ENVIRONMENTAL PROTECTION AGENCY

APTI 413: Control of Particulate Matter Emissions

Student Manual
Chapter 7

APTI: 413 CONTROL OF PARTICULATE MATTER EMISSIONS, 5TH EDITION

Student Manual

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The preparation of this manual was overseen by the organizations of the Environmental Protection Agency (EPA) and the National Association of Clean Air Agencies (NACAA*), and the revision of materials was coordinated and managed by the Tidewater Operations Center of C2 Technologies, Inc., Newport News, Virginia.

Valuable research and feedback was provided by an advisory group of subject matter experts composed of Dr. Jerry W. Crowder, TX; Dr. Tim Keener, OH; Dr. Douglas P. Harrison, LA., and Mr. Tim Smith, Senior Air Quality Specialist, EPA, Office of Air Quality Planning and Standards.

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**The National Association of Clean Air Agencies (NACAA) represents air pollution control agencies in 53 states and territories and over 165 major metropolitan areas across the United States.*

State and local air pollution control officials formed NACAA (formerly STAPPA/ALAPCO) over 30 years ago to improve their effectiveness as managers of air quality programs. The associations serve to encourage the exchange of information among air pollution control officials, to enhance communication and cooperation among federal, state, and local regulatory agencies, and to promote good management of our air resources.

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7

Fabric Filters

This chapter will take approximately 1.5 hours to complete.

OBJECTIVES

Terminal Learning Objective

At the end of this chapter, the student will be able to evaluate the performance of the different fabric filters' efficiency in removal of particulate matter.

Enabling Learning Objectives

7.1 Summarize the operating principles of fabric filters in the particle capture process.

7.2 Identify the major types of fabric filter systems.

7.3 Use performance evaluation equations to determine efficiency of fabric filtration system.

Checks on Learning

Problem Examples and End of Chapter Review Questions & Problems

This chapter explores the different types of fabric filter systems and their use in the particle capture process.

Overview

Fabric filters, also referred to as baghouses, are capable of high-efficiency particulate matter removal in a wide variety of industrial applications. Uses for fabric filters have steadily expanded since the 1960s, because of the development of new, highly effective fabrics capable of efficiently collecting particles over the size range of 0.1 μm to 1,000 μm. This particle collection efficiency, even in the difficult-to-control range of 0.2 μm to 0.5 μm, is due to the multiple opportunities for a particle to be captured as it attempts to pass through a dust cake and fabric and the multiple modes of particle capture that occur within the dust cake and fabric. These modes of capture include impaction, Brownian diffusion, and electrostatic attraction.

The conceptual simplicity of fabric filters belies the complexity of the equipment design and the operating procedures necessary to achieve and maintain high particulate removal efficiencies. Serious performance problems can develop relatively rapidly. Holes and tears in the bags can develop due to chemical attack, high temperature excursions, or abrasion and flex damage. Cleaning system problems can result in excessive static pressure drops. Particles can also seep through the dust cake and fabric due to improper design or cleaning.

This chapter emphasizes four of the major types of fabric filters: shaker, reverse air, pulse jet, and cartridge. There are many other types that are not explicitly discussed in this manual. However, the operating principles and evaluation procedures discussed are generally applicable to all types of fabric filters. All fabric filters designs typically operate with a static pressure drop of about 4-6 in. WC.

7.1 Operating Principles

Particle Collection

Multiple mechanisms are responsible for particle capture within dust layers and fabrics.

Impaction is an inertial mechanism that is most effective on particles larger than about 1 µm. It is effective in fabric filters because there are many sharp changes in flow direction as the gas stream moves around the various particles and fibers. Unlike some types of particulate collection devices, there are multiple opportunities for particle impaction due to the numbers of individual dust cake particles and fabric fibers in the gas stream path.

Brownian diffusion is moderately effective for collecting submicrometer particles because of the close contact between the gas stream and the dust cake. The particle does not have to be displaced a long distance in order to come into contact with a dust cake particle or fiber. Furthermore, the displacement of submicrometer particles can occur over a relatively long time as the gas stream moves through the dust cake and fabric.

Electrostatic attraction is another particle collection mechanism. Particles can be attracted to the dust layer and fabric due to the moderate electrical charges that accumulate on the fabrics, the dust layers, and the particles. Both positive and negative charges can be generated, depending on the chemical make-up of the materials. Particles are attracted to the dust layer particles or fabric fibers when there is a difference in charge polarity or when the particle has no electrical charge.

Sieving of particulate matter can occur after the dust cake is fully established. The net result of the various types of collection mechanisms is shown in Figure 7-1, which indicates relatively high removal efficiency levels even in the difficult-to-control particle size range of 0.2 µm to 0.5 µm.

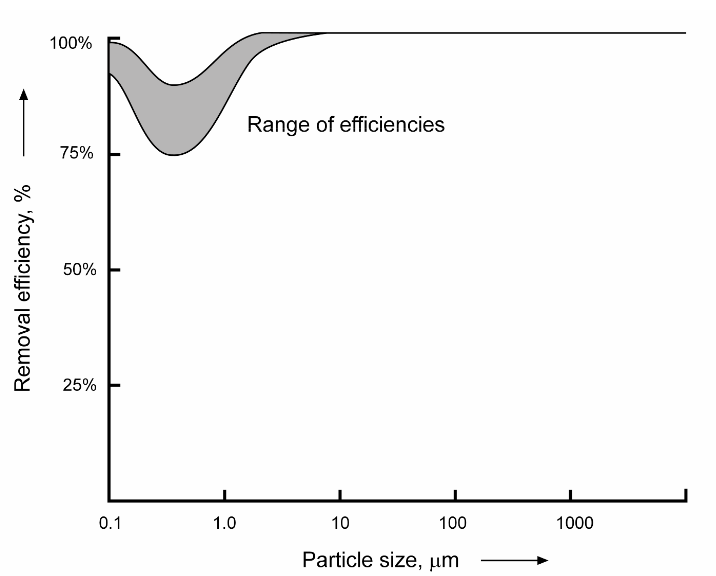


Figure 7-1. Fabric filter fractional efficiency curve

For new bags, the initial particle removal efficiency is not nearly as high as suggested in Figure 7-1. Time is needed to establish residual dust cakes on the surfaces of the fabric.

These particles provide the foundation for the accumulation of the operating mode dust cake, which is ultimately responsible for the high efficiency particulate matter removal. The particles on the fabric surface are termed the residual dust cake because they remain after normal cleaning of the bag.

The fractional efficiency curve shown in Figure 7-1 applies only when an adequate dust cake has been established. Immediately after cleaning, patchy areas of the fabric surface may be exposed. Only the residual dust cake remains in these patchy areas. Depending on the particulate matter concentration, it may take several seconds to a minute for the dust cake to repair over these patchy areas and thereby reduce emissions. During the time that the dust cake is being reestablished, particle removal efficiency can be low, especially for small particles. For this reason, excessive cleaning intensity, frequency, or duration can increase particulate emissions.

Particulate matter emissions can be increased dramatically by related phenomena such as particle seepage and pore collapse. Both phenomena are related to the quantity of gas passing through a given area of the cloth. This gas flow rate is normally expressed as the air-to-cloth ratio, as defined in Equation 7-1:

(7-1)

$$\text{A/C Ratio}\left(\frac{\text{ft}}{\text{min}}\right) = \frac{\text{Actual Gas Flow Rate}\left(\frac{\text{ft}^3}{\text{min}}\right)}{\text{Fabric Surface Area}\left(\text{ft}^2\right)}$$

As the air-to-cloth ratio increases, the localized gas velocities through the dust cake and fabric increase. At high air-to-cloth values, some particles, especially small particles, can gradually migrate through the dust layer and fabric. This is possible because dust particles within the cake are retained relatively weakly. After passing through the dust cake and fabric, these particles are re-entrained in the clean gas stream leaving the bag. Some of the factors that increase the tendencies for particle bleed-through include the following:

- Small particle size distribution
- Fabric flexing and movement
- Small dust cake quantities

Pore collapse in woven fabrics is also caused by high air-to-cloth ratios. At high air-to-cloth ratios, the forces on the particle bridges that span the holes in the fabric weave can be too large. Once a bridge is shattered and pushed through the fabric, an uncovered hole is created. The gas stream channels through this low resistance path through the bag.

The net result of seepage and pore collapse is increased particulate matter emissions at high air-to-cloth ratios. The general nature of the relationship is shown in Figure 7-2.

