DESIGN GUIDELINE FOR MATERIAL HANDLING SYSTEMS

Part 2

Florida Board of Professional Engineers
Approved Course No. 0010329

4 PDH Hour

A test is provided to assess your comprehension of the course material – 24 questions have been chosen from each of the above sections. You will need to answer at least 19 out of 24 questions correctly (>70%) in order to pass the overall course. You can review the course material and re-take the test if needed.

You are required to review each section of the course in its entirety. Because this course information is part of your Professional Licensure requirements it is important that your knowledge of the course contents and your ability to pass the test is based on your individual efforts.

Course Description:

This course is a basic design guideline that can be used in the development of a basic engineering design package. This document provides guidelines to aid in the selection of equipment for systems used in unloading, loading, transfer, packaging and collection of bulk materials including: granular materials, powders, pellets, ores, flakes etc. This guide also provides information that can be used in the selection of material handling equipment and the preparation of equipment data sheets.

This is Part 2 (4 PDH) of a two course series and covers:

1. Bulk Loading Systems
2. Packaging Systems
3. Product Sampling
4. Feeders (Weigh Belt Feeders, Screw Feeders, Rotary Feeders)
5. Storage Bins and Silos
6. Dust Collection Systems

In Part 1 (4 PDH) of the series the following systems are covered:

1. Pneumatic Conveying Systems
2. Mechanical Conveyors
3. Bucket Elevators

How to reach Us …

If you have any questions regarding this course or any of the content contained herein you are encouraged to contact us at Easy-PDH.com. Our normal business hours are Monday through Friday, 10:00 AM to 4:00 PM; any inquiries will be answered within 2 days or less. Contact us by:

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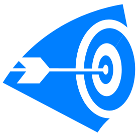
Refer to Course No. 0010329, DESIGN GUIDELINE FOR MATERIAL HANDLING SYSTEMS (Part 2)

Here's How the Course Works…

What do you want To do?	**LOOK For This!**
 **Search for Test Questions and the relevant review section**	 **Q1** **Search the PDF for: Q1 for Question 1, Q2 for Question 2, Q3 for Question 3, Etc…** **(Look for the icon on the left to keep you ON Target!)**

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24 TEST QUESTIONS

Q1. [See 3.0 PRINCIPLES OF OPERATION] A well designed system material handling system will:

A. maximize operating availability
B. provide consistent performance
C. meet government and environmental standards
D. All of the Above

Q2. [See 4.1 Bucket Elevators] Bucket elevators are an industry standard for moving bulk material to higher elevations. All of the following are categories of Bucket Elevators EXCEPT:

A. Centrifugal Style
B. Continuous Style
C. Inverted Bucket Style
D. Positive Discharge Style

Q3. [See 4.1.3 Elevator Details] The typical maximum speed for a bucket elevator that uses a chain instead of a belt for rotating the buckets is:

A. 50 meters per minute
B. 70 meters per minute
C. 90 meters per minute
D. 110 meters per minute

Q4. [See 4.2 Bulk Unloading Systems] Larger Bulk bags that are used to store bulk materials are often called:
A. Super Sacks
B. Bagsters
C. Super Stacks
D. Super Bags

Q5. [See 4.2.3 Components of a Bulk Bag Unloading Station] You have purchased a bulk bag unloading Station. What is the best option for unloading the bags:
A. Use a forklift frame on top
B. Use an Air hoist and lifting bail on top
C. Use an electric hoist and lifting bail on top
D. All of the Above

Q6. [See 4.3.2 Bag Filling Station] What are some of the DISADVANTAGES to purchasing a Manual Bag Filling Station:
A. Less Expensive
B. Less Accuracy in the Filling process
C. Wear and Tear on the operators
D. B and C

Q7. [See 4.3.3 Bulk Bag (Super Sack) Loading Station] Bulk bag loading stations are used to weigh and fill bulk bags. All of the following are the main components of a manual station EXCEPT:

A. self-contained dust filters
B. structural steel frame with pneumatic or hydraulic system for lowering or raising bags
C. bag filling system
D. platform scale

Q8. [See 4.4 Packaging Systems] What system is used to stacks bags, cartons or other containers in an orderly geometric pattern:

A. transfer equipment
B. wrapping machine
C. palletizer
D. bag conditioning equipment

Q9. [See 4.5 Product Sampling] In an effort to maintain quality control in manufacturing using bulk materials, the benefits of automatic sampling include:

A. uniformity and consistency of sampling
B. elimination of human error
C. reduction of loss
D. All of the Above

Q10. [See 4.6 Feeders] All of the following are benefits derived from continuous processing EXCEPT:

A. Higher Production Rates
B. Higher Operating Costs
C. More Uniform quality
D. Lower Unit Investment

Q11. [See 4.6.1 c. Weighing System and Controls] Some weigh belt feeder applications have a short conveying distance between the weighing and discharge points which can affect accuracy. What can be done to help in this case:

A. add a transportation lag feature in the control system
B. make the conveying distance even shorter
C. add automatic belt tracking
D. add static belt take-up tensioning devices

Q12. [See 4.6.2 Screw Feeders] What type of screw feeder is usually used for handling fine free flowing materials:

A. half pitch regular screw feeder
B full pitch regular screw feeder
C. half pitched tapered screw feeder
D. full pitch tapered screw feeder

Q13. [See 4.6.3 Rotary Feeders] In a rotary feeder, what controls the volumetric capacity of materials flow:

A. Cross sectional area of the inlet
B the volume of the rotor pockets
C. speed of the rotor pockets
D. B and C

Q14. [See 4.6.3 e. Rotary Feeders Design Considerations] Rotary valves should be oversized when installed to act as an air-lock in systems that have an uneven feed flow. This is done to avoid:

A. surging
B. aeration
C. degradation
D. stressing

Q15. [See 4.7 Storage Silos] Which type of Silo is rarely used in industrial applications:

A. Hopper Bottom Bins
B. Concrete Stave Silos
C. Stainless Steel Metal Bins
D. Rectangular Bins

Q16. [See 4.7.2 Design for Flow] If your storage silo is designed properly you should expect the idea bulk material to flow:

A. uniformly in a symmetrical flow pattern
B. in a concentric vertical flow pattern
C. with the oldest material first discharging first (first-in, first-out)
D. All of the Above

Q17. [See 4.7.4 Appurtenances] Adequate air vents allow incoming air to replace the discharged volume of the material leaving the bin. What is the risk of having inadequate air vents:

A. creation of a partial vacuum in the bin
B. creation of a positive pressure in the bin
C. potential catastrophic collapse of the bin
D. A and C

Q18. [See 4.8 Dust Collection Systems] Primary functions of a Bag Houses include all of the following except:

A. remove dry dust from a gas or air
B. classify dry dust material by size
C. prevent emission of nuisance dust
D. collect and return valuable dust material to the process

Q19. [See 4.8.1 c. Selection of Fabric Materials for Dust Collectors] You need to select a Fabric Material for a dry heat application that continuously operates at 250 F. Which is the best material:
A. Cotton
B. Polyamid
C. Polypropylene
D. Polyester

Q20. [See 4.8.1 e. Continuous Duty, Pulse-Jet Type Bag Filters] A method to deliver clear and consistent communication amongst team members may include all of the following EXCEPT:
A. one on one discussion
B. regular newsletters
C. status reports
D. group meetings

Q21. [See 4.8.2 Bin Vents] Bin Vents come in two basic arrangements, what is the DIFFERENCE between Arrangement 1 and Arrangement 2:
A. Arrangement 1 has a tube sheet
B. Arrangement 2 has a dusty air plenum surrounding the filter bags
C. Arrangement 1 has flanges for mounting directly to the bin or silo
D. Arrangement 2 has a bag cleaning system

Q22. [See 4.8.3 Cyclones] Cyclones are centrifugal collectors that depend on what to move the dust particles toward the wall of the collection chamber:
A. centrifugal force
B. gravitational force
C. orientation of the bin outlet
D. flow rate of the incoming air or gas stream

Q23. [See 4.8.4 c. 4. Components of an Electrostatic Precipitator] Which type of electrode used in a Electrostatic Precipitator is suspended from the top:
A. Rigid frame discharge electrodes
B. Rigid electrodes
C. Collection electrodes
D. Rapper electrodes

Q24. [See 4.8.4 c. 5. Control Systems] What rating of silicon rectifiers is typical for lower rated current sets:
A. 500 Amps
B. 50 Amps
C. 500 milliamps
D. 50 milliamps

END OF TEST QUESTIONS

MATERIAL HANDLING
TABLE OF CONTENTS

1.0 SCOPE

This design guideline is presented to assist in the development of a basic engineering design package. This document provides guidelines to aid in the selection of equipment for systems used in unloading, loading, transfer, packaging and collection of bulk materials including: granular materials, powders, pellets, ores, flakes etc.

This guide also provides information that can be used in the selection of material handling equipment and the preparation of equipment data sheets.

2.0 INTRODUCTION

Bulk material handling requires that individual conveying units be arranged to operate within a system or be used to tie a process together. In a material handling system bulk feeders, conveyors, elevators, pneumatic conveying systems etc. efficiently and safely interact with bins, hoppers, silos, screens, dryers, blenders, packaging machines and other types of process equipment as well as with the structures that support them. Chutes, spouts, skirt boards and gates are necessary to transfer bulk material from one unit to another. Dust collection equipment is installed to prevent particulate matter from entering the environment or is required to minimize the chance for fires or explosions that can be caused by a sufficient accumulation of dust.

This guide cannot begin to address every type of feeder, conveyor, dust collector, processor, packaging equipment available in the market place, but a thorough understanding of the information presented in this guide should prepare the engineer to understand other equipment or equipment variations available. This is a mechanical equipment guide and discusses the more common and most frequently applied equipment. Material handling systems are not covered in detail because it is the process that dictates the system.

The preliminary selection of equipment for a material handling system requires:

- A detailed description of the requirements of the system.
- Complete physical and chemical properties of the material(s) to be handled.
- A material flow diagram.
- A preliminary layout drawing.
- Coordination between process, project, mechanical and control specialists.
- Early consultations with potential equipment suppliers.

After the preliminary selections are made, equipment data sheets can be prepared, quotes can be obtained and final equipment items can be selected.

Q1

3.0 PRINCIPLES OF OPERATION

Basic principals of operation require that a material handling system and the individual equipment within that system are efficient and safe. A well designed system will maximize operating availability, provide consistent performance, optimize staff and operating control, meet governmental and environmental standards, allow effective maintenance without unscheduled interruption and ensure a safe working environment.

Operation of specific equipment is provided in the individual equipment sections that follow.

4.0 MATERIAL HANDLING TYPES/MAJOR COMPONENTS

4.1 Bucket Elevators

Q2

4.1.1 Introduction

Bucket elevators have long been, along with pneumatic conveying systems, the industry standard for any bulk material elevating application.

A bucket elevator can transfer bulk materials as high as several hundred feet. The equipment consists of a series of uniformly fed buckets attached to an endless spliced loop of belt or chain inside a fabricated housing.

Bucket elevators can handle light to heavy materials that range from dry dusty powders to wet sticky material.

The three main categories of bucket elevators are the centrifugal style, the continuous style and the positive discharge style.

a. Centrifugal Bucket Elevators

The Centrifugal Discharge design has spaced buckets that travel at a relatively high speed. It is a medium capacity unit, capable of handling materials with small-to-medium size lumps. The buckets dig the material from the casing boot section and discharge it by centrifugal force.

Foot Shaft Take-up – Elevators of this type meet the service requirements of the majority of installations using centrifugal discharge elevators. The head shafts are fixed, with the foot shaft take-up being internal gravity type or external screw type take-up. Buckets are designed for use on either chain or belt.

For most applications, chain is recommended, however, belting is used when handling materials that must not be contaminated or for materials that are extremely abrasive and corrosive.

As an alternate to the standard foot shaft take-up design, an alternate design is available. The head shaft is adjustable and the boot shaft is fixed to maintain the relationship of buckets to the inlet spout and curved bottom plate. This type is recommended when handling food products; for materials that tend to pack or build-up, or when handling materials having a large percentage of lumps.

b. Continuous Discharge Elevator

The Continuous Discharge Design has overlapping buckets mounted continuously that travel at a much slower speed. The continuous discharge design elevator handles a variety of materials from fines to large lumps. Materials that are difficult to pick up in the casing boot section or friable are normally handled in this type elevator. The buckets are fed directly from a loading leg or chute and are emptied by gravity at the discharge point. Standard operating speed is 40 m/min. When handling light or fluffy-type material, operating speeds of 50 to 55 m/min are common. When bulk material is abrasive, operating speeds are normally reduced for longer component life.

A gravity take-up is most frequently used with the continuous discharge design. The head shafts are fixed, with foot shaft take-ups being internal gravity type. Buckets are steel and spaced continuously on a strand of chain.

As an alternate to the standard continuous discharge design, an alternate design is available. The head shaft is adjustable and the foot shaft is fixed. This type of elevator is used for the handling of fine or crushed materials with lumps not exceeding 10 to 12 mm. With the addition of a loading leg and a correspondingly higher inlet spout, this type elevator can also be used for handling lumps up to 115 mm.

c. Positive Discharge Elevator

The positive discharge bucket elevator is a specialty unit built to move materials at very low speed (typically about 40 m/min.) in an L, C, T, or Z configuration to fit the plant layout. The elevator gently handles materials that must be conveyed without breakage or spillage, such as cereal flakes, nuts, and dried fruits. The elevator has pivoting buckets that are side-mounted between two chains; thus the unit can't use a belt. A positive discharge bucket moves material through all planes and remains level until it reaches the discharge point, providing the gentlest handling of any bucket elevator.

4.1.2 Components of a Bucket Elevator

A bucket elevator can be divided into four major assembles. They are listed below and indicated on Figure 38.

a. Boot Section (13)

The boot section is the fabricated steel assembly at the base of the elevator. It includes a flanged inlet opening (19), a take-up device (18), cleanout and access panels (14), access doors (15), the lower shaft assembly (17), take-up removal beam (20) for servicing internal gravity take-up, flanged bottom (16) for complete bearing on the foundation.

b. Intermediate Casing Section(s) (9)

The intermediate casing section(s) which house the chain and buckets and provide support for the head section. Hinged inspection doors (12) can be provided in intermediate casing sections.

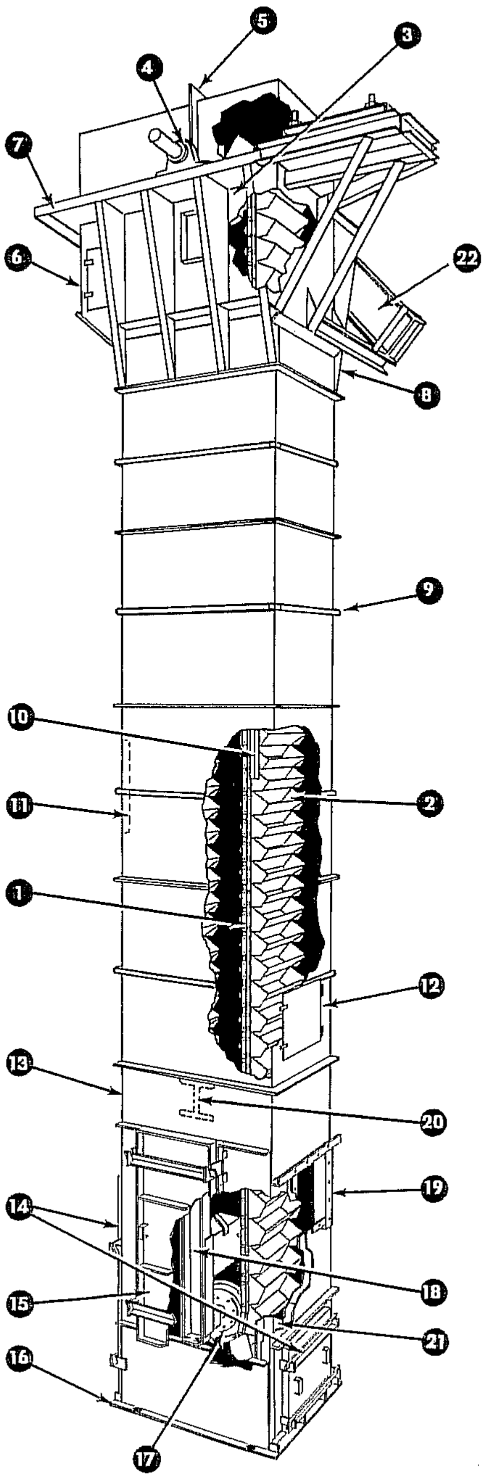
c. Head Section (5 & 8)

The head section is the fabricated assembly at the top of the elevator. It includes a flanged discharge spout (6), a split upper hood (5), the conveyor drive assembly (Not Shown), the head shaft assembly (4), holdback assembly (22), head shaft bearing supports (7).

d. Buckets (2) Mounted on Continuous Chains (1) or Belts

Change guides (10) are required for elevators with greater than 60 foot centers and optional for shorter elevators.

