SECTION 5

LEADING-EDGE CONCEPTS

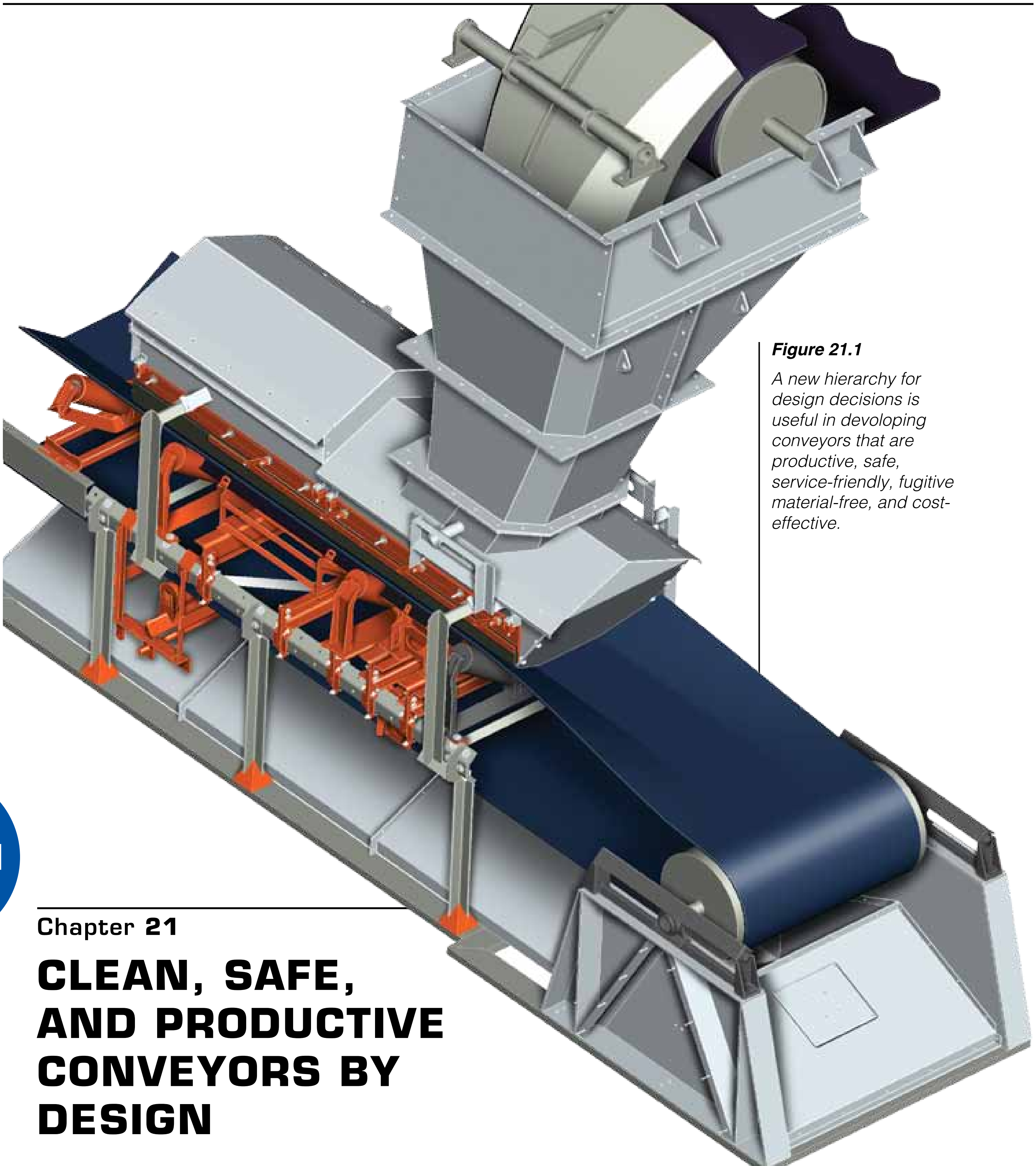

Figure 21.1

A new hierarchy for design decisions is useful in devoloping conveyors that are productive, safe, service-friendly, fugitive material-free, and cost-effective.

21

Chapter **21**

CLEAN, SAFE, AND PRODUCTIVE CONVEYORS BY DESIGN

In this Chapter...

In this chapter, the traditional conveyor design hierarchy—1: capacity, 2: minimum code compliance including safety, and 3: lowest price—is questioned. A new design hierarchy, in step with designing conveyors that are not only of the proper capacity and code compliant but also 1: clean (control of fugitive materials), 2: safe (service-friendly), and 3: productive (cost-effective and upgradable), is proposed (**Figure 21.1**).

Since the invention of the belt conveyor, there have been substantial changes in safety rules, pollution regulations, construction standards, and required carrying capacity of these systems. Unfortunately, the details of design and fabrication of belt conveyors are still governed by "rules of thumb" and design methods that have been passed down from one generation of designers to the next. Other than advances in computers to predict performance, synthetic carcasses for belts, and improved control technologies, conveyor systems are designed much the same way they were 50 years ago.

Most engineering and construction project contracts are awarded on a low-bid basis. Current supplier practice is to base a bid on the price per kilogram (per pound) of fabrication, with minimal design time, in order to be competitive in this low-bid system. Due to these competitive pressures, it is common practice for suppliers to base a proposal on specifications, drawings, and designs that were completed previously for a similar system. Regrettably for the owners, operators, and maintainers of conveyors, this practice often produces a 50-year-old design at state-of-the-art prices. Since the system was designed with old thinking, it will likely fail to meet today's expectations.

This chapter demonstrates how designing components and critical sections of conveyors can lead to clean, safe, and productive bulk-material transportation systems.

THE DESIGN PROCESS

As expressed by George E. Dieter, "To design is to pull together something new or arrange existing things in a new way to satisfy a recognized need of society" *(Reference 21.1)*. Design is just as much art as it is science. Every company's design process will differ, but most include:

A. Problem definition

B. Information gathering

C. Concept generation and evaluation

D. Modeling and simulations

E. Material selection

F. Risk, reliability, and safety reviews

G. Cost evaluation

H. Detail design

I. Communicating the design

The intricacies of this process will not be discussed in detail here, but it is important to note that the process begins with the identification of a need and a definition of the problem. This first step, although critical, is often overlooked. Based on how the problem statement is defined, the final result can differ greatly.

The purpose of a belt conveyor system is to provide a means of moving one or more bulk materials from one point to another. The total belt conveyor system can be broken down into several sections or zones with the detail and design of those sections being examined from new and different points of view. A traditional problem definition would be to transport a specific type, size, and amount of material from point A to point B. If the requirements are expanded to include considerations for safety and the minimization of the escape and accumulation of fugitive materials, then the entire conveyor system takes on a different perspective. When additional factors—such as ease of installation, maintenance, and cleanup; standardization of components; and the creation of a cost effective, upgradeable design—are included, a conveyor belt system designed under these criteria is quite different from the typical conveyor system provided today.

In order to initiate a change to new, more modern designs—designs where cleanliness, safety, and serviceability are also included in the initial design considerations—a new, more comprehensive view of how bulk materials are handled must be investigated.

SAFE DESIGN

Personnel are the single most important resource of any mine or industrial operation; therefore, engineers and designers should incorporate functionality into designs that will improve safety. While designs have changed little, the work-place environment has changed significantly. Restrictions regarding lifting, requirements for lockout / tagout / blockout / testout, regulations on confined-space entry, and a host of other safety procedures have been established. At the same time, there is increasing pressure for continuous and ever-increasing production.

Applying design principles to help ensure worker safety should include the use of barrier guards and the implementation of new designs that will improve the ease of cleaning around and changing out equipment. Employee training for enhanced awareness up to and including qualification requirements should be instigated as well.

Barrier Guards

In order to better protect personnel from coming in contact with moving conveyor components, the trend is to install barrier guards (also called area guarding) around the entire conveyor (**Figure 21.2**). These barrier guards should be installed around all pinch point locations and anywhere personnel could come into contact with moving parts. Barrier guards should be designed for easy installation and removal to allow for authorized service personnel to perform required functions safely and efficiently and to ensure the guards are returned to place when the work is completed. *(See Chapter 2: Safety.)*

Figure 21.2

Barrier guards (also called area guarding) are installed to keep plant personnel from dangerous contact with equipment.

Maintenance During Operation

With many conveyors operating around the clock, scheduled downtime is at a premium. When handling bulk materials, problems occur and equipment fails prematurely, resulting in lost productivity, emergency cleanup, and repair requirements.

Many safety standards around the world recognize that certain maintenance procedures must be performed while equipment is in operation. These standards allow for exceptions to the rules requiring equipment to be shut down for service. Exceptions are written so only personnel authorized and trained for awareness of the potential hazards can adjust equipment that is in operation. Indeed, the trend in safety standards (as specified in the International Organization for Standardization (ISO) document ISO/EN 14121) is away from task-specific restrictions toward risk-ranked restrictions based on a formal risk analysis. When a case can be made that the risk of personal injury of servicing equipment while the equipment is in operation is actually equal to or less than the risk of personnel injury while servicing equipment that is stopped and locked and tagged out, newer safety standards will recognize that the lowest-risk procedure is the preferred approach.

Some conveyor belt system components require frequent service to maintain optimal efficiency (for example, belt cleaners). In the control of fugitive materials and the ability to run a conveyor continuously, belt cleaners are critical. Due to safety concerns, most operations prohibit the servicing of belt cleaners while the conveyor is in operation. The inability to service a belt cleaner can lead to carryback and spillage problems that create safety hazards. Belt cleaners and other conveyor components can be designed to be safely serviced while the belt is running. Specialized tools can be designed and service techniques can be taught to develop authorized maintenance employees or service contractors who can safely service certain components while the belt is running (**Figure 21.3**).

CLEAN DESIGN

Clean designs are critical to operating a safe and productive material-handling system. However, in today's normal industrial facility or mine, it is not possible to operate a conveyor system that is 100 percent free of fugitive material (**Figure 21.4**). Poor initial designs, lack of maintenance follow-up, variability of the properties of bulk materials, conveyor overloading, and constant wear on system components are strong contributors to unexpected releases of fugitive materials.

Many design details contribute to creating a conveyor system as free of fugitive materials as possible. Incorporating dust-resistant structures, proper skirtboard design, external wear liners, appropriate pulley sizing, and belt-tracking alternatives; ensuring the working area is clean and free of utility components; and allowing for future upgradability are issues that will be discussed to improve material-handling operations. There are a number of leading-edge technologies that can be incorporated into a conveyor system to improve its control of material. These options include engineered flow chutes *(see Chapter 22: Engineered Flow Chutes)*, air-supported conveyors *(see Chapter 23: Air-Supported Conveyors)*, and belt-washing systems *(see Chapter 24: Belt-Washing Systems)*.

Modern 3D drafting and fabrication techniques make it feasible to arrange components in non-traditional ways without greatly increasing the costs of these systems. One of the simplest details is to ensure components are oriented in a manner that provides as few flat surfaces as possible upon which fugitive material can accumulate (**Figure 21.5**).

Dust-Resistant Structures and Components

Cleaning around conveyors is a necessity. By eliminating places where fugitive materials accumulate, cleaning requirements are reduced and simplified. Horizontal structural members should be angled at 45 degrees whenever possible in order to shed material, thus making it unlikely that cleanup crew members will have to reach under the belt with tools to remove buildup.

Structural members that cannot be oriented to reduce dust buildup should be fitted with dust plates or caps to reduce material buildup in hard-to-clean areas (**Figure 21.6**).

Figure 21.3

Specialized tools and safe designs make belt-cleaner service easier.

Figure 21.4

Fugitive material accumulates on flat surfaces.

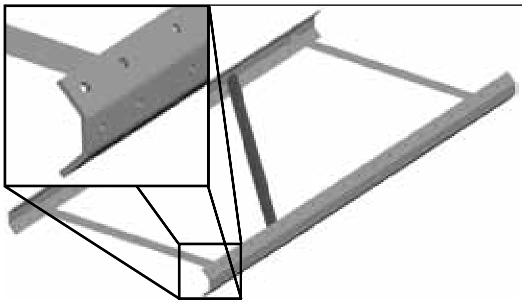

Figure 21.5

The minimization of flat surfaces, including stringers and skirt supports, can reduce the buildup of material.

21

Deck plates and drip pans should be designed to shed material toward the outside of the conveyor where fugitive material can be more easily collected (**Figure 21.7**). In order to assist in the reduction of buildup of dust and ensure any fugitive material will flow to the outside of the conveyor, these pans should be designed for the application of vibration.

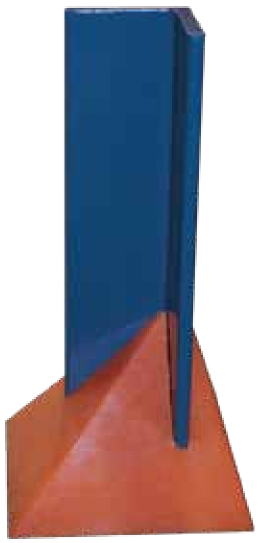

Figure 21.6

Dust caps are installed to reduce the accumulation of fugitive material.

Figure 21.7

Angle deck plates under the conveyor load zone will direct fugitive materials to the outside of the structure.

Figure 21.8

A conventional skirtboard design places the wear liner on the inside of the skirtboard.

Skirtboard Height

The height of the skirtboard (chutewall) cited in the Conveyor Equipment Manufacturers Association's (CEMA) *BELT CONVEYORS for BULK MATERIALS, Sixth Edition*, and in other references and standards, is based on the largest size lump that will be carried on the conveyor without skirtboard covers. Today, many skirtboards are covered in order to contain dust. It is recommended that skirtboards be designed to accommodate the air flow above the bulk material. (*See Chapter 11: Skirtboards.)* This leads to a requirement that is at least two times the height CEMA recommends for open-top skirtboards. *(See Chapter 11: Skirtboards for more information on calculating the proper height for covered-top skirtboards.)* Skirtboard tops should be designed to include significant pitch in order to avoid material buildup.

External Wear Liner

The practice for years has been to attach the wear liner to the inside of the vertical metal skirtboards. The wear liner is then positioned between the bulk material and the metal skirtboards (**Figure 21.8**). The skirtboard serves as the structural member that supports both the wear liner and the skirtboard seal. If incorrectly mounted, wear liners will fail to protect the skirtboard seal from wear and sometimes trap material against the belt, thus grooving or otherwise damaging the belt. In this traditional setup, with the wear liners mounted to the inside of the skirtboard, inspection and replacement are difficult due to the placement of the liners behind the skirtboard. Replacing wear liners mounted on the inside of the skirtboard is a complicated job requiring manual manipulation of heavy sections in tight quarters and sometimes even involving confined-space entry.

Wear liner repositioned so it is placed on the outside of the skirtboard—where it can be easily inspected, accurately installed, and easily replaced—is a simple modification potentially saving thousands of maintenance hours (**Figure 21.9**). Skirtboard provides structural support; raising it above the normal flow pattern of the bulk material and implementing a small design change to the skirt-seal clamps enables the wear liner to be installed on the outside of the skirtboards. The wear liner can also be made adjustable for accurate installation.

Pulley Sizes

For decades, tail, bend, and discharge pulley sizes have been selected from tables published by belting manufacturers with minimum pulley diameters based on minimizing costs and providing safe stress levels for the belt. Determining the correct size of pulleys should include consideration of ease of access for service. A larger-diameter pulley—one with a minimum pulley diameter of 600 millimeters (24 in.)—would allow adequate space between the carrying and return runs for installation of a tail pulley-protection plow and, if necessary, a return belt plow (**Figure 21.10**). The additional space that would be supplied between the carrying and return runs of the belt allows for easier inspection of plows and provides adequate space for the plows to eject fugitive materials from the belt. A larger-head pulley at the belt discharge provides needed space for installing belt cleaners in the optimal working position. The added cost of adding larger pulleys is offset by the cost savings derived by effectively controlling fugitive materials and by requiring shorter down times and less maintenance.

Indexing Idler

Belt mistracking is a major cause of spillage; therefore, much attention is given to belt-training devices in order to keep the belt centered in the structure. In an effort to keep the overall cost of a new installation down, training idlers are often supplied in lieu of belt-training devices on many new installations. Training idlers often end up tied off to one side or the other in an attempt to either compensate for a situation beyond the capability of the device or protect the device from excessive wear due to the belt continuously running to one side. Conveyor belts often run to one side or the other due to conditions such as off-center loading, conveyor structure alignment issues, conveyor component alignment problems, weather conditions, or a variety of other factors. Loose pieces of wire or rope, used to tie off training idlers, in the vicinity of the moving belt are safety hazards. This issue can be exacerbated by changing conditions or operator preferences that require an indexing idler tied off to hold the belt in one direction in the morning to be switched to tie off the belt in the opposite direction in the afternoon.

In the absence of properly aligning the conveyor structure, replacing and/or aligning conveyor components that are causing belt-alignment issues, ensuring the load is properly centered, or installing one or several belt-training devices to properly align and track the belt, these training idlers can be fitted with a mechanism that allows them to be "indexed," or locked into position, without resorting to unsafe wire or rope tie-downs (**Figure 21.11**).

Conduit and Piping

Conveyors provide convenient paths for running utilities and electrical components. For decades, utilities and electrical piping have been installed along the conveyor's

Figure 21.9

Wear liner installed on the outside of the skirtboards is a simple modification potentially saving thousands of maintenance hours.

Figure 21.10

The tail-pulley diameter should be selected to have plenty of clearance for installation and service of a plow.

21

structure with little regard to the effects of this location on the installation, maintenance, and operation of conveyor components. This issue is particularly noticeable in the discharge and loading zone areas of the conveyor belt system. For example, it is common to see plows buried behind a web of conduit that was installed after the plow was positioned (**Figure 21.12**). Plows need to be able to eject foreign objects from the conveyor in the location selected by the designer.

The utility conduits in the discharge and load zones in particular should be run in locations where they do not interfere with access to components that are essential to the control of fugitive material. The main conduit could be run overhead with flexible conduit dropped down where required to provide power to or communicate with the components. Along the carrying run of the conveyor, the structure can be used for supporting conduits as long as the conduit does not interfere with access for service or reduce the effectiveness of the individual components.

Figure 21.11

This training idler can be adjusted and locked in place safely and without tying it off with wire or rope.

Figure 21.12

Conduit placed alongside the conveyor makes access for maintenance impossible.

PRODUCTIVE DESIGN

Following design principles that establish safe, service-friendly, and easy-to-clean belt conveyor systems leads to better and more productive operating systems. A cleaner, safer operation is normally a more productive operation in the long run. Safety issues normally correspond to unsafe operating conditions, which are also detrimental to the equipment. Airborne dust can find its way into lungs and bearings; material can accumulate under and on walkways and conveyors, leading to trip, slip, and fall hazards. These unsafe operating conditions are not only hazards to health, but also to the condition of the conveyor equipment. When equipment is shut down for unscheduled repairs, it cannot be productive.

Cost Effective

The total cost of ownership, including the cost per kilogram (per pound) of dealing with fugitive material releases, should be considered in making design and purchasing decisions. Unfortunately, the lowest-bid process discussed earlier, that considers only initial purchase price, has slowed the evolution of clean, safe, and productive designs. While initial purchase price may be lower for a system with no adjustment capabilities and no consideration for future wear-component replacement, the higher costs required to properly install and maintain components, clean up fugitive materials, and cover additional equipment downtime will far exceed the costs of a system which takes these factors into consideration in the initial design.

Utilizing standard components where possible in the design may make economic sense, because some economy of purchase may be realized. With some forethought and some slight design changes, standard components (structure, cradles, skirting, etc.) can often be adapted to these new design principles. Use of standard components can provide for ease of installation and replacement due to standardization across the plant. Designing the system for ease of upgradability, by making components track mounted (**Figure 21.13**) and service-friendly, can reduce down time and control fugitive materials.

Upgradeable

Designers routinely consider capacity upgrades, but they rarely include provisions for component upgrades. A track-mount system provides flexibility for quickly installing different problem-solving components. The use of a pre-engineered mounting hole pattern in the structure around the conveyor's transfer point allows for the installation of a new or improved system quickly and easily (**Figure 21.14**). A uniform-hole pattern for accessory mounting will encourage component suppliers to adapt modular, bolt-on, or clamp-on designs for easy retrofits. Utilizing structural platform designs—which incorporate tracks, modularity, and easy retrofitability—will encourage designers to continue to modernize the way bulk materials are handled today and in the future.

Figure 21.13

This universal track allows for slide-in/slide-out maintenance.

Figure 21.14

A clamp-on bracket allows for the simple installation of a track system for belt-support components.

A NEW HIERARCHY

In Closing...

Modern design techniques—such as 3D modeling for fabrication, Finite Element Analysis (FEA) for structure, and Discrete Element Modeling (DEM) for chute design—can be used to improve conveyor reliability, productivity, and safety while reducing the total cost of ownership. To achieve clean, safe, and productive designs, designers should consider a new hierarchy for design decisions:

A. Capacity

B. Safety and code compliance

C. Control of fugitive materials

D. Service friendliness

E. Cost effectiveness

F. Upgradability

Decisions related to the design of the conveyor system or the selection of individual components should follow a hierarchy to ensure the best design possible is created.

In the future, all bulk-material handling systems should incorporate designs to safely move the required amount of material from point A to point B in a service-friendly, cost-effective manner that controls dust and fugitive materials for now and ever more.

Looking Ahead...

This chapter, Clean, Safe, and Productive Conveyors by Design, the first chapter in the section Leading-Edge Concepts, discussed the wisdom of designing bulk-materials handling systems that may cost more initially but save money in the long run. The next chapter, Engineered Flow Chutes, is the first of three chapters that present designs for cleaner, safer, more productive conveyor systems.

REFERENCES

21.1 Dieter, George E. (1999). *Engineering Design: A Materials and Processing Approach*, Third Edition. McGraw-Hill.

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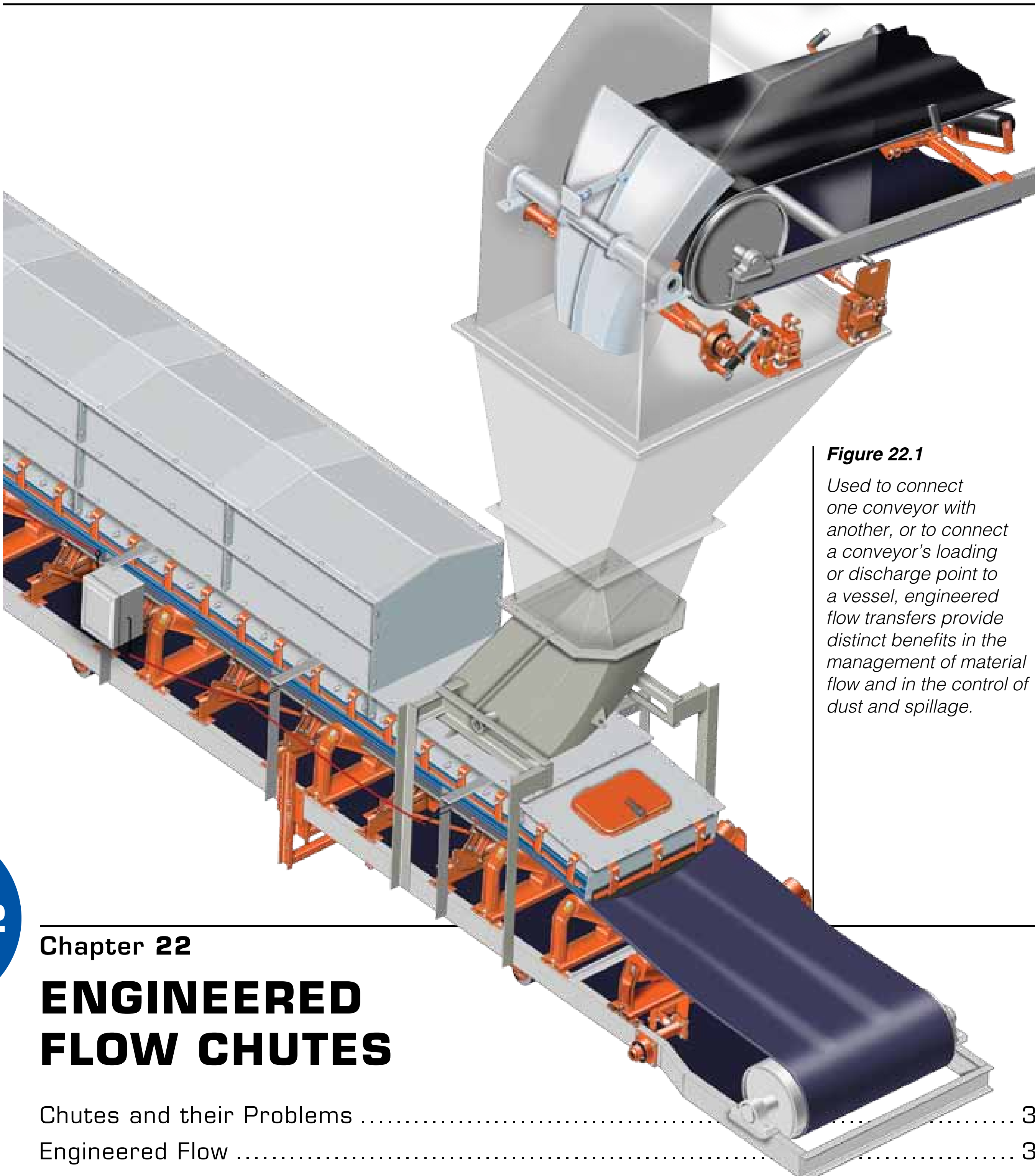

Figure 22.1

Used to connect one conveyor with another, or to connect a conveyor's loading or discharge point to a vessel, engineered flow transfers provide distinct benefits in the management of material flow and in the control of dust and spillage.

22

Chapter 22

ENGINEERED FLOW CHUTES

In this Chapter…

In this chapter, we discuss the benefits of engineered flow chutes and the ways they resolve problems common with transfer chutes. The components of engineered chutes—the hood, spoon, and settling zone—are defined. We also describe the process used to design them, along with information required by designers to do so.

One leading-edge development that improves the conveying of bulk materials is the advent of engineered flow chutes (**Figure 22.1**). Used to connect one conveyor with another, or to connect a conveyor's loading or discharge point to a storage vessel or other process step, engineered flow transfers provide distinct benefits in the management of material flow and in the control of dust and spillage.