The effect is relatively minor until a threshold air-to-cloth ratio is reached. Above this value, emissions can increase rapidly. A baghouse that is severely undersized for the gas flow being treated (high air-to-cloth ratio) can have abnormally low removal efficiency.

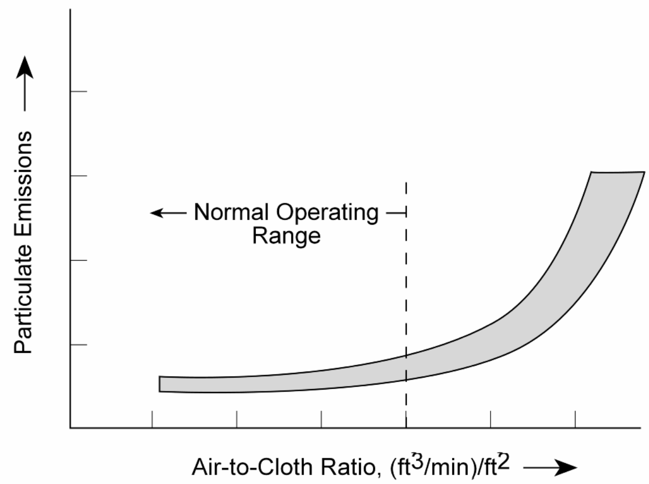


Figure 7-2. Emissions as a function of air-to-cloth ratio

Pressure Drop

The static pressure drop across a fabric filter system is important for several reasons. Lower-than-normal static pressure drop indicates that there may be insufficient dust cake thickness, resulting in reduced collection efficiency. Higher-than-expected static pressure drop increases the overall system resistance to gas flow. Decreased gas flow from the process area will result if the centrifugal fan and damper system cannot compensate for this increased resistance. Fugitive emissions can occur when the gas flow rate at the hood is too low. High static pressure drop also increases the electrical energy needed for the centrifugal fan, increasing the operating costs for the system.

There are two alternative locations for monitoring the static pressure drop of a fabric filter. As indicated in Figure 7-3, the gauge can be mounted across the tube sheet that supports the bag and separates the clean side from the dirty or unfiltered side of the unit. An instrument in this location is termed the media static pressure drop gauge because it indicates the resistance to gas flow caused only by the filter media and the dust cake on the filter media. A gauge that monitors the static pressure drop from the inlet duct to the outlet duct, also shown in Figure 7-3, is termed the overall static pressure drop gauge. In this location, the static pressure drop gauge monitors the frictional losses at the inlet of the fabric filter, the pressure drop across the media and the dust cake on the media, the frictional losses at the entrance of the outlet duct, and the acceleration losses at the entrance of the outlet duct. The overall static pressure drop value is usually 1 to 3 in. WC higher than the media static pressure drop value. This difference is due primarily to the acceleration losses and frictional losses at the entrance of the outlet duct.

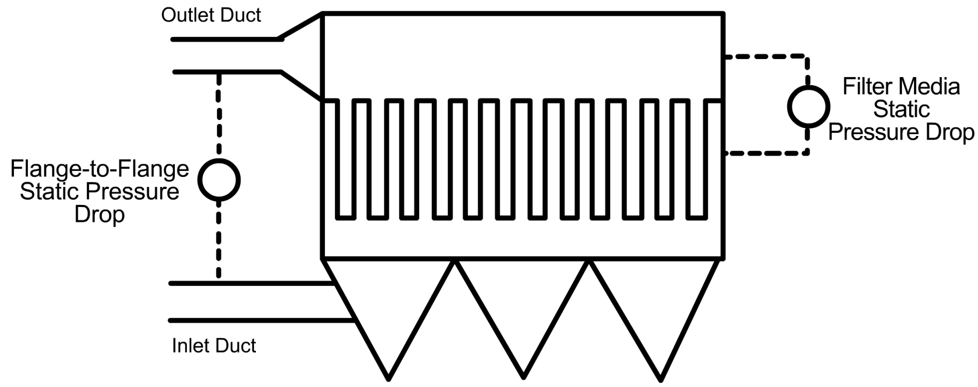


Figure 7-3. Flange-to-flange and filter media static pressure drops

One simple model for the media static pressure drop is to express it as the sum of the pressure drop across the filter media and the pressure drop across the dust cake, as shown in Equation 7-2.

(7-2)

$$\Delta P_{total} = \Delta_{Pmedia} + \Delta P_{dust\ cake}$$

The static pressure drop across filter media can then be approximated by Equation 7-3 and the pressure drop across the dust cake by Equation 7-4.

(7-3)

$$\Delta P_{media} = k_1 v_f$$

Where:

ΔP_{media} = pressure drop across filter media (in. WC)
k_1 = filter media resistance constant (in. WC/(ft/min))
v_f = velocity through filter (ft/min)

(7-4)

$$\Delta P_{dust\ cake} = k_2\, c_i\, v_f^2\, t$$

Where:

$\Delta P_{dust\ cake}$ = pressure drop across dust cake (in. WC)
k_2 = dust cake resistance constant (in. WC/(ft/min)(lb$_m$/ft^2))
v_f = velocity through filter (ft/min)
c_i = particulate concentration (lb$_m$/ft^3)
t = filtration time (min)

Substituting Equation 7-3 and 7-4 into Equation 7-2 give:

(7-5)

$$\Delta P_{total} = k_1 v_f + k_2 c_i v_f^2 t$$

Dividing both sides of Equation 7-5 by vf, the velocity through the filter, gives:

(7-6)

$$S_f = \frac{\Delta P_{total}}{v_f} = k_1 + k_2 c_i v_f t$$

Where:

S_f = filter drag (in. WC/(ft/min))

Equation 7-6 gives a straight line when S_f is plotted against $c_i v_f t$, the dust loading on the filter surface in lb_m/ft^2. The slope of this straight line is k_2 and the intercept (the value at zero dust loading) is k_1.

Unfortunately, the behavior of the static pressure drop is not quite this simple. First, during normal bag cleaning, not all of the dust cake is removed. As noted previously, a residual dust cake remains that serves as the foundation for the accumulation of the operating mode dust cake. Secondly, the repair of the dust cake that occurs after cleaning results in non-linear behavior. Accordingly, the profile for the filter drag is better represented by Figure 7-4.

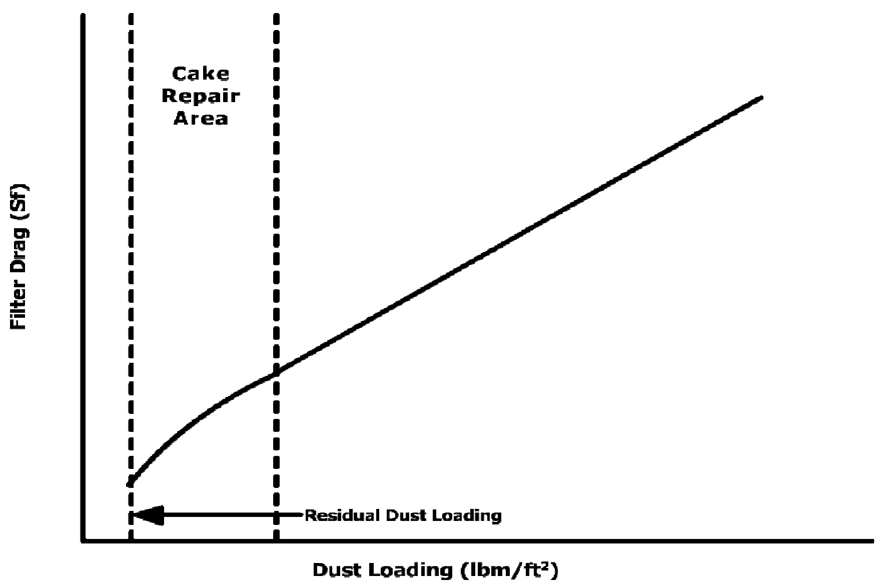


Figure 7-4. Filter drag as a function of dust loading

The pressure drop across the dust cake will increase steadily over time, as indicated by Equation 7-4. It will become necessary to clean the bags when the static pressure drop reaches the design maximum value, which is generally in the range of 5 to 6 in. WC.

During cleaning, a portion of the dust cake is removed, and the overall pressure drop is reduced. This results in the sawtooth-type pressure drop profile illustrated in Figure 7-5. The degree of variation in the static pressure drop profile depends on the frequency of cleaning, the intensity of cleaning, and the fraction of bags cleaned at any given time.

