Multiphase Flows
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Lecture – 06
Pneumatic Conveying

So, welcome back. What we were discussing in the last class is about the pneumatic conveying and we have discussed the different regimes of the hydraulic pneumatic conveying or hydraulic convey and gas pneumatic conveying on different regimes which is available.

Then advantage and disadvantages of each regimes; and how the transfer take place. And then finally, we are discussing now that how the transfer take place in the dilute phase and dense phase pneumatic conveying.

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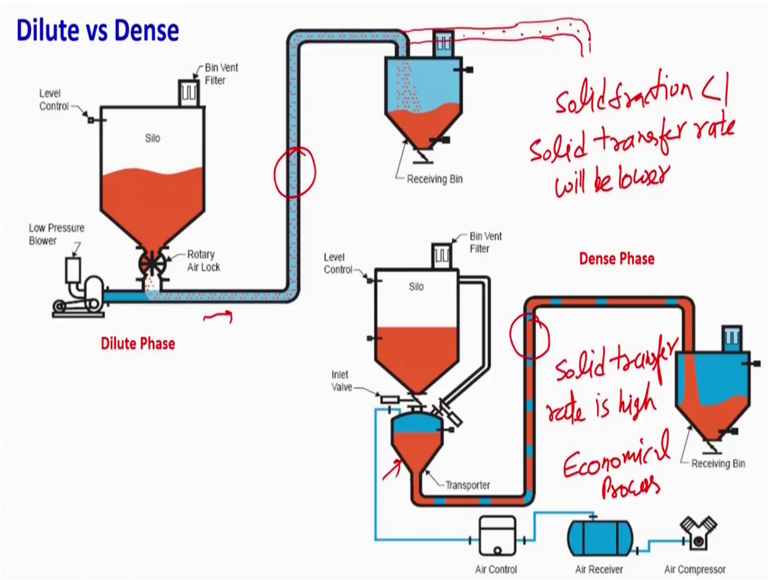

So, dilute phase means as again to just revise it briefly that where the solids are completely suspended in the pipeline or in the gas. So, this is the regime where it is a completely homogeneous or it is a in this just on the verge of heterogeneity when it starts or we call immature homogeneous and top portion of the deal flow. Now, as I discussed earlier that dilute flow it means the gas is already solid is suspended in the gas.

So, what will happen, you will see the continuous flow of the solids as you can see here that the solid is completely suspended and it is delivered at a location wherever you want.

Now, we have also discussed that the good thing in the dilute phase conveying that if I have suppose multiple input or in multiple places where I have to deliver the output, I can do it very easily. So, I can have suppose if I have a multiple output I can have an output here; I can also have one more output somewhere at this place. And there will be the gas solid suspended here. And it will be divided as per the Bernoulli equation that the fluid will be divided into if the diameter of the pipe is same; if the diameter of the pipe is different, they will be divided proportionally. So, you can have multiple input and multiple output in the dilute phase regime.

In the dense phase, you can have a multiple input, but at each input, you have to put a transporter. And what you are doing in the transporter, actually you are pressurizing it transporter and the solid is flowing in form of slur. So, we have already discussed advantage and disadvantage. Major advantage of the dilute flow is you seem that multiple input can be there, multiple output can be there without having any extra expenditure, but the solid transfer rate will be very, very low, because the overall solid fraction is very low less than 1 percent.

So, solid fraction is less than 1 percent here. So, somewhere here if I see the solid fraction, it will be less than one percent. So, overall the solid transfer rate will be very low here. So, solid transfer rate will be lower. Now, in this case, solid transfer rate is very high. So, this is considered as economical, because we are transferring more and more solids here. So, this is what about the dense phase and dilute phase regimes.

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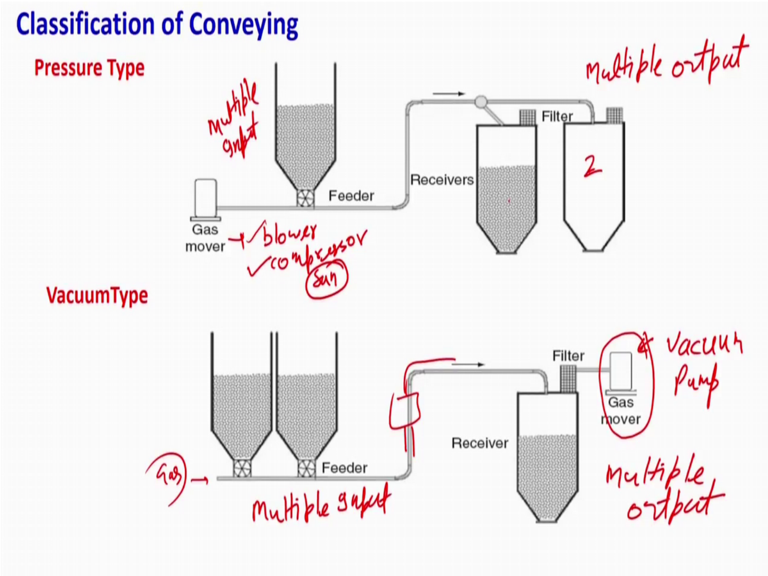

Now, one can do the same operation under the pressure or under the vacuum, we have already discussed that. So, suppose if you are want to do it under the pressure, so there is a gas mover. Gas mover can be it suppose you are doing the dilute phase transfer it can be blower. Gas mover is nothing but it can be blower, it can be compressor. And if needed even the fan, but fan is very, very difficult because the pressure generated by the fan is very very low.

