Multiphase Flows
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Lecture – 05
Flow Regime Map for Fluid-Solid System

So, last class we were discussing about the flow regime in a gas liquid system and we have discussed about the different regimes, advantages of different regimes, drawbacks in the different regimes, and how the different regimes changes with the change in the diameter or change in the orientation of the pipelines.

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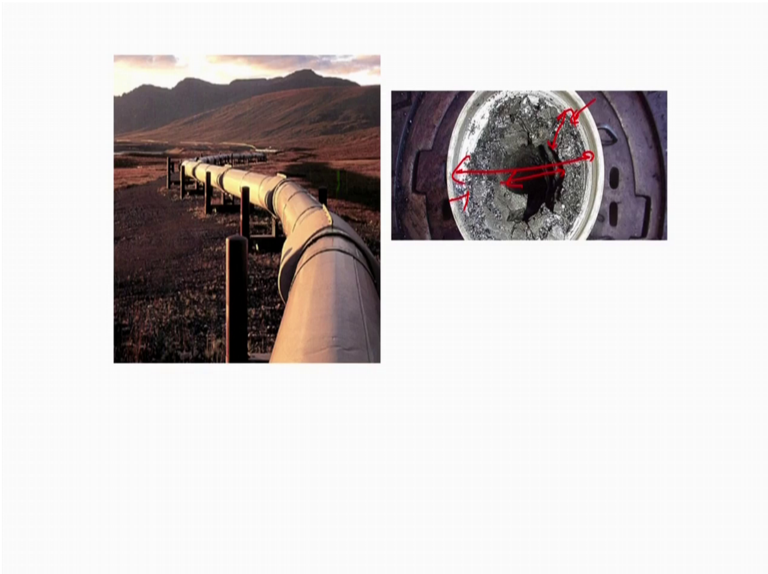

And implications if you do not operate in the desired regimes like; this is the blockage which we have discussed here.

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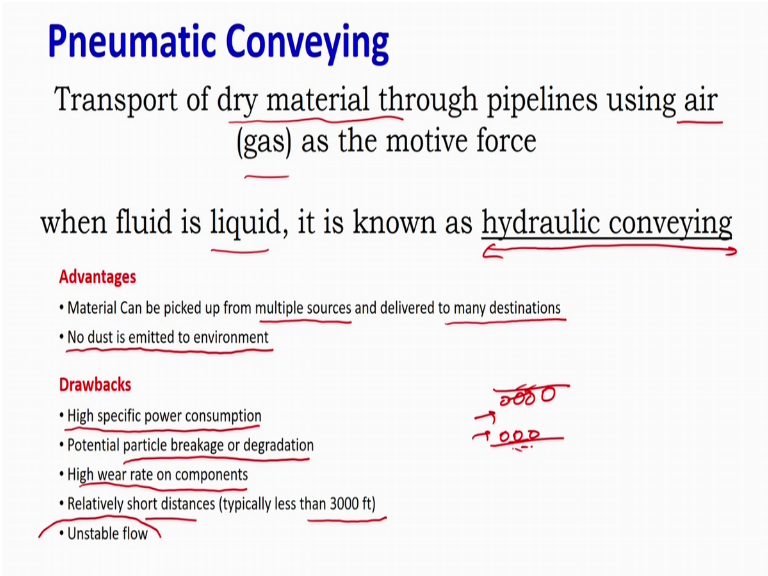

Now, moving towards the next stage and that is about the pneumatic conveying which we say or kind of a transportation of the solids. So, right what we have discussed is the gas liquid. Now, what we are going to discuss is the gas solid and liquid solid. Now, most of the industries we use to come we have to transport the solid from one place to another place. Now, there is a two way of doing that because we know that the solid it is not like a fluid which you can pump.

So, either you have to push the solid with by using air or gas any gas or by liquid or you have to physically transport it. So, physically transport means you have to transport it through the belt conveyor, bucket conveyor or by using some truck or any transporting medium. So, belt conveyor, bucket conveyor, I think you have already done in the mechanical operation course, which is not part of the multiphase flow, but whatever we are mostly interested is in the pneumatic conveying.

Now, this is widely used in many industries to convey the solid from one place to another place particularly when the solid is kind of something which you cannot convey through the belt. It means you cannot use it the open media whether the solid will be degraded or it will emit something to the atmosphere, so one need to do the pneumatic conveying in that place.

So, pneumatic conveying is nothing but whatever I said is the transportation of the drive material through pipeline using air or gas as a motive force. So, mostly it is air which is compressed air or air at a lower pressure that depends on that how much you have to energy you require to transport the solid from one place to an inter place. Or sometimes it is a gas which is being say like a flu gases which is being immersed outside of the boiler and you want transport the ash which is generated in the combustor all kind combustor from one location to another location. So, pneumatic conveying is widely used.

And if suppose instead of air or gas if you use liquid as a media then it is called hydraulic conveying. So, both is the conveying means is very clear the transporting the solid from one location to another location. As I said that it has several advantages like material can be picked up from multiple sources and delivered to the multiple destinations.

Now, this is a very very important point. So, suppose if I have two or three locations, where I have same material which is being generated or different material which is being generated. And I have two dumped at a particular location I can use a pneumatic conveying if you are using belt conveyor or any other thing, you have to have a different conveyor system there.

And the most important and significant point why it is being used that no dust is emitted to the environment; So, suppose if ash I am transferring through the belt conveyor or any of these fine materials, which I am transferring from the belt conveyor and to open to the atmosphere. And if the wind speed changes the dust or the this ash particle can suspend into the atmosphere which is hazardous to the health so that is why the pneumatic conveying is being used. And this is the one of the most important thing because it is the environmental friendly process where you do not emit anything to the environment.

Now, it has definitely several drawbacks compared to the advantage. The advantage main advantage is the environment concern, but as you know that if you have to push the solids you require high energy so that is the first disadvantage that you have high specific power consumption. You will have a very high power consumption because you push the solid from one place to another place.

Now, you think about if I have 10 kg ash and if I ask you to pull the ash from this place to from a particular location to say 100 meter how much power you have to spend, how much energy you have to spend to pull that 100 kg of the ash from one location to another location. Approximately, similar if suppose I want to transfer the 100 kg of ash from the pneumatic conveying I have to use the similar kind of a power. So, it is a waste of energy or you can say the high energy requirement is there and that is the major disadvantage of the pneumatic conveying.

Potential particle breakage and degradation can occur because now you are putting a lot of energy you have so if you have to do that energy will come in form of the velocity or the kinetic energy. So, it means you have to operate the system at a very high energy or high kinetic velocity; in that case the a and this particle can degrade and because of the friction of the wall, it can either degrade, it can even break, it can even damage the pipeline through which it is moving. So, that is the other problem that the particle can break or can change the shape or it can also degrade because of the high frictional energy generated.

