Chemical Process Utilities
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Lecture – 37
Gas-Solid Flows

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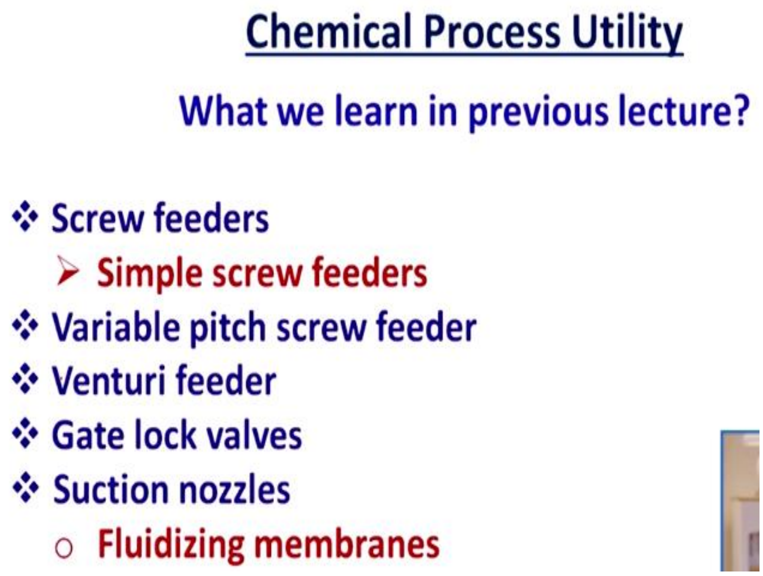

Welcome to the concept of gas-solid flows under the aegis of chemical process utilities. Now, we have studied about the screw feeders, the simple screw feeders. Discussed about the variable pitch screw feeders in the previous lecture. We had a broad discussion about the venturi feeders. We described the gas lock valves. We have discussed about the suction nozzles apart from the fluidizing membranes.

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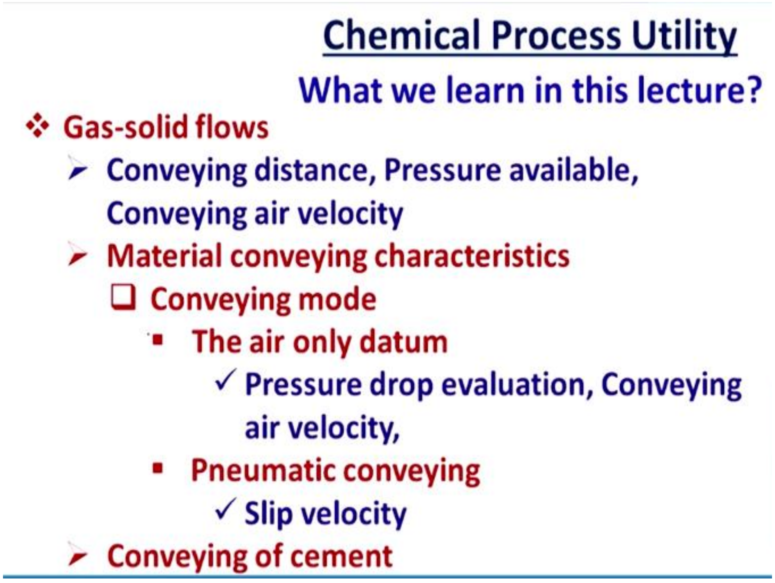

In this particular lecture, we are going to discuss the gas-solid flows because see we are conveying the system through the air and solid. So, we need to discuss about the various kinds of different concepts in this particular approach like conveying distance, pressure availability, then how the conveying air velocity impacts with the different kind of system. We will discuss about the material conveying characteristics especially the conveying mode.

We will discuss about the concept of the air only datum under the edges of a pressure drop evaluation. We will discuss about the conveying air velocity. We will discuss the pneumatic conveying under the edge of slip velocity. We will discuss one example attributed to the conveying of steam.

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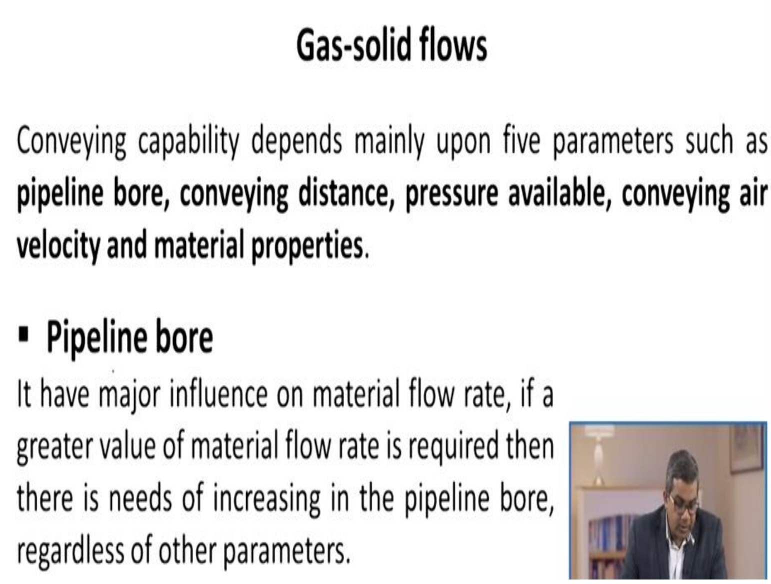

Let's talk about the gas-solid flows. Conveying capability depends mainly upon five different parameters. These parameters are pipeline bore, conveying distance, pressure available, conveying air velocity and material properties. Let us talk about the pipeline bore. Now, it has major influence on material flow rate. If a greater value of material flow rate is required, then there is a need of increasing in the pipeline bore regardless of other parameters. So, other parameters they do not impact to this particular approach.

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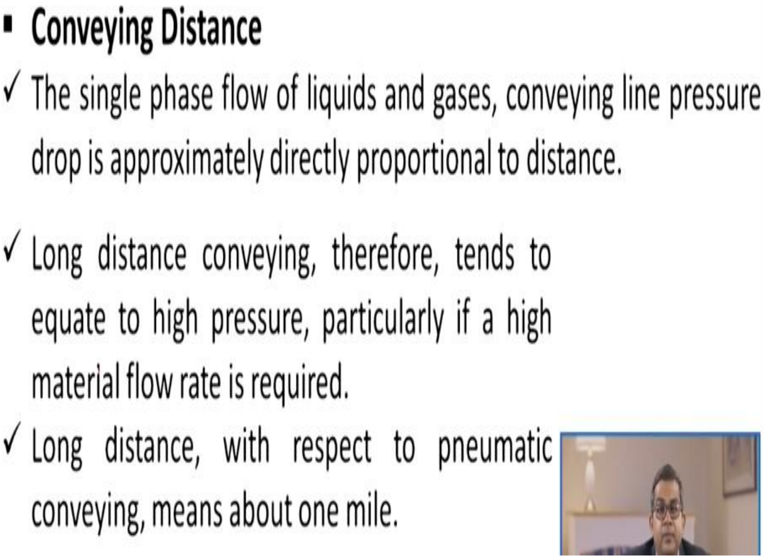

Let us talk about the conveying distance. The single-phase flow of liquids and gases, conveying line pressure drop is approximately directly proportional to distance. Long distance conveying therefore sometimes tend to equate to high pressure particularly if a high material flow rate is required. Long distance with respect to the pneumatic conveying means about one mile.

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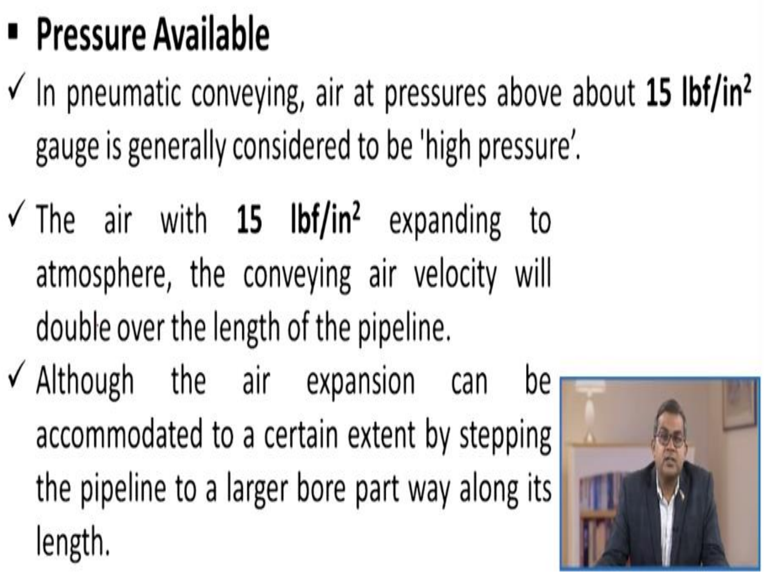

Let us talk about the pressure available. In pneumatic conveying, air at a pressure above 15 pounds force per inch square gauge is generally considered to be high pressure. The air with 15 pounds force per square inch expanding to atmosphere the conveying air velocity will double over the length of pipeline. Although the air expansion can be accommodated to a certain extent by stepping the pipeline to a larger bore part way along its length.

