PDHonline Course M325 (5 PDH)

Pneumatic Conveying Systems

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Pneumatic Conveying Systems

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A pneumatic conveying system is a process by which bulk materials of almost any type are transferred or injected using a gas flow as the conveying medium from one or more sources to one or more destinations. Air is the most commonly used gas, but may not be selected for use with reactive materials and/or where there is a threat of dust explosions.

A well designed pneumatic conveying system is often a more practical and economical method of transporting materials from one point to another than alternative mechanical systems (belt conveyors, screw conveyors, vibrating conveyors, drag conveyors and other methodologies) because of three key reasons:

1. First, pneumatic systems are relatively economical to install and operate
2. Second, pneumatic systems are totally enclosed and if required can operate entirely without moving parts coming into contact with the conveyed material. Being enclosed these are relatively clean, more environmentally acceptable and simple to maintain
3. Third, they are flexible in terms of rerouting and expansion. A pneumatic system can convey a product at any place a pipe line can run.

Pneumatic conveying can be used for particles ranging from fine powders to pellets and bulk densities of 16 to 3200 kg/m^3 (1 to 200 lb/ft^3). As a general rule, pneumatic conveying will work for particles up to 2 inches in diameter @ typical density. By "typical density" we mean that a 2 inch particle of a polymer resin can be moved via pneumatic conveying, but a 2 inch lead ball would not.

Types of Pneumatic Conveying

There are several methods of transporting materials using pneumatic conveying. In general, they seem to fall into three main categories: dilute phase, dense phase, and air conveying.

1. Dilute-phase conveying is the process of pushing or pulling air-suspended materials from one location to another by maintaining a sufficient airstream velocity. Dilute phase conveying is essentially a continuous process, characterized by high velocity, low pressure and low product to air ratio.

2. Dense-phase conveying relies on a pulse of air to force a slug of material from one location to another. Dense-phase system is essentially a batch process, characterized by low velocity, high pressure and high product to air ratio unlike dilute phase which is a low product to air ratio.

3. Air-activated gravity conveying is a means of moving product along a conveyor on a cushion of air.

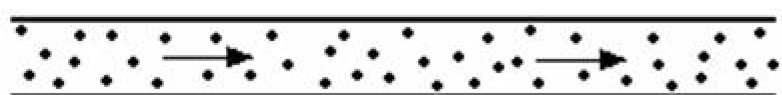
This course outlines the distinguishing characteristics of dense and dilute phase transport. The design of dilute phase systems is dealt with in detail and the approach to design of dense phase systems is summarized.

DILUTE-PHASE CONVEYING

Dilute phase conveying is the most common used method of transporting materials.

This process uses a relatively large amount of air to convey a relatively small amount of material and at lower pressures than dense phase systems. The material is transported at high velocities through the system while being suspended in air.

It is often referred to as suspension flow because the particles are held in suspension in the air as they are blown or sucked through the pipeline. To keep the material in suspension, it is necessary to maintain a minimum conveying air velocity that, for most materials, is of the order of 2500 – 6000 fpm.



Dilute-Phase - (Suspension Flow)

Dilute phase system is characterized by:

- High velocity conveying @ 3,200 to 8,000 feet per minute
- Operating pressures in range of 5-12 PSIG (positive) or negative pressures of 4-12" Hg
- High air to solids loading ratios (> 2.0)

There is virtually no limit to the range of materials that can be conveyed with dilute – phase system. Products commonly conveyed in dilute phase systems include flour, resins, specialty chemicals, ground feeds, and granular and palletized products. Of the various types of pneumatic systems, a dilute phase system will generally be lowest in capital cost.

Limitations

A relatively high air volume and velocity is required: so power requirements are also high. Higher air velocities will have the following other disadvantages:

1. The wear caused by the product on the pipe is considerably higher therefore this process is NOT suitable for materials which are susceptible to degradation and/or are abrasive in nature.
2. The products can get deformed or crushed therefore this process is NOT recommended for friable products.

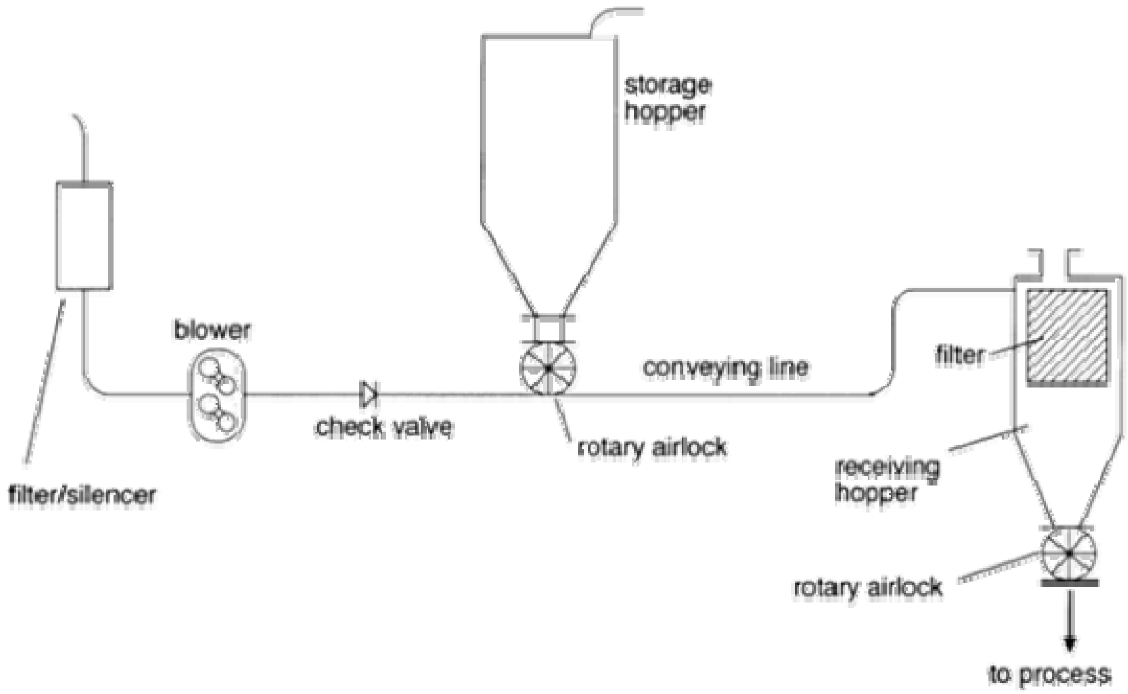
TYPES OF DILUTE – PHASE SYSTEMS

The dilute-phase system can be designed in three ways:

1. Positive pressure system
2. Negative pressure or vacuum system
3. Combination of positive – negative system

Positive pressure – Dilute phase

Positive pressure systems operate above atmospheric pressure and are used to convey bulk materials from a single or multiple sources to one or multiple destinations, over medium distances and with greater capacity than possible using vacuum systems. A typical positive pressure dilute phase system will consist of a rotary valve; pipe-work which would include long radius reinforced bends; a filter receiver or cyclone/filter arrangement; and positive displacement (roots type) air blowers. The schematic below shows a typical arrangement of the components of positive pressure systems:



Dilute phase transport positive pressure system

The product enters the convey line, which is at a higher pressure, via a special feeding device, usually a rotary valve airlock, or a venturi. The product is frequently suspended in the airflow, moving at relatively high velocities depending on the particle sizes and densities. The suspended material-air stream is separated at terminal point by means of a filter receiver/cyclone separator, or fed directly into process vessels that are vented to downstream dust collection devices.

In this type of system, the material does not go through the fan/blower. There are two advantages to this. First, the fan wheel does not damage the material. Second, the fan does not experience any wear and tear from the material. These systems generally operate on a continuous basis - product is constantly supplied at the starting point, and arriving at the destination without interruption. This allows this type of system to be easily adapted for dosing and continuous weighing applications.

Applications

Dilute phase pressure conveying is particularly suitable for systems which convey materials at low to moderate capacities over medium distances, from single or multiple sources to single or multiple destinations. These systems are versatile and adaptable for different materials and the low operating pressures allow lower cost pipelines and fittings. Cement, fly ash, food items, resins and dry chemicals are examples of products that can be conveyed successfully using this method.

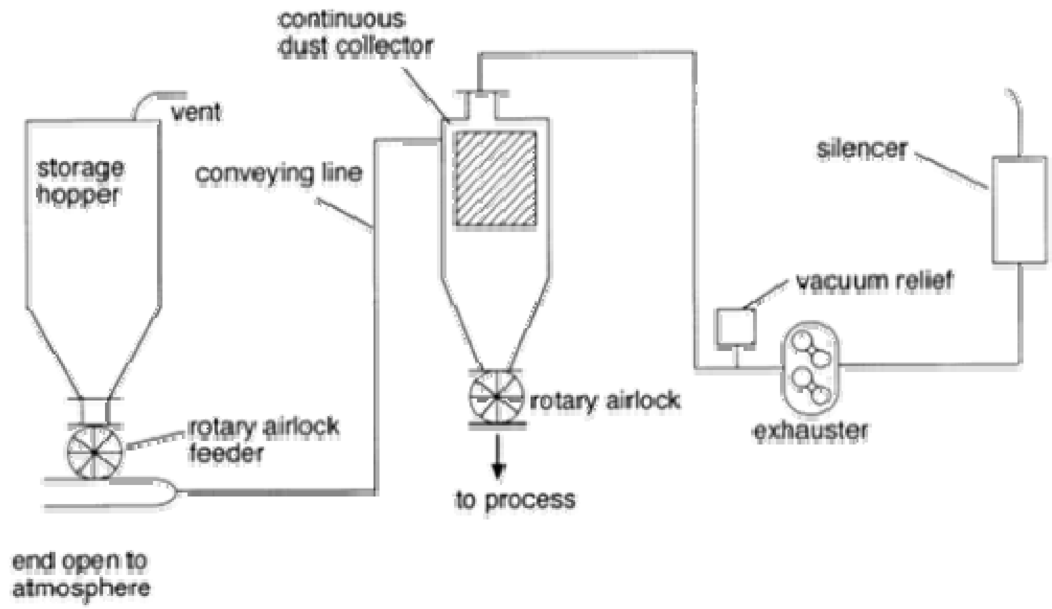
Typical Specifications

Convey Rates:	Low to High, typically from <1 to 50 tons/hr
Convey Velocities:	Typically 3200 – 8000 fpm
Convey Distances:	Up to 600 ft or longer
Air Mover:	Positive displacement (roots Type) blower, or fan
Operating Pressure:	Up to 14.7 psig
Air/Material Ratios:	> 2.0

Negative pressure – Dilute phase

Negative pressure conveying systems are those that operate with air pressures below atmospheric pressure.