High wear rate of components. As I said that suppose there is a pipeline and I am pushing the solid particles from this near the wall the friction rate will be very high. And because of that the erosion will take place, and the particle this pipeline will damage over the time or it will eroded. So, that is why it is being used for short distance and that short distances in the range of typically 3000 feet or you can say that the 1000 meter respectively so 1 kilometre in the range.

And unstable flow is the most disadvantage, and how to make the flow is stable that what we are going to see in this course. So, the flow is mostly unstable. And if you just a small change in the velocity will change your flow dynamics completely. And we will see that you may change from the moving condition, moving solid condition to the choked solid condition, it means nothing will move at all. So, the flow dynamics maintaining the flow dynamics itself is a very challenging and that is also a drawback because it is not very easy to operate the pneumatic conveying system.

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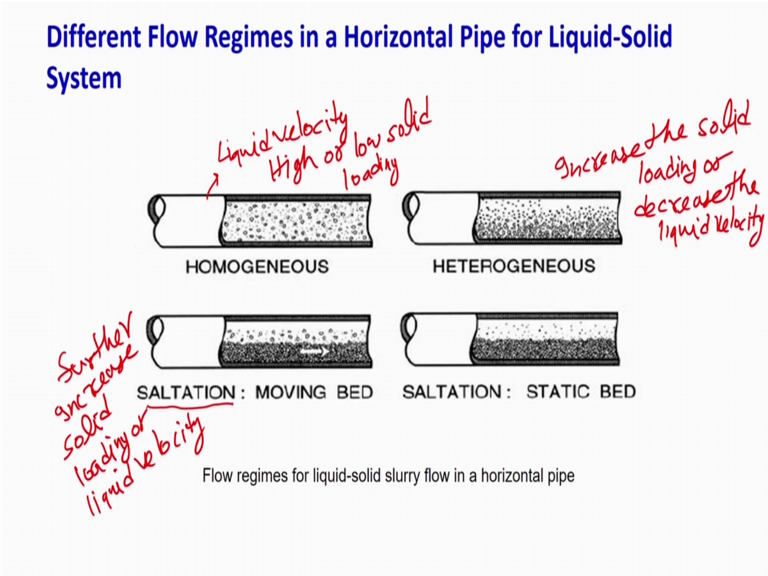

So, now first let us discuss about the hydraulic conveying which we say that liquid solid system. So, in a liquid solid system suppose if I have to convey the solid from one location to another location what will happen if the liquid velocity is high and solid fraction is lower. So, you can see that these curves whether the liquid velocity you are keep on reducing or solid loading you are keep on increasing.

So, if your liquid velocity is high or solid loading is low, so I will say that this is say liquid's velocity is high or low solid loading. Then what will happen that your solid will be uniformly suspended across the pipeline and a smooth flow of the pipe of the solids will take place and that is called homogeneous regime.

Now, either you increase the solid loading, here increase the solid loading or decrease the liquid velocity. In any of these two either you want in to increase the solid loading, you want to transfer more solid or you are reducing the liquid velocity, what you will see you will see that some of the solid will start getting suspended and settle down. And that is called heterogeneous regime where some of the solids will be suspended which will be flowing uniformly and some of the solids will start settling, so that is called heterogeneous regime. If you further increase the solid loading, it means increase again the solid loading is increasing.

So, increased further increased solid loading or decrease the liquid velocity, then what will happen that the solid will get settled and only few solid will be suspended in the liquid and both will be moving. So, solid get settled it does not mean that it is not moving; it will be moving still and some of this void fraction will not be as a packed bed void fraction which will be moving weight kind of. So, the both the solids are moving and liquid is moving so the liquid is being pushed, solid is being pushed by the liquid, but it will be mostly settled at the bottom that regime is called saltation or moving bed regime. Now, this is the saltation regime which is being actually moving as solids are moving as a packed bed.

And the liquid is being push if you further increase the solid loading you will get that what will happen that now the energy will be reduced the total energy which will be gained by the solid from the liquid, it will be kind of reduced. So, that is why the solid will start getting settled, it will no more suspended. And you will see that the solids are moving like a packed bed its regime is called saltation; and still the solid will be transported.

If you further reduce the liquid velocity or increase the solid bed then what you will see is a static bed kind of a condition; and the solid transportation will reduce like anything. So, your solid will move, but it will be very slow rate, it will move and only the solid which are suspended in the liquid on the top side. It will be moving most of the solid will be like a packed bed.

So, that these are the four regimes you operate if you found if you transport in the hydraulic conveying room conveying regime. It is homogeneous, heterogeneous, moving bed or static bed. Now, this can be achieved either by reducing the liquid velocity or increasing the solid loading. So, in that way the overall liquid a kind of a hydraulic conveying can take place.

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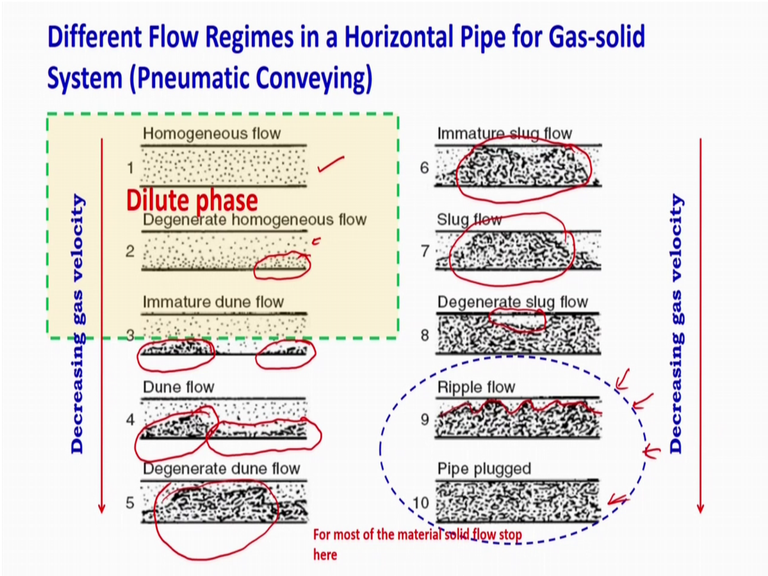

Now, coming back moving back to kind of forward to pneumatic conveying which is for the gas solid transportation and which is of major interest in industry compared to the hydraulic conveying. Hydraulic cunning is being used, but at a very limited places. Mostly the pneumatic conveying is being used where the gas solid flows gas is being used to push the solid or to convey the solid from one location to another location. Now, there are different regimes, now you see the regimes are very high compared to the liquid solid regimes.

So, the first is again the same either it will be the same either you are decreasing the velocity from once we are moving from the top to the bottom, you are decreasing the velocity or in other word you can say that I am increasing the solid loading. So, both are same either you are decreasing the velocity or increasing the solid loading you will see these regimes. So, right now whatever we are discussing is based on the decreasing the gas velocity.

