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Design of Pneumatic Conveying Systems

Introduction

Pneumatic conveying is one of the innovations that characterise industry of the 19th century with the first documented system serving for the exhaustion of dust from grindstones. Nowadays, such systems are found in a wide variety of industries whose processes involve the transfer and storage of bulk materials including agriculture, food industry, chemicals, pharmaceuticals, mining, and metal refining and processing. Some examples of particulate materials usually conveyed using pneumatic systems are sugar, flour and coffee in the food industry, polyethylene and polypropylene pellets in the plastic industry, pulverised coal and fly ash in power stations and grain and rice in agriculture.

Due to their simplicity and versatility, pneumatic conveying systems are often preferred to mechanical conveying systems. The system requires a source of compressed gas, a feed device,a conveying pipeline and a material and gas separation system at the end of the transport line. Since the system is totally enclosed, both the product transported and the environment are protected. For this reason, pneumatic conveying systems generally meet the requirements of local Health & Safety legislation with no difficulty. The carrier gas employed is usually air but if required, dry air or inert gas such as nitrogen can be used for hygroscopic or potentially explosive materials. The flexibility in both plant layout and operation adds to the attractiveness of such systems. The combination of horizontal sections, vertical sections and bends facilitates flexible routing, leading to better utilisation of floor space and the ability to avoid existing equipment and structures. Moreover, most systems can be arranged for fully automatic operation [].

While using a pneumatic conveying system presents many advantages, the design of such a system can be very tricky. It requires deep knowledge of both the flow behaviour of the material to be transported and the physical rules governing pneumatic transport. The following questions should be asked at an early project stage:

1. Can the material be pneumatically conveying?
2. If the material can be pneumatically conveying, in which flow mode will the transport take place?
3. Is the flow mode suitable for the material in line with the process requirements?
4. How is the material going to be fed into the pneumatic conveying system?
5. How is the material going to be separated from the conveying gas at the end of the pipeline?
6. What is the expected wear of the system components?
7. Is particle attrition expected and will it affect the product quality or downstream process efficiency?

Pneumatic conveying modes of flow

The choice of the most suitable type of flow to transport a given bulk material depends not only on the production requirements but also on the physical characteristics of the product to convey. Pneumatic conveying is typically categorised as either one of two modes. If the material is transported with high velocity in the form of a suspension in the air, it is referred to as dilute phase conveying. If the material is conveyed at low velocity in a non-suspension mode, it is referred to as dense phase conveying. Besides the conveying gas velocity, the occurrence of a flow pattern depends on the solids feed rate, pipe diameter and material physical characteristics (Figure 1).

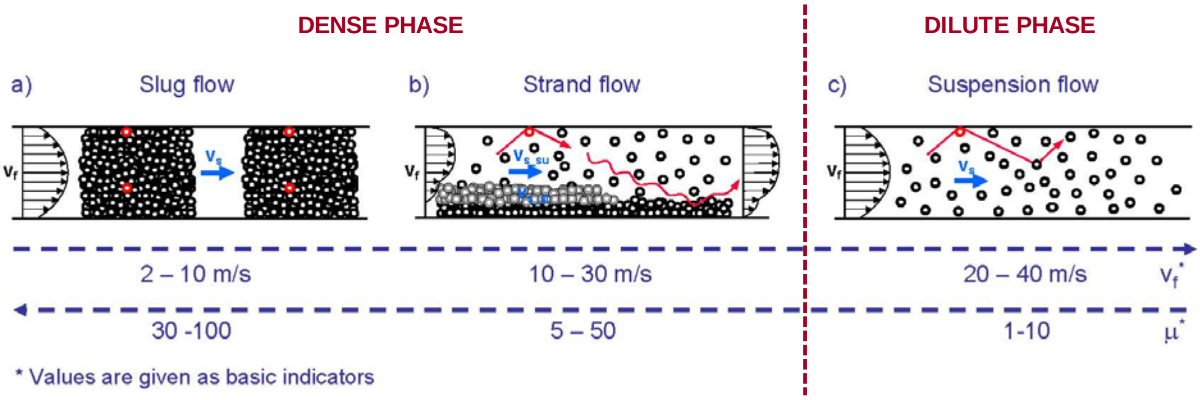

Figure 1: The three basic flow types in pneumatic conveying coarse materials.

In dilute phase conveying systems, the particles are conveyed using a gas velocity that is sufficient to ensure that the material will remain in suspension from the feeding to the discharge point. The transport takes place at low pressure with at low air solids loading usually between 1 and 10. This mode of flow presents an advantage in that the design methods for such a system have been long acknowledged and widely applied and the risk of pipe blockage is almost non-existing. However, because particles are generally in a turbulent suspension and collide frequently with the pipe wall, dilute phase conveying generally means excessive pipe wear and high rate of particle breakage in the case of friable products.