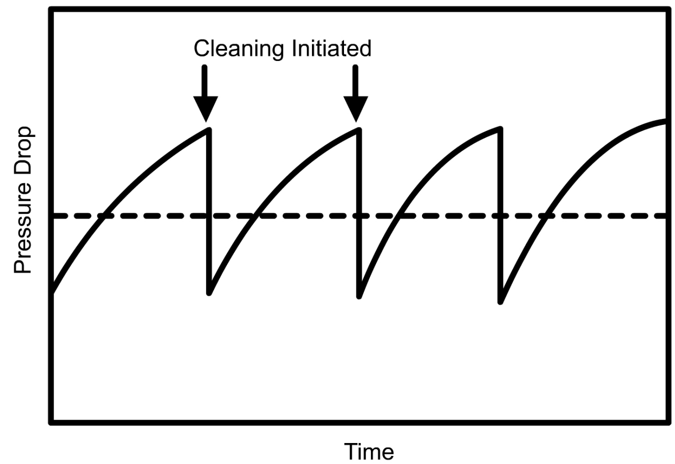


Figure 7-5. Static pressure drop profile

It should be noted that the particulate removal efficiency does not vary significantly despite these static pressure drop fluctuations. The high efficiency performance characteristics of fabrics are reestablished very soon after dust cake repair. Unlike some other devices, particulate matter removal efficiency does not increase as the static pressure drop across the baghouse increases. For example, a fabric filter operating at 9 in. WC pressure drop does not necessarily have a higher particulate matter removal efficiency than a unit operating at 4 in. WC pressure drop. In fact, quite the opposite can be true. Because of the bleed-through and pore collapse modes of emission, particulate matter removal efficiency is often lower when the pressure drop is in the high range.

Filter Media Blinding and Bag Blockage

Water droplets in the dust cake can severely increase the resistance to gas flow. At the very least, the water can fill the voids in the dust cake where the gas would normally flow. If the quantity of water is high, the dust cake can be packed tightly together or form a muddy layer. At this point, the affected portion of the bag is essentially impervious to gas flow. This is termed fabric blinding.

Water is not the only substance that can cause blinding, but it is one of the most common. Condensed water droplets can be entrained from the process being treated, or they can be carried in with the compressed air in pulse jet fabric filters. Excessive gas cooling in baghouses serving combustion sources and other sources generating high vapor concentrations can cause water condensation in the dust cakes.

Another common blinding agent is the lubricating oil often present in pulse jet fabric filter compressed air supplies. The oil droplets can deposit in the upper, clean side surfaces of the bags and prevent gas flow. The entire inlet gas stream must, therefore, be filtered in the unaffected lower portions of the pulse jet bag.

Wet materials are not the only blinding agents. Submicrometer particles can be driven deep into the fabric if the bag is exposed to a high velocity particulate-laden gas stream before a protective residual dust layer is present. This type of blinding often occurs when a new bag is installed in a compartment with a large number of seasoned bags. Due to the resistance caused by the seasoned bags' residual dust cakes, the gas velocities through the new bag are excessively high. Submicrometer particle blinding can also occur following the installation of new bags at sources that generate high concentrations of submicrometer particulate matter. In these cases, the new bags can be conditioned prior to service by exposing them to resuspended large diameter particles.

Hopper overflow or solids bridging in hoppers can cause high dust levels. A portion of the filtering area will be inadvertently isolated if these solids block some of the bag inlets in shaker or reverse air baghouses. This occurs most often around the exterior walls of the hoppers where cooling of the solids is most severe. If moisture is present, these deposits can become crusty and remain even after the solids in the hopper have been removed. Proper hopper design and frequent emptying are important in minimizing the occurrence of this condition.

The net effect of these operating problems is to remove fabric area from service. This increases the air-to-cloth ratio in the unaffected fabric and can lead to seepage or pore collapse problems. The higher air-to-cloth ratios will also result in increased pressure drop across the baghouse.

Fabric Filter Applicability Limitations

There are several limitations that should be considered when working with fabric filters. Clogging or blinding of the fabric can occur when the particulate is sticky or if moisture is present. Blinding can also occur when large quantities of small particles (0.1 μm to approximately 2 μm) pass through new bags that are not protected by a dust cake. Fabric filters can be designed to operate with moderate blinding conditions. However, they may not be appropriate for very sticky conditions.

Excessive quantities of large particles moving at high velocities can be abrasive and cause erosion of the fabric, especially near the bottoms of the bags. The gas velocities are usually highest near the bottom because of the way the particulate-laden gas stream enters the baghouse. Large particles are the most abrasive and can strike exposed fabric yarns and fibers with considerable force.

Fires and explosions can occur in fabric filters due to the high concentration of dust on the bags and in the upper elevations of the hoppers. These fires and explosions can be ignited by embers from process equipment and even by static electricity generated inside the baghouse. Baghouses can be designed to minimize the risks of fires and explosions. However, when the risk is very high, alternative particulate control systems or combinations of control systems may be necessary.

There are gas temperature limits to the application of fabric filters because of the limits of the fabric itself. At high temperatures, the fabric can thermally degrade, or the protective finishes can volatilize. Accordingly, fabric filters have usually been limited to gas temperatures below approximately 500°F, which is the maximum long-term temperature of the most temperature-tolerant fabric. Recently commercialized fabrics can tolerate much higher temperatures.

7.2 Fabric Filter Systems

One way of distinguishing between different types of fabric filter collectors is the method used to clean the filter material. As dust builds up on the filter surface, the pressure drop across the filter increases. In order to avoid excessively high pressure drops, the filter material is cleaned periodically. The most common methods of cleaning are shaking, reverse air, and reverse pulse or pulse jet.

Another way of distinguishing between different types of fabric filter collectors is based on the way they operate. The three modes of operation are intermittent, periodic and continuous. Intermittent collectors are used on processes that operate intermittently. When the process shuts down, the collector goes through a cleaning cycle and then shuts down and waits for the next processing cycle before starting up. Most intermittent collectors clean by shaking, but could also clean by reverse pulse.

Periodic collectors are used on processes that operate continuously. The total fabric is divided between several modules or compartments. This allows a compartment to be taken off line and cleaned, while the remaining compartments stay on line to provide filtration. Most periodic collectors clean by shaking or reverse air, but could also clean by reverse pulse.

Continuous collectors are also used on processes that operate continuously, but they do not have compartments that shut down for cleaning. Instead, individual rows of bags in the collector are cleaned, while the remaining bags continue to provide filtration. Continuous collectors usually clean by reverse pulse, but could also clean by reverse air.

Shaker Fabric Filters

Figure 7-6 shows the typical components of a shaker cleaned fabric filter. The tube sheet or cell plate provides the seal which separates the bags in the upper portion of the collector from the hoppers. The open bottoms of the bags are attached to the tube sheet by a clamp-and-thimble arrangement (as shown in Figure 7-7) or by a snap-ring arrangement (as shown in Figure 7-8). The closed tops are attached to the shaker mechanism. The dust laden gases enter through the hopper, where some of the larger particles in the gas stream settle out. Most of the dust will be carried by the gas stream as it passes up through the filter bag and will be deposited on the inside of the bag. The cleaned gases then exit the collector through an outlet duct or through louvers, if the collector is operating under positive pressure. Shaker collectors use woven fabrics and generally operate with an air-to-cloth ratio of 2-4 ft/min.

