Mechanical Unit Operations

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Lecture 11

Storage of Bulk Solids

Welcome to the MOOCs course Mechanical Unit Operations. This particular lecture, we will be discussing storage of bulk solids. Till now we have seen why the size reduction is required for a given bulk solid, especially when we are doing some operations involving only solid phases and then what are the kind of size analysis methods and what are the kind of size reduction equipment available. So, different types of size reduction equipment and all that we have seen and then each category of size reduction equipment, what are the commercial designs available those things we have seen in the previous three modules.

This is the 4th module, in this 4th module we will be discussing storage and conveying of bulk solid. So, once you have done the required size reduction, how to store them and how to convey them for a given operation which is involving solid-solid phases interact. So, the title of this particular lecture is storage of bulk solids. Now, before getting into the details of storage of this bulk solids what we do, we try to see how different of the solid masses from a fluid prospective. Let us say, when you have a fluid so, when it is flowing what are the kind of things happening. So, similar kind of things are happening or not, those kind of things, what are the similarities dissimilarities compare to the fluids when they are flowing in the kind of a given geometry.

So, considering those factors here, we first see what are the kind of different type of different kind of properties, what are the kind of similar properties considering the in a comparison with a fluid phases. So, those similar properties of solid masses compared to the fluid phases that we are going to see now and then after that we will be seeing the distinctive properties of solid masses which may be very much different from a kind of a given case or a fluid, ok.

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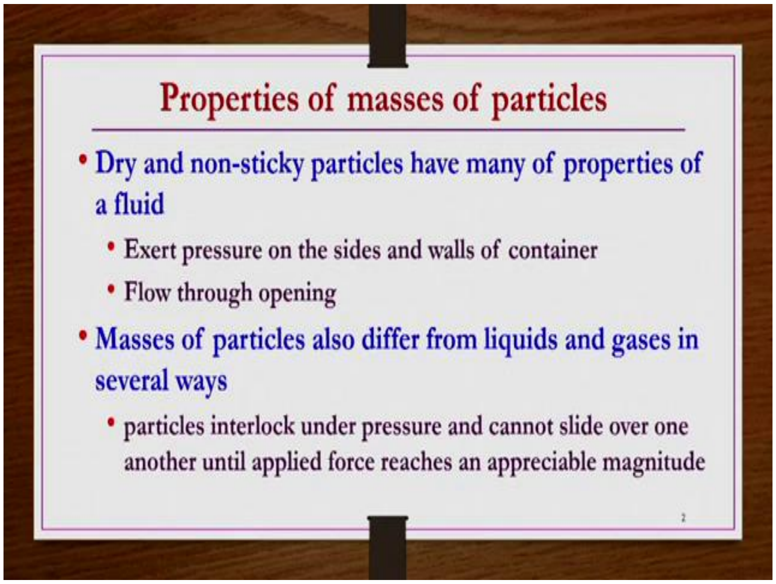

So, properties of masses of particles, this masses of particle in the sense whatever the size reduction we have done, we have taken bulk solids, and then we have done certain kind of weight reduction. So, then we may be having small grains or something various very small size particles etc. So, we are discussing the properties of those masses of particles are solid masses particles. Now, those properties we are going to discuss now. If we have a dry and non-sticky particle in your sample or if your sample is primarily dry or non-sticky then it is possible that sample may have many of properties of a fluid. So, whatever the fluids have the properties, similar kind of properties these dry and non-sticky particles or in masses may have what are such kind of properties. For example, when you have a fluid they exert pressure on the solid container walls side and walls of the container.

Is there in case of walls of the fluid and then same property we can experience, we can see here if your solid masses that kind of dry and non-sticky material. And then in fluid, what happened, they may flow through certain kind of given openings, right? So, same is possible, the same is through here in the case of dry and non-sticky solid particles as well so they also flow through openings as a kind of fluid dust. Ok? So, this kind of some of kind of properties which are similar compare to the kind of fluid but however, there are certain kind of properties which are very much different from a kind of a fluids, something like that you know.

Masses of particles differs from liquids and gases in several ways because particles interlock under pressure in general and cannot slide over one another until applied force reaches an appreciable magnitude, but in general if you have a kind of Newtonian fluid what happens if you are applying pressure the flow can be convenient and mode faster flow may be in general for a Newtonian fluid, let us not go in to the Non-Newtonian fluids and all that.

If you take a simple Newtonian fluid what happen, if you apply pressure the slow flow may be more comfortable but in the case of solids if you gradually increase the pressure it not necessary that you know flow ability of this material increases that depends on the size of the grains that we are handling. Let us say, if we have a very small size grains then what happens you know there when you apply pressure or gradually increased pressure.

So, rather increasing the probability the particles will become compact and the kind of the packing it become kind of a more strong packing kind of will take place and then the material may not flow through. So, that is what it means by that particles interlock under pressure and cannot slide over one another until applied force reaches an appreciable magnitude which is the dissimilarities compared to kind of Newtonian fluids. In general Newtonian fluids comfortably flow if you increase the pressure.

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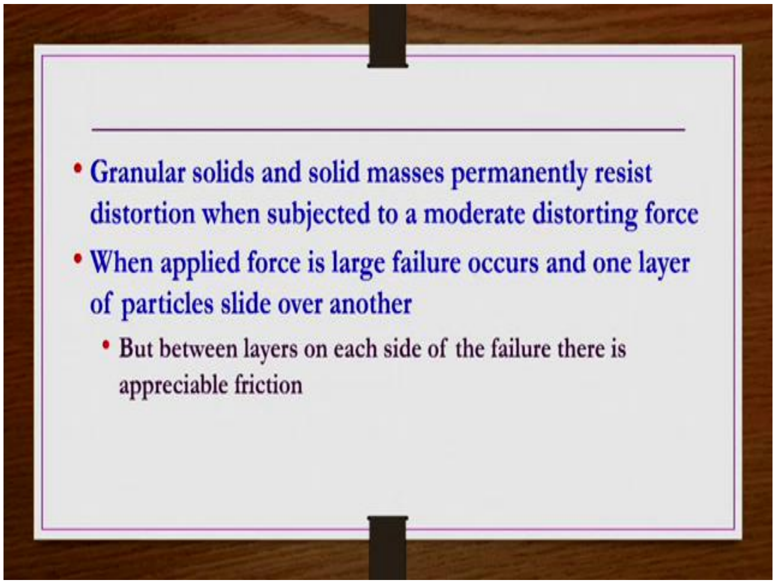

Further granular solids and solid masses permanently resist distortion when subjected to a moderate distorting force. So, if you have a Newtonian fluid when you apply kind of a force then they will continuously deform as long as the effect of that force is existing on the kind of a fluid elements. But here in the case of granular solid or solid masses as long as the force, that external force that you are applying for the distortion, if that distorting forces under small and moderate range, the granular solids and solid masses permanently resist distortion and they will not flow.

However, when the applied force is large failure occurs and one layer of particles slide over another and then may start flowing. However, between the layers on each side of the failure there is a kind of appreciable friction. Let us say, if you have a kind of a layer of the solid so when fluid layer is there then another fluid is layered is there. So, then they can more comfortably with less resistance and then that resistance is a kind of viscosity of the fluid, right? So, that is kind of thing is there. And in general in Newtonian fluid these resistances kind of friction in between the fluid layer is very small.

