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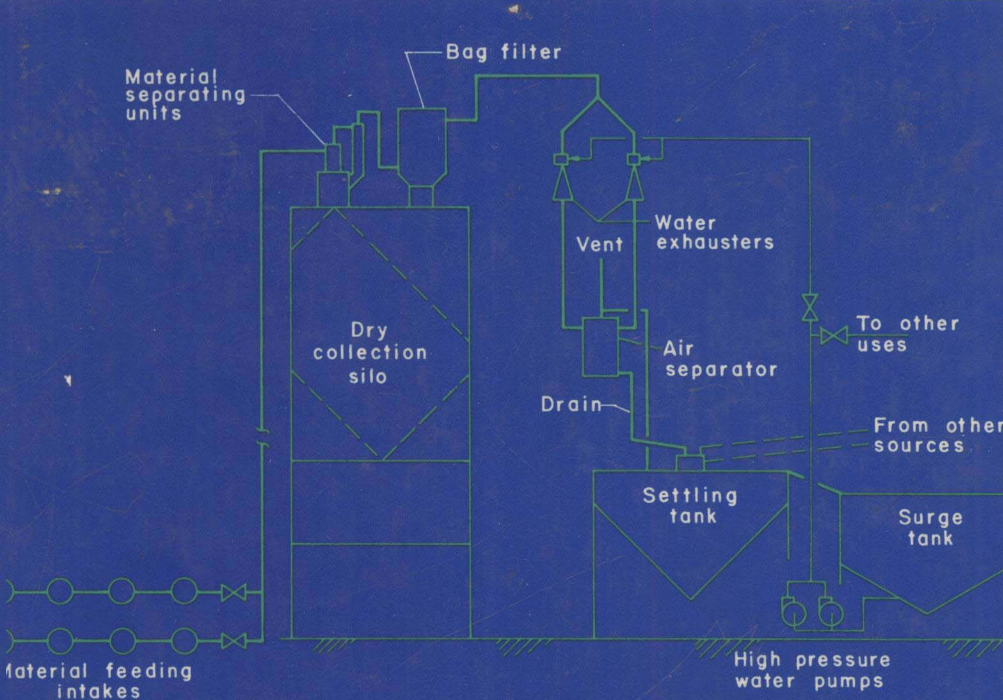
PNEUMATIC AND HYDRAULIC CONVEYING OF SOLIDS



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Pneumatic and Hydraulic Conveying of Solids

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Preface

Pneumatic and hydraulic conveying of solids actually are two complete and independent subjects. In many conveying applications, however, they are closely associated. For example, in a pneumatic vacuum conveyor powered by a water exhauster, the material is conveyed dry to the exhauster, where it is mixed with water and discharged as a slurry. This book is a compilation of materials, equipment, design, and knowledge reflecting years of experience in both fields. It is designed to aid the engineer or consultant by providing conceptual approaches to total conveying systems. It is also geared to plant management, operations, and service departments for upkeep and improvement of existing systems.

Many small conveying companies, and an increasing number of larger companies in allied fields, are now entering or contemplating entering the pneumatic conveying field. A good number of these will also be entering the hydraulic field at the same time just to stay competitive. The rapid expansion of the power industry and of governmental requirements for updating existing power installations is requiring and will continue to require many new conveyors and conveying companies. Although many of the component parts that make up a conveyor are standardized with each supplier, the conceptual design and finished product is different for every application.

Thus, each new conveying system is an entity in itself and must be engineered as such.

It is not the intention of this book to make polished system designers out of all its readers. It is intended to present the various types of systems and the component parts that make up an individual system. The basic understanding of how and why a system or the various subsystems operate is considered essential.

I have spent over thirty years in engineering, design, and research and as a consultant in the pneumatic and hydraulic fields, working mostly with abrasive materials and ash handling systems. The principles of conveying are the same for all types of materials, abrasive or nonabrasive. The materials used in the manufacture and fabrication of pipelines and component parts vary as required with the degree of abrasiveness.

The book is largely written around modern ash handling systems and practices. It is equally adaptable to any pneumatic or hydraulic conveying system regardless of whether the conveyed material is abrasive or nonabrasive. The basic system concept, selection of equipment, type of system, conveying rates, and velocity are fundamentals that I have attempted to put into perspective.

Both English and metric units are given when applicable. Although the metric system is the standard throughout most of the world, there are regional variations in common usage. In principle, most countries have adopted or are committed to SI units (the International System of Units). Even with this, local usage in various countries and regions differs from the SI. An attempt has been made in this book to adhere strictly to SI designations. For the measurement of air pressure, the bar has been used for all pressures below atmospheric and kPa for all pressures above atmospheric. For static liquid pressure the meter has been used with MPa for higher dynamic pressures.