Figure 38



4.1.3 Elevator Details

Q3

a. <u>Buckets</u>

Bucket size, materials of construction, and configuration are determined from materials handled, capacity required, conveyor type, and manufacturer's availability. Manufacturers' data should be consulted for the full range of possibilities.

b. Chain vs Belt

Chain equipped conveyors have a wide range of application, but good practice dictates that chain speeds be kept within reasonable inertia limits, usually a maximum of 90 meters per minute. Chain is used for "Z" type conveyors or those carrying heavy loads of materials which would tend to pack between buckets and the belt, or between the belt and pulley. Chain conveyors usually are used where ambient temperatures would exceed 100°C.

Belt conveyors are used where the materials to be handled are extremely abrasive, but usually should be limited to dry and free-flowing types. Belt conveyors can be operated at much higher speeds. With proper choice of head pulley and bucket type, speeds up to 240 meters per minute are attainable. Belts are more susceptible to damage than chains, and the pulleys must be aligned more accurately than chain sprockets.

c. Casing

1. Size

Casing cross-section dimensions are determined by bucket and drive pulley or sprocket size. Sufficient casing clearance for chain or belt sway should be provided to prevent internal rubbing. Particular attention is necessary for taller conveyors.

2. Construction

Casings normally are not specified lighter than 12 gage. "Z" type conveyors, and those for light duty, generally will be 16 gage. Casing corner angle size is a function of conveyor height, and the sheet gage does not enter, into this consideration. Good practice is to make boot and head sections heavier than the intermediate section. Extremely wide casings should incorporate stiffener angles to prevent sheet buckling.

3. Loading Leg

On continuous conveyors, a 7 mm plate loading leg, with a minimum length of three bucket spaces, should be bolted in place to aid in feeding directly to each bucket. Bucket to casing clearance should be held to a maximum of 10 to 12 mm around the bucket to inhibit flow of materials into the conveyor boot.

4. Access Doors

Accessible inspection and maintenance openings should be located near foot sprocket or pulley, and on both sides of the casing, if possible. Conveyor boots should be equipped with removable panels for easy boot pulley or sprocket removal. Panels should be of sufficient size to allow bucket replacement. Head section should be split-removable type for access to internal drive components.

Cleanout doors should he placed at the bottom of the casing to provide for easy cleaning of the boot section.

5. Ladders

Ladders with safety cages are optional and should be provided to access the head platform when elevator is free-standing or extends above a building roof. Ladders should be provided to meet local safety regulations. Rest platforms should be provided at 9 meter (maximum) intervals.

6. Head Platforms

Head platforms should be provided with the elevator, for access to the drive and head terminals, when the elevator is free-standing or extends above the roof of a building. Platforms should include hand rail, toe plates and non-skid grating that satisfy local safety regulations. The platforms should be supported by and form an integral part of the elevator.

c. Drives

Sprockets or traction wheels may be used for driving chain conveyors. Traction wheels are not required for chain conveyors under 15 meters high, for units handling wet materials, or for materials which have a natural lubricating tendency, regardless of height.

Crowned drive pulleys are used with belt-type conveyors. Drive pulleys should be provided with some form of lagging, usually rubber, where there is a need for increased traction, such as when handling abrasive or natural lubricating materials.

Backstops or brake systems must be added on all types of bucket conveyors to prevent runaway travel in reverse when unit is shut down, or in case of drive failure.

Differential hand brake can be used for most applications. Dust covers are advisable; however, for use in extremely dusty atmospheres this type of brake is not recommended.

Wedging roller type normally is used for heavy-duty or corrosive conditions.

Rachet and pawl (rapid, positive action). This type tends to be noisy but can be obtained in noiseless design.

e. <u>Take-ups</u>

Take-ups can be either external gravity, internal gravity, or screw type. Gravity-type take-ups are recommended for all hot service. Wing-type take-up pulleys for belts are useful in abrasive or lumpy material service in that they are self-cleaning.

f. <u>Shafts</u>

Provide adequate strength for starting and stopping under full bucket load conditions.

g. <u>Belt Splices</u>

Vulcanized splices are stronger and longer lived than mechanical splices. They are economical where a large number of splices are, needed. Belt scrapers and brushers are more effective for cleaning a vulcanized spliced belt because of its uniform smoothness. Belt clearance in the form of brushes can be used with mechanical splices.

Mechanical belt splices are used for general service and require less skill and equipment for joining. They can he made to give a strong, tight butt joint without appreciably decreasing belt strength.

h. <u>Bucket Attachments</u>

The K2 type 4-bolt hole bucket attachment is the type most frequently used. This attachment allows minimum overhung bucket load due to the short distance between bolting face and longitudinal centerline of chain.

i. <u>Guides</u>

Conveyors over 15 meters high using a single strand chain should be equipped with “slap plates,” three bucket spaces long, installed in alternate 3 meters casing sections to prevent contact of upgoing and downcoming chains.

4.2 Bulk Unloading Systems

Q4

4.2.1 Introduction

This section covers bulk unloading systems for both standard bags and the larger bulk bags, often called "super sacks". Systems for unloading bulk materials from bags are used to provide a means of emptying bags and transferring the material directly into a batch process by gravity or by a conveying system or by transferring material into bins that subsequently feed a continuous process.

4.2.2 Components of a Standard Bag Unloading Station

Bag dump stations are used for the manual opening and unloading of 25 and 50 kilogram bags. Bag dump stations should be designed to permit a safe and ergonomic operation by the batching operator. There are three basics models of bag dump stations: a bag dump station with no provision for dust collection; a bag dump station configured for external dust collection; a bag dump station with a self-contained dust collection. Bag stations with self-contained dust collection are by far the most popular and are described in detail in the following paragraphs. Collection efficiencies of 99.9% down to 1 micron are common. A sketch of a typical self-contained dump station is shown below. It consists of the following components:

a. A bag dump area, which consists of a screen deck that supports the bags and prevents any paper, plastic, foreign objects or oversize lumps from entering the process system, a bag slitter and a dust tight cover. The cover is maintained in the open or loading position by a gas filled cylinder.

b. A flanged collection hopper that can be connected to a discharge chute mounted directly over a process vessel or to a mechanical conveyor for conveying the material to a process vessel.

c. An integral bag dust collector, which is contained in the hood of the dump station and prevents any dust from entering the atmosphere. The bags are cleaned by mechanical shakers or by reverse-jet air pulsation. Dust is deposited in the discharge hopper or in a second hopper that can be added under the filter section alone to eliminate cross contra-nation of collected dust. A dust tight rear door should be provided to access the bag area for inspection and replacement of bags.

d. A blower that maintains a negative pressure at the screen deck.

e. Support legs to support the bag dump station at an elevation that is convenient for the operator.

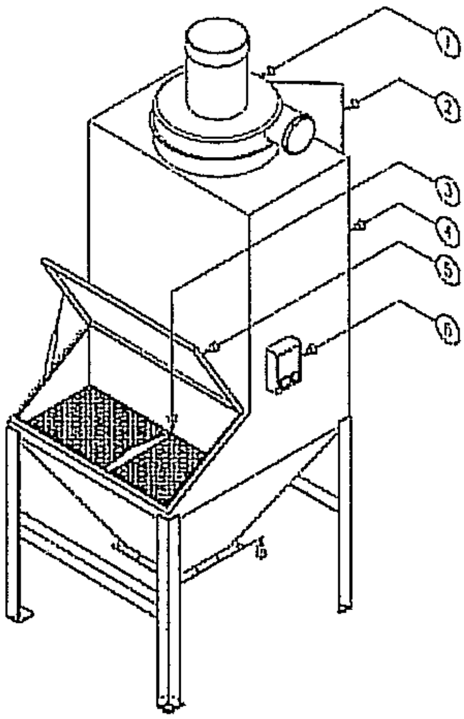
f. Control station to start the dust collector and/or the vibration of a shaker grate. Controls are available for dust tight, water tight, water tight or explosion-proof applications.

g. Optional bag compactor

Component Parts List:

1. Blower for dust collector
2. Rear access door to filter bags
3. Bag break knife edge & screen deck
4. Collection chamber
5. Dust tight door supported by gas-filled cylinder
6. Operator push button station

Figure 39



Q5

4.2.3 Components of a Bulk Bag Unloading Station

Bulk bag unloading stations must be able to handle materials from powders to fibers, with varying characteristics. They must be able to accommodate different sizes and styles of bags. They must be productive, safe and dust free. Two typical bulk unloading stations are shown below. One is shown with a forklift frame on top. The other is shown with a hoist and lifting bail on top. The main components of the basic station include:

a. A strong steel lifting and supporting frame.

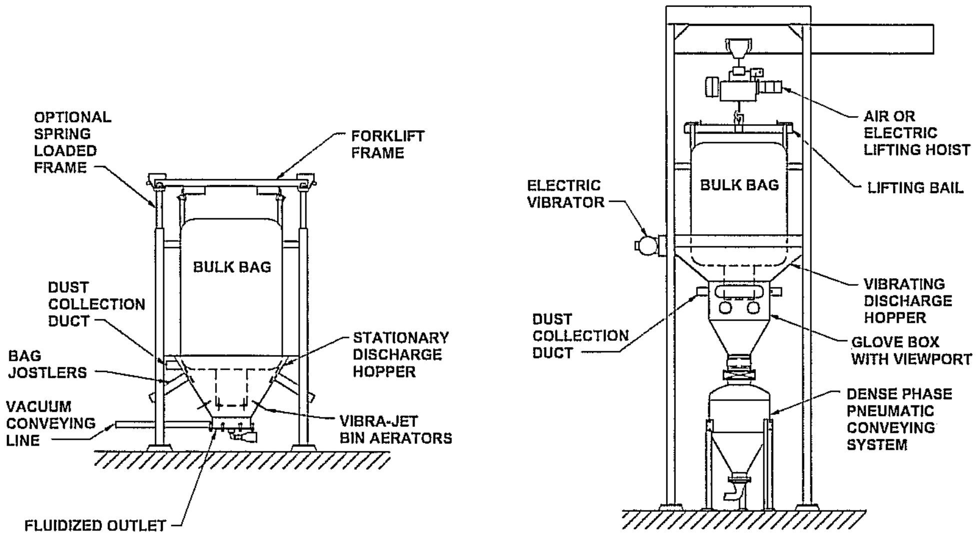
b. Either a hoist support frame or a forklift frame. Note that a forklift frame can be spring loaded as an option, which allows the bag to position itself on the bag support frame.

c. The bag support frame, which safely holds the bag. The support frame may include such options as an inflatable cuff, automatic bag slitters, a stationary discharge hopper or a vibrating discharge hopper, bag jostlers, bin aerators, a glove box with view port for handling sensitive or dangerous materials.

d. Optional methods of material transfer from the station to the process or a storage bin, can be provided. Some of these options include provision for or inclusion with a dense phase pneumatic conveying system, a vacuum conveying pick-up, a screw feeder, or other type of mechanical conveyor.

e. A dedicated self-contained dust filter can be furnished as an option. Connections for connection to a separate dust collection system are normally provided as standard.

Figure 40



4.3 Bulk Loading Systems

Q6

4.3.1 Introduction

This section covers loading systems for both standard bags and the larger bulk bags, often called "super sacks". Systems for loading bulk materials into bags provide a means of filling bags with a product material for shipping. Systems can be simple manual filling stations for a relatively small number of bags per day. However to handle any quantity of bags per day, semi-automatic or fully automatic equipment is employed. In the following paragraphs some of the equipment used in bag filling systems is discussed.

It is imperative that prior to the purchase of any loading system, the requirements and end results desired be completely defined and discussed with the loading system manufacturer. Information required by the manufacturer includes:

a. a complete description of the product(s) to be loaded, including a granulometric analysis, bulk density (loose and packed), temperature, moisture content etc.
b. a description of all shipping configurations required by the purchasers of the product, i.e.: bag sizes, volume required per bag, weight required per bag, number of bags per order etc.
c. number of bags per day to be loaded.
d. time per day allocated for bag filling.
e. automation required.
f. controls required.

4.3.2 Bag Filling Stations

Bag filling stations can be furnished for the manual, semi-automatic or fully automatic operation of weighing and loading of 50 and 25 kilogram or even smaller bags with products ranging from powders to fibers, with varying characteristics. They must be able to accommodate different sizes and styles and sometimes even materials of bags. They should be safe, efficient and dust free.

a. <u>Manual Filling Stations</u>

Manual filling stations can be as simple as feeding product into bags handled by an operator using a quick opening valve or feeder under a storage hopper. Material can be batch weighed prior to bagging or weighed on a platform scale during loading. After loading, the operator can manually load the sack onto a pallet for pick up by a forklift truck and transport to the shipping area. Bag filling stations should be designed to permit a safe and ergonomic operation by the batching operator. The advantages of a manual loading system are that it is inexpensive when compared to semi-automatic or fully automatic equipment and it is very flexible. The obvious disadvantages are the "wear and tear" on the operator, the safety of the operator and the accuracy obtained in the filling process.

b. <u>Semi-Automatic and Automatic Filling Stations</u>

In fully automatic stations operator involvement is usually limited to replenishment of the empty bags or cartons to be loaded. Automatic filling stations include taking a single bag from a stack of bags, opening the bag, preparing the bag for placement, placing the bag onto the filling spout, filling the bag, spreading the open end of the bag and transferring the bag to a closing device. Semi-automatic stations require operator involvement to start/stop certain functions or sequences. Semi-automatic stations can be employed to advantage when the quantity of bags to be filled is relatively small and/or a number of different products or container sizes need to be accommodated. Containers generally fall into one of two categories: valve bags and open mouth bags or containers.

Three of the most common types of valve bag packers are:

Air Packers
Auger Packers
Gravity Packers

Air packers use air pressure to fluidize the bulk material and blow it into the bag through a fill spout. Most air packers have a bag spout and a bag support saddle that are suspended from a load cell. As material is fed into the bag, a load cell measures bag weight and sends information to a controller, which regulates the feed of material into the bag. Air packers are typically used for the fast, efficient filling of dense, fine powders and pelleted products. An air packer with a single loading spout can load up to about 10 bags per minute.

Auger packers use an auger to screw feed bulk material into a bag through a fill spout. Similar to air packers, auger packers have a bag spout and a bag support saddle that are suspended from a load cell. As material is fed into the bag, a load cell measures bag weight and sends information to a controller, which regulates the feed of material into the bag. Auger packers are typically used for accurate filling of non-abrasive, fine powders. They are not recommended for granular or pelleted products. An auger packer with a single spout can load up to about 10 bags per minute.

Gravity packers weigh and fill valve bags in a fashion similar to those above. Gravity packers have a bag spout and a bag support saddle that are suspended from a load cell. As material is fed into the bag, a load cell measures bag weight and sends information to a controller, which regulates the feed of material into the bag. Gravity packers can load almost any free flowing material including fine powders, granular products, pellets etc.

Open mouth fillers are gravity type fillers used to fill open mouth bags or other open containers. Filling rates up to 40 bags per minute are possible.

Filling machines can be furnished with single spouts or multiple spouts. In-line as well as carousel types are available.

With the variety of methods and type of machinery available, it is imperative that the desired results be carefully considered before the purchase of a bagging station. Specialists should be consulted to ensure the result ends with an efficient and economic system. Possible future requirements should be considered in the selection of the equipment.

4.3.3 Bulk Bag (Super Sack) Loading Station

Q7

Bulk bag loading stations are able to weigh and fill bulk bags with materials ranging from powders to fibers, with varying characteristics. They are able to accommodate different sizes and styles of bulk bags and also bulk boxes and fiber drums. They must be productive, safe and dust free. Loaders for manual operation as well as fully automated units are available. The main components of the basic manual station include:

a. a sturdy structural steel frame, capable of accommodating filled bags with dimensions up to 100cm x 100cm x 175cm high.
b. a pneumatic or hydraulic system for raising and lowering the bags.
c. an adjustable bag support frame.
d. a bag filling system
e. a platform scale
f. Dedicated self-contained dust filters can be furnished as an option. Connections for connection to a separate dust collection system are normally provided as standard.

In addition to the above, fully automatic systems include:

a. empty bag inflation
b. auto loop hooks
c. auto releasing bag loop forks/hooks
d. automatic empty bag feed conveyor
e. automatic filled bag discharge conveyor
f. retracting filling spout
g. bag compaction (vibrating table)
h. bag counting and weight totalizing
i. tally roll printer

Other options available include:

a. an operators platform
b. feed hoppers
c. stainless steel construction
d. control panel enclosures to satisfy environmental conditions including explosion proof

4.4 Packaging Systems

Q8

A packaging system is an integrated series of equipment and controls that begins with filling a container with a product and ends with the shipping of that product from the manufacturing facility. It may be as basic as transporting product from a bulk bag filler by a forklift truck to a shipping dock and loading it onto a truck. Or, for example, it could be as complex as a system consisting of a continuous automatic bag filling machine, followed by automatic transfer, bag conditioning, bag placing and palletizing, shrink wrapping and automatic transfer to a shipping dock all controlled by a single control station. The control station could be local to the system or remote in a central control center.