Whereas, in the kind of solid in masses, when the applied force is strong enough, large enough then a kind of distortion will take place and then a layers will slide over on to another, but when they are sliding on to other they may flow and then when they are flowing, they also have a kind of a significant friction between the layers on each side. On the edge this is the one side of the layer, this is the other side of layer. Between these two layers there will be kind of a significant appreciable friction would be there. Whereas in the kind of fluid that friction is the kind of very small and then it is same for either of the fluid layers.

And then this friction, whatever between the fluid layers is there, that is can be represented as a kind of viscosity. But here in the case of granular solids and solid masses, the friction may be different on each layer, but it will be there on each side of the failure there is a kind of appreciable friction. So these are the kind of some common properties with respect to the fluid that we have seen what are the similarities or dissimilarities especially compare to kind of fluid properties we have seen. Now, we see some distinctive properties of solid masses, right.

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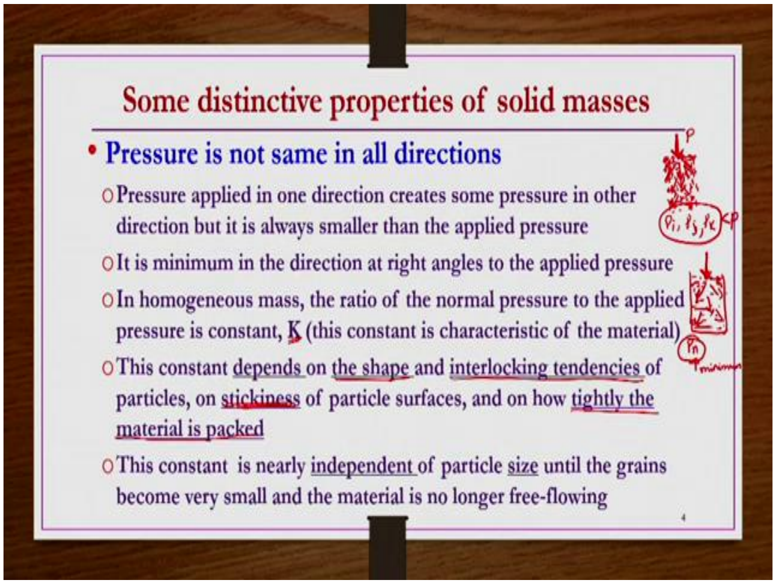

We see some details of the solid masses, right. What are the specific properties distinctive properties which are making the storage and conveying very much different compare to the kind of a fluids cases as I mentioned at the beginning of a introductorily lecture. The storage as well as the conveying of the solid is the kind of very much difficult compare to fluids or it is not as convenient as in the case of a fluids.

So, why it is, what are the kind of things that we have to consider and when we see both the storage and conveying of these kind of solid and masses? Some of the properties that we have already seen size, shape factor etc. and then density and then surface of the properties, these kind of things we have seen. So, we see some other properties which make the solid masses or the storage of the solid masses or the conveying of the solid masses very much different from a kind of a fluid perspective.

First of all in what happens in the kind of fluid, the pressure and the fluid is everywhere same as long as the fluid is Newtonian and right, whatever the pressure is there, within the system the pressure remains the same, it is constant everywhere, right. So, some distinctive properties of solid masses. First one is the pressure is not same in all directions. Let us say, you have a kind of a solid masses like this, right.

In a container or in a kind of a tube like this or grains are there in a kind of a things which may be your taking to the operations or you may be taking to the kind of storage unit something like that. So, let us say if you are applying pressure here on the top surface, for example, so the pressure would not be same in all directions. The pressure let us say this pressure would be distributed in all directions indeed that will be distributed in all directions and then that distribution is not same in all directions.

So, the pressure in the all direction may be something and then pressure may be something else and then pressure in the other direction may be something else, pressure in the normal direction may be something else. Like this you know the pressure is not a same in all directions that is what in one of the primary most important property of the solid masses. The pressure applied in one direction creates some pressure in other direction but it is always smaller than the applied pressure.

So, let us say pressure say mentioned when you applying the pressure on let us say on this particular that may be creating or distributing the pressure in the other direction as a kind of a arrows showing here. So, this kind of pressures like you know, now the pressure distribution is very different from one location within the solid masses whether it is in container or in kind of channel that is flowing. So, the applied pressure is in general very much higher or the pressure which is being created or distributed in other direction that is a kind of you knows a smaller compare to the applied pressure.

Let us say, applied pressure is P. So, the pressure in other directions let us say P_i, P_y, P_j, P_k, or in different directions it is being distributed with certain kind of angles also involved let us say. So, these P_i, P_j or P_k whatever are they, they are smaller than the applied pressure P. So, let us say the pressure that is being distributed in these three directions or let us say P_i, P_j and then P_k are there. So, all of this things are smaller than the applied pressure P in general.

Then it is minimum in direction at right angles to the applied pressure or let us say if you have a kind of a this is the solid mass that we are having here and this. Let us say, you are applying pressure here, right. So, now this pressure is being distributed in all possible directions and then it is having different magnitude each direction. But however each direction the pressure that is going distributed or you know transfer that is a smaller compare to the applied pressure P but where at in which direction it would be very minimum.

So, let us say, if you are applying this direction here so the it is normal direction or the triangle say right angles to the applied pressure it is going to be very much smaller. So, that is let us say in the normal direction the pressure is P_n. P_n is very much smaller than the applied pressure and then this Pn is in general is minimum. But, however it is not negligible. The P_n that in the normal direction, the pressure that normal pressure now we can call it as a pressure or the pressure that is being distributed or created at right angles to the applied pressure.

Let us say if this is you are the pressure that you are the applying in this direction. So, whatever the pressure that is along my hand so, that should be taken as a kind of normal direction. So, the pressure in the normal direction whatever being distributed or created so, that pressure we can call it as a normal pressure and then this normal pressure is going to be minimum compare to the pressure distributed in the other directions like this or like this or like this something like this, ok.

Compare to the applied pressure the pressure is that is being distributed to the all other different directions is definitely small amongst all the pressure that is distributed at the right angles to the applied pressure is going to be minimum one. Minimum but it is not negligible and it is very much important as well. Why important, in homogeneous masses the ratio of this normal pressure to the applied pressure is a constant K that is the reason it is important.

It is important having its information is very important because it is it is a kind of characteristics of the material. Solid masses that especially we have taken it is a characteristics of that masses, for a given material if it is a homogeneous mass that is you need to have a kind of a same material you cannot have a kind of mixture of solids. If you have one single kind of a homogeneous mass, then the ratio of the normal pressure to the applied pressure is going to be a kind of constant and then it is characteristic of the material.

So, that is K is nothing but $\frac{P_n}{P}$. as per our notations that we have used, ok. This constant depends on the shape and interlocking tendencies of particles n stickiness of particle surfaces and on how tightly the material is packed. Depends on the several kind of fact is first of all the shape of that material that you have taken and the grains whatever you have taken and then interlocking tendencies of the particle. Some particles easily interlock some particles does not interlock that depends on the surface as well as the you know shape of that material.