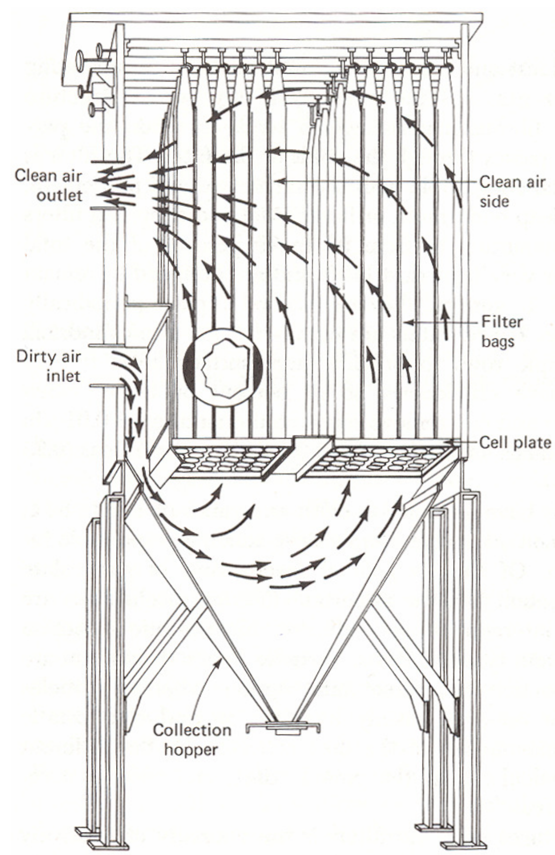


Figure 7-6. Shaker fabric filter

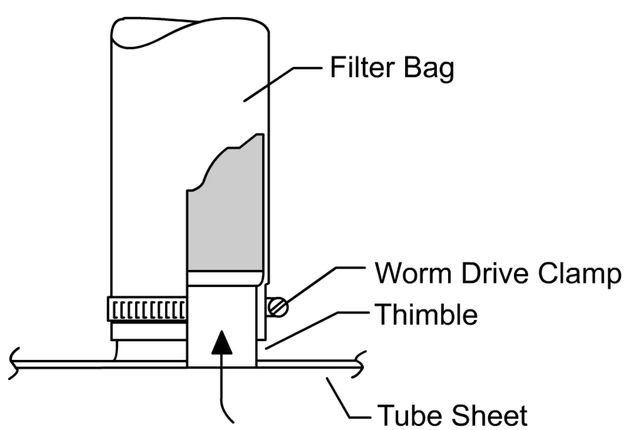


Figure 7-7. Clamp-and-thimble-type bag attachment

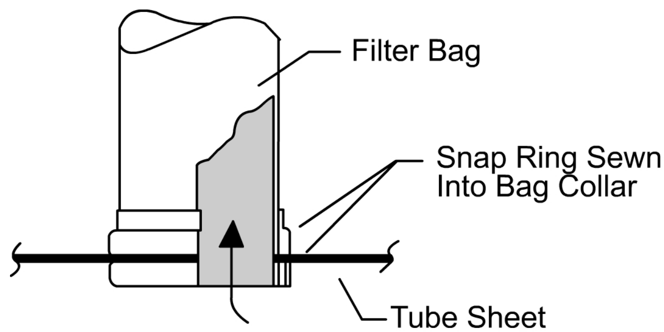


Figure 7-8. Snap-ring-type bag attachment

During the cleaning cycle, gas flow to the collector is stopped. In compartmentalized collectors, this is accomplished with a shut-off damper in the inlet duct, for a positive pressure unit, or in the outlet duct, for a negative pressure unit. It is critically important that this damper seals effectively, so that there is no air flow through the compartment during cleaning. A leaking damper will cause the bag to remain inflated during shaking and will significantly reduce the cleaning effectiveness. It may also cause particles to be driven through the fabric and carried out of the collector.

After a null period of 15-30 seconds to allow the bags to relax, the bags are mechanically shaken, and the dislodged dust cake falls into the hopper. This type of cleaning usually involves the use of a rocker-arm lever assembly to produce a motion at the top of the filter bag that is roughly horizontal. However, other shaker mechanisms may impart vertical motion or may follow an arc. The bags are usually installed slightly slack to be able to accommodate the shaking motion without tearing or pulling loose from the tube sheet. Typically, the bags are shaken from 10 to 100 cycles at a rate of 1 to 5 cycles per second with an amplitude of up to 2 inches. After shaking is completed, a second null period of 1-2 minutes is provided to allow the dust to settle before the collector or compartment is returned to service. In compartmentalized collectors, the cleaning interval for each compartment is typically 30 minutes to 2 hours.

Reverse Air Fabric Filters

The construction and operation of reverse air fabric filters is very similar to shaker collectors. There is a tube sheet that separates the bags in the upper portion of the collector from the hoppers. The open bottoms of the bags are attached to the tube sheet and the closed tops are attached to an upper support structure (see Figure 7-9). The dust laden gases enter through the hopper and pass up through the filter bag, depositing the dust cake on the inside of the bag. The cleaned gases then exit the collector through an outlet duct. Reverse air collectors usually use woven fabrics; however, membrane bags and felted bags may be used in some applications. They typically operate with an air-to-cloth ratio of 1½-3½ ft/min.

Figure 7-9. Reverse air collector hangers and tube sheet attachment

Reverse air fabric filters must be compartmentalized. During cleaning, the gas flow through a compartment is stopped, and filtered gas is passed in a reverse direction through the bags in the compartment. This cleaning procedure is the basis for the name reverse air. The main components of the cleaning system are shown in Figure 7-10. The system consists of one or more reverse air fans, a set of dampers to control gas flow to each compartment, and instrumentation to monitor compartment conditions before and after cleaning.

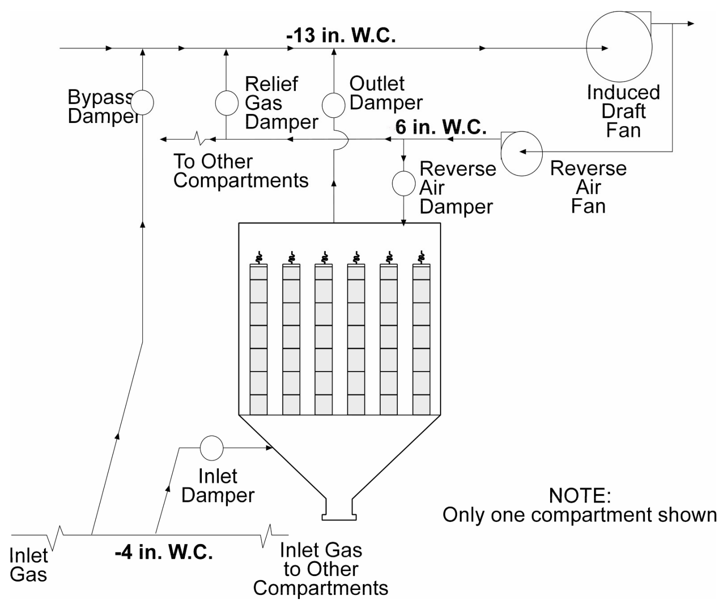


Figure 7-10. Reverse air cleaning system

The cleaning cycle is initiated by closing the outlet damper on the compartment to be cleaned, stopping the gas flow into the compartment. After a null period of 15-30 seconds to allow the bags to relax, the reverse air damper is opened to allow filtered gas from the baghouse outlet to enter the compartment. For a period of 30 seconds to a few minutes, this filtered gas is passed from the outside of the bags to the inside in order to remove some of the dust cake. The dislodged dust cake drops into the hopper, and the reverse gas passes through the open inlet damper and enters the gas stream inlet duct leading to other compartments that are in the filtering mode. To prevent the bag from collapsing during the reverse air flow, it is held under a tension of 60-120 pounds of force and has anti-collapse rings sewn into it every 4-6 feet, as shown in Figure 7-11. After cleaning is completed, there is a second null period of 1-2 minutes to allow time for particles to settle before the compartment is returned to filtering service. As with shaker collectors, the cleaning interval for each compartment is typically 30 minutes to 2 hours.

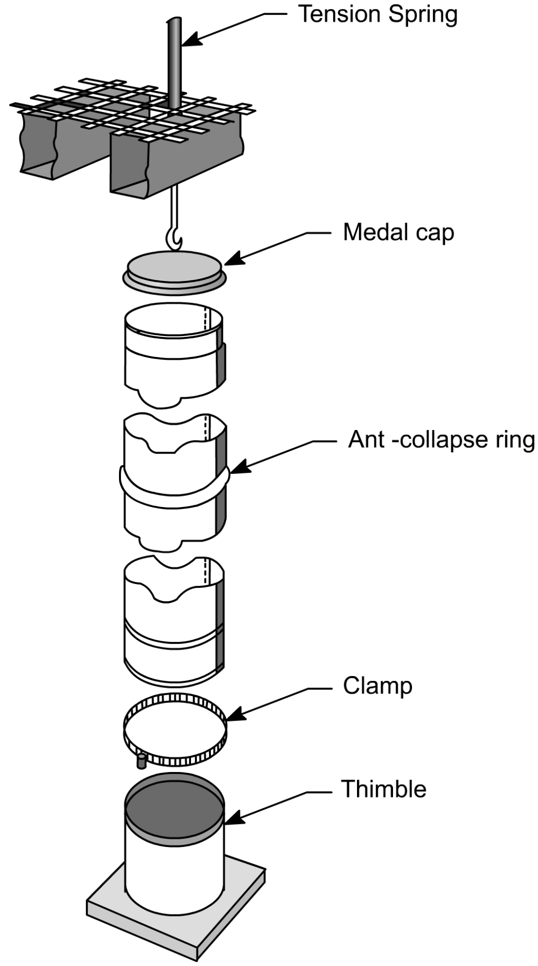


Figure 7-11. Reverse air bag

The reverse air fans are sized considerably smaller than the main system fan. The reverse air fan needs only to supply sufficient gas flow to clean a single compartment at a time. The gas flow needed to dislodge the dust cake from the interior of the bags and to carry the particulate matter into the hopper is usually less than 1/3 to1/2 the gas flow rate that passes through the compartment during filtration. Specific sizing criteria for a given system are site specific because they depend on factors such as (1) the difficulty in dislodging dust from the bags, (2) the bag dust cake retention characteristics, (3) the residual dust cake characteristics, (4) the particulate mass loading at the inlet of the fabric filter, and (5) the anticipated frequency of cleaning.