For the purpose of this guide, it is assumed that the product is a dry granular or palletized product that will be shipped in bags, super sacks, bulk boxes, fiber drums etc.

4.4.1 Equipment

a. Bulk Loading Equipment (See Section 4.5)

b. Transfer Equipment

Transfer equipment might include some of the following:

- gravity roller conveyors (See Section 4.2.3 of this guide)
- powered roller conveyors (See Section 4.2.3 of this guide)
- flat belt conveyors
- bag kickers (these are typically used at the end of a bagging conveyor to turn bags 90 degrees and feed them into a bag conditioner / bag flattener)

c. Bag Conditioning Equipment

A typical bag flattener consists of a 2-Belt conveyor that levels material in bag to allow for more uniform pallet stacking. Bag travels butt-first between two belts that force the material to lay flat in the bag.

d. Bag Positioning Equipment

Bag positioning equipment is used to orient bags as required by the palletizing and to feed the bags onto the palletizer. Bag positioners are not required when robotic bag palletizers are employed. They should be furnished with a programmable controller so that orientation for varied bag patterns can be easily accommodated.

e. Palletizers

A palletizer is a device that stacks bags, cartons or other containers in an orderly geometric pattern on a pallet so that it can be easily hoisted and moved by a forklift truck. There are several types of palletizers in current usage.

Manual palletizing stands automatically maintain the pallet load at an elevation for easy ergonomic loading. Manual stands are used where labor is cheap and quantities of containers to be palletized are relatively small. Automatic palletizers include high-level palletizers, low-level palletizers and robotic palletizers. High-level palletizers receive product through a hopper from above. Low-level palletizers are fed at ground level. For both high and low speed palletizers product is received in a flowing fashion and continuously transferred to the pallet. These types of palletizers are best used in applications where packing and shipping speed is important. Robotic palletizers are somewhat slower than high and low-level palletizers, but are very well suited where the product to be shipped is fragile, since they tend to apply less stress to the materials being transferred.

Palletizers are available as automatic or semi-automatic devices.

f. Wrapping Machines

Stretch wrapping machines are employed for wrapping pallets with pre-stretched cling film to ensure a stable, moisture-proof pallet at a minimum cost.

4.4.2 System Controls

In a packaging system control systems can vary from semi-automatic to completely automatic. Each device can have its individual control system and panel which can be operated independently from the others or completely integrated with the others. Remote control with a single control system is also possible.

4.5 Product Sampling

Q9

Modern process control requires accurate analysis of incoming raw materials, materials in different stages of processing and the outgoing finished product. A reliable system for obtaining representative samples is necessary to verifying the guaranteed analysis of incoming raw materials, improving processing systems, maintaining product quality and complying with client, industry or government standards.

Potential users for automatic sampling includes those firms that receive raw materials in bulk, blend raw materials prior to processing, manufacture by continuous processing, manufacture by batch processing, blend products to various specifications, are subject to government or industry standards, are subject to customer or corporate standards, must retain samples for record, process toxic or hazardous materials.

In today's world of advanced technology and automation there is a need for better quality control. The benefits of automatic sampling include: uniformity and consistency of sampling, elimination of human error, reduction of loss, spillage and dust, labor savings and ergonomics.

This section will address only sampling of dry materials. Suffice it to state that sampling devices/systems are also available for liquids and slurries.

Almost every sample collection requirement in flowable powders, granules, flakes or pellets will vary to some degree. Almost every area of a processing plant requires sampling from the raw materials in transit, to the raw materials in process, to the raw materials in packaging and shipping. To select the appropriate equipment/system for accurate sampling for a specific purpose requires attention to detail. Experienced application engineers can make the proper selections given the following information:

a. Material To Be Sampled
- Name and chemical composition
- Particle size and distribution
- Temperature and moisture content
- Abrasive or corrosive characteristics
- Flowability of material
- Are there any potential hazards to address? (Explosivity, toxicity etc.)

b. Sampler Installation Conditions
- Define the conditions at the desired sampling point in detail. (Is the sample point in a drop chute, a slide, in a bin or hopper, in a pneumatic conveying line, in a conveyor system?)
- What are the dimensions of the chute, hopper, pipe etc.?)
- Material movement at the sample point (static, slow movement, free falling etc.)
- Direction of movement (vertical, horizontal, diagonal, free fall etc.)
- Are sanitary conditions required?

c. Type of Sample Required
- Total volume of sample to be collected
- Time period for collecting the sample (fast as practical "grab sample" or time interval for a composite sample)
- Material characteristics to be analyzed (moisture, size, content etc.)

d. Control Requirements
   - Type of controls required (electric or pneumatic)
   - Control panel requirements (NEMA classification, programmable interval timer, adjustable dwell timer, manual capability, cycle lights etc.)
   - Location of panel (local to sampler or remote and if remote, how far away from sampler)

e. Utilities Available
   - Compressed air/gas available? (at what pressure)
   - Electrical service available? (Voltage/Phase/Hz)

Sampler Styles: There are many different types and styles of sampling devices. However, most sampler manufactures apply similar types of samplers for similar applications. Because of the many and varied requirements for material sampling, an attempt will not be made to cover all of the possible scenarios.

Several of the more typical applications and the preferred type of sampler for that application follow:

a. To sample free-flowing materials in gravity flow pipes, spouts or hoppers a type of sampler is employed that utilizes a sampling tube that has a slot opening across the diameter of the pipe, spout or hopper. When signaled from the controller, a solenoid operated 4-way valve actuates a pneumatic actuator that rotates a slotted sample tube through the product flow to catch a cross-sectional sample. Simultaneously a motor driven auger removes the sample to a collection container. This type of sampler can be flange mounted or mounted directly to the pipe, spout or chute.

b. Another type of sample that is used to sample free-flowing granules, powders, pellets and heterogeneous products in vertical or angular gravity spouts consists of a motorized cutter that traverses the product stream, collecting a true cross-cut sample. The sampler is mounted by replacing a section of the existing spouting. The spout can be round, square or rectangular. The cutter's opening is sealed when not sampling. The sample is delivered by gravity via flexible metal or plastic tubing to a collection container. The sample quantity can be controlled by varying the cutter opening.

c. At the direction of a controller (by time, by count or manually) a solenoid-activated air cylinder opens and closes a sliding gate. The sample is delivered by gravity to a collection container. On a screw (tubular or U-trough) conveyor the sampler is mounted on the underside, 25° off-center, at the side where the blade will push material to the collection point. On drag conveyors, the sampler is mounted on the underside, off-center. On gravity chutes the sampler is mounted at the underside, on the center, where material will freely fall to the collection point.

d. A patented static sampler is available that mounts in a section of vertical pipe or chute and continuously samples the entire process stream as it passes through the sampler extracting only 0.015% to 5.0% of the process stream. Sample fraction can be from 0.1 to 0.4 kg per ton. The advantages of this sampler include:

- The entire product has an equal chance of being sampled.
- There are no moving parts.
- No timers or electronic controls are required.
- Standard sizes are available from 80 mm to 300 mm for flows from 1 to 250 tons per hour. (Custom models are available for higher flow rates.)
- Can be used in high temperature applications up to 500°C.
- Installation and operating expenses are minimal.
- It has applications in dusts, powders, granulars, pellets mixed size formulations and some slurries.

The major disadvantage is that it can only be installed in free falling vertical applications.

4.6 Feeders

Q10

4.6.1 Weigh Belt Feeders

a. Introduction

The use of automatic continuous weighing equipment has become widespread. After many years of experience, along with applied and basic research, continuous weighing is now accepted as one of the most important means of proportioning bulk solids. Because of higher production rates and the demand for more uniform quality, more and more batch processes are being converted to continuous processes.

Some of the benefits derived from continuous processing:

- Higher production rates.
- Reduced plant costs per unit of production.
- Lower unit investment.
- Lower operating costs.
- More uniform quality.

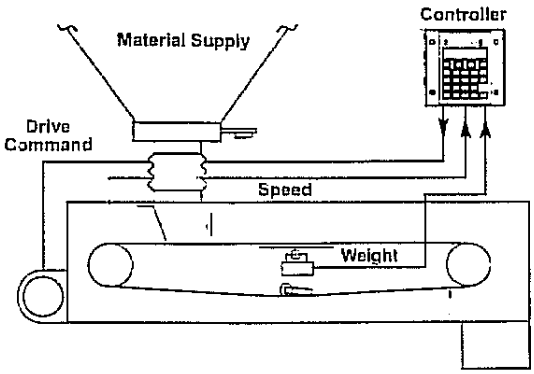
Contrary to many beliefs, the operation and design of continuous weighing equipment is much simpler than automatic batching systems which require more components and complex logic circuitry.

Due to their operating principle weigh belt feeders are often a good choice when feeding relatively free flowing materials not requiring containment. Weigh belt feeders operate by continuously weighing a moving bed of material on its short conveyor and controlling belt speed to result in the desired flow rate at discharge. Unlike most loss-in-weight feeding systems whose physical size must typically be increased to accommodate higher flow rates, weigh belt feeders can achieve high rates while remaining compact, simply through a combination of manipulating material bed geometry and operating at higher belt speeds.

Factors affecting the performance potential of a weigh belt feeder include the consistency of the material bed (formed as incoming material is sheared past an adjustable inlet gate), the resolution, responsiveness, and environmental sensitivity of the weighing system, and the effectiveness of the feeder's various mechanical and electronic systems designed to permit accurate weighing through the belt.

A typical weigh-belt feeder is shown below.

Figure 41
Typical Weigh Belt Feeder



b. <u>Components of a Weigh Belt Feeder</u>

Rigid fabricated carbon steel **frame**. Stainless steel frames are also available and provide greater corrosion resistance and washdown capabilities. Open, partially enclosed or fully enclosed **housings** are available. Some manufacturers offer dust-free housings. Careful review with the manufacturer should be done to ensure that the unit being furnished is truly dust free. Housings can be fabricated of coated carbon steel or stainless steel. Housing should be designed to permit easy and rapid changing of the belt. Access panels should be provided as required.

The conveyor is very similar to a standard horizontal belt conveyor and consists of **head pulley, tail pulley, flat carry idlers, return idlers** (when required), **endless vulcanized belt** and a **drive train**. Drives are almost always located at the tail (feed) end of the weigh belt. Belts are often of the walled type which provides maximum carrying capacity and reduces the risk of spilling. Since weigh belt feeders are relatively short conveyors, belt **take-up** typically has been accomplished by adjusting a screw mechanism located in the tail section. However, the better solution is a dynamic tensioning device that maintains constant tension on the belt. **Belt scrapers** can be provided when required. Belt conveyors are more completely described in Section 4.2.1 of this Guide.

Inlet hoppers are normally furnished with the weigh belt feeder. These will be sized according to flow characteristics and flow requirements. They should be designed to provide side-skirting in the delivery area and back-side scraping in the rear to avoid material leakage. A **cut-off or control gate** should be supplied to control the geometry of the material on the belt. Rubber **flashing** is available as are special configurations to match with inlet feeders, bins or chutes. **Starvation detectors** can also be furnished as an option.

Motors are normally totally enclosed, fan-cooled sized to provide adequate torque at any feed rate and, if required, to start with a full belt load of material. Explosion proof motors can be provided if required by the electrical area classification. D.C. motors have been furnished in the past, but they are being used less and less. A.C. variable-speed, constant torque drives are commonly applied.

c. Weighing System and Controls

Q11

At the heart of a weigh belt feeder are the weighing system and the controls. Manufacturers use different methods for weighing material on the belt. The more common methods are:

- Dual load cells, strain gages
- Non-load cell, all-flexure, counter-balanced weighing system (scale)
- K-Tron's Smart Force Transducer

See "References" Section of this guide for reference to a paper comparing the methods of control.

Firstly, bed material consistency is important. It is clear that a stable, properly formed bed minimizes the need for corrective belt speed variation, resulting in improved overall accuracy. Based on the material's properties and intended range of flow rates, the feeder manufacturer typically determines the proper bed geometry and range of permissible inlet gate adjustment.

Weigh system resolution must be high, especially at higher belt speeds where material may pass over the short weigh section in a small fraction of a second. The system must also be able to accurately weigh in a process environment where unknown levels of shock and vibration occur.

Precisely weighing material through a moving belt requires that belt tension be maintained within limits at all times. Variation in tension produces a weighing error due to a catenary effect and may also result in belt slip. While static belt take-up tensioning devices may still be found on some feeders, the preferable solution is a dynamic tensioning device that applies constant tension regardless of belt load, wear and stretch.

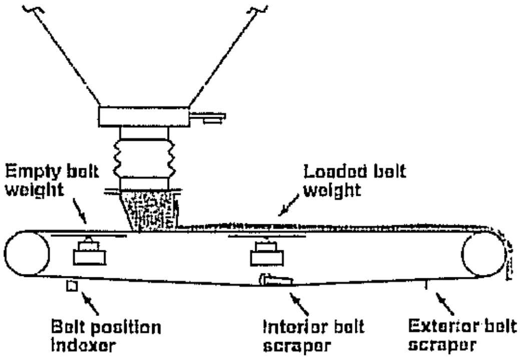
A second measure taken to assure accurate weighing through the belt acts to maintain consistent tracking of the belt. Automatic belt tracking keeps the belt centered and prevents it from drifting to one side, corrupting the weight measurement through contact with the feeder's side skirts.

Thirdly, taring or zeroing is a major concern when weighing through the belt since both the belt and material are weighed, and any error in tare produces a repetitive and systematic error in feed rate. Sources of potential changes in tare include belt wear, impregnation of material into the belt, and adherence of material on the belt. Changes in belt weight due to material buildup are inevitable, and the use of a belt scraper at discharge and elsewhere within the feeder minimizes but, for many materials, cannot eliminate the concern. Thus, periodic taring has historically been required.

Sensitive to this issue, some feeder manufacturers helped automate the taring procedure by including a self-tare feature that would, upon user demand, cycle the (empty) belt feeder through a single belt revolution and automatically compute a tare value correction. While this feature was one step in the right direction, another more refined step soon followed. To account for variations in belt weight along the length of the belt, an indexing feature was added so belt weight could be measured and recorded inch-by-inch along the belt's length. During process operation, these indexed belt segment tare values would be applied in order as the corresponding belt segment passed over the weighing section.

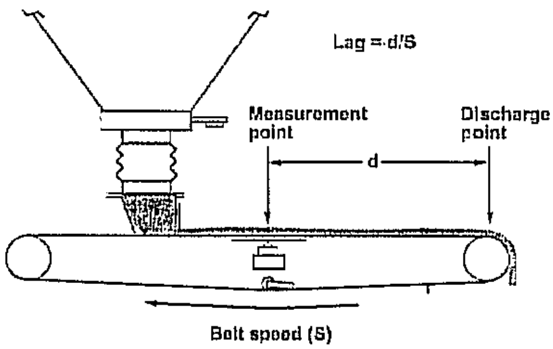
By adding a second weigh sensor upstream of the material inlet, the belt can now be continuously, accurately and automatically tared on-line without emptying the feeder. This approach to real-time, fully indexed taring eliminates concerns of belt weight variation regardless of cause, and helps assure the highest possible weigh belt feeding accuracy.

Figure 42
Continuous Automatic On-Line Belt Taring



Finally, the phenomenon of transportation lag has relevance in some weigh belt feeding applications. Since there necessarily exists a short conveying distance between the weighing and discharge points, belt feeders with a transportation lag compensation feature invoke an appropriate delay in required belt speed adjustments to produce the desired flow rate at the point of discharge. This feature is important in proportioning to variable or wild flow material streams.

Figure 43
Transportation Lag Compensation



By appropriately delaying corrective changes in belt speed, flow rate is controlled at the point of discharge rather than at the point of measurement – an important consideration when proportioning to variable or uncontrolled flows.

d. Useful References

A recent paper by Jim Foley entitled “Selling New Weighing Standards in Process Feeding and Batching” compares the different methods in weighing and presents K-Tron's 100% digital sensor designed for process weighing.

c. Operating Considerations

Assuming a properly applied weigh belt feeder, most of the typical problems encountered with this type feeder center around the mechanical systems associated with managing the belt itself - keeping it clean, tracking properly, and in constant tension. Each manufacturer takes a somewhat different approach to achieving these ends, so a complete presentation of remedies to potential problems is beyond the scope of this paper. However, it is important to mention that, regardless of the systems employed, most problems stem from lax maintenance, cleaning and monitoring of belt management systems. The best solution here is prevention through regular monitoring and replacement as required according to manufacturer's recommendations.

