after coating, if you are coating, if you are using it for the coating of defect material then the strength of the particles are also found to be strong, because within this process there is also provision kind of partial kind of thing is, in the next slide we have a figure that represents a typical production size batch fluid bed granulator.

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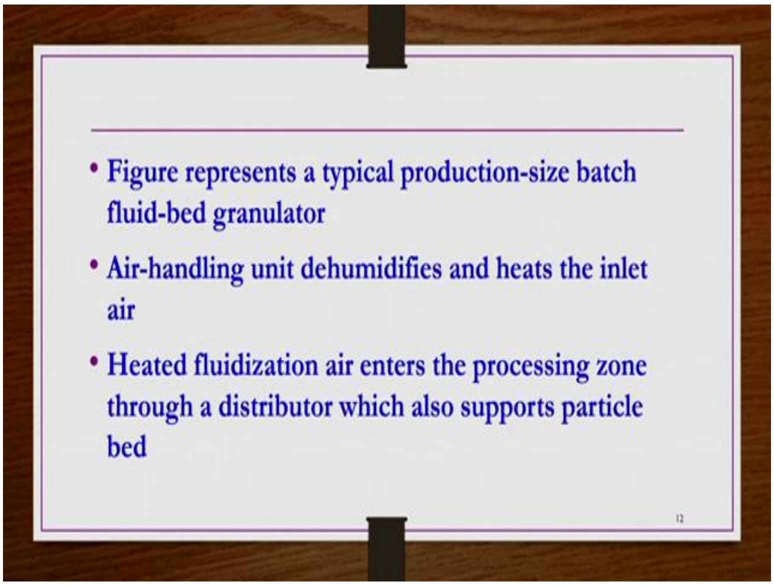

So it is having air handling unit which dehumidifies and then heats the inlet air then heated fluidization air enters the processing zone through a distributer which also supports the particle bed.

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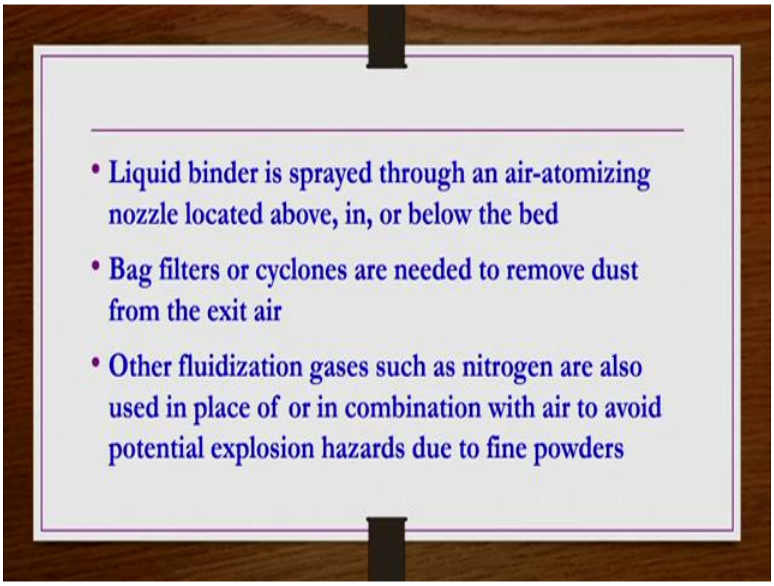

Then, liquid binder is sprayed through an air atomizing nozzle located above in or below the bed all the possibilities are there they all form, three types of designs are available, bag filters or cyclones are needed to remove dust from the exit air and then other fluidization gases such as nitrogen are also used in place of or in combination with air to avoid any potential explosion hazards due to fine powders as per the requirement if it all required.

Why, because sometimes some particles if you are using air so some particles explosive and then there is a kind of a heating is also involved then, kind of a reaction may take place with the oxygen present in the air and the in some cases explosion may take place under such condition so it is better to go for the nitrogen or fluidizing medium should be nitrogen or nitrogen mixed with air or something like that one has to see so that to avoid these explosions.

That depends on the nature of the chemicals that are being processed in fluid bed granulator for their size enlargement. It is not necessarily true for all the materials it depends on some of the, some type of the fine powders.