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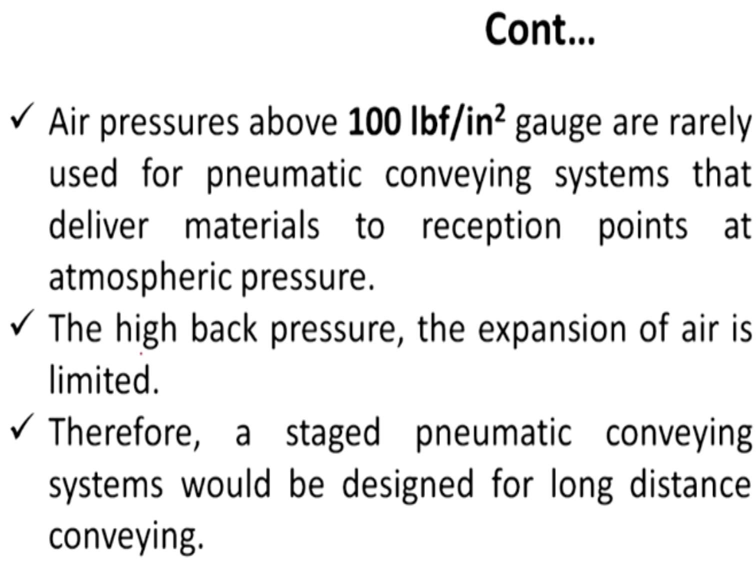

Air pressures above 100 pounds per square inch gauge are rarely used for pneumatic conveying system that deliver materials to reception points at atmospheric pressure. So, a large pressure gap is there. The high back pressure, the expansion of air is limited. Therefore, a staged pneumatic conveying systems would be designed for long distance conveying.

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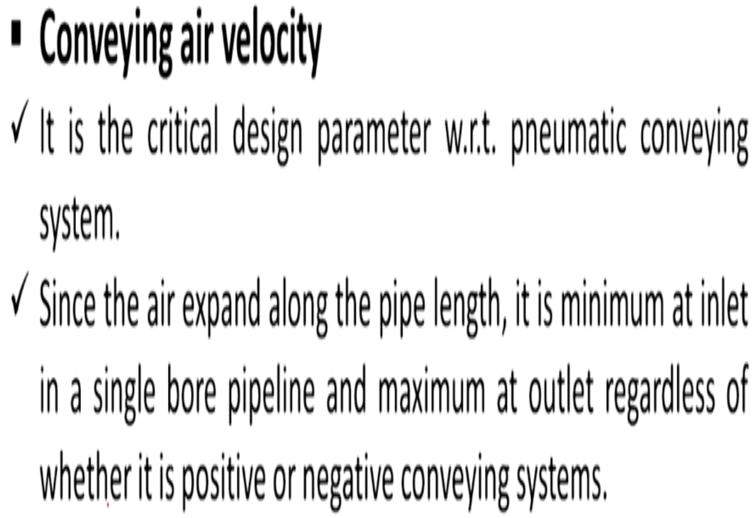

Let us talk about the conveying air velocity. It is the critical design parameters with respect to the pneumatic conveying system. Since the air expand along the pipe length, it is minimum at inlet in a single bore pipeline and maximum at outlet regardless of whether it is positive or negative conveying system.

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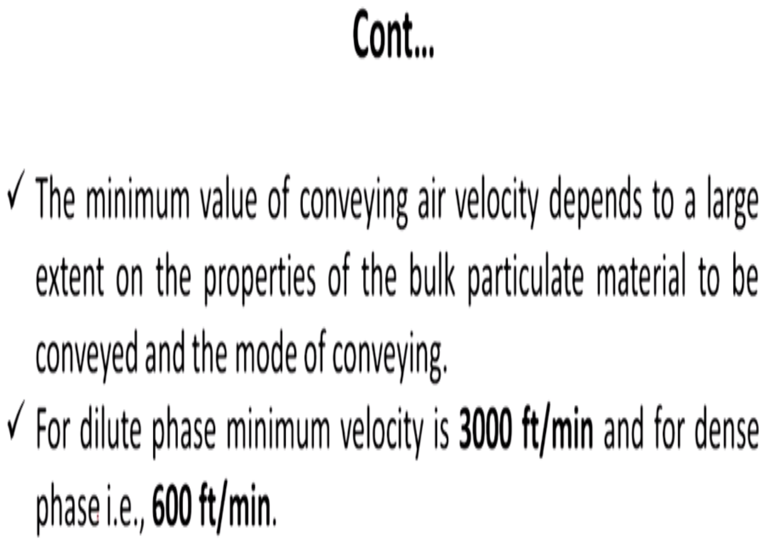

The minimum value of conveying air velocity depends to a large extent on the properties of bulk particulate material to be conveyed and the mode of conveying. For dilute phase minimum velocity is 3000 feet per minute and for dense phase it is approximately 600 feet per minute.

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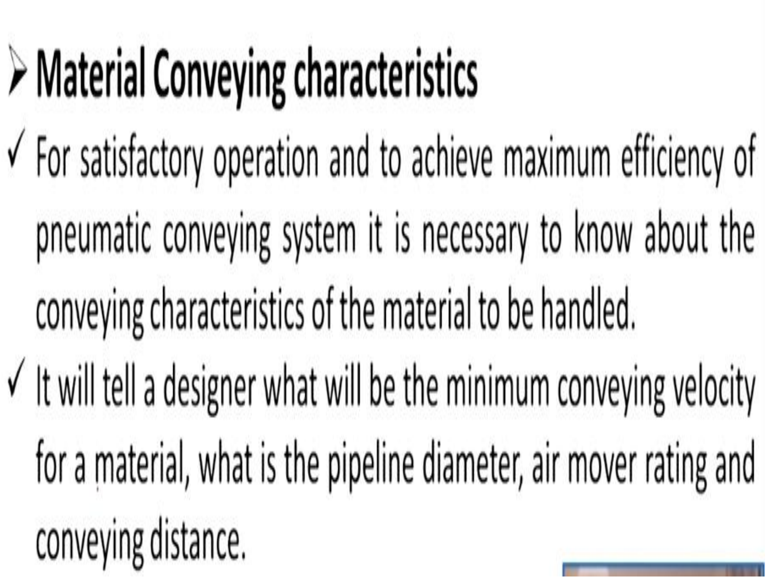

Now, let us talk about the material conveying characteristics. For satisfactory operation and to achieve maximum efficiency of pneumatic conveying system it is necessary to know about the conveying characteristics of the material to be handled. Sometimes this information is very useful. It will tell a designer what will be the minimum conveying velocity for a material, what is the pipeline diameter, what is the air moving rate and what is the conveying distance.

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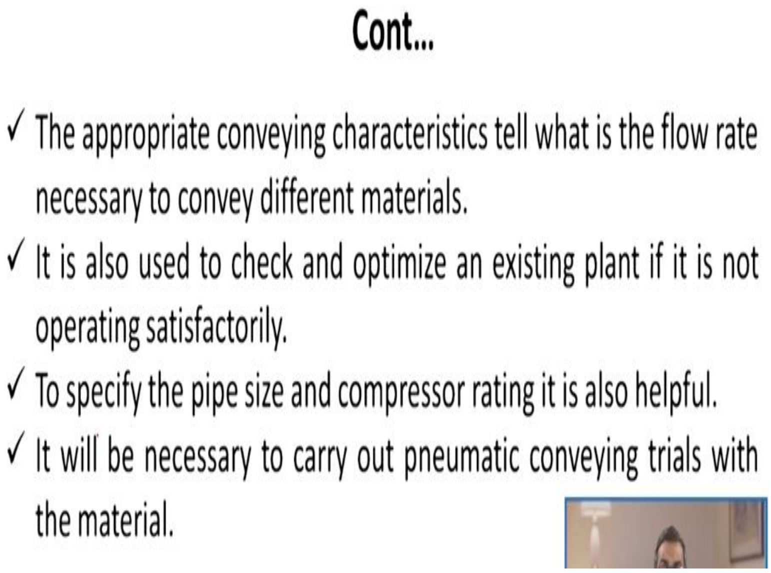

The appropriate conveying characteristics usually tell what is the flow rate necessary to convey the different materials. It is also be useful or it is also used to check and optimize an existing plant if it is not operating satisfactory. So, a cross check can be done in this regard. To specify the pipe size and compressor rating, it is also very helpful. It will be necessary to carry out pneumatic conveying trials with this particular type of system with this material.

