PNEUMATIC CONVEYING SYSTEM: AN OVERVIEW

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ABSTRACT

Pneumatic conveying system has always been economic and efficient means of conveying materials. From the historical background it is evident that there has been a considerable development to that extent where in even high density materials can be easily conveyed. With many advantages over conventional conveying system, it stands in a position where in it can replace heavy duty conveying systems in many applications. Its drawbacks are considerable path for the future scope on this conveying mechanism. This paper reviews about pneumatic conveying from the stage of history to its future study.

Keywords: Conveying System, Pressurized Air, Operational Principle, Piping, Classification

I. INTRODUCTION

Pneumatic conveying is a material transportation process, in which bulk particulate materials are moved over horizontal and vertical distances within a piping system with the help of a compressed air stream. Using either positive or negative pressure of air or other gases, the material to be transported is forced through pipes and finally separated from the carrier gas and deposited at the desired destination. This paper provides the evolution of pneumatic conveying through various stages and its future study. A schematic representation of a pneumatic conveying system is shown in Figure.1

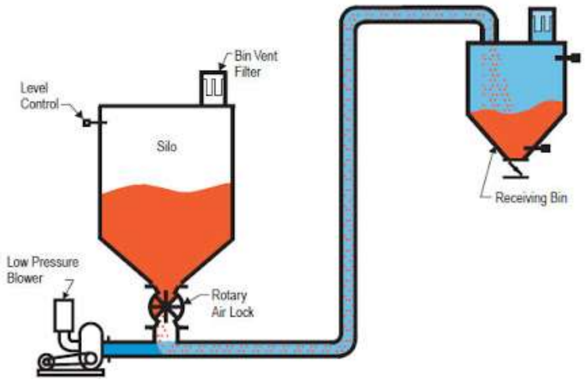


Fig. 1.Schematic Representation of Pneumatic Conveying System

II. HISTORY

The first pneumatic conveying equipment was used to unload grain from ships before the 19th Century. Later, this new continuous conveying method spread to small and middle size systems, as well as to other bulk products.

Pneumatic tubes used for transporting physical objects have a long history. The basic principles of pneumatics were stated by the Greek Hero of Alexandria before 100 BC [2].On the other hand, the concept of conveying materials in pipeline systems also goes back to pre-historical age with some evidence of that the Romans used lead pipes for water supply and sewage disposal and the Chinese used bamboo to convey natural gas [3].

Fig.2. Hollow Wood Blocks for Sewage Disposal

Although there had been various applications of pneumatic conveying earlier in many civilizations, the first documented pipeline conveying of solid particles was recorded in 1847 [4].

In Peugeot plant in France, the pneumatic conveying principle was used for the exhaust of dust from number of grindstones with the help of an exhaust fan. The first published pneumatic conveying system [4].

In 1864, an experimental pneumatic railway was built at Crystal palace with the intention of using the principle of vacuum applied to a railway tunnel to move a carriage, which had been fitted with a sealing diaphragm [5].

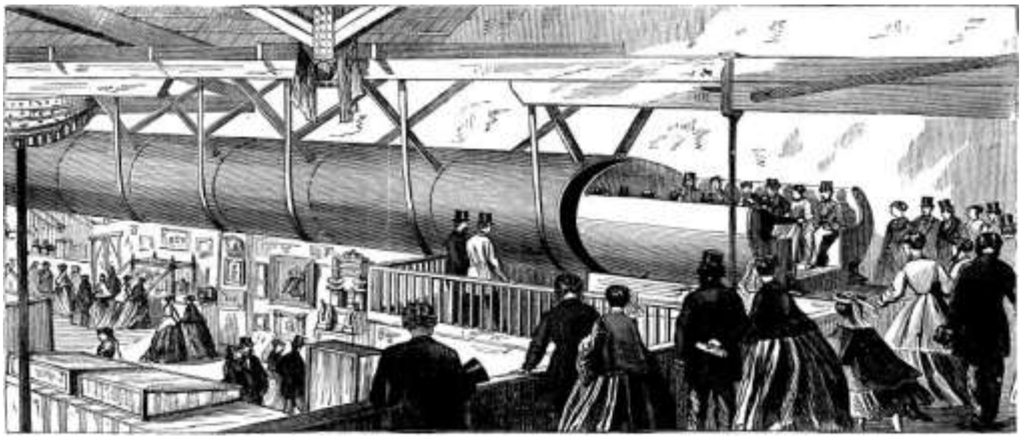


Fig.3.Experimental Vacuum Pneumatic Railway

Another application of vacuum pneumatic transport was reported in ship unloading plant in London in 1890 [5].