Negative pressure (vacuum) is generally used to convey material from multiple sources such as storage vessels, process equipment, trucks and rail cars, to individual or multiple destinations. Vacuum systems are excellent for multiple product inlets through the use of simple diverter valves; however, it becomes costly to have multiple destinations because each must have its own filter receiver with partial vacuum capability.



Dilute phase transport: negative pressure system

Negative pressure systems generally use positive displacement (roots type) exhausters providing up to 50% vacuum to convey materials through a pipeline to the destination where the air and product are separated at a receiving vessel with a filter, or a cyclone.

The product enters the convey line directly, or if metering is required, via a special feeding device such as a rotary valve or screw feeder. The conveyed product is discharged from the receiving vessel either on a continuous basis by a rotary airlock or intermittently by valves to surge hoppers, storage vessels or other discharge points.

In vacuum conveying, no moving parts contact the materials and no dust can escape into the atmosphere. Because of this superior leak containment, they are often specified on the basis of cleanliness, particularly when handling hazardous materials.

The drawback of this system is that if the loading is high or the length of the system is large, the components must be designed for high vacuum. This adds cost to the components and must be considered when comparing methods of transport.

<u>Applications</u>

Vacuum conveying systems are particularly suitable for systems which convey materials at low to moderate capacities over medium distances, from multiple points to a single destination. These systems are versatile and adaptable for different materials and the low operating pressures allow lower cost pipelines and fittings. This method is frequently used for central vacuum cleaning systems and other applications, which require a reticulated network of vacuum pipes to convey product to a single collection point.

Typical Specifications

Convey Rates:	Low to Medium, typically <10 tons/hr
Convey Velocities:	Typically 3000 – 8000 fpm
Convey Distances:	Up to 300 ft or longer
Air Mover:	Positive displacement (roots type) exhauster, or fan
Operating Pressure:	Up to 50% Vacuum
Air/Material Ratios:	> 2.0

Combination Negative- Positive pressure – Dilute phase

This pull-push system incorporates the advantages and benefits of both negative and positive pressure arrangements in a single system. These systems are used where there are multiple material entry points, and multiple delivery points. A very common application is the unloading of a standard railcar. Since the cars cannot be pressurized, air is pulled from the outside, through the car (carrying solids with it) to a filter. Then after the filter, a blower can be used to forward the solids to the final receiver. If the final receiver is next to where the rail car is being unloaded it may be practical to use a complete vacuum system.

Which system is better – Positive pressure or Negative pressure?

Vacuum systems are "distance sensitive" and can operate at a maximum pressure differential of 5.5 to 6.0 psi. This is because the limit on a full vacuum is 29.4 inches of mercury (14.7 psi) and a full vacuum is a complete lack of air. But air is what we are using to convey with. The practical maximum vacuum we can go to before the convey rate starts dropping off, or line plugging takes place, is 12.5 to 13 inches of mercury (6.5 psi).

There are few applications where vacuum system is an economical solution. Typical applications include drawing materials from several points for batching before entering process and unloading from several points such as rail cars with delivery to bulk storage. Unlike positive pressure systems, vacuum systems allow easy pick-up of materials from open containers using wands, and do not impart heat to the material.

SYSTEM DESIGN

Design Objective

New projects: The design objective for new projects is to ensure conveying capacities at specified flow rate over a given distance. The conveying capacities are usually specified in tons per hour (TPH) of material flow.

Expansion/retrofit projects: The primary consideration is to find a way to handle the increased capacities (TPH) with the minimal amount of increase in conveying air volume and/or line pressure.

The design and selection of a pneumatic conveying system involves consideration of numerous parameters such as the conveyed material properties, the conveying velocities and the conveying distance. Studying the relationship between these factors shows how changing one factor will change other factors. Two basic relationships are:

1. Conveying capacity is inversely proportional to conveying distance
2. Conveying pressure is directly proportional to conveying distance

Pressure – Volume Relationship

Air is compressible and as the material is conveyed along the length of a pipeline, the pressure will decrease and the volumetric flow rate will increase. For air the situation can be modeled by the basic thermodynamic equation:

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

Where

- p is the air pressure (psi)
- V, the air flow rate (cfm)
- T, the air temperature (K) and
- Subscripts 1 and 2 relate to different points along the pipeline.

If the temperature can be considered to be constant along the length of the pipeline this reduces to:

$$p_1 V_1 = p_2 V_2$$

This equation tells us that as the pressure decreases along the line from the pick-up point to the discharge, the air volume expands and therefore the volume (or velocity) will be continually increasing.

Air Volume – Velocity Relationship

For any given material, there is a minimum transport velocity required to convey the material, therefore, the airflow rate (volume) will depend on the size of the pipe. The airflow – velocity relationship is governed by equation:

$V = \rho * A * v$

Where

- V = volumetric air flow rate in ft^3/min (cfm)
- ρ = density of air (lbs/ft^3)

- A = conveying pipe area ft^2
- v = conveying velocity in ft/min (fpm)

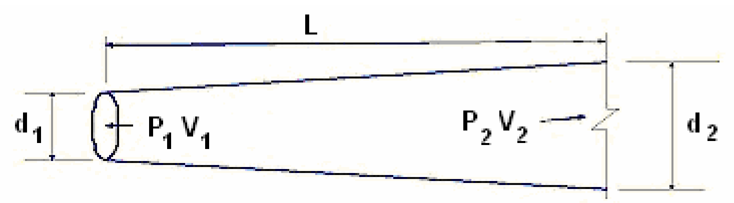
Or

v = V / (ρ * A)

Thus, actual velocity is the volume flow rate at pressure and temperature conditions per unit cross-sectional area of the empty pipe, normally expressed in feet per min (fpm).

Establishing Smooth Velocity Profile

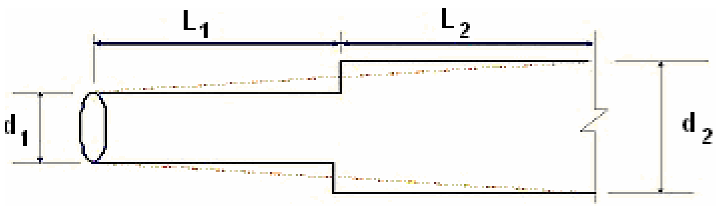
We have learnt from equation $P_1V_1 = P_2V_2$, that as the pressure decreases along the line from the pick-up point to the discharge, the air volume expands and therefore the volume (or velocity) will be continually increasing. This is true for a single bore pipe line of constant internal diameter. In order to keep velocity profile near constant, we need continually increasing area of pipe. With that thought, we can say that in an ideal world, if we could have a pipe line which is tapered, and that taper is at the same rate as the pressure ~ volume relationship is changing; we could effectively keep velocity as a constant. The following diagram reflects this thought;



Slope of the pipe taper directly proportional to P_1V_1 / P_2V_2

Pressure - Volume Relationship in a Tapered Line

Tapered pipes are not practical, so as an alternative, we can accomplish the goal from "stepped line". Stepped line is a continuous pipeline in which the diameter of the conveying pipe changes, generally to a larger bore, at points along its length. The purpose is to accommodate the change in volumetric flow rate of the conveying air as the pressure changes, without the velocity falling below the minimum value of conveying air velocity at any point. This is sometimes referred to as a telescoped pipeline.



Pressure – Volume Relationship in Stepped Line

This is very important aspect in reducing the terminal end velocities and improving the overall efficiency and productivity of pneumatic conveying system.

Material velocity

In dilute phase conveying, with particles in suspension in the air, the mechanism of conveying is one of drag force. The velocity of the particles, therefore, will be lower than that of the conveying air. It is a difficult and complex process to measure material velocity, and apart from research purposes, particle velocity is rarely measured. It is generally only the velocity of the air that is ever referred to in pneumatic conveying.

1. In a horizontal pipeline the velocity of the particles will typically be about 80% of that of the air. This is usually expressed in terms of a slip ratio, defined in terms of the velocity of the particles divided by the velocity of the air transporting the particles, and in this case it would be 0.8.

2. In vertically upward flow in a pipeline a typical value of the slip ratio will be about 0.7.

These values relate to steady flow conditions in pipelines remote from the point at which the material is fed into the pipeline, bends in the pipeline and other possible flow disturbances. At the point at which the material is fed into the pipeline, the material will essentially have zero velocity. In order for material to accelerate to conveying velocities, an initial section of straight piping is necessary. Good engineering practice dictates that a straight section equal to 25 times the pipe diameter is required before the first bend.

Here it is important to define different velocity terms used in pneumatic conveying industry:

1. Superficial velocity - This is the velocity of the air disregarding the presence of the solid particles or porous media. Note: In a pipeline it is the air velocity based upon

the cross-sectional area and neglecting the space occupied by the conveyed material. Air velocity, for a given mass flow rate, is dependent upon both pressure and temperature. When conveying air velocities are evaluated at any point in the system, the local values of pressure and temperature at that point must be used.

2. Free velocity - This is the superficial velocity of the air when evaluated at free air conditions.

3. Minimum conveying velocity - The minimum conveying air velocity is the lowest superficial air velocity that can be used to convey a material. Note: In dilute phase flow this is the lowest air velocity that can be achieved without material settling on the bottom of pipes.

4. Inlet air velocity - This is the superficial air velocity at the point where the material is fed into the pipeline. Note: In a single bore pipeline this will be the lowest air velocity in the conveying line. This is variously referred to as the pick-up or entrainment velocity. In a vacuum conveying system it is approximately equal to the free air velocity.

5. Terminal velocity - This is the superficial air velocity at the end of a conveying line where the material is discharged into the receiving vessel. Note: In a single bore pipeline this will be the highest air velocity in the conveying line. In a positive pressure conveying system it is approximately equal to the free air velocity.

System Pressure Drop

The performance of a pneumatic conveying system, in terms of achieving a given material flow rate, depends essentially on the system resistance. Higher the system resistance, higher will be the pressure drop in the system or higher will be the static pressure of the fan.

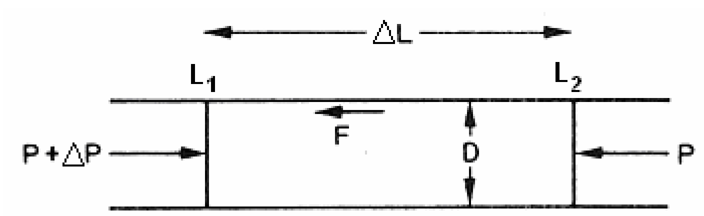
The system resistance (pipe wall friction per unit area) can be estimated using following equation:

$F/A = f \rho v^2/2$ ……………. (1)

Where,

- *F* is the friction force
- *A* is the area over which the friction force acts
- ρ is the density of the fluid
- *v* is the velocity of the fluid and
- *f* is a coefficient called the friction factor

If we carry energy balance over a differential length, L_1 to L_2, of a straight horizontal pipe of diameter D, the total force required to overcome friction drag must be supplied by a pressure force giving rise to a pressure drop ΔP along the length L_1 to L_2.



