DESIGN, ANALYSIS & FABRICATION OF PNEUMATIC MATERIAL HANDLING SYSTEM

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ABSTRACT

Pneumatic conveying system is a conventional material handling system like belt conveyor or chain conveyor. The main advantage of pneumatic conveying system is that material is transferred in close loop, thereby preventing the environmental effect on the material and vice versa. In these topic different parameters like air velocity, pressure, particle size and shape, distance to be conveyed, which govern the design of the system, are described.

The research work carried out on the pneumatic conveying system in the last decade considering these parameters are also presented. No standard procedure is available for the design of pneumatic conveying system. As the configuration of the system changes, variable involved also changes, and one has to change the design considerations based on the applications. So there is wide scope for experimentation in the field of pneumatic conveying system.

http://www.iaeme.com/currentissue.asp?JType=IJMET&VType=6&IType=8

1. INTRODUCTION

Pneumatic conveying started in 1866 with the application of a fan and ducts to remove the dust and fine particles from woodworking operations. Since then, the field of pneumatic conveying has greatly expanded to include nearly all fine granular bulk materials in the chemical, cement, agricultural, pharmaceutical and food processing industries. Unfortunately, the art of pneumatic conveying is still very empirical and can lead to many misapplications. Research is still being done by many universities around the world, but the theoretical solutions for “two-phase flow” are often too complex for the practicing engineer. Besides, many of these solutions require experimentally-derived coefficients, which are not readily available.
Venturi educators have no moving parts allowing for maintenance-free feeding of bulk solids. In applications involving fine, abrasive, or irregularly-shaped products, this is an enormous advantage. Replacement of existing rotary airlocks with venturi educators makes for simpler, more reliable conveying systems. Designing with educators from the beginning ensures the most reliable product feeding available.

All rotary airlocks have blowback. If the product conveyed is fine or abrasive, blowback can cause extreme wear problems. Even with free-flowing products, blowback can be a problem, causing bridging and housekeeping problems, or even an explosion hazard. When installed beneath hoppers, screw conveyors, or dust collectors, airlocks can be a major source of fugitive dust emissions, which are eliminated after a retrofit to educators. Educators have none of the shearing, smearing or degradation of product common with rotary airlocks. And, of course, safety is simply not a concern with educators. One of the most common applications for educators is their installation under dust collectors, replacing screw conveyors and airlocks with a better solution with no dust or moving parts. One blower can simultaneously drive many educators.

Most granular bulk solids are passing through silos, bins and hoppers prior to or after being conveyed. In some cases this process is repeated a few times. The basic requirement of a good storage bin is that it can store the required quantity of materials and that it can discharge this quantity safely and reliably by gravity. As granular bulk solids have varying particle size distributions, chemical composition, bulk densities and moisture contents, the flow ability characteristics can also vary over a wide range. In order to establish the proper dimensioning of the storage bins and hoppers, it is generally advisable to measure these flow ability characteristics carefully before any design is contemplated. A very flowable material (dry fine powder) may become aerated and subsequently fluidize, causing potential flooding problems. There are basically three flow patterns in bins. These are known as mass-flow, funnel-flow, and expanded-flow. Each of these flow patterns has its advantages and disadvantages.

Funnel-flow occurs when the material moves strictly within a confined channel above the hopper outlet. The material outside this flow channel is at rest, until such a time that the bin level drops and the materials slides into this channel. The diameter of this flow channel is established essentially by the hopper outlet dimensions.

Mass-flow refers to a flow pattern where all the material in the bin is in a downward motion, whenever the feeder is discharging. In essence, the material column slides along the hopper walls. In order to attain this type of flow pattern, the hopper walls must be steep and smooth, where the hopper slope angle is plotted against the sliding friction of the hopper wall. There is a very specific combination of slope angle and sliding friction coefficient that will result in mass-flow, as identified by the hatched area.