So, generally it is blower or the compressor where you are blowing the air here and with the feed there is a suppose a silos where the feed is solid material is there, the solid material will be dropped in this pipeline. And with this air pressure it will be moved and delivered at different location.

As I have already said that in the dilute phase regime, you can have a multiple location this is one of the such example that it will be dubbed here or it can be dumped on this place. Or depending on the this there can be a label indicated, depending upon the label it can first dump in the receiver one. And then once a particular level is achieved this wall will be closed and all the solids will be dumped in the receiver two. So, say this is receiver two. So, it will be dumped here.

So, you can make all the arrangement any alternate arrangement. Now, this kind of arrangements are very widely need if you are doing any reaction particularly. So, suppose if you are having a solid as a reactant, I want to keep the solid dosing rate constant. So, I have to keep this maintained the height of the solids in the silos, and based on that all these operations can be done. But this mover can be either the blower or the compressor; depending upon what is the gas velocity and what is the gas pressure you require.

Now, in the vacuum type operation, what you can do you can have a vacuum pump here, this can be a vacuum pump ok, so which will generate a vacuum or it can generate a suction. Now, this is what will happen because whole line will be under the suction. So, it will be automatically suck, so there will be some gas here which will be passing through and this will be under the suction mode.

So, the gas will be again now be governed with the vacuum generated here or the suction generated here with the gas movers will generate the suction. So, gas will move and again the same multiple hoppers can be there. Here the example we have taken as a multiple hopper, but it can be also on the same side way that two silos can be there at the delivery end on ones silos can be there at the inlet end, or two silos can be there at the inlet eight one silos can be there at the outlet end, anything is possible.

So, both of this geometry is possible do not get confused that entails of the pressure only one input is possible and in case of vacuum two input or more than two input is possible that is not true. You can have multiple input here also ok. You can have multiple input, multiple output. In case of the pressure operation, you can also have multiple input; and multiple output in case of vacuum operation. So, both the cases it is possible you can have both.

So, what will happen again the overall needed remains things remain same; only the kind of the way the gas is being moving. And once in pressure type operation gas is moving because of the pressure which is being generated because of the blower or compression. In other vacuum type the gas is moving because of the vacuum generated or suction generated by the pump or the blower, which is being kind of operated. And this is at the suction end or compression it is the suction end. So, what will happen the gases will be coming here and it will be thrown out and you can add the feed in the line and this feed will be get suspended, and it will transfer to the location.

So, as we discussed that it can be operated both in the vacuum regime, it can operate in the pressure, it can operate even in the combination of both. So, both dilute phase as well as the dense phase can be operated in both the ways either under the pressure or under the vacuum or in the combination of both. So, you can have even one more thinking where it is the combination. So, suppose some part you are pulling the through the vacuum. Say if I put a vacuum here and then after that this will be the compressor.

So, the I put a compressor here, so this will be the suction. So, this part will be the under the vacuum and some part will be operating under the pressure. So, it can be the combination of both it can be operated under the pressure, it can operate, it under the vacuum, it can operate it both combination of pressure and vacuum. So, anything can be designed.

And this is the typical way the conveying system has been designed or pneumatic cunning has been designed and it can the feed can be collected from one location or multiple location, the way I have sold here and can be delivered at the multiple location the way it has been shown in the figure. So, do not get confused again that pressure type and the vacuum type both can have a multiple input and multiple output.

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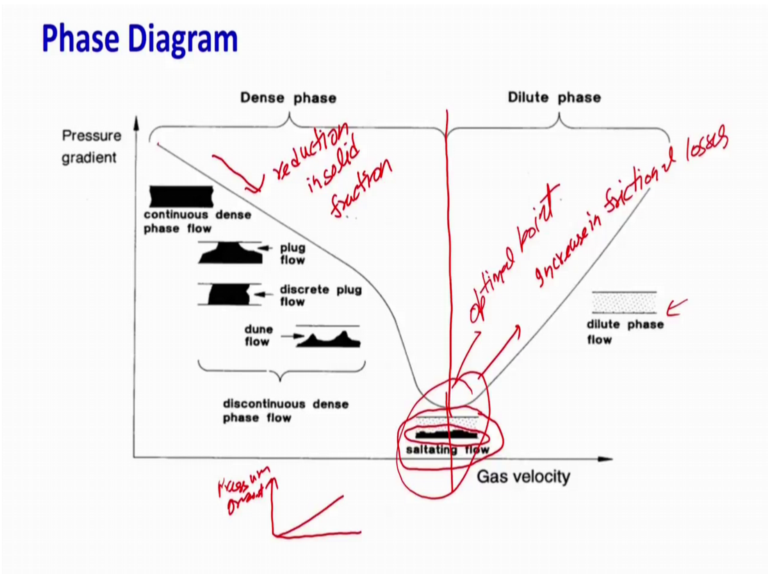