Energy balance over a length of pipe

The pressure drop force is:

$$\Delta P \text{ x Area of pipe} = \Delta P \text{ x pi} * D^2/4$$

The friction force is (force/unit area) x wall area of pipe

$$= F/A \text{ x pi} * D \text{ x } \Delta L$$

so from equation (1) $= (f\ \rho\ v^2/2) \text{ x pi} * D \text{ x } \Delta L$

Therefore equating pressure drop and friction force:

$$\Delta P \text{ x pi} * D^2/4 = (f\ \rho\ v^2/2) \text{ pi} * D \text{ x } \Delta L$$

Or

$$\Delta P = 4 * (f\ \rho\ v^2/2) \text{ x } (\Delta L/D)$$

Thus, you can see that the pressure drop is

- Directly proportional to velocity squared
- Directly proportional to the conveying distance i.e. length of the pipe and
- Inversely proportional to the diameter of pipe.

To keep pressure drop low, lower conveying velocities are advised.

Minimum Conveying Velocities

Certain minimum conveying velocities must be maintained to keep the material in suspension and flowing. A velocity that is too low will impede the material conveying capability of the system and unnecessarily high velocities will increase pressure drop and therefore, additional energy will be required to overcome that resistance.

The conveying velocity and hence air flow rate is greatly influenced by material characteristics. Particle shape, size distribution, mean particle size and particle density; all have an effect on minimum conveying velocity, pressure drop, air flow, etc. Properties such as moisture content, cohesiveness and adhesiveness may cause flow problems through vessels and valves.

<u>Material Influences</u>

The characterization of the material to be conveyed plays a very large part in the selection of the velocity regime. This can be understood by comparing, say cement powder, with wet lump coal. Although both materials can be conveyed pneumatically, the pneumatic conveying regime for cement powder is likely to be quite different for the regime selected for wet lump coal. The reason for this concerns the properties of the bulk material and how these properties interact during the pneumatic conveying process. For example, cement powder may be easily fluidized and mixed with air. When conveyed at high velocities, it will not degrade to the detriment of the bulk material. Wet, lump coal (2" mean size), on the other hand, cannot be fluidized without severely degrading the material to the extreme detriment of the coal product. These factors affect the choice of allowable material velocities through the pipeline.

It is not just different materials! Different grades of exactly the same material can exhibit totally different performances. Thus a conveying system designed for one material may be totally unsuitable for another. For practical purposes, a conservative design approach is to keep the ratio of material-to-air below a 1:2 proportion. Successful systems have been designed using material loadings of 1:1 or more when the system components are well-designed and eliminate sharp turns, abrupt junctions, or other potential points of binding, clogging, or drop-out.

Example

For example, conveying sawdust at a rate of 1800 lbs/hr through a 6" pipe with a material loading ratio of 1:2 will result in an air velocity of 4073 FPM.

1. Material conveying rate = 1800 lbs/hr material or 30 lbs/min
2. Material – air ratio = 1:2
3. Air by weight = 30 x 2 = 60 lbs/min
4. At standard air density of 0.075 lbs/ft^3, the volume of air will be
5. Air by volume = 60 lbs/min ÷ .075 lbs /ft^3 = 800 CFM
6. Pipe area of 6" diameter = 0.196 ft^2
7. Conveying velocity = Air volume / pipe area = 800 CFM ÷ 0.196 ft^2 = 4073 FPM

The fan can be selected for 800 CFM.

This is only air volume, what about material volume?

Since both the material and the air is conveyed through the pipe, the natural question will arise that fan should be sized to handle the combine volume. In most applications, the material volume is ignored owing to high bulk material density.

In above example, 1800 lbs/hr of sawdust has an average bulk density of 11 lbs /ft^3; which result in volumetric flow rate of 1800 ÷ 11 = 164 ft^3/hr or 2.7 ft^3/min. This is negligible. However, in situations where greater material volumes are being handled or when the bulk material density is much lighter, the volume cannot be ignored.

The above example considers material-air ratio (MAR) of 1:2. If the same 1800 lbs/hr of sawdust had been introduced to a system with a 1:1 design ratio and there were no other changes to the system, the resulting velocity would only be half and the material would probably settle and clog. To compensate for the lower ratio, the pipe size could be reduced to 4", but this might introduce new problems in feeding the material to the pipe or transitioning to the fan. It is best to consult an expert before initiating the actual selection.

The dilute phase system requires relatively high conveying air velocities depending on the material type. This is typically in the region of 3000 fpm for a fine powder, to 4000 fpm for a granular material, and beyond for larger particles and higher density materials. Table below provides conservative minimum conveying velocities to be used for some common materials. As a rule of thumb, materials up to approximately 50lbs/ft^3 can be conveyed with an air velocity of 5000 fpm.

Material Conveying Duct Velocities

MATERIAL	VELOCITY (FPM)	MATERIAL	VELOCITY (FPM)
Paper	5000	Cotton	4000
Powdered Coal	4000	Wheat	5800
Dry Vegetable Pulp	4500	Wool	5000
Cement	7000	Oats	4500
Sand	7000	Corn	5600
Salt	5500	Sugar	6000
Sawdust	4000	Flour	3500

Sufficient velocities must be maintained throughout the conveying system to avoid material settling. When settling occurs in the horizontal plane, it is known as saltation. When settling occurs in the vertical plane, it is called choking.

Saltation is the process of deposition of solid particles along a horizontal pipeline. This phenomenon occurs when the air velocity falls below the minimum conveying value.

Caution – Don't select a velocity higher than needed. The additional velocity would be detrimental to the system by causing increased friction, wear, and operating costs.

Choking in downward movement often occurs in the vertical line as a direct result of saltation in the adjacent horizontal line. Upward movement is often easier to control because all that is needed is sufficient momentum (velocity) to keep the material in suspension. All falling materials simply drop back into the airstream. However, choking in the upward flow directly above the fan discharge will exhibit premature wear due to excessive loading.

To minimize the potential for saltation or choking, it is recommended to minimize bends and elbows and also remove any leaks because velocity will be less downstream of leaks. It is good to consider some excess air in the system design that will effectively increase velocities in the system to assist material transportation. Some provisions may be included to keep in the system for bleeding excess air through adjustable vents or dampers.

For dilute phase conveying, higher materials loading ratio that can be achieved:

- If the conveying distance is short,
- If the conveying line pressure drop is low

If the air pressure is low or if the pipeline is very long, then the value of materials loading ratio will be very much lower.

Fans Selection

Fans are selected for volumetric flow rate (CFM) and the static pressure required mitigating system resistance. We have discussed that only the air volume is normally considered in determining the fan capacity and the material volume is ignored. However, the material content cannot be ignored when calculating system resistance and the motor rating of the fan.

System Resistance / Pressure Drop

We have discussed before that the pressure drop in pneumatic system is proportional to:

$$\Delta p \propto \frac{L \rho v^2}{d}$$

Where

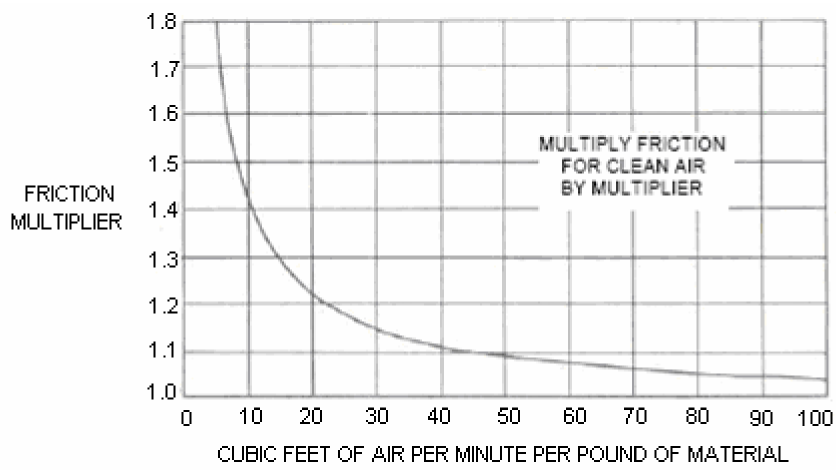
- Δp is the pressure drop
- L, the length of straight pipeline
- ρ, the air density
- v, the conveying air velocity
- d, the pipeline bore

This is cumbersome method to estimate unless you use software. Simplifying tables are available that provide friction loss (FL) per 100 ft length of the pipe.

Quantity of air flowing (CFM) and Friction loss (in inches w.g.) per 100 feet length

Duct Size	6"		7"		8"		9"		10"		11"		12"	
ft²	0.196		0.267		0.349		0.442		0.545		0.660		0.785	
Velocity FPM	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL	CFM	FL
3500	687	3.33	935	2.76	1222	2.34	1546	2.03	1909	1.78	2310	1.59	2749	1.43
3600	707	3.51	962	2.91	1257	2.47	1590	2.14	1964	1.88	2376	1.68	2827	1.51
3700	726	3.70	989	3.06	1292	2.60	1635	2.26	2018	1.98	2442	1.77	2906	1.59
3800	746	3.89	1016	3.22	1326	2.74	1679	2.37	2073	2.09	2508	1.86	2985	1.67
4000	785	4.29	1069	3.55	1396	3.02	1767	2.62	2182	2.30	2640	2.05	3142	1.84
4200	825	4.71	1122	3.90	1466	3.31	1856	2.87	2291	2.52	2772	2.25	3299	2.02
4400	864	5.14	1176	4.26	1536	3.62	1944	3.13	2400	2.76	2904	2.45	3456	2.21
4500	884	5.36	1203	4.44	1571	3.78	1988	3.27	2454	2.88	2970	2.56	3534	2.30
4600	903	5.59	1229	4.63	1606	3.94	2032	3.41	2509	3.00	3036	2.67	3613	2.40
4800	942	6.06	1283	5.02	1676	4.27	2121	3.70	2618	3.25	3168	2.89	3770	2.60
5000	982	6.55	1336	5.43	1745	4.61	2209	4.00	2727	3.51	3300	3.13	3927	2.81
5200	1021	7.06	1390	5.85	1815	4.97	2297	4.31	2836	3.79	3432	3.37	4084	3.03
5400	1060	7.58	1443	6.28	1885	5.34	2386	4.63	2945	4.07	3564	3.62	4241	3.26
5600	1100	8.13	1497	6.73	1955	5.72	2474	4.96	3054	4.36	3696	3.88	4398	3.49
5800	1139	8.69	1550	7.20	2025	6.12	2562	5.30	3163	4.66	3828	4.15	4555	3.73
6000	1178	9.27	1604	7.68	2094	6.52	2651	5.65	3273	4.97	3960	4.42	4712	3.98
7000	1374	12.42	1871	10.29	2443	8.74	3093	7.57	3818	6.66	4620	5.93	5498	5.33

Note that the table above provides friction drop due to air; what we are concerned herewith is the friction drop due to mixture of solids and air. Due to wide variations in materials, no dependable methods of how to determine the flow resistances for mixtures is proven; and only the reasonable estimates are available. Some researchers have established detailed equations (refer annexure -2 for details) to estimate resistances and others have theorized that the bulk material content merely acts to reduce the effective area of the pipe and so ignore the density effect by calculating air resistance through the resulting smaller pipe diameter. The figure below derived from pilot plant testing and experimentation provides reasonably estimate of correction factors for estimating resistance.



