Design of dilute phase pneumatic conveying system for bulk material

Divyanshu Singh#1,Prashant Kumar#2,Omprakash Kale#3

*#Student, Department of mechanical Engg., K.D.K.C.E*

1div\_great1911@yahoo.in

2prashant.pratyuesh@gmail.com

3kaleomprakash84@gmail.com

***Abstract:***

**Material handling is one major problem in many industries. In the industries where bulk materials have to be transferred within the industry from one place to another at a very high rate, pneumatic conveying can be an excellent and economic choice. Very high mass flow rates can be obtained through pneumatic conveying and also a variety of material can be conveyed through it space requirement for the installation of this system is also less.In spite of large literature available on pneumatic conveying, still there is no general design procedure available. In pneumatic conveying every problem is a new problem and hence there is large scope for research in this field.**

**Keyworlds;- Pneumatic Conveying, dilute phase, bulk material conveying, pressure drop estimation, components of pneumatic conveying.**

1. Introduction

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/m3 (1 to 200 lb/ft3). 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.

1. 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.

1. TYPES OF DILUTE – PHASE SYSTEMS

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

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

1. COMPONENTS OF DILUTE – PHASE SYSTEM

Major pneumatic system components include:

* Pressure blowers and vacuum pumps with integral sound enclosures
* Rotary airlock valves
* Transfer line including piping, elbows; divert valves (flex-tube diverters, wye- diverters, plug diverters and other line diverter configurations).
* Filter receivers
* Cyclone separators
* Dust collectors and bin vents
* Controls and electrical equipment
* Silos, day bins and other storage vessels
1. 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/in2) can be expressed as:

$$∆P\_{T}=∆P\_{acc}+∆P\_{g}+∆P\_{s}+∆H\_{g}+∆H\_{s}+∆P\_{misc}$$

Where:

* ∆PT = Total pressure loss in the system
* ∆Pacc = Pressure loss due to acceleration of the solids from their "at rest" condition at the pick up point.
* ∆Pg = Frictional pressure loss of the gas
* ∆Ps = Frictional pressure loss of the solids
* ∆Hg = Elevation pressure loss of the gas
* ∆Hs = Elevation pressure loss of the solids
* ∆Pmisc = Pressure losses from miscellaneous equipment

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

* Pressure loss due to acceleration of the solids

$$∆P\_{acc}=\frac{W\*V\_{P}}{144\*g}=\frac{W\*V\_{P}}{4640}$$

Where

* ∆Pacc = Pressure loss due to acceleration of the solids from their "at rest" condition at the pick up point.
* W = Solids mass velocity [lbs/s ft2]
* Vp = Particle velocity [ft/s]
* g = Acceleration due to gravity [32.2 ft/s2]

**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

$$∆P\_{g}=\frac{4f\*L\*ρ\_{g}\*V\_{g}^{2}}{2g\*D\*144}$$

Where

• ∆Pg = Friction pressure loss of the gas

• f = Fanning friction factor

• L = Equivalent length of pipeline [ft]

• ρg = Gas density [lbs/ft3]

• Vg =Gas velocity [ft/s]

• g = Acceleration due to gravity [32.2 ft/s2]

• 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:

$$f=\frac{0.331}{[log\_{n}(\left(\frac{ε}{3.7\*D}\right)+\left(\frac{7}{N\_{Re}}\right))]^{2}}$$

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:

$$N\_{Re}=\frac{D\*V\_{g}\*ρ\_{g}}{μ\_{g}}$$

Where

• D = Pipe inside diameter [ft]

• Vg =Gas velocity [ft/s]

• ρg = Gas density [lbs/ft3]

• µg is the gas viscosity in lbs/ft s.

* Frictional pressure loss of the solids

$$∆P\_{s}=∆P\_{g}\*K\*R$$

Where

• ∆Ps = Friction pressure loss of the solids

• ∆Pg = 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:

$$R=\frac{W}{V\_{g}\*ρ\_{g}}=\frac{m}{A\*V\_{g}\*ρ\_{g}}$$

Where

• W = Solids mass velocity [lbs/s ft2]

• m = the solids mass flow in lb/s

• A = the pipe cross sectional area in ft2.

• ρg = Gas density [lbs/ft3]

• Vg =Gas velocity [ft/s]

* Elevation pressure loss of the gas

$$∆H\_{g}=\frac{∆Z\*ρ\_{g}\*g}{144\*g\_{c}}$$

Where

• ∆Hg = Elevation pressure loss of the gas

• ∆Z = Elevation change in pipe line [ft]

• ρg = Gas density [lbs/ft3]

• g = Acceleration due to gravity [32.2 ft/s2]

• gc =Constant [32.174 ft-lb/lb s2]

* Elevation pressure loss of the solids

$$∆H\_{s}=\frac{∆Z\*W}{144\*V\_{p}g\_{c}}$$

Where

• ∆Hs = Elevation pressure loss of the solids

• ∆Z = Elevation change in pipe line [ft]

• W = Solids mass velocity [lbs/s ft2]

• g = Acceleration due to gravity [32.2 ft/s2]

• Vp = Particle velocity [ft/s]

• gc =Constant [32.174 ft-lb/lb s2]

Pressure losses from miscellaneous equipment = Estimated Misc. losses from the system

1. FAN DESIGN AND SELECTION CRITERIA

Precise determination of air-flow and required outlet pressure are most important in proper selection of fan type and size. The air-flow required depends on the process requirements; normally determined from heat transfer rates, or combustion air or flue gas quantity to be handled. System pressure requirement is usually more difficult to compute or predict. Detailed analysis should be carried out to determine pressure drop across the length, bends, contractions and expansions in the ducting system, pressure drop across filters, drop in branch lines, etc. These pressure drops should be added to any fixed pressure required by the process (in the case of ventilation fans there is no fixed pressure requirement). Frequently, a very conservative approach is adopted allocating large safety margins, resulting in over-sized fans which operate at flow rates much below their design values and, consequently, at very poor efficiency.

Once the system flow and pressure requirements are determined, the fan and impeller type are then selected. For best results, values should be obtained from the manufacturer for specific fans and impellers. The choice of fan type for a given application depends on the magnitudes of required flow and static pressure. For a given fan type, the selection of the appropriate impeller depends additionally on rotational speed. Speed of operation varies with the application. High speed small units are generally more economical because of their higher hydraulic efficiency and relatively low cost. However, at low pressure ratios, large, low-speed units are preferable.

1. 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.

1. 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.

1. 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

1. CONCLUSION:

Despite of large literature sources available on pneumatic conveying, generalization cannot be made in the design procedure of a system. Every system has to be designed separately, considering the actual parameters of the system. At the same time we cannot predict the behavior of any pneumatic conveying system for any material as there is large variety in the system and material characteristics. Slight modifications can be made after fabrication and testing of the actual system.

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