Custom designed for each individual application, engineered flow chutes control the material stream from the discharge conveyor to the receiving conveyor. *(See Chapter 8: Conventional Transfer Chutes.)* A well-designed engineered flow chute maintains a consolidated material profile that minimizes dust generation and wear, by accomplishing all of the functions of a transfer chute:

A. Feeding the receiving conveyor in the direction of travel
B. Centering the material load
C. Minimizing impact on the receiving belt
D. Supplying the material at the speed of the receiving conveyor
E. Returning belt scrapings to the main material flow
F. Minimizing the generation and release of dust

Although the initial investment in an engineered flow chute may be greater than the cost of a traditional transfer chute, the return on investment to the plant will be prompt, through reduced operating and maintenance expenses. Problems such as belt damage, premature wear of belts and chutes, chute plugs, spillage, dust, spontaneous combustion, and material degradation are greatly reduced, if not eliminated, with the controlled material stream that travels through an engineered flow transfer chute.

CHUTES AND THEIR PROBLEMS

The engineering of bulk-materials handling systems has previously been largely based on experience, "rules of thumb," and educated guesses. But now sophisticated computers and software packages provide the design and modeling technologies that allow better understanding and management of material flow. These software and hardware systems allow the designer to work through a range of iterations that determine how a system will work with a specific material—in a range of conditions from best to worst case. A computer provides the kind of calculation power required for developing the models and generating the iterations—making small, step-by-step design adjustments that allow for the comparison of alternative solutions to improve bulk-materials handling.

Traditionally, there has been little thought given to the flow of materials through the chute beyond making sure the chute was big enough to accommodate the material stream and minimizing wear. It was a common practice for chutes to be generous in size to reduce plugging and control dust, but this actually represented a shortcoming in design methodology. Chutes were kept box like to avoid running up the expense for fabrication. Because these chute angles were designed based on the angles of repose, they were prone to buildups and blockages. With changes in flow direction from conveyor to conveyor and from the downward energy of the material movement, the chutes would suffer wear in their metal walls and on the surface of the receiving belt or vessel.

Traditionally-designed chutes generate dust by throwing a stream of uncontrolled material off the end of the conveyor and allowing it to spread. The movement of material displaces air as the body of material is diffused. The air passes through the material stream, thus dispersing and entraining the small particles of dust. The traditional chute essentially can create a "chimney effect" by adding the dust to the displaced and moving air.

In addition, the receiving areas were typically small and unsupported, and they released dust. When the stream of material "crash lands" on the receiving conveyor, the profile of the material is compressed, and the induced air is driven off. This air takes with it the smaller particles of material as airborne dust. A loosely-confined stream will carry larger amounts of induced air, so more dust is driven off. If the material has been allowed to move through the chute in a turbulent stream—with what might be called "billiard flow," where the lumps bounce off each other and the chutewalls—the material lumps will degrade, creating more dust that can be carried out of the enclosure.

ENGINEERED FLOW

What is Engineered Flow?

Chutes with "engineered flow" are based on the application of the principles of fluid mechanics and an understanding of particulate movement. Engineered material flow is based on controlling the material's movement as it exits a discharging conveyor or a silo, bin, or hopper. The direction and speed of flow can be steered through subtle changes by guiding it down surfaces with known friction values. The gradual course modifications will minimize dust generation and center load the belt. This allows the energy lost through friction to be calculable and accountable.

What is an Engineered Flow Chute?

Developed from sophisticated material tests and computer flow simulations, engineered flow chutes are designed to satisfy a plant's operating requirements, so the material stays in continuous motion though the transfer chute, with the material moving as a tight, coherent stream.

This will minimize the amount of induced air carried along with the stream of material. As a result, there is less air released and less airborne dust created (**Figure 22.2**). In addition, the stream is directed or channeled, so the material is placed gently onto the receiving belt, minimizing impact and belt abrasion.

The material moves smoothly—like water through a faucet. The material slides in unison in a "fluid-like flow," rather than allowing the lumps to bounce off each other in the traditional "billiard-flow" fashion.

Benefits of Engineered Flow

There are a number of benefits to accrue from the installation of an engineered flow chute in a facility. These include:

A. Passive dust control

They reduce dust escape while minimizing, or eliminating, the need for active collection methods.

B. Increased material flow rate

They eliminate chutes as a production bottleneck.

C. Reduced material buildups and blockages

They reduce or prevent chute plugging.

D. Reduced loading impact

They extend belt-life by reducing damage and abrasion.

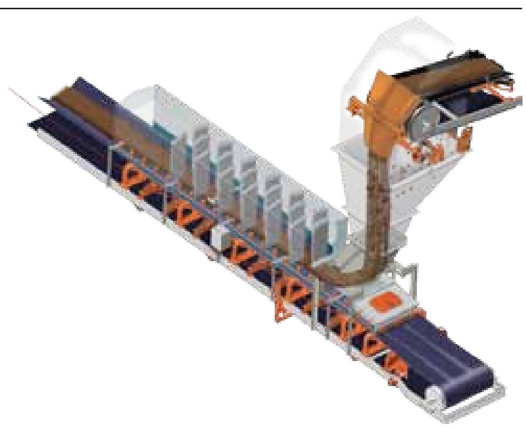

Figure 22.2

In an engineered flow transfer, the material is kept as a tight, coherent stream, minimizing the amount of induced air. Therefore, there is less air released and less airborne dust created.

22

E. Reduced degradation of material

They minimize creation of dust.

F. Controlled load placement

They prevent mistracking, spillage, and belt-edge damage.

It should be noted, however, that engineered flow chutes are designed to accommodate a narrow range of parameters. Changes in the performance of these chutes (and in the wear life of the linings inside them) will occur when conditions vary, including:

A. Inconsistent flow rates

Variations of more than 20 percent from the stated flow, other than at start up and shut down

B. Inconsistent material characteristics

Variations of more than 20 percent in any attribute from the material samples tested prior to system design

C. Inconsistent environmental conditions

Variations that create alterations in the material, such as precipitation that changes the moisture content by more than 10 percent from the stated characteristics

Components of Engineered Flow Transfers

An engineered flow chute incorporates geometry that captures and concentrates the material stream as it travels through the chute, which has the dual benefit of minimizing aeration and preventing accumulation of materials inside the chute. Preventing accumulation of materials within a chute is particularly important when dealing with combustible materials, such as coal.

Engineered chutes typically employ a design called "hood and spoon" transfer. This design is composed of a "hood" discharge chute, at the top of the system, and a "spoon" receiving chute, which places the material onto the belt being loaded. The hood and spoon are typically installed as a pair, although a particular material-handling situation might require only one or the other. These components are custom-designed using the characteristics of the conveyed material and of the materials used for chute construction. The goal of hood and spoon is to confine the moving material stream, reducing the entrainment of air and minimizing the impact forces, while placing the material in the proper direction on the receiving belt with minimal impact—or "splash"—to reduce spillage, abrasion, dust, and damage. This controlled loading also prevents side loading of material, which causes belt mistracking.

In addition, many engineered flow chutes incorporate an additional area for dust confinement—called a settling zone or stilling zone. Here the air current above the material stream is slowed so that the residual dust can settle back onto the conveyor.

Hood

Installed at the discharge, a hood captures and confines the moving material stream at a low impact angle (**Figure 22.3**). This minimizes impact force, buildup, and wear. The hood redirects the material stream vertically, so it flows smoothly toward the conveyor system below (**Figure 22.4**). Once flow is vertical, then the direction of the material stream is gently modified to align the flow with the receiving conveyor.

Spoon

A spoon is installed at the bottom of the transfer chute, where it receives the mate-

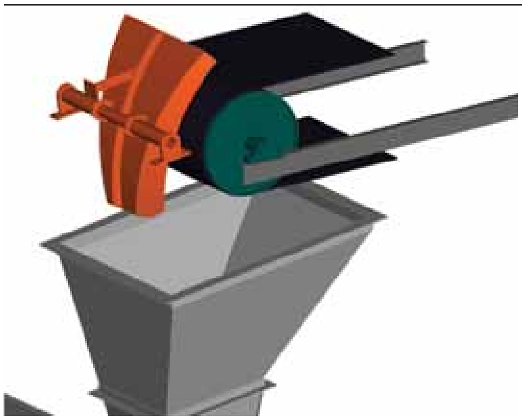

Figure 22.3

Installed at the discharge, a hood captures and confines the moving material stream at a low impact angle.

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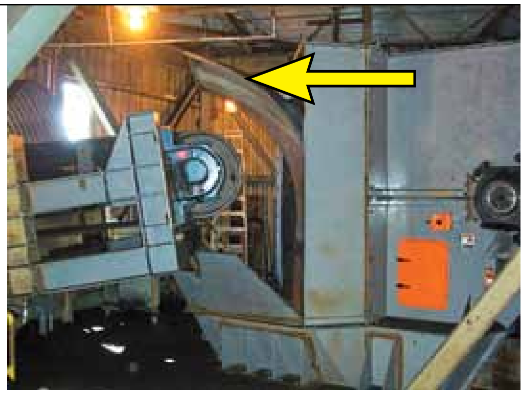

Figure 22.4

A hood is installed to redirect the material stream vertically, so it flows smoothly toward the conveyor system below.

Figure 22.5

A spoon is installed at the bottom of the transfer chute, where it receives the material stream and places it on the receiving belt.

Figure 22.6

By directing the concentrated stream of material onto the center of the receiving belt with the proper speed and angle, the spoon reduces impact on the belt, belt abrasion, dust creation, off-center loading, wear on wear liners, and other problems.

Figure 22.7

The settling zone, typically installed after the spoon on the receiving conveyor, corresponds to the conventional skirted and covered portion of the receiving conveyor.

rial stream and places it on the receiving belt (**Figure 22.5**). The spoon is designed to gently load the material onto the receiving conveyor, so the cargo is moving in the same direction as, and near the velocity of, the belt. By directing the concentrated stream of material onto the center of the receiving belt with the proper speed and angle, the spoon reduces impact on the belt, belt abrasion, dust creation, off-center loading, wear on wear liners, and other problems (**Figure 22.6**).

Another benefit of loading via an engineered spoon is that the belt may require less belt support in the load zone. Loading the material onto the belt at a similar speed and in the same direction as the belt is traveling provides less impact onto the belt and, consequently, less need for impact cradles and belt-support cradles.

In some complex chutes or transfers with large drop distances, more than one "hood and spoon" pair might be used to control flow.

Settling Zone

The settling zone, typically installed after the spoon on the receiving conveyor, corresponds to the conventional skirted and covered portion of the receiving conveyor (**Figure 22.7**). This area is carefully engineered to provide for optimum settling of dust-laden air and settlement of any airborne dust, by holding the air long enough to slow its velocity. The settling zone typically uses a higher, covered skirtboard to allow any airborne dust to settle out of the air, returning most of the dust to the main material bed without being released to the outside (**Figure 22.8**). The air currents are slowed by the larger area of the settling zone and the use of dust curtains within the area.

Some system designers omit a settling zone from their designs, using only conventional covered skirtboard designs. However, it is almost impossible to design a chute that will handle every possible material condition. Therefore, it is safer to include the settling zone to accommodate unforeseen circumstances or to handle future changes in material characteristics.

DESIGNING FOR ENGINEERED FLOW

Even if two conveyors run at the same speed, gravity can cause the velocity of the material to increase during a transfer from one conveyor to the other if the flow is left unrestrained. Both the hood and the spoon must be designed to intercept the material trajectory at a low angle of incidence. This uses the natural forces of the material movement to steer the flow into the spoon for proper placement on the receiving belt with reduced impact and wear. Because the hood and spoon are designed with both the material specifications and the flow requirements as criteria, the chute can operate at the required flow with reduced risk of plugs or chute blockages that will choke operations.

To achieve the proper design of hood, spoon, and settling area, engineered flow chutes are created using three-dimensional (3D) computer-based modeling to define the geometry of the chute (**Figure 22.9**). The angle and force of impact should be minimized to maintain as much momentum as possible. Ideally, the impact angle should be no more than 15 to 20 degrees. This design must be based on rigorous processes and procedures to provide a precise, accurate, and complete design. Dimensional data can be determined from a site survey or—particularly for new facilities—from a review of the site plans and conveyor specifications.

It is essential for the designer of an engineered flow chute to have detailed information about the material that will be flowing through the chute and the parameters of the conveyor system itself. This information includes:

A. Feed system
   a. Type of feed system (e.g., crusher, vibratory feeder, stockpile, reclaim)
   b. Number of feed systems
   c. Angle of incline or decline (**Figure 22.10**)
   d. Belt speed
   e. Belt thickness
   f. Belt width
   g. Trough angle
   h. Transfer capacity
   i. Type of conveyor structure (channel, truss, cable)
   j. Method by which material is delivered to plant (e.g., barge, railcar, truck)

B. Transfer
   a. Interface angle (**Figure 22.11**)
   b. Horizontal distance to loading point (**Figure 22.10**)
   c. Drop height (**Figure 22.10**)
   d. Transfer capacity
   e. Number of transfers

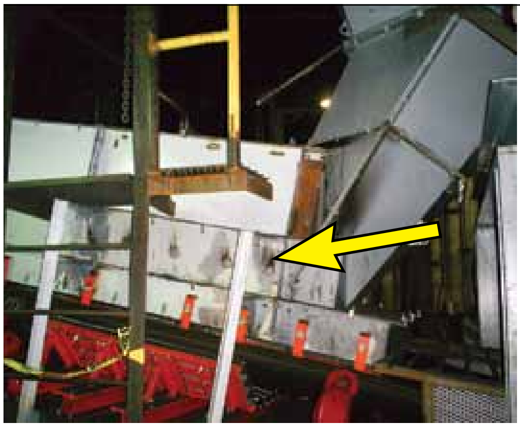

Figure 22.8

The settling zone is carefully engineered to provide for optimum stilling of dust-laden air and settlement of any airborne dust, by holding the air long enough to slow its velocity.

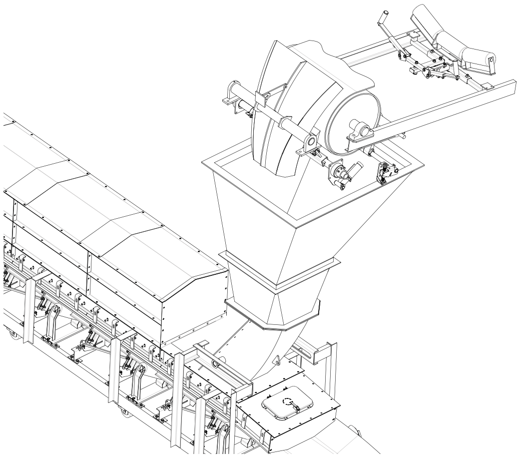

Figure 22.9

To achieve the proper design of hood, spoon, and settling area, engineered flow chutes are created using 3D computer-based modeling to define the geometry of the chute.

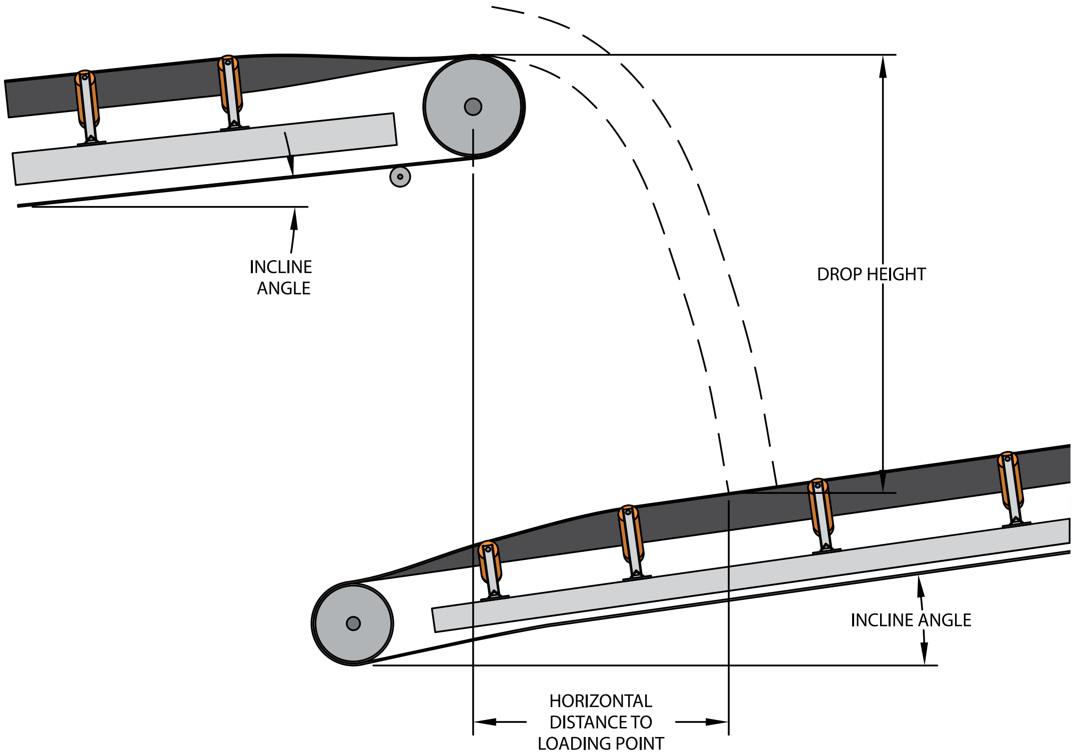

Figure 22.10

The designer of engineered flow chutes needs detailed information about the conveyor system and the material it carries.

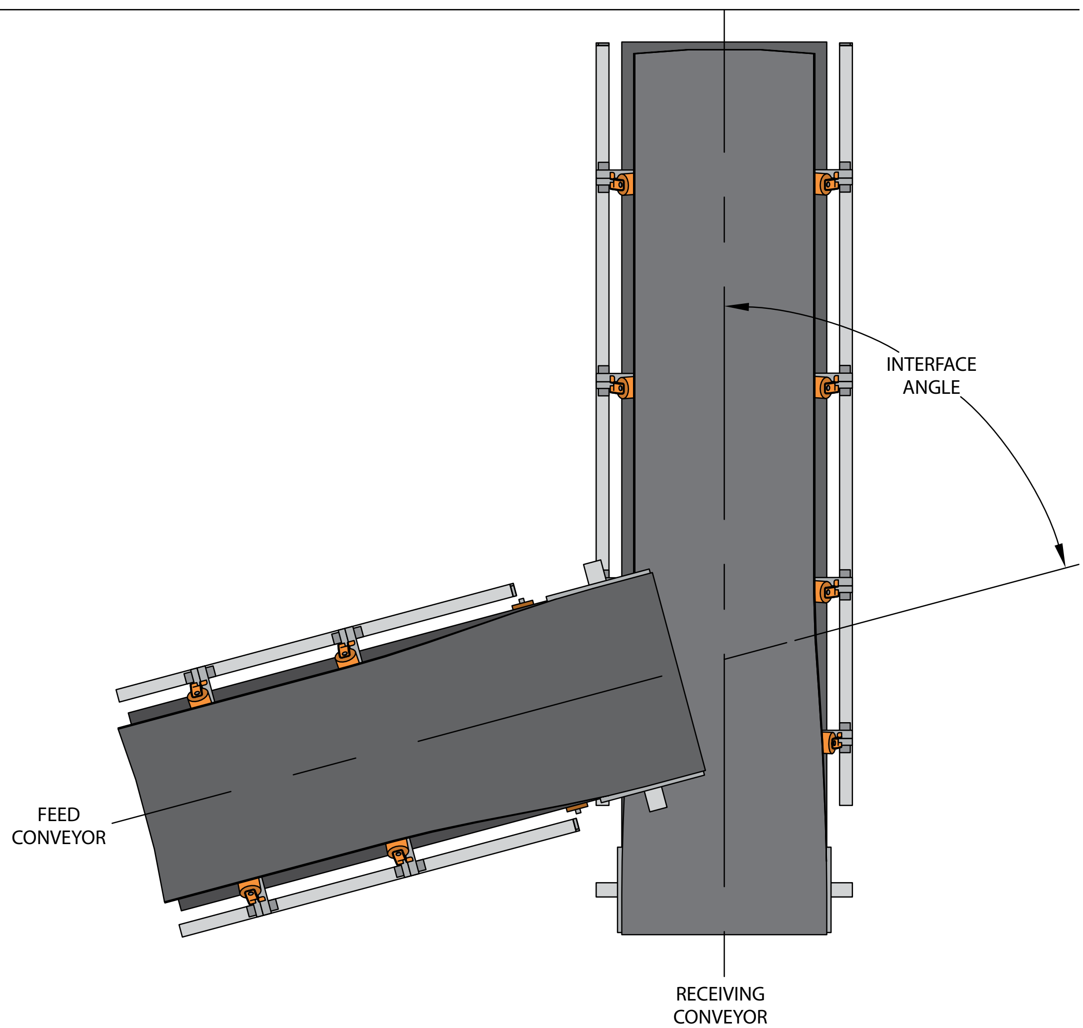

Figure 22.11

The interface angle of a transfer point is a key element in the design of engineered chutes.

22

f. Number of gates and purpose (e.g., splitting the flow or changing direction of the flow)

g. Interference due to surrounding structure

C. Receiving system

a. Type of receiving system

b. Number of receiving systems

c. Belt speed

d. Belt thickness

e. Incline/decline angle of conveyor (**Figure 22.10**)

f. Belt width

g. Type of conveyor structure (channel, truss, cable)

h. Trough angle

i. Transfer capacity

j. Belt/load support system

k. Distance of conveyor to curve or interference for settling zone

D. Material conveyed

a. Material type

b. Temperature ranges (high and low)

c. Moisture content

d. Environmental conditions that affect material condition (including distance from source/supplier and location where sample was collected)

e. Material size

f. Bulk density

g. Interface friction

h. Cohesion/adhesion properties

i. Particle size and percentage distribution

j. Average lump size and maximum lump size

k. Surcharge angle

l. Angle of repose

E. Construction materials

a. Chute construction materials

b. Chute liner materials

c. Tolerances for fabrication and installation

d. Interface friction values for construction materials in contact with the bulk material

Design of Engineered Flow Transfers

Engineered flow transfer chutes are developed in a three-step engineering process. Phase one is testing of the conveyed material properties and the interface friction values in relation to the belt and construction materials, to establish the material characteristics and its performance in materials-handling systems. After the various conveyor and material parameters are defined, the material discharge trajectory can be determined using conventional methods such as the Conveyor Equipment Manufacturers Association (CEMA) method.

The second phase of the process includes verification of current field dimensions and development of preliminary engineering. A set of two-dimension conceptual drawings and a three-dimension pictorial representation of the chutework using 3D software are created, and the flow characteristics are verified using Discrete Element Modeling (DEM) method.

The third and final phase is the creation of the final design, followed by the detailed engineering and then, in turn, by the fabrication and installation of the system.

Phase 1: Material Analysis

The first step in the design of an engineered chute is testing of the actual conveyed material that will be passing through it. Information obtained includes material composition and physical properties, moisture content, lump size range, and fines size. Testing usually includes analysis of the bulk-material strength at several moisture contents—from “as-received” to “saturation” level—to allow for changing material conditions. There are typically at least three different types of tests, including direct shear, interface friction, and bulk density, at each of these moisture content levels. Direct linear or rotational shear testers are often used to measure the material flow and interface properties. The fine components of the material are usually used in testing, because the fines define the worst-case flow properties.

Testing samples of the actual material to be conveyed in relation to the actual belting and construction materials to be used must be performed to provide this important data. *(See Chapter 25: Material Science for additional information on material testing and analysis.)*

Material testing concludes with a recommendation for the chute angles, based on boundary friction required to find a balance between reliable flow through a transfer chute and acceptable levels of chute and belt wear. Recommendations for the material(s) to be used as liners inside the chute may also be included.

The various conveyor and material parameters and the material discharge trajectory are used to develop the transfer chute design.

Phase 2: Discrete Element Modeling (DEM) Method

The parameters developed in Phase 1 are used in developing a computer-generated 3D discrete element model of the chute system (**Figure 22.12**).

DEM is a design verification tool. The basic operating equation is Newton's Second Law: Force = mass times acceleration (F = ma), solved for every interaction between particle and particle, and particle and chutewall, as modified with the properties of the particles and of the interacting elements. The forces, which act on each particle, are computed from the initial data and the relevant physical laws. Some of the forces that affect the particle motion include:

A. Friction

When two particles touch each other or move against the wall

B. Impact

When two particles collide

C. Frictional, or viscous, damping

When energy is lost during the compression and recoil of particles in a collision

D. Cohesion and/or adhesion

When two particles collide and stick to each other

E. Gravity

Solutions based on a DEM approach are more insightful than those based on basic design equations and "rules of thumb," because they enable the designer to more accurately evaluate important issues such as center loading of a receiving conveyor. The chute designer is also able to predict areas in the chute that may be prone to low material velocity—therefore plugging—and take corrective action to prevent them. When coupled with basic equations, DEM enables a designer to quickly determine the optimum chute design through a series of iterations. A minor downside of DEM is that only relatively few particles, compared to the total number of particles in the material stream, can be simulated in a reasonable length of time with computers that are commonly available, although advancements in computer technology may rapidly eliminate this problem.

An additional advantage of this computer-based system is that changes can be quickly developed to compensate for changes in the system characteristics.

Of course, the "garbage in, garbage out" principle still applies. If the data going into the software is not accurate, the

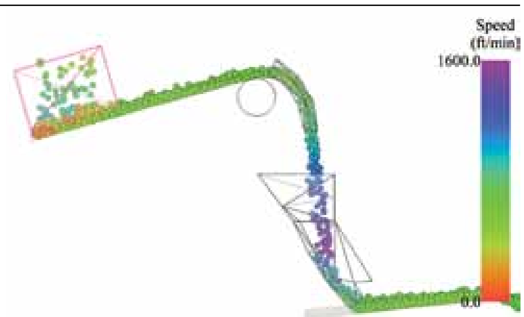

Figure 22.12

The parameters developed in Phase 1 are used in developing a computer-generated 3D discrete element model (DEM) of the chute system.

22

design coming out will not be accurate. That is why testing of the actual material to be conveyed, in the various conditions in which it will be handled—including "worst-case"—is critical.

Phase 3: Final Design

The use of computer-based modeling techniques allows the quick and efficient turnaround of a chute design to meet the requirements of a specific belt-to-belt transfer. The 3D model is used to produce the fabrication and installation drawings.