So, some kind of materials are having nearly like kind of material then can usually interlock. If you have a kind of a almost rounded ground particle kind of things so then they may be having less tendency to interlock, right. And then stickiness of the particles is also a kind of a very important factor that is affecting this constant K and then how tightly the material is packed, how tightly the material is packed that is also going to kind of a very important factor and then it is going to how effect on K. So, K depends on the shape and interlocking tendency of a particles and then how tightly the material is packed.

This constant is nearly independent of particle size however, until the grains becomes very small and the material is no longer free flowing up to that point you know it is you know it is it may have some kind of effect. However, that is you know it may depend on the size of the particle, it may not depend on the size of the particle. If the size of the particles or grains become very-very small, that they becomes you know becomes the material and grains becomes no more a free flowing nature then you know then another condition, the K constant does not depends on this size of the particle.

But however particle size is slightly bigger and then they are still free flowing then we can say kind of you know that size of the particle is also having effect on K or the K depends on the size of the particle as well. So, let us say we have the wheat, so when we take the wheat in a container and you take out of the container by opening or by tilting the container they can comfortably come out they have a kind of free flowing nature as long as the wheat is properly dried, ok. Then if you crush it to smaller sizes then still it may free flow or it crushed wheat kind of it.

But if you grind it in such a way that the when you get the flour or the wheat flour, what happens it does not flow comfortably it will not anymore free flowing that is what it means like wheat or crushed wheat which are under the free flow condition so, under that conditions the K constant depends on the size of the material as well. But once the wheat is crushed to such smaller grain size that you know you get the wheat flour then that wheat flour is not free flowing material in general. So, under such smaller size the K does not depend on the size of the particle. However, one can say this is nearly constant or independent of the particle size.

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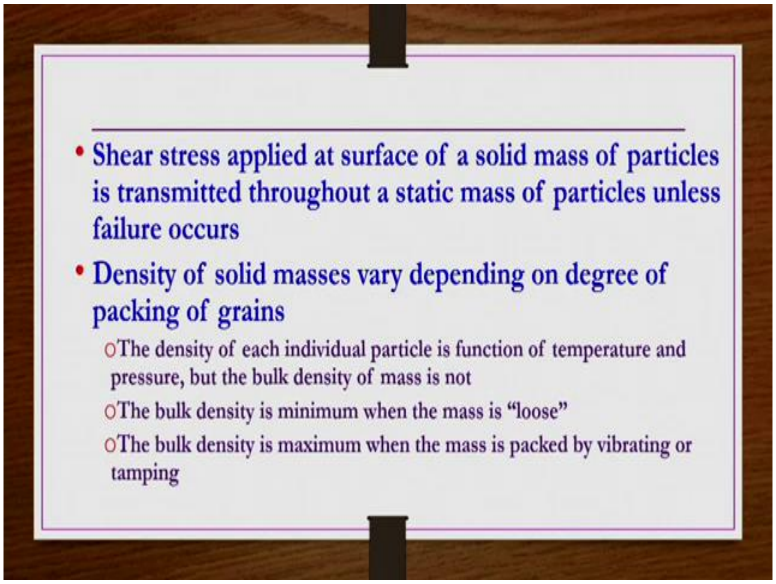

Then, the shear stress applied at surface of the solid masses of a particle is transmitted throughout a static mass of the particles unless failure occurs. So, not only the pressure whatever the shear stress that is applied on a surface of solid masses that is also going to be transmitted throughout this static mass of particle unless the failure occurs. Then the density of solid masses is also very much important and then it is a kind of the distinctive property.

So, the density of solid masses are you know masses of particles smaller particles they vary depending on the degree of packing. In general if you have a individual particle individual particle if you take then you know what happens the density of that particle is the function of temperature and pressure in general. But, if you have a kind of a packing of the solid material so solid material if you pack in kind of a you know particular manner so, then that density is not a function of temperature and pressure, that should be noted, ok.

So, density of each individual particle is function of temperature and pressure, but the bulk density of mass the solid mass of the particle is not function of temperature and pressure. However, density of or bulk density of the solid masses is minimum when the packed or when the mass is loosely packed then the density or the bulk density of the solid masses is maximum when the material, the particle is packed by the vibrating or tamping so they are very closely packed.

So, tightly few of packing the bulk density of solid masses would be high. That is as per given unit volume you can accommodate more mass of the solid by doing tight packing kind of the. If you are doing loose packing you can accommodate less material so then the density would be small in the case of loose packing and then density would be large in the case of a tight packing kind of thing. However, the density of this bulk material solid in mass of material is independent of pressure and temperature though the density of the individual particle is the function of temperature and pressure.

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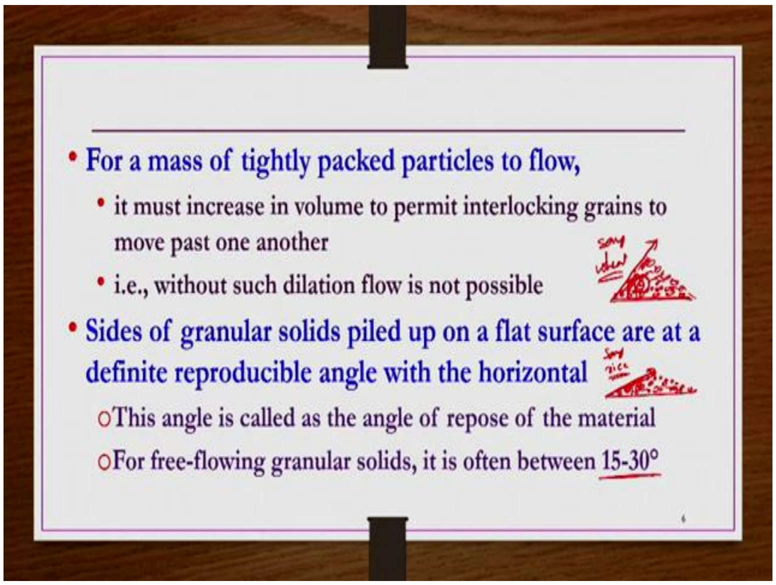

For a mass of tightly packed particles to flow, let us say for a mass of tightly packed particles packed particles you have taken and then you want it to flow, what should it be taken like initially you packed very tightly with the compactness in the kind of container and now you wanted to take out that a that material or you want to flow that material so that you can use it for a kind of required operation subsequent operation.

So, it will not be packing easily in general like if material solid grains, especially if the size is very small in microns or something like that, if you packed those materials you know under high pressure or then kind of temping or vibrating. If you closely tightly packed it that material will not flow comfortably so then if you want that bulk material to flow whatever the tightly packed bulk material if you want to flow what you have to do you have to create a kind of dilation, you have to increase its volume so that the kind of dilation takes place and then the particle or the solid masses can flow comfortably.

So, that it must increase in volume to permit interlocking grains to move past one another, when you are tightly packing so there is a kind of more stronger interlocking between the particles like this, something like that and then they may not flow comfortably, right. So, then what you have to do, you have to increase the volume of that material so that the interlocking can be relaxed and then the particles may slightly move one on to other and then particles may comfortably flow.