For proper feeder operation the inlet gate of a weigh belt feeder is set to produce a material bed of a certain height and width for the given material. If a different material is handled, or if the density of the original material is changed significantly, adjustment to the inlet gate geometry is usually required to a) avoid material spilling off the belt or coming in contact with the channeling side skirts, and b) establish the proper belt loading (e.g., kg/m) value. Ignoring this consideration sets the stage for problems.

Belt slip occurs when insufficient frictional force exists between the belt and its drive pulley. Slip causes a direct error in feed rate, and is due to insufficient belt tension and/or the accumulation of process material on the inside of the belt. Proper maintenance of the belt and tensioning system will help avoid belt slip, but if the condition persists the feeder may have to be re-configured to operate at a lower belt speed. Belt slip detection is available from most if not all manufacturers.

Finally, due to their operating principle of weighing material through the belt, accurate and frequent taring is a concern. Continuous, automatic, on-line taring is now available. However, until it is the norm, processors must make weigh belt taring a regular activity.

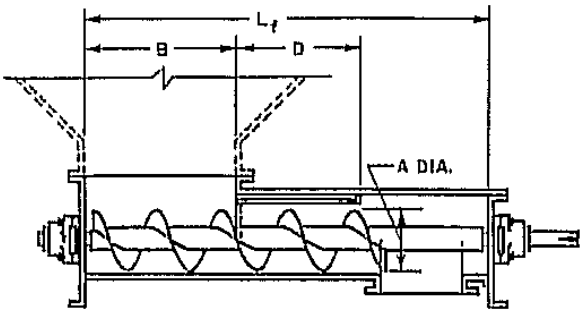
Q12

4.6.2 Screw Feeders

A feeder is a totally enclosed conveyor whose function is to control or regulate the flow or feed of a predetermined volume of material at a uniform rate from a bin or hopper.

There are four types, full pitch regular, and half or short pitch regular, full pitch tapered and half pitch tapered.

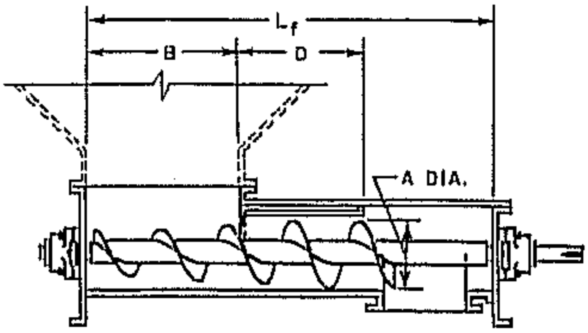
Figure 44
Regular Feeder



The full pitch regular feeders are usually used for handling fine free flowing materials where it is not objectionable for the feed to be from the rear of the hopper and bin instead of being fed uniformly across the length of the opening. It also can be used more economically and very satisfactorily where the length of the feed opening is not over twice the pitch of the conveyor.

The half pitch regular feeders are usually used where the material is of such a nature that it may flood and overload the conveyor which is being fed.

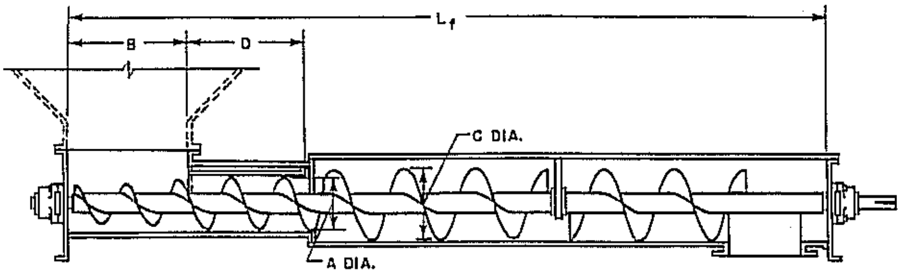
Figure 45
Tapered Feeder



Screw Feeders with tapered flights are generally used to handle material which may contain a considerable amount of lumps. They also are used extensively, when it is necessary or desirable to draw the material from the bin or hopper uniformly across the entire length of the feed opening rather than from the rear of the bin or hopper, thus probably leaving dead areas of materials in the forepart of the opening.

Using a tapered flight conveyor instead of a regular flight will in most cases, especially where the feed opening is long, consume much less horsepower.

Figure 46
Tapered Feeder With Conveyor Extension



Feeders with conveyor extensions are necessary when the material must be carried a distance that would require the use of intermediate hangers. In this case a larger diameter conveyor in a standard trough is used in combination with the feeder spiral.

Multiple screw feeders are usually in flat bottom bins for discharging material which have a tendency to pack or bridge under pressure. Frequently, the entire bin bottom is provided with these feeders which convey the material to collecting conveyors.

4.6.3 Rotary Feeders

Q13

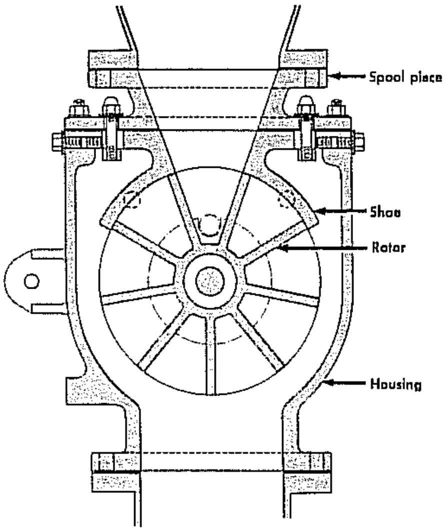
Rotary Feeders are devices that are used to control the discharge rate of fine, granular or lump, dry, solid materials from overhead storage silos, bins or collecting hoppers. They are often used to feed material into pneumatic conveying systems or in conjunction with other weighing/feeding devices such as weigh belt feeders.

Rotary seals typically seal against differential pressures of 100 kPa and down to 350 millimeters of mercury vacuum. Some valves can seal against differential pressures as great as 135 kPa.

a. Operation

The cross section of a typical rotary feeder is shown in Figure 47. Bulk material falls by gravity through the inlet opening in the spool piece and shoe, into pockets of the revolving rotor. A flange at the bottom of the shoe contacts the periphery of the rotor and spans at least three rotor pockets. This contact is an effective seal which prevents excess material from bypassing the rotor. All material handled is regulated by the volumetric capacity of the pockets and the speed of the rotor. As the loaded buckets rotate away from the closure of the shoe, material falls unrestricted through the space between the circumference of the rotor and the side of the housing.

Figure 47



b. Sizes and Capacity

Valves can be furnished in sizes from 100 mm through 600 mm with both round and square flange configurations. Capacities are a function of the solid material properties, the type of rotor, the rpm of the rotor and the function of the valve in the process. Valves are normally operated in the 20 to 45 rpm range with larger valves being operated at the lower speeds.

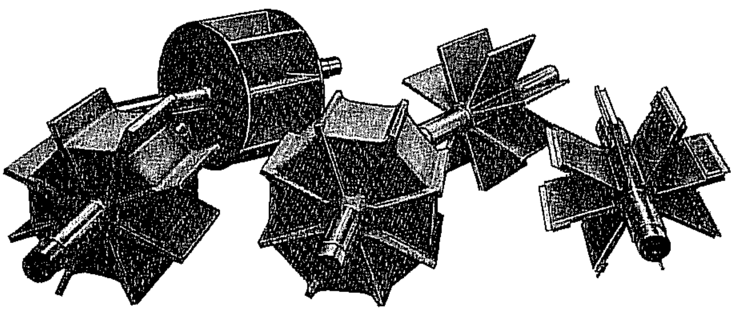
c. Design and Construction

It is desirable to select a rotary valve that is designed for long life and ease of maintenance. The parts subject to the most wear are the rotor and the shoe. In the design shown above, both of these parts can be replaced with the valve mounted in position. To ensure long life, both the rotor and the shoe should be made of hard materials (Nickel iron for example) and/or have hardened surfaces. This is a specific requirement when handling abrasive materials.

Note: Some valve designs have adjustable shoes so that, as wear occurs, the sealing surface can be maintained. In the valve shown above the shoe can be replaced without replacing the entire housing. Other designs do not have removable shoes. Some have shoes that are an integral part of the valve housing. In other designs there is no shoe and the rotor is sealed against the valve housing. In both of these cases, if wear occurs the entire housing may have to be replaced.

Rotors: Rotors come in many styles and configurations. Valves can be furnished with 6, 8, 10, or 12 vanes. A supplier has furnished rotors with 24 vanes. More vanes reduce air leakage but also reduce capacity. Most suppliers use an 8 vane rotor as their standard as this seems to strike a happy medium between minimizing air leakage and maximizing capacity. Rotors can be provided with open ends or closed (shrouded) ends. The closed end design provides for maximum rotor strength and minimizes packing damage. Air purging is recommended for closed end rotors. Rotors can be furnished with or without adjustable tips. Adjustable tips can be moved to maintain close rotor-to-housing clearances, peak valve efficiency and maximum life. Common tip materials include brass, stainless steel, abrasion resistant steel, satellite inlaid, Ni-hard, neoprene Teflon®, polyurethane and others. Rotors can be furnished with vanes that are fully open (standard) or partially filled. A partially filled rotor is used when a lower throughput is required for a given size of valve or where solid material characteristics dictate a special configuration. An example is materials that would tend to stick in fully open rotors. Several examples of valve rotors are shown in Figure 48. Special hygienic-type rotors are available for perishable products such as flour or milk powder. Sintered-metal-lined pockets are available for fluidizing the bulk product for powdered products with poor flowing characteristics or tendency to stick.

Figure 48



Valve Housings: Common available housings materials are cast iron, cast aluminum, fabricated steel, fabricated stainless steel. Cast iron lined with chrome is also available. Special materials such as Ni-hard, cast steel, monel and other alloys are available from some suppliers as are special purpose coatings like chrome, nickel and Teflon®. Housings are available with both round and square inlet and discharge flanges. Some manufacturers also furnish rectangular flanges. Round flanges are commonly sized to conform to standard ANSI Class 125 series flange dimensions.

Housings come in two styles: drop through and side entry. Drop through valves can be used for both metering and non-metering applications. Side entry valves normally operate at a fixed speed and a maximum of 40% pocket fill. For these reasons side entry valves are not used for metering applications. Their particular value is to overcome serious jamming problems common to drop through feeders when used for some types of cubes, pellets, chips, flakes, prills and other products that are commonly prevalent in the plastics industry. Housings should be provided with a venting connection.

Shaft Seals: Standard seals are gland and follower type with Teflon® impregnated yarn type packing rings. In a four ring seal, the 2nd packing ring can be replaced with a lantern ring for purging. Purging is recommended for abrasive or hard to seal applications. Compressed air is piped into the lantern ring at a pressure of two to five pounds above the valve's internal pressure. A variety of mechanical seals can also be provided. The manufacturer should be consulted in the selection of mechanical seals.

Bearings: Sealed outboard ball bearings are recommended for rotary valve service. They can be of the flange mounted type or better yet self-aligning pillow blocks.

Drives: Most standard drives are gear motor driven chain and sprocket drives. Drive arrangements should allow for a sprocket change in the field to increase or decrease the valve speed. Both parallel-shaft and right-angle gear motors are used. Sprockets should be provided with shear pins to protect the drive gear and motor from damage caused by rotor jamming. A sturdy drive guard should be provided that meets the requirements of OSHA.

Options: Special quick opening designs that allow the rapid and easy removal of the rotor assembly are available for use in the food, chemical, plastic and pharmaceutical industries where contamination is a constant concern and frequent disassembly and cleaning is required. Some designs are furnished with support carriages that attach to the valve body and fully support the rotor while it is being cleaned. Reversing drive arrangements are available from some manufacturers to cause a self-reversing motion when an obstruction tends to stall the rotor. These are special designs and beyond the scope of this guide. Other options include: variable speed drives, weather-tight or oil tight drive guards, high temperature packing, access openings for internal inspection, sight glasses for observing flow, motion switches, outlet and inlet transitions, vent hoppers, negative pressure manifolds to aid in the clean discharge of product into a conveying line, positive pressure manifolds to remove product from the rotary valve's discharge without impeding pneumatic conveying system pick-up velocity.

Special self-cleaning feeders are available for wet, sticky materials such as filter cake, wet crystals or powders, pastes and sludges. One such feeder is available from Wyssmont. Wyssmont also has a special design that can operate at temperatures as high as 500°C where as most rotary valves are limited to 150°C to 200°C maximum temperature.

d. How to Specify Rotary Valves

Selecting the most appropriate rotary valve for the application is extremely important. The selection is not difficult when the following step-by-step procedure is used:

1. Product Characteristics - The product to be handled dictates the first decision to be made, whether the conventional Drop-Thru Valve will meet the requirement, or if a Side Entry or other special valve should be used.

    a. Is it powder, granules, chips or flakes, cubes or pellets? Materials that are hard and of large grain (such as plastic pellets) may jam a conventional Drop-Thru Rotary Valve.

    b. Is it abrasive? Abrasive products may require valves of special construction or special plating at wear surfaces. Rotor vanes may require adjustable tips, and housings equipped with inspection ports. Shrouded rotors and continuous purging may be required.

    c. Does it pack or smear? Products that are heat sensitive may pack or smear and require a valve with smooth interior surface, and sometimes, a coating with low friction coefficient (such as Teflon). In some applications, the trailing edges of vane tips and sides are beveled to reduce friction.

2. Application - Is the rotary valve for metering or non-metering use? The application helps further refine the model, size and rotor type. Drop-Thru Valves are calculated at 100% pocket fill for metering applications. Non-metering valves should be selected to have a minimum capacity of 1.5 times the volume required. Side Entry Valves operate at a maximum of 40% pocket fill.

3. Volume & Weight - How much and how fast? This establishes the size rotary valve required, for either metering or non-metering applications. First determine: weight of product in kilograms per cubic meter; and, volume required in

cubic meters per hour. Output capacity is computed based on the following:

$$\frac{\text{CAPACITY PER HR. (KG)}}{\text{PRODUCT WEIGHT (KG/M}^3\text{)}} = \text{M}^3\text{/HR.}$$

Valve capacity is a function of pocket fill and valve speed. Valves for non-metering applications should be a minimum of 1.5 times required volume. Manufacturer's Tables show "Standard Speed" and "Maximum Speed" for each valve size. The Standard Speed is recommended for computing valve output. These figures are based on testing performed by using a wide variety of products. Additional speed above the "Maximum" shown, will not effectively increase output.

To determine the Output Capacity Rating of a given valve use the following:

VALVE CAPACITY (M^3/HR.) = ROTOR CAPACITY (M^3/REV.) x SPEED (RPM) x 60 (REV./HR.)

4. Differential Pressure - What will the differential pressure be across the rotor? Standard Rotary Valves are designed for negative or positive pressure of up to 100 kPa. Optional "O" ring seals make valves gas-tight to atmosphere. For requirements involving lower leakage, special rotors and seals, and tighter tolerances may be required.

5. Interface - What are the flange size requirements? Often, the rotary valve is selected based on inlet and outlet sizes. Where greater throughput is required without increasing the flange-to-flange dimension, Double-Length Valves are often specified.

6. Operating Temperatures – Will high operating temperatures be a factor? Standard Rotary Valves are designed for operation at temperatures up to 120° C. When higher temperature use is specified, special high-temperature bearings and packing are required, stress relief employed and tolerances reviewed.

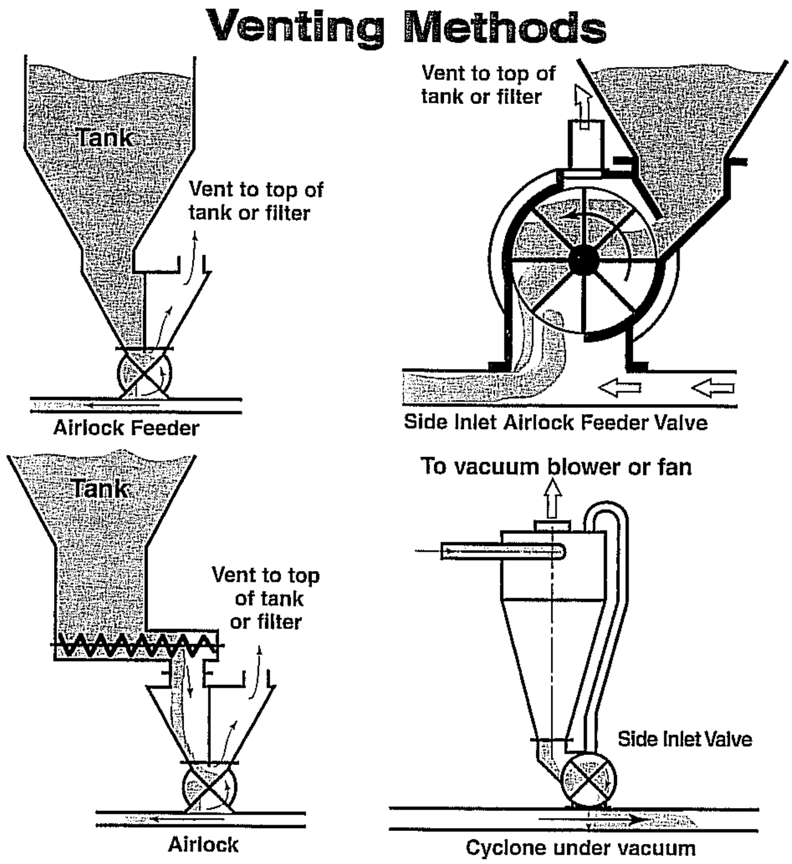
e. Design Considerations

Q14

1. Venting: Lack of proper venting is one of the major causes of poor rotary valve performance, especially in pneumatic conveying operations. Pressures in conveying systems may displace enough air back through a valve to create turbulence above it and prevent material from entering the valve. Proper venting allows the valve to function at its best when feeding a positive pressure system. Several venting methods are shown

below. Venting method should be discussed with the rotary valve supplier at the time of purchase. Manufactures publish charts and tables that allow calculation of leakage through a valve that is empty and not rotating. To estimate leakage in operation, the volumetric displacement of the rotor multiplied by the rpm must be added to the static leakage.