A number of applications of operational principles of pneumatic transport could be seen in last decade of the 19^{th} century at some places in Europe [4, 6] and especially, in the grain transport and handling field [5]. During this time period, general break through events in the evolution of pneumatic conveying systems such as use of negative pressure systems, invention of auxiliary equipment like rotary feeders, screw feeders, valves, etc., could be emphasized.During early decades of 20^{th} century, it was common practice to use pneumatic conveying to transport grain [6].

Ref. [7] presented a chronology of pneumatic pipeline highlighting the innovatory individuals and companies, especially during early and middle era of 20th century. During the First World War, the development of pneumatic conveying was influenced by the high demand for foods, labor scarceness and risks of explosion. Since the pneumatic conveying systems were seen as the answer for those situations, a huge evolution of pneumatic transport was achieved during that time period. In the post-war period, pneumatic conveying systems were used for more industrial related materials like coal and cement. Beginning of theoretical approaches, invention of blowers, introduction of batch conveying blow tanks, etc., were among the highlighted milestones of the evolution of pneumatic transport systems during this era.

Nowadays, pneumatic transport is a popular technique in particulate material handling field. It has been reported that some plants have transport distance of more than 40 km [8], material flow rate of few hundred tons per hour and solid loading ratio (the mass flow rate ratio between solid and air) of more than 500

III. BASIC COMPONENTS

There are a number of components in a pneumatic conveying plant, which are required to achieve the particular duty condition. Usually, a typical conveying system comprises different zones where distinct operations are carried out. In each of these zones, some specialized equipment are required for the successful operation of the plant. Any pneumatic conveying system usually consists of five major components;

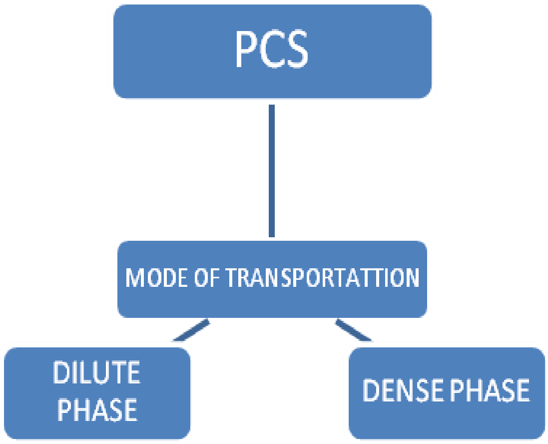
- Conveying gas supply -To provide the necessary energy to the conveying gas, various types of compressors, fans, blowers and vacuum pumps are used as the prime mover.
- Feeding mechanism - To feed the solid to the conveying line, a feeding mechanism such as rotary valve, screw feeder, etc. is used.
- Conveying line -This consists of all straight pipe lines of horizontal and/or vertical sections, bends and other auxiliary components such as valves.
- Separation equipment -At the end of the conveying line, solid has to be separated from the gas stream in which it has been transported. For this purpose, cyclones, bag filters, electrostatic precipitators are usually used in the separation zone.
- Collector -After separating the solid from the gas stream, it is necessary to store the solid in a suitable storage tank. This is called as silo

IV. OPERATION

Doing work requires energy. Energy is required to move material through a pneumatic conveying system. Energy is supplied by pressure differential (in pounds per square inch) and airflow (in cubic feet per minute).

In a pneumatic conveying system, the air pressure in the conveying line is changed by the system's air mover, which generates pressure or vacuum. Where the air mover is located in the system determines whether it generates one or the other: When located at the system's start, the air mover pushes air through the system and the system operates under pressure. When located at the system's end, the air mover pulls air through the system and the system runs under vacuum. By controlling the pressure or vacuum and airflow inside the system, the system can successfully transfer materials[1].