That is a kind of a dilation you have to generate, without such dilation flow is not possible so that is what it mean by. Then sides of granular solids piled up on a flat surface are at a definite reproducible angle with the horizontal and this reproducible angle is known as the angle of repose, right. So, let us say you can do this experiment, you take wheat and then you take a rice and then you pour them on a kind of a horizontal surface bit carefully like this, so if this is a surface so, whatever the time you pour it so this sides they may be forming a kind of pilsners, piling up like this, right.

So, these sides, whatever the sides are there, this sides you know they are always going to have a kind of a reproducible angle. Whether you take a kind of 1 kg of wheat or a 100 kg of wheat, as long as the material is same or surface is horizontal wherever you pour you may get this angle reproducibility, the angle is reproducible. And this angle is known as the angle of repose. And the all material will not form or piled up with a kind of constant same angle.

So, some material if you pour on the surface like this, so you may be seen that they are you know piling up spreading more like this and then they are kind of you know piling up you know with a less height something like this so that this angle is also less. Here in this case angle is here let us say θ_1, let us say here θ_2 so, $\theta_2 < \theta_1$. Let us say second material is rice and first material is wheat.

I am not saying this exactly the rice and wheat the rice angle would be smaller compare to the wheat angle but, for example, say you have taken wheat and piled up on a surface and then you have taken a rice and piled on a horizontal surface or you poured on a horizontal surface they are piling up. So, if you if you see their angles like you know take these angles and the sides you take this side and then try to measure the angle with the horizontal for either of the cases since the material is different they may be having the different angle, ok.

So, but as long as the material is same this angle is going to be same. So, this is a kind of a very important angle and then it is a used in kind of you knows designing of storage equipment for the solid and masses. So, there these angles are in general kind of useful, ok. So, that means indirectly rice when you piled up on a surface, it is going to pile up with in so that sides are forming a kind of reproducible angle. So this angle is called as a angle of repose of the material and for free flowing granular solids it is often 15 to 30 degrees.

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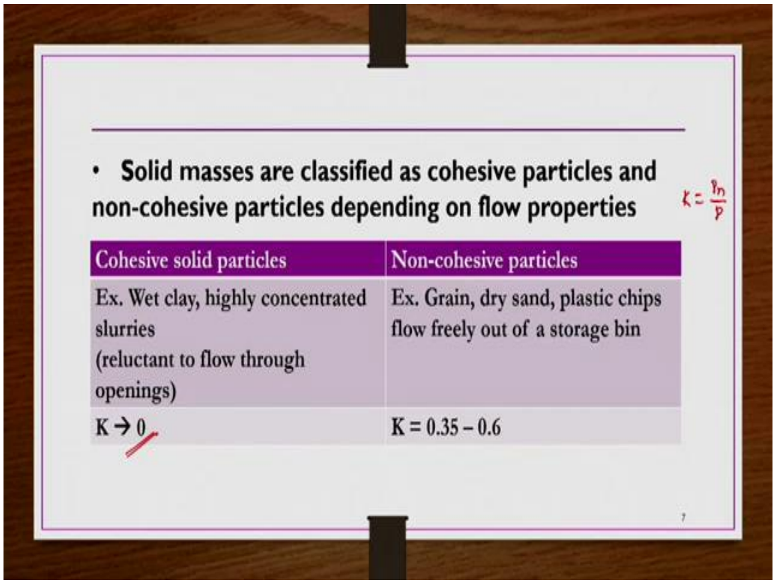

And then solid masses are classified as cohesive and non-cohesive particles depending on the flow properties or depending on that K values whatever that we have seen that $K = \frac{P_n}{P}$. So, based on that one, we can define this material solid mass as a kind of cohesive particles and then non-cohesive particles depending on the flow properties, we have a cohesive solid particle such as wet clay, highly concentrated slurries, which are reluctant to flow through opening.

In general you have a let us say container. The container in bottom you have a opening. When you open the wall opening, then what happen the material should comfortably flow. But, if the material, the solid material is kind of cohesive solid material, or wet clay or high concentrated slurries they may not be flowing comfortably an indeed the reluctant to flow through opening so, for such cases the K value, that $K \to 0$ or the ration between the normal pressure or applied pressure is going to be 0.

That is the pressure is not going to be distributed in almost all directions, in all directions it is not possible so, especially in the normal direction when you applying the pressure here the pressure is going may be distributing in these other direction here like this in angular this angular like that, but in the normal direction the pressure may not be created, may not be generated distributed, so that ratio the K would be small or close to 0 for this kind of cohesive solid particles.

But non-cohesive particles such as grains, rice and plastic chips, etc. they flow freely out of the storage bin and for then the K value is between 0.35 and 0.6. Now, we see the storage of solids, having the solids distinctive properties of these solids known so then it is again becomes a kind of question so how to store them and how to convey them. So, first we start with storage of solids. Storage can be done in a bulk storage or a kind of bin storage in general.

Bulk storage is in general used when you have a kind of tons of hundreds of tons of material is there. So, then in general you store them in open outdoor storage kind of thing, right. But if you have a kind of a valuable or two soluble materials are there, in general you store in a kind of bin or silo something like that. So, those things we are going to see in this slide. So, storage of solid can be done bulk storage or bin storage so, first we do bulk storage.

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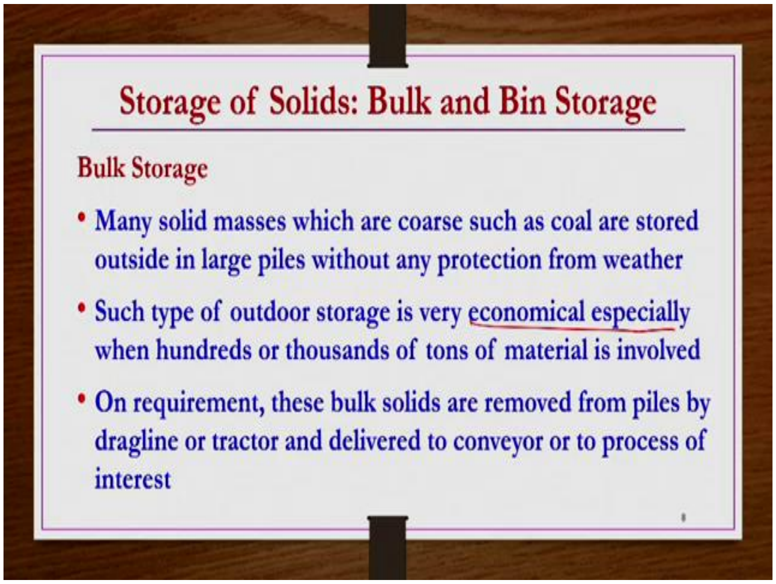

Bulk storage in general many solid masses which are coarse such as coal or you know crushed minerals etc. now that we get from the natural resources from earth whatever we get the big-big lumps we crush them into a kind of a smaller particle by primary crushers. So, those crushed materials are sometimes directly run away from the mines whatever material is there that also store outside in large piles without ant protection from weather.