**Figure 1** Pneumatic Material Handling System
2. CONSTRUCTION

Pneumatic conveying systems are generally sinuous. A very wide variety of materials can be handled and they are fully enclosed by the System and pipeline. Based on the quantity of air used and pressure of the system. A typical pneumatic conveying system comprises of four basic units, air mover (Blower), feeder (Hopper or Silos), and conveying pipe line loop and filtration unit. Feeder is a device that is intended to feed the material in to the conveying loop uniformly and that to with lowest leakages. Numerous devices have been developed to feed the materials in to the pipelines. Some of them are blow tank, rotary valve, screw feeder etc. Blow tank is a type of feeder, which could serve the purpose both for low and high-pressure requirements.

Material and air mixture is conveyed through the pipeline loop, containing some stipulated number of bends to provide flexibility of routing. The material of the pipeline is usually mild steel. The bends can, however be made of a hard, erosion resistant material. Bends can be used as horizontal section or as a vertical section in the loop depending upon the flexibility of installation.

The factors involved in the perfect construction of the pneumatic conveying systems can be grouped in to the following categories.

- The variables associated with the conveyed product.
- The variables associated with the carrier medium.
- The variables associated with the pipe surface material.
- The variables associated with the geometry of system.

The first two factors cover the particles being transported and carrier gas employed, the third one covers the pipe surface material and the fourth one covers the geometry of the system. Pipeline bends suffer from major losses due to erosion. Severity of erosion at the bends and diverters etc. is more because there is change of direction of gas solids suspension flows at these components. The main factors affecting bend erosion and consequently affecting the conveyed product quality are particle velocity, size, and shape and bend geometry. Amongst all the variables that influence the problem of erosion for a particular product and the bend material, velocity is probably the most important of all.

2.1. Design Considerations

The designs of pneumatic transfer systems (whether push or pull) requires careful consideration of a number of important considerations:

- Material considerations include particle attributes such as particle size, size distribution, particle shape, density, hardness and friability. Physical properties such as density, compressibility, permeability, and cohesion and other properties such as toxicity, reactivity, and electrostatic effects.
- System attributes include the resistance of pipe and fittings to chemical reactivity and abrasion, the efficient design or routing of the system to transfer materials from and to multiple points, and the maintenance of adequate airflow over the range of
conditions expected. These considerations can be complex and it is recommended that you consult with a qualified and experienced engineer to assure that your system is properly designed.

3. WORKING

Pneumatic conveying involves moving of bulk material in a stream of various carrier gases in closed tubes (pipelines). Air mover supplies the specified volumetric flow rate of the free air maintaining the appropriate pressure in the conveying system. Air movers available for the pneumatic conveying system applications ranges from the fans and blowers producing high volumetric flow rates at relatively low flow rates and vice versa. A relatively high velocity is required and controlled by blower. Hence keeping the power requirement same the velocity of conveying medium i.e. air can be increased by implementing venturi feeder. Venturi feeder consists of a short length of pipe shaped like a vena contracta, or the portion with the least cross-sectional area, which fits into a normal pipe-line.

The hindrance caused to the flow of liquid at the throat of the venturi produces a local Pressure drop in the region that is proportional to the rate of discharge. The throat diameter is typically between 1/3 and 3/4 of the inlet pipe diameter. Filtration unit is a gas solid separation device performs two functions. Firstly, it recovers conveyed material as much as possible for the next stage of handling or treatment process. Secondly, it minimizes the pollution of the working environment.

3.1. Basic Systems of Pneumatic Conveying

3.1.1. Induction Circuit

- Low or medium pressure Fan.
- Loading hopper with venturi nozzle.
- Suitable for short distances and small outputs.
- Systems for loading, transporting and/or bulk product download.
- Essential for the transport of grain, chemical and all kinds of granular products not very fine, abrasive sticky.

3.1.2. Pressure Circuit

- Medium of High pressure Fan (blower).
- Dosifier valves in the loading hopper and in the discharge of the cyclone.
- Suitable to cover distances up to 200 meters and larger medium outputs.

3.1.3. Closed-Circuit

- Very efficient and dustless system.
- Distance up to 100 meters.

