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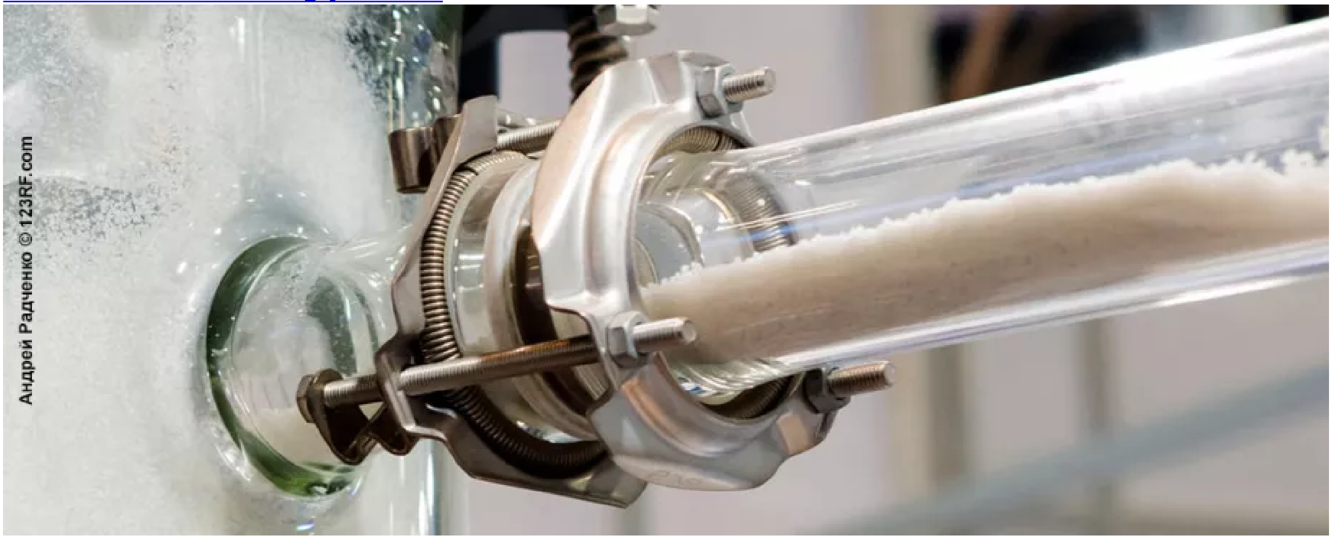

Technical Article

The Proper Flow Rate – Material Feed Rate Control for Pneumatic Conveying Systems

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The material feeding device is particularly critical to the successful operation of any pneumatic conveying system and a considerable number of devices have been developed over the years for the purpose. This applies to both positive pressure and negative pressure (vacuum) conveying systems. Numerous developments have been made, particularly with regard to their suitability for different types and properties of conveyed material, system operating pressure and air leakage across the device. In this article it is the feed rate control capability of rotary valves, screw feeders and blow tanks that is considered. With positive displacement feeders this is not generally a problem but many feeders have no moving parts and it is not always obvious how material flow rate can be reliably achieved.

Introduction

Many diverse devices have been developed for feeding. Some are specifically appropriate to a single type of system, such as suction nozzles for vacuum systems. Others, such as rotary valves, screws and gate valves, can be used for both vacuum and positive pressure systems. The approximate operating pressure ranges for various pipeline feeding devices are shown in Fig. 1. It will be seen that there is no scale on the vacuum side of Fig. 1. This is because the pressure of operation is only atmospheric and there will be essentially no pressure difference across the feeder, regardless of the type of feeder.

Developments have been carried out on most types of feeding device, both to increase the range of materials that can be successfully handled, and to increase the operating pressure range of the device. Each type of feeding device, therefore, can generally be used with a number of different types of conveying system, and there are usually many alternative arrangements of the feeding device itself.

Blow Tanks

For high pressure systems, and particularly where the material has to be fed into a system that is maintained at a high pressure, blow tanks are often employed. These are generally used for conveying batches, although they can quite easily be adapted for continuous conveying by the use of lock hoppers. A continuous conveying capability is the particular advantage of all the other feeding devices shown in Fig. 1. Although blow tanks are generally associated with high pressure conveying, they can also be used for low pressure systems.