So, these kind of things are you know can be done this kind of a bulk storage can be done for such kind of a material you know where you do not need protection from weather in general and then when you have a kind of a huge amount of material, tons of material is there something like that so that we can use. So, the examples in general we can say as a kind of a coal directly from the mines whatever the coal that you get, you can pile them of you know kind of a large empty space and then leave them as it is without any protection from weather in general.

Though it is not advisable but however the point of mentioning is that we do not need any kind of a special protection from the weather. However, such type of outdoor storage is very economical especially when hundreds or thousands of tons of material is involved. So, let us say in coals you know daily from coal mines daily you get you know hundreds and thousands of you know several hundreds of thousands of tons of coal is digged out mined and then taken out on to the earth surface.

You cannot effort to have a kind of a separate you know designated kind of storage equipment and all that, you will not able to have them economically when you few go try to have so then such kind of material may be piled on a earth surface you know without any protection from the environment. So, on requirement, these bulk solids are removed from piles by dragline or tractor and delivered to conveyer or to process of interest. So, let us say coal you piled on a surface on a empty free earth surface, so whenever you need to transport you can use the draglines or tractors and then load in a kind of lorries or a kind of you know a trucks, etc. then you can take to the process or location where you need to do process or if it is already in the process, you can through the draglines or tractors you can take them into the kind of process of interest where you may be doing the size reduction something like that.

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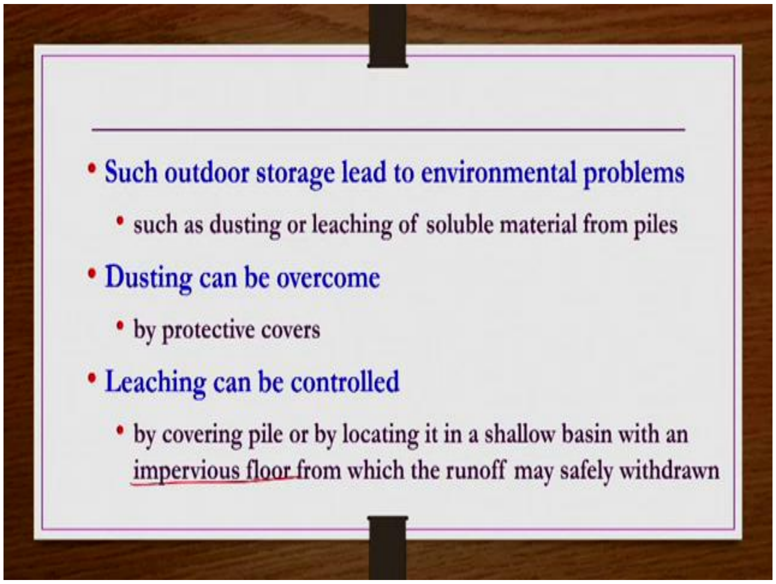

However such outdoor storage lead to environmental problems usually, as usual it is possible, one of the primary you know environmental issue is you know the dusting. Another one is the leaching of the solvents from piles. And then getting into the earth surface something like that those kind of things. So, what are the environmental problems such as dusting or leaching of soluble material from piles but however this can also be controlled?

So, dusting can be overcome by protective covers whatever the piles that you have you can cover with the kind of protective covers so that dusting can be reduced and then leaching can also be controlled by covering pile or by locating it in a shallow basin with an impervious floor from which the runoff may safely withdrawn. The surface has to be impervious so that the soluble material from pile should not get onto the surface and then cause a kind of soil pollution. So, that way you can have a impervious and then pour that material and then covered. So, that way both dusting and the leaching can be controlled.

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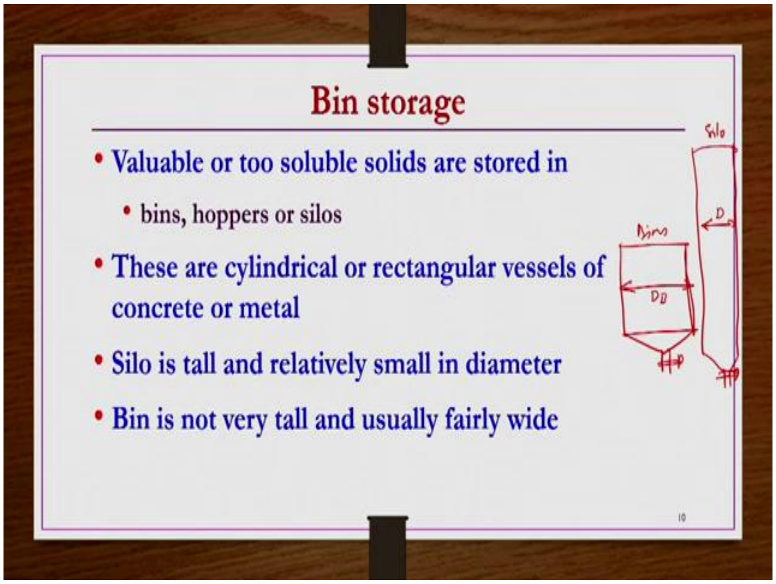

Then bin storage, actually wherever you have valuable or two soluble solids, they are stored in general in bins, hoppers, or silos. Small quantities or the material which are very valuable or too soluble then they have to be properly stored in bins, hoppers and silos but they may not be in a kind of huge quantities they may be few tons or something like that, not very you know hundreds of thousands of tons not be there this kind of material. So, the smaller amount of material which are valuable or too soluble then those kinds of materials are in general stored in bins, hoppers or silos.

In general these equipments are cylindrical or rectangular vessels made up of concrete or metal. And then silo is tall and relatively small in diameter container. Let us say you know here the container something like this very tall cylindrical container with a kind of a opening here at the bottom, right. So, this bottom is not exactly this way but just for indication I am mentioning. So, this are usually called as silo. Whereas other kind of you know container are there.

You know, they are not tall but they are wide in general. So, these container in general known as a kind of bins. So, small d here the diameter is small in a kind of a silo. Whereas in the kind of a bins diameter is very large compare to the silos, ok. Bin is not very tall usually and then it is fairly wide as of shown here. So, by the design they are given different names but purpose is the same thing they are used in the storing valuable or too soluble solids in general like this, ok.

