UNLOADING PRESSURE DISCHARGE TRUCKS

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Abstract

In many industrial processes where raw materials are required in bulk, pressure discharge trucks (usually referred to as PD trucks) are commonly used to transport them from the supplier's warehouse or mine to the processing plant or final client. As the name implies, pressure discharge trucks unload their contents by means of a pneumatic conveying system and transport it through a pipeline into a storage silo. This type of material handling system does not employ bags or containers to transport the materials, it is enclosed and easy to operate, and hence, it is less expensive overall when large quantities of materials are to be transported in bulk on a regular basis.

In this article, attention is centered on the design and operation of PD trucks, from a pneumatic conveying viewpoint, including a description of several problems encountered in the field. Examples of different applications and bulk materials are also presented.

1. INTRODUCTION

The pneumatic transport of bulk materials, or more precisely the flow of a two-phase gas-solids suspension inside a pipe, has been practiced for over a century and has been defined as "the art of transporting bulk materials through a pipeline by either a negative or a positive pressure gas stream" [1]. Pneumatic conveying represents an important topic in engineering and is encountered in a variety of industrial processes. It is not a simple matter because of the large number of variables involved, the interaction between the phases, and the complex dynamic developments occurring in the pipeline. Although gas-solids flows obey all of the basic laws of fluid mechanics, there is not yet a thorough understanding of them and theoretical predictions from first principles have yet to be developed.

Several methods to model the flow of gas-solids suspensions can be found in the literature. Most of these models are based on empirical correlations, discrete-particle simulations, on averaging techniques, and mixture theory [2]. But experimental testing remains the most reliable method for understanding and designing gas-solids flow systems, usually using pilot-scale units. Perhaps the most important constraint to model gas-solids suspensions is the turbulent nature of the flow and the fact that each bulk material has its own unique flow characteristics, making the design of pneumatic conveying systems still "an art rather than a science".

Pneumatic conveying is widely used in industry to handle and transport dry and free-flowing powdered and granular materials because it is suitable for a variety of processes. Fine particles of less than 1 micron as well as 15 mm rocks can be conveyed vertically and/or horizontally from distances of a few meters to a few kilometers at rates of hundreds of tons per hour. Although pneumatic conveying requires a greater power supply and more technology than mechanical conveying, it has a lower initial capital investment, requires less control and maintenance, takes up little floor space (pipelines are easily routed), protects the material from the environment by enclosing it, and it is cleaner and easier to automate. Systems are totally enclosed, which means that potentially hazardous materials can be safely conveyed, and dust generation is minimized. Disadvantages of pneumatic conveying include pipe erosion and potential solids degradation when the system has not been properly designed.

Pneumatic conveying systems can be found in many diverse industries: chemical, pharmaceutical, food, glass, cement, plastics, mining, ports and other industries. Typical applications include: delivery of materials through pipelines to remote plant areas; filling and unloading of silos, rail cars, trucks and ships; feeding and metering of materials into reactors, furnaces and converters; vacuum cleaning and fugitive dust handling systems; etc.

A relatively new industrial application is the pneumatic unloading of pressure discharge trucks, the main focus of this article. For example, lime (calcium oxide) represents a primary ingredient used in many concentrators to prepare ‘milk of lime’ for milling and flotation processes and for neutralization of acid waters in mines. To satisfy this demand at one mine, several 28-ton trucks are unloaded daily, some of them after traveling days from the supplier’s source (see Figure 1). The cement industry also uses this type of transport system to deliver cement in bulk from a cement plant to batch plants or construction sites. Other materials transported in PD trucks include: suggar, flour, plastic pellets, coke, coal, gypsum, flyash, dust, etc.

Figure 1: Examples of two Chilean applications with PD trucks ready to unload lime. [3]

2. BASIC COMPONENTS

The main purpose of pneumatic conveying is to move materials at a controlled rate from one point (i.e. the feed point) to another (i.e. the delivery point) by means of a gas stream flowing inside a pipe. To achieve it, a pneumatic conveying system consists basically of four distinct components as shown in Figure 2 for a positive pressure system: the prime mover, the silo / feeder arrangement, the pipeline, and the separator, each of them with its own characteristics. Controls, safety equipment and instrumentation are also required. A challenge for every designer is to match all the components and to "combine" the different equipment so that the system operates efficiently at the design conditions.