Now, if the gas velocity is very high, you will get homogeneous flow it means what the solid will be suspended across the bed like this, and across the whole pipeline and it will be moving. So, you will see the smooth transportation of the solid and that is called homogeneous bed. If you further reduce the velocity of the gas, then what will happen again some solid will start getting settled and it is called degenerated homogeneous flow. It means the homogeneous flow is now being kind of being transferred to the heterogeneous or you can say that is a start of heterogeneous flow, so that is why we call it degenerated homogeneous flow where some solids you can see that is now started settling or going towards the bottom of the solid pipe line the solid concentration is high compared to the top part.

And then if you further reduce the solids then what will happen you will see the dune kind of a structure will be formed solid dune. It means what the solid is being settled down and they are forming the clusters or dunes, in fact, the flow is taking place. So, some of the solids are suspended, some of the solids are formed deuce is being settled. So, solid fraction near the lower wall is further increased and it is still moving.

Now, if you further reduce the velocity, the dune height will keep on increasing and more and more solid will come and settle down bottom side. So, you see that the dune side is increasing and number of solids at the bottom portion of the pipeline is increasing. So, you will see that dune flow. So, this is called the complete dune flow. Now, if you further reduce the velocity again what will happen that the more and more solid will be settled and we called it as a degenerated dune flow. So, you will see a lump of the solid which is actually moving together ok. So, these are the lumps and this lumps is actually keep on increasing. So, this is called a degenerated dunes flow.

Now, if you further reduce the velocity, now you will see that the whole pipeline is now being slugged. So, the similar why we call it is a slugged flow because the size of the dune is equivalent or similar to the size of the pipeline. So, we call it as a solid plug. So, slug the way we were talking about is the gas slug or liquid slug, here we are talking about the solid slug. So, solid will form a slug, a big shape and the diameter of this it will be equivalent to the or equal to the diameter of the pipeline through which the transportation is taking place. And you will see that whole slug is actually moving.

Now, if you further reduce the velocity then the slug will actually keep on increasing and with this we called as a slug flow completely. And if you further reduce the velocity, you say that degenerated slug flow it means now you will see the whole pipeline is actually being filled with the solids. And you will have very small patches of the air you will see where the solid is being suspended. Most of the time you will see a slug the whole pipeline will be filled with the solids.

If you further reduce the velocity, we will see the ripple flow, it means it is like a complete solid now. And you will see that only at the top some boundaries is being emerges if you will see this boundary which I am just drawing here and it is called ripple flow because its make a ripple kind of a structure. So, now, the only the gases are flowing on the top and the solid is being now fixed at the bottom. If you further reduce the velocity, then you will not see any flow of the gas, you will see that the complete pipe is plugged. So, it is completely filled with the solid. And so what will happen in this case definitely the flow will be completely stopped and you will not see any solid movement at all.

So, if you keep on reducing the gas velocity by at the same condition by sort the same solid loading, you will see these condition to be occur or other way you can also get the same if you fix the gas velocity, but keep on increasing the solid loading, you will see exactly the same thing is happening. So, these are the conditions. And these are the different flow regimes this occurs and that is why operating a pneumatic conveying is very very tough and that is what I said that earlier that it is not a stable flow it is unstable operation. And small change in the velocity can change from complete moving bed to a complete plugged bed where the move no movement is taking place.

Now, most of the solids these two ripple flow and plug flow the solid movement is completely stopped and hence no transportation take place; So, most of the material this happens because it is so plugged that it is almost impossible to move anything inside. So, this is kind of something which is completely undesirable regimes because here you will not see any moment of the solid, these are the called dilute flow regime.

Now, if you see that where I have cut this box, I have cut this box on immature dune flow and on the top parts where the solid is homogeneously failed here. So, these are the dilute phase. The bottom phase of bottom part of the, this immature dune flow is not the dilute flow at all it is started the dense phase. So, we have already discussed what is called dilute flow, what is called dense phase flow. So, if you see that these are the dilute phase flow, and rest everything is the dense phase flow.

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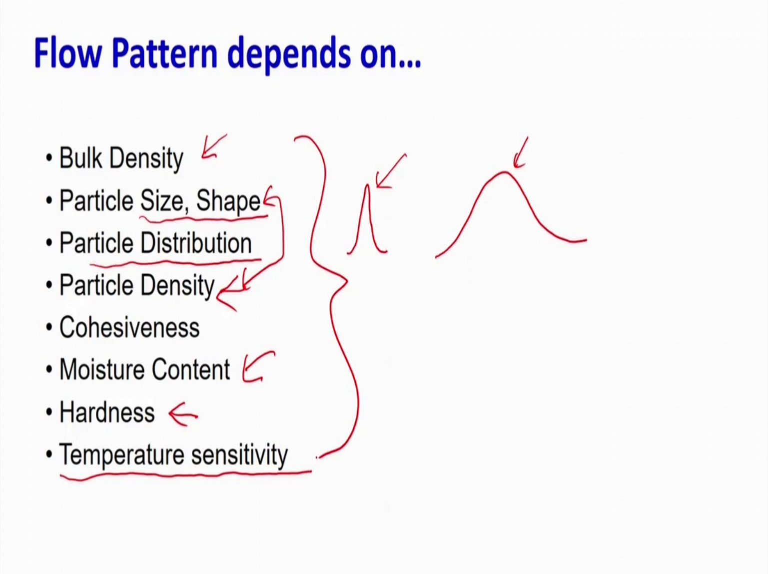

Now, the flow pattern inside you just not only depend on the velocity or the solid loading, it also depends on the many other factor and that again make the system more complicated and difficult to operate and design. The first thing which also matters is the bulk density that the solids which we are transporting, what is the density of that and what is the bulk density of the solid, we have already defined the bulk density.

Then what is the particle size, particle shape, this also is matters that what is the size of the particles if your size is particle size is very big or if your particle size is very small, very fines, what is the shape of the particle. Now, why it depends on the particle size and shape we will discuss it some after some slides. Then the particle size distribution is also very important. So, most of the time we design the system for our uniform solid size based on the outer mean diameter or weight average diameter, but the particle distribution is also very important.

Suppose, if you have to design an pneumatic system for a system which is very narrow distributed, particle size is very narrow distributed and the system where the distribution is very wide your design of the pneumatic conveying system will be completely different. Because there will be some bigger size particles which may starts settling down even at a lower velocity or even at a higher velocity. So, this is kind of very difficult to understand and that is why the particle distribution plays also a very critical role in designing this kind of a system. Then the particle density, bulk density also play a role and particle density also play a role and this two we will discuss that how it plays a role, and it is actually classified the type of the particles you have.

The cohesiveness of the particle is also playing the role. Suppose, if particles are cohesive in nature and they comes and agglomerate over the time then what will happen your particle diameter will keep on changing with the length of the pipeline. And you will see the regime transition as you will move forward the way we have discussed the two phase flow evolution where the kind of the one phase is being the gas liquid is being transported or kind of converted to the gas phase.