V. CLASSIFICATION



Classification of Pneumatic Conveying System

5.1 Dilute Phase Conveying System

Dilutephasepressureconveyingisparticularlysuitableforsystemswhichconveymaterialsatlowtomoderatecapacitiesovermediumdistances,fromsingleormultiplesourcestosingleormultipledestinations.Thesesystemsareversatileandadaptablefordifferentmaterialsandthelowoperatingpressuresallowlowercostpipelinesandfittings.Cement,flyash,food items,resinsanddrychemicalsareexamplesofproductsthatcanbeconveyedsuccessfullyusingthismethod

By employing large volumes of gas at high velocities, particulate material transportation in suspension mode is usually termed dilute phase conveying. In this mode, the bulk material is carried by an air stream of sufficient velocity to entrain and re-entrain it for a distance, which depends on the available pressure[1].

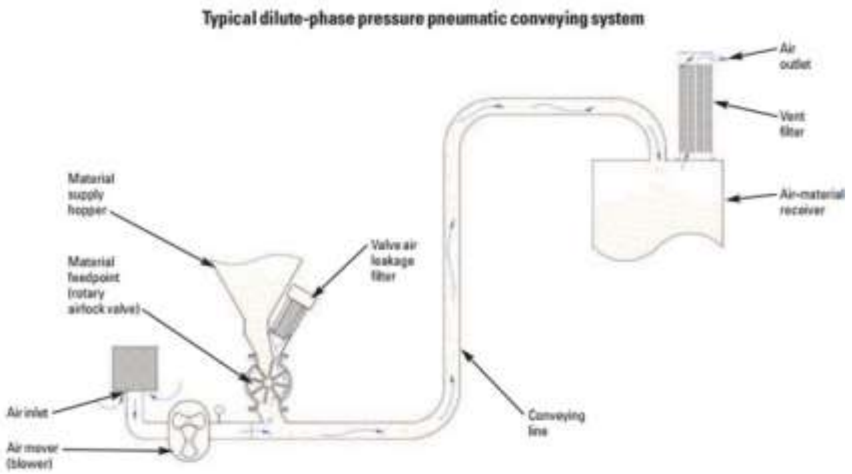


Figure.4. Dilute Phase Pneumatic Conveying System

5.1.1 Typesofdilute–Phasesystems

The dilute-phase system can be designed in three ways [1]:

- Positive pressure system
- Negative pressure or vacuum system
- Combination of positive–negative system

5.2 Dense Phase Conveying System

By reducing the gas velocity, bulk materials can be transported in stratification mode with non-uniform concentration of solids over the pipe cross-section. The material is pushed through a pipeline as a plug, which occupies the whole cross section or as a moving bed for a pressure dependent distance. Even though there are different terms to define the different conveying patterns under reduced gas velocity, such as plug flow, slug flow, strand flow, moving beds, etc, in general, they all come under dense phase conveying.

The definition of the above two modes of transportation is controversial with the different views of different researchers regarding the setting up of boundary in between them. Some researchers use solid mass loading ratio, which is the ratio between the solid mass flow rate and the gas mass flow rate, to demarcate the boundary, while others use conveying air velocity. Even with those concepts, many discrepancies have been reported in literature in case of the definition of transport mode[1].