Now, what is important in the pneumatic conveying is the phase diagram. And I just keep on telling that everything in multiphase flow we are going to do we are going to have a phase diagram now or regime diagram. Now, what the phase diagram says here, so if you see the phase diagram, what we are interested in we are interested in how much solid we can transfer in the pneumatic conveying ok. Now, what are the parameter which is going to govern definitely the gas velocity, the solid loading, and what is the pressure loss we are saying, because more the loss what will happen it means you have losing more and more energy. So, what I want I want minimum loss and minimum gas velocity at which I can deliver the maximum solids. So, if I can do that that will be the best thing to do.

Now, what will happen suppose if I have a very low velocity gas velocity as we have already discussed the phase this regime. And regime says that if the velocity is very very low, then what will happen you will see all this the dense phase. So, if you see that below this, the lower velocity it is here. So, below this everything is in the dense page. It means what you are having a low velocity so solid loading will be very very high or solid fraction will be very very high.

If you keep on increasing the velocity for the same solid loading, it will be converted to the dilute phase. So, this graph is for a particular solid loading for a particular solid loading, it says that if the phase is velocity is very, very low. You will see a completely packed condition which is still may be moving as a moving bed or you can see the plug or discrete plug flows or dune kind of a flow all these flows you can see the completely plug. You can see the plug flow complete it is a complete slug flow which is completely a packed bed kind of a flow of whole bed is being packed. There may be a movement; there may not be any movement.

There will be a plug in which you can see some movement here. There can be a discrete plug and this discrete plug or slug commonly known is moving together to transfer. The fluid or transfer the solid, then you can also see the dunes flow if you keep on increasing the velocity. After that you will see the saltation, where some of the solids will be certain at the bottom and they will be moving like a back bed or moving bet and top some of the gases will be some of the solids will be suspended into the gases, but major movement of the solid will be because of the bottom saltation so this. And if you further increase the velocity will. So, for homogeneous flow regime which is the dilute phase regime.

Now, this can be further divided in immature homogenous and homogenous. So, you keep on increasing the velocity, you will see that. So, what we are done here, we have plotted the pressure gradient with the gas velocity. Generally, we do this delta P versus velocity, this is the notion we have developed from the single phase loop dynamic equations. If you remember your fluid matrix in the first the B.Tech first semester or second semester when you have studied the fluid mechanics; We always see that how the delta P is going to change with the velocity there is of laminar flow or the turbulent flow and we always try to plot that.

So, similar thing we have tried to do here to draw the analogy that what will happen if the multi phase flow introduced here and multi phase flow in this time it is a solid, which is the second phase is being introduced. So, what will happen we know that if you keep on increasing the gas velocity, what will happen for the single phase flow the delta P will keep on increasing. So, suppose if it is a single-phase flow, and if I say the pressure gradient ok, it will keep on increasing, because delta P will be keep on increasing with the velocity ok. Now, depending upon laminar flow or turbulent flow, the nature of the curve can be different.

Now, here what we are seeing here that if you keep on increasing the velocity initially the pressure gradient is reducing. Why it is reducing, because your solid fraction is reducing. So, initially solid fraction is very high, so pressure drop is enormously high and you are seeing a very maximum pressure drop where the solid are completely packed in the whole channel or whole pipeline. So, you see the maximum pressure drop here. And then you keep on increasing the velocity, your pressure drop will keep on reducing because solid fraction is reducing. And you see the minimum pressure gradient at a saltation regime, where the pressure loss is actually minimum.

What happened after that if you keep on increasing the velocity, the frictional losses because of the pressure because of the pipeline walls is keep on increasing because you are increasing the velocity very high. So, the frictional losses is now going to be dominating, and you will again see the rise in the pressure drop. So, initially this drop is because of reduced reduction in solid fraction. And here it is increasing and that is mainly reason because increasing the frictional losses. So, if you reduce it further the gas velocity will be very high to make it dilute and your frictional losses is going to be dominating.

So, what will happen again your pressure drop will be increasing. Now, as an engineer what we want we want to operate always at a condition where the pressure drop is lower, so the saltation may be the point which will be the optimal point. So, this can be a optimal point. At least from the pressure drop point of view, it can be optimal point where one should operate the system so that we can have a minimum pressure drop or minimum pressure loss, so for this system. So, if the pressure loss is minimum finally, my energy loss is also being reduced. So, it means what if I given a chance I would always try to operate near the saltation regime particularly for the pressure drop region.

Now, one can also see that what will happen where the mass transfer will be maximum. It means where the maximum mass of the solids can be transported. So, we will also try to plot the phase diagram with the mass transfer rate or you can say the mass loading rate or the transfer capacity of the solids.