The completed engineered chute project includes hood(s), drop chute, spoon(s), wear liner, belt-support cradles, belt-tracking system, belt-cleaning systems, dribble chute, access doors, skirtboard seal, tailgate sealing box, and settling zone.

Other Items

Other items to be considered during chute design are the requirements for heaters, insulation, access to the interior of the chute, lighting, access platforms, plugged-chute switches, appropriate guards, and adequate space for replacement of belt cleaners, flow aids, or other components.

Other Design Considerations

In its simplest sense, a transfer chute should have internal surfaces that are sufficiently steep and smooth, with rounded corners, to prevent flow problems—such as material buildups and choking—even when transporting material with worst-case flow properties. Ideally, this geometry would be governed by the effects of gravity only. The reality is that there are a number of other considerations that should be included and calculated when planning for the installation of engineered flow transfers. These factors include:

A. Material trajectory

Calculation of the trajectory of the material stream as it leaves the discharge conveyor involves consideration of the center of mass of the material, velocities, the point on the discharge pulley where the trajectory begins, and the shape of the load. (A detailed discussion of discharge trajectory can be found in Chapter 12 of CEMA's *BELT CONVEYORS for BULK MATERIALS, Sixth Edition*.)

B. Wear

Impact, corrosion, and abrasion are primary contributors to chute wear, which takes place where the material stream hits the chute surface. Sliding abrasion is the passing of the material stream along the surface of the chutewall. The amount of abrasion that takes place is dependent on the difference in hardness between the material stream and the wear liner and on the amount, velocity, and force of the load on the wear liner surface. Because the design of engineered flow chutes links the material behavior with the interface at the chutewalls, analysis of impact and sliding abrasion is important in controlling the shape and speed of the material stream.

C. Tolerances

Even small differences in the installation of the components can affect the smooth flow of material and air through the transfer point. Manufacturers' recommendations for installation of components and materials must be strictly followed.

D. Two-phase flow analysis

Two-phase flow analysis takes into consideration the movement of both the material stream through a transfer chute and the induced air that travels with it into the settling zone of the receiving conveyor. If the material stream remains in contact with the chute surface—rather than bouncing off from it—there is less aeration and reduced impact force in the loading zone. During the chute's design phase, the analysis of the movement of both material particles and air through the transfer chute enables the chute designer to minimize induced air, which, in turn, reduces dust generation.

A variety of computer-based techniques, including DEM, Computational Fluid Dynamics (CFD), and Finite Element Analysis (FEA) are used to model two-phase flow. This analysis should include the displaced air, induced air, and generated air. *(See Chapter 7: Air Control.)*

Depending on the calculated airflow and the properties of the material, including particle size distribution and cohesion level, various systems—from rubber curtains to dust suppression and filter bags—can be utilized to minimize the effects of air currents in the transfer chute.

E. Structural concerns

Design of the support structure for a transfer chute generally requires analysis of four factors:

a. Dead load

Weight of chute (and structure) itself

b. Live loads

Wind, snow, and ice accumulations and fugitive material accumulating on flat surfaces

c. Dynamic load

The forces resulting from the movement and impact of material in the chute and other process equipment

d. Loaded capacity

Weight of the material in the chute—calculated using the highest value of material bulk density in the worst-case scenario of chute plugging

Figure 22.13

To ensure accurate designs as well as to ensure that the engineered system will fit properly into place without requiring field adjustments, a site survey using laser measurement technique is recommended.

The objective of this analysis is to efficiently and effectively support the transfer chute without spending excessive amounts on the support structure. Developing a support structure that complies with local building codes is another important consideration.

INSTALLATION OF ENGINEERED FLOW SYSTEMS

Project Installation

Engineered chutes can easily be designed into new conveyor systems. They can be pre-assembled and aligned into manageable assemblies that can easily be rigged, hoisted, and bolted-in-place to reduce construction cost.

Engineered flow chutes can also be retrofit into an existing operation as a way of controlling dust to improve operations and achieve regulatory limits on dust, usually without installation of expensive “baghouse” systems. Regardless of whether it is a new or retrofit installation, the design and installation of engineered chutes should be left to companies experienced with the technology.

Chutes for Retrofit Applications

One of the earliest applications of engineered flow chutes was in the improvement of the transfer points in existing conveyor systems. The incorporation of these engineered systems into existing plants can pose some problems with fitting within existing structures.

To ensure accurate designs as well as to ensure that the engineered system will fit properly into place without requiring field adjustments, a site survey using laser measurement techniques is recommended (**Figure 22.13**). This precise survey uses a pulsed-laser technology to scan target areas and return a 3D “point cloud,” which looks like a detailed rendering of a scene (**Figure 22.14**). Because this point cloud is three-dimensional, it can be viewed from any perspective, and every point has accurate

22

x-, y-, and z-axis coordinates. The geometry of the points can then be exported to 3D modeling software packages as a starting point for the development of chute geometry. This will ensure the engineering of systems that will fit within the existing clearances.

In a retrofit application, before and after release of fugitive materials testing and analysis can also be performed, allowing the opportunity for performance to be compared and for improvements to confirm the justification for the project.

Flow Aids and Engineered Chutes

Even a well-engineered chute should make provision for the future installation of flow-aid devices by incorporating mounting brackets in the original design. Changes in material flow properties, or less-than-optimum design constraints, may lead a designer to require flow-promotion devices, such as vibration or air cannons, in a given design. It is difficult, especially in retrofit applications, to have the luxury of an optimum design. Compromises are often inevitable, because the locations of the feed and receiving conveyors are set, and moving them would be economically unfeasible. Potential flow problems, caused by variations in material characteristics in the future, can then be accommodated with the installation of vibrators or air cannons. Including the brackets during the initial installation of the chute will save money and time over retrofitting a bracket (**Figure 22.15**).

Flow aids enhance material flow in those situations where compromises are made to what would have been an optimum design. *(See Chapter 9: Flow Aids.)*

SYSTEM MAINTENANCE

An operation should keep accurate records of chute and liner design and positioning to simplify the fabrication and installation of replacement liners as they become needed.

In order to simplify the replacement of liners, the chute should be designed with an easy-opening flange system that allows one wall—in most cases, the back wall and liner-bearing wall—of the chute to slide away from its position (**Figure 22.16**). This will allow more efficient access for inspection and replacement of liners inside the chute structures (**Figure 22.17**).

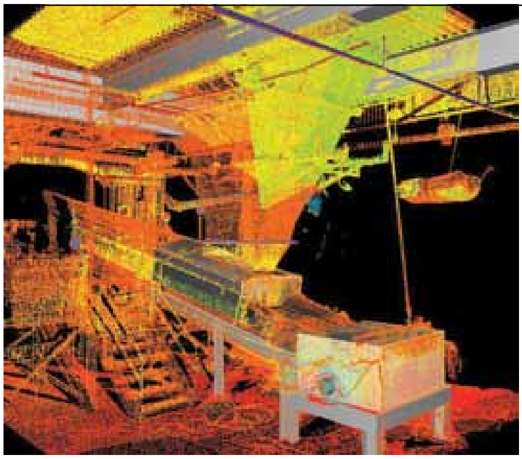

Figure 22.14

Pulsed-laser technology is used to scan target areas and return a 3D "point cloud," which looks like a detailed rendering of a scene.

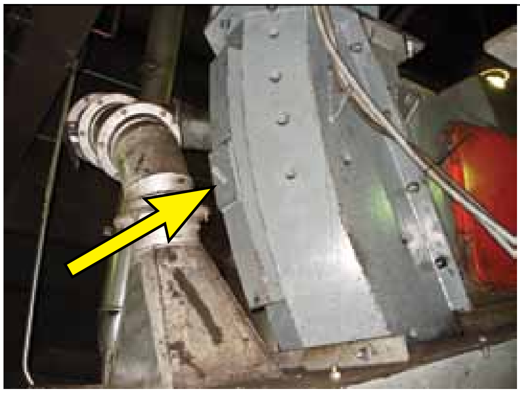

Figure 22.15

Including brackets for the installation of flow aids during the initial construction of the chute will save money and time over retrofitting a bracket.

Figure 22.16

To simplify the replacement of liners, the chute should be designed with an easy-opening flange system that allows one wall—in most cases, the back wall and liner-bearing wall—of the chute to slide away from its position.

22

Figure 22.17

The flanged back of the chute will allow more efficient access for inspection and replacement of liners inside the chute structures.

TYPICAL SPECIFICATIONS

A. Material specifications

The material-transfer system will incorporate belt-to-belt transfer chutes custom engineered to match material specifications and flow requirements. Through testing of material properties, the chute system will be designed to provide the required flow rate without plugging and to eliminate the creation of additional dust from the degradation of material and the entrainment of air.

B. "Hood" and "spoon"

Included in the chute system will be a "hood" discharge chute and a "spoon" receiving chute. The "hood" will take the flow of material from the discharging belt, confining it to limit air entrainment and creating a consistent inertial flow through its trajectory onto the receiving "spoon." The "spoon" receiving chute will receive the material stream and place the material on the receiving belt with the proper direction and speed to minimize material turbulence, impact, belt abrasion, and belt mistracking.

C. Volume

The volumetric design of the head chute and skirted area will be calculated to reduce air speed and turbulence. Fugitive and respirable dust levels will be greatly reduced through the settling features of the design.

D. Access

The chute will be fitted with an easy-opening flange closure system to enable simplified inspection and replacement of liners inside the chute structures.

E. Settling zone

The exit of the receiving conveyor will be fitted with an extended covered skirtboard system to form a settling zone. The settling zone will incorporate multiple dust curtains to form a serpentine plenum that reduces the air velocity and provides time for airborne particles to return to the main material cargo by gravity.

22

SAFETY CONCERNS

Engineered chutes should be designed with an access opening on the non-flowing side of the enclosure. These doors should be fitted with restricted-access screens to reduce the hazard from materials flying out of an opening, and warning labels should be applied.

Personnel entry to any chute should be governed by confined-space entry regulations.

ADVANCED TOPICS

Engineering Calculation: Continuity

The continuity calculation determines the cross section of the material stream within a transfer chute and is important in determining the ideal chute size (**Equation 22.1**). This helps to keep the cost of chute fabrication under control. The industry and CEMA's standard indicates the chute should be at least four times the material cross-sectional area at any position.

More important than the calculation of the area is the acknowledgment of the relationship between velocity and cross-sectional area. A designer must keep this continuity relationship in mind when the velocity of the material needs to match the speed and direction of the receiving belt (**Equation 22.1**). Material velocity is influenced by many things, such as fall height, change in direction of flow, surface friction, internal friction, and instantaneous density to name a few. These factors will alter the stream velocity in a predictable way, but it is important to note that this change in velocity will influence the cross-sectional area of the stream. Conversely, the area can be altered to influence the velocity. The cross-sectional area of the stream is vitally important when designing to prevent problems with chute blockage.

THE PAYBACK OF ENGINEERED CHUTES

In Closing...

An engineered transfer chute can be applied in virtually any transfer chute application, so facility management often will use a cost justification procedure to evaluate its payback for the operation. Applications in which there is a significant drop height from the discharge conveyor to the receiving conveyor will usually warrant the investment. Facilities that are attempting to meet regulatory requirements or satisfy environmental and safety concerns may find the investment in an engineered flow chute has a short-term payback. The additional investment required for an engineered flow chute over the cost of a traditional transfer chute is promptly repaid through increase in productivity, accident reduction, and meeting environmental regulations rather than cleaning up fugitive materials, coping with plugged chutes, or tracking an improperly loaded belt.

Looking Ahead...

This chapter, Engineered Flow Chutes, the second chapter in the section Leading-Edge Concepts, provided information about another method of reducing fugitive materials. The next chapters continue this section, focusing on Air-Supported Conveyors and Belt-Washing Systems.

$$A = \frac{Q \cdot k}{\gamma \cdot v}$$

Given: *A coal stream carrying 1800 tons per hour (2000 st/h) with a density of 800 kilograms per cubic meter (50 lb_m/ft^3) is traveling at 4,0 meters per second (800 ft/min).* ***Find:*** *The cross-sectional area of the coal stream.*

Variables		Metric Units	Imperial Units
A	Cross-Sectional Area	square meters	square feet
Q	Flow Rate	1800 t/h	2000 st/h
γ	Material Bulk Density	800 kg/m^3	50 lb_m/ft^3
v	Average Materials Velocity at Cross Section in Question	4,0 m/s	800 ft/min
k	Conversion Factor	0,278	33.3

Metric: $A = \frac{1800 \cdot 0,278}{800 \cdot 4,0} = 0,16$

Imperial: $A = \frac{2000 \cdot 33.3}{50 \cdot 800} = 1.67$

A	Cross-Sectional Area	0,16 m^2	1.67 ft^2

Note: The stream cross-sectional area will be different from the cross-sectional area when the material is on the belt due to the differences between conveyed density and loose bulk density. (See Chapter 25: Material Science for additional information.)

Equation 22.1

Continuity Calculation for Cross-Sectional Area of Material Stream

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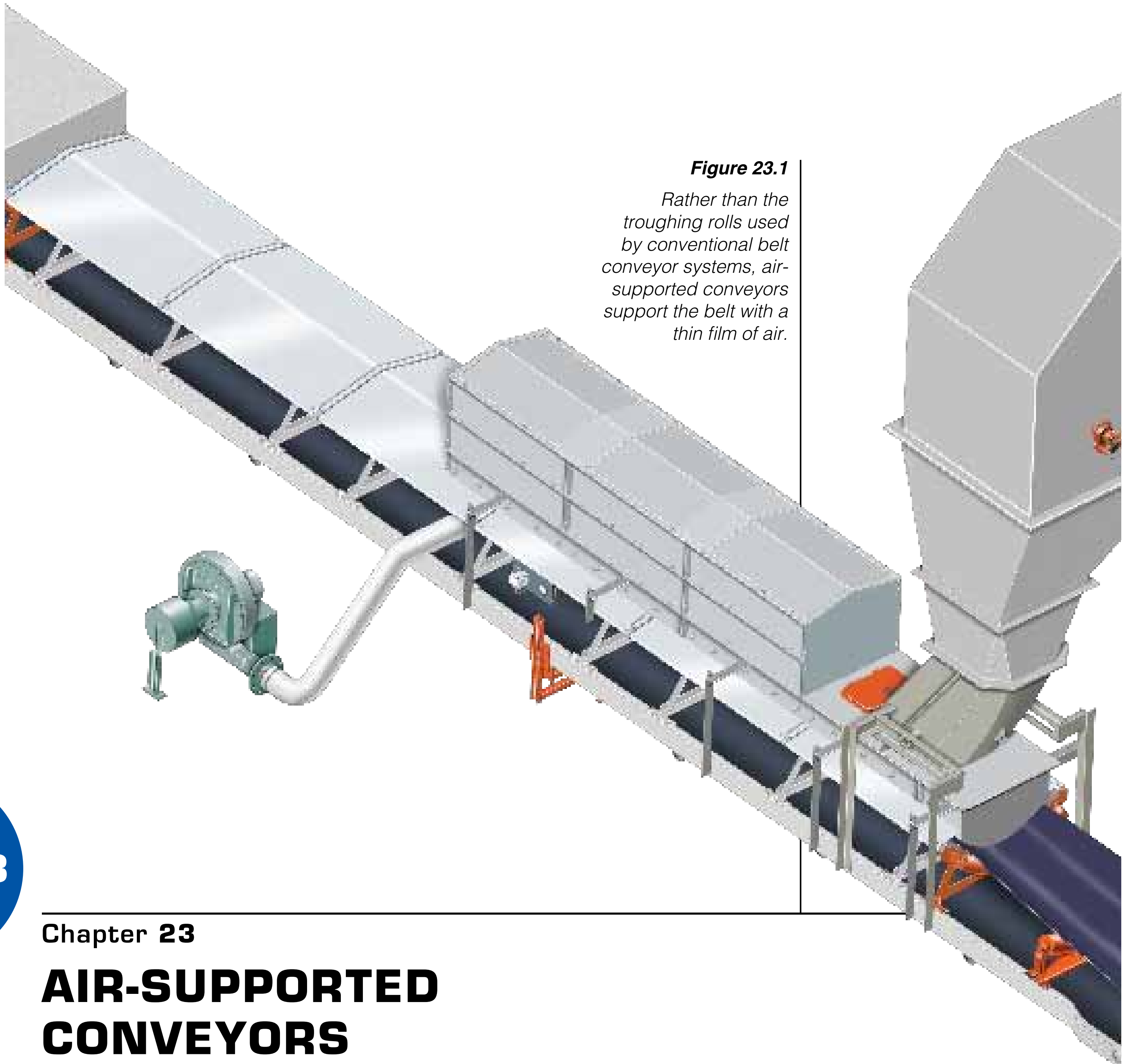

Figure 23.1

Rather than the troughing rolls used by conventional belt conveyor systems, air-supported conveyors support the belt with a thin film of air.

23

Chapter **23**

AIR-SUPPORTED CONVEYORS

In this Chapter...

This chapter focuses on the basic concepts of air-supported conveyors and applications for which they would be appropriate. We also present both the benefits and drawbacks of their use, along with information about the size of fan needed for various conveyor lengths and widths.

One example of "leading-edge" conveyor technologies is air-supported conveyor systems (**Figure 23.1**). Rather than the troughing rolls used by conventional belt conveyor systems, air-supported conveyors support the belt with a thin film of air. This method of conveying bulk materials limits the areas of mechanical friction, which results in a dramatic reduction in maintenance and operating costs. A fully-enclosed, weather-resistant, air-supported conveyor requires less structural support than a traditional conveyor, and it minimizes material segregation, spillage, and dust (**Figure 23.2**). While not suitable for all applications, air-supported belt conveyors offer a number of advantages, including a smooth ride for the bulk materials and containment of dust. Air-supported conveyors, like conventional conveyors, must be designed by an experienced conveyor engineer.

BASICS OF AIR-SUPPORTED CONVEYORS

An air-supported conveyor uses low pressure air to raise and support the belt and cargo. The air is supplied by a low-pressure centrifugal fan and released through a trough-shaped pan below the conveyor belt (**Figure 23.3**). A series of holes drilled in the center of the pan along the length of the conveyor—between the air-carrying chamber (plenum) and belt—enables the air, supplied by the blower through the holes in the pan, to lift and support the loaded belt (**Figure 23.4**). The edges of a troughed belt act as a pressure regulator, automatically balancing the pressure required to lift the load. The air film eliminates the need for most idlers on the carrying side of the conveyor; conventional return idlers may be used for the return run of the belt. With no troughing idlers, budgets typically designated for replacement of rolling components and maintenance labor needed to accomplish that replacement are reduced.

The plenum runs below the pan. As the top of the plenum, the pan provides the form for the trough of the belt. The most common and economical trough angles are 30 and 35 degrees. The plenum can be a box or a V shape that sits on conventional conveyor structural stringers (**Figure 23.5**). These plenums can be modular to simplify installation (**Figure 23.6**).

Figure 23.2

A fully-enclosed, weather-resistant, air-supported conveyor will minimize material segregation, spillage, and dust.

Figure 23.3

An air-supported conveyor utilizes a stream of air to raise and support the belt and cargo.

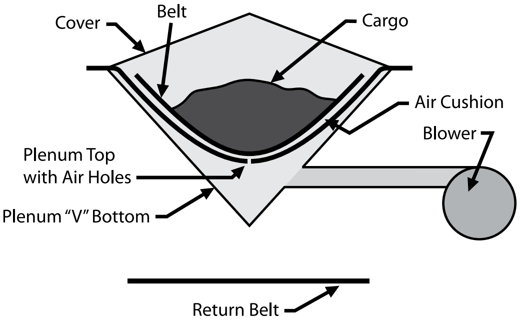

Figure 23.4

Holes drilled in the center of the pan along the length of the conveyor between the plenum and belt enable the air supplied by the blower to lift and support the loaded belt.

23

Figure 23.5

The plenum can be a box or a V shape that sits on conventional conveyor structural stringers.

Figure 23.6

The plenums of an air-supported conveyor can be modular in construction to simplify installation.

Figure 23.7

The typical air-supported conveyor, of less than 180 meters (600 feet) in length, requires a single centrifugal fan.

Figure 23.8

A plant may specify the installation of a redundant, or back-up, fan to assure conveyor operation in the event of a fan failure.

Because an air-supported conveyor uses a thin film of low-pressure air—approximately 1 to 2 millimeters (0.04 to 0.08 in.) thick—to support the conveyor belt, air consumption is low. Consumption is typically 180 to 270 liters per minute per meter (2 to 3 ft^3/min/ft) of belt length. The film of air is created by a blower supplying 5 to 7 kilopascal (0.7 to 1.0 lb_f/in.^{2}, or 20 to 30 in. of water gage) of air pressure.

The speed and pressure of the air film are sufficient to help keep material from accumulating between the belt and pan but low enough so that additional dust is not created.

SYSTEM COMPONENTS

Plenum

The plenum, through which the air from the fan flows, can be formed of plastic or galvanized (or stainless) steel troughs, sized to match the belting required for the conveyor application.

The plenum must be smooth, without irregularities in profile or surface. The plenum sections should be flush and sealed at each connection of the modular units. The structure must be designed to minimize deflection under various loads and climate conditions, to protect the integrity of the seal between plenums.

Air Supply

The air to support the belt is provided by one or more centrifugal fans (**Figure 23.7**). The typical conveyor of less than 180 meters (600 ft) requires a single fan, although a plant may specify the installation of a redundant, or back-up, unit to assure conveyor operation in the event of a fan failure (**Figure 23.8**).

It is important the air supply to support the belt is sufficient to handle the entire range of loading conditions for that particular conveyor. The number of blowers required depends on both the length of the conveyor and the width of the belt. For long conveyors, more than one air supply may be required to prevent loss of volume and static pressure. The volume of air is minimal, because the thickness of the air film required to raise the belt is only 1 to 2 millimeters (0.04 to 0.08 in.).

The size of the centrifugal blower required depends on the width of the belt and the length of the conveyor, with sizes ranging from 2,5 to 12 kilowatt (3 to 15 hp) common (**Table 23.1**). Direct-drive fans as specified improve efficiency and reduce the maintenance problems that can arise with mechanical couplings. In hazardous-duty situations, such as handling grain or coal, no-spark blades and hazardous-duty motors must be specified.

The spaced holes in the center of the pan allow the air to raise the belt (**Figure 23.9**). The size and spacing of the holes in the pan are critical to proper operation, because they directly affect the static pressure and volume at the interface between the belt and the plenum/pan.

For best results, the air source(s) should be located in the middle of the system—equal distance from the head and the tail of the conveyor; if there are two or more fans, they should be located equidistant from each other and from the head and tail of the conveyor.

The fan is controlled by a pressure switch, typically located at the conveyor's head section, close to the electric supply, to save conduit and labor costs. The fan is interlocked with the conveyor, so the fan must be running before the drive can start. The conveyor's normal start up procedure is to start the fan first and allow it to come up to pressure before engaging the drive motor. If the fan fails to start or come up to pressure, the pressure switch will sense low air pressure, and the conveyor will not run.

The intake air for the fan should be from

Figure 23.9

The spaced holes in the center of the pan allow the air to raise the belt. The size and spacing of the holes in the pan are critical to proper operation.

Table 23.1

Typical Sizes for Centrifugal Fans Used with Air-Supported Belt Conveyors

Belt Width	Conveyor Length			
mm (in.)	Up to 45 m (150 ft)	45-90 m (150-300 ft)	90-140 m (300-450 ft)	140-185 m (450-600 ft)
500-650 (24)	Fan Size A	Fan Size B	Fan Size C	Fan Size D
650-800 (30)	Fan Size A	Fan Size B	Fan Size C	Fan Size D
800-1000 (36)	Fan Size A	Fan Size B	Fan Size C	Fan Size D
1000-1200 (42)	Fan Size A	Fan Size B	Fan Size C	Fan Size D
1200-1400 (48)	Fan Size A	Fan Size B	Fan Size C	Fan Size D
1400-1600 (54)	Fan Size A	Fan Size B	Fan Size C	Fan Size D
1600-1800 (60)	Fan Size B	Fan Size C	Fan Size D	Fan Size D
1800-2000 (72)	Fan Size B	Fan Size C	Fan Size D	Fan Size D

Fan Size	Power Output
Fan Size A	2,5 kW (3 hp)
Fan Size B	6 kW (7.5 hp)
Fan Size C	7,5 kW (10 hp)
Fan Size D	12 kW (15 hp)

Metric measurements and fan size ratings are conversions of Imperial specifications.

Fan size represents the size of the centrifugal fan only (which supplies air to raise belt and reduce friction). It does NOT include conveyor drive power.

23

a fresh air source and filtered to reduce buildup of dust in the fan and pan. In some cases, the air must be heated to avoid condensation, which can cause the belt to stick to the pan or allow fines to choke the holes in the pan.

Conventional or Air-Supported Return

The return run of an air-supported conveyor may also be air supported (**Figure 23.10**), or it may have traditional return idlers (**Figure 23.11**).

Without the idlers on the return side, a completely air-supported conveyor has reduced maintenance costs. In fact, this system may allow the elimination of walkways along the conveyor, due to its minimal maintenance requirements. Because an air-supported return run is totally enclosed and the belt is visible only at the head and tail of the conveyor, it can provide a cleaner system.

Figure 23.10

An air-supported belt conveyor may incorporate an air-supported return side.

Figure 23.11

The return run of an air-supported conveyor may have traditional return idlers.

Roller return systems may be preferred in applications where optimal belt-cleaner performance cannot be maintained, because fugitive material can interfere with the operations of the air-supported return. Return rollers can be hung from brackets below the conveyor or enclosed in the structure below the air-supported plenum. A typical return run has idlers installed every 3 meters (10 ft).

Enclosing an air-supported conveyor's return run is recommended only when contamination is a critical problem. An enclosed return run can use as much energy as the carrying side, and the cost of the enclosure often outweighs any benefit. In addition, there is the problem of accumulation of dust and fines in the return-run chamber. It is usually more economical to install and maintain a good belt-cleaning system. On an air-supported return run, the belt tends to want to lift in the center, and the edges touch the pan if the belt is not of the proper stiffness. It is sometimes difficult to balance the airflow and pressure required for the return run and the carrying run with one fan. Air support of the conveyor return also increases the cost of fabrication. The cost of an effective belt-cleaning system and related maintenance is usually much less than the added cost of enclosing the return run.