Figure 49



2. Valve Sizing: Rotary valves for metering applications must be sized on the basis of 100% fill of the rotor. Rotary valves installed as airlocks should be oversized for the following reasons:

   a. Aeration: Some materials, such as paper-sizing clays, may decrease in bulk weight with a proportionate increase in volume as they are aerated by the moving air in a pneumatic system, requiring a valve at least ten times the normal capacity.

   b. Surging: Valves for unloading systems that feed unevenly, causing surges, should be at least twice as large as a normal airlock for the same capacity.

   c. Speed: Some powdered materials do not flow as fast as others and a valve pocket may go by before it is filled.

Experiment with different valve sizes to handle this condition.

d. Preventing Degradation: To maintain the original shape of granular or flaky products, the valve inlet can be restricted to control product flow, thus minimizing shearing between the rotor and the leading edge of the housing.

e. Stressing: Rotary valves are not structural members and must not be subject to unusual stresses created by installation. Distortion of the housing may disrupt rotor clearances. Air locks installed under storage bins must be protected from thermal expansion of the bin. Valves may be suspended from the bin with expansion clearance underneath.

4.7 Storage/Silos

Q15

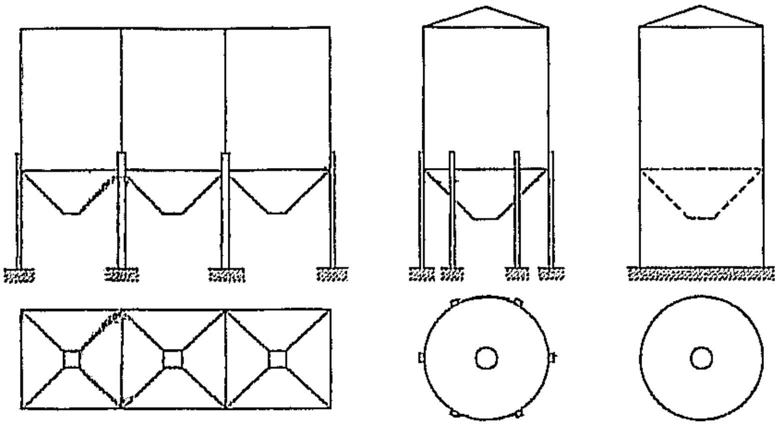
4.7.1 Configuration

Bins and silos may be circular, square, or rectangular in cross section and may be arranged singly or in groups (Fig. 34). For the same height and width, a square bin provides 27% more storage than a circular bin. The term “bin” and “silo” are interchangeable and apply to any upright container for storing thy bulk granular material. Other terms with very similar meanings include “bunker”, “hopper” and “tank.” The term “hopper” refers to the sloping-walled part of a bin bottom. Some large silos have flat bottoms instead of hoppers, while some small bins may only have only sloping walls.

Bins with hopper bottoms are usually supported on columns or on skirts. Flat-bottom bins are usually grade-supported. Flat-bottom silos require less height for a given volume and their initial cost is relatively low, but mechanical means may be required to discharge. Hopper bottom bins are more common and are self-discharging.

Bins of circular cross section have a structural advantage compared with rectangular bins because hoop tension resists lateral pressure very efficiently. However, thin walls can buckle under the vertical compression caused by friction (drag) between the bin wall and the stored material. Thin-walled circular bins are also sensitive to asymmetric loads most often caused by eccentric filling or discharge. Increasing thickness or adding stiffeners may be required to strengthen a circular bin against compressive and asymmetric loads. Since rectangular bins are typically stiffened they are generally less sensitive to asymmetric loads. Normally stiffeners are added to the outside of a silo to prevent interference with flow. If internal stiffeners or other structures are required they should be provided with self-cleaning sloped surfaces.

Figure 50
Typical Bins



Silos typically are made of reinforced concrete or metal. Metals used include steel, stainless steel and aluminum. Metal bins may be welded or bolted. Metal is more efficient in resisting tensile loads while concrete is more efficient in resisting compressive loads. Concrete silos may be cast in place or slip formed. Concrete stave silos are rarely used in industrial applications.

Other considerations when selecting the type and size of a bulk solid storage silo include: Can the roof slope match the angle of repose for economical storage? What is the type and quantity of material to be stored, storage duration, filling and discharge rates? Is the material segregation tolerant? What are special requirements (e.g. blending needs, humidity control, flowability, etc.)

Q16

4.7.2 Design for Flow

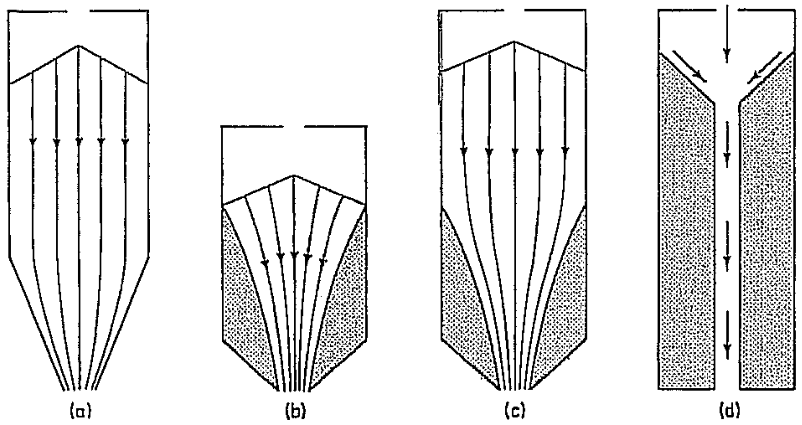
Dry granular materials possess a wide range of properties - from pulverized to lumpy. Some flow freely when dry but not at all when damp. For many granular materials the flow characteristics are well known. However, the more demanding the granular material, the more critical it is to use actual measured properties for silo design. A flow analysis, conducted on a sample of the dry material may be necessary. The success of bin operation depends largely on the design of the hopper. Depending on the shape of a bin, the roughness of its interior surfaces, and the properties of the stored material, different patterns of flow during emptying are possible. Silos have been built and filled only to discover that the stored material will not discharge!

The ideal bulk material should flow uniformly in a symmetrical and concentric vertical flow pattern. The top layers of the stored material should drop evenly, like water, and this mode of flow should continue until the bin is completely empty, discharging the oldest material first (first-in, first-out or “FIFO”). In practice it can be very difficult or impossible to achieve ideal flow. The type of flow described above is called “mass flow.” Mass flow occurs when the entire volume of stored material flows during emptying. Funnel flow occurs in flat-bottom fins and bins with hoppers not steep enough to promote mass flow. The effect of funnel flow is always to reduce storage capacity, but it is also an opportunity for the stagnant granular material to age, compact (set), decay, or spontaneously burn.

Eccentric or off-center vertical flow patterns should be avoided, particularly for large bins or silos. This kind of flow will reduce the possibility of FIFO and will cause added stresses in the side walls. The higher stresses deserve respect, because they can become large enough to cause the complete collapse of the bin.

a. Types of Flow in Bins

Figure 51



Types of flow: (a) mass flow, (b)–(d) funnel flow.

b. Mass Flow Bins

The total volume of stored material is in motion during discharge.
A first-in, first-out flow pattern.
There are no dead regions.
Flow is relatively uniform, and the bulk density of the discharged solid is constant.
Blending is practical.
Low-level controllers and indicators work reliably.
The steep hopper and tall bin requires more headroom.
Much more wear on the walls.

Mass flow configurations are used for cohesive solids, fine powders, solids that degrade or those that exhibit flow segregation. As a general rule, steeper hoppers are required to produce mass flow characteristics.

c. <u>Funnel-Flow Bins</u>

Only a portion of the stored material is in motion during discharge
A last-in, first-out flow sequence prevails.
Materials stored in dead regions may gain strength and obstruct flow.
Segregation usually occurs.
Blending is not practical.
Low-level controllers and indicators are unreliable if embedded in nonflowing material.
Less headroom is required.
Walls are protected from wear by non-flowing material.

Funnel flow bins can provide more economical storage due to lower headroom requirements. Applications that are acceptable for funnel flow include coarse, free-flowing, non-degrading granular material where segregation is not important. Funnel-flow bins are useful for storing free-flowing nonperishable granular materials and for hard, abrasive and lumpy materials.

d. <u>Conditions Affecting Flow Properties</u>

Granular materials which flow freely from a bin under conditions of continuous flow may gain strength and obstruct flow after storage at rest. Some granular materials will not flow because of arch formation across the discharge opening. Flow will stop when internal compressive and shearing forces in the solid (due to cohesion, humidity, time of storage, electrostatic forces, etc.) prevail over gravity forces. Considerations for flow design include:

- Moisture Content
- Temperature
- Gradation
- Segregation
- Degradation
- Corrosiveness
- Abrasion
- Particle Shape
- Particle Size
- Surface Finish of the Hopper
- Angle of Repose
- Spontaneous Combustion
- Dew Point
- Decomposition

Self-discharge by gravity flow is generally preferred. Since gravity is the material mover, power is not required. Flow assist devices, if used, will require some power and maintenance. Where it is impracticable or impossible to design a bin or hopper that will be self-discharging, flow inducers can be used. Flow promotion devices are available in too many forms to address in this guide. It is important to obtain data from the device manufacturer to understand the effects these devices have on the bin and on the stored material. These devices can overcome flow problems caused by inadequate bin design, extreme conditions of stored materials, retrofit applications or design limitations. Improper use of these devices can produce excessive loads on the bin and can consolidate the stored material making flow worse. Flow inducers can be classified according to type as mechanical, pneumatic, and vibratory.

Mechanical - These devices may be as unsophisticated as a sledge hammer. Silos should be equipped with “banging plates” if hammering is anticipated. Rubber walls are also available to withstand hammer blows. Rods are also used to dislodge granular material. Rod ports made from half couplings should be provided for rod insertion. More complicated mechanical unloading devices include multi-auger “live bottoms,” and hoppers using a large feed conveyor as its bottom. Powered mechanical devices will usually require the most maintenance and most amount of power resulting in the most expensive approach.

Pneumatic - Air can induce flow three ways: (1) by aeration of the material by a uniform, gentle flow of air, (2) by jets of compressed air by lance or air blasters as needed; and (3) by inflation of cushions attached to the bin or hopper walls.

Vibratory - If the unit is specifically designed for the vibratory service, and it is properly operated, very little maintenance will be required. Vibrating hoppers may require a flexible connection to the bin to avoid structural damage. “Inducing” flow by vibration requires minimal power since gravity is the primary material mover. Since the units are machines, they will add to the cost of the installation.

4.7.3 Design for Strength

Early designers of vessels for the storage of bulk solids assumed that stored granular materials behaved like liquids and designed the vessels for equivalent fluid pressures. This approach is incorrect because, unlike liquids, granular materials exhibit some strength and some of the granular material weight is transferred to the walls by friction. Janssen confirmed this and in 1895 published a theory that accounts for wall friction. Later, Reimbert & Reimbert published a similar confirmation.

During discharge, pressures higher than predicted by either Janssen or Reimbert are produced. These overpressures can be two to four times larger than initial pressures even in bins with central discharge.

American practice is to use the Janssen method, but parts of Europe prefer the Reimbert method. While the two methods give different static pressures, the factors used to account for overpressure also differ. The result is that the design pressures are more nearly alike, so that the question of which method to use takes on less importance. Methods for calculating silo loads are published in ACI 313 and DIN 1055. These methods require that properties of the bulk materials be known.

Figure 52
Bin Dimensions for use in
Reimbert's and Janssen's Equations

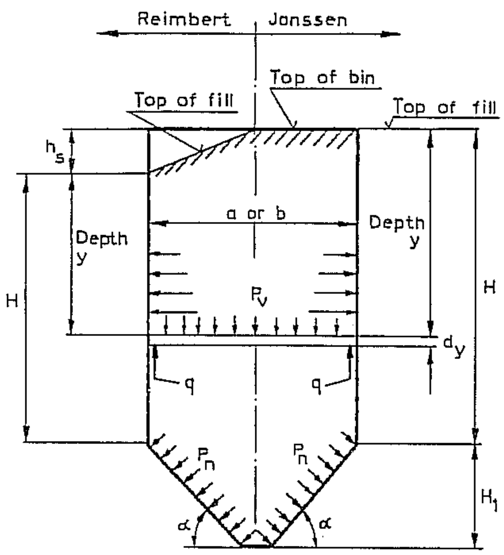
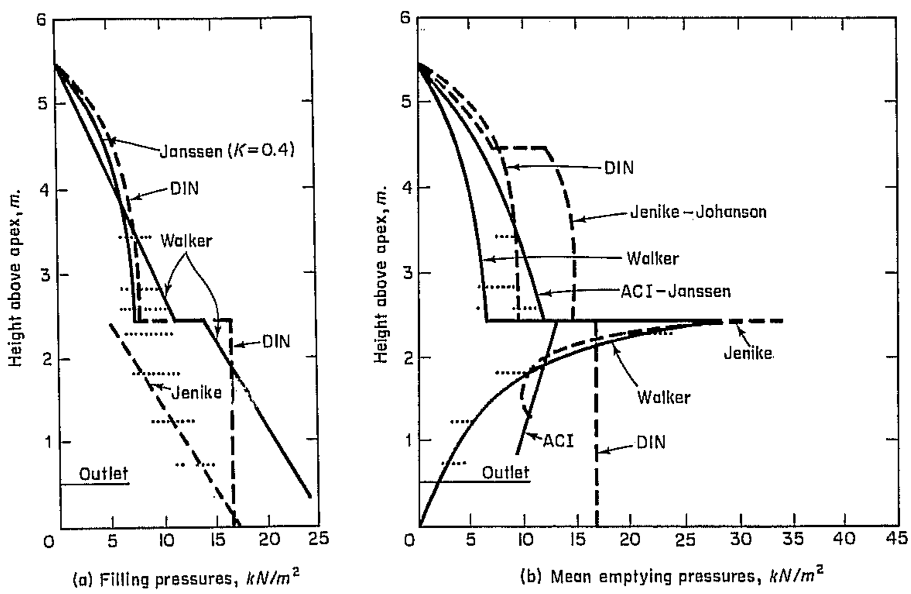


Figure 53
Experimental Pressures Normal to Wall of Bunker



Overpressure or switch loads occur when the stored material switches from a static or dormant condition to the dynamic state of flowing. These pressures are greatest at the junction of the hopper with the vertical sidewall and are illustrated in Figure 53.