3.1.4. Circuit for Depression

- Medium or high pressure Fan.
- Capacity according section ducts.
- Distance up to 100 meters.
- We recommended these highly efficient facilities for pneumatic conveying of powders and finely milled.
• Depression or vacuum system avoids loss of product leakage in the pipe system, ensuring a working atmosphere completely free of dust.
• The fan is always placed at the exit of the cyclone, preventing the product from blocking or wear out the fan impeller.

3.1.5 Fabricated P.M.H. System

(Side View)

![Figure 3 P.M.H. System (Side View)](image)

(Front View)

![Figure 4 P.M.H.S. (Front View)](image)

3.2. Details of Component Utilised

A number of different components exist in a pneumatic conveying plant. A typical conveying system comprises different zones where distinct operations are carried out. In each of these zones, some specialised pieces of equipment are required for the successful operation of the plant.

Typical modern pneumatic conveying system consists of the following major components

3.3. The prime mover [Blower]

The prime mover is an essential element in pneumatic conveying system. (fig 5) A wide range of compressors, blowers, fans and vacuum pumps are used to provide the necessary energy to the conveying gas. The centrifugal blower because of its positive displacement characteristics is extremely well suited to pneumatic conveying systems. Essentially, these prime movers have an almost linear P-V relationship, which facilitates higher solids loading than can be achieved with a fan system.

The use of centrifugal type blower systems extends over a wide range of products to include fine sub-micron powders as well as large (3 inch) lumps of coal and rock.
Their popularity is largely attributable to their relatively low cost. They are normally restricted to maximum output pressures of 12 – 15 psig & normally classified as being very noisy and it is common to find a blower unit fitted with both inlet and discharge silencers. In recent years many manufacturers have devoted a lot of attention to this noise aspect and at least one supplier claims to have included internal design modifications which have reduced noise production considerably.

![Centrifugal Blower](image)

**Figure 5** Centrifugal Blower

### 3.4. Feeding & mixing component [Hopper]

This zone is considered critical in pneumatic conveying system. (fig 6 &7) In this zone, the solids are introduced into the flowing gas stream. Initially, the solids are essentially at rest and a change in momentum occurs when solids are mixed with the flowing gas. Associated with this momentum change is the need to provide an acceleration zone. The acceleration zone consists of a horizontal pipe of certain length designed such that the solids are accelerated to some ‘steady’ flow state. The selection, design and operation of feeders for controlling the delivery of bulk solids into the pneumatic conveying line are critical. The feeder and hopper bottom should be designed as an integral unit. There are a number of different feeders that can be considered for pneumatic conveying systems. The most common type of dilute phase systems is the rotary-vane feeder, sometimes called the rotary-air-lock feeder. The rotary feeder is the heart of a dilute phase system where an airlock feeder is needed. In many cases, a system that was almost inoperable has been put back on its feet by simply removing an improperly sized or wrong style of feeder and installing the right unit for the job.

Many designers try to skimp on the rotary feeders, but it is generally penny-wise and pound-foolish to do so because of the troubles that can develop with reduced system capacity, frequent plug-ups, and especially with subsequent high maintenance of misapplied feeders. Apart from conveying systems that utilize “blow pots” as a feeder, there is generally a pressure differential involved across the rotary vane feeder, either positive or negative. Under negative (vacuum) conditions the feed problems are usually minimal. However, under positive pressure conditions in the pipeline, a certain amount of the air will try to flow through the feeder in the opposite directions from the solids.

![Rectangular Hopper](image)

**Figure 6** Rectangular Hopper
Most granular bulk solids are passing through silos, bins and hoppers prior to or after being conveyed. In some cases this process is repeated a few times. The basic requirement of a good storage bin is that it can store the required quantity of materials and that it can discharge this quantity safely and reliably by gravity.

There are basically three flow patterns in bins. These are known as mass-flow, funnel-flow, and expanded-flow.

- **Funnel Flow** Occurs when the material moves strictly within a confined channel above the hopper outlet. The material outside this flow channel is at rest, until such a time that the bin level drops and the materials slides into this channel. The diameter of this flow channel is established essentially by the hopper outlet dimensions. When the cohesive strength of the material is high enough, it may be possible to empty out this flow channel without the upper layers in the bin sloughing off into this channel. Then an open channel will be formed right within the bin. This is referred to as a “stable rathole”.