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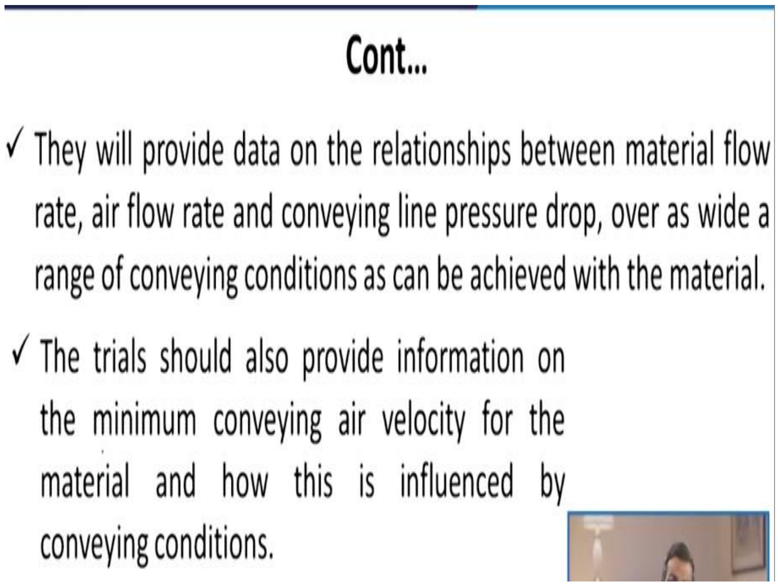

Now, they will provide data on the relationships between the material flow rate, air flow rate and conveying line pressure drop over as wide range of conveying condition as can be achieved with the material. The trials should also provide information on the minimum conveying air velocity for the material and how this is influenced by the conveying conditions.

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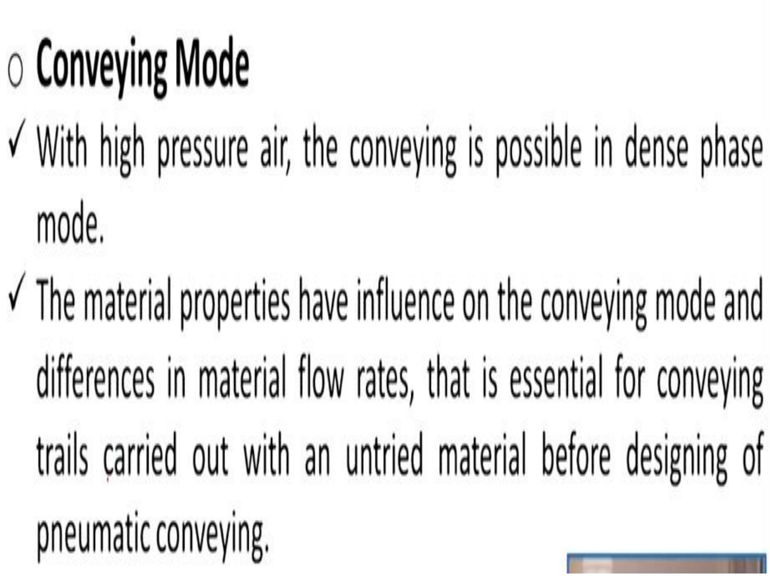

Let us talk about the conveying mode. With high pressure air the conveying is possible in dense phase mode, although the power requirement would be on the higher side. The material properties have influence on the conveying mode and the difference in material flow rates that is essential for conveying trials this can be carried out with an untried material before designing of pneumatic conveying. So, basically this particular information if you are not having this trial data, then you need to carry out this type of approach.

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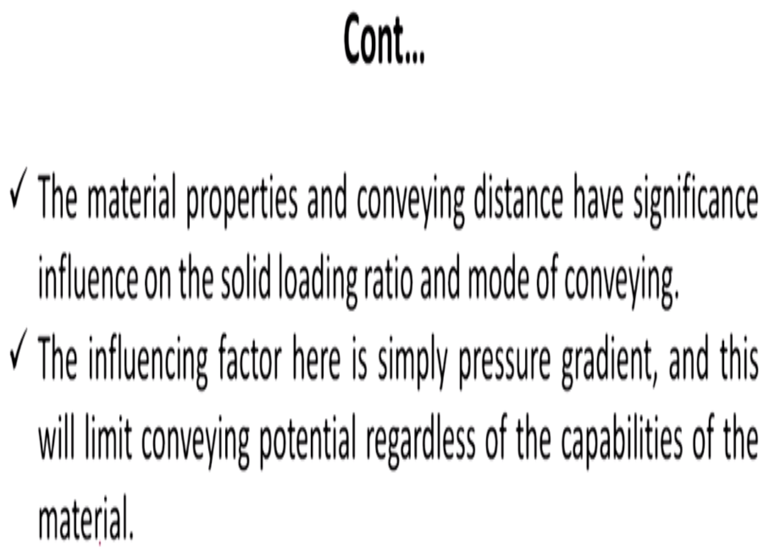

The material properties and the conveying distance they have significance influence on the solid loading ratio and mode of conveyance. You see that these two are important parameters like solid loading ratio and mode of conveying. The influencing factor here is simply a pressure gradient because the over the period of time or over the period of distance, the pressure gradient is usually established and this will limit conveying potential regardless of capabilities of the material.

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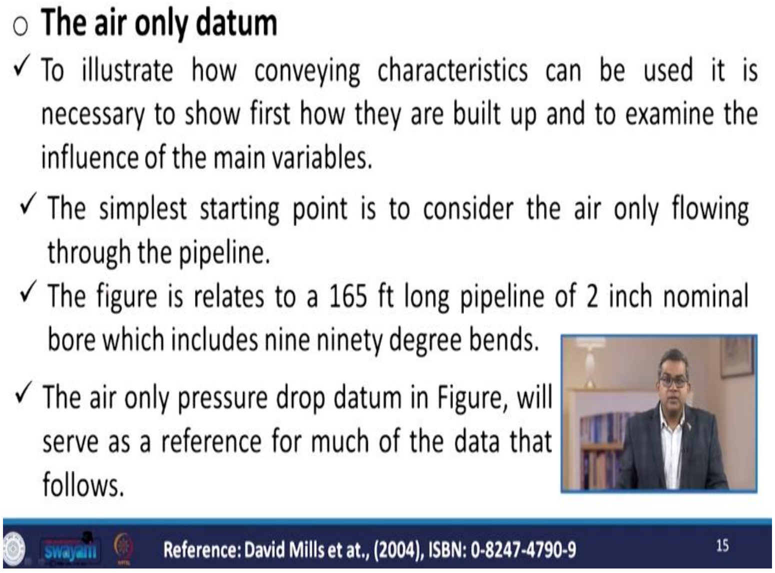

Next is the air only datum. To illustrate how conveying characteristics can be utilized or used it is necessary to show first how they are built up and to examine the influence of the main variables. The simplest starting point is to consider the air only flowing through a pipeline. Now, this particular figure relates to 165 feet long pipeline of 2 inches nominal bore which includes 990 degrees bend. Now, the air only pressure datum in that particular figure will serve as a reference for much of the data that follows.

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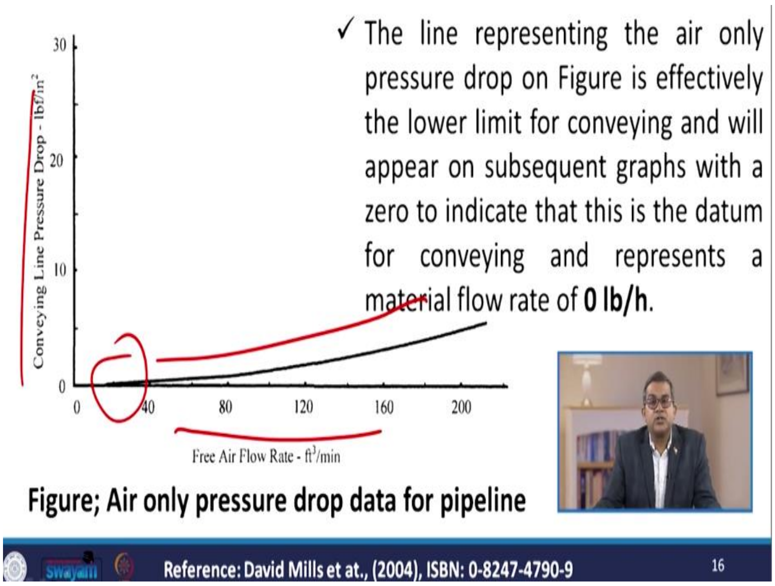

Now, this line representing the air only pressure drop is effectively the lower limit of conveying and will appear on subsequent graph with 0 to indicate that this is the datum for conveying and represent a material flow rate of say 0 pound per hour. So, here you see that free air flow rate in cubic feet per minute and this is the conveying line pressure drop is 1 pound force per square inch.