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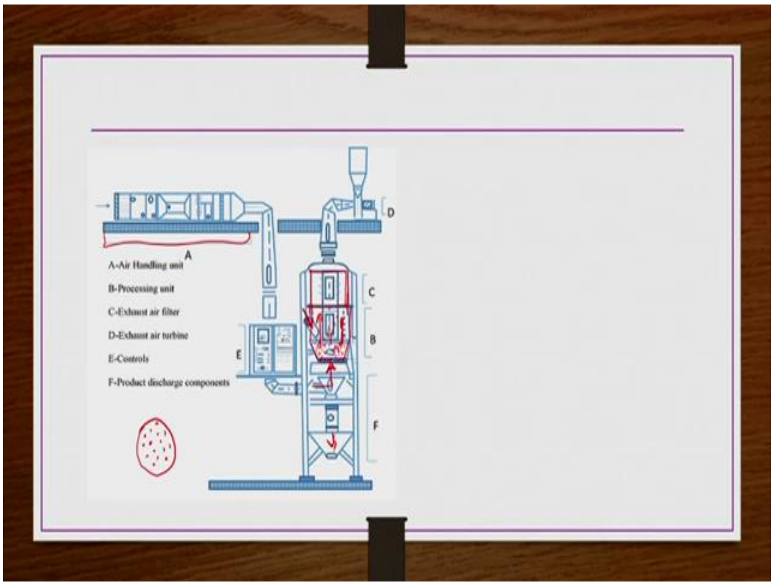

So the schematics as already stated here, we have a kind of a dehumidifying section here, so actually this air handling unit entirely. What it does, it does a kind of a dehumidification of the air and then heats the inlet air if it requires and then that air comes through this processing section so, actually this entire section is a kind of processing section here, of course it is all single section only in probably here we have the we can have something like this.

So this is the distributer here, this distributer also supports the bed of the particles so the opening of the distributor, distributing plate let us say. Let us say there is a distributer plate like this, so it may be having the perforated holes like this, it is a perforated and it will be having holes like this, and then this perforation or the size of the holes depends on the size of the particles that you are handling.

So, they should be much smaller that the size of the particles whatever the fine particles that are we are using otherwise that particles may come down here. Because now through this holes if the fluidization air will last here, fluidizing medium will last here so not sufficient. So that is the reason should be having the very small size opening smaller than the fine particles which are going to handle.

So the air comes in here something like this, and then it whatever the bed the particle bed is here, so it causes a kind of lifting, lifting of the particles because slowly when the air comes in at certain stage the whatever the drag that is there on the particles that is balanced by the weight of the particles so then after that further if you increase velocity particles start getting into the fluidized condition, they start floating that is fluidized condition will prevail and then particles will move out like this.

So, they will be spreaded so inside initially when the bed is the porosity the what space between the particles is very small, voidage is small so now, when the air comes in that lifts the particles in gradually as this the velocity of the air or the fluidization medium increases the particles are being lifted so the space between the particles increases so the void is increases.

Now, here there is kind of a nozzles, spray nozzles so that spray the a liquid continuously here so, here it is shown in the top, it can be at the bottom, it can be inside also it is possible so, when this liquid comes, then particles are being fluidized so, these are interacting, that is the particles fluidized particles and then liquid, binding liquids are interacting, granulation takes place. The size enlargement takes place evenly coating also done does the similar way.

Then what happens here, it is not necessary that all particles will be agglomerating or all the particles being coated when you are trying to do this one so, some particles are still remains finer size, they may not be coming into the proper contact with the spraying liquid or what so ever may be the reason some particles maybe without being affected by this binders so, they may just come out they may be floating in this area so, this particular exhaust air filter area so here what they do whatever the particles are there, they will be taken to the cyclone separators or bag filters where this particles are separated, this particles are separated before that air is being sent out.

So, those particles again will be taken back and then continuous this process may be taken further like recycle, and then after the granulation process is over whatever the dried particles are there, a granulated grate particle are there, they will be collected through the product discharge region from here. So this is the typical straight forward similar operation that is fluidized bed whatever the fluidized bed that we have in general if you take a bed of fine particles and then you allow the air to pass through it so, that to see the fluidization so, you might have seen in the kind of fluid this fluid mechanics course or fluid particle mechanics course.