So, what will happen over the pipe length, you will see the transition in the flow regime. Similarly, the particle is cohesive in nature they are agglomerative in nature they are forming agglomerates. Then what will happen their size will change over the length and if their size will change over the length you will see the regime will transfer because now the momentum requirement will be different.

Moisture content is again a various this kind of important parameter because if the solid is moist or wet then it will have a different density altogether, and they will be very susceptible to the agglomeration. The hardness is matters now why you feel that hardness is matter because if the particles are very hard, they will have very good erosion properties. So, they will erode the pipeline. So, you should understand that what is the hardness of the pipeline, hardness of the particle.

And the temperature sensitivity is very very critical for the pneumatic conveying because of the frictional losses as we are transferring the solid we are operating the system at a very high velocity as I said earlier, the frictional losses is going to be high. And because of the frictional losses, thus there will be some temperature generation or some temperature rise.

So, we need to understand that the solid should not be very highly temperature sensitive, because if they will be very temperature sensitive then what will happen there will be degradation of the solid will take place. So, all these things we need to take care not only the velocity and solid loading all these parameters also plays a equally important role in understanding the pneumatic conveying.

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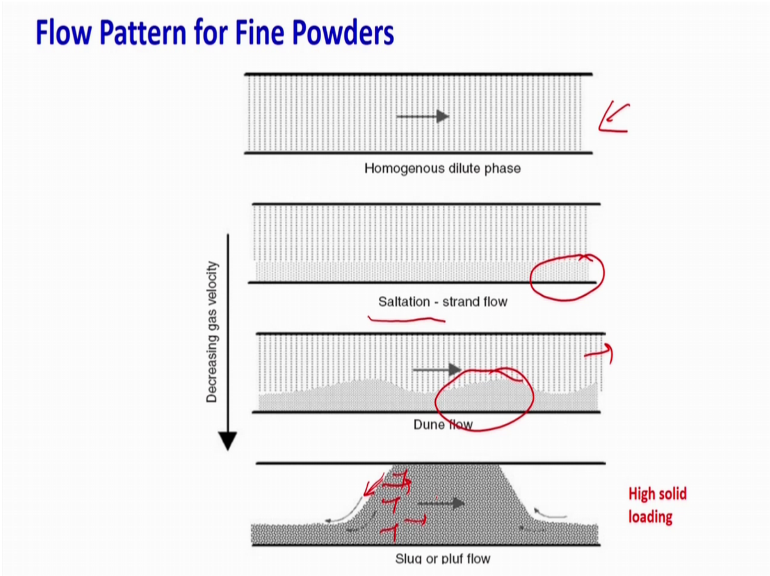

Now, the flow of fines as I said that the particle size also matters, so why it matters because the flow of fines and flow up the coarse particles are different. And the flow regimes for the fines is also different and flow regime in the case of the course particle is different. So, some of the regimes you will not see in the coarse particles, which you can see in the fine and some of the regimes you will not see in the fine particles, which you can see in the coarse.

So, in the fine particles, if you have very fine particles then what will happen that what are the regimes which have the kind of commonly seen is the homogeneous regime which is the dilute phase because the particles are very small. So, they will be suspended in the particle even at a lower velocity. So, it will be kind of a uniformly suspended. If you decrease the velocity then what will happen, the solid will get settle down and you will see a small layer of the packed solid near the bottom, and that is called the saltation regime.

So, it means what is happening now it is a kind of a moving bed of the solid which is moving. If you further reduce the velocity then you will see the dunes, you will see the dune shapes and that is called the dune flow. So, some of the solid will be suspended which will be flowing on the top and most of some of the solids will be kind of settled down and we should be moving like a dune and so called a dune flow. And if you further reduce the velocity, then you will see a slug or plug of the solids. And what will happen that the solid loading at this conditions will be very, very high and you will see some recirculation of the gases along this bed because this is completely filled.

So, what will happen some of the gases will be passed through here some of the gases which are coming from the bottom will pass through here some of the gases will go and come back is kind of it will be re-circulated along this bed. So, there will be some recirculation of the solids will also be seen; recirculation of the gases will also be seen. And this slug will be moving.

So, this slug can move. If the further reduce the velocity it will be completely choked and there will be no movement at all. So, these are the kind of some regimes which is being find in the fine particles. So, you can see that some of the regimes like immature duals, ripple flow and all those things is you get rid of all the very fine particles.

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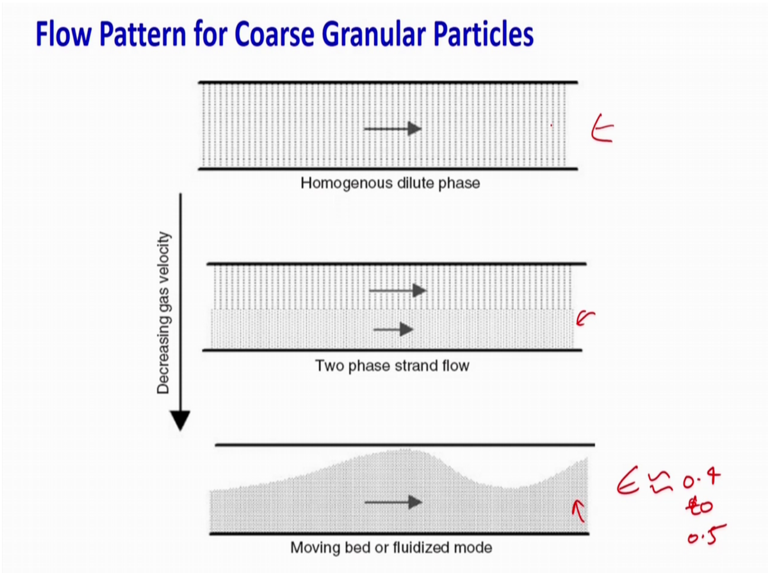

Now, if you have a coarse particles, then what will happen the regimes will actually get further simplified and you will get either the homogeneous flow regime. So, for the coarse particle, the velocities would be very high to get the homogenous regimes. So, all the particles will be uniformly suspended. Now, if you reduce the velocity gas velocity, what will happen the solid will immediately get settled and you will see the two kind of a phase flow.

One is the top the gases are flowing and the bottom the liquid will be solid will be flowing and that is called again saltation regime where the solids are actually moving like a packed bed. So, it will be a moving bed regimes.

If you further reduce the velocity you will see kind of a moving bed or dunes kind of a flow which will be completely moving or you will get a fluidized bed. So, in which the solids actually is moving and the solid fraction is increased, but the solid fraction will be in the range of 0.4 or 0.5. So, epsilon solid will be in the range of say around 0.4 or to 0.5. So, you will see this kind of flow where this will be still moving. I am discussing only those regimes where the flow is taking place. If you further reduce the velocity we will get the repel flow and plugs a complete plug flow, where the solid will not move at all. So, these are the regimes you will see in the coarse particle conveying.