RESISTANCE FACTORS

In our example, 800 CFM of air is needed for 30 lbs/min of material, which is equal to approximately 26 CFM of air per lb of material. The friction multiplier factor is thus 1.17. *Refer to Annexure-2 for the detailed methodology.*

<u>Fan BHP</u>

The fan brake horsepower (BHP) will increase in response to material-air ratio and is dependent on the bulk density of the mixture. In our example, the combined weight and total volume can be used to determine the maximum airstream density for selecting a motor that will handle the fan BHP at the bulk density.

Mass of material = 1800 lbs/hr

Material-air ratio = 1:2

Mass of air = 3600 lbs/hr

Total mass of mixture = 1800 lbs/hr material + 3600 lbs/hr air = 5400 lbs/hr

Total mass of mixture = 5400 ÷ 60 = 90 lbs/min

Volumetric flow rate of material = 3 cfm

Volumetric flow rate of air = 800 cfm

Total volumetric flow rate of mixture = 3 + 800 = 803 cfm

Therefore bulk density of mixture = Total mass / total volume = 90 ÷ 803 CFM = 0.112 lbs/ft^3 bulk density

Since the BHP rating of motor is based on the standard air conditions of 0.075 lbs/ft^3, corrections need to be applied for bulk density of 0.112 lbs/ft^3. The approximate correction factor in this case is 1.5 obtained by dividing bulk density to standard air density i.e. (.112 ÷ .075) = 1.5

Conveying Distance

Conveying pressure is directly proportional to conveying distance

Conveying capacity is inversely proportional to conveying distance

Conveying distance has a very significant influence on pneumatic conveying system performance. Higher conveying distance signify higher pressure drop. Assume, for example, that a system is capable of conveying 100 tons/hr over a distance of 300 ft with a pressure drop of 30 psi. If the distance is doubled, and there is no change in pressure, the material flow rate will be reduced by at least half, to a maximum of 50 tons/hr, if there is no change in pipeline bore. With a halving of material flow rate and no change in air flow rate, the solids loading ratio will also be halved and the specific power consumption will increase.

Conveying distance or line length does impose a practical limit on capacity. When we refer to line length, what we actually mean is equivalent line length which not only takes into account the summation of horizontal runs and vertical runs, but the number of bends in the system as well. If we can find a way to reduce the equivalent length of pipe, we can effectively reduce the pressure differential required to move the material through the line. Shortening the conveying line with minimum number of bends seems obvious. The other simple technique is “line stepping” as discussed before.

Note that when you compare pneumatic handling with hydraulic conveying system, the conveying capability of pneumatic system is far lesser. With water having a density that is about 800 times greater than that of air, at free air conditions, the difference in density between the conveyed material and that of the conveying fluid is widely different. As a consequence conveying air velocities are a factor of about ten times greater than those required for water in order to convey material in suspension.

COMPONENTS OF DILUTE – PHASE SYSTEM

Major pneumatic system components include:

1. Pressure blowers and vacuum pumps with integral sound enclosures
2. Rotary airlock valves
3. Transfer line including piping, elbows; divert valves (flex-tube diverters, wye-diverters, plug diverters and other line diverter configurations).
4. Filter receivers
5. Cyclone separators
6. Gain-in-weight and loss of- weight batching systems
7. Dust collectors and bin vents
8. Controls and electrical equipment
9. Silos, day bins and other storage vessels

FAN SELECTION CONSIDERATIONS FOR MATERIAL HANDLING

The fan / blower is the heart of the dilute phase pneumatic conveying system. If the material does not come in contact with the fan, backwardly inclined fan will be a good choice. If the material being conveyed will be going through the fan, special considerations must be given to the fan design. The fan blade type selection is very important because one does not want to select a blade type that is prone to collecting material. Backward curved and airfoil blades are efficient, but they often collect material on the blades. Radial blades are better suited for material handling applications.

Fan speed is also important. The operating speed should be minimized as much as possible. High-speed fans with high tip speeds create higher velocities that correspond directly to the level of erosion and impact on the fan and system components. The fan should be selected with the critical speed significantly higher than the operating speed. Good engineering practice dictates that for material handling fans, the critical speed shall be at least 1.5 times greater than the operating speed.

If the material comes in contact with fan, special materials may be required to resist corrosion, abrasion, and impact depending on the material being handled. In some applications, liners are added to the fan wheel at locations where the most abrasion will occur. These liners can then be replaced periodically without having to replace the entire wheel. Special coatings may also be required to resist corrosion or to make cleaning easier.

If the material being handled is explosive or flammable, spark resistant construction shall be required. AMCA Standard 99 specifies Type A, B, and C spark resistant construction, which are available for many fan designs. If materials such as coal are being transported, the National Fire Protection Association requires the fan housing design to withstand an explosion.

Special consideration may need to be given to bearing selection. The fan arrangement should be selected such that the bearings are out of the air stream. Also, higher capacity bearings may need to be used to allow for loads created by the material impacting on the impeller. Fan orientation can also be important in material handling applications. In centrifugal fans, bottom horizontal or bottom-angular-up discharges are preferred. In other configurations, if material settles in the fan housing, it drops to the bottom and stays there. With bottom horizontal or angular up discharges, material tends not to settle due to high velocities at the bottom of the housing.

It is essential that the correct type of fan is selected and that it is correctly specified, particularly in terms of free air delivered.

PIPING

Design of a piping system requires careful consideration of factors that can doom a system to failure or marginally acceptable operation. Some basic rules that should be strictly adhered to:

1. All runs should be direct between material pick up and drop off with the least number of direction and elevation changes as possible.

2. A straight horizontal run of alt least five to six feet should be present before every direction change (elbow). This run should be progressively longer for larger pipe sizes. A good rule of thumb is to allow a five foot run for two inch pipe and adding an additional 5 feet for ever inch the pipe diameter increase. A five inch diameter conveying line would require 5 + 5 + 5 + 5 = 20 feet of horizontal run before each elbow. Downstream the material inlet, a straight section equal to 25 times the pipe diameter is required before the first bend.

3. Angled risers should not be used unless necessary.

Construction of piping system generally involves consideration of both the type and material to be used. Most pneumatic conveying is made of aluminum because of aluminum's light weight and corrosion resistance. Galvanized carbon steel is also used in smaller line sizes of 1¼ inch and 2 inch ID. Galvanized steel is slightly less expensive installed than aluminum thin wall tubing. It is also heavier and more prone to corrosion especially when used outdoors. Thin wall stainless steel tubing and schedule 10 and 40 aluminum pipes are used less frequently and at an obviously higher cost. A frequently used combination is aluminum thin wall tubing for low wear straight runs with thin wall stainless steel elbows for high wear bends. This combination is both durable and cost effective.

Tubing lengths and elbows are normally connected together by galvanized or stainless steel, gasketed compression type three or four bolt couplings. These should always have grounding strap included since the gasket is usually an insulator. Isolated section of conveying tubing can build up a substantial and potentially dangerous static charge from the conveying process.

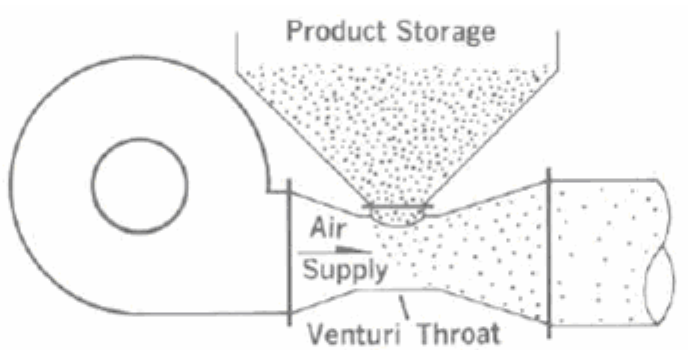
MATERIAL INTAKE METHODS

There are many different types of feeders that are used to introduce the material being conveyed into the air stream. Some common feeders are screw, venturi, and hood feeders.

Gravity Feed

A hood or hopper can be used for dry, free-flowing materials. It is important to remember that it is the velocity moving around and past the material that induces it to flow. If the entry becomes plugged with material, the required velocity cannot be maintained, significantly impeding air and material flow.

A venturi feeder can be used to introduce material into the airstream. Like the hood, it has no moving parts so there is virtually no maintenance. However, the design of the venturi must be tailored to each application and even the best ones can be rather easily blocked if system conditions vary. Typical throat velocities are 2 to 3 times the velocity in the main duct.



Typical Venturi Feeder

Mechanical Feed

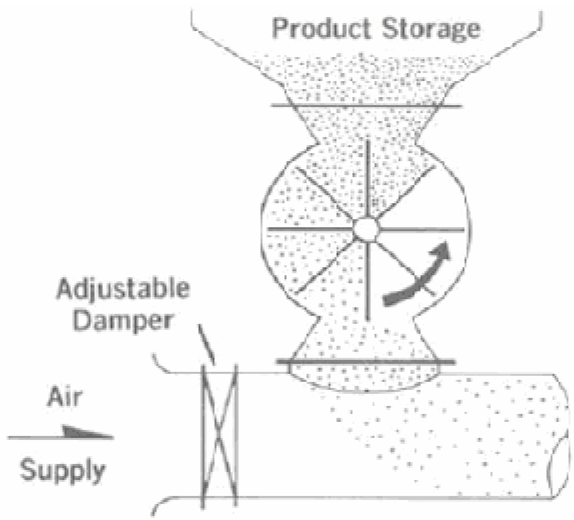
The most common feeder used in pneumatic conveying is the rotary valve, which is also known as a rotary feeder, star feeder, rotary seal, rotary airlock or cellular wheel.

Rotary valves enable solids to be fed at a controlled rate into the air stream against the air pressure. It consists of a rotor that is divided into a number of pockets or vanes (eight vanes would be typical). Product from the hopper above flows by gravity into each rotor pocket as it passes the hopper to which it is attached. The pockets rotate to the bottom and the product drops out of each pocket in succession into the conveyed air stream and through the convey line. The pockets completes the rotation to the top filled with the compressed convey air which expands into the airlock inlet hopper. Therefore, some convey air is lost into the airlock inlet hopper.