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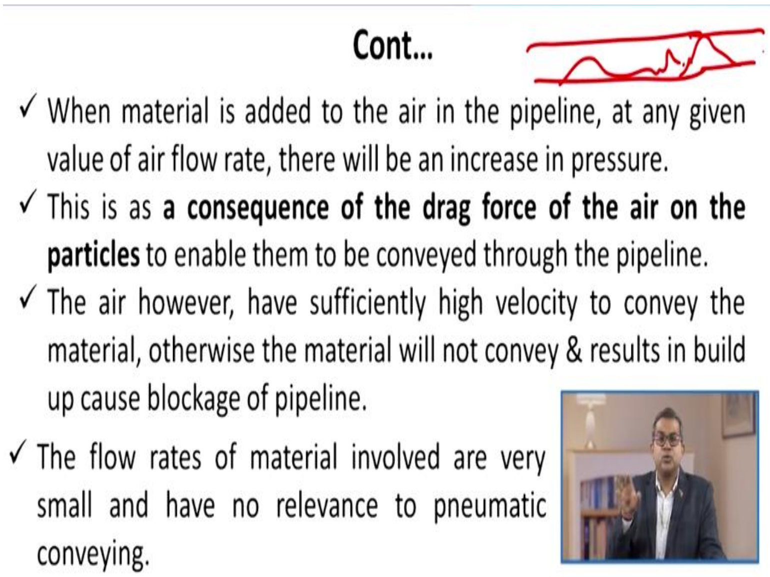

When material is added to the air in the pipeline at any given value of air flow rate, there will be an increase in the pressure. This is as a consequence of drag force of the air on the particles just to enable them to be conveyed through the pipeline. The air, however have a sufficiently high velocity to convey the material, otherwise sometimes you may observe the material will not convey and result in build-up cause the blockage in the pipeline. So, see this is the pipeline and it may create a problem and over the period of time it may block the pipeline. The flow rates of material involved are very small and have no relevance to pneumatic conveying.

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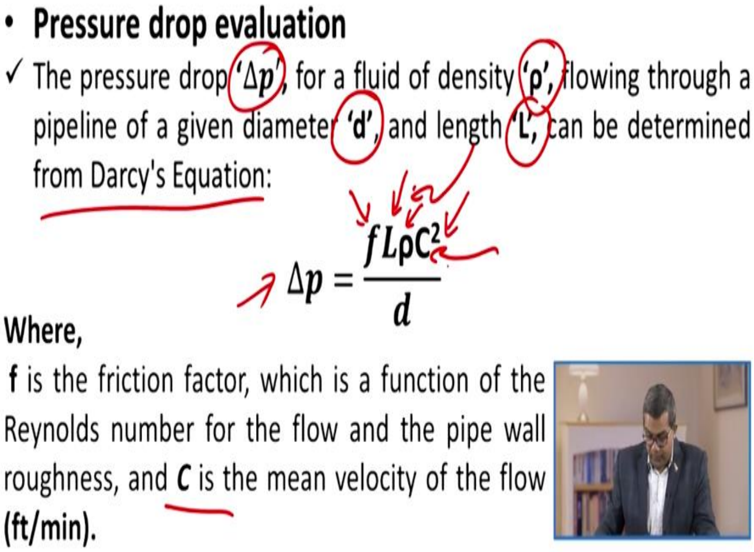

Now, how we can evaluate the pressure drop? The pressure drop referred as delta p for a fluid density rho flowing through a pipeline with the given diameter d and the length L this can be determined from the Darcy's equation that is delta p = f L that is the length multiplied by a density into C square upon d that is the diameter. Now, here f is the friction factor which is the function of the Reynolds number for the flow and the pipe wall roughness and C is the mean velocity of the flow and that is represented as feet per minute.

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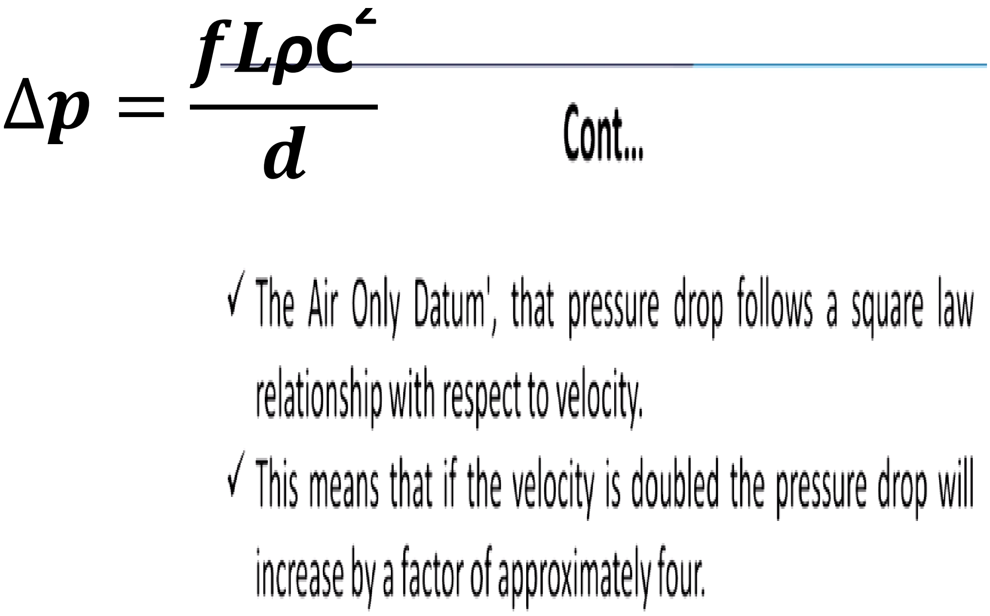

The air only datum that pressure drop follows a square law relationship with respect to velocity. This means that if the velocity is doubled, the pressure drop will increase by a factor of approximately four.

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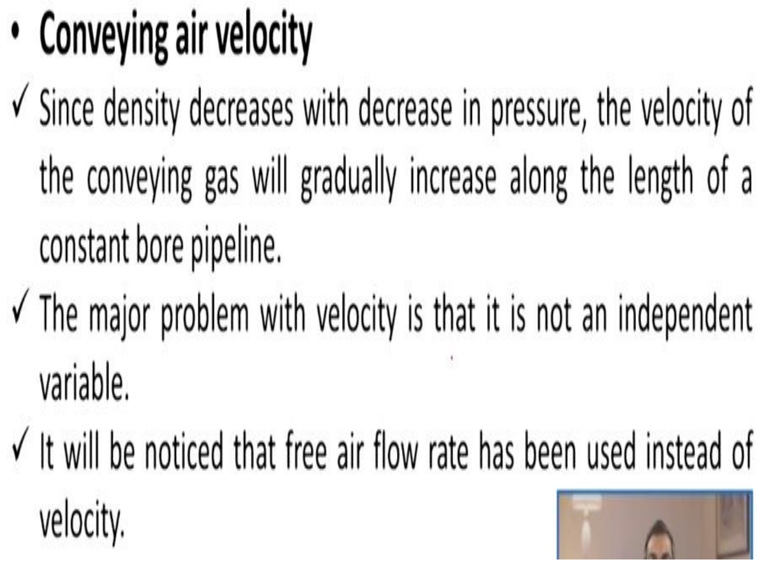

Now, let us talk about the conveying air velocity. Since density decreases with decrease in pressure, the velocity of the conveying gas will gradually increase along the length of a constant bore pipeline. So, always you see that the decrease in density is sometimes more feasible. The major problem with the velocity is that it is not an independent variable, it comes with a different type of package. It can be noticed that free air flow rate has been used instead of velocity.