This fluidization to might have studied. So, the exactly the same process in exactly the same equipment but, here we have a kind of a provisional to spray the liquid also so, that the contact between this liquid and fluidized particles takes place and then, agglomeration may takes place as per the operating conditions, the degree of the agglomeration may be changing as per the operating conditions and all that.

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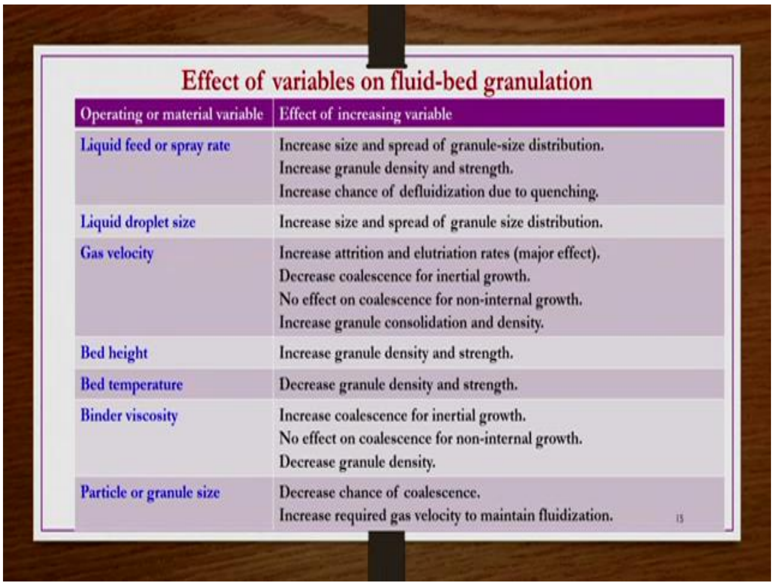

Effect of variables on fluid-bed granulation

Operating or material variable	Effect of increasing variable
Liquid feed or spray rate	Increase size and spread of granule-size distribution. Increase granule density and strength. Increase chance of defluidization due to quenching.
Liquid droplet size	Increase size and spread of granule size distribution.
Gas velocity	Increase attrition and elutriation rates (major effect). Decrease coalescence for inertial growth. No effect on coalescence for non-internal growth. Increase granule consolidation and density.
Bed height	Increase granule density and strength.
Bed temperature	Decrease granule density and strength.
Binder viscosity	Increase coalescence for inertial growth. No effect on coalescence for non-internal growth. Decrease granule density.
Particle or granule size	Decrease chance of coalescence. Increase required gas velocity to maintain fluidization.

So now, the effect of variables on fluid bed granulation we will be seeing in, in the tabular problem so let see we have a different operating material variables then what is the effect of increasing variable so, let us say if you consider liquid feed or spray rate then increase size and spread of granule size distribution then increase granule density and strength then increase chance of defluidization due to quenching then liquid droplet size when you are spraying this liquids required for granulation they form a kind of a droplets, the size of droplet depends on the opening of the nozzle opening of the sprayer or atomization that be used for the spraying.

And then the rheology specially viscosity of the liquid so, if you take higher viscosity liquid in general it is possible that you may get the bigger droplet from the same size opening nozzle opening compare to be a kind of a if you compare with the kind of a low viscous liquid that is if we will take a low viscous liquid and then you take a high viscous liquid and then, you pass them through a nozzle of same size and then, high viscous liquid is going to form a kind of bigger droplet.

So let us see liquid droplet size then what will happen increase the size and sprayed of granule size distribution then gas velocity increase attrition and elutriation rates in general when you increase the gas velocity that causes increase the attrition elutriation rates also so, if the gas like that is nothing but the fluidizing medium air or nitrogen or mixture combination of these two when use so, if you use higher velocity the attrition being between the particles will take place that is very important factor.

Because of that one granulation may not take place rather granulation size reduction may take place so, that is the reason gas flow rate or the fluidizing medium flow rate should not be very high. Because the aim is here is the size enlargement not the size reduction. Attrition cause a kind of size reduction. It also decrease coalescence for internal growth and no effect on coalescence for non-internal growth and then cause increase granules consolidation and density as well.