In contrast, dense phase pneumatic conveying systems permit minimisation of pipe wear, dust generation and product attrition. The transport takes place at low velocity but high pressure. Because of high solids loading of the gas phase, high mass flow rates can be achieved. While dense phase pneumatic conveying presents numerous advantages over dilute phase conveying, practitioners often hesitate applying such a system. This hesitation typically comes from the high risk of having random system performance as a result of inadequate design. In fact, the design of a dense phase pneumatic conveying system relies on the knowledge and understanding of the complex physical mechanisms involved in the transport of high particle concentrations in a gas phase. While complex design methods exist, it is acknowledged that a certain empiricism may always be present in the planning of a dense phase conveying system. In particular for slug flow, the design of industrial plants is generally based on expensive pilot plant tests, mostly using a 1:1 scale where correlation of pressure loss, transport gas velocity and solids mass flow rate are generated each time for a specific material conveyed in a predetermined pilot plant (Figure 2).

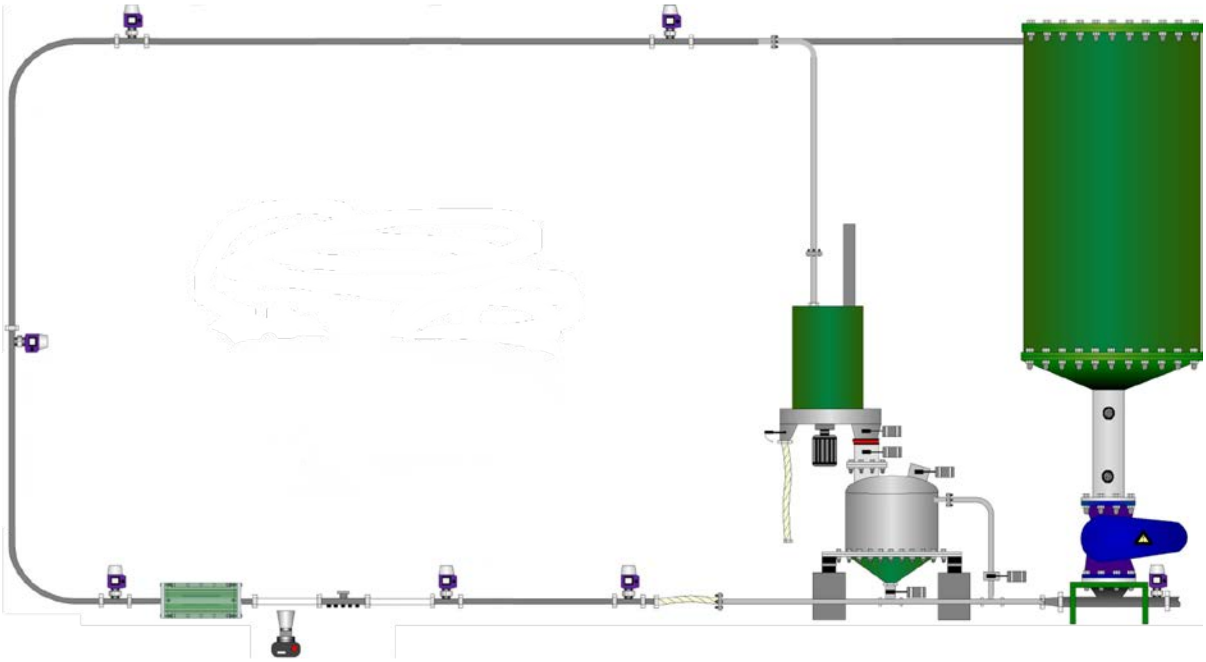

Figure 2: Typical test pilot plant for dense phase pneumatic conveying with full instrumentation.

Dense phase pneumatic conveying is usually divided into various flow types, the most common being:

- Strand flow,
- Slug flow,
- Fluidised dense phase (in the case of fine powders only).

More than from a choice, the occurring flow mode in a pipeline is the result of the physical properties of the material. Those properties determine the capability of a bulk material to be transported in dense-phase flow. They include:

- Particle size distribution and shape,
- Particle density, loose poured and tapped bulk density,
- Permeability,
- Behaviour during fluidisation,
- Behaviour during aeration and de-aeration.

Some materials can only be conveyed with high air velocity, i.e. in dilute phase. This includes materials with low permeability, medium or high cohesive strength, heterogeneous composition, high moisture content, aspherical shape, high particle density or materials with a wide particle size distribution.