The other regimes whatever I have discussed you will see that once the fine particles are conveying. But if you will try to understand then the most of the solids are actually being conveyed in these two regimes here the overall solid can the amount of the solid which is being transported is very, very less because solids are uniformly distributed. And you require a very high velocity here to operate because if the velocity will be low then solid will not be suspended.

So, homogeneous regime or dilute regime that is why it is very very few cases people use this for the transportation of the solids. Because it requires very high energy and transport the less amount of the solids compared to the saltation regime of moving bed regime or fluidized bed regime where the amount of the solid being transferred is very high at lower energy.

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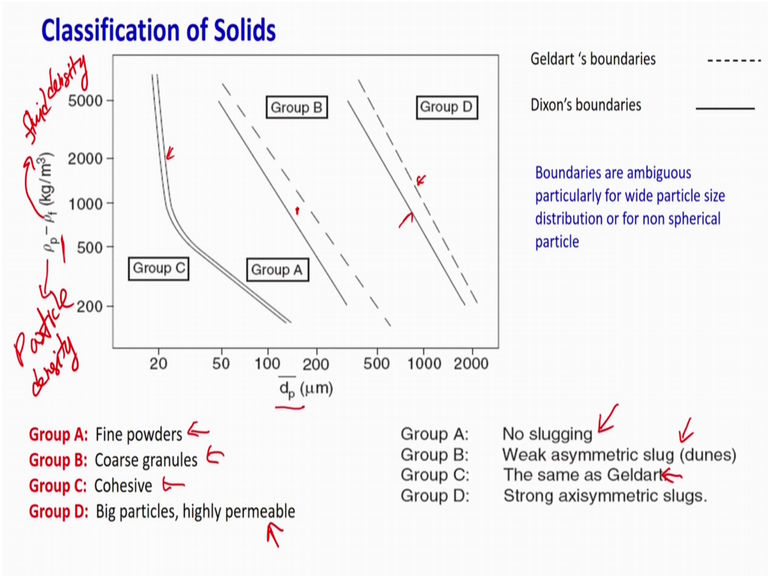

Now, the whole solid before moving to the pneumatic conveying further, the whole solid actually is being classified and in four groups that is called group A, group B, group C, group D by Geldart in 1972. This is a major work which actually classified the whole solids in four parts and that is the region that because of the Geldart chart we came to know that the particle size and solid density. It is a factor which is going to tell that what are the regimes; we are going to operate and the pneumatic conveying about the behaviour of the pneumatic conveying.

So, what Geldart did actually Geldart has classified the whole solids whatever is available in four parts group A which is called fine powders; group B which is called granules coarse granules; group C which is cohesive particle, and group D which is very very big particle or highly permeable particle. Now, he plotted the graph between the d p which is the mean diameter of the particle versus the rho p minus rho f where rho p is the particle density, this is the particle density and rho f is the fluid density.

So, this chart is valid for the gas for flow for the liquid solid flow; both the flow it is valid. Only the few density will be the gas density in case of the gas solid flow, and then it will be equal to the liquid density in case of the liquid solid flow. So, he divided the whole solids in this four part based on the rho p minus rho f and d p. And he found certain boundaries. Now, this boundary is are not fixed its ambiguous in nature and that depends on the particle size distribution and knowledge that whether the particle is spherical or non spherical; based on that the regimes boundaries are not very fixed.

And in later on Dixon has found the another boundary. So, the dotted boundaries whatever you are seeing is here for the Geldart particle, and like this, this is called the Geldart's particle, and continuous line is for the Dixon's particle so Dixon's boundaries. So, if you see that Dixon's boundaries and Geldart's boundaries, there is certain difference.

So, at the boundary lines you are not very sure that whether you are in group A or group B. So, the boundary line particles is always dangerous to operate and it can behave like a group A or it can also behave like a group B. So, suppose the particle which is somewhere here as per Geldart classification, it can behaves like a Geldart A ideally should behave as a Geldart A, but as for diction it will be Geldart B. And it has been seen that it can behave in any way it can either behave as a Geldart at a particle or Geldart B particle.

Now, what is this classification all about. So, what he did, he put the x-axis as a diameter of the particle; y-axis as a density difference between the particle density to the fluid density. Now, for very fine particles all density does not matter that what is rho p minus rho f; if the particle size is very, very small say less than 20 micron they comes into group C. It means they have cohesive in nature. So, what will happen they will cohesive and they will form a bit clusters of the particles ok. And because of that the transportation of this kind of a solid is very, very difficult.

Group A is the base to transport it are fine particles which has density the kind of diameter which is more than 20 to 20 micron and density in the range of 500 to 5000 micron. The size of the particle kind of if you keep on increasing the size of the particle then what will happen it will try to move from group A to group B and any particle which is more than say 500 or 600 micron of a density difference of around 1000.

So, if you are operating a gas solid you will be in a group B. So, it will be kind of a group B particle. Then if you further move down if you further increase the velocity sorry further increase the particle size we will go to the group D size.

So, the different particle have a different characteristics as I said here that A is fine particle, B is coarse granular, C is cohesive, D is big particle. And as per the Dixon, what it can be further classified as A it means there is no slugging. So, if you have a group A particle, you will not see any slug flow.

Group B, you will see the weak asymmetric slug or very weak dune fluid you will see in group B particle. Group C particles, the same this is very cohesive in the nature, so the transportation of this kind of a particle is very very challenging. And group d is very highly susceptible to the slug conditions. So, it will make the slug flow very fast, so that is the way it has been classified.

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Classification of Solids and Conveying Characteristics

Geldart or Dixon Classification	Dense Phase Conveying Characteristics
A	Can be conveyed in fluidized mode, easy to convey, do not form slugs naturally
B	Difficult to convey in "conventional" dense phase, unsteady and unpredictable plug formation, large pipe vibrations
C	Very difficult to convey in conventional dense phase, forms impermeable plugs that break up. Special techniques required to convey
D	Natural slugging ability and high permeability helps in dense phase conveying. Operationally easiest to convey in dense phase

And if you see from the transportation characteristics of each of those group A particle, so if you have group A particle, it can conveyed in the fluidized bed mode and can easily convey do not form any slugs naturally. So, in so group A particle you can convey very easily in the fluoride bed mode; it means you can keep your solid reloading very high you will not see any slug condition. So, the chances of complete stop of the flow is very very low.

Group B is difficult to convey in conventional dense phase flow. So, it is kind of if you want to convey in case of the like a fluidized bed or any conventional flow it will be difficult. It is unsteady unpredictable flow formation can possible and the pipeline vibration will be very very high because these particles are coarse particles. So, it can form plug at any time; if you do not maintain the condition properly it will just kind of settle down at the bottom, and it will form a plug flow. So, this kind of a flow is kind of it is very difficult to operate and you will see the kind of the vibration a lot because the size particle is very big the energy requirement is also very big. So, your pipe will be keep on fluctuating or vibrating.