Bed height if you increase granule density and strength as well they will be increased bed temperature if you increase, granule density and strength both will decrease, if we increase the binder viscosity or the viscosity of the liquid then, that increase coalescence for the internal growth and there will not be effect on coalescence for non-internal growth and then, that will be decreasing the granule density then coming to the particle or granule size if you increase it then, decrease chance of coalescence and then increase required gas velocity to maintain the fluidization, if the particle velocity is increases so then, you need to give the larger fluidization velocity.

So, that the particle can be fluid like conditions, like fluidized conditions so, these are the effect of variables on fluid bed granulation. Let us see all these variables we have in the left column that each column when it is increasing in this table these are shown in a kind of increasing order, in the left column whatever the operating variables or material variables are there. If you increase them, what kind of effect you see, that is shown in the kind of right column of the table.

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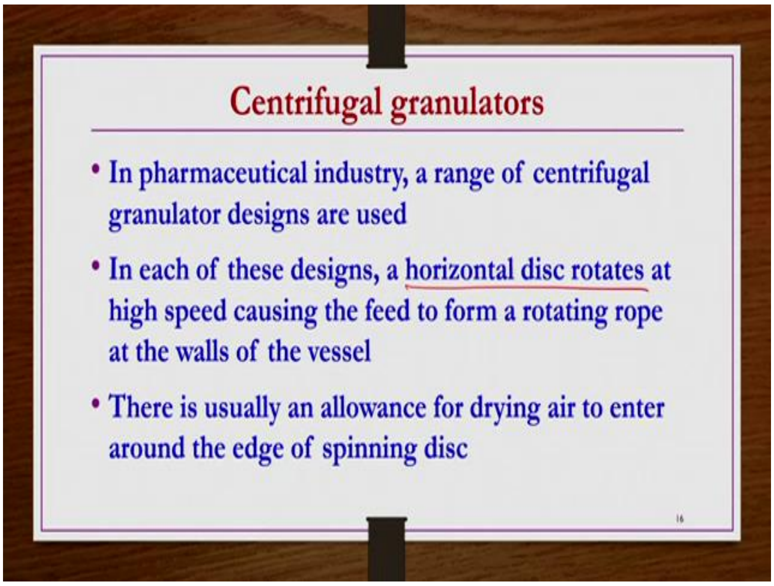

The, centrifugal granulators is the next category, they are extensively used in pharmaceuticals industry and then, each of this designs they have a horizontal disc which rotates at high speed causing the feed to form a kind of rotating rope at the walls of the vessel because of the centrifugation action, centrifugal forces so that we schematic we seen of any way, and there is usually an allowance for drying air to enter around the edge of spinning disc, so within this centrifugal granulators we can also have a kind of provision for the drying of the granules.

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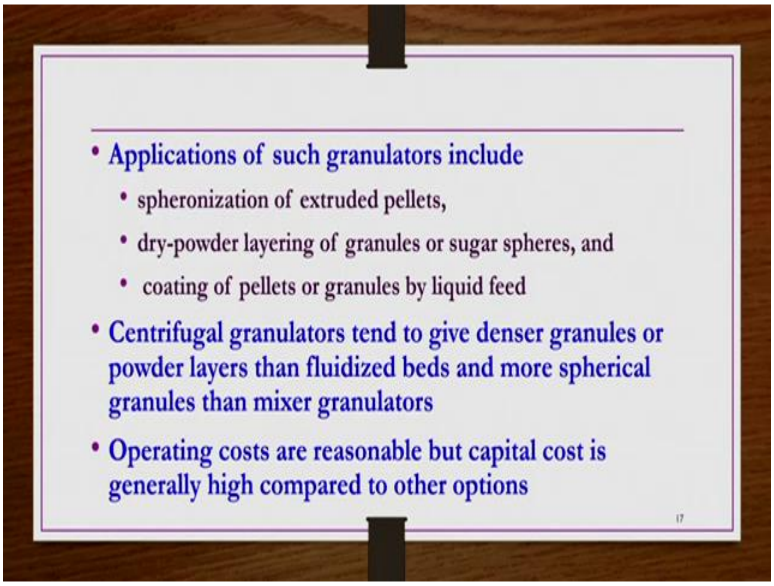

They are in general have the applications in spheronization of extruded pellets then dry powder a layering of granules or sugar spheres and then coating of pellets or granules by liquid feed. Centrifugal granulators tend to give denser granules or powder layers that fluidized bed and more spherical granules that mixer granulators. Tumbling granulators are the best one to produce very spherical granules after that the best one is centrifugal granulator if you wish to have a kind of spherical granules, that is they are better than a mixer granulator if you are willing to have a spherical granules.