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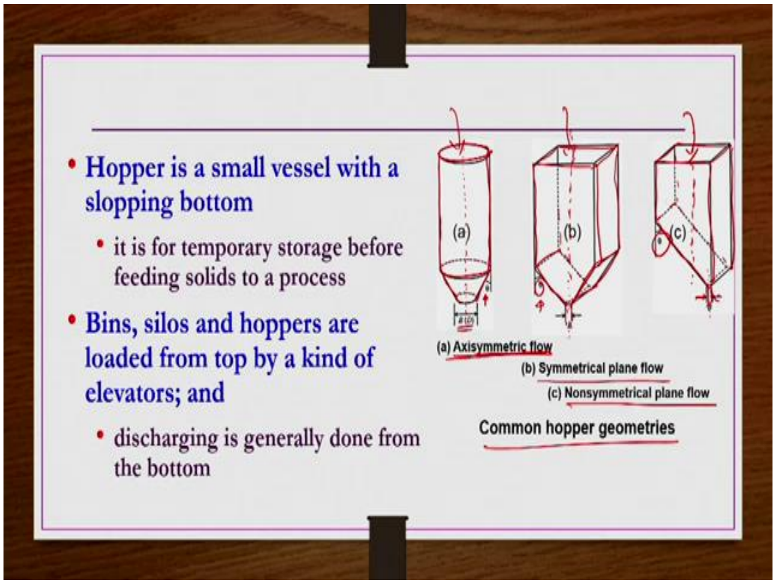

Then we have the hopper. Hopper is a small vessel with a sloping bottom. It is for temporary storage before feeding the solids to a process. Let us say you have a heterogeneous reaction. So, the solid material that is going to be reacted with a fluid in a kind of a heterogeneous reactor so, before the reactor you will be having a kind of a container which is called kind of hopper, the container for the storage of these solids. These solids are a properly processed and ready for the reaction or the ready for the subsequent operation.

So, they are a kind of a you know temporary storage just feeding solids to your process and then this hoppers are a small vessels with a sloping bottom. Small in the sense compared to the bins and then silos, their capacity, hopper's capacity smaller. And usually they are located just before the process where the solids are going to be processed. So, if you have a you know common hopper geometries if you see we these three different types of a possible. So, first one is the cylindrical container with axisymmetric flow condition like we have a kind of a cylindrical vessel like this, and then we have a kind of a slope slopping bottom like this

And then there is a kind of sufficiently bigger size of opening here. So, this opening is B and then this angle we can say this angle is theta. This angle is same either side so, and then if you see the flow is a kind of a symmetric flow. Flow would be there in this, whatever the solids flowing out of them they will be more or less symmetric. So, on then this in the kind of cylindrical coordinates so, shape is cylindrical shape so, we call it as a kind of a symmetric flow. We are going to see their details again.

So, then symmetric plane flow, here what we have we have this container rectangular, we have already seen that is a equipment use for this storage not necessarily be cylindrical always, they can also be rectangular something like this. So, this rectangular equipment are there and then they are a kind of a opening at the bottom, alright. So, here also the angle is there, right. So, now this angle you can say this one, so here again it is a symmetric that is the opening is a kind of at the center, it is in the kind of center.

Here also the opening at the kind of center or the central axis whatever is there that is same for the opening as well as the container and the same is true here also, whatever the center axis of the opening is there that is also a kind of center axis for the container let say the middle like that so that you can have a kind of a symmetric flow. So, here this is known as the symmetric plane flow because its container is not in the kind of a cylindrical shape.

Here it is container is in cylindrical shape so, we call it as axis symmetric flow, right. So, this angle is kind of important factor that you know that is that is going to decide how much pressure the solids are going to exerts on the walls as well as the on the floor of the container. So, this pressure is going to be very much important then designing of these hoppers etc. So those things in a way we are going to see in the subsequent lecture.

So, the third one is the non-symmetric plane flow here again the container we have taken a kind of a you know non cylindrical kind of container here, right like this. And there is a kind of angle here again at what angle the sloping is there something like that. So, the angle is this angle is nothing but the sloping angle. We have a cylindrical container to the bottom of that one there is sloping bottom is there. That sloping bottom angle how much it is that is this theta, right. And then there at the bottom there is a opening again for all of this things.

Now here the center line axis, center axis for this container is different. So, that is the reason this kinds of containers are known as a kind of a non-symmetrical plane, flow container are non-symmetric harbors. This are the kind of a common geometry, hopper geometries these are possible. So, bins, silos and then hoppers are loaded from by a kind of elevators you have the elevators you can pour the material from the top and then store them for the time that you wanted to store and then they can be discharge from the bottom. Usually done through the bottom only whatever the discharging is there that is generally done through the bottom only for this bins, silos, hoppers.

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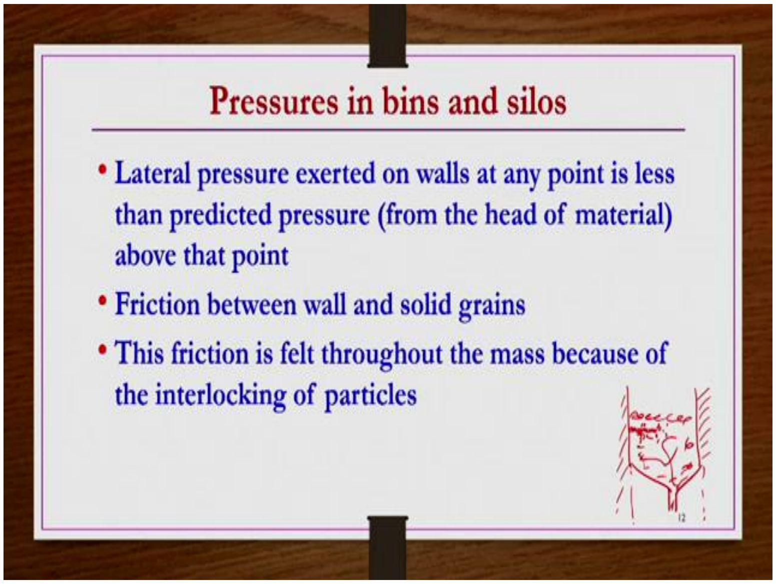

Next, pressures in bins and silos is going to be very much crucial and important kind of thing this is. This one has to be careful while designing. This will be very useful in designing the silos and hoppers, etcetera. So, how much the pressure that is taken by the side walls of the container and how much the pressure is taken by the floor, etcetera. those kind of thing and how is the kind of foundation. The foundation is also there so, that foundation how much pressure is taking. So, which one is important, how to calculate all of them are very kind of very much essential part in designing of this hoppers and silos, etcetera. So, those design things we are going to see anyway.

So, first we see how the pressure in bins and silos is going to affect operation in general. Lateral pressure exerted on walls at any point is less than predicted pressure from the head of the material above that point. Whatever the pressure, the container whatever the pressure in the line the lateral pressure is there not the pressure flow in the direction the lateral pressure whatever is there that one can predict and then that predicted pressure in general less compare to the a lateral pressure exerted on walls at any point is less than predicted pressure from the head of the material above that point as, as in the kind of liquid by the head up to what head the material is fed.

So, $h\rho g$ like that whatever the hydrostatic pressure that you obtain for the case of liquid, similarly, from the head also we can find out the pressure. So, that is you know, that is known as the predicted pressure so, usually true lateral pressure exerted on the walls at any point is less than that predicted pressure from the head of the material above that point. And there will always be friction between wall and solid grains and then this friction is going to be sufficiently large unlike you know kind of the fluids where the friction is small.

Fluids also when they are in container at the solids at the at the solid fluid you know interaction point there will be a kind of friction, but in the case of solids the friction between wall and solid grains is very much high. This friction is felt throughout the mass because the interlocking of the particles. Let us say we have a kind of a container like this and these are the kind of given by a support foundation here like this, right. So, these are the foundation, ok. So, now this hopper we have a material like this, the solid material whatever you say that you have taken like this and there is bottom so, what happens here whatever the let us say a I take, I make some space here, so you have a kind of a solid material here it is having some kind of friction with the wall, right.