Support Structure for Air-Supported Conveyors

Compared to conventional stringer or truss conveyors, air-supported conveyors can span longer distances with less structure because of the structural strength of the air-supported system plenum/pans (**Figure 23.12**). This provides the benefit of reducing the capital investment in the conveyor system.

In a traditional conveyor, for example, a support pier is required approximately every 15 meters (50 ft). Because of the strength of its plenums, an air-supported conveyor may require fewer support piers, thus reducing the investment in concrete pillars and structural steel. In one example, an air-supported belt conveyor system was installed at a wood waste-fired power plant close to the North Sea near Emden, Germany. Designed with a triangular-truss system, this air-supported conveyor spans distances of approximately 50 meters (160 ft) and covers the conveyor's 167-meter (550-ft) length with only two intermediate supports. Each application must be reviewed by qualified engineers to determine the requirements for foundation and structure.

Conventional Components

Air-supported conveyors can use standard take-up conveyor drives, loading and discharge chutes, and support structures. This allows the conversions of, or the connections to, many existing standard belt conveyors to air-support systems.

Although an air-supported conveyor will use conventional conveyor belting, the belt should be vulcanized rather than joined with mechanical splices. This will prevent damage to the pan and the splice from metal-on-metal contact associated with mechanical splices passing over the system. Mechanical belt fasteners can be used as long as the splices are properly recessed and then dressed with belt patching rubber.

Loading an Air-Supported Conveyor

Because of the low friction against the belt, misalignment from forces such as off-center loading is particularly troublesome for air-supported conveyor systems. Consequently, proper placement of the cargo is critical to the successful operation of an air-supported conveyor. The load must be properly centered and placed with as little impact as possible. This may require loading through a spoon to place the material gently on the belt, with the proper speed and direction. In many ways, air-supported conveyors are ideal for use with "hood and spoon" engineered flow transfers (**Figure 23.13**). *(See Chapter 22: Engineered Flow Chutes.)*

To regulate the delivery of cargo to an air-supported conveyor, feeders or flow-controlling gates are sometimes used in conjunction with a load-centering spoon. These gates help to deliver a consistent load to the air-supported conveyor and prevent material from piling up in one area. A regulated delivery of material to the belt eliminates the "starve and flood" conditions that impede smooth operation of the system.

Operating the air-supported conveyor when not loaded is not recommended. When there is no load on the belt, the air gap under the belt increases, which increases the volume of air used. The pressure goes down; however, the volume contributes more to the power consumed than does the pressure.

Air-supported conveyors should not be subjected to loading impacts above the light-duty impact ratings as found in the Conveyor Equipment Manufacturers Association's (CEMA) publication CEMA STANDARD 575-2000 *Impact Cradle/Bed Standard*. One solution to high-impact loading conditions is to use conventional trans-

Figure 23.12

Using a triangular-truss system, this air-supported conveyor needs only two intermediate supports to cover the system's 167-meter (550-ft) length, much fewer than a conventional conveyor would need.

Figure 23.13

Proper placement of the cargo is critical to the successful operation of an air-supported conveyor, making "hood and spoon" engineered flow transfers ideal for air-supported systems.

fer-point components (e.g., impact cradles and impact idlers) to cushion impact in the loading zone, and then switch to the air-supported system outside the loading zone. Sections of conventional conveyor can be easily inserted in air-supported-conveyor systems to allow the use of accessories such as scales. It is still important to have the load properly centered in the air-supported portion of these hybrid systems.

ADVANTAGES OF AIR-SUPPORTED SYSTEMS

The Benefit of a Smooth Ride

Traditional belt-support systems in load zones consist of standard or impact idlers (rollers) that are placed as close together as possible. Even in the best of installations, however, the troughing idlers provide a less-than-perfect belt line. The material follows a path similar to a roller coaster (**Figure 23.14**). The belt moves up and down as it crosses over the idlers. This up and down motion agitates the material, allowing some particles to become airborne, causing the material to segregate by size, or pushing some material to the outsides of the belt where it can be spilled from the belt.

If the rolls are spaced just 225 millimeters (9 in.) apart, the belt can still sag between rollers, allowing dust and spillage to escape from the belt. In addition, this sag creates entrapment points between the belt and vertical steel in skirtboards or wear liners. These pinch points can catch material that can then abrade the belt surface. In many cases, the sealing system is blamed for belt damage, when it is material entrapment that has actually caused this abrasion.

As air-supported conveyors use a pan rather than rollers to create the belt line, they present a smooth surface and level belt line that when combined with center loading may allow the elimination of skirtboard and sealing systems. Stable belt support and the elimination of skirtboards prevent entrapment points that allow material to become wedged or jammed.

On conveyors with a steep incline, the movement of the belt over the idlers may disturb the material sufficiently that it causes lumps of material to roll back down the conveyor as the belt progresses up the incline. With its stable path, the air-supported conveyor eliminates the disturbance of the cargo as it goes over the rollers in a conventional conveyor. This smooth path will allow the air-supported conveyors to operate at a steeper angle than roller conveyors. This benefit is of interest to operations handling bulk materials that tend to roll back on the conveyor. A typical gain in slope is three degrees. This increase in angle acts to reduce the overall length of the conveyor, reducing the installed cost when compared to a roller conveyor.

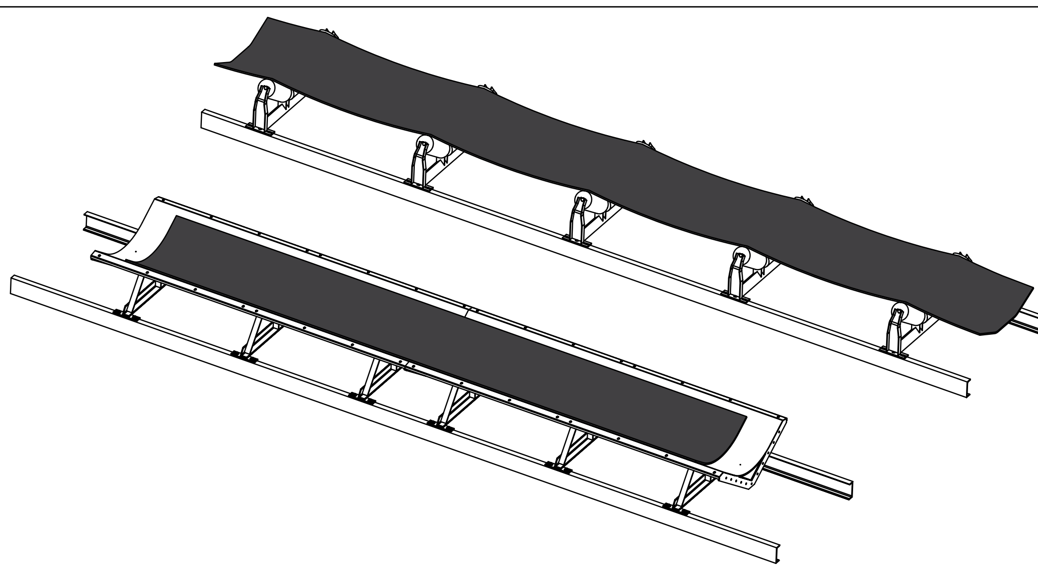

Figure 23.14

The idlers of a conventional conveyor provide a less-than-perfect belt line, so the material follows a "roller coaster" path. An air-supported conveyor uses a troughed pan to provide a smooth, stable ride for the belt and cargo.

Containment of Dust

Dust is generated when the material stream encounters air movement, which can result from the velocity of the material drop, from mechanical equipment, or from other outside influences. Higher velocities of air moving across the material stream may entrain greater quantities of dust. A well-designed and properly-installed air-supported conveyor has a totally-enclosed

Benefits and Drawbacks of Air-Supported Belt Conveyors

Benefits

A. Effective Dust Control: When the air-supported system is utilized from the loading area to the head chute, total dust control can be achieved.

B. Improved Belt Tracking: Air-supported conveyors have self-centering action.

C. Stable Belt Path: Troughing idlers spaced along the conveyor create hills and valleys in the belt line where the cargo is agitated and begins to segregate; the fines end up on the bottom and larger pieces on top. The air-supported conveyor offers a smooth ride for the cargo, with less spillage, segregation, and degradation of material.

D. Lower Operating Cost: On horizontal conveyors, the air-supported conveyors can use up to 30 percent less energy; on inclined conveyors, the energy saving is up to 5 percent.

E. Reduced Maintenance Expense: There are no carrying-side idlers, so there are no rollers to replace and no idler lubrication required.

F. No Skirtboard Seal: No skirting is required in the loading area, because the chutewall/wear liner forms a barrier to contain the material being loaded.

G. Retrofit Availability: New designs allow air-supported conveyors to be installed on existing (conventional conveyor) stringer and support systems. Air-supported and conventional roller sections can be mixed in a single conveyor, to allow for loading zones, tracking idlers, belt scales, or other requirements.

H. Improved Product Condition: An air-supported belt is gentle to the cargo. There is no bumpy “roller coaster” ride over the idlers, so there is no material segregation, no product degradation, and no breakage. Because the conveyor is fully enclosed, there is no contamination of conveyed material.

I. Greater Inclines Allowed: By eliminating load agitation, air-supported conveyors can allow for steeper inclinations, depending on the bulk-material properties.

J. Savings on Walkways: By eliminating troughing idlers and so reducing routine lubrication and conveyor maintenance, air-supported conveyors may allow omission of walkways.

K. Improved Safety: The system has fewer moving parts that pose risk to workers.

Drawbacks

A. Required Engineered Belt-Cleaning Systems: Air-supported conveyors require aggressive belt-cleaning systems to ensure carryback is controlled. Carryback may also blind the air supply holes when allowed into the plenum area.

B. Tracking Affected by Material Accumulation: Belt tracking can be affected by fugitive material building up on system components.

C. Necessary Center Loading: The air-supported conveyor must be center-loaded, or belt mistracking will occur. No belt tracking devices can be installed within the air-supported system.

D. Required Stable Flow: Surges of material must be avoided, because the system is totally enclosed and blockage and system shut down could occur.

E. Limitations in Impact Loading: Impact must be minimized in the loading zone, or plenum damage will occur.

F. Higher Initial Investment: The initial cost is higher than for a conventional conveyor system.

G. Reduced Access for Observation: The conveyor is totally enclosed, so it is difficult to inspect cargo or interior of system.

H. Unsuitability for Heavy-Duty Applications: The system may not be suitable for heavy-duty applications.

I. Reduced Margin for Error in Design or Installation: Success of installation may depend on belt path and joints between plenum/pans.

conveying system that may prevent generated dust from being expelled into the environment (**Figure 23.15**). Air-supported conveyors generally need a smaller dust-collection system, such as an insertable collector, than comparable conventional conveyors and transfer points (**Figure 23.16**).

"Hood style" conveyor covers installed over the trough side of conventional conveyor belts will not prevent the wind from blowing material off the belt, but in many cases, the air velocity will be increased due to wind rushing up from the return side of the conveyor. A properly designed air-supported system is totally enclosed on its carrying side; consequently, there are no outside influences to "fluff" the material or blow it off the belt.

As the length of the enclosure created by the air-supported conveyor system is increased, the airborne dust gains more time to "settle out" and return to the bed of material on the belt. As a result, air-supported conveyors are well suited for carrying materials that present fire or explosion hazards, including pulverized coal or grain.

To improve dust control, some operations select air-supported conveyors that are fully enclosed on both the top and bottom strands of the belt and also on the take-up tower (**Figure 23.17**). Total enclosure of the conveyor's load-carrying side will improve the performance of dust-collector systems, because it will reduce to a minimum the open area and prevent outside air from entering the collector's intake.

Figure 23.15

A well-designed and properly-installed air-supported belt conveyor is totally enclosed on its carrying side to limit the escape of dust.

Figure 23.16

An insertable dust collector can be used with an air-supported conveyor to prevent the escape of airborne dust.

Figure 23.17

This cement plant air-supported belt conveyor incorporates a totally enclosed gravity take-up for complete containment of fugitive material.

23

APPLICATIONS AND INSTALLATION

Ideal Applications for Air-Supported Conveyors

An application where air-supported conveying may provide the most advantageous return on investment is one in which the cargo is a lightweight material that is easily entrained in the air. These materials would include ground cement, pulverized coal, wood chips, bark fuel, and grain.

The air-supported system is even more advantageous when there are safety concerns about exposure to the material itself, or where any spillage or dust presents an environmental hazard. Because of their fully-enclosed nature, air-supported conveyors are well suited for carrying dusty materials that present fire or explosion hazards, including pulverized coal or grain.

Applications Not Suitable for Air-Supported Conveyors

Merely changing from a standard conveyor to an air-supported conveyor system will not eliminate pre-existing problems. Although air-supported conveyors have been successfully installed and operated in a wide variety of industrial settings, there are certain applications where this equipment is not recommended:

A. High degree of impact

Situations where there is a high degree of impact in the loading zone are not conducive to air-supported conveying.

B. Prone to plugging

Applications where the material or chute design is prone to plugging are not good applications for air-supported conveyors.

C. Power circuit tripping

If a conveyor power circuit was tripping because the operators are overloading a conventional system, it will probably also "trip" as a result of the operators overloading the air-supported system.

D. Significant head load pressure

Applications where there is significant head load pressure, as might be found under a feeder hopper or a fully-loaded chute, are not conducive to air-supported conveying.

E. Heavy load at loading point

Air-supported conveyors are capable of lifting 975 kilograms per square meter (200 lb_m/ft^2). If the load on the belt at its loading point exceeds that amount, a conventional conveyor with idlers may be more appropriate for the application.

F. Large lumps

Material containing occasional lumps larger than 125 millimeters (5 in.) should include a significant portion of fines to be suitable for air-supported conveying.

G. Lack of maintenance or sticky materials

Plugging of the plenum and the holes in the pan can occur when there is a lack of belt cleaner and fan filter maintenance or sticky materials.

H. Tight curves

Installations with tight horizontal or convex vertical curves are generally not good applications for air-supported conveyors. Convex curves are possible with the use of conventional idlers in the curved section.

Installation of an Air-Supported Conveyor

Regardless of whether the air-supported conveyor is new construction or a retrofit, the installation will require some special details and a high level of workmanship to assure efficient operation. Placement of the plenum may require heavy equipment or cranes to lift the sections into position. The plenums will need to be carefully aligned, and the air passage through the base of the sections should be tightly sealed (with caulk or gasket materials) to prevent air leakage. The edges of the pan need to line up precisely to prevent any raised edge from shaving off the belt cover.

Retrofit vs. New Construction

The modular construction of air-supported conveyors makes them suitable for retrofit applications. Because their design matches the CEMA or International Organization for Standardization (ISO) profiles of the existing idlers, the air-supported sections may easily be incorporated into existing conveyor systems (**Figure 23.18**). The plenums may be installed on top of existing stringers. This allows the air-supported conveyors to be used for a retrofit upgrade of an existing system, and the air-supported conveyors' compatibility with CEMA or ISO standards will allow the systems to

Figure 23.18

Because their design matches the CEMA or ISO profiles of the existing idlers, the air-supported sections may easily be incorporated into existing conveyor systems.

23

upgrade portions of existing belt conveyor systems. It is possible to convert an existing conveyor to the air-supported system without taking the whole conveyor off-line by installing one section at a time. The fan is sized for the completed installation and the airflow adjusted with a damper to match the number of sections installed.

For greenfield projects (new construction), the air-supported conveyor plenums may be integrated into the conveyor support structure.

SYSTEM MAINTENANCE

By eliminating (or nearly eliminating) the idlers on an air-supported conveyor, the expense of both the replacement rolling components and the manhours of labor required to maintain the system is significantly reduced.

Another opportunity for reduced expenses for maintenance and replacement components is the elimination of a skirtboard-sealing system. With their stable belt path, air-supported conveyors will allow the placement of wear liners very close to the belt. This might eliminate the need for a skirtboard-sealing system, or at least reduce the length of the system required.

It is essential that the belt-cleaning system on an air-supported conveyor function at an optimum level to eliminate fugitive material. Effective belt cleaning is even more important on a system with an air-supported return to prevent material residue from building up on the return plenum or choking the air holes in the pan.

If the air holes become plugged, they can be cleaned by blowing them out with compressed air, or, in a worst case, by re-drilling. In extreme cases, new plenum holes can be drilled with the belt in place by drilling through the belt and plenum and then covering the holes in the belt with an elastomer patch.

Regular maintenance of the intake air filter is required to maintain fan output.

TYPICAL SPECIFICATIONS

A. Design

The bulk-materials handling system will incorporate an air-supported conveyor system. This air-supported belt conveyor will be designed by an experienced conveyor engineer and constructed to CEMA standards.

SAFETY CONCERNS

Because every rolling component on a traditional conveyor system is not only a maintenance concern but also a safety issue, air-supported conveyors are inherently safer to operate and maintain, because they have fewer moving parts. The enclosed conveyor also poses less risk to plant personnel, because there is less danger of becoming entangled in the moving conveyor belt or entrapped in rolling components.

However, there are still pinch points that will need to be guarded. Proper lockout / tagout / blockout / testout procedures must be followed with air-supported conveyors.

Air-supported conveyors can be less noisy than traditional conveyors, because they have fewer rolling components (idlers and bearings) that generate noise when the belt passes over them. The fan is the noisiest part of the system, typically operating at 75 to 85 decibels; the air-supported conveyor operates at a very quiet 60 decibels.

B. Air support

This conveyor will use a film or stream of air released through a trough-shaped pan below the conveyor's belt to support the belt and the cargo without need for idlers on the carrying side. The air will be supplied by a low-pressure centrifugal fan.

C. Idlers

Conventional idlers will be used for the belt's transitions and return run.

D. Plenum

The air-supported conveyor will use a "V"-shaped plenum to allow air movement along the conveyor length. The pan will trough the belt at a 30- or 35-degree angle without distortion of the belt line.

E. Retrofit applications

The structural integrity of the plenum shall allow its use in retrofit applications without requiring modification/re-engineering/reinforcement of the existing conveyor structure.

F. Enclosed carrying side

Constructed of galvanized mild (or stainless) steel, this air-supported conveyor assembly will be totally enclosed on the belt's carrying side to prevent the release of fugitive material. The structure will be modular in construction to simplify installation.

G. Loading zone

The loading zone of the air-supported belt conveyor will incorporate an engineered chute system to load the material onto the conveyor with centralized placement and minimal impact levels. Proper placement of the material will allow material loading without requiring rubber skirting.

H. Belt cleaning

The air-supported conveyor will incorporate a suitable multiple-element belt-cleaning system. This system will be composed of a minimum of a urethane primary cleaner installed on the head pulley below the material's discharge trajectory and one or more secondary cleaners incorporating tungsten carbide cleaning elements. The cleaning system will also include a rubber-bladed V-plow to protect the tail pulley. Additional and/or specialty cleaners shall be incorporated to maintain effective cleaning as determined by material characteristics and operating conditions.

I. Manufacture/installation

To achieve uniform belt support, the air-supported conveyor plenums should be manufactured to strict tolerances, and the sections must be carefully aligned during installation.

THE RIGHT CONVEYOR FOR THE RIGHT CIRCUMSTANCES

In Closing...

While not suitable for all circumstances, air-supported belt conveyors offer significant improvements over conventional conveyors, including improved control of dust and spillage. The key to a successful air-supported conveyor system is a commitment to provide suitable belt loading conditions. By addressing concerns such as high-impact or off-center loading with the installation of load-centering spoons, a plant may reap the benefits of clean, efficient, low-maintenance air-supported conveying. Air-supported belt conveyors can be particularly beneficial when installed in combination with engineered flow loading chutes.

Looking Ahead...

This chapter about Air-Supported Conveyors, the third chapter in the section Leading-Edge Concepts, explained how they can improve control of dust and spillage. The following chapter continues this section, focusing on Belt-Washing Systems.

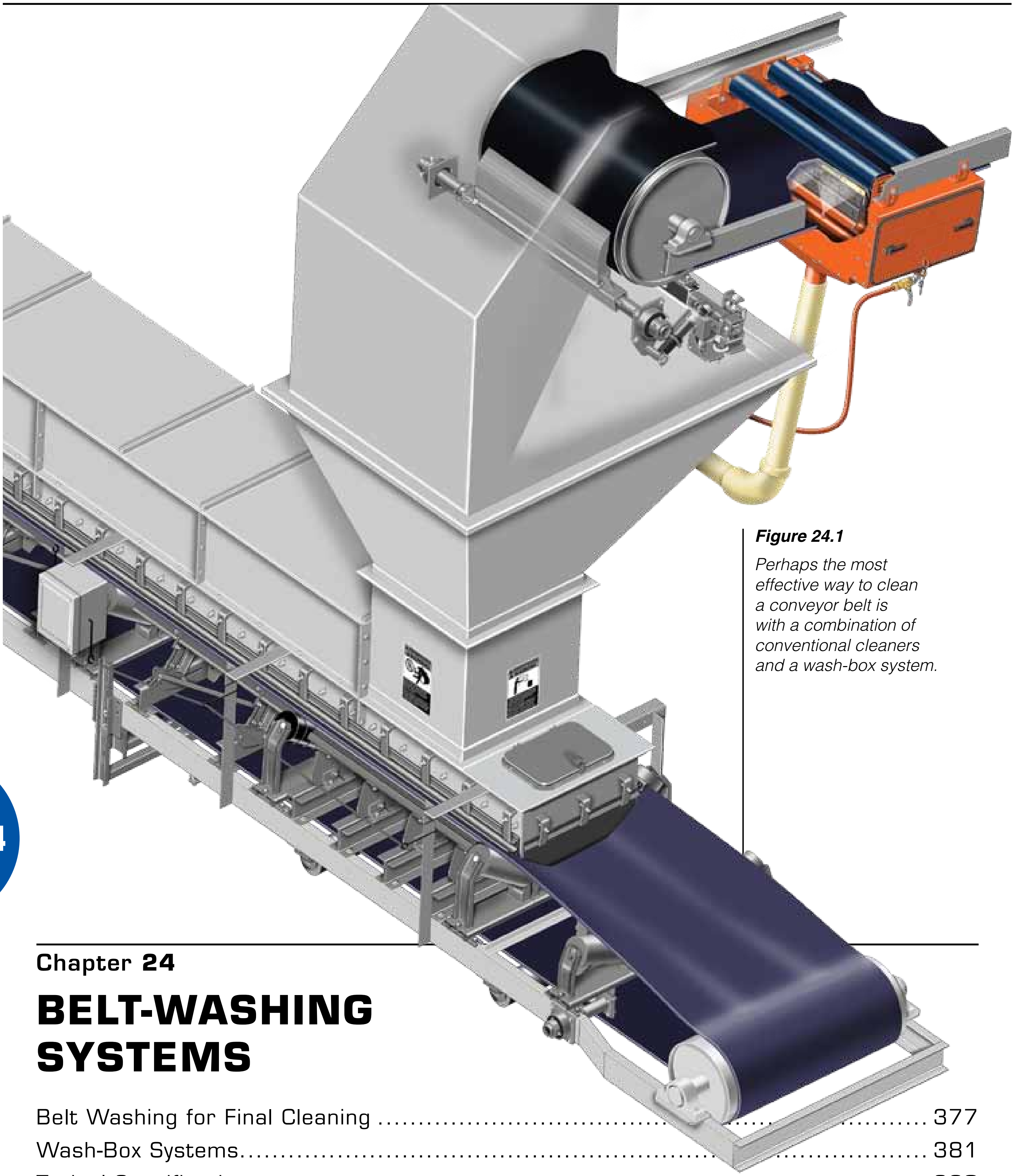

Figure 24.1

Perhaps the most effective way to clean a conveyor belt is with a combination of conventional cleaners and a wash-box system.

24

Chapter **24**

BELT-WASHING SYSTEMS

In this Chapter…

This chapter will cover the principles of wash-box systems, discuss how washing systems are specified and designed, and review the options for water handling, belt drying, and recycling of water and solids.

Perhaps the most effective way to clean a conveyor belt is with a combination of conventional cleaners and a wash-box system (**Figure 24.1**).

Belt-washing systems are a proven method to remove residual material from conveyor belts in applications where environmental issues, regulatory concerns, or other issues mandate high-efficiency cleaning. The typical belt-washing system, or wash box, will contain some configuration of water-spray bars or nozzles covering the load-carrying width of the belt, followed by any of a variety of belt-cleaning devices, from scrapers to rotating brushes. Some variation of a belt-drying system, from pressure rollers to squeegee blades to forced-air nozzles, may follow. In addition, the system must include arrangements for handling the discharge of the effluent (the slurry of water and removed solids) and for the separation, recycling, and/or disposal of the water and removed material. The system will also include an enclosure, sealing components to reduce overspray, controls, and access to allow inspection and maintenance (**Figure 24.2**).

BELT WASHING FOR FINAL CLEANING

Water in the Belt-Cleaning Process

Water assists the belt-cleaning process in a number of ways. *(See Chapter 14: Belt Cleaning.)* The addition of water to the belt-cleaning process has its own drawbacks, but ones that can be overcome with other belt-washing system components and features. With the proper design, a belt-washing system can dramatically reduce the amount of material that is carried back through the conveyor system.

The main concern is the use of water, which is frequently limited in industrial operations. Many plants have severe restrictions on how much water can be consumed in the plant or added to the material.

Other operations have stringent requirements about what must happen to the removed effluent (solids/water mix). Water recycling is a viable option in these cases. Some plants will use a settling pond or a settling basin to separate the fine materials from the water so that the water may be reused. Others will collect the water/solids for disposal. The effluent material is then run through a water-recycling system (or material-separation system) to remove the solids and return the "clean" water back to the system for reuse. The solids can then be returned to the material-handling system.

A second drawback of adding water to the cleaning process is that water itself can cause problems "downstream" on the conveyor. Water will prematurely "age" bearings, rollers, and other equipment vital to the conveyor's operation. Even small amounts of residual water remaining on the belt can cause problems. Methods for drying the belt have been developed that can help reduce these problems, keeping the water local to the washing system and not allowing it to be carried back into the conveyor system or plant.