So, if we have that point, so where both the point will cut it means the pressure drop is minimum transfer of the solid is maximum that should be the operating regime. So, as per this phase diagram which is delta P versus velocity, it clearly shows that at the velocity will at a condition which is saltation regime, your delta P is minimum and if that is the case we should operate quietly as per the pressure drop point optimal point will be the saltation regime.

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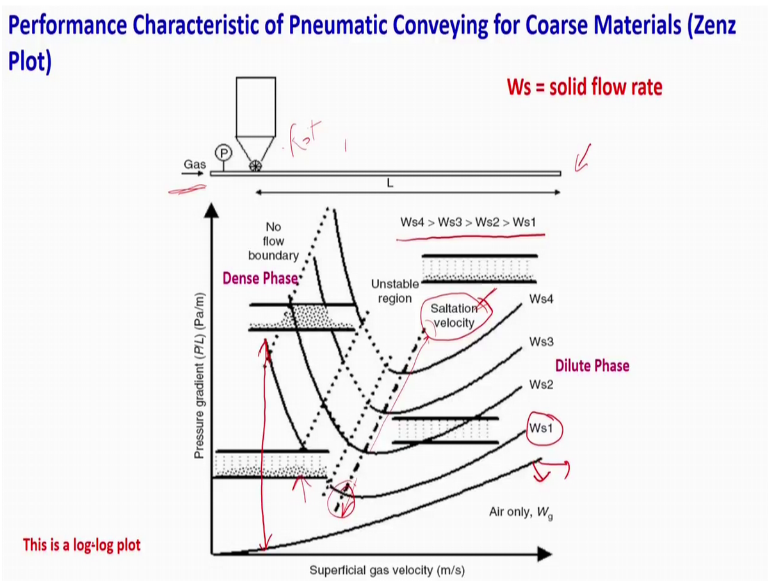

Now, to verify again many people have plotted this for different mass flow rate or different solid flow rates. So, if you see that W 1, W 2, W 3, W 4 is the solid flow rate different solid flow rate which is being operated W 4 is maximum if you see this and W 1 is minimum. Now, this is whatever I told you that this is only because of the air. If suppose there is no flow no solid flow is there only air is flowing inside the pipeline and this is with the air velocity this the x-axis is the superficial gas velocity. And gas is nothing but the air. And here it is pressure gradient delta P upon L.

Now, what it is says that again the same thing that if you have only air single-phase flow. If you have very low velocity, the pressure gradient will be almost zero or very low. If you keep on increasing the velocity, the pressure gradient will keep on increasing. So, this is for the single phase flow you are going to get this much pressure gradient.

If you load the solid here then what will happen even for the lowest solid fraction, if your pipe is completely filled and it is a complete dense phase flow. So, what you will see you will see that the pressure gradient has increased many fold. So, you see that this much you have increased the pressure gradient.

So, the multi phase flow that is why it is critical that is why it is more in one is it is important to understand the flow before designing the system. So, if you design the system for single-phase flow, operate a multi phase you see that how many times a fold of increased several fold of delta P has increased. So, if you will not design it properly your flow will never occur. So, it will stop because your delta P increases be enormous.

So, dense phase for the same velocity, delta P will be very high because the solid fraction is very high, solid loading at this location is very very high. You are operating almost in the packed regime packed bed regime. Now, you keep on increasing the velocity for of fixing the solid loading Ws 1 a is fixed. What will happen solid flow rate is fixed, you keep on increasing the velocity you will see that you are actually reducing the delta p; why, because now your solid diffraction is reducing. And at the saltation regime what is happening that the delta P is minimum at the saltation regime.

Now, if you increase the solid flow rate for the same velocity, what will happen your delta P will increase. It means the pressure gradient filling you keep on increasing the solid flow rate for the same velocity, your delta P or pressure gradient will keep on increasing ok. It means it is going to be the function of both velocity as well as the solid loading ok. So, if you keep on increasing the solid flow rate definitely your solid loading is going to be increased. So, it will keep on increasing ok.

However, if you will see here this line, if you see this line, this line is pretty much same; and it is remains always minimum at the saltation regime. So, no matter what is your solid flow rate, your minimum pressure gradient always remains at saltation regime and that is a very good news or it is a very good point or it is a very good thing.

Because it means if I have to design a pneumatic conveying, I would like to design a pneumatic conveying at the saltation regime. So, that what will happen that I will get the minimum pressure drop. And the velocity at which that regimes occurs is called saltation velocity. So, if I plot a graph delta P upon L with the flow rate or with the velocity, I will get this kind of a curve in the pneumatic conveying. And wherever this curve is minimum that velocity, I should operate the pneumatic conveying.

So, the pneumatic conveying should be operated it in that way. The standard setup can be prepared which is shown here. So, there can be a silos, you can put a pressure here ok, pressure gauge and the inlet and pressure gauges at the outlet to measure the pressure drop, then a gas can be flown here.