There are two main types of rotary valve:

1. The more common "drop-through" rotary valve, which is used mainly for relatively free-flowing materials (e.g. grain, rice, poly pellets and powder, granulated fertilizer, alumina, coffee beans, sugar);

2. The "blow-through" rotary valve, which is used mainly for more cohesive or sticky powders (e.g. cocoa powder, flour, milk powder) that may not discharge properly from a drop-through rotary valve (i.e. fine powder compacts and sticks to the inside of the wedge-shaped rotor pockets).



Typical Rotary Valve Feeder

The sizing/selection of a rotary valve will depend on (among other things) whether or not the valve is being used as the feed rate controller of the system. For example:

1. If a rotary valve is connected directly to a hopper that is "full" of product, then the valve is said to be "flood-fed" and the feed/conveying rate can be altered by varying rotor speed – here the rotary valve is the feeder or feed rate controller.

2. If the rotary valve is located downstream of another feeding device (e.g. screw feeder) or another feed rate controller (e.g. hammer mill), then the rotary valve is being used for another purpose (e.g. pressure seal or airlock, explosion non-return valve).

Rotary valves feeding positive-pressure pneumatic conveying systems can experience numerous problems, such as inadequate feed rate capacity, loss of air from the system, unstable flow conditions, conveying pipeline blockages and excessive wear inside the rotary valve. In many cases, the root cause of such problems is the leakage (loss) of air through the rotary valve (due to clearances).

The amount of leakage depends on many factors, such as system pressure, rotor clearances, material properties, head of product above the valve and whether venting is used or not. Disregarding leakage or inaccurately estimating leakage at the design stage of a conveying system can result in the incorrect sizing of the air mover (i.e. fan, blower or compressor).

An airlock is a precision machined device where the clearances between the rotor and the housing are 0.004 to 0.005 inch. This clearance does wear out over time, resulting in increased leakages.

MATERIAL DISCHARGE METHODS

Material typically exits via filter receivers or cyclone separators. Positive pressure systems can additionally employ fill/pass valves to discharge material from the system at one use point, or redirect the material to another use point.

Filter Receivers - Filter receivers separate solids from the air stream using filter media and gravity, and are generally specified when materials contain smaller particles that are prone to dusting and/or when dust containment is a primary requirement. They are normally located above material use points, and employ reverse-pulse jet filter cleaning to dislodge accumulated dust from filter surfaces, allowing continuous and efficient separation of material from the air stream. These can be used in both pressure and vacuum systems.

Cyclone Separators - Cyclones operate by generating a vortex of particulate laden air. Centrifugal force pushes the particulates toward the outer cyclone wall where they lose velocity and spiral downward to the discharge. The relatively particulate-free air is then exhausted through the clean air discharge port which is attached to the top of the cyclone. Filters of various types and with various methods of solids recovery are used to clean up the transport gas before discharge or recycle.

Fill/Pass Valves - Fill/pass valves are commonly used to discharge material directly into individual or multiple process vessels and/or to deliver it to several destinations along a common conveying line. Downstream of the last fill/pass valve, the conveying line is normally routed to the original material source point or into a dust collection device. It is used only in pressure systems.

Directly Into Process Vessels - Both pressure and vacuum systems can feed material directly into blenders, reactors and other enclosed process vessels that are vented to a downstream bag house or other dust collection device, eliminating the need for individual filter receivers. It can be used in both pressure and vacuum systems.

Ways to Increase Capacity

1. Optimize solids/air ratio
2. Minimize the number of bends
3. Shorten the total conveying distance
4. Reduce conveying velocities to just above saltation
5. Step up the line diameter near the end of the system
    - Doing so decreases the total system pressure drop
6. Minimize flex hose length and eliminate where possible

Ways to Minimize Wear in Conveying Lines

1. Reduce conveying velocities
2. Use wear resistant materials for more prevalent abrasive materials - Sand, carbon black, etc.

3. Minimize line length and number of bends

4. Enter the vessel radially, not tangentially

5. Hang a flapper in the middle of the bin to allow the material to contact it instead of the vessel wall

6. Step up the line diameter before the vessel entrance

Top Ten Tips for Dilute Phase Pneumatic Conveying

1. Do not use sloping pipe runs. The refluxation, (run-back and re-conveying of the same material), will require the pipe to re-transfer the product slipping back on top of its normal load, and the effect is accumulative. At best it will significantly increase the conveying burden, but is more than likely tend to block the lower bend.

2. Allow a 'reasonable' horizontal conveying length before the first bend to allow the bulk material to accelerate to a stable conveying speed and reduce the sectional loading of the conveying pipe. Material slowed by the bend occupies a greater proportion of the pipe's cross sectional area and thereby offers more obstruction to the air flow, which increases the pressure drop along the system.

3. Do not fit bends close together on the pipe run for reasons similar to the above.

4. Consider stepping the pipeline on long runs. Air expands with pressure drop, so velocities inevitably increase along a constant pipe run. Higher material velocities increase wear on bends and product degradation.

5. 'More air' can be 'less transfer capacity' in dilute phase systems. Larger solids and gas frictional losses caused by higher gas velocities can absorb more energy than the extra input of energy. There is an optimum gas flow rate for a given lean phase flow system. Check with a specialist for the correct solids/gas ratio balance and top performance.

6. Product damage and wear at bends is very material dependent. Blind Tee does usually have much merit, but cause a higher pressure drop than long radius bends.

7. Rotary valves do leak and also pass air differentials through the returning empty pockets. They also tend to fill with product on one side of the valve as the empty pockets are rotated to present a space for material to flow in. Back flow of gas and biases intake causes many feed problems. Make sure that the valve is properly vented and that the feed channel is of good form for flow across the whole cross section. A short inlet standpipe is useful for such duties as a cyclone outlet or a feed into a high pressure line.

8. Check that cyclones have an unobstructed outlet. If there is intermittent or periodic discharge, allow clear buffer capacity to avoid interfering with the cyclone operation.

9. Allow for the pressure drop on the supply line to the blower. Include an allowance for any filter, silencer, acoustic box or compressor enclosure and extended supply run, as may be appropriate. Be sure to compensate for the temperature increase due to gas compression.

10. Provide adequate instrumentation; this is essential to know what is going on and to facilitate a proper investigation of any problems that may arise.

DENSE PHASE CONVEYING

In a dilute phase conveying system, the product is transported by lift, or suspension, of the individual particles in the air stream. As the velocity is subsequently reduced, the larger particles cannot sustain this lift and they begin to fall from suspension to the bottom of the pipe. The technical term used in the industry that describes the velocity at which particles fall from suspension from the air stream is "saltation velocity".

Unlike dilute phase conveying systems that typically use larger amounts of air to move relatively small amounts of material at high velocities in suspension, dense phase offers the enormous advantage of efficiently "pushing" a much denser concentration of bulk solids at relatively low velocities through a conveying line. The best, single description for identifying if a system is dense phase is whether the product velocities in the pipe are designed to be operating below the saltation velocity.

Why Dense Phase?

The number one reason to apply a dense phase design is when the product being handled is highly friable. Many products within the food industry fall into this category. As an example, if a consumer opens a bag of cheese puffs and finds them broken, he will quickly change loyalty to the brand. Broken pieces do not command the salable price and are usually discounted for wholesale use. The cost effect of material damage due to degradation can be huge and preventing degradation is thus a high priority especially in food processing and canning operations of meat lumps, softened grains and vegetables etc.

By virtue of the low velocity characteristics, the next best application for dense phase is transportation of highly abrasive materials. The higher velocities associated with dilute phase conveying can lead to rapid pipe wear. Many materials such as sand, alumina etc. are so abrasive that they can wear a hole in a pipe elbow in just a few weeks. The pipe wear can also result in a contamination of the product.

There is really only one other main reason for selecting dense phase. This is typically found within the plastics and petrochemical industry. Some of the softer plastics, such as polypropylene and polyethylene, will smear onto the pipe wall when the product slides along the outer wall of an elbow in a dilute phase transport system. The plastics will actually melt from the frictional contact with the pipe wall and will leave a long thin layer of material. The layers are peeled off into strips and re-entrained into the system. These strips are commonly referred to as a "streamers" and they will quickly build up in awkward places and stop product flow. Dense phase transportation will eliminate the streamers that are commonly associated with dilute phase conveying.

Dense Phase Theory

The main principle of a dense phase conveying system is to slow down the velocity of the product in the pipe to a point that is below the speed at which the product breaks or degrades. At low velocities, the product lies for periods of time in the bottom of a horizontal line and it is blown under pressure to the discharge point in slugs or plugs.

The dense phase pneumatic conveying systems uses low volume, medium pressure air stream and relies on a continuously expanding volume of air pushing cohesive slugs of material along the pipe. This system uses a transfer vessel/pump tank to feed the material into the conveying line. It is a batch system with plugs of material separated by cushions of air. The velocity range at the source can be as low as 200 fpm for the majority of products. The product velocity at the destination is always a function of the system differential pressure, but in most cases it rarely exceeds 2000 fpm.

Dense phase technology reduces the air consumption to the absolute minimum by allowing the system to convey at maximum density. This maximum density conveying technique has three main advantages.

1. First, because the conveying pipe line is so dense with the bulk material, the air cannot "slip" past the bulk material, which is a common inefficiency in dilute pneumatic conveying systems. If we eliminate the slip, we can improve efficiency.

2. Second, when the conveying pipe is at maximum density, only a small percentage of the particles are in contact with the conveying pipe at any given time. The majority of the particles are in the interior of the pipe, therefore not abrading the pipe. So, this significantly decreases pipe wear.

3. Third, by increasing the pipe density, the conveying velocity can be decreased for a given transfer rate and pipe diameter.

   The transfer rate, Q, in lbs/min can be expressed as:

   $Q = p * A * v$

   Where

   - Q = rate of material transferred lbs/min
   - ρ = bulk density of mixture lbs/ft^3
   - A = conveying pipe area ft^2
   - v = conveying velocity in fpm

   Rearranging the equation:

   $v = Q / (\rho * A)$

Therefore, if the conveying density is increased while holding all of the other variables constant, the conveying velocity will decrease. It has become well established that the cause of pipe erosion is largely due to the velocity of the material as it is conveyed. Work carried out by a number of organizations indicates that a relationship between specific erosion and velocity given by:

Specific erosion = (Ratio of velocity) $^{2.65}$

In numerical terms, this would mean, for example, if a dense phase system was operating at 500 fpm and dilute phase system at 3500 fpm, the increase in wear on the pipeline using the dilute phase system would be:

$(3500/500)^{2.65}$ or about 175 times greater!