Group C, it is very, very difficult to convey because they are cohesive in nature conventional dense phase method cannot be used here too like a slug flow or something it cannot be used here. They are kind of impermeable plug is being formed. So, they are cohesive in nature. So, they form a plug which is impermeable. So, even the gases will not come through it; and it will stop the flow completely. And kind of some special techniques are needed to transfer this kind of a particle mostly this kind of a particles are transferred in the slurry fetch by using the screw pump or something. So, this C, group C type of particle is very very difficult to convey.

Then group D is natural slugging ability and high permeability. So, this is the major thing which helps in the transportation of the solid. So, they make a slug, but they are permeable in nature because the particle size is very very big and they are permeable. So, because they are permeable, they can easily transfer it in form of the slug big slug there air will be passing through in so that what will happen the movement will take place. And you will see the dense phase conveying easily, and you can transfer it in form of the slug. It is very easy that is what I said that to convey this kind of a particle.

The group D particle if you want to move from one place to another place, it is very easy. It will form a big slug and we have a very low velocity in form of the slug you can move them. So, this is the way the solid conveying characteristic take place. So, group A, and group D is relatively easier to convey. Group B is difficult to convey, but still it can be converted through the pneumatic conveying.

Group C is very very difficult, it will be cohesive nature, and you need a special technique to measure to convey the group C particles. So, what this problem is the group B. And if you have a group B particles, you have to be very careful because it can be can make the flow on this table at any time and you can see that plug formation and which can block the whole flow all together.

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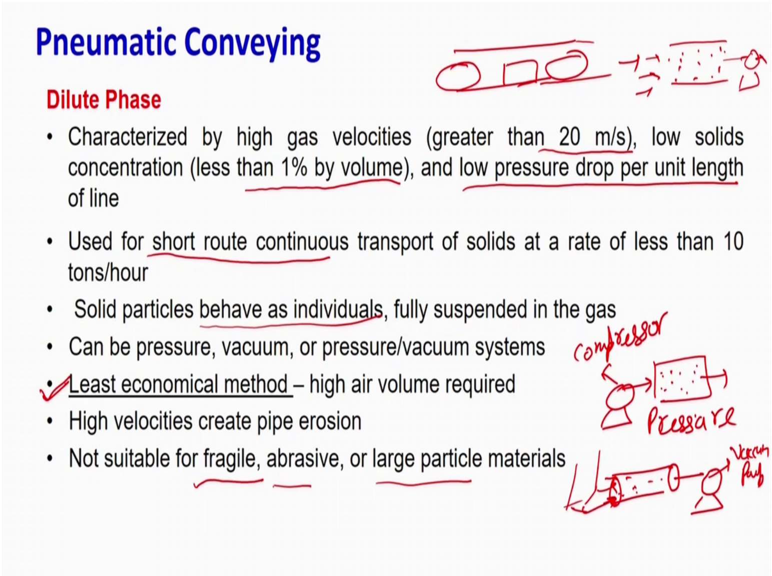

So, the whole pneumatic conveying as I said that dilute phase and dense phase is being divided in two parts. One is the dilute phase conveying; another one is the dense phase conveying. As the name suggests dilute phase conveying and we have already discussed it that the dilute phase conveying means the overall discrete phase fraction is very, very less.

Here the discrete phase fraction or solid fraction should be less than 1 percent and it is called the dilute phase conveying. You require a very high velocity to maintain the dilute finish cutting because this is homogeneous it means all the particles are suspended or it just started immature this kind of homogeneous. It means just started settling or the top part of the dune slope it means so that is what I just discussed here.

So, these three regimes are called the dilute freeze regimes here whatever we are seeing here. In all this, the particles are suspended. And because the particles are suspended you require a very high velocity and we require a velocity for this kind of a suspension around roughly around 20 meter per second or more than that. And solid concentration should be very, very low less than 1 percent the pressure drop per unit length will also be very low here and that is the reason why the pressure drop is very low because the amount of the solid used is very, very low.

So, ideally you will see the pressure drop which will be very close to the pressure drop of the gas phase and gas phase pressure drop will be only because of the friction.

So, what will happen that overall pressure drop in this kind of flow will be very very low, but the amount of the solid being transferred per unit energy whatever you are using operated the gas whatever you are slipping will be very very low, so that is why because the energy loss is very, very high. It is used for the very short routes ok. And most importantly, where you need the continuous transport of the solid because other transportation where it is because transported in form of the dunes or slug or at a moving bed what you will see, you will see the fluctuations in the solid.

So, sometimes a slug will flow, a slug will come other that time there will be no slug. So, it suppose there is a pipeline and the particle is moving like a slug like something like this.

So, what you will see at the outlet you will see a pulsation flow. So, sometimes we get the solid, sometimes we will not get the solids. So, pneumatic conveying if you are having a dilute phase where the particle is uniformly suspended then what will happen you will see the continuous flow of the solids. So, suppose if it is feeder to any reactor where if this is used as a reactant solid, or used as a reactant or as a catalyst, we need a dilute phage because the overall the flow should be continuous.

So, this is the solid particles behaves as a individuals because they are settled down, they are kind of they are not interacting with each other, their fraction is very very low. So, you can see that the particle interactions are very very low here in this case and they are behaving like an individual solids which is suspended in the gas.

It can be used in the pressure medium; it can be used in the vacuum medium. You can use the pressure and vacuum system combination of both; it means you can transfer this gas either by using some compressor that will be called as a pressure medium or you can use a vacuum pump to suck the gas from the atmosphere or something gas on the pipeline. So, it can be called as a vacuum system.

So, we will discuss about the pressure system and vacuum system later on. So, it can be used either in this pressure system, it means again it means suppose this is the compressor, I am blowing the air here and moving the solids inside. So, this is being transported; this is called pressure and this is a compressor and; if I am using instead of this, here if I connected something which is a vacuum pump. Then what will happen the solids will be moving, the gas will be moving suppose this is coming from some hopper.

So, this will be sucked inside and the solid will be moving here. So, because the solid volume fraction is very very small, it can be operated both in terms of the vacuum, in terms of the pressure in terms of the both vacuum and pressure so that is the good thing about it.

But the most disadvantage which I said that it is a least economical why because you are putting lot of energy and you are transferring very low amount of the solids. So, solid loading is very, very low; solid transportation is very, very low. So, energy required to transfer per kg of the solid is very, very high. So, it is very low economical to use this kind of a transportation system. Then high velocity create the pipe erosion, because the pipe velocity, if the velocity is very high solids are moving also very high velocity, these solids will do lot of erosion because the velocity of the solids will be also very high the velocity of the gases is also very high.