There are many tables in the technical literature listing granular material properties as silo design parameters. However, in using those parameters for structural design, the engineer should be aware that they are, at best, a guide (often a poor one) and they may inadvertently lead to unsafe design. Other loads that may be significant include impact loads due to arch collapse and thermal stresses caused by ambient temperature changes (e.g. in the heat of the day the bin will expand and the granular material will settle, but when the bin cools at night the strength of the granular material will resist bin contraction, resulting in thermal stress or crushing of the granular material). The usual design parameters, density, internal angle of friction, and wall angle of friction, all used in computing pressures, are affected by the conditions of the material as well as the operating conditions. Other considerations for strength design include:

- Openings in any part of a storage bin must be adequately reinforced.
- Temperature stresses due to thermal gradients.
- Location (wind, snow and seismic loads)
- Loose density of granular material
- Maximum compacted density of granular material
- Angle of repose
- Hopper slope & other geometrical requirements for flow
- Clearance from foundation to hopper discharge
- Hopper discharge diameter
- (Mass flow) (Funnel flow) design loads
- Operating pressure and vacuum
- Dust collector and/or roof mounted equipment loads
- Roof live load
- Critical buckling criteria
- Center fill or eccentric fill
- Center discharge or eccentric discharge
- Impact loads due to granular material falling
- Other loads
- Internal design pressure
- External design pressure
- Dead Load
- Loads from Accessories

Filling equipment can affect the structural design of the bin. The weight of spouts and conveyors may need to be supported or braced by the bin. Eccentric filling will normally produce asymmetrical material loads. Eccentric flow generally causes unequal lateral pressure distributions along the circumference of a silo. The generally accepted methods or design codes for silo design, such as DIN 1055 and ACI 313, may not be sufficient to establish the adverse effects of eccentric flow patterns and asymmetric loads

Any accessory or component within the granular material may be subjected to drag loads caused by friction. For example, sometimes temperature probes must be suspended by cables to monitor temperature at points within the stored material. Depending on the stored material, depth, and flow pattern in the bin, friction forces on the cables can produce vertical loads between 3,000 and 10,000 lbs per cable. These loads typically are supported by the bin roof. Obviously, the cable and the probe also must be strong enough to resist these loads.

Most liquid storage tanks are hydrotested by filling with water. However, hydrotesting of silos is unusual and may be unsafe unless the silo is designed for hydrostatic loads. Some form of leak testing may be appropriate for granular material storage that cannot tolerate air leaks.

4.7.4 Appurtenances

Q17

Air Vents: Adequate air vents or make-up air are required for bins and silos. As the bulk solid is discharging, incoming air or bulk granular material is required to replace the discharged volume. If it doesn't, a partial vacuum can be created which could cause catastrophic collapse of the bin. Ventilation and relief valves should be sized according to fill rates, operating conditions in the bin.

Weigh Cells: Weigh cells are addressed elsewhere in this guide. When they are used under silo supports make sure they are capable of transferring lateral loads to the foundation.

Explosion Panels: May be necessary for some services and are addressed elsewhere in this guide.

Fire Protection Sprinkler systems may be required inside some silos. Fire protection is addressed elsewhere in this guide.

Level-Indicating Devices: There are two common types: 1) The plumb bob type: a probe similar to a plumb bob on a cable is lowered into the bin, while a counter records the length of cable used and calculates the amount of granular material. When the probe reaches the material level, a trigger reverses the motor, stops the counter, and returns the probe to its original position. 2) Stop motion type: a turning paddle or vibrating sensor is immobilized by the granular material stored around it. As the granular material level goes down during withdrawal, the sensor is freed and signals the level.

4.7.5 References

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"Classification and Definitions of Bulk Materials," ANSI/CEMA 550-1980. Conveyors Equipment Manufacturers Association, Washington, D.C. 20005.

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Jenike, A.W., "Storage and Flow of Solids," Bulletin No. 123 of the Utah Engineering Experiment Station, University of Utah, Salt Lake City, Utah, 1989.

ACI Standard 313, "Recommended Practice for Design and Construction of Concrete Bins, Silos and Bunkers for Storing Granular Materials," American Concrete Institute, Detroit.

Deutsche Normen, DIN 1055, Blatt 6, Lasten Silozellen.

4.8 Dust Collection Systems

Q18

4.8.1 Bag Houses

a. Introduction

Bag houses (more commonly called fabric filters, dust filters or dust collectors) are devices that remove dry dust from an air or gas stream. They may be used to prevent nuisance dust from being emitted to the atmosphere and they may be used to collect valuable material that can be returned to a process or sold as a product.

They consist of a housing, filter media and a method to separate and collect dust deposited on the filter media.

b. The major types of dust filters are:

- Continuous duty, mechanical shaker type bag filters
- Continuous duty, pulse-jet type bag filters
- Continuous duty cartridge type filters
- Continuous duty, pleated bag type filters

c. Filter Media

Purpose of Filter Media

The main purpose of the filter media is to separate the gaseous air from the solid dust particles in the process air stream by using a membrane material or more commonly referred to as “filter media”. The filter media forms a support surface that allows the gaseous air molecules to pass through, while the larger dust particles are captured. A second vitally important capability is for the filter material to easily release the captured dust particles when, for example in an air pulse arrangement, a separate burst of clean air temporarily reverses the flow of the process air stream. The clean air burst has a higher velocity and a greater velocity pressure potential than the process air stream so that the cleaning air is able to overcome the process air flow and thereby release a large percentage of the captured dust particles. A third important capability is for the filter media to prevent a high percentage of the dust particles from passing through the filter media. To assist the filter media in capturing 99.99 percent of the dust particles, a layer of dust or “dust cake” is generated on the incoming surface of the filter media. As more dust particles arrive at the dust cake which rests on the surface of the filter media, the thickness of the filter cake increases and filter efficiency also rises. During the burst of cleaning air, most of the dust cake will be separated from the surface of the filter media and drop downward into the hopper area.

There are other important capabilities of the filter media for specific application needs that will be briefly listed here and will be discussed in more detail later in this chapter.

1. Temperature considerations of the process air stream and the filter media with normal upper limits of 90°C for cellulose to 250°C for fiberglass material.

2. Fire retardant coatings which will retard combustion. (Note: It is not fireproof.)

3. Static dissipation properties:

   a. Carbon Impregnation - Applies to wet-laid media (cellulose) and gives excellent static dissipation properties.

   b. Metallized Finish - Applies to polyester media (spun-bonded) and gives an improved dust cake release and excellent static dissipation properties.

4. Hydro and Oleophobic Finish - Applied into the polyester/media resulting in excellent moisture and mild oil mist tolerance, dust collection efficiency, and material strength.

<u>Selection of Fabric Materials for Dust Collectors</u>

Q19

There are many types of fabric materials available that have been developed in order to satisfy the specific requirements of a given application. The basic criteria for selecting a specific material are listed below:

- Temperature of the process air stream in the collector
- Moisture level inside the collector and/or hydroscopic nature of the dust
- Electrostatic characteristics of the dust
- Abrasion of the dust particles on the filter media
- Acid chemical resistance
- Alkali chemical resistance
- Ease of release of the captured dust particles from the media
- Permeability of the fabric to allow only air to pass through the media
- Cost of fabric materials
- Size of the dust particles to be collected

There are a wide variety of media types used in dust collection filters. The most common are:

Baghouse Filters:

- Polyester: the standard and most widely used baghouse material in the industry.
- Singed Polyester: used for improved dust cake release.
- PTFE Membrane Polyester: used for capture of fine particulate where an artificial dust cake is required.
- Aramid: used for high temperature applications.
- Fiberglass: has very good performance in acid or alkaline environments where high temperatures are present.
- Polypropylene: has superior chemical resistance.

Cartridge Filters:

- Cellulose: the standard and most widely used cartridge material in the industry.
- Cellulose/Polyester: synthetic fibers blended with cellulose to create a high durability media with very good abrasion resistance.
- Spun Bonded Polyester: media having good release characteristics with moisture tolerance and excellent abrasion resistance.

Pleated Bag Filters:

- Spun Bonded Polyester: the standard material in this application.

A general filter material selection table is presented below which correlates key application parameters with the various strengths and limitations of the filter media.

Fiber — Generic Name / Trade Name	Cotton	Polyamid Nylon 66	Polypropylene Herculon®	Polyester Dacron®
Recommended continuous operation temperature (dry heat)	180°F 82°C	200°F 94°C	200°F 94°C	270°F 132°C
Water vapor saturated condition (moist heat)	180°F 82°C	200°F 94°C	200°F 94°C	200°F 94°C
Maximum (short time) operation temperature (dry heat)	200°F 94°C	250°F 121°C	225°F 107°C	300°F 150°C
Specific density	1.50	1.14	0.9	1.38
Relative moisture regain in % (at 68°F and 65% relative moisture	8.5	4.0 – 4.5	0.1	0.4
Supports combustion	Yes	Yes	Yes	Yes
Biological resistance (bacteria, mildew)	No, if not treated	No Effect	Excellent	No Effect
*Resistance to alkalies	Good	Good	Excellent	Fair
*Resistance to mineral acids	Poor	Poor	Excellent	Fair +
*Resistance to organic acids	Poor	Poor	Excellent	Fair
*Resistance to oxidizing agents	Fair	Fair	Good	Good
*Resistance to organic solvents	Very Good	Very Good	Excellent	Good

Fiber — Generic Name / Trade Name	Aramid Nomex®	Glass Fiberglass®	PTFE Teflon®	Polyphenylene Sulfide Ryton®
Recommended continuous operation temperature (dry heat)	400°F 204°C	500°F 260°C	500°F (1) 260°C	375°F 190°C
Water vapor saturated condition (moist heat)	350°F 177°C	500°F 260°C	500°F (1) 260°C	375°F 190°C
Maximum (short time) operation temperature (dry heat)	450°F 232°C	550°F 290°C	550°F 290°C	450°F 232°C
Specific density	1.38	2.54	2.3	1.38
Relative moisture regain in % (at 68°F and 65% relative moisture	4.5	0	0	0.6

Fiber — Generic Name / Trade Name	Aramid Nomex®	Glass Fiberglass®	PTFE Teflon®	Polyphenylene Sulfide Ryton®
Supports combustion	No	No	No	No
Biological resistance (bacteria, mildew)	No Effect	No Effect	No Effect	No Effect
*Resistance to alkalies	Good	Fair	Excellent	Excellent
*Resistance to mineral acids	Fair	Very Good	Excellent	Excellent
*Resistance to organic acids	Fair +	Very Good	Excellent	Excellent
*Resistance to oxidizing agents	Poor	Excellent	Excellent	(2)
*Resistance to organic solvents	Very Good	Very Good	Excellent	Good

* At operating temperatures.

(1) 475°F (250°C) for reverse air & shaker collector

(2) PPS fiber is attacked by strong oxidizing agents.

Comments: Based on typical fiber manufacturers published specifications.

Since there are many possible options for some applications, price and availability will also need to be considered before the final filter media material is chosen.

Also, there are some different ways of making the filter material and optional surface treatments that enhance the properties of the material. The filters can be either natural or manmade and are combined together in various ways as briefly mentioned below:

1. Woven or interlacing of fibers is a process to construct a fibrous material which generally consists of the following types of weaves:

    a. Plain weave is the most basic and consists of the filtering yarn having an over and under construction. By controlling the counts per centimeter of the interlacing yarn, the weave may be made porous or tight.

    b. Twill weave consists of having the warp yarn pass over two or more filling yarns. Typically, the twill weave has fewer interlacings than the plain weave; therefore, the twill weave tends to have a greater porosity and is more flexible than the plain weave.

c. Sateen weave has even more distance between the filling yarns than the twill or plain weave which makes it more porous, flexible, and smoother than the other weaves.

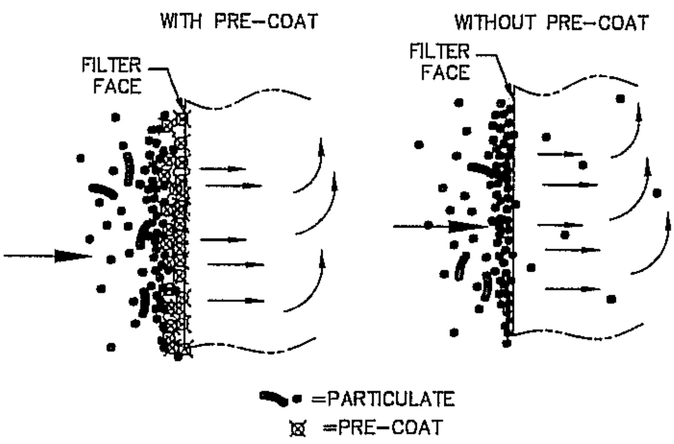
2. Needled-felt material has the short felt fibers pressed together and mechanically fixed by needle punch machine. The main advantage is the low pressure operation that is coupled with excellent dust collection efficiency and a higher flow rate.

3. Singed materials made by a heat process that slightly burns or singes the material surface in order to enhance the surface of the bag material.

Filtration Aid

In some applications where the dust collector contains some moisture, oil and/or very small dust particle sizes, the addition of an inert material or “pre-coat” may be helpful. See Figure 54.

Figure 54



Preferably, the pre-coat material is initially applied onto the new, clean surface of the filter media which forms a protective dust cake layer. The benefits are:

- Aids in dust cake release.
- Pre-coat material is porous which helps to prevent blinding.
- Helps to capture the small particles and limits their ability to penetrate the filter media.
- Increases initial dust collection efficiency to over 99.99 percent.

There are some limitations to the use of pre-coat materials:

- Frequent applications of pre-coat may be required in order to replenish the protective coating that was partially removed during the pulse cleaning.

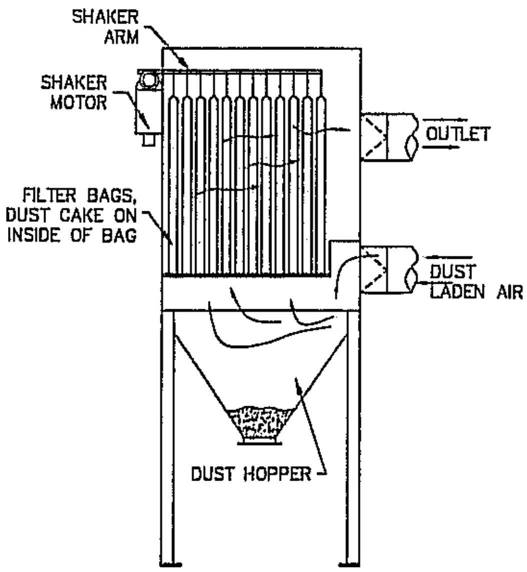
- Recycling dust from the hopper is made more difficult due to the mixing of pre-coat material with product dust.

In making a decision to apply or not apply the pre-coat material the end user must evaluate his unique application and determine whether the benefits are worthy enough to incur the extra material and labor expense of incorporating the pre-coat material into his system.

d. Continuous Duty, Mechanical Shaker Type Bag Filters

To handle the difficult embedded dust particles, the tubular shaker collectors were developed. These collectors (Figure 55) have the opening to the bag at the bottom of the collector, gathers the dust on the inside of the bags, contains some form of tensioning device to keep the cloth light on the bag, and uses a variation of some type of shaker mechanism. Typically each specific design can be evaluated by its mechanism designs. Other parameters include the relatively small bag opening diameters as compared to the overall length. Usually the bag diameter varies from three to twelve inches in diameter and has an overall length that corresponds to a length to diameter ratio of 20 to 35. This ratio gives the cleaning motion a better action and is able to remove the dust more successfully than other shaker types.

Figure 55



Many of these processes require continuous cleaning and cannot tolerate stopping the process for cleaning. To accommodate this requirement, continuous cleaning compartmental collector systems were developed and consist of dividing the unit into multiple modules that have separate dampers.

By closing a damper in one compartment and diverting the flow into the other compartments, the isolated module can be cleaned. These effective filter units have at least two compartments and are produced with as many as 20 compartments. First, the tan flow is stopped momentarily by a damper in one compartment and the isolated compartment unit is effectively now “off-line”. Then, the cleaning action occurs with no fan flow moving through the compartment.

The main drawback of this type of collector is the off-line cleaning process as well as higher maintenance due to its internal moving components. Since it is required to operate at a low air to cloth ratio compared to other designs, this type of collector is usually larger and more costly than other models. Its main advantage is in low volume applications or in environments where compressed air is not available for filter cleaning requirements.

With the advent of pulse-jet type filters, mechanical shaker type filters are rarely used today.

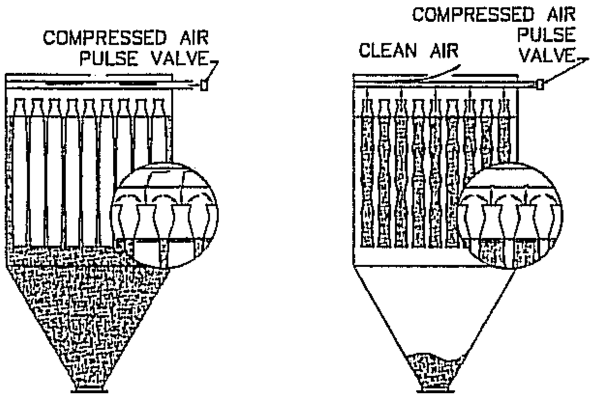
e. Continuous Duty, Pulse-Jet Type Bag Filters

Q20

The majority of bag houses in service today are the pulse-jet type. Their design has evolved over time and new innovations should be considered at the time of purchase.

Fabric pulse jet collectors were developed to expand in the application area for process streams that operate at higher temperatures and corrosive conditions. An early design is illustrated in Figure 56. Features of the collector include the collecting of dust outside of the bag, the grouping of bags into rows, and the cleaning of the bags by rows. Each bag was typically 100 to 150 mm in diameter, 2 meters long, and arranged with 6 to 10 bags in a row. The cleaning sequence was accomplished by cleaning each row of bags individually. The cleaning energy consisted of a compressed air powered eductor or reverse jet that injected compressed air into each bag in the row. A pipe or purge tube was common to all of the bags in a given row and it was located over the center of each bag in the row. Orifice holes were positioned in the purge tube at the center of the bags which directed the compressed air jet into the throat of the bag.