- **Mass flow** - Refers to a flow pattern where all the material in the bin is in a downward motion, whenever the feeder is discharging. In essence, the material column slides along the hopper walls. In order to attain this type of flow pattern, the hopper walls must be steep and smooth.

- **Expanded flow** - Uses the mass-flow pattern in the lower hopper section up to the point where the “stable rathole” diameter is reached, and then the flow pattern continues as funnel-flow. The “stable rathole” diameter can be calculated when the flow properties are known.

Conveying by Flow Feeder is continuous. In comparison with other conveying systems it comes here to less abrasion of conveying pipeline. Compared with conveying by pressure vessel expansion of dilute material phase into conveying pipeline at the end of conveying cycle is omitted. Because of conveying air expansion here comes to mass of air flowing through conveying pipeline in high velocity and to maximum pipeline abrasion because of it.

The next advantage of conveying by Flow Feeders is their long service life and low maintenance costs. How you can see from scheme picture of Flow feeder does not bear any moveable parts coming into contact with conveying material. Their abrasion and maintenance are omitted then as it is at using of screw or rotary feeders. Above it moveable velocity of material in gravity chamber and in feeder body are very small. Mixer is the only part where comes to material flowing at higher velocity and the following tendency of abrasion. It is constructed in fortified anti abrasive construction for conveying of abrasive material, like power plant flying ashes. The only moveable parts in pneumatic conveying system by Flow-Feeder are functional elements of closures in air distribution but they only move in clean air flow and do not suffer by abrasion. As it is about continuous conveying the operation of equipment is fluent and stable. It enables select comparatively low conveying velocity of air (18 – 20 m/s at air state at the end of conveying pipeline) and mixing
ratio approximately 15 - 25 kg/kg. Equipment has not tendency to plugging up on one side and to abrasion of conveying pipeline on the other side.

3.5. The conveying component [Venturi System]
Once the solids have passed through the acceleration zone, they enter into the conveying zone. (fig 8) The conveying zone consists of a pipe to convey the solids from point A to point B over a certain distance. The selection of piping is based on a number of factors including the abrasiveness of the product and the pressure required.

3.6. Air-solid separation component [Baffle Plates]
At the end of any negative or positive pneumatic conveying system, a separator is needed that separates the solids from the carrier gas or air in order to recover the solids transported (fig.10) The selection of an adequate gas-solid separation system is dependent upon a number of factors, the primary factor being the size of solids requiring to be separated from the gas stream. After material has been transported through the system, it is necessary to separate the solids from the air stream. There are many devices available to affect efficient solids recovery. The type of system selected will depend upon the degree of recovery required and also the harmful effects on the product being conveyed. It is also possible to achieve some form of sizing of the product.

4. TESTING AND PERFORMANCE

Equations to Calculate Flow Rates
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1) \[ \frac{P_a}{\rho g} + \frac{v_a^2}{2g} = \frac{P_b}{\rho g} + \frac{v_b^2}{2g} \]

[**Bernoulli’s Equation**]

2) \[ A_a V_a = A_b V_b \]

[**Continuity Equation**]

**DISCHARGE THEORETICAL (Q)**

1) \[ \frac{C_d \times \frac{A_a}{A_b} \times \sqrt{2gh}}{\sqrt{A_a^2 - A_b^2}} \] \[ C_d = \text{Coefficient of Venturi} \]

or \( h = x \times \left[ \frac{S_b}{S_0} - 1 \right] \) (Liquid heavier than liquid flow through pipe)

\( h = x \times \left[ \frac{S_l}{S_0} - 1 \right] \) (Liquid lighter than liquid flow through pipe)

\( S_h & S_l = \text{Specific gravity of heavier & lighter liquid} \)

\( S_0 = \text{Specific gravity of liquid flowing through it.} \)

\( X = \text{Diff of heavier liquid column.} \)