Now, you can see here with the help of blower or compressor the solid can be fed at a particular feeding rate; and that feeding rate can be maintained with the rotary wall which is placed here; this is the rotary wall. So, the solid can be placed here with the rotary wall. And you can measure that what will be the delta P in this length of the pipe. So, based on that, you can plot this regime for different solid flow rate. And wherever the delta P is minimum that is the velocity, you can find for different solid ratings you can find that velocity and that velocity is called the saltation velocity. You can see the if you can take a photograph or you can see through you will see that that is the saltation regime.

So, this regime one can operate the system, so that you can transfer the maximum amount of the solids and you can have a minimum delta p. So, your loss will be minimum, your trolley transport rate will be maximum this plot is called dense plot. And this is a log plot because your delta ps will vary enormously and change in the velocity will also be very high. So, it is a log plot where it is has been plotted and that is why you are seeing that this is looking like a linear movement.

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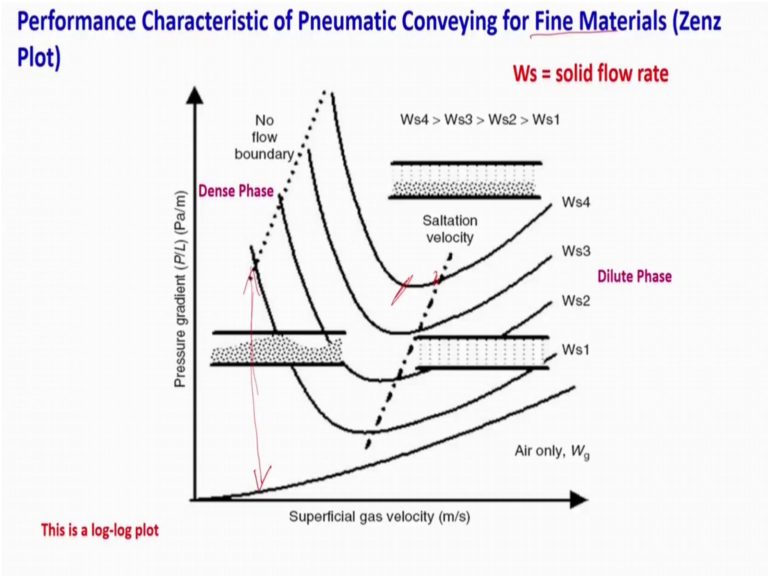

Now, similar thing one can draw for the fine particles similar to one control for the coarse particle like this graph was for the coarse particles coarse material. One can also draw it for the fine material the graph nature remains same; only thing whatever is changed is that the values which is going to be changed. And again if you see that if you have a either the dilute phase or dense phase regime, the fine particles or fine particles which is coarse. If you are operating in the dense phase or in a completely pad bed mode then your delta P will increase several fold increase in the delta P will be seen.

So, you will see a very high increase in the delta P at the saltation regime again you can get it here and that the saltation regime you will find that the delta P is minimum. Now, in the case of the fine, the nature of the curve is same only thing is observed here is that. If you will see this curve the saltation velocity or saltation regime observed at a minima, where it is the minimum there the saltation regime has been observed. Why with the fine the saltation regime was little bit far from the minima.

So, minima is at this location at this location and saltation regime is got from this as observed at this location. For in case of the fine, this has been observed and that is mainly because the fines also have the cohesive forces which is will be acting and because of that the saltation regime is being little bit delayed. And you see the minima not at the saltation, but somewhere before the saltation starts actually so that is the region that this minima is there, but still saltation is a good place to operate and you can still have a maximum transfer of the solid at the saltation regime. So, if you see that in that way, this minima will be in between the dunes and saltation regime, so that will be the better regime for the fine materials for the coarse material saltation is the back based scheme so to operate or base regime to operate.

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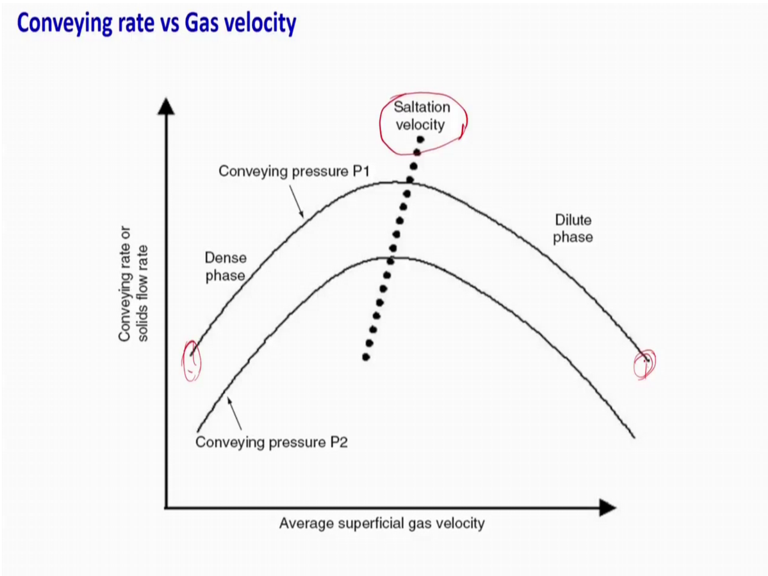

Now, that is the conveying rate that is what I was talking about that the conveying rate of the solid with the average velocity, so where the conveying rate will be lower, where the conveying rate will be higher, this is for the two different pressure. So, if you keep on changing the pressure, definitely your conveying rate will 1 different. So, these are the turning pressure P 1 this is the conveying pressure P 2, P 1 is higher than the P 2. Now, if you keep on increasing that this, so you can see that if you increase the pressure definitely your solid transfer rate will be higher.