Design method

Step 1: Assessment of the capability of a bulk material to be conveyed pneumatically and determination of the appropriate mode of flow

This is realised by carrying out bench-scale tests to determine relevant material properties including:

1. Particle Size Distribution
2. Particle density
3. Loose poured bulk density
4. Tapped bulk density and compressibility
5. Fluidisation velocity and pressure
6. De-aeration behaviour

The mode of flow likely to occur in the conveying pipeline is then determined by using a series of predictive diagrams in which selected physical properties are plotted. Two types of diagram exist. The first type involves basic physical parameters such as mean particle size or density. The second type is based on the interactions between the conveying gas and solid particles. Those interactions are characterised using tests such as fluidisation and aeration/de-aeration. Using those charts, each material can be classified into a flow mode.

The most popular diagram is the one established by Geldart [2] in which particulate materials are classified into four different groups from A to D according to the difference between particle and air density and the mean particle size.

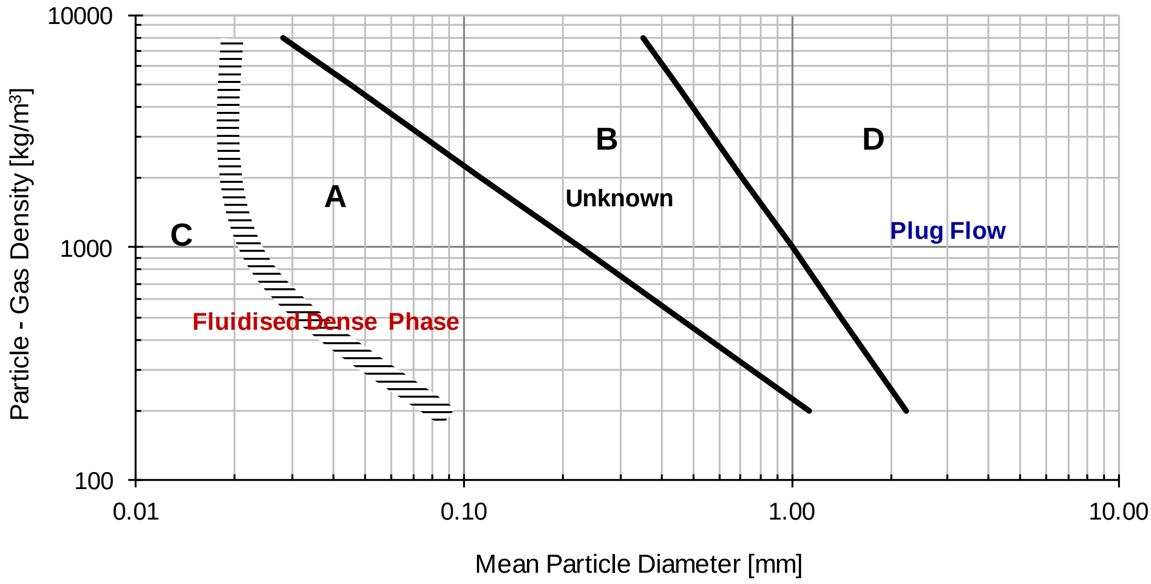

Figure 3: Geldart diagram to predict material ability to fluidise [2].

Step 2: Determination of the key design parameters

The first phase of the conceptual design of a pneumatic conveying consists of determining:

- the optimal pipe diameter

The choice of the pipe diameter has a significant impact on the solids mass flow rate achievable. In some cases, the pipe diameter will determine which mode of flow is occurring.

- the necessity of using stepped pipelines

The decrease of the pressure along the pipeline will lead to an increase of the conveying gas velocity. In turn, the increase of the gas velocity may result in a change of the flow mode, especially in the case of long pipelines. Increasing the pipeline diameter part way along its length will permit an increase of the cross-sectional area and consequent decrease of the gas velocity. It is sometimes necessary to step the pipeline to a larger bore at several positions along its length.

- the required upstream pressure

Calculation models are generally used to predict the pressure loss along the pipeline. Those models can be very complex, in particular in the case of strand flow and slug flow. The prediction of the pressure loss is a key step of the design.

- the optimal conveying gas velocity

Conveying gas velocity and pressure along the pipeline are interrelated. Therefore, calculation models used in the design of a pneumatic conveying system generally use a system of equations with two unknowns, namely the pressure drop and the gas velocity, which are simultaneously solved.

Step 3: Determination of the pipe layout and system components

The choice of the pipe layout and system components will depend on many factors including:

- whether the system is a positive or negative pressure system
- the number of feeding and discharge points
- whether the system should operate in-batch or continuously
- the type of flow in the pipeline
- whether the system is a low, mid- or high pressure system
- the physical properties of the material to be conveyed including abrasiveness and dustiness

References

[1] Mills D., Pneumatic conveying design guide, Elsevier Butterworth-Heinemann, 2nd Edition, 2004

[2] Geldart D., Types of gas fluidization, Powd. Technol. 7, 285-292, 1973