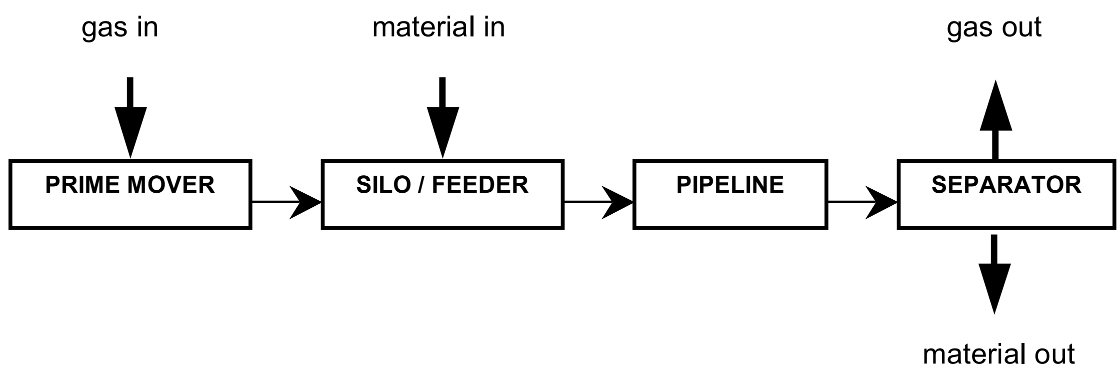

Figure 2: Basic components of a positive-pressure pneumatic conveying system.

The prime mover provides the proper flow rate of gas required for the transport at the right pressure. A wide variety of positive-displacement Roots type blowers and compressors available in the market could be used to unload the material contained in a truck silo. In some cases, the blower is mounted on the truck and is driven by the truck's engine, i.e. a self-unloading PD truck. In other cases, the blower or compressor air supply is fixed at the plant and the driver connects a rubber hose from the plant air supply to a manifold on the truck. Usually, the air is divided to pressurize the top of the stored material in the truck silo, to fluidise the bottom discharge point, and the main stream is directed to transport it through the pipeline.

The material stored in the truck silo is introduced into the pipeline by gravity, usually fluidizing the bottom discharge of the stored material, mixed with the conveying gas, and accelerated to some "steady" transport velocity. This is a crucial zone in all pneumatic conveying systems, and special care must be taken when designing and operating PD truck unloading systems. Reliable flow of material from the truck silo and into the pipeline is an absolute necessity as a starting point. Properly designed silos with mass flow hoppers and aerated bin bottom discharge should be based on the material flow characteristics [4].

The pipeline corresponds to the conveying zone itself, including a connecting rubber hose at the truck's feed point and the pipeline up to the delivery point on top of the storage silo in the plant, using horizontal and vertical pipes, bends, couplings and/or diverters. The most common pipes used in these type of unloading systems are standard 4″ or 6″ in diameter, ASTM

Sch. 40 or 80 carbon steel pipes. Systems handling ligther, non-abrasive material often use 4″ or 5″ O.D. tubing.

In the separator, the solids are recovered from the gas stream in which they have been transported and then stored in a silo. This is the final point of the transport process where the solid particles are decelerated and the gas is typically released to the environment. Environmental regulations should be considered for the proper release of the conveying gas into the environment. The following most common types of separators may be used: cyclones, settling chambers, bag filters, reverse-jet filters and Hepa absolute filters, depending mainly on material characteristics.

While the conveying gas is usually air at ambient conditions, other gases may be used such as nitrogen and carbon dioxide in applications where there exists a risk of explosion or health and fire hazards.

It is interesting to point out in the case of PD trucks the so-called 'feed point' is not fixed but travels with the truck, from plant to plant, and during discharge, the truck silo itself becomes a "blow tank", as shown in Figure 3, i.e. a positive, low pressure pneumatic conveying system operating in dilute-phase with a Roots type blower.