So, there will be frictional losses, there will be losses because the erosion and that erosion will because of that the pipe will be kind of being kind of being a break very fast and erosion problem will be very severe. It is not suitable at all for fragile solids the solids which can break the abrasives and very large particle materials. So, if you have a particle size which is very very large, you cannot use this because if you are using for the coarse particle, your velocity requirement will be enormous for the dilute phase things. So, it is almost kind of a kind of impossible to transfer the large particles by the dilute phase regime so almost ruled out.

So, you can do the dilute phase regime transfer only through for the fine particles which are very fine and very low density. So, that it can easily be transported, but still it will require a very high energy. So, it is not a very economical method to transfer, but is being used because of the requirement; if the requirement of the system is to have a continuous flow of the solid, you do not have any other option other than the pneumatic conveying.

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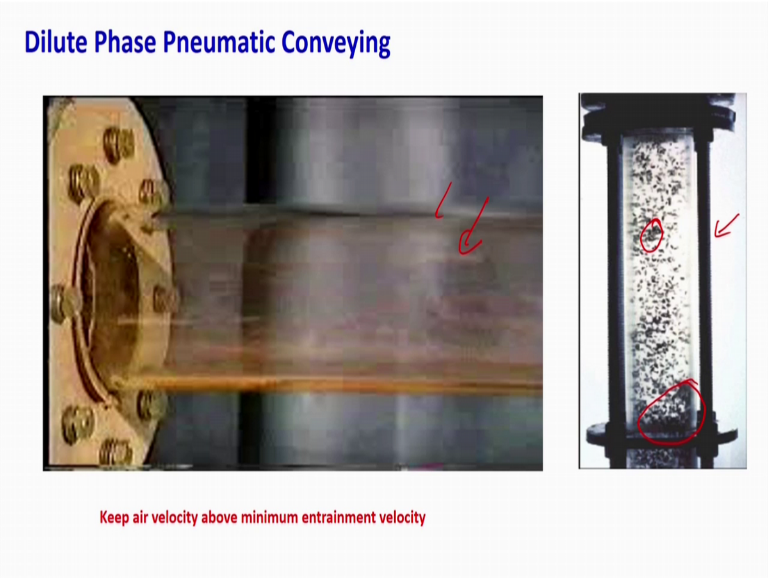

So, this is the typical photograph I have taken for the pneumatic conveying you will almost not be able to see anything here in this photograph. But there are certain particles we kind of suspended the camera resolution was not very good, you will not able to see much things here. This is the photograph taken from the literature and you see some of the solids here, but this is not exactly value phase regime.

This is the start of kind of homogeneous heterogeneous regime or you can say the immature homogeneous regime where some of the solids now start getting settled, you can see that this is a vertical flow, so some of the solids are near the bottom. But most of the solids are flowing at the centre and the solids are moving kind of uniformly other than some chunk most of the solids are suspended individually.

So, these are kind of a dilute phase regimes, this is the real kind of a dilute phase regime where all the solid particles are suspended individually because the solid fraction is very very small less than 1 percent; it is almost impossible to see the fines inside.

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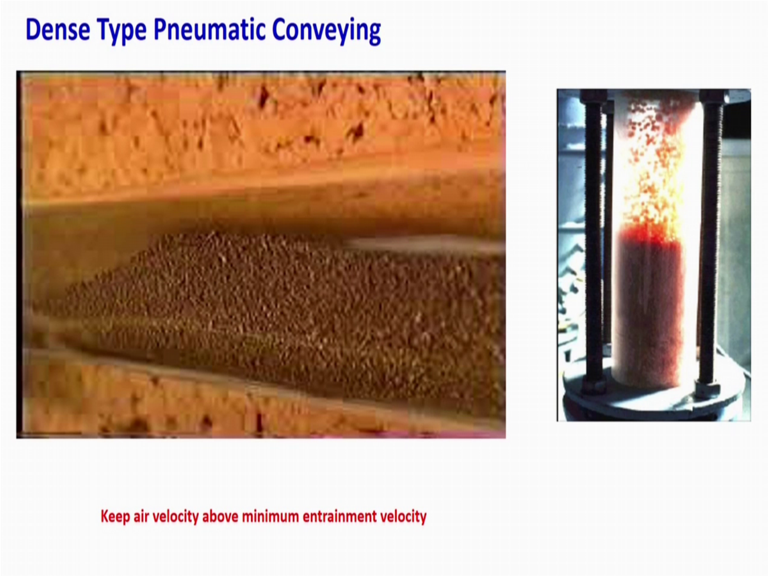

So, this is this now there is a dense phase, this before starting the dense phase I just give the photograph of the dense stage. So, you see that this is the dense phase, this is a dune or slug you can say or moving bed whatever you want to call it. So, it is moving as a slug or as a dunes where the all the solids are being suspended at the bottom, and it is moving you can see that the air on the top.

But most of the solids are settled at the bottom or this is in the vertical regime you can see that most of the solids are suspended near the bottom and it is slowly moving towards the top as a moving bed. So, this is kind of a dense type regime where the solid moves as a chunk in this form of the slug; dunes are in form of the moving beds, so that is called the dense pneumatic conveying; previous was the dilute pneumatic conveying where individual solids were suspended inside the pipeline. And it was almost impossible to see anything.

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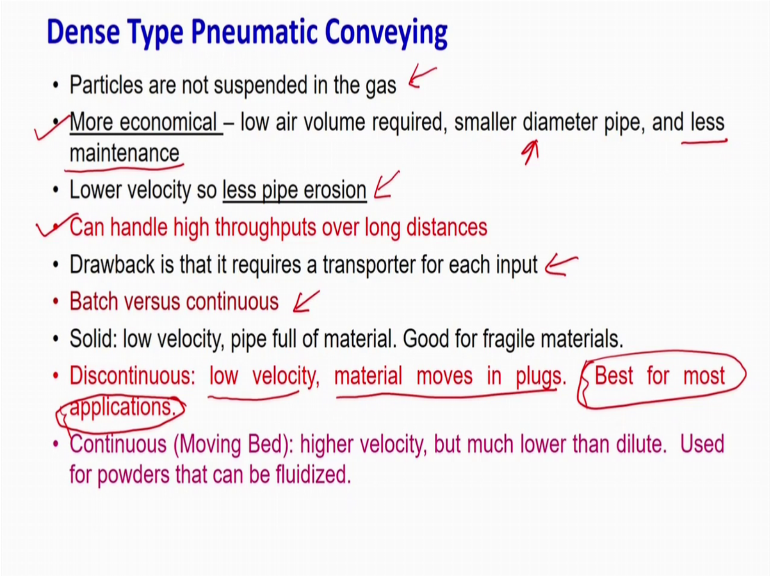

So, this is pneumatic conveying. As I said that you are seeing kind of particles are being suspended in the gas. So, it is not like any particles are being suspended; it will move in form of the dunes or in form of the slug or in form of the moving bed. So, particles are no more suspended in the gas phase that is called the dense phase. It is more economical, because now you require less air volume, and you are transferring more amount of the solids.