Figure 56



When the compressed air travels through the orifice, it becomes an air jet that expands by the Law of Conservation of Momentum until it is stopped by one of the following:

The opening of the bag itself.

A tube which is inserted into the center throat of the bag and the tube diameter is calculated to generate the proper jet velocity in relation to the size of the orifice in the purge tube.

A so-called venturi, which serves the same purpose as the tube described above, is basically a tube with smooth transitions attempting to reduce the pressure drop as the fan air flows from the bag into the clean air chamber.

An orifice plate that is centered in the throat at the top of the bag has the same purpose as the tubular insert or venturi.

Approximate characteristics of these early cleaning jets were as follows:

Average velocity at throat of the tube, venturi or orifice	76 m/sec
Venturi throat opening	47.625 mm diameter
Jet flow	4.90 m^3/h
Bag diameter and length	115 mm x 1.8 m
Bag area	0.65 m^2
Filter flow rating per bag	170 m^3/h
Nominal filter ratio	0.07 m/sec *
Average pressure drop	0.86 kPa
Average Air Consumption	filtered air
Average dust penetration at 10 gr./cu. ft. load	0.018 gr./m^3

* Actual filter ratio or filtering velocity was lowered by various dust and process characteristics, primarily because of the dust laden air entering into the hopper. Average filter ratios were approximately 10:1 or 0.05m/sec filtering velocity through the bags.

The original design was later modified by the original patent holder and the characteristics of the cleaning jet were altered, presumably to accommodate ten foot long bags. This "generic" cleaning design was then copied by the whole industry. The new characteristics were:

Average jet velocity at the throat	127 m/sec
Venturi throat opening	47.625 mm
Jet flow	840 m^3/h
Bag diameter and length**	115 mm x 3.0 m
Bag area	1.1 m^2
Filter flow rating per bag	150 m^3/h
Nominal filter ratio	0.04 m/sec *
Average pressure drop	1.5 kPa
Average Air Consumption	1.25 m^3/min/100 m^3/min of filtered air
Average dust penetration at 10 gr./cu. ft. load	0.028 gr./m^3

** Overtime there were a variety of bag diameters and lengths introduced by different suppliers. However, the jet characteristics and performance were similar.

The new design was expected to operate at the same nominal filter ratio as the early designs. However field experience showed that the nominal filter rate actually dropped from the designed 14:1 ratio to an actual ratio of 10:1. In reality, the nominal filter ratio for the new design was 8:1, however, most collectors actually operated between 5:1 to 6:1 ratios.

In the new 8:1 ratio design, the air consumption and pressure drop increased dramatically. Unfortunately, in the general selection of dust collectors, the air-to-cloth ratio became the dominant specification in selecting the pulse jet collectors. In time it was generally accepted that the pressure drop, air consumption, and dust penetration would be at the new higher levels. In addition, the average bag life went from 5 to 6 years for the original design to 2 to 3 years for the revised design. In the rapidly expanding market of the early 70's, this deterioration of performance was accepted by the engineers. In fact, to solve any operational or application problems, the cure was to lower the filter ratios even further.

It is important to understand the reason for this deterioration of performance. There were two main factors: 1) upward velocity of dust entering the filter compartment from the prevalent hopper inlets (sometimes referred to as "can" velocity), and 2) the change in the velocity characteristics of the cleaning jet.

Changes in Jet Characteristics ("Generic" Baghouses)

The obvious change was that the jet velocity for cleaning had increased from 75 m/sec to 125 m/sec. It has been well documented that on the revised design, the bag inflated and formed a cylindrical shape during cleaning. This change from a concave shape between the vertical wires on the cage during cleaning has led many to believe that the primary cleaning mechanism was this flexing of the bag during the cleaning cycle. Like all engineering determinations, there was a certain underlying truth to these studies. The fact was that when the collectors were compartmentalized and cleaned off line, this so-called "flexing" of the bag allowed the application of the pulse jet collectors to be used in many processes where no other collector, including the continuous cleaning pulse jet, was effective. However, with the development of the cartridge collector, this type of flexing could not happen during the cleaning of the media; therefore, these theories seemed to be discarded with the passing of time.

It is important to note that if the aggregate open area in the filter cake is larger than the venturi or jet area, suitable pressure will not develop and the bag will not leave the wires. Therefore, no flexing of the bag or media will develop from the velocity of the cleaning air. Typically, when collectors are running below 0.5 kPa, whether cartridge or fabric, this indicates that the effective area of the cake and media combination is very large and the flexing of the bag does not occur. When the pressure drop is over 0.9 kPa, the flexing of the bags will occur on generic venturi-based fabric collectors. After the cleaning cycle, the aggregate area of the opening in the bag/cake is increased. It is in this newly opened area that the dust collects and the pressure drop is lowered until an overall pressure balance is reached.

Velocity of Dust Ejected During the Cleaning Mode

It can be concluded that the dust leaves the bag during the cleaning cycle at the velocity of the cleaning jet. The change from the original design increased from 75 m/sec to 125 m/sec. If these velocities are converted to velocity pressure, we get 3.5 kPa and 9.5 kPa respectively. This indicates that the propelling force of dust from the bag has increased by 2.7 times during the cleaning mode. At the higher velocity, the dust is thrown from one row of bags in the cleaning mode towards the adjoining row of bags.

This dust at the higher velocity drives itself through the adjoining bag and its cake. The dust cake becomes increasingly denser and develops a more resistant baffler until equilibrium conditions are reached.

When examining the dust collected from the clean side of the collector during performance testing, a wide range of dust particles are noted which includes those that are in the 20 micron range and smaller.

On many applications, “puffing” can be observed from the exhaust of collectors immediately after the pulsing of each cleaning valve. This phenomenon is dependent on the effective density of the dust. The lower density dusts tend to penetrate the adjoining bags more than the higher density dusts. Very low density dust such as paper and many fibrous dusts can also operate at low pressure drops, low air consumption, and extremely low penetrations.

Effect on Media Selection

The phenomenon of driving dust through adjoining bags has led bag suppliers to offer a wide array of bag media formulations. If we ignore the requirements imposed by temperature and chemical attack, the main consideration in selecting filter media is its ability to resist the penetration of the propelled dust that traveled through the bag and its associated cake. There are several approaches.

The most effective approach is to use bags with laminated construction where PTFE media is laminated to the felted or woven bag. This laminate has such fine openings that the coating can hold water, yet allows air to pass through the laminate freely. Its original application was to make waterproof fabrics that prevent water from entering the fabrics yet allows the vapor and air to pass through unimpeded. Unfortunately, PTFE bags are expensive when compared to the standard media and therefore are usually used only in special applications.

Another approach is to fabricate the filter cloth with finer threads, especially near the filter surface, to provide a more complex serpentine path so that the dust penetration is reduced. Dual demier felts and woven felts are examples of materials that have a layer of fine threads on the filter surface and coarser threads below the surface.

Bag Modifications

Use pleated filter elements. When a pleated filter is cleaned, the dust can be driven against adjoining elements at high jet velocities, but since the dust is directed at another dust collecting surface that is also blowing dust in the opposite direction, penetration does not occur. There are some limitations and principles that must be applied to selecting and applying pleated filter elements that are beyond the scope of this discussion.

Insert bag diffusers. These proprietary inserts reduce the velocity of the jet cleaning forces as the bags are cleaned. The inserts consist of perforated cylinders that fit into the cage but around the outside of the venturi.

Baffles. Baffles have been inserted between the rows of bags to prevent the dust from impacting the adjoining rows.

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4.8.2 Bin Vents

Bin Vents are simplified versions of bag houses that are flanged to the top of bins, silos and storage tanks. Like bag houses they remove dust particles from dust laden air, most frequently just before the air is vented to the atmosphere.

Bin Vent Filters can be furnished to handle air volumes ranging from 80 to 8,000 cubic meters per hour. Bin Vent Filters are equipped with automatic on-line pulse-jet cleaning. Individual unit sizes range from 1 to 50 square meters of fabric.

a. Types of Bin Vents

Bin vents are available in two (2) basic arrangements:

Arrangement 1: Clean air plenum, tube sheet, bag cleaning system and bag support cages with flanges for mounting directly to the bin or silo.

Arrangement 2: Clean air plenum, tube sheet, bag cleaning system, bag support cages, and dusty air plenum surrounding the filter bags, with flanges for mounting to the bin or silo.

b. Bin Vent Design

Almost all bin vents being put into service today are of the pulse-jet type. A quality bin vent should have the following features and options available:

- Adjustable pulse-cycle timing for optimum performance and maximum bag life. Optional intelligent timers are also available for these units.

- Selection from a wide range of filter media and finishes to match gas/dust composition requirements.

- Venturis matched to collector/media/bag length for optimum cleaning characteristics.

- Rugged welded housings.

- No internal moving parts to wear, repair or replace.

- Materials of construction including carbon steel, stainless steel, aluminum, fiberglass, Inconel, Hastelloy, etc., to fit special requirements.

- Broad selection of internal coatings, special exterior finishes, and insulations.

- Sanitary or 3-A dairy standards construction.

- Accessories to include internal steel grid, roof vent kit, roof top exhaust fan, quick release bag clamps, epoxy-coated and stainless steel bag cages, pulse-on-demand sensors, explosion-proof electrical components, static electricity grounding systems, support legs, and access platform.

Bin vents can be furnished with top access to replace bags or bottom access to replace bags. Top access is required for Arrangement 1 bin vents, since bottom access to the bags would require replacement from inside the hopper, silo or storage tank.

c. <u>Operation of Bin Vents</u>

Operation of bin vents is very similar to that of bag houses. Particles collect on the outside surface of the bags as the air stream passes through the filter media and up to the clean air plenum.

At timed intervals, a selected solenoid valve actuates a diaphragm valve, releasing a pre-determined volume, or pulse, of compressed air into distribution pipe, producing a shock wave along the length of the bag, flexing the fabric and dislodging dust particles from the surface.

The cleaning cycle can also be initiated by monitoring the differential pressure across the filter media as a result of dust build-up. Referred to as "cleaning on demand," this pulsing system only operates when bags require cleaning, minimizing compressed air consumption and lengthening bag life.

d. Advantages of Bin Vents

- High Efficiency. Filter media removes 99.99+ percent of entrained particles.
- Low Energy Requirements. Compressed air usage is minimized through precise matching of cleaning requirements and cleaning frequency.
- Low Maintenance Requirements. No moving parts inside the Collector. Pulsing system can be inspected without shutting down the collector.
- Quick Installation. Welded housing is shipped ready to install for minimum erection costs. Collector may be mounted directly to the bin or silo, or supplied with a hopper and support legs as a freestanding unit.
- Quality, Economy, Dependability
- Can perform in abrasive atmospheres.
- Can operate in high temperature applications (up to 450°F with a proper secretion of filter media).

e. Disadvantages

A major disadvantage of Arrangement 1 type bin vents is that if a bag comes off it will fall into the vessel. The bag can eventually cause plugging in the vessel hopper bottom discharge nozzle or cause damage to a rotary valve mounted to the discharge flange.

A bag-catching grid should be installed on Arrangement 2 type bin vents to prevent bags from falling into the storage vessel.

4.8.3 Cyclones

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a. Inertial Separators

The simplest type of collector is an inertial separator (often called a knock-out pot in pneumatic conveying systems).

This design depends on slowing the flow through the system so that the air velocity is not sufficient to hold the particles in suspension in the air stream. This design utilizes both inertial and gravity forces upon the dust particles.

As the dirty air enters the inlet of the collector, the air immediately reacts to an internal baffle that causes the dirty air to take a downward direction which is followed by a 180 degree upward turn. The inertia and gravity forces drive the particles toward the open hopper.

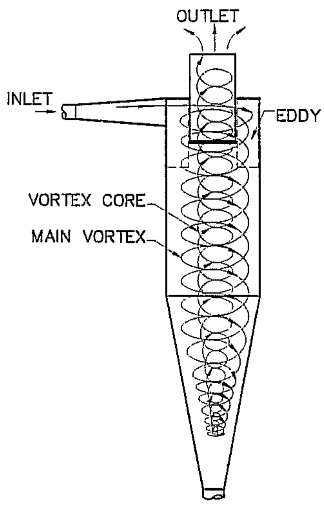
The hopper is shaped such that it intercepts the particles. The particles will often agglomerate and slide toward the hopper outlet. This agglomeration will allow the collection of smaller particles than those particles that might be captured by only the action of gravity and inertia forces.

A common application of this type of collector is as a pre-filter to separate the large particles that might harm some collector models. On process venting hot applications it will remove large sized hot particles that are not cooled by the process gas.

b. Cyclones

Cyclones are centrifugal collectors and depend on centrifugal force to move the dust particles toward the wall of the collection chamber.

Figure 57



The dust laden air enters the collector tangentially at the top and the flow forms a vortex pattern as it travels down the inside vertical wall or barrel of the cyclone (see Figure 57). The tangential forces propel the particles toward the wall. In the whirling air stream, these particles are held against the wall by the centrifugal forces, agglomerate, and slide downward toward the cone of the hopper. The acceleration exerted on the particle is according to the centrifugal equation:

$$A = Rw^2$$

where w is the rotation in radians per second, R the radius of rotation, and A is the acceleration on the dust particles. If we assume that the inlet velocity to the cyclone is a fixed velocity V, then:

$$w = V/R$$

and since the force F is from the familiar equation:

$$F = MA$$

where M is the mass of the particle.

We can deduce the following:

The forces on the larger particles are greater than the smaller particles since the larger particles have more mass.

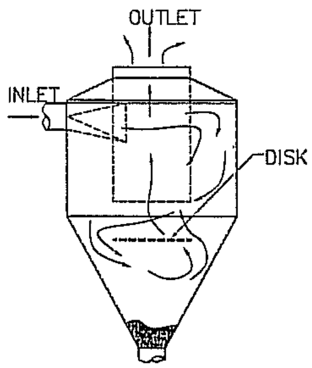
A smaller diameter cyclone has higher forces than a large diameter cyclone. But, as we can see in Figure 57, the air can take multiple revolutions as it travels down the barrel of the cyclone. The efficiency of the collector depends on the size of the particle, the exerted force, and the time that the force is exerted on the dust particles. When the force brings the dust to the cyclone barrel and it is agglomerated, the dust will slide down the wall. The designer has a choice of designing a cyclone with a small diameter and a shorter barrel or a larger diameter with a longer barrel to get the same performance.

High narrow inlets reduce the distance that the dust must travel to reach the wall. In designing ducts for carrying these air streams, the transitions must be smooth to get the maximum performance from the cyclone.

As far as the dust carrying capacities; there are two opposite characteristics. In general, small diameter cyclones will collect dust efficiently even at relatively low loads (200 to 14,000 grains per actual cubic meter), but the pressure drop will range from 1.5 to 2.5 kPa. However, at high dust loads, some of the dust outlets may have a tendency to plug. Large diameter cyclones can handle dust loads in the 100,000 to 200,000 milligrams per cubic meter range with low pressure drops (0.4 to 0.8 kPa), but the collector efficiency will be lower at the low dust loads because the dust particles may be swept from the walls of the collector before the dust particles can agglomerate.

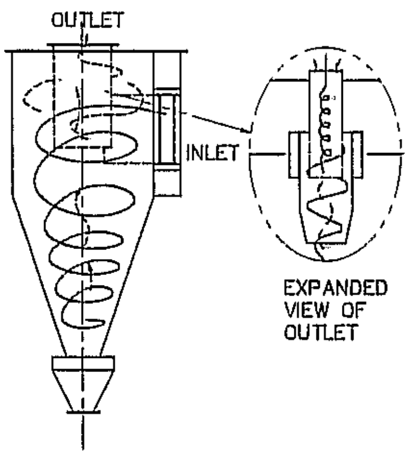
The first generation cyclones (Figure 58) had low pressure drops (0.4 to 0.5 kPa) and relatively large diameters. These collectors were usually arranged so that a fan would blow the dust laden air stream into the inlet. The bottom of these collectors were at atmosphere pressure and the collected dust would drop into a bin or truck.

Figure 58



Dust Discharge Considerations: In high performance, high pressure drop cyclones (Figure 59), a very intense vortex is formed inside the main swirling stream at the discharge point. If this dust is allowed to collect at this junction, it will reentrain and be swept upward into the outlet tube. Expansion hoppers are necessary to allow the dust to be discharged through an airtight feeder. Also, in some heavy moisture applications, they can be effective in "wringing" out moisture before moving onto the baghouse.