24

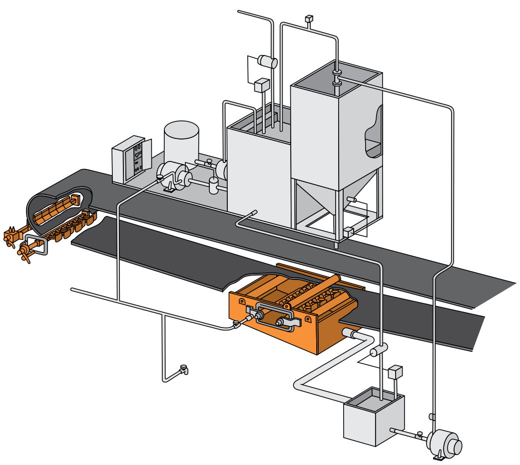

Figure 24.2

The typical belt-washing system contains water-spray bars or nozzles, belt-cleaning devices, and possibly a belt-drying system. It also includes arrangements for handling discharge of the effluent and for separation, recycling, and/or disposal of the water and removed material, along with an enclosure, sealing components, controls, and access.

Many plants or operations will be reluctant to add water into the material-handling system at any point, mainly because of a somewhat limited understanding of the effect water has on the flow of bulk materials. While it is true that an increase in the moisture content of the bulk material can have a dramatic effect on the behavior of the material that is detrimental to other processes and handling equipment, the amount of water added to the system for carryback removal is very small in proportion to the total conveyed cargo. Carryback causes far more problems than the addition of these small amounts of water to the system.

Most instances in which conveyor belt(s) are washed by some version of the technology discussed in this chapter are applications where high levels of belt-cleaning performance are required. These would include ship loading and unloading systems, where the escape of carryback might pollute the environment and lead to issues with regulatory agencies, neighbors, and environmental activists. Another application in which the same concerns lead to use of belt-washing systems are overland conveyors, where the cross-country nature of the conveyor's path might allow material to escape into the outside environment. Belt-washing systems are also seen on conveyor systems used to carry several different cargos; the belt is washed to eliminate the potential for cross contamination.

24

The Principles of Belt Washing

The principles of belt-washing systems are not significantly different from the principles of belt-cleaning systems in general. However, washing systems are technically more sophisticated and are far more effective than traditional mechanical methods of belt cleaning. Water improves the effectiveness of a cleaning system in a number of ways:

A. Water "softens" the bulk material, making it easier to remove.

B. Water keeps the belt-cleaner blades free from buildup, maximizing their cleaning efficiency.

C. Water reduces friction between the belt and cleaning blades, decreasing the forces that generate blade and belt wear, which improves the life expectancy of the blades and so extends the maintenance interval.

Softening the Bulk Material

During belt conveying, the motion of the belt across the idlers will cause the fines and moisture present in the cargo to sift downward and become compacted on the belt surface. The mission of the water in the belt-washing system is to soften the bulk material and reduce its internal strength (cohesion) and its ability to stick to the belt (adhesion). This allows the cleaning elements to remove material more effectively from the belt.

The addition of water will typically increase the cohesion and adhesion of a bulk material up to a maximum level, at which point these properties decrease in a dramatic manner (**Figure 24.3**). This critical point is the saturation moisture of the bulk material. The strength of "buildup" properties of the bulk material depend on its cohesion and adhesion properties. Consequently, the strength of a bulk material will decrease dramatically once the material is beyond its saturation point. At this point, the material becomes more of a slurry. If the material can be "wetted" enough, it is far less likely to build up or stick to any surfaces, including the belt and the belt-cleaning blades. Wetting the material makes the belt-cleaning process far more efficient than using mechanical scraping alone.

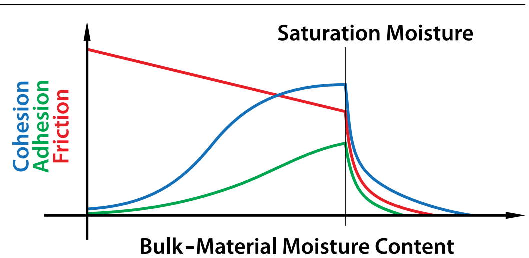

Figure 24.3

The addition of water increases the cohesion and adhesion of a bulk material up to a maximum level, at which point these properties then decrease in a dramatic manner.

Keeping the Blades Free from Buildup

A second benefit of water in belt cleaning is keeping the leading edge of the cleaning blades free from buildup (**Figure 24.4**). On conventional ("dry") belt-cleaner installations, this region of stagnant material will almost certainly form a buildup of material on the tip of the blade (**Figure 24.5**). Unless it is "cleared," this material will either eventually pass through the cleaner blades and be carried back through the conveyor system or continue to grow larger, increasing the surface area in contact with the belt and reducing the cleaning pressure, allowing more carryback to be carried through the system. Water sprays are used to keep the material from forming this stagnant layer on the surface of the belt-cleaner blade (**Figure 24.6**).

Reducing Blade-to-Belt Friction

Water also improves the performance of a belt-cleaning system or belt-washing station by acting as a lubricant between blade tip and belt surface (**Figure 24.7**). This has a number of advantages. The presence of water reduces the drag, or frictional forces on the belt-cleaner blades and on the belt itself. The reduction of these forces increases the wear-life of the cleaner blades: Less friction means less blade wear.

Another advantage is that the reduction in these frictional forces will reduce heat buildup at the tip of the belt-cleaner blades, minimizing the thermal breakdown of the blades and so extending their life.

In addition to improving the wear-life of the blades, the presence of water will also minimize wear on the conveyor belt.

Field trials have shown that a single, low-volume water spray on the pre-cleaner of a dual-cleaning system increases the system's cleaning efficiency by seven to ten percentage points and can double the interval between required maintenance procedures. In a paper presented to the 1990 International Coal Engineering Conference in Australia, J.H. Planner reported that adding a water

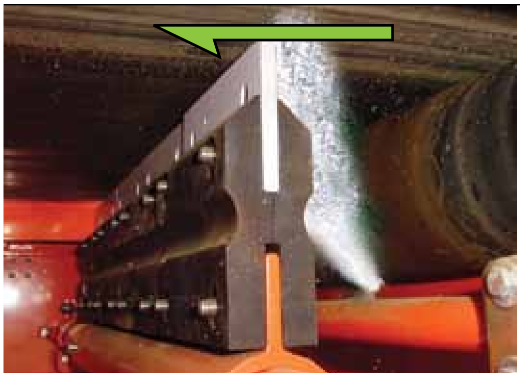

Figure 24.4

One benefit of water in belt cleaning is keeping the front edge of the cleaning blades free from buildup.

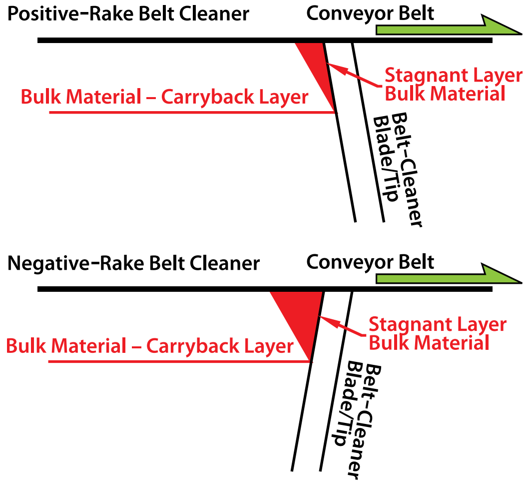

Figure 24.5

On conventional ("dry") belt-cleaner installations, a region of stagnant material will form a buildup of material on the tip of the blade.

Figure 24.6

Water sprays are used to prevent the formation of the stagnant layer on the surface of the belt-cleaner blade. Left: Functioning water spray. Right: Non-functioning water spray.

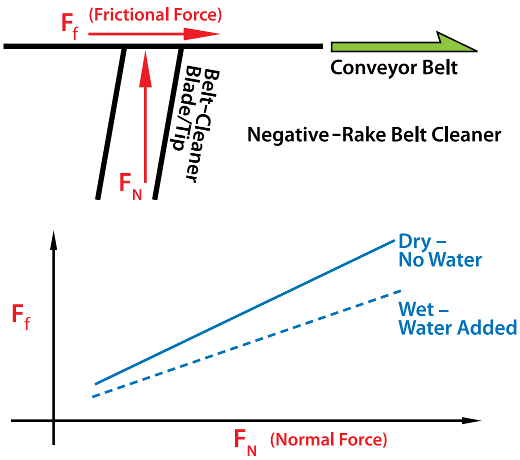

Figure 24.7

Water also improves the performance of a belt-cleaning system or belt-washing station by acting as a lubricant between blade tip and belt surface.

24

spray to various conventional cleaning systems raised cleaning efficiency from the 85 percent range to the 95 percent range *(Reference 24.1)*.

Methods for Washing the Belt

Several methods have been used to wash conveyor belts. As described by Dick Stahura in a 1987 paper *Conveyor Belt Washing: Is this the Ultimate Solution?*, the methods are flood, bath, and wash box *(Reference 24.2)*.

Flood Method

The flood method utilizes jets of water that literally blast the particles off the belt (**Figure 24.8**). Pressures of 400 to 700 kilopascals (60–100 lb_f /in.^{2}) are used, and compressed air can be added to increase the effect. High-pressure sprays can be difficult to use in a belt-washing system, because they require specialty nozzles and clean water for operation. Behind the water blast, a squeegee-type blade is used to remove the water.

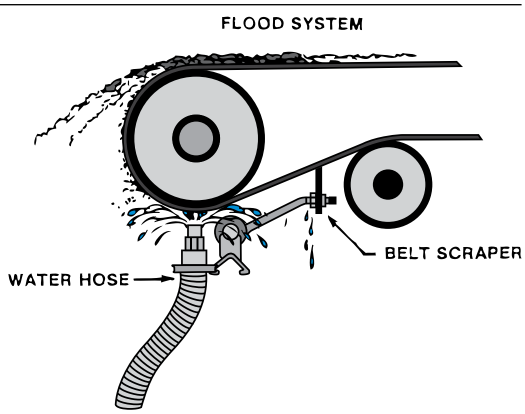

Figure 24.8

The flood method utilizes jets of water that literally blast the particles off the belt.

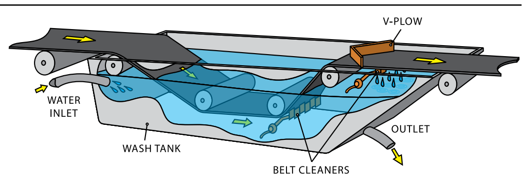

Figure 24.9

The bath method consists of pulling the belt through an enclosure filled with water.

Figure 24.10

In the wash-box method, a water-spray method is combined with one or more conventional belt cleaners in an enclosure installed as a tertiary belt-cleaning system.

Belt speed (that is, the time the belt is exposed to the spray) and the adhesiveness of the carryback are factors that generally limit the application of this approach to conveyors that operate at less than 5 meters per second (1000 ft/min) *(Reference 24.3)*. Water consumption can be quite high with this method.

Bath Method

The bath method consists of pulling the belt through an enclosure filled with water (**Figure 24.9**). This enclosure could be located along the belt return or even at the gravity take-up, where the weight of the "bath tub" of water can become part of the conveyor's counterweight tensioning system. There are no spray jets or nozzles, only a method of maintaining the water level. The water is exchanged as necessary to keep sediment from building up in the bath. The length of the "bath tub" has to be considerable to achieve any significant "dwell" (belt in the water) time and resultant cleaning effect.

This system poses some difficulties, including carcass damage and problems in maintenance and in drying the belt as it leaves the bath.

Wash-Box Method

The state-of-the-art in belt washing is the wash-box method. In this system, a water-spray method is combined with one or more conventional belt cleaners in an enclosure installed as a tertiary belt-cleaning system (**Figure 24.10**). The design and specification of a wash-box system will depend on application specifics (such as belt speed, material conveyed, belt width, and belt composition); the desired level of cleaning (and drying); and the presence of any site constraints (limits on the use of water or compressed air and/or environmental requirements) (**Figure 24.11**).

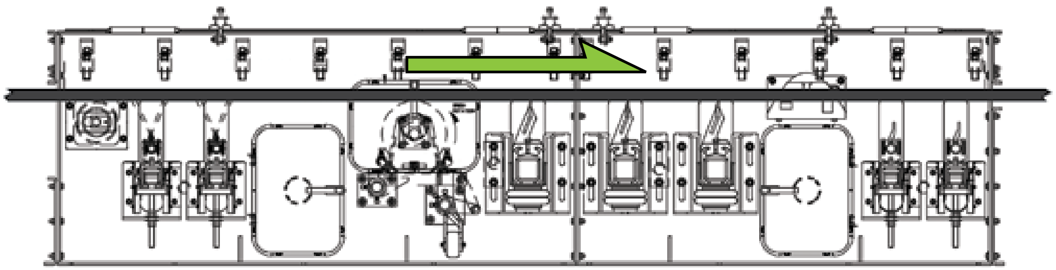

Figure 24.11

The design of a wash-box system will depend on application specifics, the desired level of cleaning, and the presence of any site constraints.

WASH-BOX SYSTEMS

The typical "wash-box" configuration is one or two spray bars for applying water followed by two or three secondary belt cleaners of a more-or-less conventional design (**Figure 24.12**). The wash-box system is engineered so that the adjustment of the cleaner's angle of attack and cleaning pressure can be performed from outside the enclosure, with the operator looking in through an access door (**Figure 24.13**).

These cleaning elements might be conventional secondary belt cleaners or brush cleaners. Brush cleaners may be more effective in cases where the belt is significantly grooved or damaged, making cleaning by flat-edged blades difficult, if not impossible (**Figure 24.14**). Depending on the application, brush cleaners can also require a significant volume of water to keep the brush clean and free from the material buildup that would render it useless.

Historically, the vast majority of wash box applications have been custom-designed out of necessity, due to each application's unique blend of conveyor specifications, material characteristics, and space limitations. A more recent development has been the concept of a "modular" wash-box system. Unlike the custom wash boxes that are designed on an application-by-application basis, the modular wash boxes use a number of "standard" components and configurable modules to combine increased flexibility and ease of use with economy in engineering and construction. The concept includes the "basic elements" of a wash-box system in a modular container (**Figure 24.15**). These modular units can then be "joined" to form more elaborate systems and customized solutions.

The modular approach allows for a number of features to be incorporated with minimal increase in the cost of the system. The modular approach includes options that provide for improved accessibility, simplified installation, easier maintenance, and the ability to easily swap components as application requirements change over

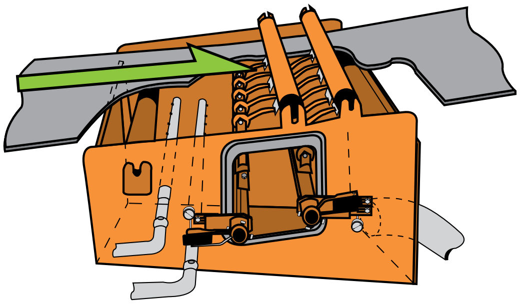

Figure 24.12

The typical "wash-box" configuration is one or two spray bars for applying water, followed by two or three secondary belt cleaners of a more-or-less conventional design.

Figure 24.13

The wash-box system should allow the inspection and adjustment of belt cleaners from outside the enclosure by the operator looking in through an access door.

Figure 24.14

Brush cleaners may be more effective in a wash box in cases where the belt is significantly grooved or damaged.

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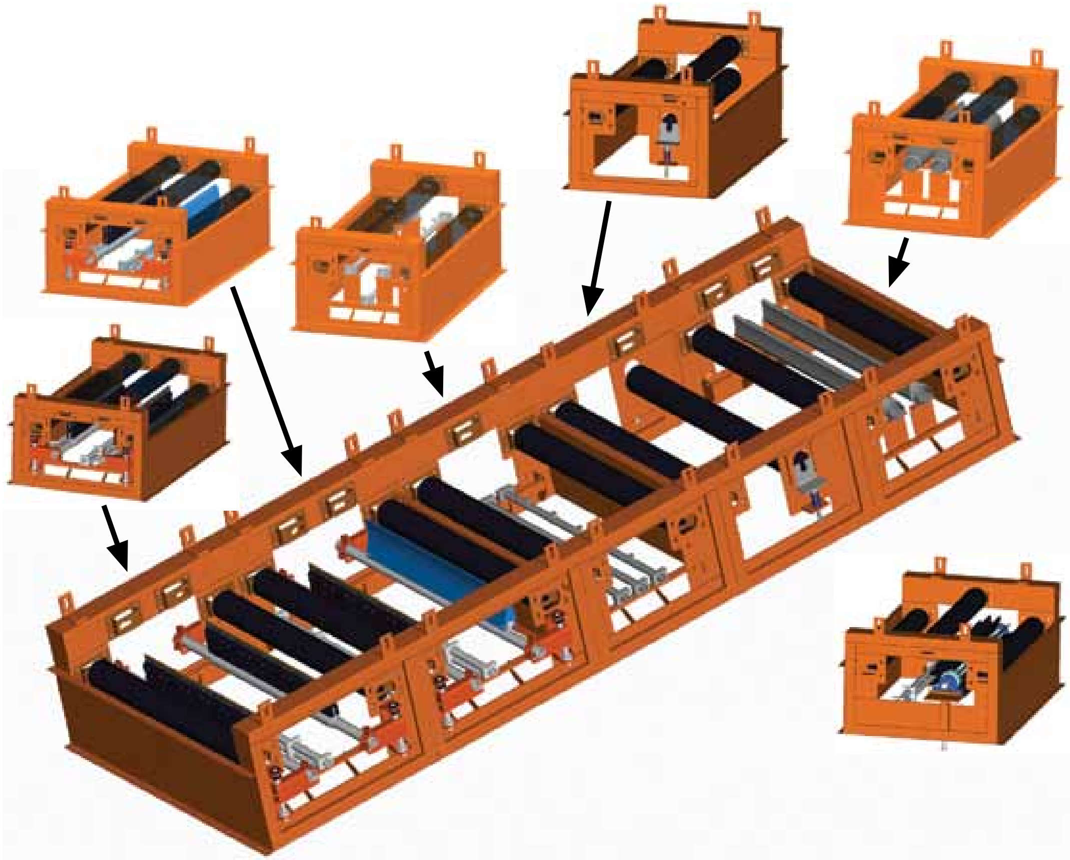

Figure 24.15

A modular wash box uses a number of "standard" components and configurable modules to provide flexibility with economy in engineering and construction.

Figure 24.16

The modular approach allows the separation of components to place greater distance between the components or for installation around conveyor structural members and other obstructions.

Figure 24.17

A wash-box system can require a distance of more than 2 meters (7 ft) of belt length and at least 0,6 meters (2 ft) of headroom for the installation at a point where the belt is free of the head and bend pulleys.

time. In fact, the modular approach allows the separation of components—putting the drying mechanisms in a different enclosure from the scraping components, for example—to allow greater distance between the components or to allow installation around conveyor structural members and other obstructions (**Figure 24.16**). An additional benefit is the modular wash-box approach allows for system expansion with different or additional modules added later, as material characteristics, cleaning requirements, or budgetary limitations change.

The drawbacks of wash-box systems include the problems that the belt-washing system can require a distance of more than 2 meters (7 ft) of belt length and at least 0,6 meters (2 ft) of headroom for the installation at a point where the belt is free of the head and bend pulleys (**Figure 24.17**). The drain for the effluent must be as vertical as possible with minimal bends to prevent it from becoming plugged (**Figure 24.18**).

Belt Washing for Final Cleaning

Belt-cleaning systems installed so the belt passes through them before it reaches the belt-washing system have an effect on the amount and pressure of water required and on the effectiveness of the wash box. It is strongly recommended that at least one primary cleaner and one or two secondary cleaners be used on any conveyor where a washing station is being considered. These cleaners—installed upstream (closer to the material discharge) of the point where the wash box will be installed—will greatly reduce the amount of carryback to be removed in a washing station, with resulting savings on water usage and operational costs (**Figure 24.19**). Without these cleaners, there will be more material to be removed from the belt by the wash box and more solids in the effluent. Belt-washing stations are intended as the ultimate in cleaning the belt; they are designed to deal with only the final removal of any residual amount of material that passes the upstream cleaning equipment.

Applying the Water

The challenge for any belt-washing application is to get the water to the correct place(s) in the cleaning system in an effective and efficient manner. There are a number of ways to apply water to the belt and material. They range from a simple hose pointed at the belt, to a pipe with drilled holes (**Figure 24.20**), to a more elaborate system of nozzles and spray bars. Engineered nozzles accomplish the application of water in a far more effective manner than a hose or pipe with holes. While the latter are effective methods of water delivery, the water usage requirements of a hose or pipe are far higher than for a system utilizing engineered nozzles. The question then becomes: What is the most effective combination of water pressure, spray pattern, contact angle, and the other variables?

The most effective and efficient way of spraying the cleaning water in these systems is a series of engineered nozzles placed along a pipe (**Figure 24.21**). Selection of a specific nozzle typically depends on a number of factors, including the type and amount of carryback material, the speed of the belt, the cleanliness of the water supply, the spray pattern needed to achieve uniform spray across the belt's width, the impact pressure of water needed to saturate the material, and the water pressure and flow rate required to keep the blades clean. As with many other aspects of

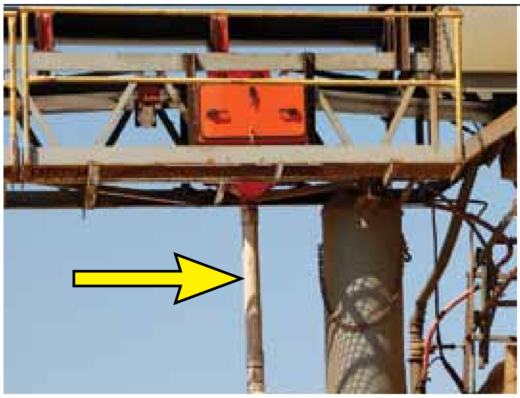

Figure 24.18

The drain for the effluent must be as vertical as possible with minimal bends to prevent it from becoming plugged with solids.

Figure 24.19

Conventional belt cleaners installed in advance of the wash box will greatly reduce the amount of carryback to reach the washing station.

Figure 24.20

There are a number of ways to apply water to the belt and material: e.g., a simple hose pointed at the belt or a water pipe with drilled holes.

conveyor system design, the washing system must be designed to function when carryback conditions are at their worst.

The two most critical factors in the choice of spray nozzles are the amount of carryback present and the speed of the belt. The higher speed belts require more water to thoroughly cover the belt and soften the carryback during the shorter time the belt is exposed to the spray. High levels of carryback will require more water: The thicker carryback layer will require more water to "soften" the material, because there is more material to be softened. High levels of carryback also require water to be delivered to the system at higher pressures so the water will penetrate the material mass to reach the belt surface. The pressure does not need to be high enough to remove the material, but it must be sufficient to allow the water to reach the belt surface.

Nozzles are available offering a wide variety of spray pattern, flow rates, and pressures. Factors such as distance from the belt to the spray bar, spray pattern, rate, and pressure must be considered in determining the configuration of the spray bars.

Figure 24.21

The most effective and efficient way of spraying the cleaning water in these systems is a series of engineered nozzles placed along a pipe.

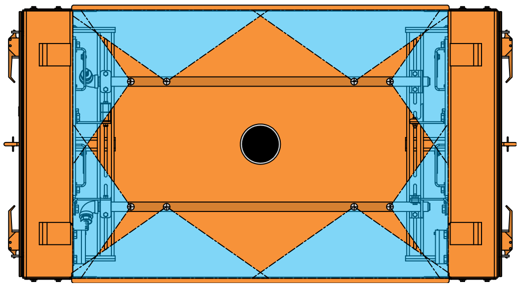

Figure 24.22

Wide spray angles are typically used to maximize the coverage area while minimizing water consumption.

Typically, wide spray angles are used to maximize the coverage area while minimizing water consumption (**Figure 24.22**). The nozzle selected, with its spray pattern and spray angle, will control the spacing and mounting distance of the spray bars used in the washing system. In some cases, specialty nozzles are required. Nozzles that are resistant to corrosion, abrasion, or chemicals encountered in the process can be specified.

A typical wash box, operating with sprays at moderate pressure—138 kilopascals (20 $lb_f/in.^2$)—will require approximately 63 liters per meter (5.1 gal/ft) of belt width per minute of operation (**Table 24.1**). As noted above, appropriate water pressure and volume should be selected after consideration of both belt speed and carryback (material adhesion) levels.

The need for and use of additional water-spray nozzles to maintain material movement by flushing the wash box and drain system will typically double the required water volume.

The engineering of a belt-washing system can be a complicated process with a number of options compounded by wide-ranging variables in conveyors and materials. A comprehensive understanding of system, material, and process requirements is required. Trained and experienced personnel need to be involved to assure the system will meet customer expectations and applications requirements.

Water Quality

The quality of the water is perhaps the most critical part of designing a high-performing system and if neglected, can render the system non-functional or prone to maintenance intervals and clean-out requirements that are not acceptable.

Belt-washing systems are best when designed for the water-flow rate and pressure required, as determined by material testing and application specifics. Some plants have severe limitations on water usage and flow rate/pressure available. These constraints can limit the wash box effectiveness to well below what was designed or specified.

Since engineered nozzles are typically "optimized" to provide a wide spray area, minimized flow rates, and optimal pressure for a given application, the orifice size of the nozzles is typically small and of a unique shape. If the water to be used in a washing system is not "clean enough," the water quality must be evaluated to ensure that there are no particulates large enough to plug the spray nozzles. This is often far easier to say than it is to accomplish, because plant water quality can change dramatically in a matter of minutes. Consequently, a water-filtration system is a valuable addition to the belt-washing system.

Drying the Belt

Following the addition of water to the cleaning process, many applications will require that the belt be dried before it leaves the washing system. In some cases, this is simply to prevent carryback suspended in the water on the belt from being flung from the return rollers. In other cases, the material-handling process requires a dry belt. In still other applications, the belt is used for transporting several bulk materials, and cross-contamination cannot be allowed, so the belt must be clean and dry before the cargo is changed.