But, not better than the tumbling granulators, of course the size ranges also very large in the tumbling granulators in general 2 to 20mm something like that. Further, operating cost are reasonable but capital cost in generally high compare to other options.

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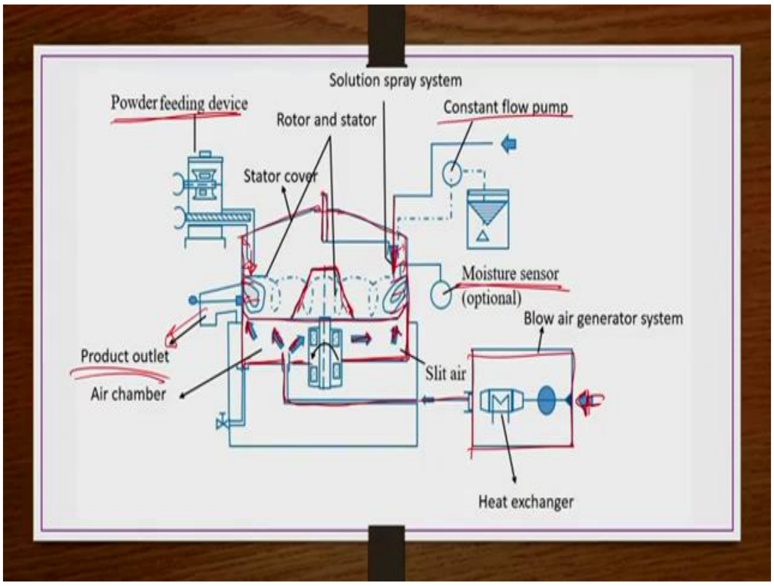

Now, we have schematic here, for a kind of a general centrifugal granulator we have a stator cover here, something like this, like probably this is up to this one only but we have a kind of separate section for the air also because if you want it to dry these granules within the centrifugal granulator so then it is having a rotor also. Vertical rotor something like this, so here what we have we have a bottom driven rotor, it can be top driven rotor also, here to this is the main section actually.

So, to this section the powder is coming through powder feeding device and in joining this container here, and then there is also provision for the constant flow pump so that the liquid whatever the binder that you need to use for the size enlargement that can come here. They are just schematic representation only not necessarily they may be coming at the wall, the container they may be coming somewhere here, they may also come somewhere here, something like that.

So when they are coming and this rotor is moving rotating in kind of in a direction, in a specific direction so mixing between these particles and then binding liquid will take place so, the rotational speed has to be controlled. If the rotation too high and whatever the particles are coming they will be directly hitting on to the walls and then being centrifuged or they may be rotating as kind of a wall, rope wall along the container wall so, that may be, that may also take place or if you have a design like that where this material, feed material as well as the binding liquid are coming through the container walls like this, so then it is better to have a high speed centrifugation rotation.

So that, particles are sticking to the wall and there, along these walls only their liquid is coming so then, particles would be coming and contact with those liquid along the walls, and then kind of mixing takes place and as mentioned a particle rope is along the wall is forming and then agglomeration takes place.

So, then here we can also have a provision at this optional, additional provision so, the blow air generator system is here, shown here so it is having the heat exchanger also whatever the air that you take from the compressors that will pass through the heat exchanger to get it heat at all, because we sending it to dry the granules. So it has to be heated up so that, air heated air is sent to this slit and then entering to the regions where this drying I mean to the inside of the region it is heating up the centrifugation device, so that whatever the granule material is the that can be dried. And then after this complete granulation takes place, and with proper sufficient drying the product whatever is there, that is taken out from the product outlet.