The design of the dampers used to control gas flow in and out of the compartment is very important in ensuring that the reverse air fabric filter will perform properly. A typical poppet damper is illustrated in Figure 7-12. This consists of a damper seat, a damper plate, the support rod, an actuator, and limit switches. The poppet damper can be oriented to use either the upper or lower surface of the damper plate for sealing against the damper seat. The damper shown in part A of Figure 7-12 uses the lower surface for sealing. When the damper is closed, the damper sealing plate often deflects slightly. The maximum gap around the circumference of the sealing surface is minimized to prevent improper gas movement through the closed damper. When it is necessary to open the damper, the actuator lifts the support rod until the limit switch indicates that the damper plate is fully lifted. A second limit switch is used during closing of the damper to shut off the actuator when the damper has returned to the closed position.

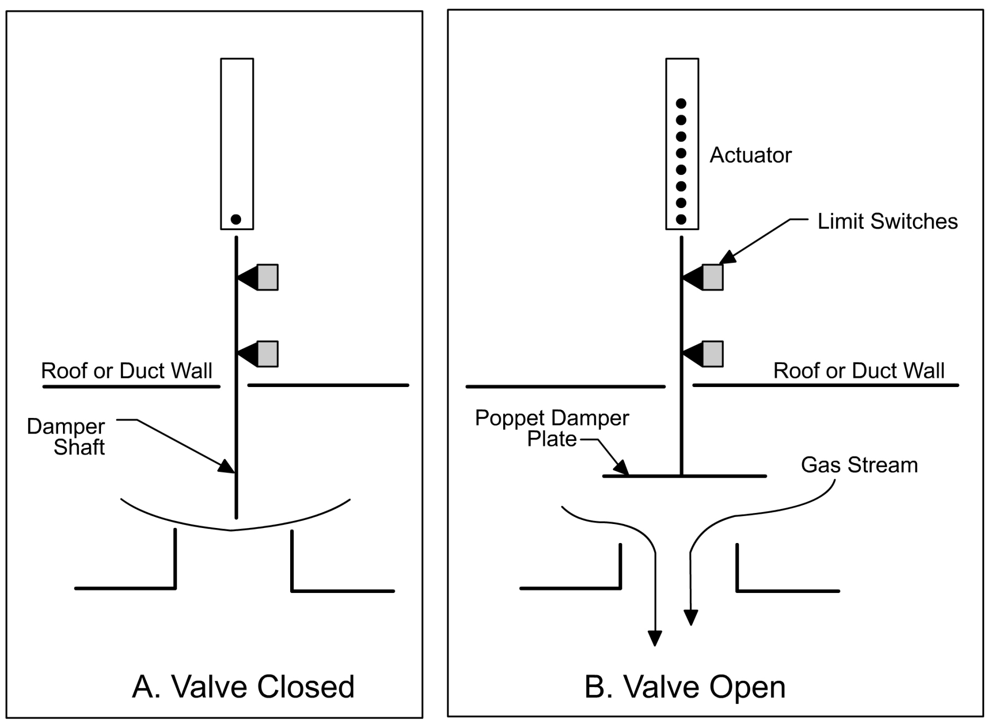


Figure 7-12. Poppet valve in open and closed positions

Sealing the outlet and reverse air dampers is critical to the performance of the baghouse. If the reverse air dampers do not seal properly, the cleaning air supplied by the reverse air fan can be lost to compartments in filtering service. If the outlet dampers do not seal properly, the cleaning gas short-circuits through these openings rather than passing through the bags to be cleaned.

Pulse Jet Fabric Filters

There are two major types of pulse jet collectors: top access and side access. The more common top access design has a number of large hatches across the top of the baghouse for bag replacement and maintenance. The side access design has one large hatch on the side for access to the bags. The side access units often have a single small hatch on the top of the baghouse for routine inspection.

A cutaway drawing of a typical top access type pulse jet fabric filter is shown in Figure 7-13. In pulse jet collectors, the tube sheet is located near the top of the unit and the bags are suspended from it. There are no frames or attachments at the bottom of the pulse jet bags. This free-hanging design is necessary in order to facilitate bag replacement, to allow gas stream movement upward, and to eliminate any abrasive surfaces near the bottom of the bags.

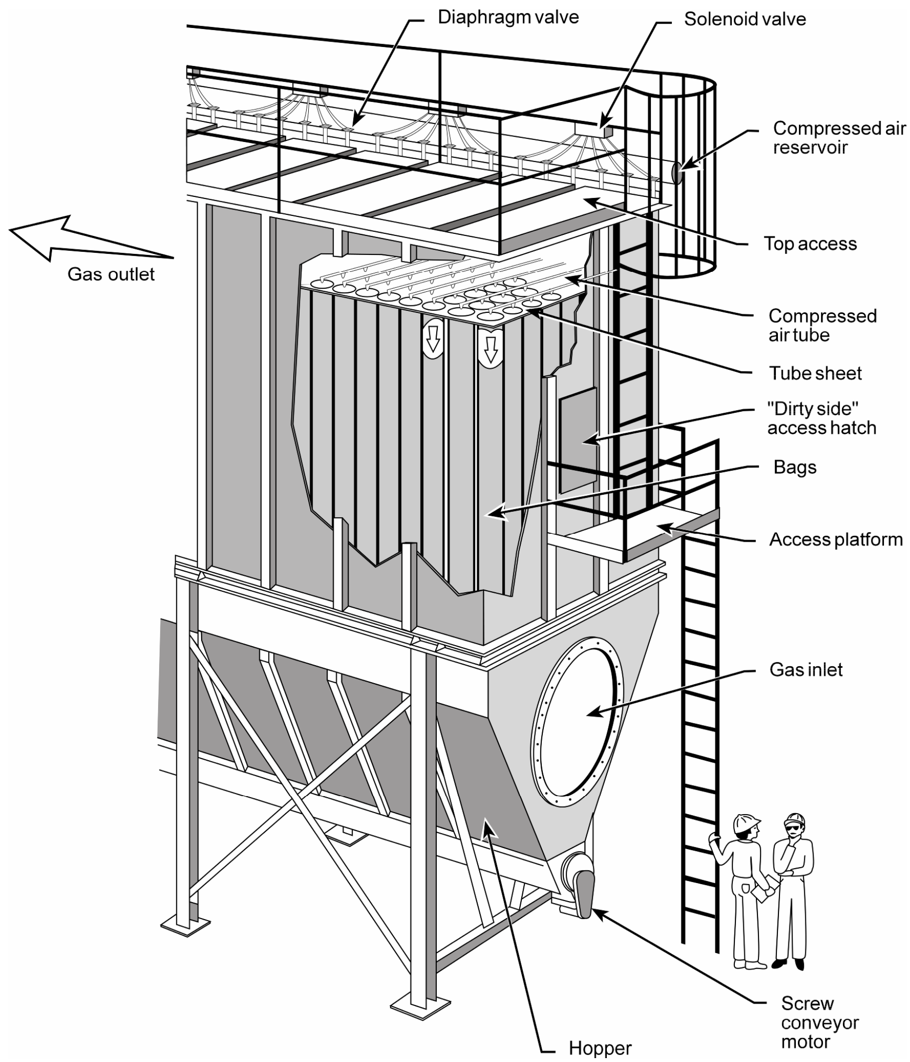


Figure 7-13. Pulse jet fabric filter

In top access designs, the bags are clamped and sealed to the top of the tube sheet to allow for bag removal and replacement from the top of the unit. Two of the many techniques for bag attachment are shown in Figures 7-14 and 7-15. A proper bag seal is very important to prevent dust-laden gases from short-circuiting to the clean side of the baghouse without passing through the dust cake and bag. Even small leak sites can cause significant particulate emissions due to the static pressure drop across the bags.