And if you see that from the dense to dilute if you move initially for the dense phase it is a complete packed bed, your total transferred solid rate is minimum, because the solid movement is very, very small. You keep on increasing the velocity what will happen you will go to the slug you go to dunes and then you go to saltation and we observed the maximum solid flow rate or solid condition solid flow rate at a saltation velocity. So, again this is the saltation velocity at which the conveying rate for the solid is the maximum. And if you further increase the velocity in the dilute phase your keep or you will keep on reducing the transfer rate of the solids.

So, if you see here at a very why the dense the dilute phase regime is not considered very good for the pneumatic conveying because you see that here at this rate and this rate. So, at the dense phase regime, where the velocity is very, very low at the dense regime where the velocity is very, very low; I am still getting this velocity if you see the solid can transfer rate here and this you see that the velocity and that a solid transfer rate these two are approximately same.

But here you require enormously high velocity of the gas to transfer approximately same amount of the solid, which you can do in the dense phase regime at a much much lower velocity. And at the saltation that solid transportation rate will be very high compared to any regime. So, the saltation velocity or the saltation regime is the most preferable regime for the transfer of the solid in the pneumatic conveying. So, most of the pneumatic conveying, we try to operate in the saltation velocity regime or at the saltation velocity, so that my pressure gradient will be lower, my mass transfer rate or solid conveying rate is the higher.

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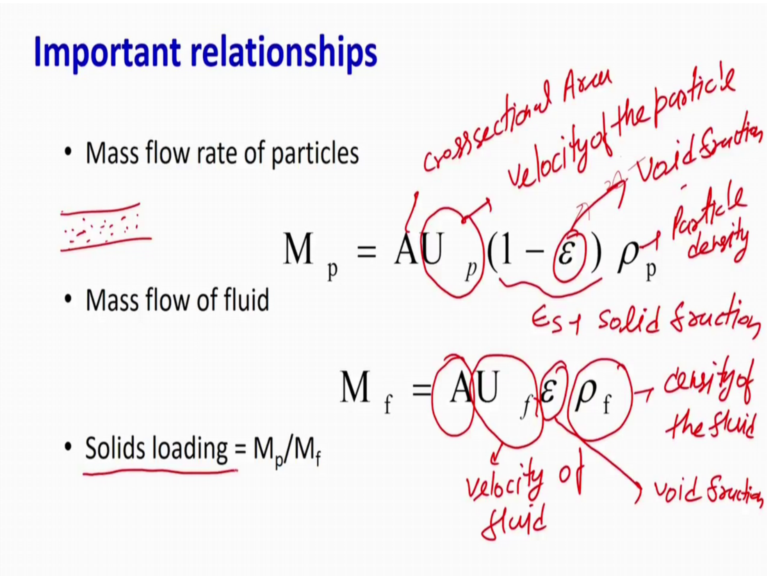

Now, we can also derive these things with the formula by writing the basic equations. So, what we can write here is that the first thing is that what will the mass flow rate of the particle. So, the mass flow rate of the particle can be given by this equation, where A is nothing but the cross sectional area, area. U p is nothing but the velocity of the particle; and epsilon is nothing but the void fraction. So, 1 minus epsilon will show you that this whole quantity will be equal to epsilon s which will be equal to solid fraction. And rho p is nothing but the particle density. So, if you see that this is nothing but whatever I have written is rho U A which is nothing but the mass flow rate of the particle now because this is a multi phase flow where two particles or two phases are present.

So, suppose this is a channel where the solids are being suspended in gas, then there are two phases. So, definitely the cross sectional area is not completely filled by the solid or by the gas. So, I need to multiply with the 1 minus epsilon which is taking that how much fraction of the pipe is being filled by the solid phase or by the gas phase. So, this is about that how much mass of the solid will be flow.

Similarly, for mass of the fluid you can get the same thing where A is the cross sectional area; U f is the velocity of the fluid of fluid. And rho f is nothing but the density of the fluid; and epsilon is void fraction. So, again rho U A and into epsilon to find it out that what will be the fluid flow rate.

And if I just divide it by M p upon M f I will get that how much solid loading is there. So, definitely if M p is very high it means solid flow rate is very high solid loading is going to be high and you are going to be in the dense phase regime or maybe in the saltation regime.

If solid loading is very low it means M p is very low you are going to be into dilute phase regime, it means total amount of the solute present is very very low. So, this is the way to calculate that how much of mass of solids or how much mass of the fluid is being transferred, and whether you are what is your solid loading and whether you are in the dense phase or in the dilute phase.