The low velocity, dense phase system, therefore, is far more effective in reducing pipe wear, and in general should always be used for materials that are abrasive.

An additional benefit of high density conveying is that the smaller air requirements permit the use of smaller air-solids separation devices at the end of the process.

Typical Specifications

Convey Rates:	High, up to 100 tons/hr or higher
Convey Velocities:	Low, 200 to 2000 fpm
Convey Distances:	High, up to 10000 ft or longer
Air Mover:	Compressor (Screw, rotary, reciprocating)
Operating Pressure:	Up to 125 psig
Air/Material Ratios:	< 0.2

TYPES OF DENSE PHASE SYSTEMS

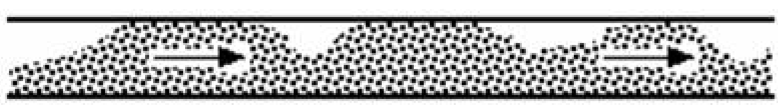
The following different modes of dense-phase conveying are in use.

1. Fluidized dense phase
2. Low velocity slug flow
3. Low velocity plug flow
4. Bypass conveying
5. Single slug conveying
6. Extrusion flow
7. Air assisted gravity conveying

Fluidized Dense- Phase

This mode of transfer takes advantage of the fluidization and air retention properties of the bulk material. Fluidization describes the state some bulk materials achieve when a gas has been entrained into the void spaces between the particles of the material. Material in a highly fluidized state tends to behave more like a fluid (as the term implies) than a solid bulk material.

Designed along "traditional" lines, this type of system will utilize large pressure vessels with double butterfly valve or slide gate valve in-feed arrangements. The vessels may be equipped for additional fluidization and be provided with discharge valves. Air is also injected into the pipeline via boosters.



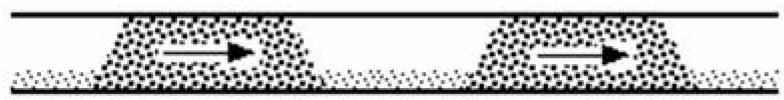
Fluidized Dense- Phase

The system is characterized by high velocities, although not as high as for dilute phase systems. Product degradation and pipe wear may be lower.

Some materials that are being conveyed successfully in fluidized dense-phase include cement, fly ash, pulverized coal, soap powder, zircon sand, crushed bauxite, electrolytic manganese dioxide, lead dust, limestone and flour.

Low - Velocity Slug Flow

This mode is suitable for friable and/or granular products (e.g. sugar, wheat, barley, skim milk powder, poly pellets, peanuts, milled grain, semolina, muesli, powdered and granulated coffee, sand grinding media).



Low-Velocity Slug-Flow

The main features of this technology that allow friable or easily damaged products to be transported in this manner are listed below:

1. The average material transport velocity can be controlled and maintained easily between 50 and 800 fpm (depending on degradation/throughput requirements). Even products, such as granulated sugar, have been conveyed successfully without even scratching the crystal surface.

2. Due to material characteristics (e.g. permeability) and the relatively low velocities that are used, the conveying cycle can be stopped and restarted at any time.

3. Due to the high volumetric concentration of product inside the pipeline, reasonable conveying rates still can be obtained despite the relatively low velocities that are used for transport.

4. There is very little inter-particle movement in the full-bore moving slugs and hence, segregation effects are avoided (even around bends). This aspect was confirmed in two recent cases studies, where milled/mixed grains (with particles of different size and density) and muesli (with rolled oats, sugar, coconut, sultanas, etc) were conveyed successfully in low-velocity slug-flow.

Low – Velocity Plug Flow

The low velocity conveying systems typically transport the product as a series of discrete plugs. This mode appears similar to slug-flow but actually this technology does not “produce” a stationary layer of material. It is most suited to cohesive or sticky powders, such as full-cream milk powder, drinking chocolate and cocoa powder. It also provides a solution to the problems of conveying delicate granular and friable materials and products such as plastic granules which form "streamers" in high velocity conveying systems.

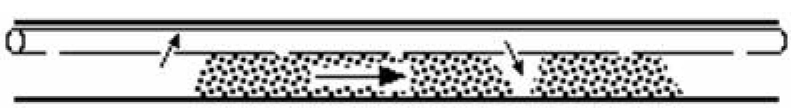
Low-Velocity Plug-Flow

Usually, a plug-forming method or device is employed at the feeder to ensure stable plugs are generated along the pipeline. The advantages and features of this mode of dense-phase are similar to those listed previously for low-velocity slug-flow.

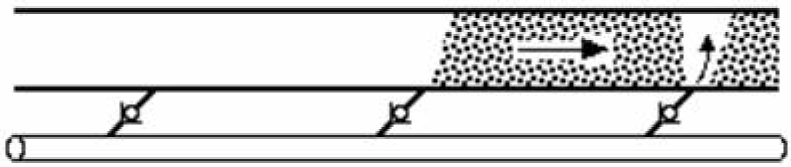
Bypass Conveying

A relatively unique range of “gritty” bulk materials (e.g. alumina, poly powder, fine sand, coarse fly ash) tend to dam and pack in conveying pipes at velocities of 600 – 2000 fpm, causing long plugs of material to form, with the material tightly wedged against the pipe wall. Stronger the damming forces; the less permeable the material is to air. For such products the conveying air must be supplied through a bypass pipe to the point where it is capable of conveying the product, splitting up the plug of material.

Various types of bypass technology are available, such as multi-point injection, external bypass and internal bypass. The main concepts involved in this design are controlling the length of material “build-up” along the pipeline and preventing the conveying air from being “forced” through this material.



Internal Bypass

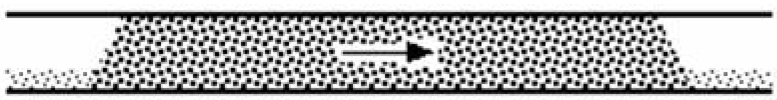


External Bypass

Bypass Conveying

Single – Slug Conveying

This dense-phase mode involves the transportation of a limited batch of material per conveying cycle. It can be used to transport granular materials (e.g. crushed coal, sand, grains, diamond ore aggregate, petroleum coke, food products, bone char) over relatively short distances (e.g. up to 600 ft).

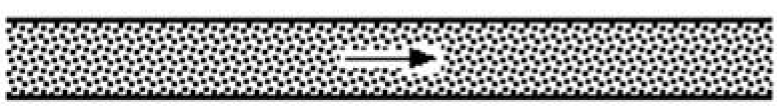


Single-Slug Conveying

Note: the materials suited to low-velocity slug-flow also can be conveyed successfully in single-slug mode, but this would result in inefficient conveying performance.

Extrusion Flow

Occasionally, it may be beneficial to maintain the total conveying pipeline full of material and produce an extrusion mode of flow. Usually, specially designed blow tank feeders are employed for this purpose.



Some successful applications of this technology include:

1. Meat lumps for canned dog food, where the product basically is conveyed in the form of a long sausage along the pipeline;

2. Chopped fish chunks and gravy, as well as whole fish pieces and gravy, for canned cat food;

Other possible applications include the transportation of softened grains, vegetables, etc for food processing and canning operations. It is important to emphasize that:

1. The dilute-phase option would cause excessive damage to such products;

2. These types of material are not suited to most of the other dense-phase options;

3. The single-slug mode of conveying could be used for such materials, but would be relatively inefficient in terms of conveying capacity and maintaining a constant product velocity along the pipeline (especially if the length and/or diameter of pipeline is significant);

4. Mechanical pumps can be used for these applications but may cause excessive damage to the particles – a properly designed blow tank feeder is preferred.

Dense Phase v/s Dilute Phase

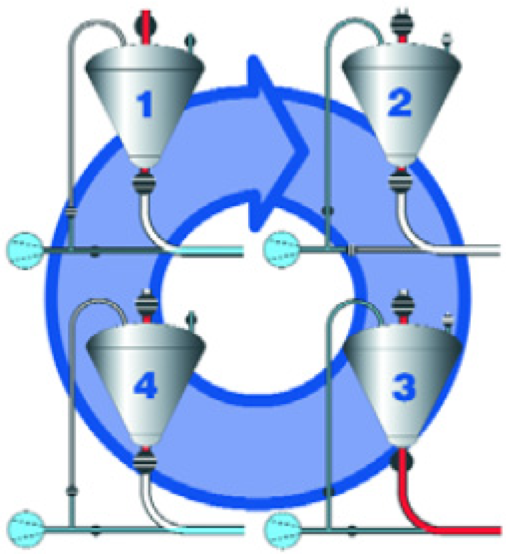
Systems which use pressure vessels or transmitters to feed product directly into the convey line are often referred to as "Dense Phase" systems and systems which use airlocks are referred to as "Dilute Phase" systems. This generalization is true about 75 percent of the time.

One advantage pressure vessels have over airlocks is that they do not depend upon closely machined parts to operate. This advantage makes them inherently more adapted to handle abrasive products. The inability of airlocks to handle abrasive products has been somewhat overcome in recent years by airlocks constructed of abrasion resistant materials like Ni Hard castings and Stellite tipped rotors.

The other advantage of pressure vessels is their inherent ability to operate at higher pressures that makes it possible for them to convey products longer distances. There is almost no limit on how high pressure vessel systems could go but for practical reasons very few go over 60 psig internal vessel pressure. The airlock systems on the other hand are limited to about 15 psig although some go as high as 50 psig.

The limitation of dense phase system is that it is batch type process unlike an airlock system, which is a continuous flow system. The pressure vessel conveying involving four distinct steps:

1. Loading – The vessel filled with product to be conveyed
2. Pressurization – The vessel pressurized up to convey pressure
3. Transportation – The product is conveyed through the convey line
4. Purge – The convey line is purged of the product and the vessel depressurized to prepare it to receive another batch



Dual vessel systems can be configured to operate in a semi-continuous dense phase manner where the first vessel loads with product while the second vessel conveys the product.

Dense phase systems are more complicated than dilute phase systems to control properly because of the narrow operating velocity ranges in which the systems will perform with stability. It is necessary to constantly change the gas amounts for varying conditions in the system. Therefore, the heart of all dense phase systems is the gas control device.