The first seven chapters are devoted to pneumatic conveying systems. The various types of systems and system components are outlined and discussed. System design calculations and examples are presented to help design engineers more fully understand system operation and power requirements. Such topics as air gravity conveyors, fluidizing, and silo unloaders are covered. Sluice systems and sluice system designs are treated in an additional nine chapters. Sumps and sump pumps along with jet pumps, material handling pumps, dewatering bins, and system calculations are covered in such a manner that designers and maintainance people can understand them. Chapter 17 is devoted to dry landfills, sluice ponds, and material haul trucks, and this material is structured in such a way as to allow future land area and trucking requirements to be estimated.

In writing this book I have attempted not only to encompass the broad range of pneumatic and hydraulic conveyors but to present material that I have personally been involved with. Much of the data and information given I have, over the years, used, designed, developed, and serviced, and have spent my entire working life enjoying.

O. A. Williams

Pneumatic and Hydraulic Conveying of Solids

Contents

1

Introduction to Pneumatic Conveying

Pneumatic conveying can be defined as the movement of dry material through an enclosed pipeline by the motion of air. This occurs in either a negative pressure (vacuum) system or a positive pressure system. Material -- ash, coal, stone, lime, grain, or any of numerous other substances -- is transported through the pipeline by the motion of air. Pneumatic conveyors have been divided into two broad, well-defined classes. The vacuum or negative pressure conveyor operates at pressures below atmospheric, whereas the positive pressure conveyor operates at pressures above atmospheric. Both are further divided into subcategories of dilute and dense phase. (See Table 1.1 and Fig. 1.1.) Although many attempts have been made to develop a single definition that covers the entire range of dilute and dense phase systems, it is doubtful that one definition is possible. Surely there is a transition velocity range between the two and it is different for each material. To complicate the process further, both types of flow can and do take place within one pipeline, depending largely on the feeding method. The transition velocity between the dense and dilute phase may not always be a smooth flow zone. Some materials will drop out of suspension at saltation velocity and cause slug flow through a portion of the conveying line.

TABLE 1.1 System Definitions

Category	Type of System
Dilute phase	The material is carried by an airstream of sufficient velocity to entrain and reentrain it for a distance dependent on the available pressure.
Dense phase	The material is pushed through a pipeline as a slug or as a fluidized slug for a distance dependent on the available pressure. Additional air may be added along the length of the pipeline to refluidize the material.
Air assist gravity flow	Air is passed through a porous membrane of low permeability, filling the voids of the material directly above it at a low pressure, changing the angle of repose of material on material and causing it to flow by gravity.

The dense phase system operates at vacuum or pressure to about 125 psi (862 $kPa_{(g)}$). The starting velocity may be 50 to 2000 ft/min (0.254 to 10 m/s). This merely indicates that the initial velocity is low and the flow is definitely in the dense phase range. Depending on the method of feeding material into the pipeline and the operating pressure, a dilute phase system may be present in the latter part of the same conveying line. The criterion of system loading in pounds (kilograms) of material per pound (kilograms) of air is often used as a dividing point between a dilute and a dense phase system. This gives the designer an indication of load conditions, but in no way clearly defines the systems. A well-defined dilute phase system is one capable of picking material off the bottom of the pipeline and reentraining it throughout the length of the pipeline. The required velocity to convey a material depends on many factors, such as particle size, shape, weight, specific gravity, and inclination of the conveying line. There are many published tables showing these values; however, most of them do not agree since there is no one correct value for any material. Most of the values were obtained experimentally or from experience and were set by the judgment of the observer. It is also true that for any given material the required minimum velocity can change because of the