Feeding Requirements

For a given conveying system the air mover can be positioned at either end, see Fig. 2. If the air is blown into the pipeline, therefore, the air at the feed point will be at a pressure close to that of the air supply. In this case the material has to be fed into the pipeline at pressure, and so consideration has to be given to the possibility of air leakage across the device. If the air mover is positioned downstream, acting as an exhauster to the separator-discharge hopper, the air at the feed point will be close to atmospheric pressure, and the effect of a pressure gradient on the feeding device need not be taken into account.A further requirement of the feeding device, in most applications, is that it should feed the material into the conveying line at as uniform a rate as possible. This is particularly so in the case of dilute phase systems, for the material is conveyed in suspension and quite high values of minimum conveying air velocity have to be maintained. With a mean conveying air velocity over the length of the pipeline of 20 m/s, for example, it will only take about 5 seconds for the air to pass through a 100 m long pipeline.In case of surges in material feed, the pipeline could be blocked very quickly. Alternatively, if the air mover pressure rating allows for such surges, the output from the system could be increased if the flow rate, and hence the conveying line pressure drop, was kept constant at a higher value to match the rating more closely.

Flow Metering

Positive displacement feeding devices, such as screws and rotary valves, can serve the dual purpose of metering the material into the pipeline, whilst affecting the airlock that is necessary for successful operation, in the case of positive pressure systems. Some feeders act only as air locks and so require additional equipment for metering. Some feeders have no moving parts, and so particular attention is given to these, as their means of material flow control may not be obvious.

RotaryValves

The rotary valve is probably the most commonly used device for feeding material into pipelines. It consists of a bladed rotor working in a fixed housing. In many applications in which it is used its primary function is as an air lock, and so is often referred to as a rotary air lock. This basic type of valve is generally suitable for free flowing materials. This type of valve is usually referred to as a ‘drop-through’ feeder and is depicted in Fig. 3.

Discharge Period and Pulsations

It should be borne in mind that for an eight bladed rotor as shown in Fig. 3, rotating at a typical speed of 20 rpm, a time span of only 0.375 s is available for the material to be discharged from each pocket. The time available for discharge, therefore, is very short, and although this is generally satisfactory for free flowing materials it is generally not for cohesive materials and hence the need for an alternative blow- through valve [1].The reciprocal of this time period provides another important operating parameter. The importance of feeding material into a pipeline as smoothly as possible was mentioned above, and it was stated that in a dilute phase conveying system the air would traverse a 100 m long pipeline in about 5 seconds. For the rotary valve being considered above, about 13 pockets of material would be deposited into the pipeline in this period. Such a frequency of pulsations is generally acceptable for most conveying applications. Consideration of such pulsations in combustions systems, however, would be recommended.

Material Feed Rate

The feed rate of a rotary valve is directly proportional to the displacement volume of the rotor and its rotational speed. The displacement volume is simply the volume multiplied by the number of rotor pockets. If a mass flow rate of material is required this must then be multiplied by the bulk density of the material. The constant of proportionality here is the volumetric or filling efficiency of the valve:

$$m_p = V \cdot n \cdot N \cdot \rho_b \cdot \eta \cdot \frac{60}{100}$$

where m_p is the material mass flow rate, V the pocket volume, n the number of rotor pockets, N the rotational speed, ρ_b the bulk density, and η the filling efficiency.

Pocket Filling Efficiency

If air leakage impedes material flow, the pockets will not fill completely and so the volumetric efficiency will be reduced. Air leakage may also have the effect of reducing the bulk density of the material, for with some materials the fluidised bulk density can be very much lower than the ‘as poured’ bulk density. It should be not-ed that, because of air leakage, the volumetric efficiency of a rotary valve when feeding a negative pressure system will generally be much greater than when feeding a positive pressure system.