So, kind of that is why it is more economical. The only thing is the diameter of the pipes should be small and the maintenance cost here is very, very low because the erosion problem is very low, solids velocity is very low. So, the erosion does not take place. The only losses take place because of the friction. And because of the friction the pipe material may get kind of eroded, but because the velocity is very less, the rate of erosion will be also very less. Then that is what I just explained that velocity is very less or less of this kind of erosion rate it will be also very, very less.

The major important point for this is this that it can handle a lot of solids high throughput can be handled. It can transfer to a very high distance around 1 kilometre or 3000 feet you can transfer it easily, so that is the better thing in the dense phase. The drawback is that it requires transporter for each input now what is that we will see that it means we will require a compressor in each line if you have a multiple line in each line you will be required the compressor. So, it is not a kind of a continuous flow; it is kind of a batch flow or a kind of a pulsation flow. So, between the dilute end dense, you have to you can tell it that it is a batch versus continuous, here you are getting a pulse of the solid, you are getting the solid in terms of the pulsation.

There in the dilute phase you are getting a continuous solid flow. So, if you can say that how one can compare it as a batch versus continuous, but if you can afford a pulsation, then the dilute dense phase regime or dense phase pneumatic conveying is much much better much economical compared to the dilute phase things.

Now, what is the disadvantage. The major disadvantage is the velocity is very low. So, you will see the slugging materials can move kind of moves in form of the plug. So, you will get a pulsation. And then based this is actually best for most of the applications. So, this is the only thing which is very, very critical that it is discontinuous but most of the application it is more than sufficient to have a discontinuous operation, because the basic aim of the pneumatic conveying is to transfer the liquid solid from one place to the another place ok.

You can make the operation continuous by making it as a moving bed condition, but that requires a big power or you can flow rise the system and make the particle flow rising and then you can make it continuous and you can still transfer the solids.

So, these are the advantages of something but the major advantage what I will say is in terms of the energy because this is for the transportation I definitely want to transfer more solid per unit energy I am spending on the transportation. So, in this case, you can transfer the most of the solids because you are transferring the chunk of the solids the throughput is very very high. So, energy required to transfer per kg of amount of the so far I am on this specific amount of the solid is much lower compared to the dilute phase regime.

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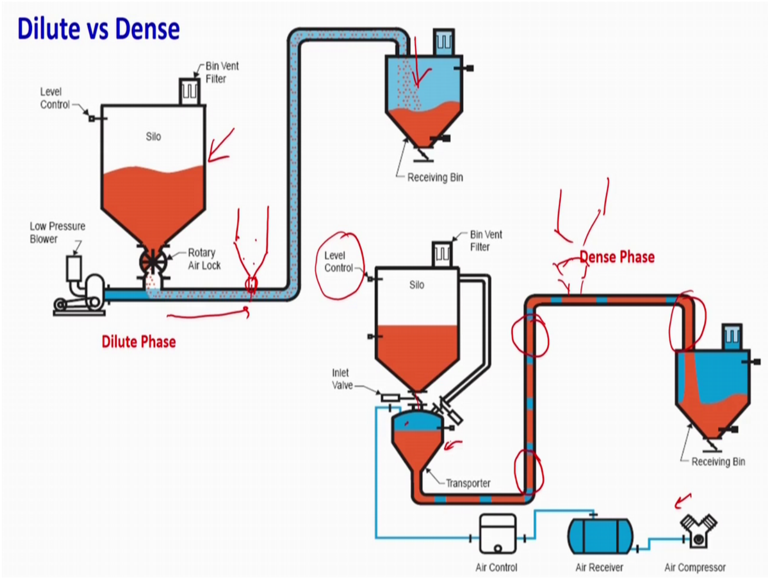

Now, these are the two things which I have already said discussing in one way, but this is the pictorial diagram. So, what you can have in the dilute phase regime, you will have a blower or a compressor of pressure is not very important because here the solid fraction is very very low.

So, what will happen, we will have a silos, suppose I have a place where silos there the solid is being kept and I want to transfer the solid from this place to some another unit where we have to process the solids. Then what will happen there will be a rotary valve, through which the solids will be actually put in the this pipeline the air will be blown through the blower because the solid loading is very very low. The blower will do the job we need a higher velocity, we need do not need high pressure.

So, what will happen the solid will fall down in the pipeline and they will be flown up with the kind of a blown up you can say a flow with the gases and they will be transferred to this next silos or the next location there it has to be processed. And you can see that these are uniformly solids, distributed across the pipeline, and there is a continuous flow of the solids is coming here, so that is called dilute phase regime.

Now, in the dense phase regime what will happen there will be a silos you require an additional transporter because you need to now post the solid here so that is why this is called transporter. And that is what I said that if you have a multiple input then what will happen you will have a multiple transporters requirement.

Here what will happen if suppose I have a second input through which also I have to transport the solid then I will just put another silos here with a rotary wall and this diode will again jump the solids in the same pipeline. So, I do not need anything in arrangement other than the silos of the solids which will be fit from the another location. But if you have a dense stage every location you need a transporter. Now, what does transporter do actually this.

So, here there is a silos in the silos the flows actually come from the silos to the this it comes to the transporter. What the transporter does, transporters is being operated at a high pressure. So, there is a compressor high pressure compression; which actually pump a kind of compress the air and then it flows the air at a control flow rate into the transporter. So, this regime is being pressurized and the solid is actually falling in this regime. So, once the solid will fall here the pressure will be maintained.

Now, the inlet valve will be open based on in such a way that the pressure balance can be taken place neither if the pressure here will be less then there will be no flow of the solids. So, the pressure balance is a very, very critical thing here, so that is why we used to have a level controller to control the level in the silos of the solid layer also and the gas layer also that some of the gases being recycled here. So, that the silos can also be compressed and the solid smooth solid flow can take place.

Now, the transporter the solid will be collected it will be pressurized. Now, once it will be pressurized it will flow in the pipeline, but it will be flow in form of the slug. So, you see that it will be flow in form of the slug, plug dual flow or fluidized kind of, but this will be a kind of a dense bed where the plug will be formation or slug formation will be there dual formation will be there. It will be flowing form of the slug and you will see a pulsating regime of the solids. So, what will happen you will see the solid, then you will see gas, then again you will see solid. So, the pulsation will take place.

Now, if suppose I have a another cycle is here then again I need iron in the transporter. So, the transporter need to be placed so that it can push the solid again into the same light. So, dense page conveying this is the problem that every location if you have a multiple input, you should have a multiple transporter also. While in the dilute phase regime that is not the case, but the problem is in the dilute phase regime who require much more energy to transfer the same amount of the solid compared to the dense phase system. So, with this, we will start our discussion again in the next class.