In general, truck unloading systems are laid out so that the truck can park as close as possible to the storage silo. When the truck can park next to the silo, the pipeline has a vertical run of 20 to 30 meters and may include only one 90 deg. bend, or a single 180 deg. bend. This minimizes the conveying distance which in turn minimizes the unloading time. For truck silos containing roughly 28 to 30 tons of material, the usual unloading time is 1 to 2 hours, depending mainly on conveying gas density (i.e. altitude of the plant) and material characteristics such as particle size and particle density. But in cases where the truck has to park up to hundred meters away from the silo, the unloading time could be several hours. The truck silo (or just silo tank) can be made of carbon steel or stainless steel, with a maximum working pressure rated at 1 barg.

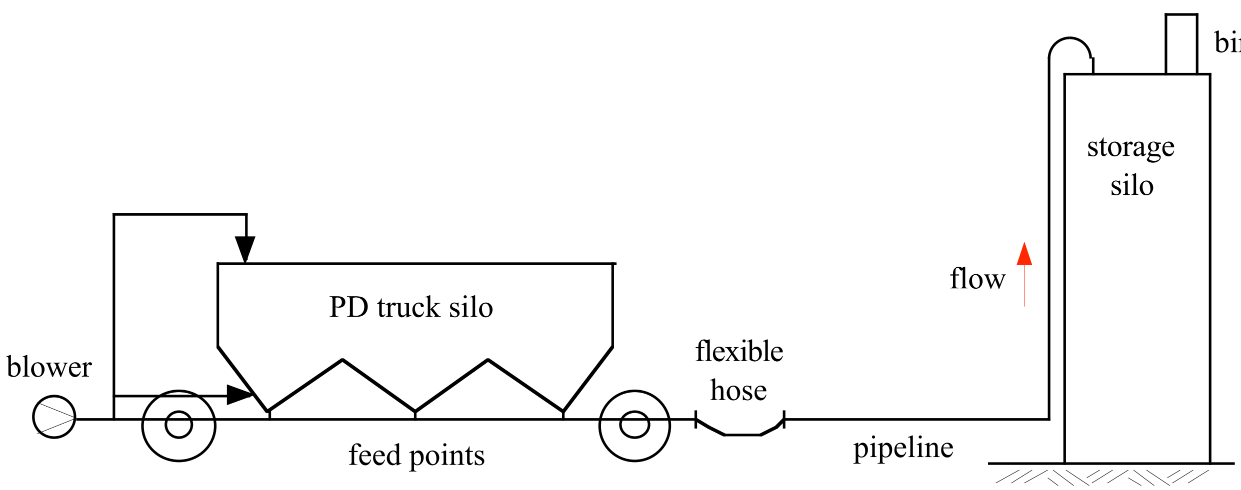

Figure 3: Schematic representation of the pneumatic unloading of a PD truck.

3. GENERAL STATE DIAGRAM

Perhaps the most common way to describe the characteristics of pneumatic conveyance of bulk materials is using the so-called "general state diagram." Here, the pressure drop is plotted as a function of mean gas velocity, with constant solids mass flow rates as a parameter. Figure 4 shows a typical "general state diagram" in which the curve "gas alone" represents the friction loss for the gas-phase alone (Ws=0). Point A represents the saturation carrying capacity at solids flow rate Ws1, usually referred to as "saltation." This point may represent the limit of conveying, where the line plugs and conveying at lower velocities is impossible, or it may represent the point at which conveying becomes unstable and a transition is possible to lower velocity conveying in a dense phase mode. Some materials can be conveyed successfully with a bed of material sliding along the bottom while other materials cannot. Point B represents the optimal operating condition in terms of energy consumption.