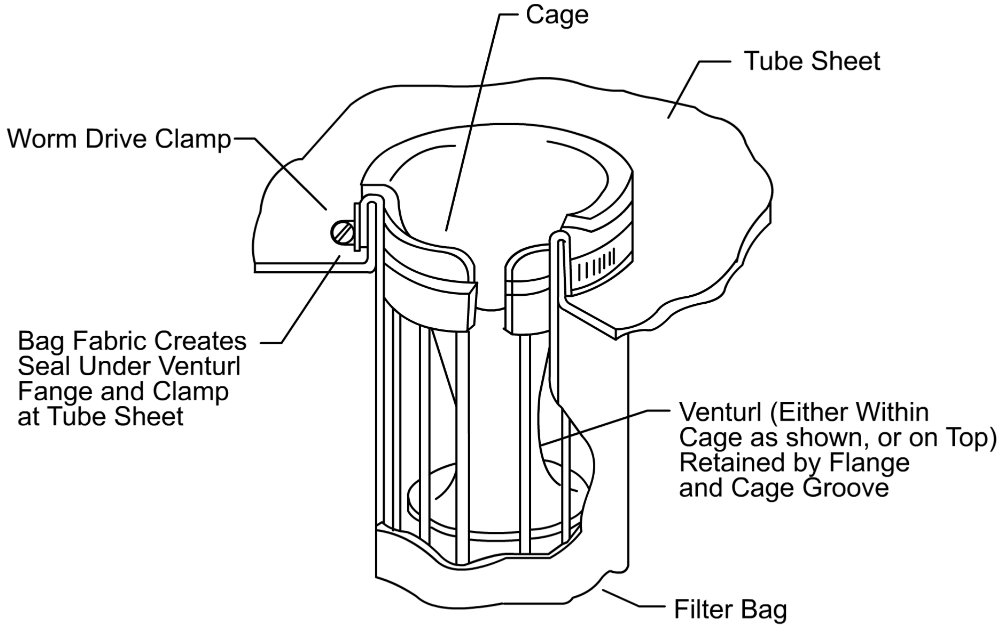


Figure 7-14. Worm-drive-clamp-type bag attachment

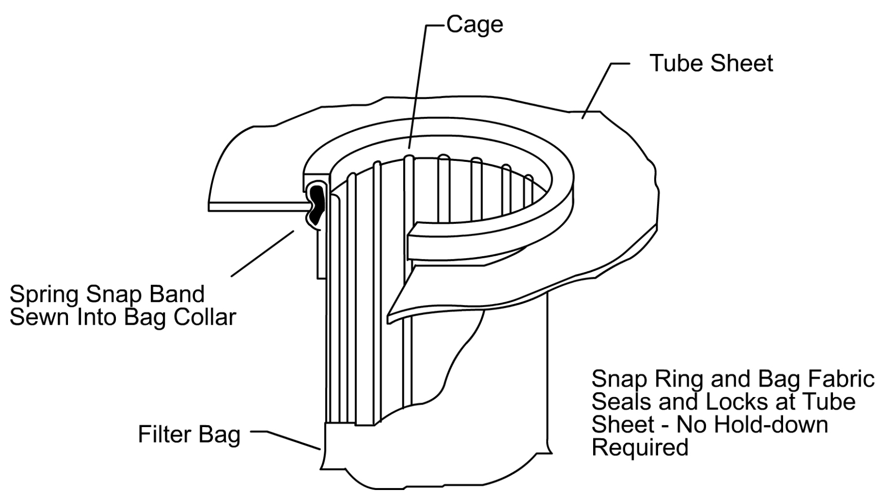


Figure 7-15. Snap-ring-type bag attachment

The gas stream enters either into the side of the casing or into the hopper. The gas flows into the bags and moves upward into the clean gas outlet plenum at the top, leaving the dust cake on the outside of the bag. The bags are supported on metal cages to prevent them from collapsing. Because the fabric tends to wrap around the cage wires during filtering, as shown in Figure 7-16, some fabric wear is possible. To minimize this potential problem, cages with closely-spaced wires are used for fabrics that are especially vulnerable to flex-type wear. More economical cages are used for fabrics that are very tolerant of flex. Pulse jet collectors use felted fabrics and generally operate with an air-to-cloth ratio of 3-10 ft/min.

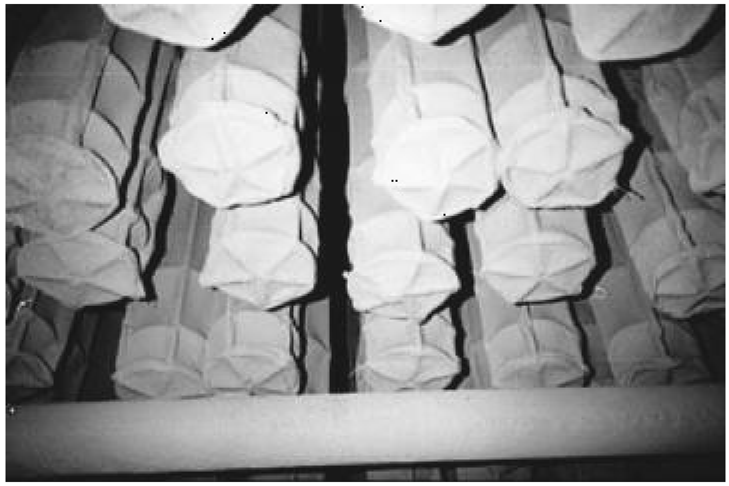


Figure 7-16. View of the bottoms of pulse jet bags

A portion of the dust must occasionally be removed from the bags in order to avoid excessively high pressure drops. The bags are cleaned by introducing a high-pressure pulse of compressed air at the top of each bag. The sudden pulse of air generates a pressure wave that travels down inside the bag. The pressure wave also induces some filtered gas to flow downward into the bag. Because of the combined action of the pressure wave and the induced gas flow, the bags are briefly deflected outward. This cracks the dust cake on the outside of the bags and causes some of the dust to fall into the hopper. Cleaning is normally performed on a row-by-row basis while the baghouse is operating. However, with this operating practice, dust released from one row of bags can either return to the bag because of settling problems or be recollected on a bag in an adjacent row that remains in filtering service. Both problems can be avoided by using off-line cleaning. This is accomplished by dividing the pulse jet baghouse into compartments and isolating the compartment being cleaned to prevent gas flow through it.

Excessive cleaning of pulse jet bags can simultaneously cause increased emissions, increased static pressure drop, and accelerated bag wear. If there is insufficient dust cake on the bag when it is cleaned, particles or small agglomerates of particles can be dispersed. These particles do not settle by gravity and simply return to the bag at an area where the dust cake is thin. Here, they can accumulate as a low porosity cake, increasing the pressure drop. Over time, these fine particles can seep through the bag and cause opacity spiking after each cleaning pulse. This seeping of emissions is caused, in part, by the deceleration shock occurring when the just-pulsed bag snaps back against the cage as the bag returns to filtering service. Insufficient cleaning of pulse jet bags can cause high static pressure drops and reduced air flow from the source. The frequency of cleaning should be set by balancing the limits on high static pressure drop with the need to allow a moderate dust cake to accumulate on the bags between each cleaning cycle.

The main components of the pulse jet cleaning system are illustrated in Figure 7-17. The major components include (1) a source of compressed air, (2) a drier, (3) a coalescing oil filter, (4) a compressed air header, (5) diaphragm and solenoid valves, (6) a solenoid valve controller, (7) compressed air delivery tubes, and (8) instrumentation.