Feed Rate Control

As the rotary valve is a positive displacement device, feed rate control is done by simply varying the speed of the rotor. However, the feed rate doesn't increases continually with rotor speed. There are a number of factors that tend to reduce the feed rate below this maximum. The pocket filling efficiency of a rotary valve, for example, is a function of rotor speed, for at increased speed the time available for pocket filling reduces. Up to a speed of about 20 rpm the filling efficiency is reasonably constant, but above this speed it starts to decrease at an increasing rate (Fig. 4). There is also a lower limit on speed because of the problems associated with the low frequency pulsations caused by pocket emptying. Thus there is a limit on feed rate with any given rotary valve, but they do come in a very wide range of sizes to meet almost any duty.

Screw Feeders

Much of what has been said about rotary valves applies equally to screw feeders. They are positive displacement devices, feed rate control can be achieved by varying the speed, they can be used for either positive pressure or vacuum feeding, air leakage is a problem when feeding into positive pressure systems, and they are prone to wear by abrasive materials.

The Simple Screw Feeder

Rotation of the screw moves a continuous plug of material into the pipeline, where it is dispersed and entrained with the conveying air. A particular advantage of screw type feeders is that there is an approximate linear relationship between screw speed and material feed rate, and so the discharge rate can be controlled to within fairly close limits.

This type of screw feeder, however, is rarely used for feeding positive pressure conveying systems. This is because there is little in their design to satisfy the basic requirement of feeding across an adverse pressure gradient. Air leakage represents a major problem with many materials, and so they are generally limited to vacuum systems where operating pressure differentials do not have to be considered. The simple screw feeder, however, can be used in high pressure applications in combination with a lock hopper.

High Pressure Design

The simple screw feeder was developed by several companies into a device that can feed successfully into conveying lines at pressures of up to 2.5 barg. One such device, which was manufactured by the Fuller Company of the USA, is known as a Fuller-Kinyon pump. In Germany, Claudius Peters developed a similar Peters pump at about the same time, see Fig. 5. The main feature of these screw feeders is that the screw decreases in pitch along its length. By this means the material to be conveyed is compressed to form a tight seal in the barrel. The material is fed from the supply hopper and is advanced through the barrel by the screw.

Since the screw pitch decreases towards the outlet, the material becomes compacted as it passes through the barrel. This is sufficient to propel the plug through the pivoted non-return valve at the end of the barrel and into a chamber into which air is continuously supplied through a series of nozzles. A pressure drop of about 0.5 bar must be allowed for the air across these nozzles, which adds significantly to the power requirement, and the screw itself requires a very high power input. It is partly because of these high energy requirements that the device has gone out of favour.

BlowTanks

Blow tanks are often employed in pneumatic conveying systems because of their capability of using high pressure air, which is necessary if it is required to convey over long distances in dilute phase, or to convey at high mass flow rates over short distances through small bore pipelines. Blow tanks are neither restricted to dense phase conveying nor to high pressure use. Low pressure blow tanks are often used as an alternative to rotary valves, particularly if abrasive materials have to be conveyed. Materials not capable of being conveyed in dense phase can be conveyed equally well in dilute phase suspension flow.As the blow tank has no moving parts both wear of the feeder and material degradation are significantly reduced. Another advantage of these systems is that the blow tank also serves as the feeder, and so the problems associated with feeding against an adverse pressure gradient, such as air leakage, do not arise. There will, however, be a small pressure drop across the blow tank in order to achieve material feed, which must be taken into account when evaluating air requirements.In most blow tank systems the air supply to the blow tank is split into two streams. One air stream pressurises the blow tank and may also fluidise or aerate the material in the blow tank. This air stream serves to discharge the material from the blow tank. The other air stream is fed directly into the discharge line just downstream of the blow tank. This is generally referred to as supplementary air and it provides the necessary control over the material flow in the conveying line.

There are numerous different types of blow tank, and for each type alternative configurations are possible. Their basic features are essentially similar, but different arrangements can result in very different conveying capabilities and control characteristics. There are also a variety of blow tank configurations that are widely used, for apart from single blow tanks there are twin blow tank possibilities, with both parallel and series arrangements.