Table 24.1

Water Consumption for Typical Belt-Washing Systems

Belt Width mm (in.)	Nozzles Used	Approximate Liters per Minute (gal/min)						
		34 kPa (5 $lb_f/in.^2$)	69 kPa (10 $lb_f/in.^2$)	103 kPa (15 $lb_f/in.^2$)	138 kPa (20 $lb_f/in.^2$)	207 kPa (30 $lb_f/in.^2$)	276 kPa (40 $lb_f/in.^2$)	414 kPa (60 $lb_f/in.^2$)
400-500 (18)	6	16 (4.3)	23 (6.0)	27 (7.2)	32 (8.4)	39 (10.2)	45 (12.0)	57 (15.0)
500-650 (24)	8	22 (5.7)	30 (8.0)	36 (9.6)	42 (11.2)	51 (13.6)	61 (16.0)	76 (20.0)
650-800 (30)	9	24 (6.4)	34 (9.0)	41 (10.8)	48 (12.6)	58 (15.3)	68 (18.0)	85 (22.5)
800-1000 (36)	11	30 (7.8)	42 (11.0)	50 (13.2)	58 (15.4)	71 (18.7)	83 (22.0)	104 (27.5)
1000-1200 (42)	13	35 (9.3)	49 (13.0)	59 (15.6)	69 (18.2)	84 (22.1)	98 (26.0)	123 (32.5)
1200-1400 (48)	15	40 (10.6)	57 (15.0)	68 (18.0)	79 (21.0)	97 (25.5)	114 (30.0)	142 (37.5)
1400-1600 (54)	16	43 (11.4)	61 (16.0)	73 (19.2)	85 (22.4)	103 (27.2)	121 (32.0)	151 (40.0)
1600-1800 (60)	18	48 (12.8)	68 (18.0)	82 (21.6)	95 (25.2)	116 (30.6)	136 (36.0)	170 (45.0)
1800-2000 (72)	22	59 (15.6)	83 (22.0)	100 (26.4)	117 (30.8)	142 (37.4)	166 (44.0)	208 (55.0)
2000-2200 (84)	26	70 (18.4)	98 (26.0)	118 (31.2)	138 (36.4)	167 (44.2)	197 (52.0)	246 (65.0)

There are three basic methods for drying a moving conveyor belt that can be applied to the conveyor as it exits the washing station: evaporation, mechanical water removal, and forced-air drying.

Evaporation

Evaporation is a natural process that will dry the belt (**Figure 24.23**). Evaporation can be accelerated by forcing heated air over the moving belt. However, evaporation of the water film by forced air alone is not a feasible means of complete water removal for typical bulk-materials handling conveyor belt applications, because there is a limit to how fast water can be evaporated.

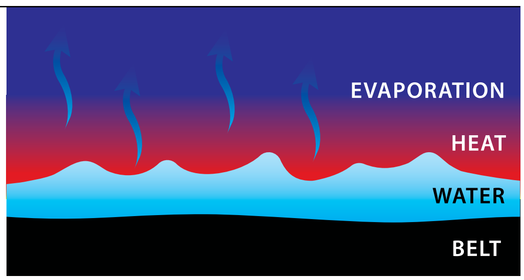

Figure 24.23

The natural process of evaporation can be accelerated by forcing heated air over the moving belt.

Figure 24.24

A squeegee blade is an effective and economical means of removing water from a conveyor belt.

Mechanical Drying

There are a number of mechanical methods to remove water from the belt. The first is mechanically wiping the belt, using what is commonly called a "squeegee" blade. This is similar to a car's windshield wipers.

A squeegee blade placed as the final cleaning device in the wash-box system will remove a significant amount of excess water. The result will vary depending on the type of squeegee used, its material of construction, and its location, as well as application specifics such as belt speed and the amount of water present on the belt. In general, the squeegee blade is an effective and economical means of water removal (**Figure 24.24**).

The use of squeegee rollers, either as single or dual rolls, is also an effective way of removing excess water from the moving conveyor belt (**Figure 24.25**). A study from the University of Newcastle Research Associates (TUNRA) explored the effectiveness of a single-roll squeegee system and examined the effect of using different diameter rolls on various belt speeds *(Reference 24.4)*. The results of this study clearly showed the smaller the roller, the better the squeegee action, regardless of belt speed (**Figure 24.26**). Squeegee rollers are generally effective in reducing the thickness of the film of water on the belt to approximately 50 microns, with an effective lower limit of 20 microns (**Figure 24.27**).

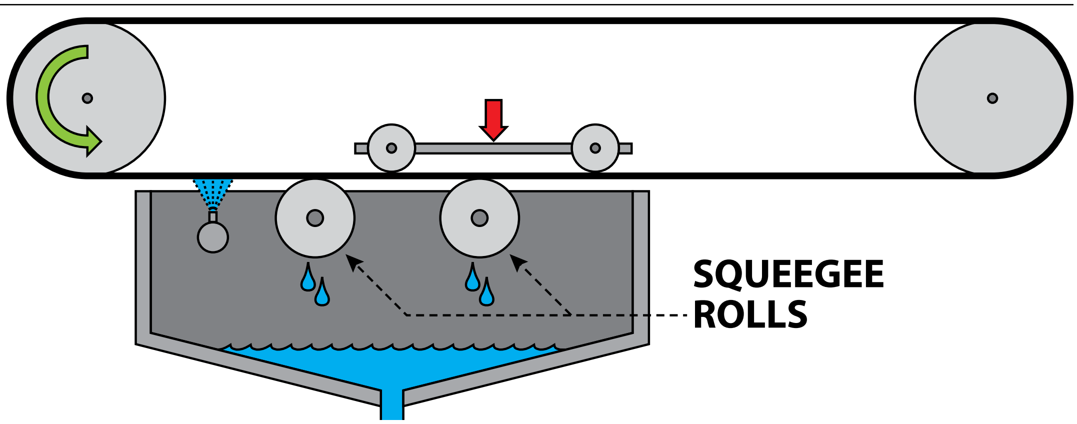

Figure 24.25

The use of squeegee roller systems, with either single or dual rolls, is an effective way of removing excess water from the moving conveyor belt.

Forced-Air Drying

The third technique for drying the belt is using high-velocity air to separate the water film from the belt. Two mechanisms can be dominant: hydrodynamic instability and disjoining. Hydrodynamic instability occurs when the water film is exposed to moving air. The film will form a wave, which grows rapidly, causing the formation of droplets that then leave the surface. Disjoining occurs when the water film is exposed to high-velocity air, and the water is "peeled" from the belt surface (**Figure 24.28**).

High-velocity air can be highly effective in the removal of thicker films of water. There are a number of systems commercially available, including air "knives" that use blowers to generate the air velocity and pressure required; other systems operate from compressed air lines (**Figure 24.29**).

To remove the largest quantity of water, the velocity of air must be maximized. However, the achievable velocity of air is limited by several factors, including the power consumed to generate high velocities using a blower or compressed air line as

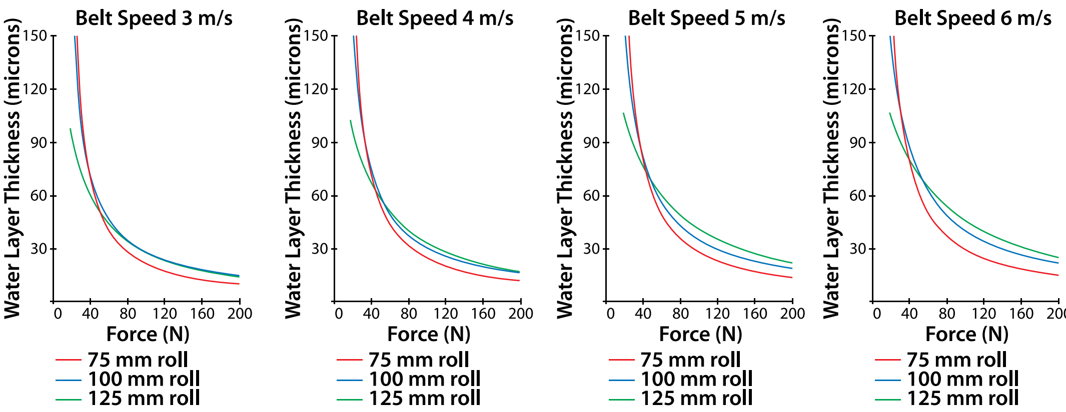

Figure 24.26

The results of this study clearly showed the smaller the roller, the better the squeegee action, regardless of belt speed.

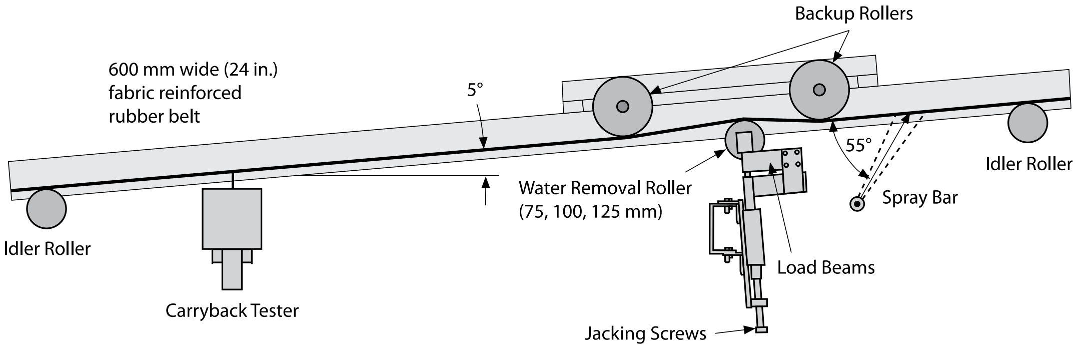

Figure 24.27

Squeegee rollers are generally effective in reducing the film of water on the belt to approximately 50 microns, with an effective lower limit of 20 microns.

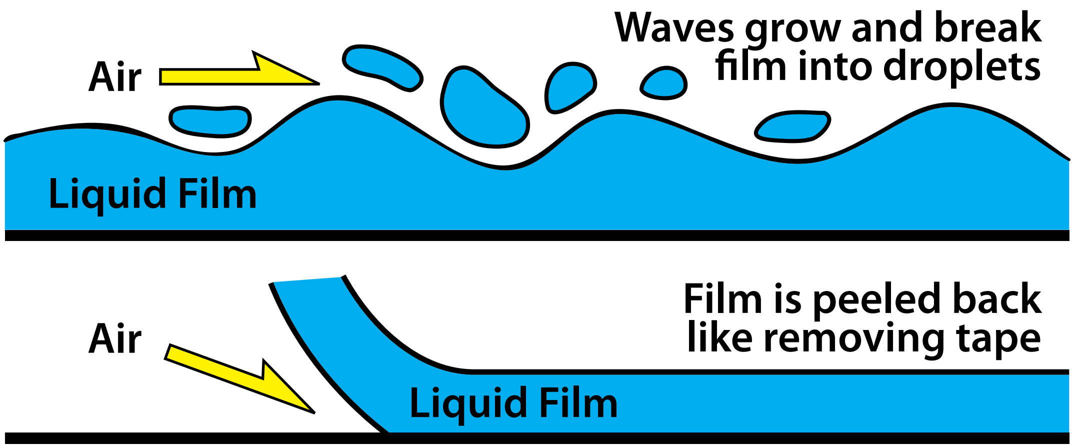

Figure 24.28

Hydrodynamic instability occurs when moving air forms the water film into a wave, from which droplets then leave the surface. Disjoining occurs when the water film is exposed to high-velocity air so the water is "peeled" from the belt surface.

24

well as the noise associated with extremely high velocities of air.

Research has indicated the dominant factor in water removal was the relative speed of the air; the angle of contact was not critical in terms of water removal. A feasible range of air velocity at the belt is 80 to 100 meters per second (15000 to 20000 ft/min). Within this air speed range, experimental results show that water can be removed from a moving belt down to a film thickness of 7 to 11 microns *(Reference 24.5)*. These velocities can be reached with specially designed nozzles and regenerative blowers for about 7,5 kilowatts per meter (3 hp/ft) of belt width dried. Compressed air can also be used—with other air nozzle types—with similar power requirements. As typical belt speeds are from 1 to 5 meters per second (200 to 1000 ft/min), belt speed is not a major parameter compared to the speed of the air.

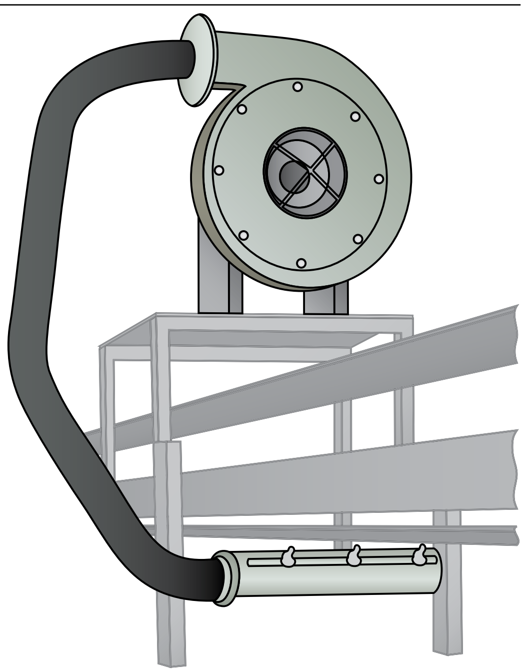

Figure 24.29

There are a number of systems commercially available, including air "knives" that use blowers to generate the air velocity and pressure required to dry the belt.

Performance of Water-Removal Systems

The relative performance of the various water-removal systems can be assessed and compared (**Table 24.2**). These three water-removal methodologies can be used individually, but the best approach may be to use a combination of the different possibilities.

Reclaiming the Water

Once the basic components of a belt-washing system are established, it is possible to examine the systems for dealing with the effluent—the dirty water—removed from the belt. In many industrial environments, the amount of water used and the quality of water released are strictly controlled. In other cases, the material has a high value and, therefore, it is cost effective to recover the solids. In both cases, a system to separate the solids from the water is often required.

In choosing a mechanical water-separation system, several factors need to be considered. Principal among them is the quantity of water and its solids content, as well as the location in which the water-recycling system can be installed. Depending on the method of treatment, the rate of settlement of the solid in water can be the main criteria, but due to the size of the devices, relying solely on settling is often impractical.

In the most simple water-treatment system, the effluent is channeled to a settling pond and, by the process of sedimentation, the water is clarified and filtered for reuse as plant water (**Figure 24.30**). This has several potential problems, including keep-

Table 24.2

Comparison of Various Water-Removal Methods

Method	Water-Removal Efficiency	Energy Use	Purchase Cost	Operating Cost
Squeegee Blade	1	2	1	1
Squeegee Roller	2	1	3	2
Compressed Air Knife	3	3	2	3
High Pressure Blower	4	4	4	4

1 = Lowest, 4 = Highest

ing the drainage system from plugging with solids, the periodic dredging of the solids from the settling pond, and the subsequent disposal of this recovered material.

Concrete settling basins are sometimes used close to the point of effluent generation. These can be designed so a front-end loader can drive into the basin and collect the settled solids. On a smaller scale, dumpsters can be used as the location for settling, with the advantage the solids can often be returned to the material-handling system simply by emptying the container (**Figure 24.31**).

Engineered water-separation and -reclamation systems are available (**Figure 24.32**). Modular water-recycling systems can provide up to 1250 liters per minute (300 gal/min) of continuous recycling; the modules can be combined to provide higher volumes of clean water.

In some cases, a chemical additive can be used to expedite solids settling, but this will require periodic inspection and service of the equipment to assure that the chemical is available to the system at all times.

Mechanical-filtration or chemical-additives systems are occasionally necessary for bulk materials that do not wet easily or that have a specific gravity close to or less than water. There is a variety of mechanical means available including filter presses, dewatering screens, hydrocyclones, and clarifiers. However, most bulk materials that are handled in large quantities are heavier than water and so can be separated using a simple and effective inclined screw separator system.

When designing a complete wash-box system, the washing portion should be designed first, to define the system's operational requirements. Following that, the water-recycling system can be developed to provide the water-handling capacity to meet the washing requirement. One detail that is often overlooked is that the discharge from a wash box is prone to plugging. For this reason, the discharge should be either

Figure 24.30

In the most simple water-treatment system, the effluent is channeled to a settling pond and, by the process of sedimentation, the water is clarified and filtered for reuse as plant water.

Figure 24.31

Dumpsters can be used as the settling tank, with the solids returned to the material-handling system simply by emptying the container.

Figure 24.32

Engineered water-separation and -reclamation systems can provide up to 1250 liters per minute (300 gal/min) of continuous recycling.

an open channel or a large-diameter pipe with minimal bends. It should also have many removable fittings or plugs to allow clean-out and use plenty of flushing water (**Figure 24.33**).

Recovering the Solids

The materials in the wash-box effluent can be recovered. This is important in those operations in which the cargo is especially valuable and/or the cargo has already been subjected to some processing or treatment.

If the addition of water to the process is not a concern, the slurry can be returned to the conveyor cargo or plant process directly from the wash box by means of a pump. If the plant needs to minimize the water added to its process, the water can be recycled and the recovered solids can then be placed on the belt or process through a mechanical means such as a screw conveyor. A simple settling test, in which the material is placed in a container of water and the rate at which it settles is observed, will give a good indication of the dwell time needed for settling and whether or not chemical additives might be needed to promote settling.

Figure 24.33

The discharge from a wash box should be either an open channel or large diameter pipe that has minimal bends, has several removable fittings to allow clean-out, and uses plenty of flushing water.

TYPICAL SPECIFICATIONS

A. Spray-wash system

The conveyor system will be equipped with a spray belt-washing system installed directly after the head chute to provide final removal of any residual cargo from the belt. This spray-wash system will be contained in a watertight metal enclosure fitted with water supply and an oversized drain.

B. Size

The belt-washing system will be sized based on the amount and properties of expected carryback per square meter (/ ft^2) of belt.

C. Water-spray bar

The enclosure shall be fitted with at least one water-spray bar with engineered nozzles that are positioned to wet the entire cargo-carrying portion of the belt and to flush removed material out of the box through the drain.

D. Secondary cleaners

The wash box will be fitted with a minimum of two secondary cleaners to remove fines and water from the belt's load-carrying surface.

E. Access

The wash box shall be fitted with watertight access door(s) to allow easy inspection and service.

F. Hold-down rollers

The spray-wash system shall include a minimum of three hold-down rollers above the belt that hold the belt in position against the spray-applied water and cleaning edges.

G. Drain system

The volume and flow rate of flushing water and design of the drain system shall be sufficient to prevent settling of bulk solids in the drain system.

ADVANCED TOPICS

The Process for Developing a Wash-Box System

When developing a belt-washing station, it is desirable to provide a complete system analysis that takes into account a number of factors including the physical layout of the conveyor and water-recycling system, the amount of energy required for drying and water recycling, and the ability of the solids to be separated from the water.

When considering the installation of a wash box, there are a number of questions that must be considered. These include:

A. How much water will the wash box use?

B. How clean will the belt be as it enters the wash box?

C. How clean must the belt be as it leaves the wash box?

D. How dry will the belt be?

E. What will be done with the effluent (the mix of solids and water)?

These questions can be answered with reasonable accuracy if there is detailed information available about the properties of the bulk material, the belt and bulk material interface conditions, the amount of carryback present, and the general choice of equipment in the wash box.

Sample Problem

The approach to develop a preliminary design of a Wash-Box System is as follows:

A. Determine the amount of carryback entering the wash box per day ($Cb_{day\text{-}in}$).

B. Determine the desired amount of carryback leaving the wash box per day ($Cb_{day\text{-}out}$).

C. Determine the amount of effluent to be handled per minute.

D. Consider options and other questions.

These four stages can be answered by following the four steps below.

Step 1. Calculate the carryback on the belt entering the wash box per day ($Cb_{day\text{-}in}$) (**Equation 24.1**)

$$Cb_{day-in} = BW \cdot CW \cdot S \cdot T \cdot Cb_{in} \cdot k$$

Given: *A 1,2-meter (48-in.) belt with a cleaned width of 67 percent traveling 3,5 meters per second (700 ft/min) has a measured carryback of 100 grams per square meter (0.33 oz/ft²) in a 24-hour operation.* ***Find:*** *The carryback entering the wash box per day.*

Variables		Metric Units	Imperial Units
Cb_{day-in}	Carryback Entering the Wash Box per Day	tons	short tons
BW	Belt Width	1,2 m	4 ft
CW	Cleaned Width of Belt	0,67 (67%)	0.67 (67%)
S	Belt Speed	3,5 m/s	700 ft/min
T	Time in a Day	86400 s	1440 min
Cb_{in}	Amount of Carryback Reaching Wash Box	100 g/m²	0.33 oz/ft²
k	Conversion Factor	1 x 10⁻⁶	3.12 x 10⁻⁵
Metric: $Cb_{day-in} = 1,2 \cdot 0,67 \cdot 3,5 \cdot 86400 \cdot 100 \cdot 1 \cdot 10^{-6} = 24,3$			
Imperial: $Cb_{day-in} = 4 \cdot 0.67 \cdot 700 \cdot 1440 \cdot 0.33 \cdot 3.12 \cdot 10^{-5} = 27.8$			
Cb_{day-in}	Carryback Entering the Wash Box per Day	24,3 t	27.8 st

Step 1 Answer: There are 24,3 tons (27.8 st) of carryback entering the wash box per day.

Equation 24.1

Calculating the Amount of Carryback Entering the Wash Box per Day

24

Step 2. Calculate the desired carryback on the belt as it leaves the wash box per day ($Cb_{day-out}$) (**Equation 24.2**)

Step 3. Determine the amount of effluent to be handled per minute (**Equation 24.3**)

Step 4. Consider options and additional questions

A more detailed study and theoretical analysis combined with field testing at the actual site would produce additional factors and variables that could be used to further investigate options. Additional questions that can now be considered include:

A. Is 10 grams per square meter (0.033 oz/ft²) too much carryback material left on the belt as it leaves the wash box? (Carryback is measured as the dry weight of the material.)

B. How wet is the belt as it leaves the wash box?

C. How can the overall water usage be reduced?

For the purpose of keeping this example short, some assumptions regarding moisture content of the carryback (50 percent) and of the effluent (15 percent) must be made to answer these questions. These assumptions are based on experiences in wash-box design.

Is 10 Grams per Square Meter Too Much Carryback Material to Leave on the Belt Leaving the Wash Box?

As noted in the discussion of carryback levels, 10 grams per square meter (0.033 oz/ft²) is considered a clean belt. *(See Chapter 31: Performance Measurements.)* Testing has shown that on average, only about 50 percent of the carryback left on the belt at this level of cleanliness will fall from the belt on the return run.

Belt cleaning is a process with results in a bell-shaped curve. A 10-grams-per-square-meter carryback level could range from 20 grams per square meter (0.066 oz/ft²) to sometimes 0 grams per square meter. To achieve a belt cleaner than 10 grams per

Equation 24.2

Calculating Desired Carryback Exiting the Wash Box per Day

24

$$Cb_{day-out} = BW \cdot CW \cdot S \cdot T \cdot Cb_{out} \cdot k$$

Given: *A 1,2-meter (48-in.) belt with a cleaned width of 67 percent traveling 3,5 meters per second (700 ft/min) has a desired carryback of 10 grams per square meter (0.033 oz/ft²) in a 24-hour operation.* ***Find:*** *The carryback exiting the wash box per day.*

Variables		Metric Units	Imperial Units
$Cb_{day-out}$	Desired Carryback Exiting the Wash Box per Day	tons	short tons
BW	Belt Width	1,2 m	4 ft
CW	Cleaned Width of Belt	0,67 (67%)	0.67 (67%)
S	Belt Speed	3,5 m/s	700 ft/min
T	Time in a Day	86400 s	1440 min
Cb_{out}	Amount of Desired Carryback Exiting the Wash Box	10 g/m²	0.033 oz/ft²
k	Conversion Factor	1 x 10^{-6}	3.12 x 10^{-5}
Metric: $Cb_{day-out} = 1{,}2 \cdot 0{,}67 \cdot 3{,}5 \cdot 86400 \cdot 10 \cdot 1 \cdot 10^{-6} = 2{,}4$			
Imperial: $Cb_{day-out} = 4 \cdot 0.67 \cdot 700 \cdot 1440 \cdot 0.033 \cdot 3.12 \cdot 10^{-5} = 2.8$			
$Cb_{day-out}$	Desired Carryback Exiting the Wash Box per Day	2,4 t	2.8 st

Step 2 Answer: The desired carryback exiting the wash box is 2,4 tons (2.8 st) per day.

square meter (0.033 oz/ft²) of carryback, so much cleaning pressure would need to be applied that it would endanger the belt's top cover. Therefore, 10 grams per square meter is an acceptable and practical lower limit for carryback material remaining on the belt.

How Wet is the Belt as it Leaves the Wash Box?

The amount of water left on the belt can be estimated based on the type of water-removal system used. The most effective method is a high-velocity air-knife system.

Testing has confirmed that for moving conveyor belts, the theoretical value of 6,0 grams per square meter (0.020 oz/ft²) of water left on the belt is about as low as is practical to obtain.

In the example, assuming 10 grams per square meter (0.033 oz/ft²) (dry weight) of carryback is left on the belt at 50 percent moisture content means there will be an equal amount, or 10 grams per square meter, of water left on the belt. *(Note: A film of carryback or water 1,0 micron thick, with a specific gravity of 1.0, is equal to 1,0 grams per square meter.)*

How Can Overall Water Usage Be Reduced?

Overall water usage can be reduced by recycling all the water from the effluent and adding only the required makeup water to the wash-box system. Theoretically, the amount of makeup water needed would equal the amount of water left on the belt as it leaves the wash box and in the effluent. However, there will be other system losses

Equation 24.3

Calculating the Amount of Effluent Handled per Minute

$$E_m = \frac{(Cb_{day\text{–}in} - Cb_{day\text{–}out}) \cdot k}{\rho \cdot T} + (W_{SB} + W_F)$$

Given: *A wash box where 24,3 tons (27.8 st) of carryback enter and 2,4 tons (2.8 st) of carryback exit, and the density of the material is 1 kilogram per liter (62 lb_m/ft^3). The spay bar and the flush system in the wash box each consume 100 liters per minute (25 gal/min) in a 24-hour operation.* ***Find:*** *The amount of effluent per minute of operation.*

Variables		Metric	Imperial
E_m	Effluent Handled per Minute	liters per minute	gallons per minute
$Cb_{day\text{–}in}$	Carryback Entering the Wash Box per Day	24,3 t	27.8 st
$Cb_{day\text{–}out}$	Desired Carryback Exiting the Wash Box per Day	2,4 t	2.8 st
k	Conversion Factor	1000	14960
ρ	Bulk Material Density	1 kg/l	62 lb_m/ft^3
T	Time in a Day	1440 min	1440 min
W_{SB}	Water Consumption for Spray Bar	100 l/min	25 gal/min
W_F	Water Consumption to Flush Wash Box	100 l/min	25 gal/min

Metric: $E_m = \frac{(24{,}3 - 2{,}4) \cdot 1000}{1 \cdot 1440} + (100 + 100) = 215$

Imperial: $E_m = \frac{(27.8 - 2.8) \cdot 14960}{62 \cdot 1440} + (25 + 25) = 54$

E_m	Effluent Handled per Minute	215 l/min	54 gal/min

Step 3 Answer: The system handles 215 liters per minute (54 gal/min) of effluent.