And then these particles again connected or attached to some other particles like this so, there will be a kind of interlocking of particles again like this, like this, right. So the other direction also it may be having the friction between the particles and a wall so these particles are connected other particles, neighboring particles being the whatever the kind of things so what happens, whatever the friction that is the particles that material solid particles are experiencing at the wall that is also being in a felt trough out the material within the material because of the interlocking kind of thing.

So, it is not this only that layer near the layer of that material that is near to container is only experienced in the friction because of the interlocking the material in the other area, this area, also being experienced. Whereas in the kind of fluids what happens in primary linear friction is experienced by the fluid layer attached to the solid surface. But, that is not true here in the case of solids. If friction between solid and wall whatever it that is container wall and then solid material whatever the friction is stay that is being experienced by the rest of the material as well not the layer which is attached to the container wall itself along because of this interlocking of the particles.

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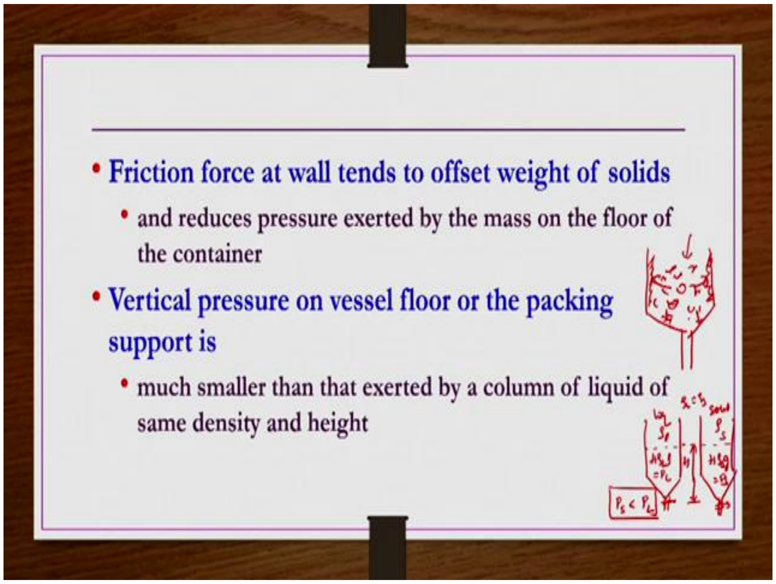

Then friction force at wall tends to offset weight of the solids systems that may be you know very much higher but because of this friction you know what happens, whatever the friction at wall is stay that slightly offset the weight of the solids. And then all together it reduces the pressure exerted by mass on the floor of the container.

So, that way it is going to be a kind of a beneficial only that is one way whatever the friction that is stay at the wall, the friction between the solid particles and then container wall, whatever the friction is there that friction is experienced throughout the material because of the interlocking and because of this friction throughout the material that offset some of the weight of the solids and then all together it reduces the pressure exerted by the solid mass we are pouring, it the reduces the pressure by the mass on the floor of the container.

You design a kind of a container with a certain kind of a you know design pressure for the especially for the floor and then if you pour on large material by somehow what happens that may break down, right. But luckily such kind of issues may not arise because some of the pressure or the some of the weight you know of the solids is offset by the friction between the particles and then walls so that reduces the pressure.

So, be specifically let us say you have a kind of a container here and then this is the kind of a floor of the container. So, whatever the material that is stay here so, that material when you are taking more material here, so, this is the weight some of the weight is being you know taken away by the friction between the particles and solids. So, overall the pressure that is acting on the floor that is going to be reduce because some of the weight of the solids is taken by the friction force at the wall, friction force between particles and the wall of the container.

However, the vertical pressures on vessel floor are the packing support is much smaller than the exerted by a column of liquid of same density and height. Whatever the, let us say you fill the container with the liquid up to height h, now you obtain the hydrostatic pressure $h\rho g$ how much it is. Now, up to the same height you take a solid material of the same density as a kind of liquid and then by height, whatever the static pressure that you calculate so that vertical pressure you calculate you know that that is going to be much smaller in the case of a solids compare to the case of liquids.

So, that is vertical pressure on vessel floor or packing support is much smaller than that exerted by a column of liquid of same density. So, you have a kind of a same containers like this, right. So, here you have taken liquid you have taken solid but the density same here, you have taken up to the same height. Here, this height whatever is there that h. So, then here a rho l, rho s so, rho l is equals to rho s we are taking.

So, $h\rho_1 g$, $h\rho_s g$. So, whatever the pressure let us say here it is P_1, let us say it is P_s. So, solids pressure is always going to be liquid pressure under identical condition as long as the density and then a density of the solid and liquid are same. So, that is what mean by vertical pressure on vessel floor or the packing support is much smaller than that exerted by a column of liquid of same density and then same height.

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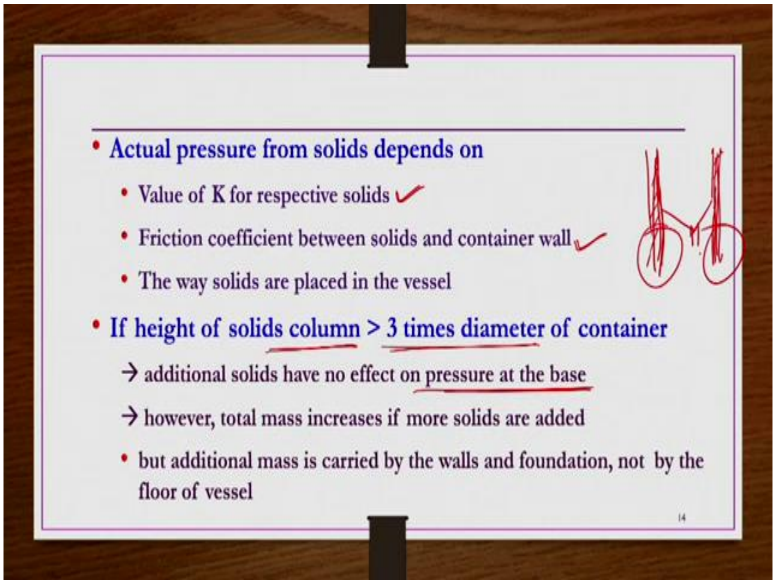

Then, actual pressure from solids depends on several factors. First and most important one is that on the value of K for a respective solids that we have taken. So, the value of K is going to have a kind of strong influence on the actual pressure from solids as I already mentioned it is a kind of a very much essential thing and then this now in the later course, we are subsequent lecture, we are going to design this hoppers etcetera. So, we are going to calculate or obtain the expression for this pressure and we will be see this pressure is going to be a strong function of K.

So, actual pressure from solids depends on the value of K for respective solids and then friction coefficient between solids and container wall because that friction coefficient is offsetting some of the weight of the material. So, it is reducing the overall pressure that because of this solids. So, whatever let us say when you take hundred kg of solids so, whatever the pressure supposed to be exerted let us say, you know 500 kilo Pascal. But you know because of this friction that pressure is going to be less than 500 kPa in general.