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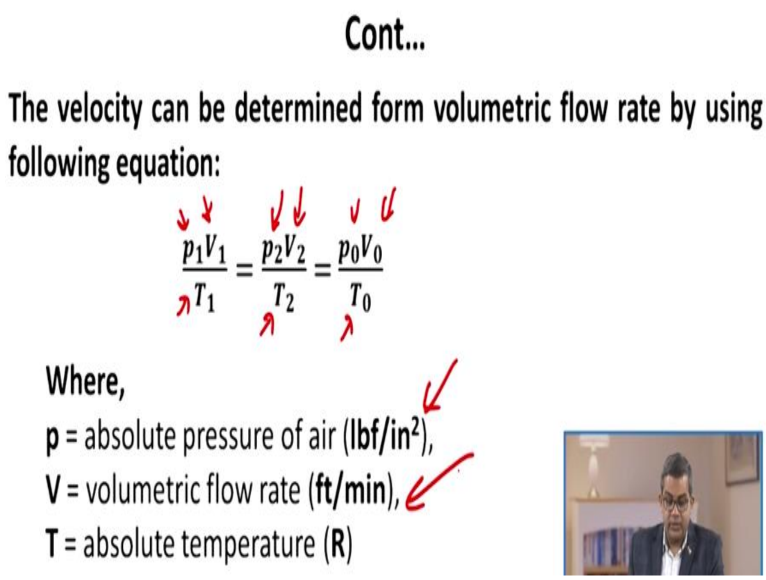

Now, when we talk about the velocity, the velocity can be determined from volumetric flow rate by using the usual ideal gas equation. Here p 1 V 1 upon T 1 = p 2 V 2 upon T 2 = p 0 V 0 T 0 where p is the absolute pressure of air, you may decide the unit as per the system in question, V is the volumetric flow rate, T is the absolute temperature.

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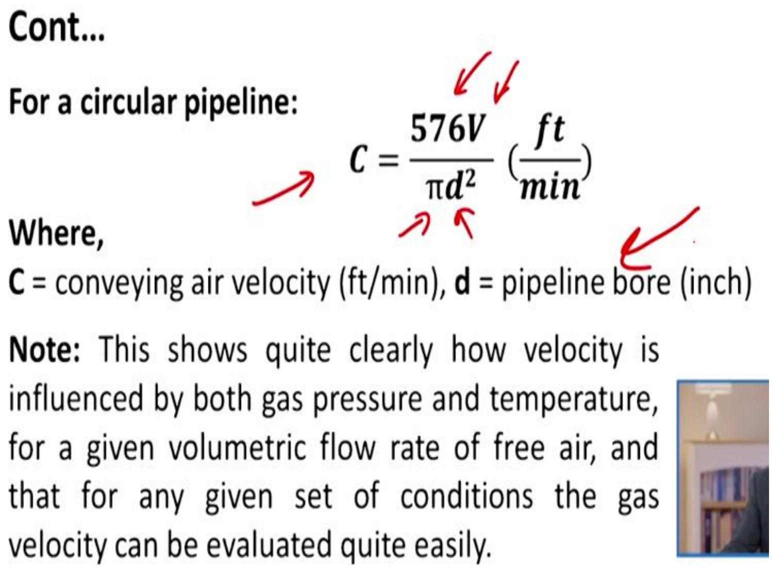
$$\frac{p_1 V_1}{T_1} = \frac{p_2 V_2}{T_2} = \frac{p_0 V_0}{T_0}$$



Now, if we talk about the circular pipeline, now circular pipeline the mathematical representation or the conveying air velocity here in the case that it is represented as feet per minute can be represented as 576 V upon pi d square feet per minute, now d is the pipeline bore represented in inch. This shows quite clearly how velocity is influenced by both gas pressure and temperature and that is for a given volumetric flow rate of free air and that for any given set of condition the gas velocity can be evaluated quite easily.

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$$C = \frac{576V}{\pi d^2} \left(\frac{ft}{min}\right)$$

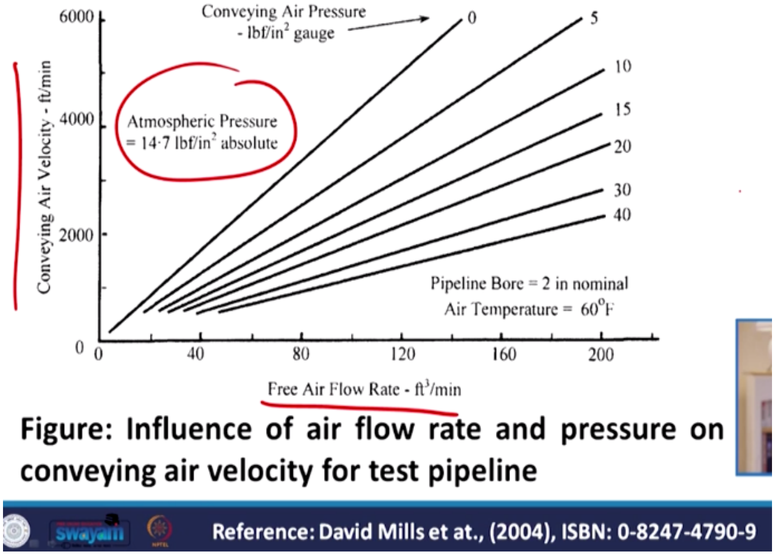

Figure: Influence of air flow rate and pressure on conveying air velocity for test pipeline

In this particular diagram, you see the influence of air flow rate and pressure on conveying air velocity for any kind of test pipeline, this is represented with the free air flow rate in cubic feet per minute and the conveying air velocity in feet per minute. You see that you have taken the atmospheric pressure 14.7 pounds force per square inch and different bores and air temperature is taken as 60 Fahrenheit.

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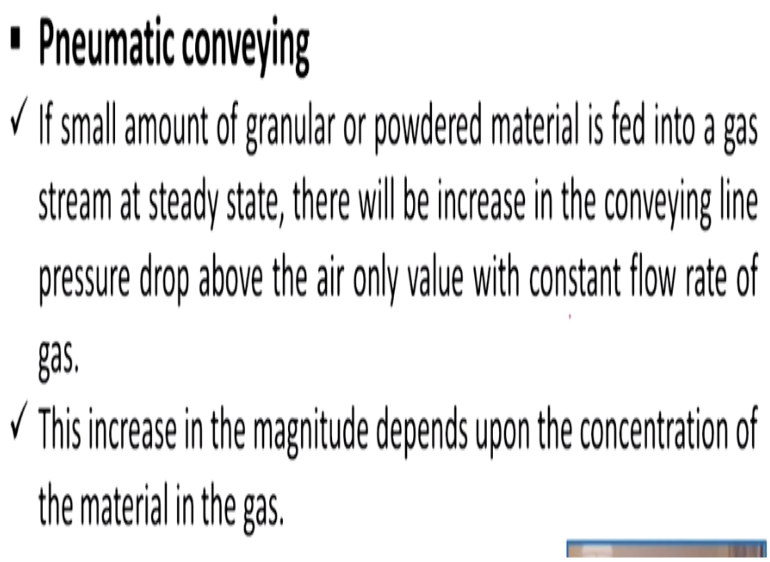

Let us talk about the pneumatic conveying. If a small amount of granular or powdered material is fed into a gas string at a steady state, there will be increase in the conveying line pressure drop above the air only value with constant flow rate of gas. This increase in the magnitude depends upon the concentration of the material in the gas. Now, as the material flow rate into the conveying line increases, the conveying line pressure drop will also increase. In two phase flow, the particles are conveyed at a velocity below that of the conveying gas and therefore a drag force exerted on the particles by the gas.

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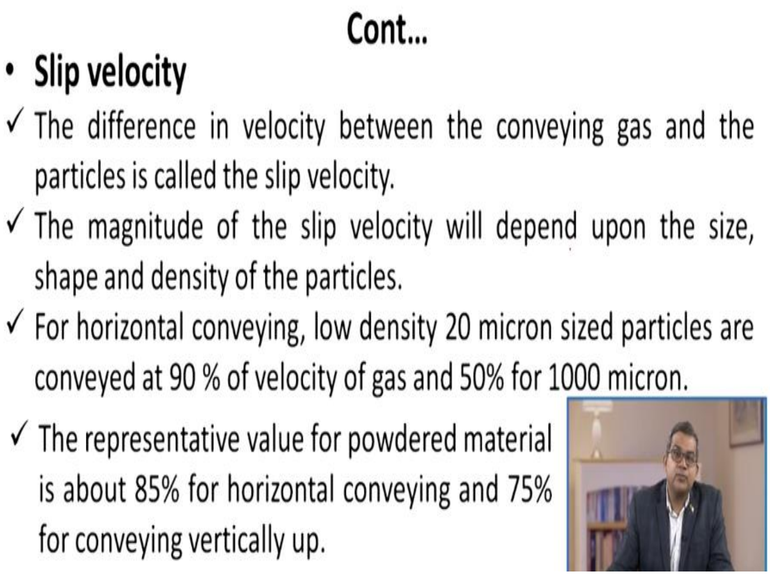

Let us talk about the slip velocity. The difference in the velocity between the conveying gas and the particle is called the slip velocity this is the basic definition of the slip velocity. The magnitude of the slip velocity depends on the size, the shape and the density of the particles. For horizontal conveying low density 20 microns sized particles are conveyed at 90% of the velocity of gas and 50% of 1000 micron. The representative value for the powdered material is about 85% for horizontal conveying and 75% for conveying vertically up.