24

in a wash box such as leaks and splashing as well as evaporation. The amount of water that leaves the wash box, contained in the carryback and recycled solids, is usually at least half of the required makeup water. Because the addition of makeup water is usually controlled by some type of level indicator in the settling tank, the demand is not constant. Therefore, the makeup water system should be oversized to keep the tank at the proper level without having to run continuously.

The makeup water required can be calculated (**Equation 24.4**).

The wash box requires 200 liters per minute (50 gal/min) of water. By using only the required makeup water and recycling the effluent water, the operation will consume only 8,6 liters per minute (2.5 gal/min). This produces a water savings of 191,4 liters per minute (47.5 gal/min) of water. The recycled water can be used to flush the wash box and/or in spray bars with large orifices. Most of the makeup water can be added as a low-volume clean water spray on the last belt cleaner or squeegee inside the wash box. This example, although simplified, is typical of a conveyor belt-washing system for this belt width and speed using a mechanical means of recycling the water and solids.

ON THE DESIGN OF BELT-WASHING SYSTEMS

In Closing…

Combining effective belt cleaners, spray-washing technology, effluent treatment, and belt-drying systems produces a state-of-the-art belt-washing station. Such a station can meet the need for keeping the belt reasonably clean and dry, provide for the recovery and recycling of the solids at a reasonable cost, and use a minimum amount of clean

Equation 24.4

Calculating Required Makeup Water per Minute

$$M_W = \left[\left(\frac{Cb_{day-out}}{\left(\frac{1-M_{Cb}}{M_{Cb}}\right)}\right) + \left(\frac{Cb_{day-in} - Cb_{day-out}}{\left(\frac{1-M_E}{M_E}\right)}\right)\right] \cdot SF \cdot k$$

Given: *A wash box where 24,3 tons (27.8 st) of carryback enter and 2,4 tons (2.8 st) of carryback exit, with a carryback moisture content of 50 percent and an effluent moisture content of 15 percent.* ***Find:*** *The amount of makeup water needed per minute.*

Variables		Metric Units	Imperial Units
M_W	Makeup Water per Minute	liters per minute	gallons per minute
Cb_{day-in}	Carryback Entering Wash Box per Day	24,3 t	27.8 st
$Cb_{day-out}$	Desired Carryback Exiting Wash Box per Day	2,4 t	2.8 st
k	Conversion Factor	0,69	0.17
M_{CB}	Moisture Content of Carryback	0,5 (50%)	0.5 (50%)
M_E	Moisture Content of Effluent	0,15 (15%)	0.15 (15%)
SF	Safety Factor to Account for Other Losses	2	2

Metric: $M_W = \left[\left(\frac{2{,}4}{\left(\frac{1-0{,}5}{0{,}5}\right)}\right) + \left(\frac{24{,}3-2{,}4}{\left(\frac{1-0{,}15}{0{,}15}\right)}\right)\right] \cdot 2 \cdot 0{,}69 = 8{,}6$

Imperial: $M_W = \left[\left(\frac{2.8}{\left(\frac{1-0.5}{0.5}\right)}\right) + \left(\frac{27.8-2.8}{\left(\frac{1-0.15}{0.15}\right)}\right)\right] \cdot 2 \cdot 0.17 = 2.5$

M_W	Makeup Water per Minute	8,6 l/min	2.5 gal/min

24

SAFETY CONCERNS

Generally speaking, the safety issues for belt-washing stations are no different from those for other belt-cleaning systems, with the exceptions that fluids under pressure are usually present and there may be auxiliary equipment such as pumps or screw conveyors that may start automatically. *(See Chapter 14: Belt Cleaning for a review of the safety concerns with belt-cleaning systems.)*

Appropriate lockout / tagout / blockout / testout procedures must be followed. Auxiliary equipment, such as pumps and screw conveyors, should be de-energized, and all pressure sources, such as compressed air and water, must be turned off and depressurized before servicing.

Inspection and service of wash boxes require access from both sides of the conveyor. Adequate work space should be provided. The presence of water can make decks, floors, and stairways slippery, so caution is always advisable when approaching or working around these systems. Workers should use caution when inspecting belt-washing systems in order to avoid being subjected to overspray and the material particles it can contain.

water. Where space is limited, the elements can be designed to fit into confined spaces, but the difficulties may result in corresponding reductions in cleaning effectiveness and increased difficulty in operation and maintenance.

Belt-washing systems combine all of the desired features of a complete belt-cleaning system into a single operating system. By selecting the equipment appropriate for the application, the cost can be minimized and a return on investment can be calculated based on meeting environmental regulations, recovering the carryback material, reducing cleanup expense, and increasing component-life.

Looking Ahead...

This chapter about Belt-Washing Systems, the third chapter in the section Leading-Edge Concepts, discussed using water with belt-cleaning systems to reduce both carryback and the damage it can cause to the conveyor. The following chapter, Material Science, is the final chapter in this section.

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24.7 Roberts, A.W.; Ooms, M.; and Bennett, D. *Conveyor Belt Cleaning – A Bulk Solid/Belt Surface Interaction Problem*. University of Newcastle, Australia: Department of Mechanical Engineering.

24.8 Spraying Systems Company (http://www.spray.com) contains a variety of useful material on the basics and options available in spray nozzles.

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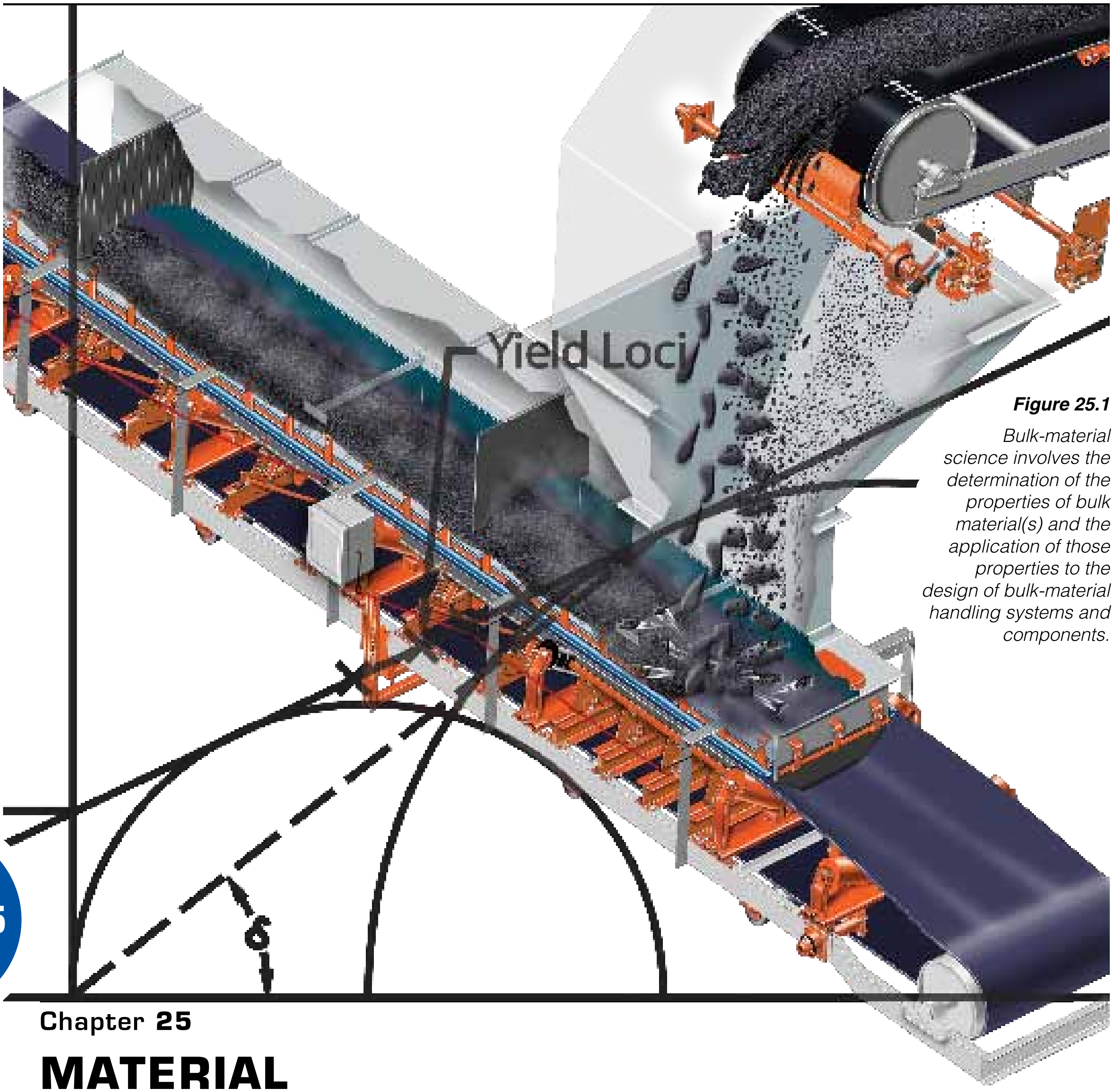

Figure 25.1

Bulk-material science involves the determination of the properties of bulk material(s) and the application of those properties to the design of bulk-material handling systems and components.

25

Chapter 25

MATERIAL SCIENCE

In this Chapter…

In this chapter, we discuss the importance of testing the actual bulk materials to be conveyed for proper conveyor design. We describe both basic and advanced properties of bulk materials and the test methods used for measuring those properties, along with typical applications for which these tests are performed.

Bulk-material science is an interdisciplinary field involving the determination of the properties of bulk material(s) and the application of those properties to the design of bulk-material handling systems and components. This science investigates the interaction between bulk material(s)—both as a body and as individual particles—and the surfaces over which the material(s) will flow.

Since the design of the first conveyors, the basic properties of bulk materials, such as bulk density and angle of repose, have been used to size equipment and to calculate the power requirements of bulk-material handling systems. Modern bulk-material science traces its roots to Andrew W. Jenike's work at the University of Utah, in which the critical dimensions required for bins to operate in a mass flow condition were determined based on the strength of the bulk material under various conditions. The methods developed by Jenike are used to determine the internal strength of bulk materials and the friction between the bulk material and the surfaces it will contact (e.g., the belt or chute). These properties are used with increasing success to predict the behavior and flow of bulk materials as they travel on conveyors and through chutes, thus allowing the design of cleaner, safer, and more productive systems.

A number of references are published with typical properties for many bulk materials *(Reference 25.1)*. This reference data is normally a general description, and while useful for preliminary equipment design, it does not represent a specific bulk material under the actual conditions of use. Serious errors can be made by designing a material-handling system without determining the appropriate basic and advanced properties of the specific bulk material.

There are many applications for bulk-material science, such as the design of bins, screw conveyors, and stockpiles. This chapter will discuss the importance of the application of the properties of bulk materials to the design of belt conveyor systems and components for handling bulk materials (**Figure 25.1**).

BASIC PROPERTIES OF BULK MATERIALS

Many of the basic properties and tests for bulk materials are described in the Conveyor Equipment Manufacturers Association (CEMA) publication CEMA STANDARD 550-2003. The properties most often used (or misused) in the design of belt conveyor systems are described below.

Bulk Density

Bulk density (ρ) of a bulk material is the weight per unit of volume—kilograms per cubic meter (lb_m/ft^3). Differences in bulk density will occur at different moisture contents and as the bulk material travels on the conveyor belt and is compacted due to vibration.

Loose Bulk Density

Loose bulk density (ρ_1) of a bulk material is the weight per unit of volume that has been measured when the sample is in a loose or non-compacted condition (**Figure 25.2**). The loose bulk density must always be used when designing the load-zone chutes and the height and width of the skirtboards, or the design capacity may not flow through the transfer point, due to the increased volume in the loose state.

Consolidated Bulk Density

Consolidated bulk density (ρ_2)—sometimes called vibrated bulk density—is normally the heaviest density that can be found in the conveying of bulk materials (**Figure 25.3**). This is achieved by apply-

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Figure 25.2

Loose bulk density (ρ_1) of a bulk material is the weight per unit of volume that has been measured when the sample is in a loose or non-compacted condition.

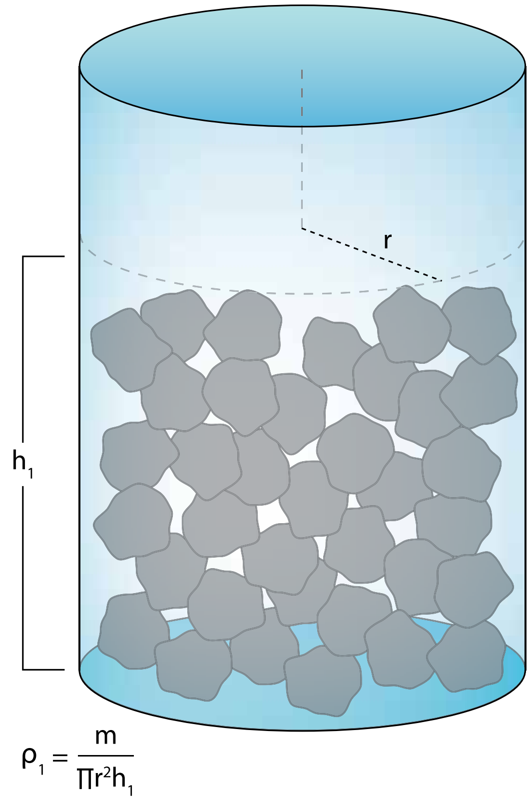


Figure 25.3

Consolidated bulk density (ρ_2)—sometimes called vibrated bulk density—is normally the heaviest density that can be found in the conveying of bulk materials, achieved by applying a compressive force (F) or vibratory energy to the body of material.

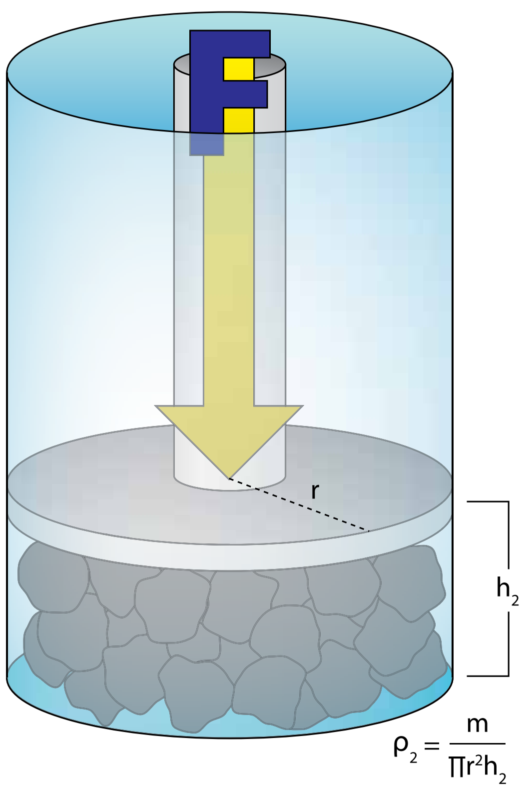
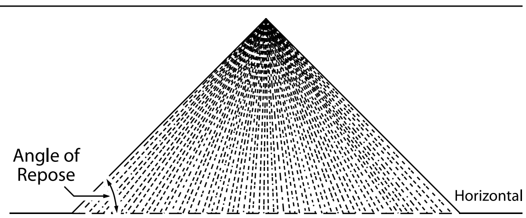


Figure 25.4

Angle of Repose



ing a compressive force (F) or vibratory energy to the body of material. The consolidated bulk density is used for determining the weight of material conveyed on the belt based on surcharge angle. A compressibility percentage may be found by taking vibrated bulk density minus loose bulk density divided by vibrated bulk density times 100. The above ratio is rarely above 40 percent and may be as low as 3 percent, indicating that a caution must be used when making density-related calculations.

There are a number of standards published for determining bulk density, such as American Society for Testing and Materials International (ASTM) ASTM D6683-01 *(Reference 25.2)*, but it is recommended that the test methods described in CEMA STANDARD 550-2003 be used when the density will be applied to the conveying of bulk materials.

Angle of Repose

The loose angle of repose for bulk materials is that angle between a horizontal line and the sloping line from the top of a freely formed pile of bulk material to the base of the pile (**Figure 25.4**). The angle of repose for a given material may vary, however, depending upon how the pile is created and the density, particle shape, moisture content, and size consistency of the material. Because the angle of repose is relatively easy to measure, it is often used as a convenient design parameter. However, this can lead to serious errors due to large variations in the angle for a given category of bulk material. For example, the angle of repose range for various types of coal as listed in CEMA STANDARD 550-2003 runs from 27 to 45 degrees. The application of the angle of repose should be limited to the shape of freely-formed stockpiles.

Surcharge Angle

The surcharge angle is the angle of the load cross section measured by the inclination in degrees to the horizontal (**Figure 25.5**). The symbol Θ_s is frequently used to represent the surcharge angle. The angle of surcharge of a bulk material on a moving conveyor depends upon the kind of conveyor involved. With a troughed belt conveyor, the top surface of the load cross section of the bulk material is assumed to be part of a circular arc, the ends of the arc meeting the inclined sides of the belt at the free-edge distance. *(See Chapter 11: Skirtboards for a discussion about edge distance.)* On conveyors with vertical pan sides, the top of the load cross section may be assumed as a portion of a circular arc, the ends of which meet the vertical sides (**Figure 25.6**). The surcharge angle is measured by the inclination of the line tangent to the circular arc. On a flat belt or apron conveyor, the top surface of the bulk material is presumed to be triangular in cross section (**Figure 25.7**).

The surcharge angle is useful in conveyor design for determining the profile of the load on the belt for various belt widths and trough angles, which therefore provides the theoretical carrying capacity of the belt. Standard test methods for determining surcharge angles for bulk materials are described in CEMA STANDARD 550-2003.

Material Size

The size of the bulk material is often described using either the material's maximum lump size or as the percent of particles that pass a series of defined sieves through a process typically called screening. Both measurements are important to conveyor design.

The material size is often described as the width and height of the largest lump. For example, a material with a maximum lump width and height of 50 millimeters x 50 millimeters (2 in. x 2 in.) would be described as 50 millimeter (2 in.) minus material. However, it is common practice to assume the length of the lump can be as much as three times the larger of the width or height; the above example yields a length up to 150 millimeters (6 in.) long. This information is useful in determining the size for various components, including the width of chutes and skirtboards. A common "rule of thumb" is that chute or skirtboard width should be at least two times the largest lump dimension in order to prevent plugging.

A screening analysis provides the most complete representation of the size of the bulk material (**Figure 25.8**). ASTM D6393-99(2006) *(Reference 25.3)* provides

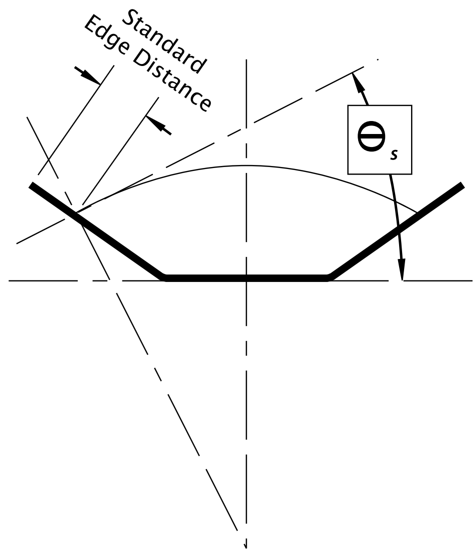


Figure 25.5

Surcharge Angle (Θ_s) for a Troughed Belt

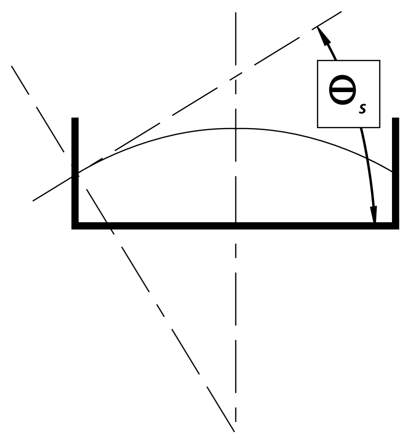


Figure 25.6

Surcharge Angle (Θ_s) for a Pan or Apron Feeder

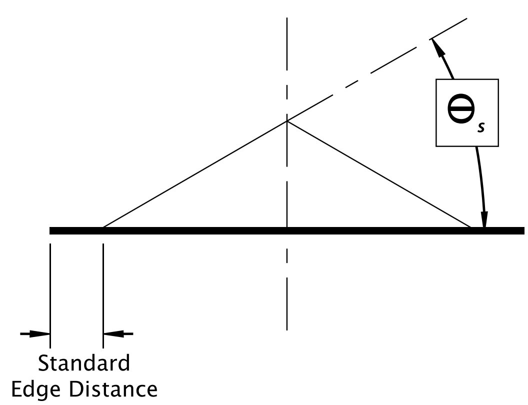


Figure 25.7

Surcharge Angle (Θ_s) for a Flat Belt one test method for screen analysis of bulk materials. Particle size distribution is a tabulation of the percent of the material represented in each size range as a part of the total sample, as demonstrated by passing through a given screen size and being retained on the next smaller screen. A particle-size distribution curve is usually a semi-log plot using the particle size as the abscissa on a logarithmic scale and the cumulative percentage by weight passing a given screen size as the ordinate (**Figure 25.9**). The shape of the curve and the slope of any straight portion indicate the relative uniformity of size distribution of the sample. This information is useful for determining the particle size needed for calculating airflow. *(See Chapter 7: Air Control for calculating induced air that includes particle diameter (D) in the denominator.)* The amount of induced air is inversely proportional to particle diameter; the smaller the diameter the more induced air. Knowing the average particle diameter presents a simplified way to calculate induced air, based on the percentage of particles at each sieve size.

ADVANCED BULK-MATERIAL PROPERTIES

Moisture Content

Moisture content is the total amount of water present in a bulk material. A bulk material can have surface (or free) moisture content and inherent moisture content. Surface moisture is the mass of water that is between particles, on the surface, and in open pores. The surface moisture content can have a major effect on the material's values for adhesion, cohesion, and wall friction angle. Inherent moisture content is

Figure 25.8

Screening analysis provides the most complete representation of the size of the bulk material.

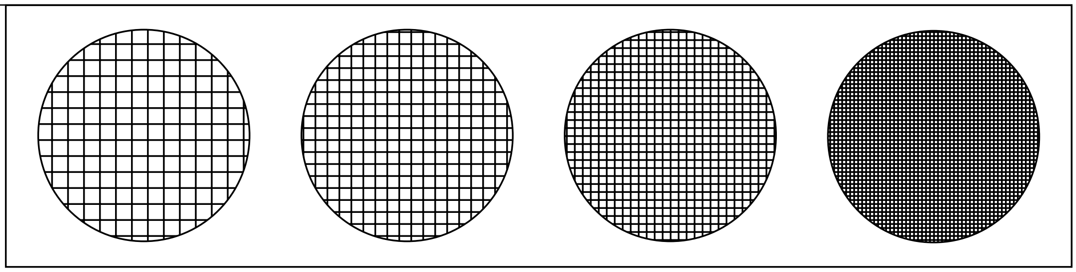
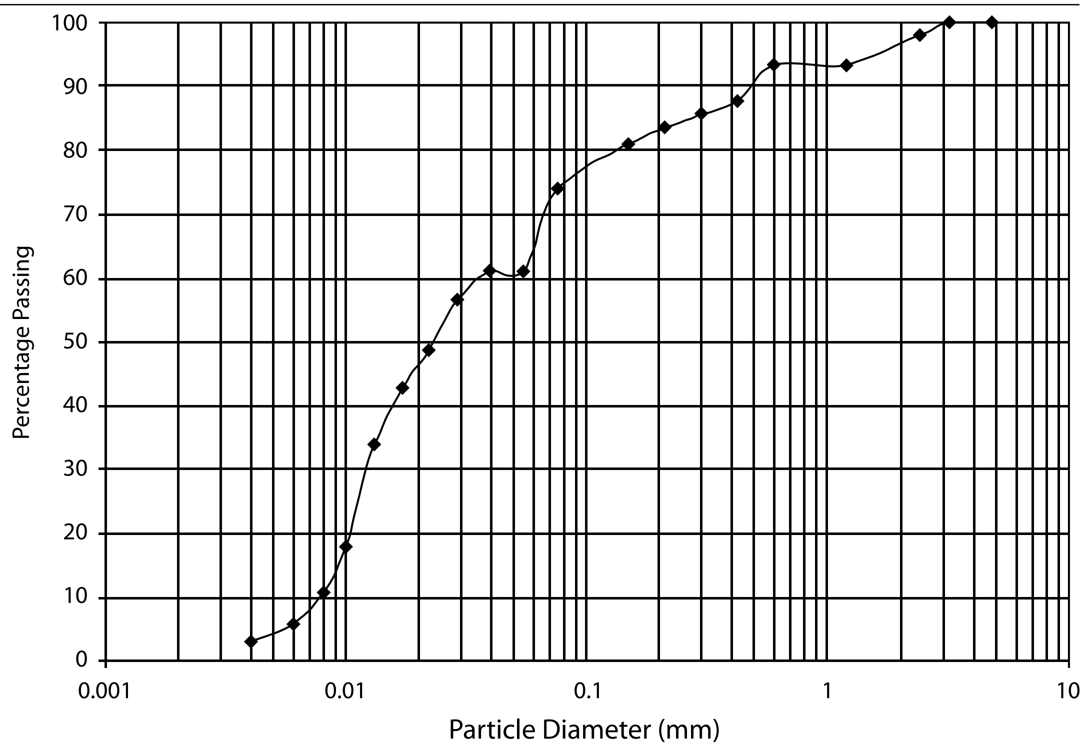


Figure 25.9

A particle-sized distribution curve is usually a semi-log plot.



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the mass of water contained within closed pores but does not include moisture that is chemically bound within the particles. Moisture content is defined on a wet basis in the bulk-materials handling industry; the moisture content is expressed as a percentage of the total wet weight. The most common method of determining surface moisture is to dry a sample in an oven until equilibrium is reached and then measure the weight loss.