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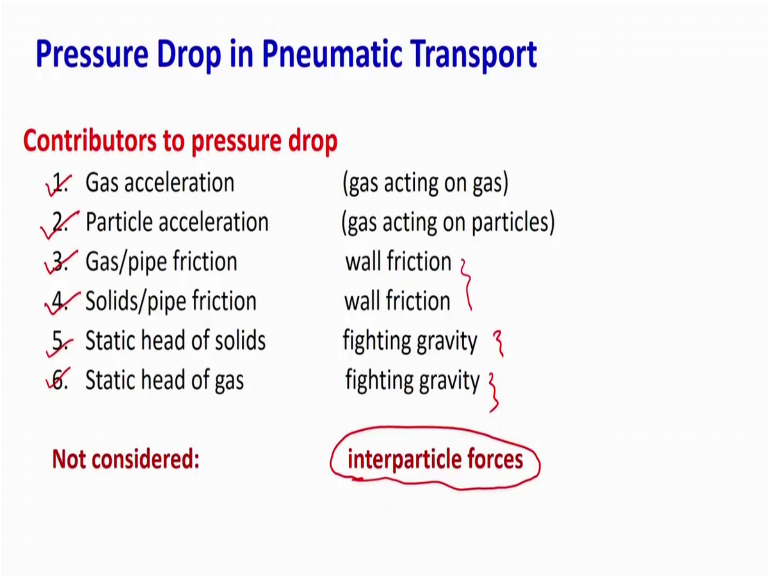

Now, moving towards the same discussion that the pressure drop if you have to calculate and we will discuss more about this in the future classes. But just to give you the brief idea that the pressure drop is pneumatic conveying is going to be function of many things. Now, what can be that parameters which actually contribute to the pressure drop, so they are definitely the gas acceleration that how is the what is the velocity of the gas at what rate the gas is accelerating.

The particle acceleration or how the particle is changing its velocity or the particle velocity, how much is the frictional losses is there by the gas in the pipeline, how much frictional losses will be there by the solids in the pipeline ok, these are all contributed to the wall friction.

Then static head of the solids if the solids are moving in a packed bed or even in the suspended what is the static head. So, it means the gravity part of it, and the static head or the gas it means the gravity part of the gases. Now, whatever we are not considering here is the inter-particle forces.

Now, this is very, very critical and we will discuss more about this in the later on classes. But most of the time we are transferring it in the dilute phase regime even the dense phase is very, very low volume fraction it is not like very high volume fraction. So, that is why what we do we can easily negate the inter-particle forces here inter particle forces means the collisional forces or Van der Waals forces which are acting between the particles we are neglecting them. And we can calculate the delta P based on these parameters which we have already putted it down here. Now, to calculate that to calculate the delta P across the pipe line, so that you can design the flow through system.

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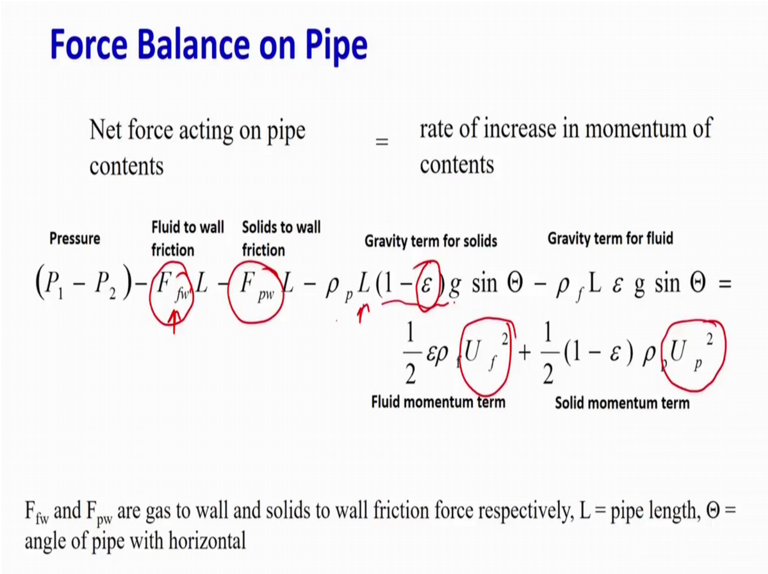

We can write a very simple equation and the simple equation can be written as that net force acting on the pipe content will be equal to the rate of increase or rate of change in momentum of the contents. It means if suppose what is the net force acting on the body will be equal to the rate of change of the momentum ok, so that is what the way we have defined our fluid mechanics. And we will do the revision and we will try to see these equations again, but just for the sake of completion that how to calculate the delta p. So, delta P net force acting on the pipe will be nothing but what is the delta P acting on the pipe.

So, P 1 minus P 2 then what will be the frictional component which of the which will be acting on the fluid. So, fluid to wall friction factor which we have said we have written it as F fw into L, where F fw is nothing but the wall frictional coefficient of the fluid and its length of the pipe then again solid it will be F pw, pw is nothing but the solid frictional component of the force.