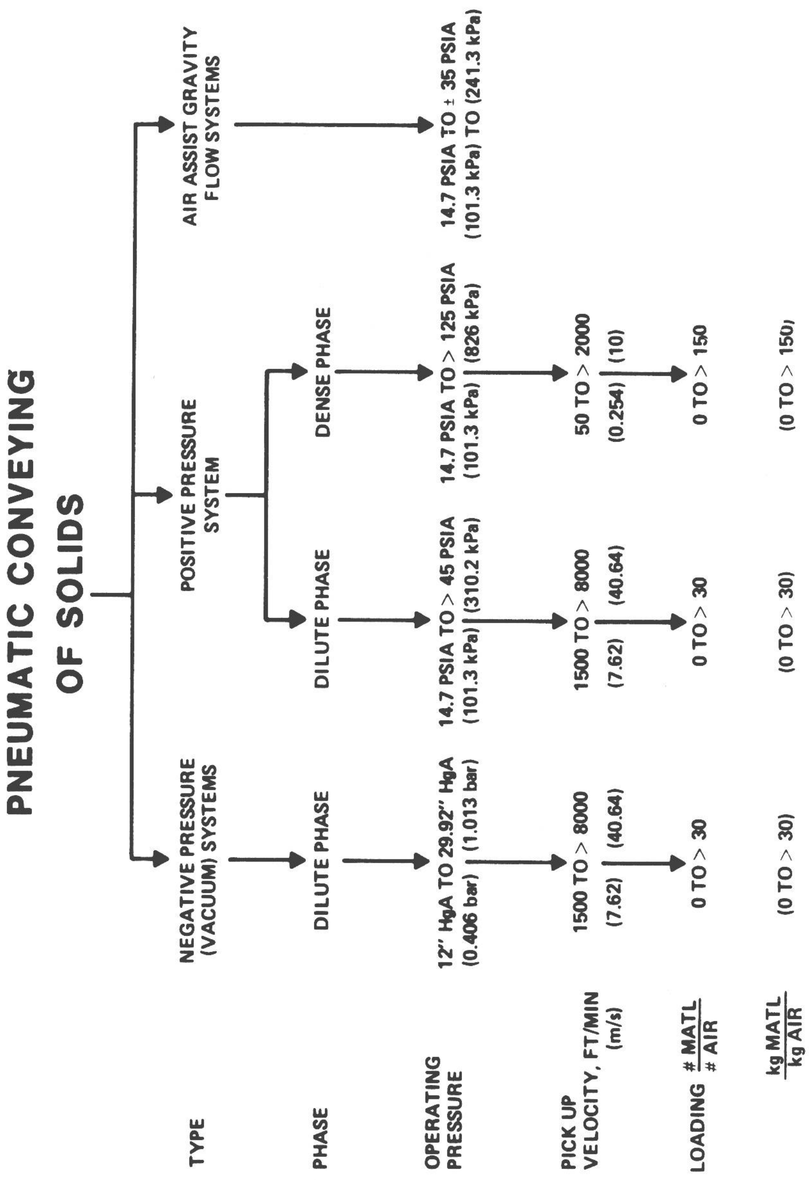

FIG. 1.1 Flow chart for pneumatic conveying of solids.

type of feeding control and system control used. For example, in a negative pressure system, if the material feed into the system is carefully controlled, the velocity can be lower than if it were introduced in slugs. Thus the designer must know the types of equipment and controls that are to be used and the compatible velocity values. Here again, these values are not hard to obtain and anyone designing this type of equipment should take the time to obtain them experimentally. See Table 1.2 for some values that are in common use.

The values listed in Table 1.2 are for atmospheric pressure. Therefore, they are good for all negative pressure systems. They can also be used for positive pressure systems, but due to the increased density of air under pressure, the minimum conveying velocities decrease as the pressure rises. This decrease varies with the various materials but can be closely approximated by

$$V_1 = V_A\{14.7/[14.7 + (P_1 - P_A)]\}^{0.225} \tag{1}$$
$$(V_1 = V_A\{101.325/[101.325 + (P_1 - P_A)]\}^{0.225})$$

where

V_1 = velocity at point 1, ft/min (m/s)

V_A = velocity at atmospheric pressure, ft/min (m/s)

TABLE 1.2 Material Pickup Velocity in Pneumatic Conveying

Type of material	Velocity range ft/min	Velocity range m/s
Bottom ash		
PC boiler	3880-5100	19.7 -25.9
Chain grate stoker	4260-5600	21.6 -28.4
Underfeed stoker	4720-6200	24.0 -31.5
Fly ash	3000-4600	15.24-23.4
Pyrites	5325-7000	27.0 -35.6
Cement dust	3500-4600	17.8 -23.4
Hydrated lime	3800-5000	19.3 -25.4
Pebble lime	3800-5000	19.3 -25.4

P_1 = pressure at point 1, psi (kPa)
P_A = atmospheric pressure, psi (kPa)

It is suggested that designers design to the high side of the values listed when test data are unavailable. One method is to set the design velocity at least two to two and a half times that of the minimum velocity required just to move the material along the bottom of the pipeline (slug flow). Another method is to set the velocity higher than that required to reentrain material from the bottom of a horizontal pipe run.

Note that the velocities listed do not cover the full range of velocities as published by the various manufacturers. They do encompass what are considered realistic values. Many lower-velocity values are commonly used and were not listed because many of these systems are actually combination dense dilute phase. These systems require different design criteria.

Until now only horizontal pipeline velocities have been discussed. In a horizontal line, the velocities must overcome the forces of drag, gravity, and those associated with reentrainment of the material. A particle is not conveyed linearly in a straight line, but due to gravity it continuously drops to the bottom of the pipe, slides along on the bottom of the pipe, and is continuously bounced back into the airstream. This is true regardless of particle size. It requires less velocity to convey material vertically upward in a vertical pipeline than it does in a horizontal line. This is because the only forces the velocity has to counteract are drag and gravity. More power is associated with moving material vertically, but not more velocity. The greatest velocity required to convey material is associated with inclined pipes. Here the velocity must overcome all the forces associated with horizontal pipelines plus the tendency of the material to slip back down the incline. For all practical purposes, a slope of less than 15 or more than 80 deg from horizontal need not be considered an incline. The incline may also be ignored if less than 10 ft (3 m) long.