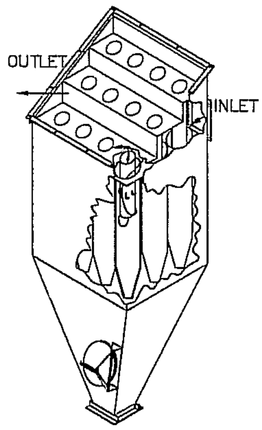
Figure 59



c. Multi-Clones

Multiclone Collectors with vane spinners are a very effective compromise. These are illustrated in Figure 60. The sloped dirty air plenum allows for effective air and dust distribution on the dirty side and even distribution on the clean air side. The most prevalent design uses 150 mm diameter barrels. These multiple cyclones were often applied in boilers as the only acceptable dust collectors. More recently, they are used as the preliminary cyclones and followed by more efficient fabric collectors to meet discharge codes.

Figure 60



d. Summary

Mechanical collectors are mostly used as a preliminary filter in front of other filters or dust collection devices. They can increase the overall efficiency of a solids separation process, especially when the final collector is a water scrubber or an electrostatic precipitator. Also, they are sometimes used for capturing the larger particulates from an air stream where this separation fits into process requirements.

The collection efficiency of these mechanical "cyclone" or inertial separators have some limitations and will not perform as well as cartridge or baghouse collectors. The fact that these mechanisms have few internal parts is a definite advantage, however, ongoing and future requirements for higher filtration efficiency are causing these devices to take a "back seat" to other more sophisticated methods.

4.8.4 Electrostatic Precipitators

a. Introduction

An electrostatic precipitator (ESP) is an electric/mechanical device which removes particles from a gas stream. It accomplishes particle separation by the use of an electric field which:

- imparts a positive or negative charge to the particle,
- attracts the particle to an oppositely charged plate or tube,

- removes the particle from the collection surface to a hopper by vibrating or rapping the collection surface.

Electrostatic precipitators have been used to reduce particulate emissions in many industrial applications for over fifty years. ESP's have been designed to collect particles with diameters of from 0.1 µm to 10.0 µm; collection efficiency is considered high, sometimes exceeding 99%. The ability of ESP's to handle large exhaust gas volumes at temperatures between 175 and 700°C makes them very attractive to many industries. ESP's are commonly used for particulate emission reduction for black liquor operations in the pulp and paper industry, for blast furnaces and sintering operations in the steel industry, and for fly ash control from industrial and utility boilers.

b. Types of Electrostatic Precipitators

Electrostatic Precipitators can be classified as either dry or wet types. Precipitators are further classified as high temperature design and low temperature design. Precipitators can be single stage design or have two stages.

A hot precipitator is designed to operate at gas temperatures in the range of 320°C to 420°C and is usually of the single stage, parallel plate design. It has the advantage of collecting more particulate from the hot gas stream because particle resistance to collection decreases at higher temperatures. The ability to remove particles from the collection plates and hoppers is also increased at these temperatures. However, hot precipitators are usually large in construction in order to accommodate the higher specific volume of the gas stream.

Cold precipitators are designed to operate at temperatures around 150°C. The term "cold" is applied to any device on the low temperature side of the exhaust gas heat exchanger. Cold ESP's are also generally of the single stage, parallel plate design. They are smaller in construction than hot precipitator types because they handle smaller gas volumes due to the reduced temperature. Cold precipitators are most effective at collecting particles of low resistivity since particle resistance to collection is greater at lower temperatures. These precipitators are subject to corrosion due to the condensation of acid mist at the lower temperatures.

A wet precipitator uses water to aid in cleaning the particulate collection plates. It may employ water spray nozzles directed at the collection plates, or inject a fine water mist into the gas stream entering the precipitator. Wet precipitators enhance the collection efficiency of particulates by reducing reentrainment from the collection plates. Care should be taken so that water addition does not lower gas temperature below the dewpoint temperature, thus allowing the formation of acids. A wet precipitator can be of either plate or tube type construction.

Two stage precipitators are designed so that the charging field and the collecting field are independent of each other. The charging electrode is located upstream of the collecting plates. Two stage ESP's are used in the collection of fine mists.

Single stage precipitators are designed so that the same electric field is used for charging and collecting particulates. Single stage ESP's are the most common type used for the control of particulate emissions and are either of tube or parallel plate type construction.

The tube type precipitator is a pipe with a discharge wire running axially through it. Gas flows up through the pipe and collected particulate is discharged from the bottom. This type of precipitator is mainly used to handle small gas volumes. It possesses a collection efficiency comparable to the parallel plate types, usually greater than 90 percent. Water washing is frequently used instead of rapping to clean the collecting surface.

Parallel plate precipitators are the most commonly used precipitator type. The plates are usually less than twelve inches apart with the charging electrode suspended vertically between each plate. Gas flow is horizontal through the plates.

c. Electrostatic Precipitator Design

1. Design Standards and Guides

NFPA 70, National Electric Code

VDI 3678 Blatt 1, Electrostatic Precipitators – Process and Waste Gas Cleaning (German)

Institute of Clean Air Companies (ICAC) Technical Standards:

2. Useful References

United States Environmental Protection Agency (EPA) Air Pollution Control Fact Sheets

EPA-452/F-03-027 Dry Electrostatic Precipitator (ESP) - Wire-Pipe Type, 5 pages

EPA-452/F-03-028 Dry Electrostatic Precipitator (ESP) - Wire-Plate Type, 6 pages

EPA-452/F-03-029 Wet Electrostatic Precipitator (ESP) - Wire-Pipe Type, 4 pages

EPA/452/B-02-001, (EPA) Air Pollution Cost Control Manual: Sixth Edition; Section 6: Particulate Matter Controls, Chapter 3: Electrostatic Precipitators, 61 pages

3. Description of an Electrostatic Precipitator

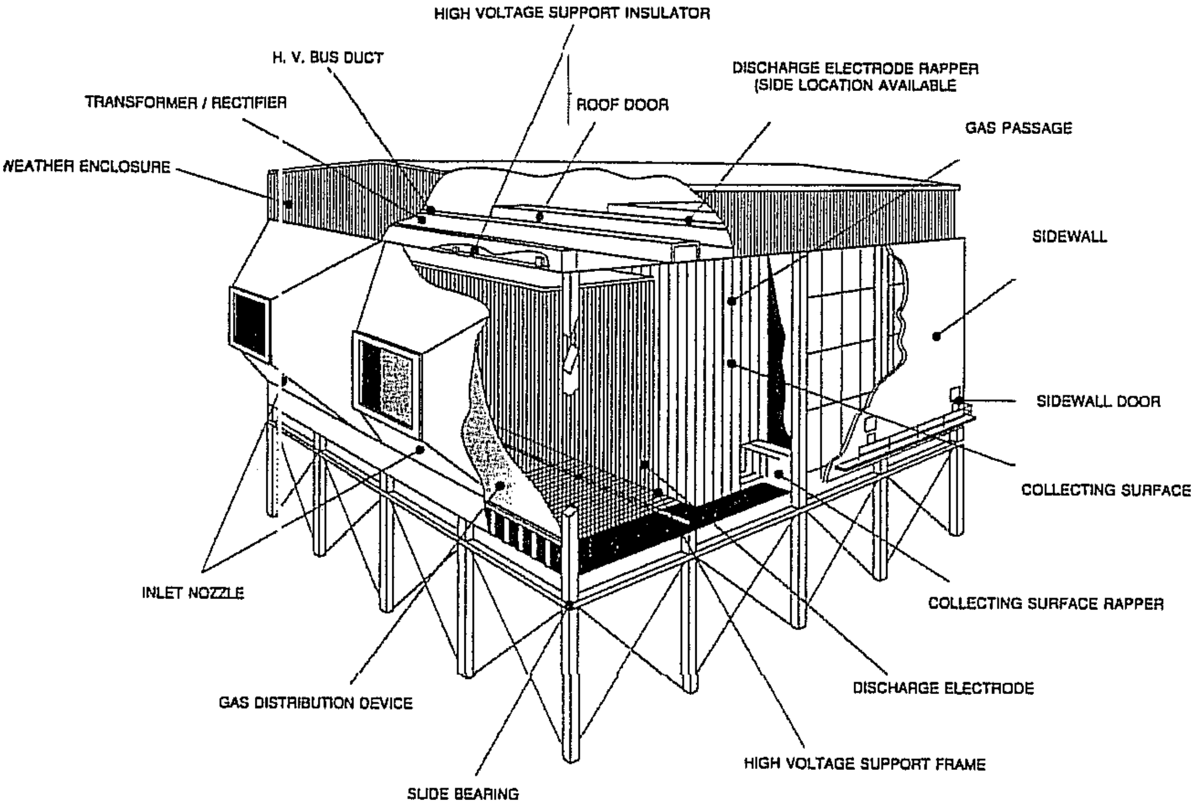
A typical electrostatic precipitator as shown below contains six essential components namely: discharge electrode, collection electrode, electrical system, rapper, hopper, and shell.

The **discharge electrode** is usually a small-diameter metal wire. This electrode is used to ionize the gas (that charges the particles) and to create a strong electric field. The **collection electrode** is either a tube or a flat plate with an opposite charge relative to that of the discharge electrode. The collection electrode collects charged particles. The **electrical system** consists of high voltage components used to control the strength of the electric field between the discharge and collection electrodes.

The **rapper** imparts a vibration or shock to the electrodes, removing the collected dust. Rappers remove dust that has accumulated on both collection electrodes and discharge electrodes. Occasionally, water sprays are used to remove dust from collection electrodes. These precipitators are called water-walled ESP's. **Hoppers** are located at the bottom of the precipitator. Hoppers are used to collect and temporarily store the dust removed during the rapping process. The **shell** structure encloses the electrodes and supports the entire ESP.

ESP's that use plates as collection electrodes are called plate precipitators. ESP's that use cubes for collection electrodes are called tubular precipitators.

Figure 61 - Typical Electrostatic Precipitator (Institute for Clean Air Companies)



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4. Components of an Electrostatic Precipitator (Figure 61)

   a. **Shell**. The shell of an ESP has three main functions: structural support, gas flow containment, and insulation. Shell material is most commonly steel; if necessary, insulation can be applied to the exterior to prevent heat loss. Brick or concrete linings can be installed on shell interiors if gas stream corrosion of the metal may occur. Corrosion resistant steel can also be used as a lining, but the cost may be uneconomical and at times prohibitive. Since the shell is also used for structural support, normal civil engineering precautions should be taken in the design.

   b. **Weighted wire discharge electrodes**. Wires vary in type, size, and style. Provision is made to keep the discharge wire from displacement by attachment to a suspended weight. The wires can be made stiff consisting of a formed sheet, or they can be simple variations of the normal straight round wire such as being barbed or pronged. Steel alloys are commonly used for wire construction, but actually any conducting material with a proper configuration and sufficient tensile strength can be used.

1. **Rigid frame discharge electrodes**. Rigid frame designs incorporate a framework which supports the discharge electrodes. By using the rigid frame design the need for wire weights is eliminated since the frame keeps the wires properly supported and aligned.

2. **Rigid electrodes**. The rigid electrode design uses electrodes that have sufficient strength to stay in alignment their entire length. The electrodes are supported from the top and kept in alignment by guides at the bottom. Rigid electrodes are the least susceptible to breakage.

c. **Collection electrodes**. There are numerous types of collection electrodes designed to minimize reentrainment and prevent sparking. The material used in construction, however, must be strong enough to withstand frequent rapping. In order to insure correct electrode application, it is wise to see if the electrode chosen has exhibited good performance at similar installations.

d. **Hoppers**. A hopper is used to collect ash as it falls from the precipitator. The hopper should be designed using precautions against corrosion in the precipitator as any leakage due to corrosion will enhance entrainment. If the precipitator is dry, a hopper angle should be chosen that will prevent bridging of collected dust.

Hoppers must be sized so that the amount of dust collected over a period of time is not great enough to overflow and be reentrained. Seals also must be provided around the outlet to prevent any air leakage. If the precipitator is wet, the hopper should allow removal of sludge in a manner compatible with the overall removal system. In general the collected dust in the hoppers is more free flowing when kept hot. The hoppers should be insulated and should have heaters to maintain the desired temperatures. Hoppers heaters will also prevent the formation of acids that may occur at low temperatures. Provisions should be made for safe rodding out the hoppers should they become plugged.

e. **Rappers**. Rappers are used to remove dust from the discharge and collection electrodes. Rappers are usually one of two types, impulse or vibrator. The vibrator type removes dust from the discharge electrode by imparting to it a continuous vibration energy. They are used to remove dust from the collection electrodes. Impulse rappers consist of electromagnetic solenoids, motor driven cams, and motor driven hammers. Important features to note in choosing rappers are long service life without excessive wear and flexible enough operation to allow for changing precipitator operating conditions. Low intensity rapping of plates (on the order of one impact per minute) should be used whenever possible to avoid damage to the plates. Visual inspection of the effect of rapping on reentrainment is usually sufficient to determine a good rapping cycle.

f. **High tension insulators**. High tension insulators serve both to support the discharge electrode frame and also to provide high voltage insulation. The materials used are ceramic, porcelain, fused silica and alumina. Alumina is the most common. The insulators must be kept clean to prevent high voltage shorting and resultant equipment damage. Compressed air or steam can be used for this purpose.

g. **Four point suspension**. Rigid electrode and rigid frame units may utilize a four point suspension system to support the discharge electrode framework in each chamber. This type of suspension system assures a better alignment of the discharge and collection electrodes. This in turn provides a more consistent operation.

h. **Distribution devices**. Perforated plates, baffles or turning vanes are usually employed on the inlet and outlet of an ESP to improve gas distribution. Improper distribution can cause both performance and corrosion problems. These distribution devices may require rappers for cleaning.

i. **Model testing**. Gas flow models are used to determine the location and type of distribution devices. The models may include both the inlet and outlet ductwork in order to correctly model the gas flow characteristics. Gas flow studies may not be required if a proven precipitator design is installed with a proven ductwork arrangement.

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5. Control Systems

The electric power control system is the most important component system of any ESP. The basic components of this system are: step-up transformer; high voltage rectifier; voltage and amperage controls; and sensors.

a. **Automatic power control**. By utilizing a signal from a stack transmission meter the power level in the precipitator can be varied to obtain the desired performance over a wide range of operating conditions.

b. **High voltage transformer**. The standard iron core transformer is the only instrument generally used to step-up the input voltage. The only care that need be taken is that the transformer is of superior quality and able to put out the quantity of voltage required by the precipitator. Transformers are designed to withstand high ambient temperatures and electrical variations induced by sparking. For high temperature operation, the most common transformer cooling method is liquid immersion.

c. **High voltage rectifier**. Silicon rectifiers are the latest advance in rectifying circuitry. They are solid state devices which have a few of the disadvantages of the other types of rectifiers. An assembly of silicon rectifiers is used for lower rated current sets, typically 500 miliamperes (mA).

d. **Voltage and amperage controls**. Controls are needed to insure that the precipitator is supplied with the maximum amount of voltage or power input, and to control the effects of sparking. The most modern method of accomplishing these aims is through the use of silicon controlled rectifiers (SCR). Other modern control devices are saturable reactors and thyristors (four element, solid state devices). Voltage control can also be accomplished by tapped series dropping resistors, series rheostats, tapped transformer primaries, and variable inductances.

e. **Auxiliary control equipment**. As with any control device, gas flow should be monitored either by readout of amperage from the fans or by measuring static pressure. It is also useful to have sensors which measure the sulfur dioxide (SO_2) concentration and temperature of the inlet gas stream in order to determine the dew-point temperature.

6. Advantages and disadvantages

Advantages

1. The pressure drop through a precipitator is a function of inlet and outlet design and precipitator length. Pressure drop rarely exceeds 0.15 kPa.

2. The ESP can be designed to have 99.9 + percent collection efficiency.

3. Silicon control rectifiers and other modern control devices allow an electrostatic precipitator to operate automatically.

4. Low maintenance costs.

Disadvantages

1. Due to the size of a typical ESP and the erratic nature of most processes (especially if frequent start-up and shutdowns occur) the temperature in different parts of the structure could at times drop below the acid dew point. Corrosion can cause structural damage and allow air leakage.

2. An ESP is sensitive to its design parameters. A change in the type of coal used, for example, could drastically affect performance.

3. High capital costs.

5. High voltages are required.

6. No SO_2 control is possible with an ESP.

7. Special Types of Electrostatic Precipitators

Using a grant from the United States Department of Energy's National Technology Laboratory, Ohio University, Southern Environmental, Incorporated and Croll-Reynolds Clean Air Technologies have combined talents to develop a lower cost, new design wet electrostatic precipitator. This new type of wet/saturated precipitator utilizes fabric membranes made from materials capable of dispersing the cleaning liquid by capillary action, instead of the traditional electrodes made from solid metal sheets or tubes (high alloy metals for corrosive applications).