This is a general working principle of centrifugal granulators. One can have a kind of modify this and then changes or different designs are also possible. So, we have taken only one particular way so let say here moisture sensor is also there that is again the optional if you wanted to control the amount of the moisture you do not want to have a more this thing moisture inside the equipment so then you can have this one. And then accordingly you can control the spraying of the solution binding solution.

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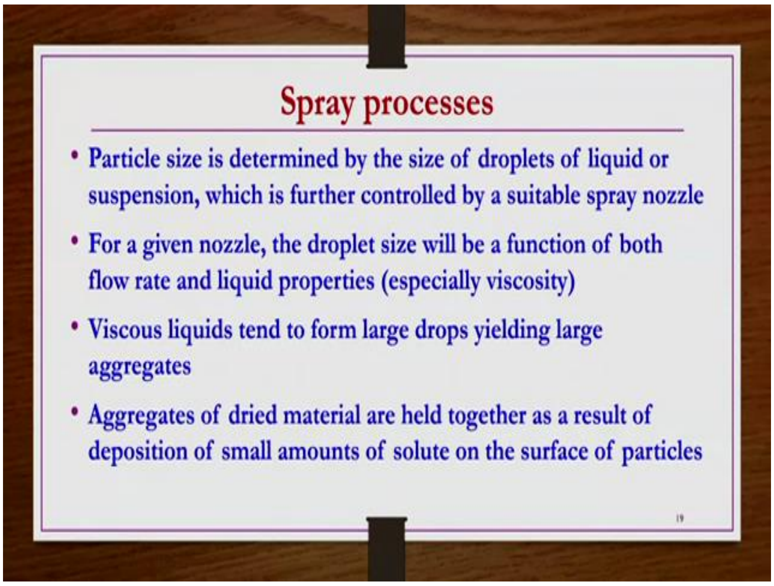

Next, spray processes in general in spray processes particles has determine by the size of the droplets of liquid or the suspension which is being used which is further controlled by suitable spray nozzles depending on the spray nozzles the size of the droplets will be there and then depending on the size of the droplets particles size or the granule size will be determined. How bigger granules are we going to get, for a given nozzle the droplets size will be a function of both flow rate and then liquid properties specially viscosity.

As I mentioned viscous liquid tends to form larger drops yielding a large aggregates or the bigger size granules then aggregates of dried material are held together as a result of deposition of small amounts of solute on the surface of particles it is a kind of simple drying process.

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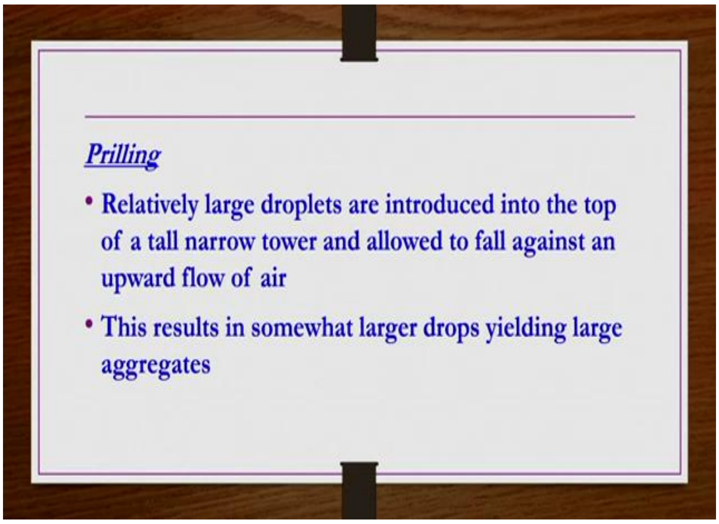

Next is the prilling it is also similar to spraying process. Prilling relatively larger droplets are introduced into the top of a tall narrow tower and allowed to fall against an upward flow of air, because of which somewhat larger droplets yielding larger aggregates will take place.