2) \[ Q = \rho A_b V_b \] \[ \text{[m}^3/\text{S]} \]

\[ \text{---------------- (1)} \]

Here, \( \rho = \text{density [Kg/m}^3\]\)

**5. MAIN CALCULATION**

**Calculation Table [Actual Values]**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Venturi Specification</th>
<th>Velocity ( V_a ) (m/s)</th>
<th>Material Flow (Kg/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cement</td>
</tr>
<tr>
<td>1</td>
<td>( D_a = 10.16 \text{ cm} ) ( D_b = 7.62 \text{ cm} ) Convergent length = 50 cm Divergent length = 50 cm</td>
<td>9</td>
<td>0.136</td>
</tr>
</tbody>
</table>

**6. THEORETICAL CALCULATION**

Length of the system (L) = 2 m

Area of Convergent part \( (A_a) = \frac{\pi}{4} D_a^2 = \frac{\pi}{4} (0.102)^2 = 0.008 \text{ m}^2 \)

Area of throat part \( (A_b) = \frac{\pi}{4} D_b^2 = \frac{\pi}{4} (0.076)^2 = 0.005 \text{ m}^2 \)
CEMENT
Density (\(\rho\)) = 1600 Kg/m\(^3\) [Std. Value]
Continuity equation, \(A_aV_a = A_bV_b\)
\[0.008 \times 9 = 0.005 \times V_b\]
\[V_b = 14.4 \text{ m/s}\]
Discharge (Q) = \(\rho A_bV_b\)
\[= 1600 \times 0.005 \times 14.4\]
\[= 115.20 \text{ m}^3/\text{s}\]

SAND
Density (\(\rho\)) = 1920 Kg/m\(^3\) [Std. Value]
Continuity equation, \(A_aV_a = A_bV_b\)
\[0.008 \times 9 = 0.005 \times V_b\]
\[V_b = 14.4 \text{ m/s}\]
Discharge (Q) = \(\rho A_bV_b\)
\[= 1920 \times 0.005 \times 14.4\]
\[= 138.24 \text{ m}^3/\text{s}\]

WHEAT
Density (\(\rho\)) = 280 Kg/m\(^3\) [Std. Value]
Continuity equation, \(A_aV_a = A_bV_b\)
\[0.008 \times 9 = 0.005 \times V_b\]
\[V_b = 14.4 \text{ m/s}\]
Discharge (Q) = \(\rho A_bV_b\)
\[= 280 \times 0.005 \times 14.4\]
\[= 20.16 \text{ m}^3/\text{s}\]

COAL ASH
Density (\(\rho\)) = 700 Kg/m\(^3\) [Std. Value]
Continuity equation, \(A_aV_a = A_bV_b\)
\[0.008 \times 9 = 0.005 \times V_b\]
\[V_b = 14.4 \text{ m/s}\]
Discharge (Q) = \(\rho A_bV_b\)
\[= 700 \times 0.005 \times 14.4\]
= 50.40 m³/s

**TALCUM POWDER**

Density ( ) = 320 Kg/m³ [Std. Value]

Continuity equation, \( A_a V_a = A_b V_b \)

\[
0.008 \times 9 = 0.005 \times V_b
\]

\( V_b = 14.4 \text{ m/s} \)

Discharge (Q) = \( \rho A_b V_b \)

\[
= 320 \times 0.005 \times 14.4
\]

\( = 23.04 \text{ m}^3/\text{s} \)

7. CONCLUSION

After doing all calculation & analysis it is conclude that high nozzle velocities are always require to convey the material having high densities like sand & cement. The implementation of venturi is necessary for balancing pressure & velocities in the pneumatic conveying system. The material feeding areas in conveying system have more importance to calculate the efficiency of the system.

The theoretical & practical values of discharge are equal in range with standard values. Hence this system is efficient to use in any powder manufacturing industry or for the handling of plant ash.

8. ABBREVIATION

- P.M.H.S. – Pneumatic material handling system
- BHP – Brake Horsepower.
- CFM – Cubic Feet per minute.
- SP – Static Pressure.
- ha – Hectare
- t – Tons

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