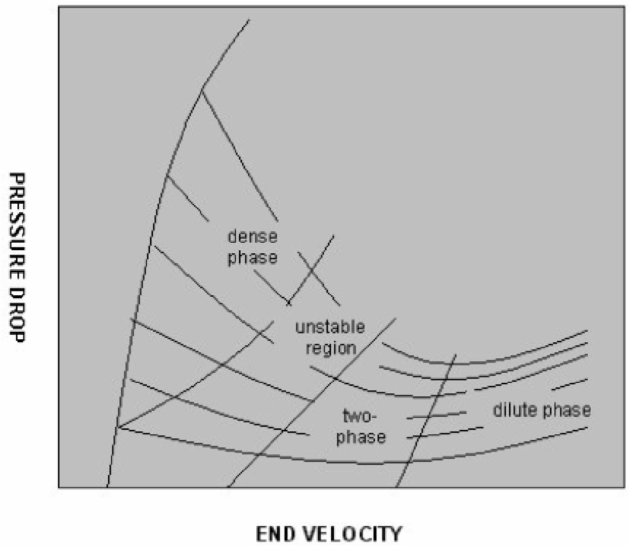
The gas source can be from a screw compressor, piston compressor, plant air, or other sources. The compressor works on load / no-load basis. Whenever conveying is in progress, there is a requirement of compressed air which is fed by conveying air compressor through air receiver. When there is no material available and conveying does not take place, compressor switches over to no-load condition, thus saving power.

Dense phase systems are not as flexible as dilute phase systems when it comes to varying product transfer capacities, varying products, or varying product grades that result in dissimilar physical product characteristics.

Top Ten Tips for Dense Phase Pneumatic Conveying

1. Many designers define "dense-phase" as a flow mode with solids loading greater than 10 or 15. This is not correct. Using solids loading as an indicator of flow mode can be misleading (e.g. solids loading is a mass concentration parameter that depends on the mass or density of the particles; some dilute phase systems are operating at a solid loading greater than 40 and some dense phase systems less than 10). Ensure that the choice of a flow mode (and system) is based on the product properties (rather than an imprecise definition or misleading solids loading), and that the selected or supplied flow mode is confirmed during commissioning.

2. The dilute phase systems have wider Δv range and are easier to operate. The dense phase system exhibit narrower Δv range and are more difficult to operate (easier to plug). The dense phase regime is bound by a high-velocity (unstable zone) boundary and a low-velocity (blockage) boundary. Make sure the operating point (air flow rate, solids flow rate) falls well within these bounds at all locations in the system and for all pipeline configurations (if applicable).



Pneumatic Handling Phase Diagram

3. The minimum and maximum conveying rates in a process must be defined upfront. Compared with dilute phase, the dense phase regime can be more limiting and sensitive to variations in air flow and/or conveying rate. For some materials, a reduction in solids flow rate can shift the operating point into the unstable zone, thereby causing severe instability (line vibrations and pressure spikes).

4. Dense phase conveying performance can be quite sensitive to variations in material property (particle size, size distribution, shape, density, moisture, cohesion, etc.). It is highly recommended that pilot scale or full scale testing be conducted on representative material, especially for new or different products where no prior experience is available.

5. Using a conventional or "off-the-shelf" pipeline, not all materials can be conveyed reliably in dense phase. Some materials can be conveyed in single or multi slug/plug mode, some in fluidized moving bed type flow, while others can only be conveyed in dilute phase. Not selecting the right flow mode for a particular material or the right operating condition for a given flow mode can result in excessive pressure spikes, system shutdown, unstable vibrations and/or pipeline blockages. For materials that do not have a natural tendency for conventional dense phase conveying, consider specialized systems with controlled and regulated air injection or bypass pipeline technology. Also, ensure proper dense phase flow actually is achieved during commissioning.

6. Feeder air leakage can be a significant fraction (up to 50%) of total air consumption. The air leakage at the feeder (esp. rotary valves) must be considered in design calculations and compensated appropriately. Ensure proper venting at the feeder to avoid feeding problems that may result from the air blowback.

7. Use an air flow control system for multi-product and multi-destination systems to ensure that the operating point is maintained within the stable operating zone. Also, ensure that the air flow control system provides a constant air mass flow rate for the full range of operating pressures and pressure fluctuations.

8. In dense phase systems, air expansion can be significant between feed point and destination. This will result in a corresponding increase in air velocity, and a possible transition from dense to dilute phase flow along the conveying pipeline. For high

pressure drop systems (7 psi and higher), consider *stepping the line diameter to reduce the velocity and maintain dense phase conditions*.

9. The motion of slugs and stresses generated within the conveying line during directional changes (bends or diverter valves) results in significantly higher stresses on pipe supports as compared to dilute phase systems. It is essential to work closely with an experienced vendor to design and install proper pipeline supports to prevent excessive deflection and line movement, and reduce the prospect of fatigue failure.

10. To purge a dense phase line clean, a controlled increase in air velocity may be required. A proper purge control sequence may need to be designed and tested to avoid unnecessary product degradation and/or pipeline blockage. The dust collector must be designed to handle the peak air flow rates.

Other Good Practices

1. When handling plastics, reduction of streamers and fines is high priority. Transfer piping should run horizontally and vertically only (diagonally sloped lines can increase pellet slide and allow product to drop back in the system). The length of transfer pipe from the storage silo to the processing area should not exceed 300 feet, and the number of directional changes in the layout should be minimized to reduce pressure drop. Plugged fittings and special bends should be used whenever possible to reduce the formation of streamers and fines.

2. In order for pellets to accelerate to conveying velocities, an initial section of straight piping is necessary. The general rule of thumb is that a straight section equal to 25 times the pipe diameter is required before the first vertical bend.

3. Cool air should be used as far as possible and in any case the temperatures should not exceed 120°F for polyethylene material. Higher temperatures in the transfer system will compound the effects of frictional heat on the pellets and lead to the formation of streamers.

4. The air velocities through the transfer system must be maintained at a rate high enough to prevent pellets from dropping out of the air stream (saltation); however, the velocity should not exceed 4200 ft/minute.

5. Every pound of air pressure increase correlates approximately to a 15°F increase in temperature. The operation of the transfer system requires a balance between velocity and temperature.

6. The piping and fittings of the transfer system should be inspected on a regular basis to assess the amount of wear on the system. Heavily worn piping, elbows, and other fittings should be replaced or serviced before continued operation. Straight section of pipe can be rotated 90 or 180 degrees to extend the service life of the pipe.

7. Flexible hoses used in the loading and unloading of railcars should be inspected to ensure that product flows in the direction of the coils or spirals. The flow of product in the opposite direction can create fines and dust.

AIR-FILM CONVEYING

This method of pneumatic conveying uses a film or cushion of air to move items such as cans, boxes, or plastic containers through a plant. Used primarily in the packaging industry, air film conveying usually requires fan static pressures of no more than 8" WG. In most cases, the system utilizes several smaller fans as opposed to one large fan. Because the air is clean, various fan types can be used in these systems, including backwardly inclined and radial-bladed designs. Selection is based on pressure and flow, but configuration is equally important.

Either positive pressure or vacuum can be used to move the containers. In a pressurized system, air is directed through a drilled or slotted surface, where the air is discharged at a slight angle in the direction of flow. The greater the discharge angle, the higher the velocity from one station to the next. Vacuum elevators are used to raise or lower containers to different levels in the system by holding them to a moving, perforated belt. Vacuum transfer devises allow fallen or damaged product to drop out of the system, thereby reducing downtime and maintaining efficient high-speed processing. Both techniques may be employed in different portions of complex conveying systems.

The benefits of air film conveying over conventional mechanical conveying include:

1. Increased process speed

2. Lower maintenance costs (fewer moving parts)
3. Reduced energy consumption
4. Reduced noise and safety hazards
5. Reduced downtime from jamming
6. Gentler handling of the product

Many companies in the packaging industry use a combination of air and mechanical conveying systems in their manufacturing processes.

CONCLUSION

Essentially, the two most distinct categories of pneumatic conveying can be described as either low pressure (dilute phase) or high pressure (dense phase) systems. The choice between dilute and dense phase operation is typically dependent on the material properties. In general, bulk materials with poor air retention capabilities are less suited for dense phase system and granular products with narrow particle size distribution have good air permeability and are well suited for dense phase conveying.

In addition, dense phase operation (with its relatively low velocities) is usually preferable if the conveyed material degrades easily or is highly abrasive. Dense phase conveying can handle high throughputs over long distances while requiring smaller line sizes than either dilute-phase or vacuum conveying. A drawback of the dense phase option is that dense-phase conveying is essentially a batch process, which is less convenient for most chemical process operations than is the continuous mode used by dilute phase and vacuum systems.

Key Points of Dilute Phase Conveying

1. Material is suspended in the conveying air
2. The transfer velocity is greater than the “saltation” velocity
3. Low system pressures (< 15 psig)
4. High air to solids loading ratios (> 2.0)

5. High linear velocities (3,200 –8,000 ft/min)

6. More wear and tear -mostly due to the high velocities

7. Lower capital costs at startup

8. Easier to operate

Key Points of Dense Phase Conveying

Use dense phase pneumatic systems for minimum particle attrition and lowest pipe wear. The key design points are:

1. The transfer velocity is less than the “saltation” velocity at some point in the system

2. High system pressures (15 – 90 psig)

3. Low air to solids loading ratios (< 0.2)

4. Low velocities but high pounds capacity

5. Less erosion – a result of lower velocity

6. Higher capital costs at startup

7. Pressure rated lines, valves, etc.

8. More difficult to operate due to narrow velocity profiles

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Annexure-1

Glossary of Pneumatic Handling Terms

1) Abrasiveness - The abrasiveness of a material is determined by Moh's hardness factor and the shape of its particles. A material which has a high Moh's hardness factor and has sharp, angular-shaped particles will be considered highly abrasive.

2) Adhesion - Adhering of the material to a surface or particle other than itself. (After material has been squeezed in your hand for one minute, observe the adhesive characteristic by noting particles sticking to your extended fingers.)

3) Adhesiveness - Adhesiveness can be described as "external cohesiveness" which is the ability of material to adhere to other surfaces.

4) Aeration - The action of introducing air (or gas) to a bulk material by any means. Aeration may cause the material to become fluidized or agitated.

5) Air Retention - Air retention is the ability of a material to retain air (or other gas) in the void spaces of the material after the air (or gas) supply to it has been terminated. Air retention capability can vary between almost zero and several days, depending on the material's other physical characteristics.

6) Angle of Repose - The angle of repose of a bulk material is the angle formed between the horizontal and sloping surface of a piled material, which has been allowed to form naturally without any conditioning.

7) Bulk Density (Fluidized) - Fluidized bulk density is the apparent bulk density of a material in its fluidized state. It is generally lower than either the packed or loose bulk density due to the air absorbed into the voids.

8) Bulk Density (Loose) - The loose bulk density (sometimes called the poured bulk density) o a bulk material is the weight per unit of volume (usually pounds per cubic foot) that has been measured when the sample is in a loose, non-compacted or poured condition. The loose bulk density may be close to the 'as conveyed" bulk density and is preferred for the purposes of pneumatic conveying system design.

9) Bulk Density (Packed) - The packed bulk density of a bulk material is the weight per unit volume (usually pounds per cubic foot) that has been measured when the sample has been packed or compacted in. For instance, a silo or bin or after containerized transportation. The packed bulk density does not compare to the conditions that the loose bulk density is preferred for the purposes of conveying system design.