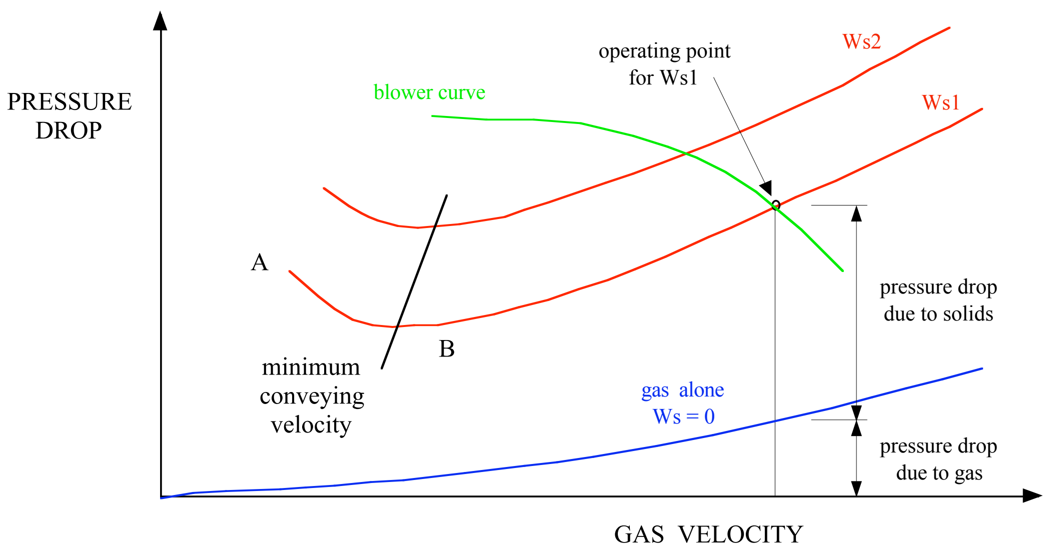

Figure 4: General state diagram for the pneumatic conveyance of bulk materials.

3.1 Minimum conveying velocity

The conveying velocity is one of the most important parameters in the design and operation of pneumatic transport systems, affecting the pressure drop and thus the energy requirements for the transport, pipe erosion, particle attrition, and the flow patterns of the gas-solids suspension. Keeping the mean gas velocity above a minimum value in all horizontal sections of a pipeline ensures no deposition or accumulation of solids in the system. This minimum conveying velocity can be defined as the safe gas velocity for the steady horizontal transport of solids. If this velocity is set at the beginning of a piping system, the velocity will increase along the pipeline due to compressibility effects (density decrease) so the rest of the pipeline should be well above this lower velocity bound. A slightly lower gas velocity results in the deposition of solids on the bottom of the pipe, which can lead to blockage of the system.

There are many terms wrongly used to refer to minimum conveying velocity: saltation velocity, pickup velocity, suspension velocity, deposition velocity, rolling or sliding velocity, critical velocity, etc. Definitions of these terms are based on visual observations and pressure drop measurements, and they are often applied to indicate some transition in the way in which the particles are moving or begin to move. In fact, the terms pickup and saltation represent two completely different mechanisms, but they are often used interchangeable in pneumatic transport. Extensive work has been carried out on the prediction of minimum conveying velocity and its relationship with both pickup and saltation mechanisms of solid particles for different materials [5].

3.2 Flow regimes

Two main distinct regimes exist for horizontal gas-solids conveying: flow at gas velocities above and below the saltation velocity, as illustrated in Figure 5, sometimes referred to as dilute and dense-phase conveying. Above saltation velocity, at high gas velocities, the solids are dispersed and homogeneously suspended in the gas-phase, moving in the same direction as the gas. In this regime, the pressure drop increases with gas velocity. As the gas velocity is decreased, however, the suspension becomes more stratified and a non-uniform solids flow distribution can be obtained. With further decreases in gas velocity, the suspension's velocity for carrying solids is eventually exceeded and solids begin to deposit on the bottom of the pipeline.

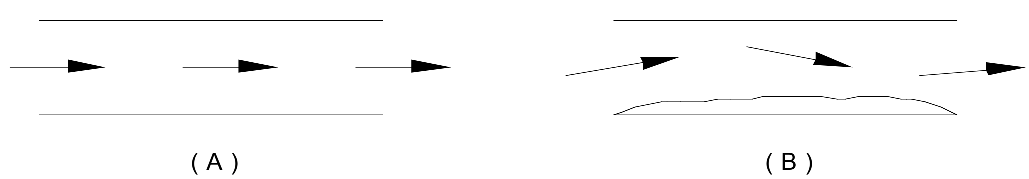

Figure 5: Flow regimes in horizontal pneumatic transport: (A) mean gas velocity above saltation, (B) mean gas velocity below saltation.