So, that is what it might be. So, that friction coefficient between solids and container again is going to have a kind of huge impact and the actual pressures from solids. So, probably it may be reducing the actual pressure exerted by the solids that have been taken in the container. And then the way solids are placed in the that is also going to have a kind of a influence on actual pressure from solids. And then if height of solids column is three times is larger than three times the diameter of the container.

Let us say, if your h, your height of the column of that you know up to which you are filling this solids, ok. Let us say, diameter of the column or the container is d. If $h > 3d$ then whatever the additional solids you pour in that is not affect pressure at the base at base so that is important one. So, when you have a design such a way that the height of the solids column is greater than three times diameter of the column then whatever the additional material additional solids you take inside the container that is not going to have effect on pressure at the base that is not going to increase the pressure.

Usually what happens, when you take the more material so, definitely the pressure should increase but as long as if you maintain the design such a way that height of solids column is three times or greater than three times diameter of the container. So, additional solids will not having effect on pressure at the base. However obviously when you take the more material the total mass of the solids will be added up. But this additional mass is carried by the walls and foundation, not by the floor of vessel.

So, that is what you know addition mass whatever is there that frictional force that is offsetting the this additional mass or whatever the pressure is there because of the additional mass that is taken care by the foundation of the container, foundation in the sense let us say we are have drawn only you know hoppers like this only, right. But these things are having a kind of given a kind of support foundation support with the kind of some kind of you know cement or a metal poles or something like that, ok.

So, this foundations will take some amount of the you know additional force additional mass. So, whatever the additional pressure that is going to be exerted because of the additional mass that is going to be taken by this foundation as well as the friction between the walls and then particles.

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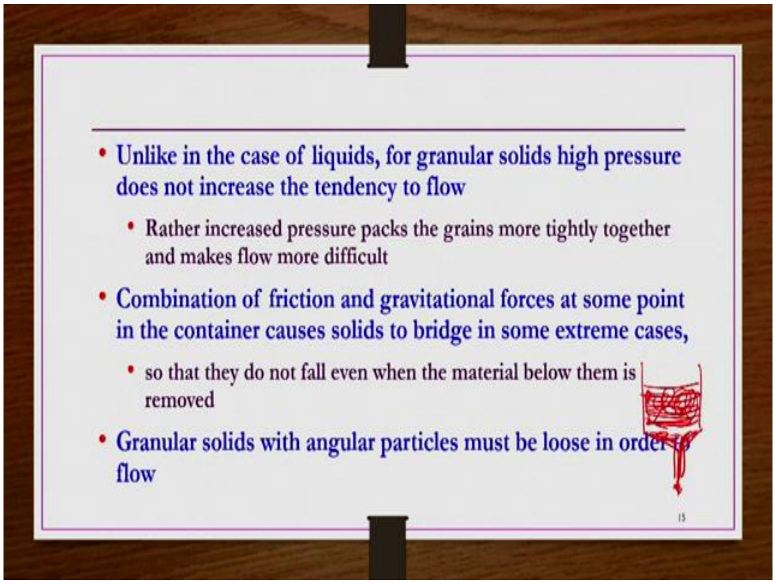

And then, unlike in the case of liquids, for granular solids high pressure does not increase the tendency to flow. In general what happens into an liquid when you increase the pressure usually you more flow rate comes out and then fluid may flow comfortably. But that is not true in the kind of a solids especially granular solid of very small size. If you have a granular silos when you increase pressure what happen a kind of a more compacted packing will take place bulk density will take place and then they may not flow comfortably rather flowing comfortably the increasing pressure more compactness of the packing take place in the case of granular solids.

Which is unlike in the kind of liquids. In liquids case what happens when you increase the pressure usually you get the more flow rate, ok. Comfortable flowing high flow rate you get. But, here in the kinds of grains you know when you gradually increase the pressure, what happens more and more interlocking kind of particles will take place or more and more compact packing of a material will take place and then tendency to flow will decrease.

So, rather increased pressure packs the grains more tightly together and makes the flow more difficult. So, finally combination of friction and gravitational forces at same point in the container causes solids to bridge in some extreme cases a kind of bridging of the material will also take place. That you know you know something like this bridge kind of things are there this things we are going to see in the kind of flow ability of the materials because of the bridging what happens.

You know when you have this kind of containers you know if they are forming a kind of bridging when you take them off what happens whatever the material that is there so let us say you take the material. So, some material will be taken out from the bottom so whatever the material that is there that is being taken out here. But, above that material will be having a kind of bridge kind of structure they will be still packed. Though the bottom material that is there whatever that has been taken out the upside material will not flow because of this kind of bridging effect, ok.

So, these things we are going to see and we study the flow out of them. So, they do not fall even when the material below them is removed. So, when the bridging effect is there, whatever the material below them here at the bottom of the bottom layers of the material even if you remove, so the above material above this bottom layers will not move, they will have a kind of bridge kind of thing and they will be a kind of hang in kind of, ok. Granular solids with an angular particles must be loose in order to flow, if you have a granular solids and then if you wanted to flow them comfortably, so they must be loosely packed.

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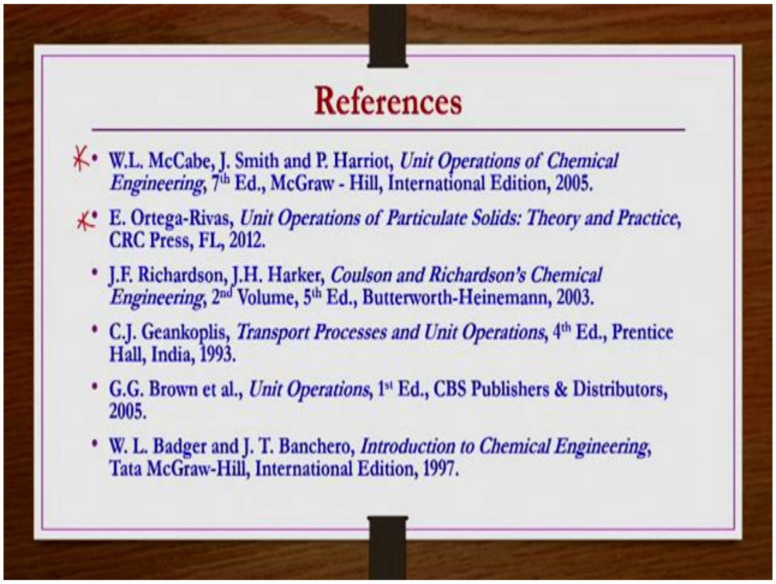

The references of the books for this particular lecture or you know unit operations of chemical engineering by McCabe, smith and Harriot. Unit Operations of Particulate Solids: Theory and Practice by Ortega Rivas. Coulson and Richardson’s Chemical Engineering Series 2nd volume by

Richardson and Harker. Transport Processes and Unit Operations by Geankoplis. Unit Operations by Brown et al. Introduction to Chemical Engineering by Badger and Banchero.

But however most of the details have been taken from this first book McCabe Smith and Harriot for this particular lecture. Some of the images presented here in this particular lecture are taken from the second reference book that is Unit Operations of Particulate Solids: Theory and Practice by Ortega Rivas, thank you.