10) Choking Velocity - The choking velocity of a material is the actual gas velocity in a vertical pipeline at which particles in a homogeneous mixture with the conveying gas settles out of the gas stream.

11) Conveying Pressure - The conveying pressure for any system is that pressure required overcoming resistances in the system caused by interactions between the conveying as the material being conveyed, the pipeline, and other system components. It is also referred to as "pressure drop". The conveying pressure is the difference measured between the beginning and the end of the pneumatic system and is applicable to both positive pressure and vacuum (negative pressure) systems.

12) Dense Phase Conveying - A dense phase system is any pneumatic conveying system for which the conveying gas velocity is generally below the saltation velocity of the material being conveyed.

13) Dilute Phase Conveying - A dilute phase system is any pneumatic conveying system for which the conveying gas velocity is generally equal to or above the saltation velocity of the material being conveyed.

14) Gas Velocity (actual) - Actual gas velocity is the volume flow rate at pressure and temperature conditions per unit cross-sectional area of the empty pipe, normally expressed in distance/time. Actual gas velocity varies throughout the entire length of the pipeline.

15) Gas Velocity (average) - The average (also called mean) gas velocity of a system is usually defined as the mean of the beginning (of pick-up) gas velocity and the terminal gas velocity.

16) Flotation Velocity - The flotation velocity at which material will be suspended in air. Knowing flotation velocity is critical to determining "enclosure velocity", which is the upward velocity of gas in a filter receive or bin vent. This term is most commonly used in the design of bag houses and dust collection systems.

17) Floodability - Reflects a material's tendency to aerate and act as a fluid. (Squeeze material quickly in your fist. If it squirts through your fingers, then it is floodable.) Floodable materials are difficult to restrain in controlled feeding applications, and deserve conscientious sizing.

18) Flowability - Flowability is the ease with which a bulk material flows under the influence of gravity only.

19) Fluidized - Fluidized describes the state some bulk materials achieve when a gas has been entrained into the void spaces between the particles of the material. Material in a highly fluidized state tends to behave more like a fluid (as the term implies) than a solid bulk material.

20) Friability - Friability describes a bulk material where particles are easily crumbled or pulverized.

21) Material Mass Flow Rate - The mass of material conveyed over a specified period of time, usually expressed in tons/hour or lbs/minute. Material mass flow rate is also called conveying rate or system capacity.

22) Material To Air Ratio - A parameter used by pneumatic system designers. It is the ratio of the mass of material conveyed to mass of air. It is also referred to as "phase density", "solids loading ratio", and "mass flow ratio".

23) Material Velocity - The material velocity is the velocity of the material itself, which is somewhat lower than the gas velocity. Material velocity is usually specified as either average (or mean) velocity or terminal velocity. There are no reliable means, at the present time, for measuring the actual material velocity, and only an estimate can be made.

24) Minimum Conveying Velocity - The minimum conveying velocity is the lowest gas velocity that can be used to insure stable conveying conditions. This term is generally applied to dilute phase systems.

25) Saltation Velocity - The saltation velocity of a material is the actual gas velocity in a horizontal pipeline at which particles in a homogeneous mixture with the conveying gas will begin to fall out of the gas stream.

26) Terminal Gas Velocity - The terminal gas velocity in a pneumatic conveying system is the velocity of the gas as it exits the system. It is also known as the ending gas velocity and conveying line exit velocity.

27) Two-Phase Flow - All bulk solid materials pneumatic conveying systems operate on a two-phase flow principle. That is, a solid phase (the materials being conveyed) and the gaseous phase (the conveying gas).

28) Volumetric Gas Flow - There are several different terms used when considering volumetric gas flow. The volumetric gas rate during conveying is expressed as "free air delivered" or FAD. Most air movers, such as blowers and compressors, are specified in terms of FAD measured in standard cubic feet per minute (SCFM). FAD is the volumetric gas flow at the suction port of a positive pressure blower or compressor or at the discharge port of a vacuum blower or compressor or at the discharge port of a vacuum blower or vacuum pump. SCFM is the volumetric gas flow rate at standard atmospheric conditions (i.e. barometric pressure at sea level, 68°F and 36% relative humidity).

Annexure - 2

ESTIMATING PRESSURE DROP

IN

DILUTE PHASE CONVEYING SYSTEM

The design method presented here is based on the work of Dr. F.A. Zenz and Dr. D.F. Othmer as published in their book "Fluidized and Fluid Particle Systems" published in 1960. This method has been widely used and is generally found to be within 10% of measured pressure losses.

Pressure losses experienced in pneumatic conveying systems are the result of the following forces:

Friction of the gas on the inside of the pipe + force required to move the solids through the pipe, + forces required to support the weight of the solid and the gases in vertical pipe runs + force required to accelerate the solids + friction between the solids and the inside of the pipe.

Friction losses as the result of the solids being in contact with the inside of the pipe are usually very small and can be neglected when considering dilute phase transport.

The total pressure loss of the pneumatic system (expressed in psi or lbs/in^2) can be expressed as:

$$\Delta P_T = \Delta P_{acc} + \Delta P_g + \Delta P_s + \Delta H_g + \Delta H_s + \Delta P_{misc}$$

Where:

- ΔP_T = Total pressure loss in the system
- ΔP_{acc} = Pressure loss due to acceleration of the solids from their "at rest" condition at the pick up point.
- ΔP_g = Frictional pressure loss of the gas

- ΔP_s = Frictional pressure loss of the solids
- ΔH_g = Elevation pressure loss of the gas
- ΔH_s = Elevation pressure loss of the solids
- ΔP_{misc} = Pressure losses from miscellaneous equipment

Let's see the component wise break up of equations:

Pressure loss due to acceleration of the solids

$$\Delta P_{acc} = \frac{W \cdot V_P}{144 \cdot g} = \frac{W \cdot V_P}{4640}$$

Where

- ΔP_{acc} = Pressure loss due to acceleration of the solids from their "at rest" condition at the pick up point.
- W = Solids mass velocity [lbs/s ft^2]
- Vp = Particle velocity [ft/s]
- g = Acceleration due to gravity [32.2 ft/s^2]

Particle Velocity

Particles also move at a velocity lower than the gas velocity due to drag forces. The difference between these velocities is called the slip factor. For most course or hard solids, the slip factor is around 0.80.

Vp = 0.8 * Vg

For fine powders, the solids velocity can be closer to the gas velocity and a factor of 0.90 may be more appropriate. Depending on the size of the particles, the slip factor can range from 0.70 to 0.95.

Frictional pressure loss of the gas

$$\Delta P_g = \frac{4f \cdot L \cdot \rho_g \cdot V_g^2}{2g \cdot D \cdot 144} = \frac{4f \cdot L \cdot \rho_g \cdot V_g^2}{9266 \cdot D}$$

Where

- ΔPg = Friction pressure loss of the gas
- f = Fanning friction factor
- L = Equivalent length of pipeline [ft]
- ρg = Gas density [lbs/ft^3]
- Vg =Gas velocity [ft/s]
- g = Acceleration due to gravity [32.2 ft/s^2]
- D = Pipe inside diameter [ft]

The Fanning Friction Factor

The friction factor is calculated from the following equation derived from pages A-23 and A-24 of Crane's Technical Paper No. 410:

$$f = \frac{0.331}{\left[\log_n\left(\left(\frac{\varepsilon}{3.7 \cdot D}\right) + \left(\frac{7}{N_{Re}}\right)\right)\right]^2}$$

Where

- ε is the pipe roughness factor which can be estimated as 0.00015 for smooth pipes or 0.0005 for shot-peened pipes.
- D = Pipe inside diameter [ft]
- NRe = Reynold's number

Reynold's Number

The Reynolds number is calculated using equation:

$$N_{Re} = \frac{D \cdot V_g \cdot \rho_g}{\mu_g}$$

Where

- D = Pipe inside diameter [ft]
- Vg =Gas velocity [ft/s]
- ρg = Gas density [lbs/ft^3]
- µg is the gas viscosity in lbs/ft s.

Frictional pressure loss of the solids

$$\Delta P_s = \Delta P_g \cdot K \cdot R$$

Where

- ΔPs = Friction pressure loss of the solids
- ΔPg = Friction pressure loss of the gas
- K = Friction multiplier for the solids conveyed
- R = Solids to gas mass flow ratio (lb/lb)

Solids to Air Ratio, R

The solids to air ratio is calculated as:

$$R = \frac{W}{V_g \cdot \rho_g} = \frac{m}{A \cdot V_g \cdot \rho_g}$$

Where

- W = Solids mass velocity [lbs/s ft^2]
- m = the solids mass flow in lb/s
- A = the pipe cross sectional area in ft^2.
- ρg = Gas density [lbs/ft^3]
- Vg =Gas velocity [ft/s]

Elevation pressure loss of the gas

$$\Delta H_g = \frac{\Delta Z \cdot \rho_g \cdot g}{144 \cdot g_c}$$

Where

- ΔHg = Elevation pressure loss of the gas
- ΔZ = Elevation change in pipe line [ft]
- ρg = Gas density [lbs/ft3]
- g = Acceleration due to gravity [32.2 ft/s^2]
- gc =Constant [32.174 ft-lb/lb s^2]

Elevation pressure loss of the solids

$$\Delta H_s = \frac{\Delta Z \cdot W \cdot g}{144 \cdot V_p \cdot g_c}$$

Where

- ΔHs = Elevation pressure loss of the solids
- ΔZ = Elevation change in pipe line [ft]

- W = Solids mass velocity [lbs/s ft^2]
- g = Acceleration due to gravity [32.2 ft/s^2]
- Vp = Particle velocity [ft/s]
- gc =Constant [32.174 ft-lb/lb s^2]

Pressure losses from miscellaneous equipment

ΔH_{misc} = Estimated Misc. losses from the system

Pipe Equivalent Length

For straight pipe runs (either horizontal or vertical) use the actual length of the pipe. For bends and other devices, use the table below as a guide:

Component	**Equivalent Length**
Bends, 90° bend, long radius (10 to 1 radius to diameter ratio)	40 x diameter or 20 ft (whichever is larger)
Diverter Valves 45° divert angle 30° divert angle	 20 x diameter 10 x diameter
Flexible Hoses Stainless steel, with lined interior Rubber or vinyl hose	 3 x pipe length 5 x pipe length
For bends that are less than 90°, use the following equivalent lengths: L = 40 x (Degree of bend / 90)	

Setting up the Calculation

These equations can easily be set up in a spreadsheet to show the performance of your system. For pressure systems, start from the end of the conveying line and return to the solids inlet point. For vacuum systems, start from the solids inlet point and end at the blower inlet.

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