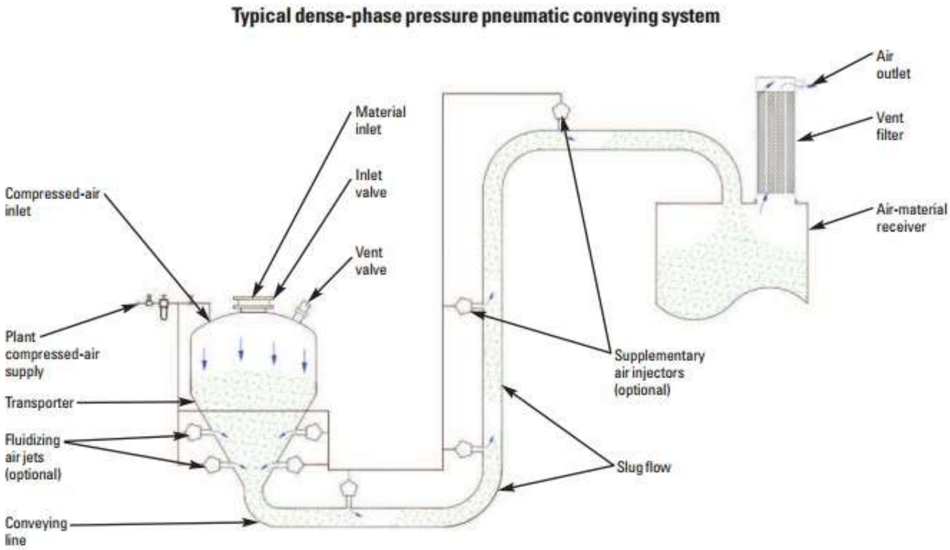


Figure.5. Dense Phase Pneumatic Conveying System

The main principle of dense phase pneumatic transfer system is to slow down the velocity of the product in the pipe to a point that is below the speed at which the product breaks or degrades. At low velocities the product lies for periods of time in the bottom of a horizontal line and it is blown under pressure to discharge points in slugs or plugs.

Thedensephasepneumaticconveyingsystemsuseslowvolume,mediumpressureairstreamandreliesonacontinuouslyexpandingvolumeofairpushingcohesiveslugsofmaterialalongthepipe.Thissystemusesatransfervessel/pumptanktofeedthematerialintotheconveyingline.Itisabatchsystemwithplugsofmaterialseparatedbycushionsofair.Thevelocityrangeatthesourcecanbeaslowas200fpmforthemajorityofproducts.Theproductvelocityatthedestinationisalwaysafunctionofthesystemdifferentialpressure,butinmostcasesitrarelyexceeds2000fpm.

Densephasetechnologyreducestheairconsumptiontotheabsoluteminimumbyallowingthesystemtoconveyatmaximumdensity.Thismaximumdensityconveyingtechniquehasthreemainadvantages.

- First,becausetheconveyingpipelineissodensewiththebulkmaterial,theaircannot“slip”pastthebulkmaterial,whichisacommoninefficiencyindilutepneumaticconveyingsystems.Ifweeliminatetheslip,wecanimproveefficiency.
- Second,whentheconveyingpipeisatmaximumdensity,onlyasmallpercentageoftheparticlesareincontactwiththeconveyingpipeatanygiventime.Themajorityofthe

particlesareintheinteriorofthepipe,thereforenotabradingthepipe.So,thissignificantlydecreasespipewear.

- Third,byincreasingthepipedensity,theconveyingvelocitycanbedecreasedforagiventransferrateandpipediameter.

5.2.1 Types of densephase systems

The following different modes of dense-phase conveying are in use[1].

- Fluidized dense phase
- Lowvelo city slug flow
- Lowvelo city plug flow
- By pass conveying
- Single slug conveying
- Extrusion flow
- Airassisted gravity conveying

VI. APPLICATIONS

The applications of pneumatic conveying systems can be seen in many industrial sectors. A list of industrial fields where it has extensively been used is given below;

- Chemical process industry
- Pharmaceutical industry
- Mining industry
- Agricultural industry
- Mineral industry
- Food processing industry
- Automotive industry
- Aerospace
- Bottling
- Packaging
- Rubber - plastic industry
- Wine and oil making industry
- Ceramic industry

VII. ADVANTAGES AND DISADVANTAGES

In recent years, pneumatic transport systems are being used much more often, acquiring market sectors, in which other types of transport were typically used, especially in the field of bulk solids handling and processing. The reason is a series of advantages it has over the other methods of material conveying such as mechanical conveyers. Because of the flexibility of installation, this mode of bulk solids conveying is specially used to deliver dry, granular or powdered materials via pipelines to remote plant areas that would be hard to reach economically with mechanical conveyers. Since pneumatic systems are completely enclosed, product contamination, material loss and dust emission (thus, environment pollution) are reduced or eliminated. Particularly, to convey materials hazardous to health, a negative pressure (vacuum) pneumatic system is the best option. On the other hand, pneumatic conveying systems can be adopted to pick up the conveying bulk material from multiple sources and/or distribute them to many different destinations. In addition, reduced dimensions, progressive reduction of capital and installation costs, low maintenance costs (due to the small number of moving parts), repeated usage of conveying pipelines, easiness in control and automation are among the favorable advantages of pneumatic conveying over the other traditional methods of particulate material handling.