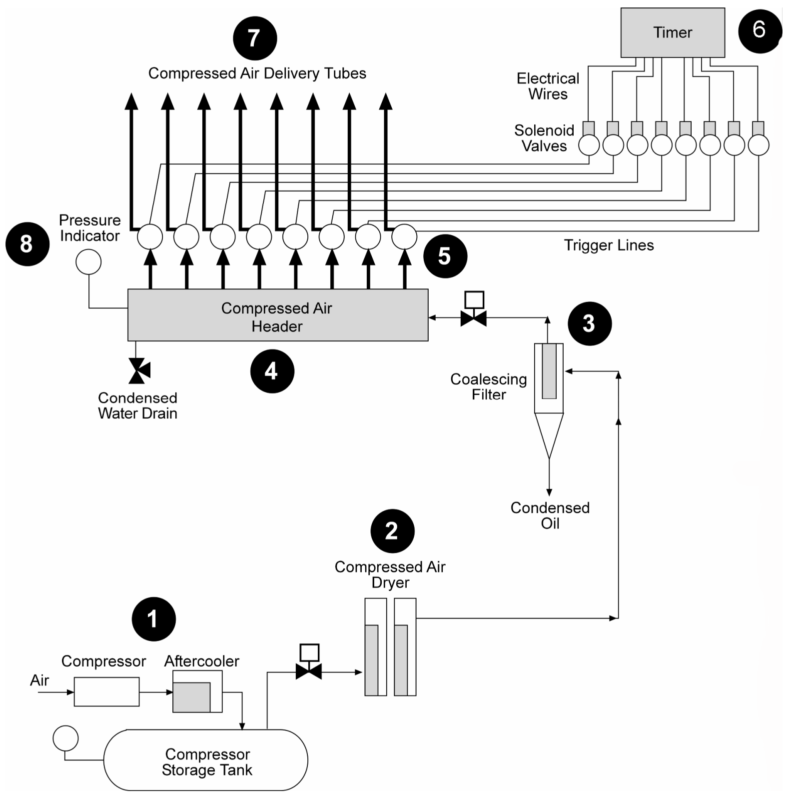


Figure 7-17. Components of a pulse jet cleaning system

The source of compressed air for bag cleaning can be an air compressor dedicated to the specific baghouse or the plant air system. Dedicated compressors usually include an aftercooler to reduce the high temperature caused by compression, a pressure regulator to control the compressor, and a compressed air storage tank. The compressed air is piped from the storage tank to the compressed air header mounted on the side wall of the pulse jet unit.

A drier is sometimes used on a compressed air supply to reduce the water content. Ambient moisture compressed along with the air can condense once the compressed air stream begins to cool. This moisture can accumulate in the compressed air header and be entrained in the cleaning air injected into the bags. Water entering the bags can cause blinding of the filter due to the formation of muddy deposits. The types of driers used on compressed air supplies include refrigerant and desiccant driers. These driers usually reduce the dew point of the gas stream to levels 20°F to 30°F below the lowest ambient wintertime temperature. These low dew points mean that the water vapor levels are less than 5% of the levels of untreated compressed air. For baghouses that do not have driers on the compressed air supply, the compressed air header is usually mounted below the elevation of the diaphragm valves to prevent condensed water carryover into the bags.

A coalescing filter is often used after the compressor to remove entrained oil droplets. The oil is introduced into the compressed air stream by the vaporization of lubricating oil used in certain types of compressors. After the compressed air cools, the oil vapor can condense to form oil droplets. If they are not removed, the oil droplets can accumulate on the bag surface and eventually cause blinding. In dedicated systems, oil-less or oil-free compressors are typically used to significantly reduce the amount of oil introduced into the compressed air stream.

A typical compressed air header is shown in Figure 7-18. This provides a reservoir of compressed air to support the operation of the diaphragm valves during a cleaning cycle. There is a connection to each diaphragm valve serving each row of the baghouse. It is important that these connections and the header itself be leak free to ensure that the header remains at the necessary air pressure. In most systems, the compressed air pressure is in the range of 60 to 90 psig.

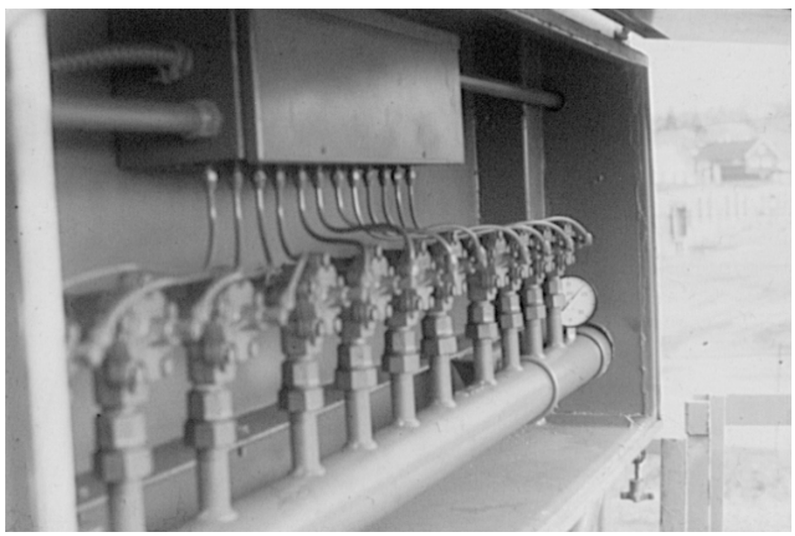


Figure 7-18. Pulse jet compressed air manifold and valves

The cleaning cycle can be regulated by either a standard timing board or with a differential pressure transmitter and controller. The timing board simply activates the cleaning cycle on a frequency set by the operator. The differential pressure transmitter and controller monitors the media static pressure drop and activates the cleaning cycle whenever the static pressure drop exceeds the maximum level set by the operator. In either case, bags are cleaned on a relatively frequent basis, with each row being cleaned from once every five minutes to once every several hours. Cleaning usually starts with the first row of bags and continues through the remaining rows in the order the bags are mounted.

The opening and closing of the diaphragm valve serving each row of bags is controlled by a solenoid valve. When the solenoid valve is closed, compressed air fills the small tube, called a trigger line, running between the solenoid valve and the back of the diaphragm valve. This pressure keeps the diaphragm valve closed. When it is necessary to activate the diaphragm valve, the cleaning cycle controller sends an electrical signal to the solenoid to open the valve and the compressed air in the trigger line is exhausted to the atmosphere. The release of compressed air from the back of the diaphragm valve causes the diaphragm valve to open, allowing the compressed air to enter the delivery tube passing above the row of bags.

The compressed air delivery tube, usually called a lateral or blow tube, transports the compressed air from the discharge side of the diaphragm valve to the inlet of each bag in the row (see Figure 7-19). These tubes have either a small orifice or an extension tube on the lower side. This hole or extension tube directs the compressed air into the center of the bag. After a period of 0.1-0.2 seconds, .the cleaning cycle controller sends a signal to close the solenoid valve. The trigger line again fills with compressed air and the diaphragm valve closes. If the trigger line is broken, the diaphragm valve cannot be closed, and compressed air continues to flow through the affected valve.

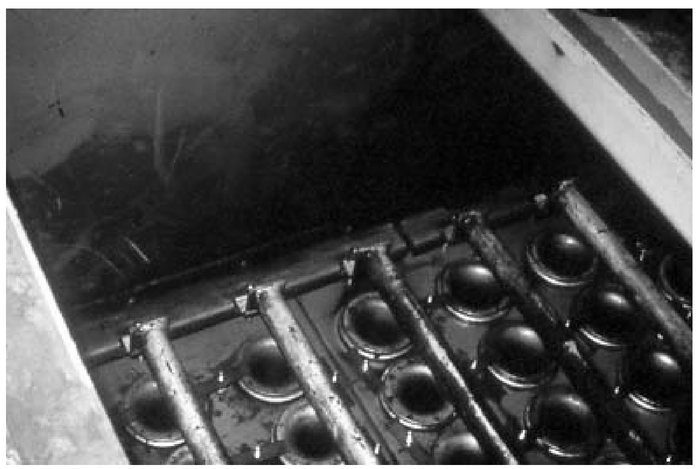


Figure 7-19. Compressed air delivery tubes

It is important that the delivery tube be oriented so that the orifice or extension tube points straight into the bag. Rotation of the delivery tube causes the compressed air pulse to strike the side of the bag near the top and holes are created. It is also important to securely fasten the compressed air delivery tube. This tube experiences a pressure rise from ambient pressure to more than 60 psig in a time period of 10 to 50 milliseconds. If this tube is not firmly secured, it can break free. Most baghouses have a fastener on the end of the delivery tube to ensure that it does not move. This same fastener is often used to ensure that the delivery tube is properly rotated. The use of the clamps and other fasteners is important because baghouse operators must remove and reinstall the delivery tubes each time it is necessary to change one or more bags.