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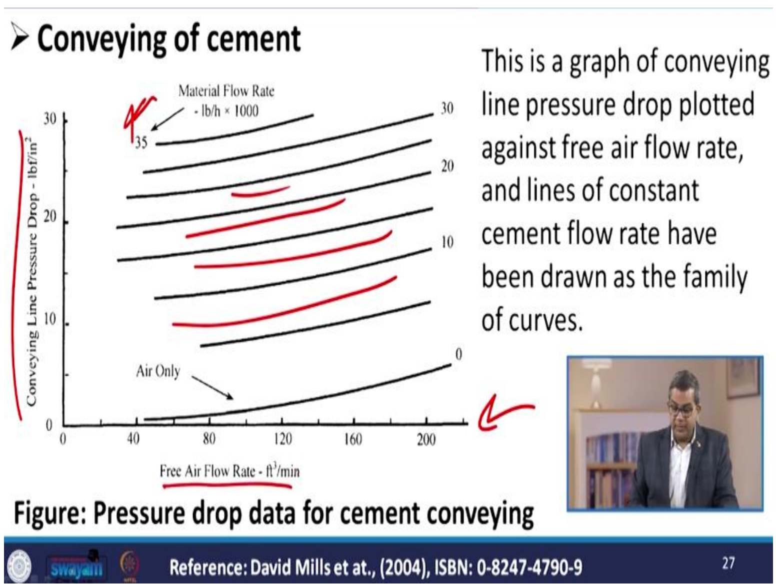

See they are giving one example and this graph that is the conveying of cement and that is a very common example that is the pressure drop data for the cement conveying. Now this is a graph for conveying line pressure drop plotted against a free air flow rate and the lines of constant cement flow rate have been drawn as the family of the curves. Here you see that this one. Now, here you see that the material flow rate and the conveying line pressure drop 1 pound force per square inch and free air flow rate in cubic feet per minute.

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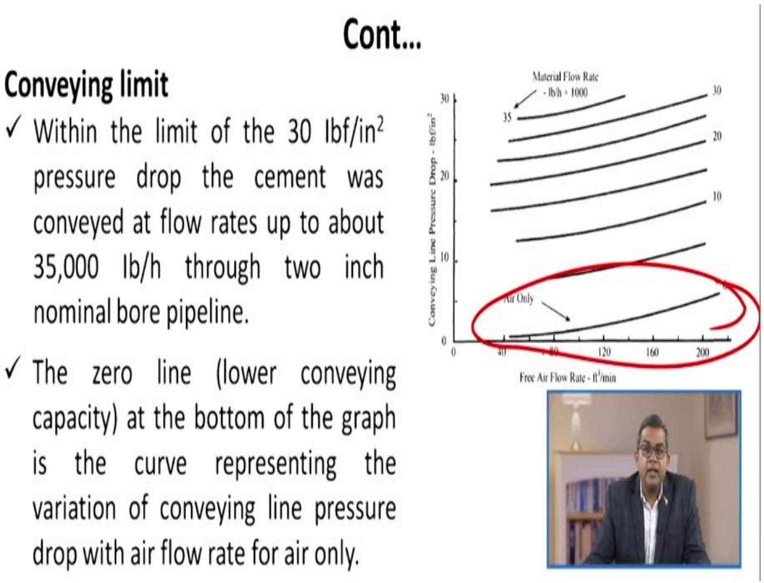

When we talk about the conveying limit within the limit of 30 pounds force per square inch pressure drop the cement was conveyed at a flow rate up to about 35,000 pounds per hour through 2 inches nominal bore pipeline. The zero line that is the lower conveying capacity at the bottom of the graph here is the curve representing the variation of conveying line pressure drop with air flow rate for air only.

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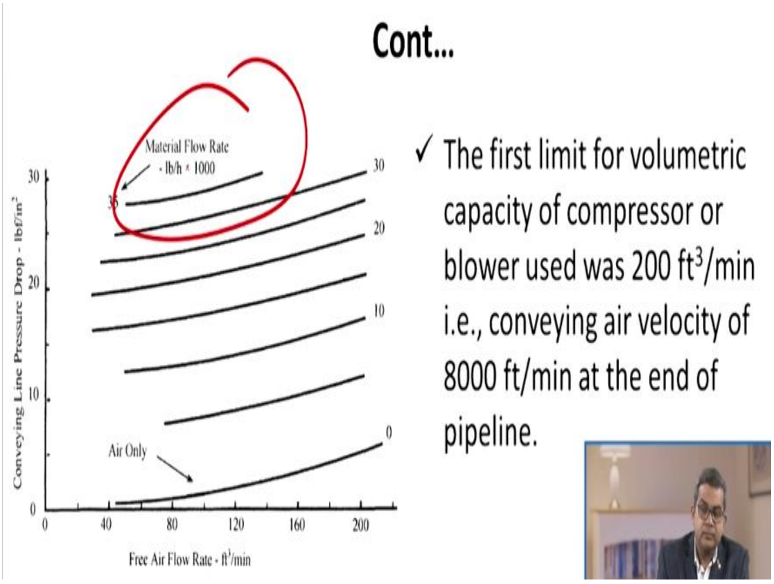

The first limit of a volumetric capacity of compressor or blower that was used was around 200 cubic feet per minute that is the conveying air velocity of 8000 feet per minute at the end of the pipeline.

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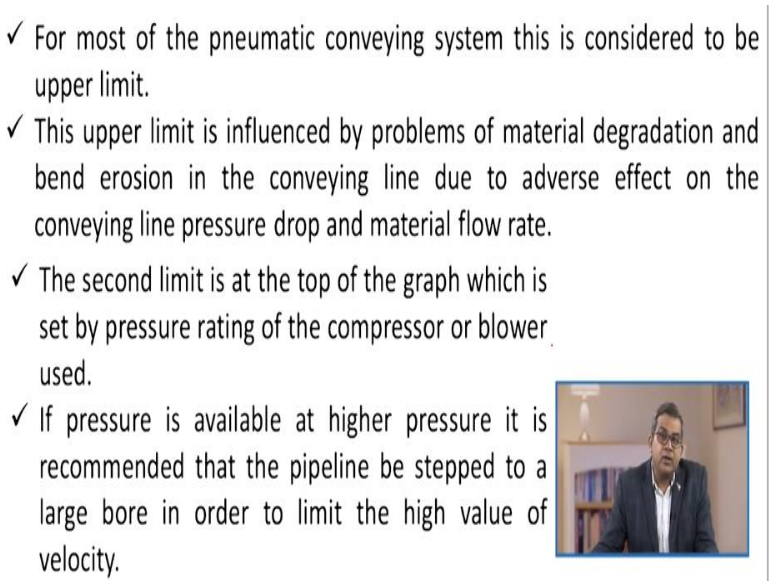

For most of the pneumatic conveying system, this is considered to be the upper limit. This upper limit is influenced by the problem of material degradation and the band erosion in the conveying line due to adverse effect on the conveying line pressure drop and material flow rate. The second limit is that is at the top of the graph this one, this is set by the pressure rating of the compressor or blower used. If a pressure is available at higher pressure, it is recommended that the pipeline be stepped to a large bore in order to limit the high value of velocity.

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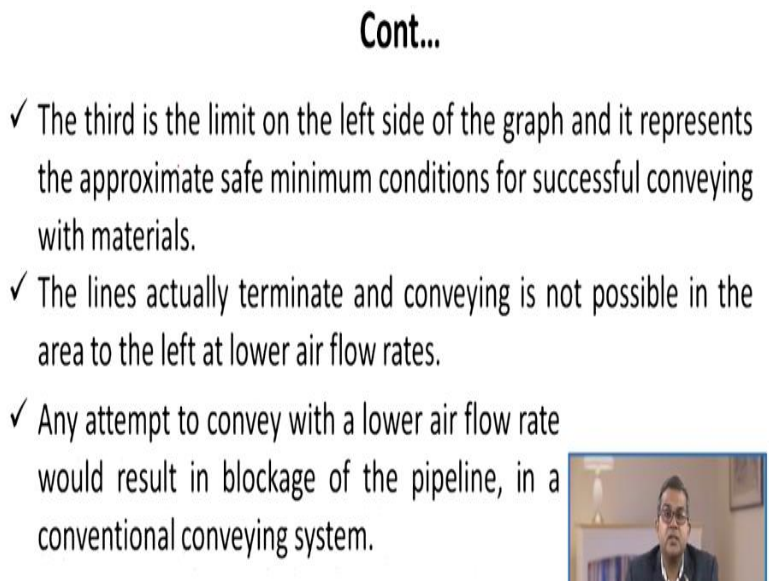

The third is the limit on the left side of the graph and it represents the approximate safe minimum conditions for successful conveying with material. The line actually terminated or terminate and conveying is not possible in the area to the left at the lower air flow rates. Any attempt to convey with the lower air flow rate would result in the blockage of pipeline and there may be chances that is a stagnant zone may fall. So, this will be quite evident in the conventional conveyance system.