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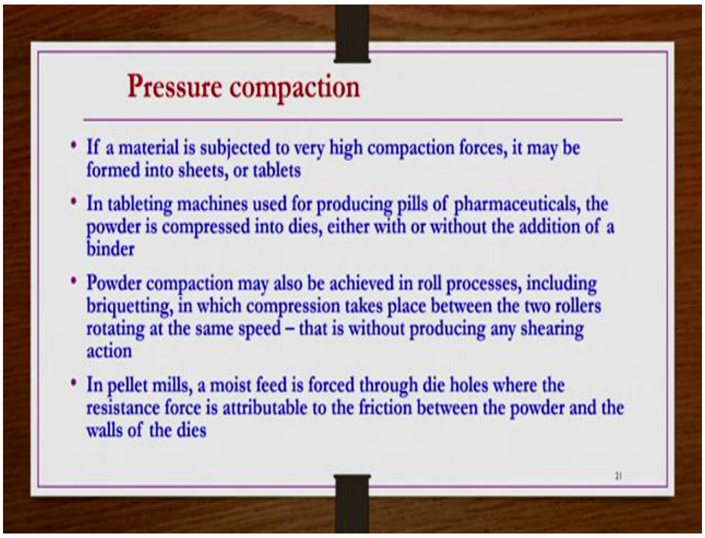

Then the last one is the pressure compaction method in order to do the size enlargement it is very much used in pharmaceutical industries if a material is subjected to very high compaction forces it may be formed in to sheets or tablets. In tableting machines used for producing pills of pharmaceuticals the powder is compressed into dyes, either with or without the addition of a binder as per the requirement of the active ingredient of the fine powder that we have taken.

Powder compaction may also be achieved in roll process, including briquetting, in which compression takes place between two rollers rotating at the same speed so, since they are rotating in the same speed there will not be any kind of shearing action. There will be only compressive pressure forces acting and there will not be any shearing action because both of them are rotating at the same speed. In pellet mills, a moist feed is forced through die holes where the resistance force is attributable to the friction between the powder and walls of the dyes.

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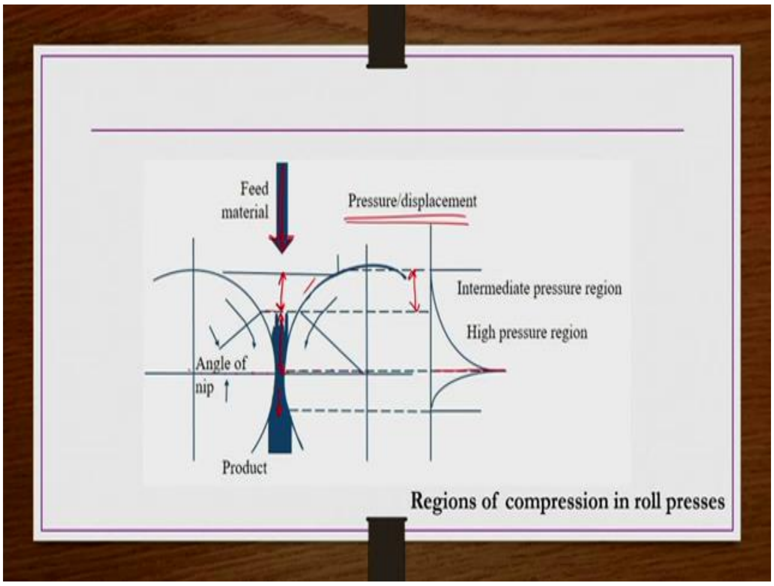

So typically, pressure compression if you see by using the roll presses so, these are the two rolls this is one roll and then this is the other roll, the feed material either the solids, pure dry solids, dry fine powders or mixed with kind of the binders they are individually or a kind of mixed with binders which as per the requirement of the application they comes between these two, and then these are rotating in the same direction these rolls are rotating in the same direction and then, same rotational speed so, that there will not be any friction so, then material whatever that comes in between these two, there is a small gap, the gap is of suitable size depends on the what size of a sheets or what size of a tablets you want get out as a product.

So depending on that one the size between these rolls is controlled so, the material that comes in here, that will be compressed and then as a kind of tablet that will coming out from here. Now, the pressure forces if you see the pressure is going to be very much high at the center or the point at which they are the contacting over the lines let us say, this a, this is the center axis of the two rolls so, on that point in general you may be having the high pressure at the contact point here.