3.3 Pressure drop calculation

The pressure drop (ΔP) for dilute-phase, fully developed flow inside a straight and horizontal pipe is usually splitted in two contributions, the pressure drop due to the gas-phase (ΔPg) and the additional pressure drop due to the solids (ΔPs):

$$\Delta P = \Delta Pg + \Delta Ps \qquad (1)$$

Gasterstadt [6] defined the specific pressure drop (α) dividing equation (1) by the pressure drop due to the gas-phase (ΔPg):

$$\alpha_{HOR} = \Delta P / \Delta Pg = 1 + \Delta Ps / \Delta Pg = 1 + Ks\, \mu \qquad (2)$$

Yang [7] proposed a similar model for dilute-phase, fully developed flow inside a straight vertical pipe, including the static head contribution of the solids:

$$\Delta P = \Delta Pg + \Delta Ps + \rho p \, (1 - \varepsilon) \, g \, H \tag{3}$$

The voidage ε is defined as follow: $\varepsilon = 1 - (\rho g / \rho p) \, (Ug / Up) \, \mu$ (4)

where ρg and ρp represent the gas and particle density, respectively, and Ug and Up represent the gas and particle velocity, respectively. There are numerous correlations available in the literature for predicting the particle velocity but the one proposed by Konno and Saito [8] in terms of the particle terminal velocity (Ut) is normally selected by simplicity:

$$Up = Ug - Ut \tag{5}$$

Dividing equation (3) by the pressure drop due to the gas-phase (ΔPg) yields:

$$\alpha_{VER} = \{ \Delta P - \rho p \, (1 - \varepsilon) \, g \, H \} / \Delta Pg = 1 + Ks \, \mu \tag{6}$$

In equations (2) and (6) Ks is a solids friction factor and represents the slope of a straight line when plotting α as a function of the solids loading ratio $\mu = Ws / Wg$.

These models have been studied in details, in both horizontal and vertical pipelines, and the results obtained for the homogeneous and stable flow of different materials above minimum conveying velocity show that these models work very well in reducing the experimental data obtained [9]. It is interesting to point out that the solids friction factor Ks for vertical flow was found to be slightly lower as compared to the solids friction factor for horizontal flow, approx. 83% on average for all the materials tested. Also, the solids friction factor increases with particle size and particle density, and it is independent of solids flow rate.

Finally, to estimate the total pressure drop required in a pneumatic unloading system like the one shown schematically in Figure 3, other terms should be added to account for the aerated bin bottoms of the truck silo, acceleration length, bends, air disengagers and filter receivers.

4. FLOW PROBLEMS

PD trucks represent a unique class of pneumatic conveying systems because of the mobile nature of the "feed system." Self unloading trucks arrive with their own blower and operator and connect to a fixed system at the plant. Since each plant system that an operator visits is slightly (or, in some cases significantly) different, they have to adapt their operation to each system. Operators may change frequently and may not be knowledgeable in the finer points of pneumatic conveying.

Truck equipment can also vary so that some trucks will perform differently while unloading in the same system with the same material. An operators motivation for choosing operating conditions may also depend on factors other than maximum efficiency. Typically an operator will wish to unload the cargo as quickly as possible in order to complete his shift, but many other factors can affect this decision. Also, an operators perception of the "best" conditions for unloading may not always lead to the most efficient operation. One common misconception about pneumatic conveying systems in general is that more air flow leads to faster transfer rates. In systems constrained by an upper pressure limit and fixed piping, this logic often leads to less efficient conveying and problems such as:

- Excessive wear of the pipeline and/or bends, when handling abrasive materials,
- Excessive particle attrition of the material, when handling friable materials,
- Pipeline pluggage,
- Excessive power consumption,
- Material build-up inside the truck silo,
- Arching problems in the aerated bin bottoms of the truck silo,
- Limited unloading capacity (low tonnage), which results in high unloading times.

By knowing the material flow properties of the bulk solid handled and the general state diagram of the system, these flow problems can be avoided in properly designed new facilities, and also corrected in existing applications.

5. CONCLUSIONS

Pressure discharge trucks (usually referred to as PD trucks) are commonly used to transport materials in bulk such as lime, cement, suggar, flour, plastic pellets, coke, coal, gypsum, flyash, dust, etc. from the supplier's warehouse or mine to the processing plant or final client. By means of a pneumatic conveying system the content of the truck silo can be unloaded and transported through a pipeline into a storage silo. This type of material handling system does not employ any bags and/or containers to transport the materials, it is enclosed and easy to operate, and hence, it is less expensive overall when large quantities of materials are to be transported in bulk on a regular basis. However it is not free of potential flow problems, as described in this article. To avoid them, a proper design must be done.

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