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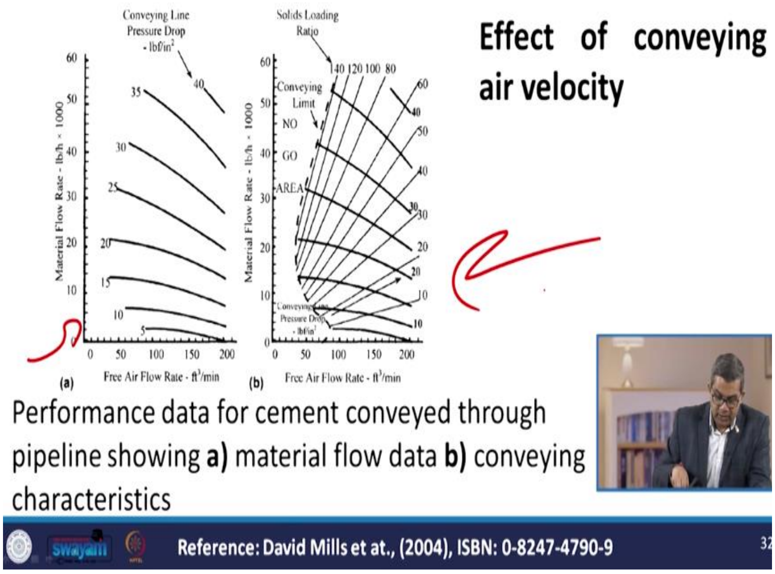

Now, let us talk about the effect of conveying air velocity. This is the performance data for the cement conveyed through the pipeline. This shows the material flow data and this shows the conveying characteristics.

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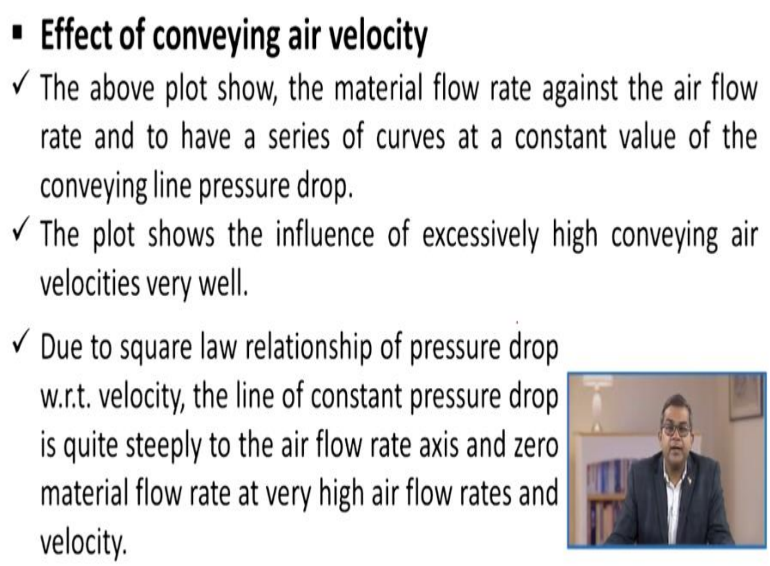

So, when we talk about the effect of conveying air velocity this plot which we discussed here, this shows the material flow rate against the air flow rate and to have a series of curves at a constant value of the conveying line pressure drop. Again, this particular plot shows the influence of excessively high converting air velocity very well. Due to square law relationship of pressure drop with respect to velocity, the line of constant pressure drop is quite steeply to the air flow rate axis and zero material flow rate at very high air flow rates and velocity.

If the conveying system has compressor or blower with maximum rating in terms of delivery pressure, a considerable amount of this pressure will be taken up by moving the air through the line if air flow rate and velocity is too high. The pressure drop is due to the material concentration in the air and that is greater the concentration greater will be the pressure drop. If the conveying air velocity is very high, the concentration of the material will have to be reduced in order to match the available pressure drop.

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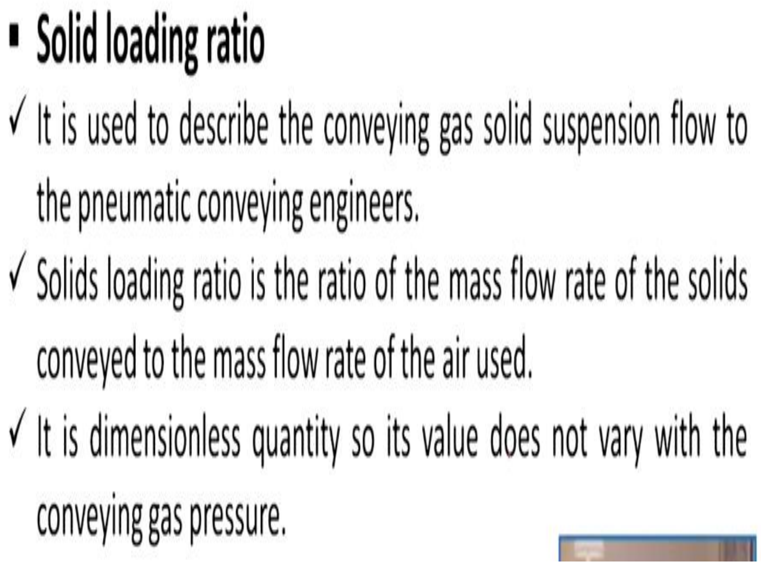

Now, if we talk about the solid loading ratio, it is used to describe the conveying gas solid suspension flow to the pneumatic conveying engineering. Solid loading ratio is the ratio of the mass flow rate of the solids conveyed to the mass flow rate of the air used, it is quite common. It is a dimensionless quantity, so its value does not vary with the conveying gas pressure.

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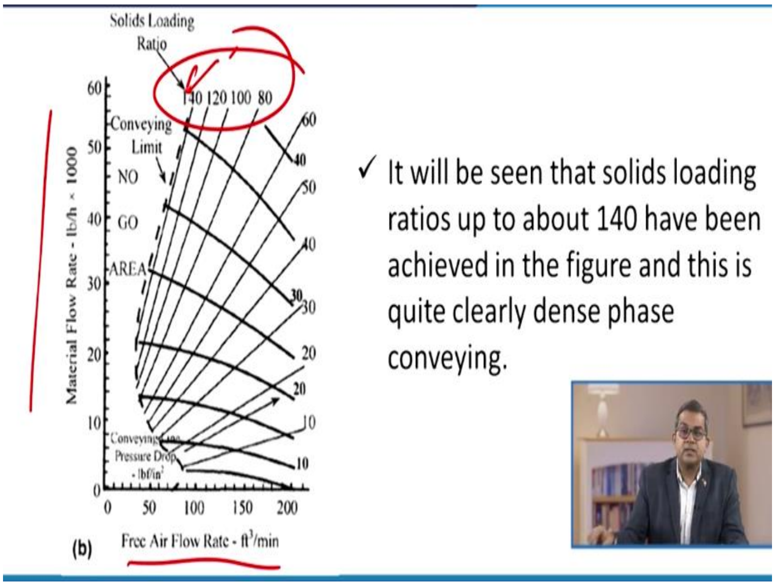

Now, here you see that we have a graph here this represents the solid loading ratio and Y axis the material flow rate 10 pounds per hour and free air flow rate in cubic feet per minute. So, it will be seen that solid loading ratio up to say 140 have been achieved in this particular figure and this is quite clearly dense phase conveying.

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✓ With a low air pressure and a high air flow rate, however, the cement is conveyed at solids loading ratios below ten and this is quite clearly dilute phase, suspension flow.

✓ It will be seen that there is no transition between dilute and dense phase flow and so the dividing line between the two modes of flow is not clearly defined.

With a low air pressure and high flow rates, however the cement is conveyed at solid loading ratios between 10 and this is quite clearly the dilute phase, suspension flow. It will be seen that there is no transition between dilute and dense phase flow and so the dividing line between the two modes of flow is not clearly defined.