Although pneumatic conveying has seen increased use in many industrial sectors, there are still many major problems hampering its employment in a wider range of industrial conveying applications. Specially, in dilute-phase transport, high energy consumption, excessive product degradation and system erosion (pipelines, bend etc) are some of the major problems. In an alternative method, in dense-phase conveying also, unstable plugging phenomena, severe pipe vibration and repeated blockages are experienced frequently. Further, the lack of simple procedures for the selection of an optimal system is a major problem in pneumatic transport system design[1].

VIII. COMPARISON WITH CONVENTIONAL SYSTEM

8.1Advantages

Let's start by looking at mechanical conveying systems. A conventional mechanical conveying system runs in a straight line, with minimal directional changes, and each directional change typically requires its own motor and drive. The mechanical conveying system may be open rather than enclosed, potentially generating dust. It also has a relatively large number of moving parts, which usually require frequent maintenance. The system also tends to take up a lot of valuable real estate in a plant.

On the other hand, a pneumatic conveying system uses a simple, small-diameter pipeline to transfer material. The pipeline can be arranged with bends to fit around existing equipment, giving the system more layout flexibility, and the system also has a relatively small footprint. The system is totally enclosed and typically has few moving parts[1].

8.2 Disadvantages

A pneumatic conveying system typically requires far more horsepower to operate than an equivalently sized mechanical conveying system. The reason is that changing the air pressure to achieve pneumatic conveying consumes a large amount of power and is inherently less efficient than a mechanical conveying system's mechanical transfer. In fact, in applications with the same transfer rate over the same conveying distance, a pneumatic conveying system can require 10 times the horsepower of a mechanical conveying system.

A pneumatic conveying system also requires a larger dust collection system than a mechanical conveying system. This is because the pneumatic system has to separate the conveyed material from the conveying air at the system's end.

Some materials have characteristics that make them difficult to convey in a pneumatic system. Examples are a material with a large particle size and high bulk density, such as gravel or rocks, and an extremely sticky material, such as titanium dioxide, which tends to build a coating on any material-contact surface. In a pneumatic conveying system, such buildup often leads to total pipeline blockage. These difficult materials can be easier to transfer in a mechanical conveying system that's been carefully chosen to handle them[1].

IX. TYPES OF CONVEYING OPERATION

Various flow regimes exist inside the pipeline in a pneumatic conveying system, straddling the entire range of conveying conditions from extrusion flow (packed bed) to fully dilute suspension flow. Through numerous experimental studies together with visual observations using glass tubes, etc. scientists have concluded these varieties of flow regimes. It has been seen that these different flow regimes could be explained easily in terms of variations of gas velocity, solids mass flow rate and

system pressure drop. This clarification also explains the general operation of a pneumatic conveying system. Most of the research workers and industrial system designers have used a special graphical technique to explain the basic operation of a pneumatic conveying system. This technique utilizes the interaction of gas-solid experienced inside the conveying pipeline in terms of gas velocity, solids mass flow rate and pressure gradient in pipe sections in a way of graphical presentation, which was initially introduced by Zenz. Some researchers named this diagram as pneumatic conveying characteristics curves, while others used the name of state or phase diagram. The superficial air velocity and pressure gradient of the concerned pipe section are usually selected as the x and y axes of the diagram and number of different curves are produced on these set of axes in terms of different mass flow rates of solids.

There is a distinguishable difference between the relevant flow regimes for horizontal and vertical pipe sections. On the other hand, the particle size and particle size distribution also have influence on the flow patterns inside the pipelines. The general operation of horizontal and vertical pneumatic conveying systems are briefly explained below[1].

9.1Horizontal Conveying

One typical horizontal phase diagram is shown in Figure 7, together with various cross-sectional diagrams showing the state of possible flow patterns at different flow situations.