Top and Bottom Discharge

The blow tank shown in Fig. 6 is a top discharge type. It is shown with a discharge valve so that it can be isolated from the conveying line. It also has a vent line and valve so that it can be de-pressurised independently of the conveying line. Discharge is arranged through an off-take pipe positioned above the fluidising membrane. The material is discharged vertically up and the discharge pipe exits the blow tank through the top of the vessel, and hence the term ‘top discharge’ in this case.In a bottom discharge blow tank there is no membrane. Material has an uninterrupted passage to be gravity fed into the pipeline and so the contents can be completely discharged (Fig. 7). The arrangement shown in Fig. 7 is one that is commonly found in industry, but will generally be difficult to control the feed rate reliably as illustrated.A feature of blow tanks is that most designs will work, and for most materials to be conveyed. For those materials for which it will not work very well it would be suggested that it should be modified by adding an air supply to a point close to the discharge point so that the material can be fluidised in this area, and that the supplementary air be introduced a short distance downstream (Fig. 9).

Feed Rate Control

Flow control for a feeder having no moving parts is by air proportioning. Part of the air is directed into the blow tank to pressurise the vessel and aerate the material. The rest of the air effectively by-passes the blow tank, but is used to dilute the very high concentration of the material discharged from the blow tank to a solids loading ratio appropriate for conveying. This air flow is often referred to as the supplementary air supply. Where the two air streams meet is effectively the start of the conveying pipeline and the air supply needs to be sufficient to achieve the required velocity for conveying the given material. The nature of the flow control, by proportioning the air supply in the way described, is illustrated in Fig. 8.It will be seen from Fig. 8 that the blow tank is capable of feeding material over a very wide range of flow rates – much wider than could be obtained with a single rotary valve. Where blow tank systems are sold ‘off the shelf’ they come in a small number of sizes. The lines of constant air proportion do terminate as shown in Fig. 8 as this represents the conveying limit for the material considered, which was cement in this case. This limit is dictated by the minimum conveying air velocity, and hence the air flow rate required for this minimum value of velocity. The 100% line represents the maximum discharge capability of the blow tank.It should be noted that the discharge characteristics of a blow tank, illustrated in Fig. 8 for cement in a top discharge blow tank, will vary with both the configuration of the blow tank and the material being conveyed [3, 4].

Blow Tank Control Systems

If a blow tank is required to convey a variety of materials or just one material over a range of distances, so that the material flow rate will need to be changed, an automatic control facility would be essential. In case of the blow tank, air supply pressure is the controlling parameter and so some form of feedback control should be provided on the air supply to the blow tank to ensure that the system always works to the maximum capacity allowed by air supply pressure.The most effective way of controlling the blow tank discharge rate is to provide a modulating valve on one of the air supply lines. This will automatically proportion the total air supply between the blow tank and the supplementary line. A sketch of such a system, fitted to a bottom discharge blow tank, is shown in Fig. 9. Here the feedback signal is from the air pressure in the supplementary air supply line.If the pressure monitored is below the operating value, the modulating valve will restrict air flow to the supplementary line so that more air will be directed to the blow tank and the feed rate will increase. If the pressure rises too much, the modulating valve will open a little to allow more supplementary air, and hence the material flow rate will be reduced.This type of control is particularly useful on the start-up and tail-out transients associated with the conveying cycle. During start-up, for example, all the air will be automatically directed to the blow tank to effect a rapid pressurisation, and control will automatically be achieved with lines of different length.The sensing device for the valve is often positioned in the supplementary air line rather than in the air supply line, because in the supplementary air line, changes in pressure will be monitored very quickly. In the air supply line the blow tank has a damping effect and consequently there will be a slight delay in sensing pressure changes.

Use of Lock Hoppers

If a lock hopper is positioned between the supply hopper and the blow tank, the system pressure drop occurs across the lock hopper. Then the blow tank will operate at the conveying line inlet air pressure and so it will be possible to fit a conventional rotary valve or screw feeder into the bottom of the blow tank as there will be no pressure drop across the pressure vessel. If headroom allows a vertically in-line arrangement of vessels can be used. For larger systems it is usual to arrange the discharge blow tank vessel alongside the su ply hopper and lock hopper. This requires the material in the lock hopper to be conveyed to the blow tank, but it does allow continuous operation.

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