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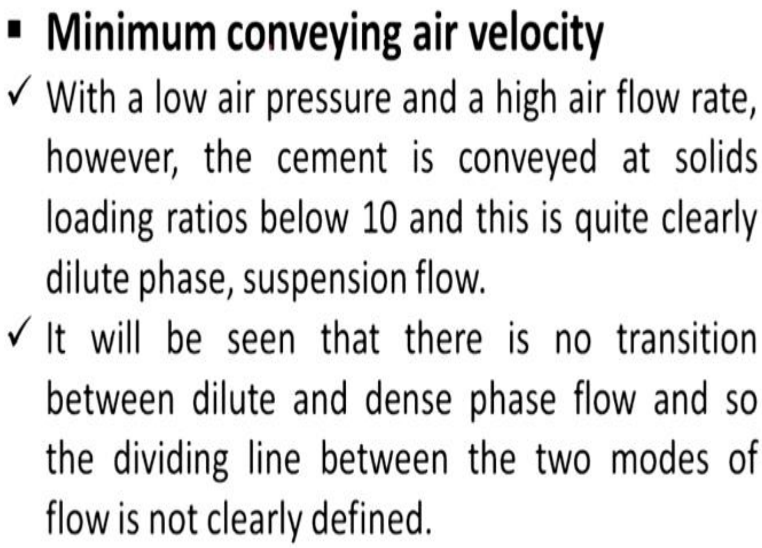

Let us talk about the minimum conveying air velocity. With a low air pressure and a high air flow rate, the cement is conveyed at solid loading ratios between 10 and this is quite clearly dilute face suspension flow. It can be seen that there is no transition between dilute and dense phase flow so the dividing line between the two modes of flow is not clearly defined.

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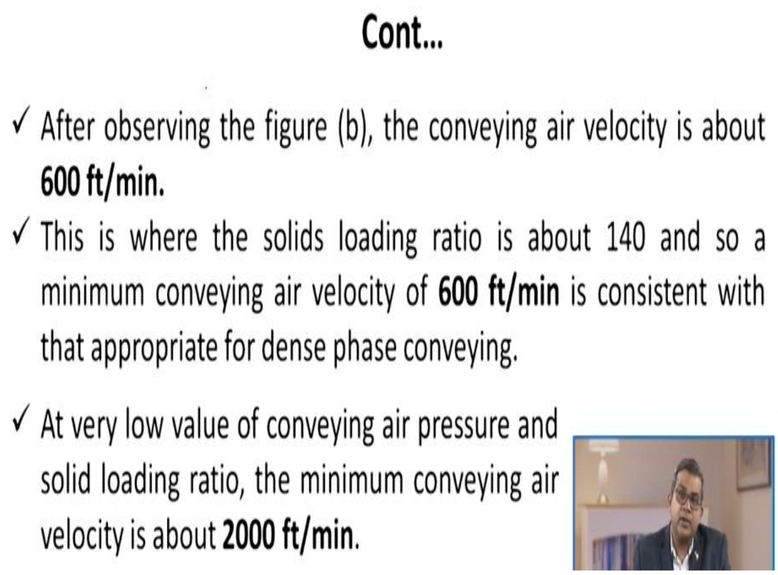

After observing the previous figure, the conveying year velocity is about 600 feet per minute. This is where the solid loading ratio is about 140 and so a minimum conveying air velocity of 600 feet per minute is consistent with that appropriate for dense face conveying. You can say at a very low value of conveying air pressure and solid loading ratio, the minimum conveying air velocity is around 2000 feet per minute.

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- ✓ This is consistent for dilute phase conveying of this type of materials.
- ✓ The slope of the conveying limit curve is positive in both of these extreme areas of dilute and dense phase conveying.

Now, this is consistent for dilute phase conveying of this type of material. The slope of conveying limit curve is positive in both of these extreme areas of dilute and dense phase conveying.

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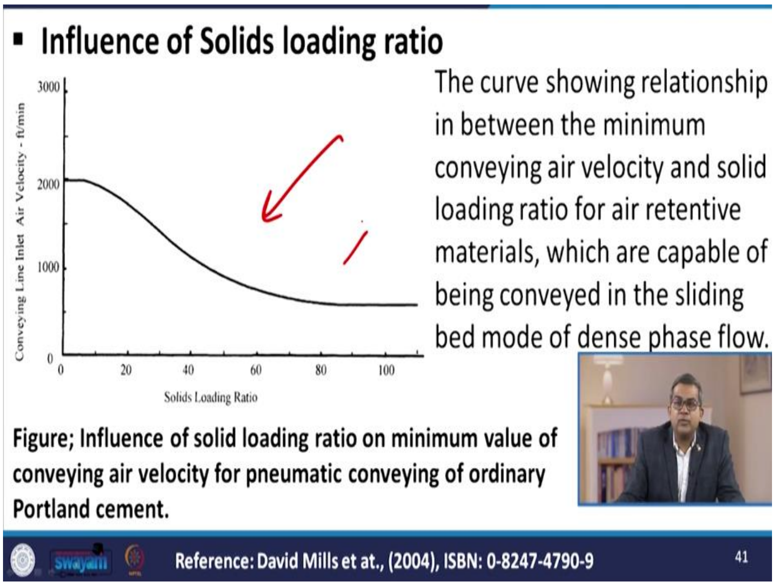

Now, let us briefly talk about influence of solid loading ratio. Now, this is the curve which shows the influence of solid loading ratio on minimum value of conveying air velocity for pneumatic conveying of ordinary Portland cement. Now, the curve is showing the relationship in between the minimum conveying air velocity and the solid loading ratio for air retentive material, which are capable of being conveyed in the sliding bed mode of dense base flow.

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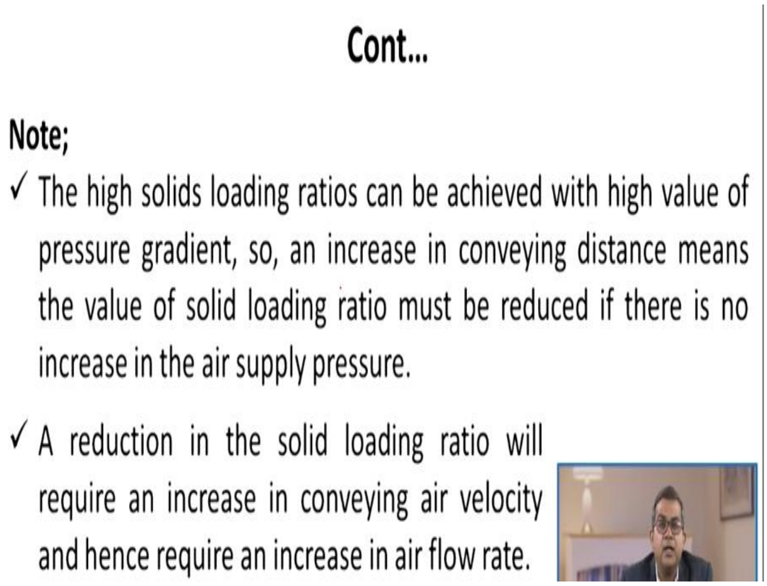

A reduction in the solid loading ratio will require an increase in conveying air velocity and therefore require an increase in air flow rate.

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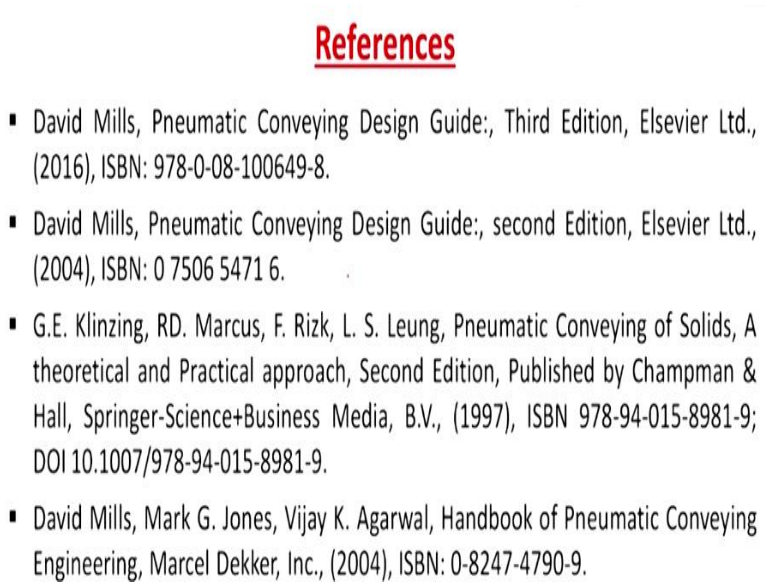

So, in this particular chapter or lecture, we discussed about the various factors attributed to the pneumatic conveying system. We discussed about the different factions those who are influencing this pneumatic conveying and for your convenience, we have enlisted different types of references and you can go through these references if you need further studies. Thank you very much.