So, F pw then the gravitational term will come which will be because of the gravity of the fluid we are neglect we can have the fluid the gravity term you can have a solid gravity term, so that solid gravity term will be what it will be nothing but rho g into L sin theta.

So, here rho g L rho p rho a particle and of the length into 1 minus epsilon because complete pipe is not filled with the only solid, so 1 minus epsilon where epsilon is nothing but the void fraction into sin theta we are assuming that pipe is inclined at a particular angle. So, sin theta will be there. If it is horizontal, sin theta component will be 0.

It means theta will be 0. If it is vertical, theta will be 90; it will be 1, sin theta value will be 1. If it is horizontal sin theta 0 value will be equal to 0, it means no gravity will take place. Similarly, for the fluid element gravity component we have added and that all is equal to the rate of change of fluid momentum term to the rate of change of the solid momentum term. So, rate of change of momentum is nothing but half rho f into epsilon U square of the fluid and if you want to have the solid it will be 1 upon 2 1 minus epsilon it means the epsilon has solid fraction into rho p into U square.

So, with this equation, if you solve this equation if you know all these terms F pw, F fw, F pw ok, if you know that what is your void fraction if you know what is the fluid phase velocity and solid phase velocity or particle velocity inside, you can calculate that how much delta P will take place. And it means if you calculate the delta p, you can know that at what delta P the system need to be operated, what should be the pumping power you need to supply, what should be the pressure, you need to give to the system, so that the flow can take place.

So, that is the way one can design the pneumatic conveying system by calculating the delta P across it by just measuring this values or calculating this values.

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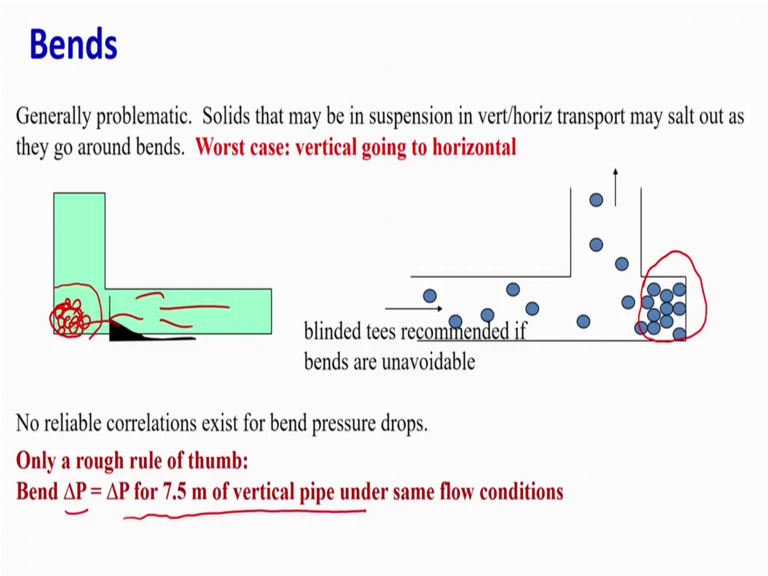

Now, we have already said that the flow can be dilute; the fluid flow can be dense. In case the flow is dense, what will happen then the Stokes number will be more than one it means particle will have their own say whatever we have already discussed. So, what will happen in such kind of a flow, if you have a bend then what will happen you will start seeing the particle agglomeration here, because what will happen the particle will go and it will hit on this place. And you will see that particle actually get agglomerated or it will stuck here and the area of the bends will be reduced and you will see huge pressure drop and it may occur that the flow can choke.

To avoid that kind of a condition we give for the bend instead of bends we give a tee kind of structure. So, what will happen the particle will go it will stuck here. Once it will be hit, the particle will get agglomerated in the P section the T will start jamming. And most of the particle will then start trying to move towards the bed.

So, you will not see the complete choking condition the choking condition will be occur at this place and the flow can still be taking place. So, these all are the rules this all out the ways, how to make a pneumatic conveying working how to do it. You can calculate the Stokes number to find it whether the particle will follow its own path or it will move with the gas; if it is not for moving with the gas then you have to give some extra space for the blockage ok.

Generally, the thumb rule says that the delta P of the bend should be equal to delta P of 7.5 meter vertical pipe, so that is the thumb rule. It means the bend you will get that much delta P which you will get in a 7.5 meter of the straight pipe line vertical pipe line operated at the same flow condition as it is being operated at the bend. It means you have to have calculate the delta P losses because of the bend it is going to be 7.5 times of the loss in the straight pipe line whatever you are going to get instead of 7.5 meter long pipe you will get exactly the same in the bend if you are having the same operating condition.

So, these things will need to be taken care before designing the pneumatic conveying system. We will discuss about the delta P equation for the individual flows once again and we will try to see that how to precisely control or how to precisely measure the delta P or how to precisely calculate the delta P to design a system, which will be working perfectly fine.

So, this is all about the flow regimes in the gas solid, the gas liquid flows. And with this our second part of the course is completed.