And then kind of a intermediate pressure would be there somewhere here, when the material is first coming and interacting with these rolls and that here, from here, to this side if towards the center when it comes and the material gradually experiences the gradually increase in pressure. The pressure outside is normal pressure, whatever the feeding pressure is there. So moment here, that comes the pressure that is intermediate pressure region.

So, here this is our intermediate pressure region will be there from here, moment these start interacting with the rolls the high pressure region starts so that is the high pressure region is this one, and then it is maximum at the center, at the point of the center lines whichever the joining the center lines 2 center lines are their at that point it is going to be max and then again as material goes down towards the product section the pressure is again high pressure region, the pressure decreases when it comes down here, so then what happens, the as product the pressure gradually decreases here.

And then these regions are here, as a dotted lines shown, so this region between whatever section is the this region not inside the rolls but, here when the material is coming so, this region is a kind of a intermediate pressure region and this region a kind of high pressure region and then at the center at the this point, and this kind of pressure is very high and then again is, when it comes down as a product the pressure gradually decreases.

But, it will not be same as intermediate pressure region when it is entering the material. So, when comes in as a feed, it experiences more pressure, though it is intermediate region. So, while it is going out in the similar region, in the similar region, the pressure is not going to be so high, smaller pressure it is experiences, so this is about the pressure regions, the regions of compression in roll pressures which are used for the tableting of, making the sheets out of the feed material or fine powder either individual powder or kind of a mixed with some kind of binding liquid.

So, this is about a size enlargement equipment. So, the two lectures we have seen different size enlargement methods and then types of a equipment under each size enlargement method that is like, agitative granulation or pressure compaction or centering whatever. So, under each categories different types of equipment, we have listed out and then we have also seen the advantage, disadvantage of this equipment. However, coming to the equipment design principles we have not seen because of the time factor.

So, primarily we have seen the working principles or the working methodology of some of the existing designs and then their merits, demerits, applications etc. those kind of things we have seen under each category of size enlargement take place. However, if anybody wanted to see more details about the design of this kind of size enlargement equipments so, they are suggested to refer this book.

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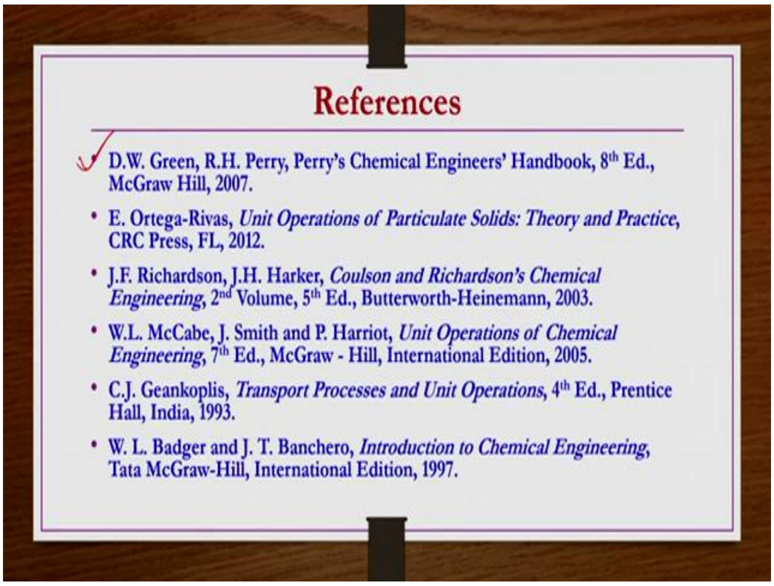

Perry's Chemical Engineers' Handbook, 8th edition by Green and Perry. Indeed the entire lecture has been prepared from this reference book. More details and design etc. those kind of things can be find out from this reference book, then Unit Operations of Particulate Solids: Theory and Practice by Ortega-Rivas also you can find some design aspects about some of this size enlargement equipment, other reference books are standard references we have, Coulson and Richardson's Chemical Engineering 2nd volume by Richardson and Harker.

Then Unit Operations of Chemical Engineering by McCabe, Smith and Harriot. Then Transport Processes and Unit Operations by Geankoplis and finally Introduction to Chemical Engineering by Badger and Banchero. Thank You.