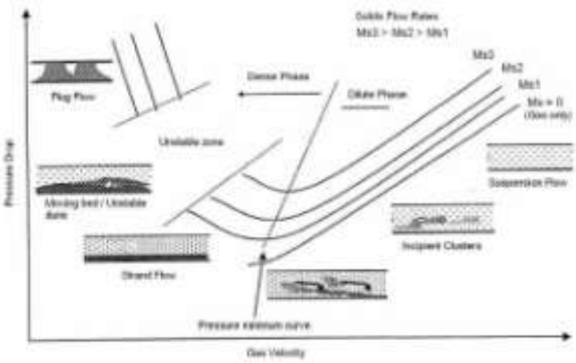


Figure.7. Phase Diagram for Horizontal Conveying

The curves show the variations of constant solids mass flow rate contours, when the conveying gas velocity and system pressure drop varies independently. The gas only line shows the pressure drop vs. gas velocity curve, which is characteristically a single phase flow. When the solids particles are

introduced to the system with a particular solids mass flow value, the pressure drop increases to a higher value than in case of gas only transport even though the gas velocity is maintained constant. By keeping the solids flow rate constant and reducing the gas velocity further, pressure drop decreases down to a certain point where the minimum pressure drop is experienced[1].

The pressure minimum curve connects such points for different solids flow rate values. Generally, the flow regimes up to this point from the right hand could be categorized as the dilute phase flow with low values of mass loading ratios. Further reduction of gas velocity leads to particle deposition in pipe bottom and then the flow mode is called dense phase conveying. Pressure drop can be seen increasing, when gas velocity is decreasing. After an unstable flow region, the conveying pattern shows a plug flow characteristic, which will cause the pipeline to be totally blocked in attempts of further reduction of gas velocity[1].

9.2Vertical Conveying

The orientation of the pipe makes a considerable effect to the flow patterns and conveying regimes, because of the influence of gravity force. Consequently, the cross-sectional diagrams are totally different for the vertical pipe sections from those of horizontal sections, although the general appearance of the mass flow rate contours are similar to each other. Figure.6 shows a typical phase diagram of a vertical pipe section, together with various cross-sectional diagrams showing the representative state of possible flow patterns.

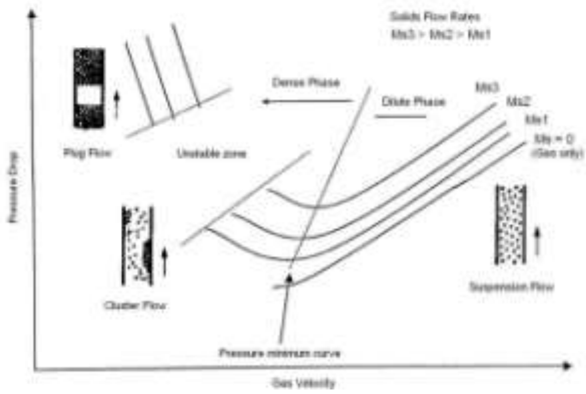


Figure.8.Phase Diagram for Vertical Conveying

- **Some common problems**

Attrition: Attrition is one of the key issues and can lead to Poor product performance, Environmental, health and safety issues, Changes in flow properties of material:

- Increasing conveying system throughput
- Line failure in dense phase system
- Plugging due to poor layout
- Pressure drop: This is due to Solids friction, Bends in pipeline, Lift, Particle acceleration, Air, Dilute phase
- Saltation: When the gas velocity is slowly decreased during dilute phase conveying, material will begin to deposit or “salt out” at the bottom of the horizontal sections of the conveying system.Saltation is loading dependent – typically the higher the loading, the higher the saltation velocity. No single correlation predicts saltation across all gas and particle parameters[1]

X. CONCLUSION

With proper care and thought, pneumatic conveying systems can be designed and operated to give excellent performance with minimal product degradation. There is considerable science behind how these systems work.A properly designed air flow system to transport bulk material from one point to another is often the most practical and economical means. Pneumatic conveying systems usually require less plant space, can be easily automated, and can be readily installed. Pneumatic conveying systems do have their limitations, such as material size and temperature. However, they still provide many benefits. In addition to being very economical, they are also useful in controlling or minimizing product loss, improving dust control, and thus improving overall plant conditions.

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