Wetting and Settling Rate

The wetting ability of a solution is a measure of its ability to "wet" (spread across) and penetrate a bulk material. This is important, because it affects and reflects the performance of dust-suppression systems and chemicals with the particular material.

Sedimentation measurement methods are based on the application of Stokes' Law, which describes the terminal velocity for an isolated sphere settling in a viscous fluid under the influence of a gravitational field (i.e., free falling). For materials with low Reynolds numbers (i.e., laminar flow conditions) the terminal velocity depends on the density contrast between the particle and medium, the viscosity, and the particle size.

Sedimentation or settling rate is similarly important to help assess the performance of belt-washing and dust-suppression systems with specific materials. A simple and common test for the settling rate of bulk materials in water is commonly called a "Jar Test." In its simplest form, a sample of the bulk material is put into a beaker of water, and the time for the material to settle to the bottom is recorded. Detailed procedures are described in ASTM D2035-08 *(Reference 25.4)*.

Internal Stresses

Internal stress in a material cannot be measured directly. It must be deduced from the force acting across a unit area of a bulk material, as it resists the separation, compacting, or sliding induced by external forces. Normal stress refers to the stress caused by forces that are perpendicular to a cross-sectional area of the material. Shear stress arises from forces that are parallel to the plane of the cross section (**Figure 25.10**). Stress is expressed as a force divided by an area.

The original work by Jenike centered on the properties of bulk materials as derived from the shear stress capacity of the material. Jenike's work focused on determining the outlet dimensions of a storage bin for reliable gravity flow and the stresses on the hopper wall for safe bin design. Many of the same methods from his original work are successfully applied to the transport of bulk materials on conveyor belts.

Flow properties of a bulk material can be derived from measuring the force to shear the bulk material, using a shear cell (**Figure 25.11**). There are several shear cell manufacturers and test methods used to determine bulk material properties such as ASTM D6128-06 *(Reference 25.5)* or ASTM D6773-02 *(Reference 25.6)*. Normally, only the fines from the bulk material are tested, because they typically yield the greatest adhesion and cohesion values. Shear cell tests are time-consuming, due to the large number of tests required to determine the properties at different moisture levels and consolidating pressures. Repeatability of the test results requires careful sample preparation and testing procedures by a skilled technician.

When conducting these tests, the values that are known are the principal or consolidating force (V) and the sample area.

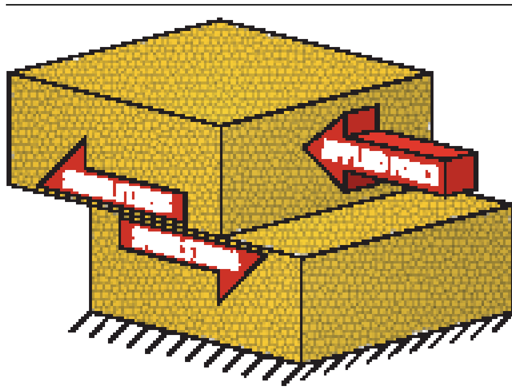


Figure 25.10

Shear stress arises from forces that are parallel to the plane of the cross section.

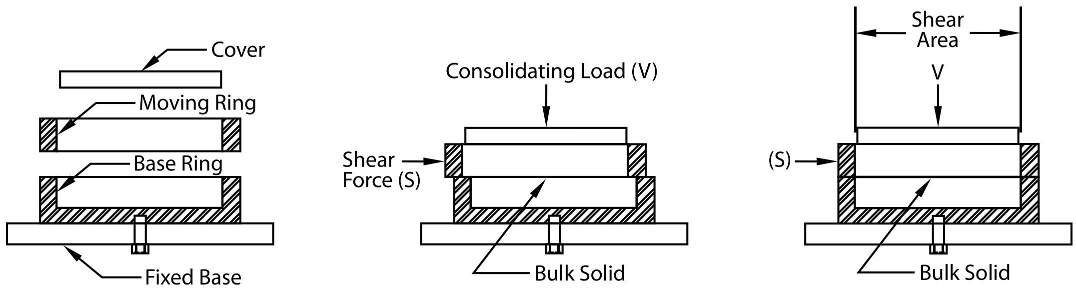


Figure 25.11

Using a shear cell, flow properties of a bulk material can be derived from measuring the force to shear the bulk material.

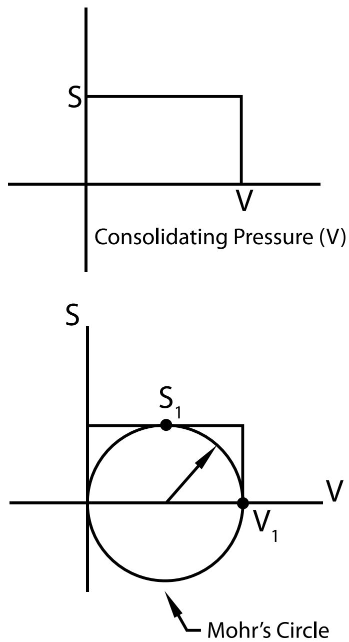


Figure 25.12

Mohr's Circle Concept

What is measured is the shear force (S) required to shear the bulk material. The shear force and shear area are used to determine the shear and normal stresses at different consolidating pressures and moisture contents using a Mohr stress circle. The Mohr stress circle represents the stresses in cutting planes that are inclined through all possible angles. The position of the Mohr stress circle is defined by the two principal stresses (**Figure 25.12**). It is important to note that a bulk material can transmit shear stresses even if it is at rest. Also, in bulk materials, compressive stresses are defined as positive stresses.

Internal Friction Angle

By running a series of shear tests at various consolidating pressures, values of internal friction can be determined. Internal friction angle is the angle at which the particles within a bulk material slide over one another within a pile, or, in other words, failure due to shearing. This angle is between the horizontal and the tangent of the line defining the change in shear stress as the consolidating stress is increased (**Figure 25.13** and **Figure 25.14**).

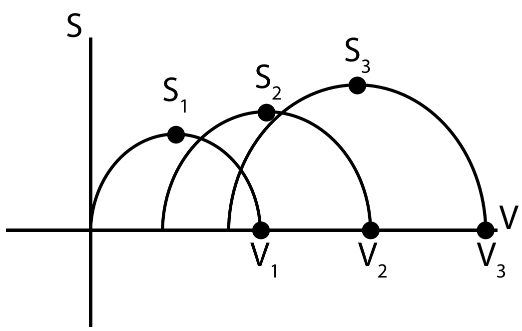


Figure 25.13

A Series of Shear Tests of Various Consolidating Pressures

The Jenike Method exclusively uses an effective angle of internal friction, which is the angle from the horizontal of a line passing through the origin while remaining tangent to the Mohr's circle representing the consolidation condition (**Figure 25.15**).

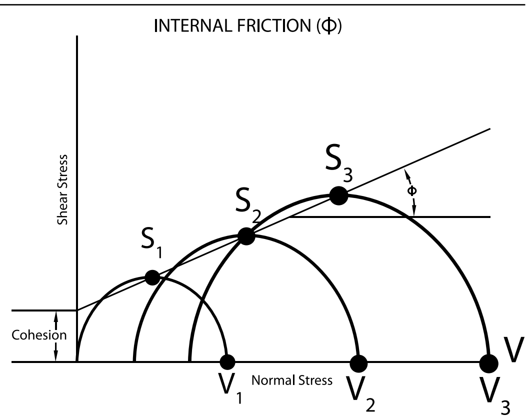


Figure 25.14

Internal Friction (Φ)

Bulk materials do not conform to the stress strain relationships that metal, glass, and rigid plastic materials do. Bulk materials do not have a unique yield stress like steel or other materials, but rather have a yield surface. This surface is built up of

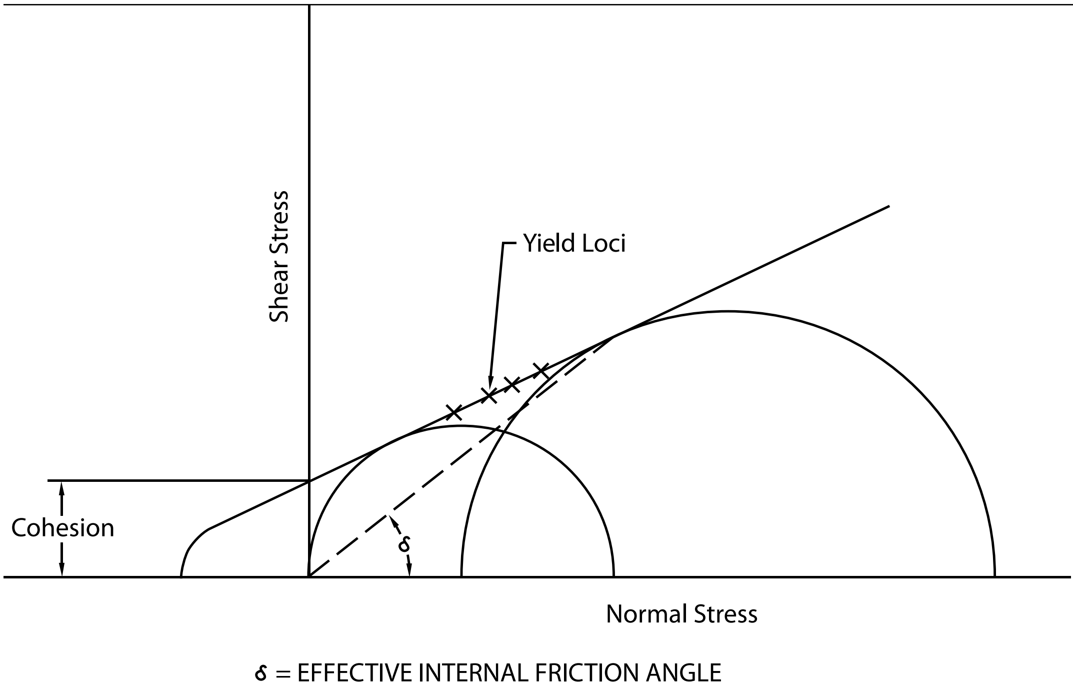


Figure 25.15

Effective Internal Friction Angle

yield points or loci. This yield locus increases in length as the consolidating stress increases at a fixed particle size and moisture content. Increasing the consolidating stress increases the bulk density, giving the graph a three-dimensional failure surface.

Interface Friction

Interface friction (ϴ) for chutes handling bulk materials can be determined with a shear cell and a sample of the actual interface material—that is, the material that will be in contact with the bulk material (**Figure 25.16**).

The interface friction (sometimes referred to as the wall friction) is usually high at low consolidating pressures and reduces rapidly as the pressure increases (**Figure 25.17**). The significance of this in chute design relates to the depth of the bed of the material flowing in the chute. This property is especially critical when determining the slope needed for a chute to be self-cleaning when the flow stops and the depth of the bed of material approaches zero. In this situation, the resistance to the flow of the material off the chute is at a maximum.

Two values of friction (μ) are important in chute design: the coefficient of friction between the bulk material and the chute-wall and the coefficient of friction between the bulk material and the belt. The coefficient of friction is equal to the tangent of the interface friction angle (determined the same way as the effective angle of internal friction) (**Figure 25.18**). Bulk materials, particularly the fines, have the ability to

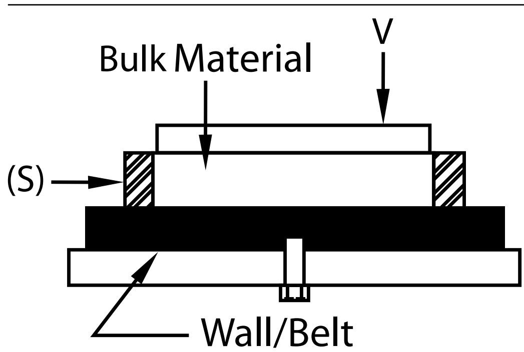


Figure 25.16

Shear Cell Test for Bulk Material Interface Friction Values (ϴ)

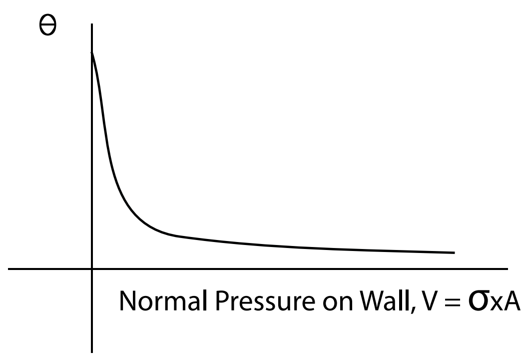


Figure 25.17

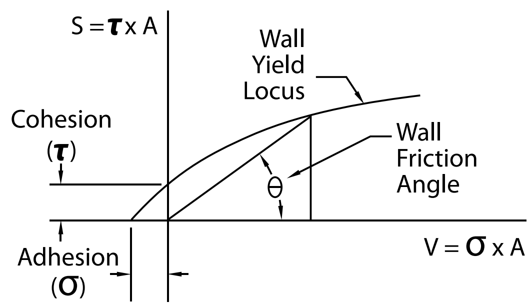
Effect of Consolidating Pressure on Wall Friction cling upside down on horizontal surfaces and thus exhibit strength even under negative consolidating forces greater than that of gravity. The shear force at negative consolidating forces is of particular interest in chute design in determining adhesion and cohesion values. An adaptation of the shear cell to apply negative consolidating forces can be used, or the wall yield locus can be extrapolated to estimate these values (**Equation 25.1**).

Cohesion

Cohesion (τ) is the resistance of the bulk material to shear at zero compressive normal stress. Cohesion can be thought of as the ability of the particles to stick to each other. Moisture content (surface tension), electrostatic attraction, and agglomeration are the three principle conditions that affect the level of cohesive stress in a bulk material. Cohesive stress increases as moisture is added to the bulk material until a maximum value is reached (**Figure 25.19**). As more moisture is added, the ability of the bulk material to withstand shear—its cohesion—begins to decrease. Cohesive stress can be determined from shear cell tests. It is given by the relationship that cohesive stress is equal to the consolidating stress times the tangent of the internal friction angle plus constant [$\tau = \sigma_c \tan \Phi + k$].

Figure 25.18

Coefficient of friction is the slope or tangent of the wall friction angle.



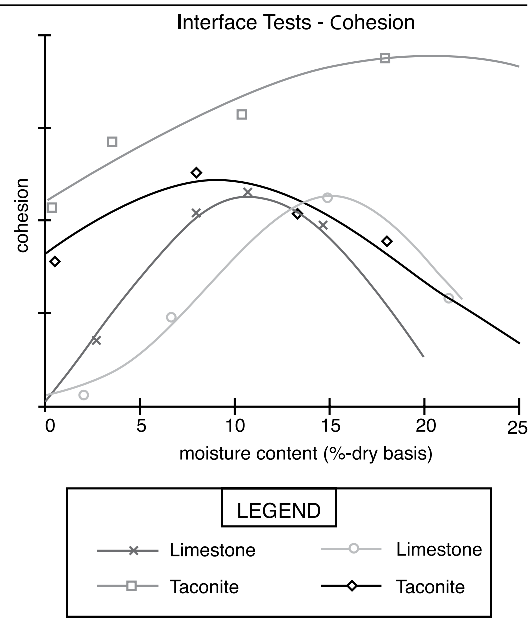
Equation 25.1

Interface Friction Relationship

$$\tan \Theta = \frac{S}{V} = \frac{\tau}{\sigma} = \mu$$

Figure 25.19

Testing has shown that cohesion and adhesion increase as moisture increases until enough moisture has been applied to begin fluidizing the material and reducing the cohesion. The exact variation in adhesion and cohesion with moisture content will vary from material to material and from site to site. Note: Moisture content is the % of weight loss between the wet material and the material after it has dried.



Adhesion

Adhesion (σ) is the resistance of the bulk material to movement at zero shear stress. Adhesion can be thought of as the stickiness of the material to surfaces, such as chutes and belts. Surface condition, moisture, and impurities such as clay are the three principle conditions that affect the level of adhesive stress in a bulk material. Adhesive stress can be determined from shear cell tests and is very useful in determining the likelihood that a material will stick or cling to surfaces.

TYPICAL APPLICATIONS OF BULK-MATERIAL PROPERTIES

Conveyor Capacity

Conveyor capacity, usually expressed as tons per hour (st/h), is one of the basic design parameters directly calculated from the density—kilograms per cubic meter (lb_m/ft^3)—of the bulk material.

Density is a familiar term used when referring to material like steel or concrete; this is called the particle density. In conveyor design, both loose and vibrated densities must be considered. A material's bulk density changes from its stockpile state, both through transfer points and while it is conveyed. If a transfer point is designed using the vibrated bulk-density value, it is likely the chute will plug at less than rated capacity. As the bulk material falls, air is induced, increasing the material's volume;

there is just too little space for the loose material to move at the full flow rate. The loose bulk density can be as little as half of the vibrated bulk density.

If the designer looks in a general engineering handbook for a material's density, the value listed will most likely be particle density, which can be compared to vibrated density. If this value is used, it will lead to an undersized design by a factor of 2 to 4 times. The designer needs to be aware of changes in densities and design accordingly.

Chute Design

Chute design is more than a matter of having the correct cross-sectional area based on the loose bulk density. The reliable flow of bulk materials through a chute depends, among other factors, upon the friction between the bulk material and the chutewalls and wear liners. The design of curved chutes for reliable flow depends upon knowing the properties of the bulk material in relation to the flow surfaces. When a typical value of chute angles is used, the result is often material buildups, leading to chute blockage. For example, lignite has a significantly higher coefficient of friction on stainless steel than bituminous coal, but the coefficients of friction are similar when Ultra-High Molecular Weight (UHMW) polyethylene is the liner. Serious flow problems can result from not testing the actual bulk material and liners being considered for use in the design.

One significant property of bulk materials that is not normally considered in chute design is the effect of time and consolidating pressure on the strength of the material. Bulk materials generally gain strength in storage. However, in chute design, the consolidating pressures are usually low, and the time spent in the chute should be minimal. The effect of changes in moisture content is significant, however, especially in regard to the accumulations of material in chutes. One result of this phenomenon is that carryback usually gains strength as it dries on belts or dribble chutes.

Belt Cleaning

Adhesion and cohesion are important properties used to predict the nature of the challenges in belt cleaning. Knowing how the strength of material is affected by changes in moisture content gives guidance in the use of water to weaken the bulk material so carryback can be efficiently cleaned from the belt. Knowing the critical moisture content allows a designer to calculate the volume of water needed. Absent this knowledge, the point of view that "adding water to the process is a bad thing" will remain, even though there may be significant advantages to using it.

Designing a functional belt-washing system requires knowledge of how the bulk material behaves in water. The transport and treatment of the effluent is directly related to the rate at which the material settles in water. The size of the separation tank or settling pond is directly related to the material's sedimentation rate. Heavy materials such as iron ore need a lot of flowing water to keep wash boxes and piping from plugging. Other materials that will not settle, such as some coals, may not be suitable for a belt-washing station.

Dust Suppression

Selection of a dust-suppression method requires knowledge of how the material will react with water and with the various chemicals used to improve the wetting and agglomeration of the particles. Some bulk materials do not react—or react too slowly—to be good candidates for water alone as the suppression agent. Testing must be done to determine if chemical additives need to be used to provide effective dust suppression.

TYPICAL SPECIFICATIONS

When testing bulk materials for design of material-handling systems, the bulk material shall be tested for the range of conditions that are anticipated to occur during normal and extreme operating conditions and for all variations expected in material source, quality, and properties. These tests would include:

A. Particle size

A sieve analysis shall be performed for all expected qualities and variations of the bulk material in accordance with test methods described in ASTM D6393-99(2006) *(Reference 25.3)* or CEMA STANDARD 550-2003.

B. Density

The bulk density of the material shall be determined at three different consolidating pressures—representing the loose, average, and maximum expected bulk densities—in accordance with test methods described in ASTM D6393-99(2006) *(Reference 25.3)* or CEMA STANDARD 550-2003.

C. Angles of repose and surcharge

The angles of repose and surcharge shall be determined for the bulk material in accordance with test methods described in ASTM D6393-99(2006) *(Reference 25.3)* or CEMA STANDARD550-2003.

D. Strength of the material

The adhesion and cohesion values shall be determined at a minimum of three different moisture contents by testing at minimum, average, and saturation moisture levels and at each of three different consolidating pressures—zero, average, and maximum pressure—in accordance with test method ASTM D6128-06 *(Reference 25.5)* or ASTM D6773-02 *(Reference 25.6)*.

E. Interface friction values

The interface friction values shall be determined for the bulk material and the chutewall and wear-liner material(s) at a minimum of three different moisture levels and three different consolidating pressures, in accordance with test method ASTM D6128-06 *(Reference 25.5)* or ASTM D6773-02 *(Reference 25.6)*. The interface friction values for the bulk material and the belt shall be determined at a minimum of three different moisture levels and three different consolidating pressures in accordance with test method ASTM D6128-06 *(Reference 25.5)*.

25

SAFETY CONCERNS

Testing a bulk material's properties improves the ability of a designer to create safe methods for storage and conveyance. For example, it is well known that flowing bulk materials can create unequal wall pressures on silos. Without testing the specific materials under the expected conditions for storage, a designer can only guess at the forces involved. Many examples of failure in storage vessels demonstrate the wisdom of testing the material and of using the structure for only the specified materials. Less catastrophic, but just as damaging to productivity, are systems that fail to deliver on design capacity due to the use of typical or "handbook-published" values for a material's bulk density.

Most bulk materials are inert. Generally, the testing of the properties of bulk materials is a relatively safe process if the procedures in the test standards are followed. Some materials will pose chemical, explosive, or health hazards. Material Data Safety Sheets are a good source of information about the safe handling of a particular material.

ADVANCED TOPICS

Belt Capacity with Different Coal Properties Example

The sixth edition of CEMA's *BELT CONVEYORS for BULK MATERIALS* gives detailed equations for calculating the capacity of a conveyor based on the trough angle and the surcharge angle. The same formulas can be used with the angle of repose to determine the capacity of the bulk material in a loose state such as when the material is first transferred from one belt to another.

CEMA STANDARD 550-2003 lists nine different classifications for coal. The loose bulk densities listed for these different classifications run from 720 to 960 kilograms per cubic meter (45 to 60 lb_m/ft^3); the angles of repose vary from 27 to 40 degrees. The angles of surcharge are typically 10 to 15 degrees less than the angles of repose. *(Note: CEMA offers only Imperial measurements; the metric measurements are conversions by Martin Engineering.)*

In this example, the design capacities are compared across the range of properties of nine different coals (**Equation 25.2**). This demonstrates how sensitive a conveyor or transfer-point design is to the properties of the bulk material. Example 1 analyzes the densest coal; Example 2 analyzes the coal with the least density.

For these examples, a comparison of the cross-sectional areas found using the values near the extremes of nine different coals demonstrates how sensitive a design will be to the properties of the bulk material.

$$Q = A \cdot \rho_{lb} \cdot S \cdot k$$

Given #1: *A conveyor belt transporting coal with a density of 960 kilograms per cubic meter (60 lb_m/ft^3) is traveling 2,5 meters per second (500 ft/min). The coal has a surcharge angle of 30°.*
Find: *The capacity of the conveyor belt.*

Variables		Metric Units	Imperial Units
Q	Belt Capacity	tons per hour	short tons per hour
A	Cross-Sectional Area of Load (per CEMA)	0,195 m^2	2.1 ft^2
ρ_{lb}	Loose Bulk Density	960 kg/m^3	60 lb_m/ft^3
S	Conveyor Speed	2,5 m/s	500 ft/min
k	Conversion Factor	3,6	0.03

Metric: $Q = 0{,}195 \cdot 960 \cdot 2{,}5 \cdot 3{,}6 = 1685$

Imperial: $Q = 2.1 \cdot 60 \cdot 500 \cdot 0.03 = 1890$

Q	Belt Capacity	1685 t/h	1890 st/h

Given #2: *A conveyor belt transporting coal with a density of 720 kilograms per cubic meter (45 lb_m/ft^3) is traveling 2,5 meters per second (500 ft/min). The coal has a surcharge angle of 20°.*
Find: *The capacity of the conveyor belt.*

Variables		Metric Units	Imperial Units
Q	Belt Capacity	tons per hour	short tons per hour
A	Cross-Sectional Area of Load (per CEMA)	0,168 m^2	1.804 ft^2
ρ_{lb}	Loose Bulk Density	720 kg/m^3	45 lb_m/ft^3
S	Conveyor Speed	2,5 m/s	500 ft/min
k	Conversion Factor	3,6	0.03

Metric: $Q = 0{,}168 \cdot 720 \cdot 2{,}5 \cdot 3{,}6 = 1089$

Imperial: $Q = 1.804 \cdot 45 \cdot 500 \cdot 0.03 = 1218$

Q	Belt Capacity	1089 t/h	1218 st/h

Equation 25.2

Calculating Belt Capacity with Different Coal Properties

Our examples assume:

- Loose Bulk Density: 720 to 960 kilograms per cubic meter (45 to 60 lb_m/ft^3)
- Angle of Repose: 27 to 45 degrees
- Angle of Surcharge: 20 to 30 degrees
- Belt Width: 1200 millimeters (48 in.)
- Trough Angle: 35 degrees
- Edge Distance: Standard CEMA edge distance
- Belt Speed: 2,5 meters per second (500 ft/min)

Analysis

If a conveyor were designed by using the published values for coal from a book rather than testing the actual coal, the design capacity could be off by more than 600 tons per hour. This discrepancy would have a major effect on the rest of the process and the desired outputs. This example shows that the actual material properties must be measured.

MATERIAL SCIENCE FOR IMPROVED DESIGN

In Closing...

No matter what the generic classification is, no two bulk materials are the same. Therefore, physical testing of the actual materials is of critical importance to the proper design of the systems that will handle the bulk materials. The typical costs to determine the flow properties required to properly design a chute are from $1,000 to $3,000 USD per sample per moisture level. The cost of this testing is a minor part of the overall cost of engineering and constructing a conveyor system. Having this basic data will be an important tool for future troubleshooting of the conveyor, as when processes or raw materials change.

Looking Ahead...

This chapter about Material Science, the fifth and final chapter in this section Leading-Edge Concepts, explained how to test properties of bulk materials to help design conveyor systems for total material control. The following chapter, Conveyor Accessibility, begins the new section Conveyor Maintenance.

25

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25