Diaphragm valve freezing is a problem that can occur when the baghouse is located outside in cold climates. Diaphragm valve freezing can be minimized by one or more of the following actions:

- Using a compressed air drier
- Relocating the compressed air manifold below the elevation of the diaphragm valves
- Enclosing the diaphragm valves, manifold, and solenoid valves in a weatherproof enclosure and, if necessary, providing heat
- Using drains on manifolds to remove accumulated water on a routine basis

The instrumentation for the compressed air pulsing system is usually quite limited. There is usually a compressed air pressure gauge on the storage tank of the compressor and on the compressed air header serving the baghouse. The compressed air pressure data can be used in conjunction with the overall static pressure drop data for the baghouse to confirm that the baghouse cleaning system is performing properly.

Cartridge Filters

Cartridge filter systems are similar to pulse jet fabric filter systems. The filter elements are supported on a tube sheet that is usually mounted near the top of the filter housing. The gas stream to be filtered passes from the outside of the filter element to the inside. Filtering is performed by the filter media and the dust cake supported on the exterior of the filter media. The filter media is usually a felted material composed of cellulose, polypropylene, or other flex-resistant material.

The unique feature of a cartridge filter is the design of the filter element. Essentially all cartridges are shorter than pulse jet bags. Some cartridges have simple cylindrical designs. Others can have a large number of pleats as shown in Figure 7-20 or other complex shapes as shown in Figure 7-21 in order to increase the filtering surface area. Due to the shortness of the cartridge filter elements, they are usually less vulnerable to abrasion caused by the inlet gas stream. The shorter length also facilitates cleaning by a conventional compressed air pulsing system identical to those used on pulse jet collectors.

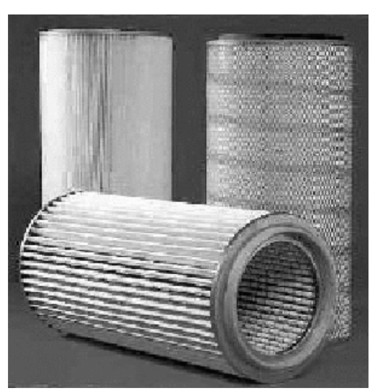


Figure 7-20. Pleated cartridge filter element

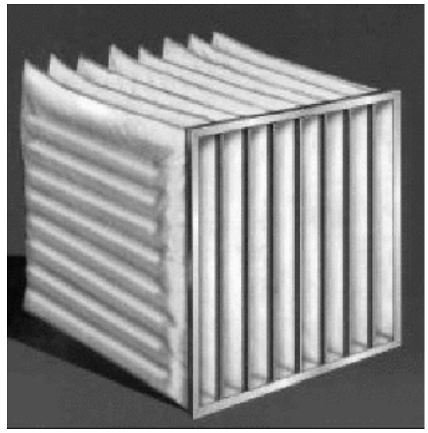


Figure 7-21. Flat cartridge filter element

Cartridge filter elements are used in a wide variety of industrial applications. Due to their inherently compact design, they can be used in small collectors located close to the point of particulate matter generation. They are generally used on gas streams less than approximately 400°F. This temperature limit is due to the capabilities of the flex resistant, high temperature fabrics and by the limitation of the gasket material used to seal the cartridge filter element to the tube sheet.

Fabrics

There is a wide variety of commercially available filtration media. These can be categorized into five different groups:

- Woven fabric
- Felted fabric
- Membrane fabric
- Sintered metal fiber
- Ceramic cartridge

A woven fabric is composed of interlaced yarns, as shown in Figure 7-22. The yarns in the warp direction provide strength to the fabric, and the yarns in the fill direction determine the characteristics of the fabric. The pores, which are the gaps between the yarns, can be more than 50 μm in size. Small particles can easily pass through these pores until particles are captured on the sides of the yarns and bridge over the openings. The dust cake is critical for proper filtration by woven fabrics.

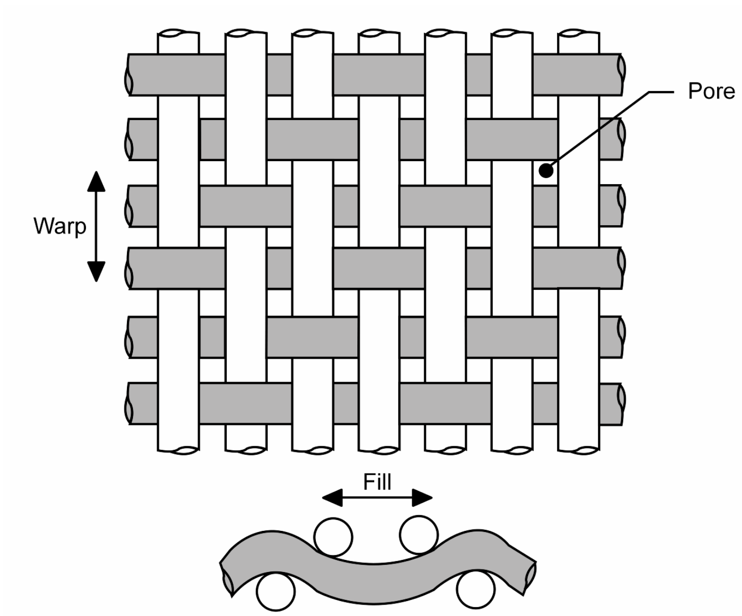


Figure 7-22. Woven fabric

There are a variety of weave types used to modify the characteristics of the fabric. For example, the twill weave shown in Figure 7-22 is less vulnerable than other weaves to fabric blinding due to the penetration of fine particles into the fabric. Overall, the weave characteristics influence the strength of the cloth, the difficulty of dust cake release during cleaning, and the resistance to gas flow.

Felted fabrics are composed of randomly oriented fibers attached to a very open weave termed the scrim. The felted fabrics are usually much thicker than woven cloths because of the layer of fibers on both sides of the scrim. With this type of fabric construction, there are no pores as indicated in Figure 7-23. The fibers on the filtering side provide a large number of targets for particle impaction, Brownian diffusion, and electrostatic attraction. However, even with felted fabrics, the dust cake that accumulates on the surface is primarily responsible for particle capture.

Membranes are another major category of fabrics used in air pollution control. These are composed of a polytetrafluoroethylene (PTFE) membrane that is laminated to either a woven or felted support fabric. The membrane is placed on the filtering side of the fabric. Particle collection occurs primarily due to the sieving action of the membrane's very small pores (less than 5 μm). In membrane fabrics, the dust layer is not especially important in particulate removal. Furthermore, static pressure drop is relatively low due to the good dust cake release properties.

Sintered metal fiber bags are composed of small metal fibers randomly oriented on a cylindrical surface. The bags are heated to high temperatures to bond the fibers together. The bags are rigid and require specially designed pulse jet type cleaning systems. Sintered metal fiber bags can be used for hot gas streams. They can also be aggressively cleaned if they become blinded by sticky or moist dust.

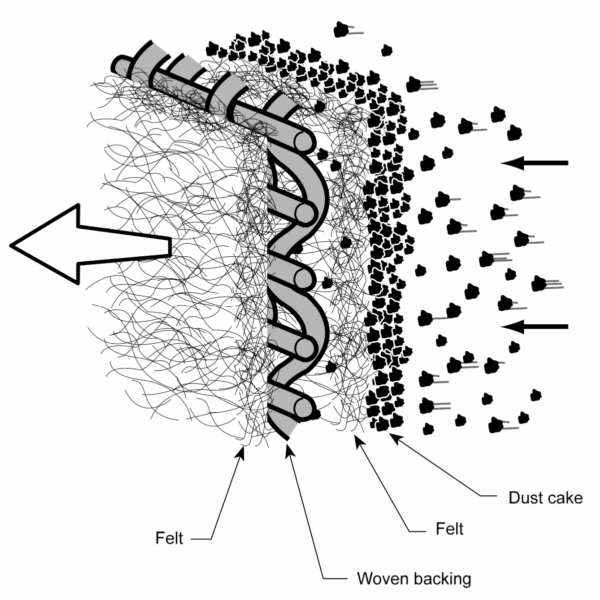


Figure 7-23. Felted fabric

Ceramic cartridge filters are fabricated in cylindrical candle or honeycomb forms. Particle capture occurs as the dust passes through the dust cake on the exterior surface and through the pores through the ceramic media. These filters are designed for applications where the gas temperatures are extremely hot.

The fabrics used for baghouses can be composed of a variety of synthetic and natural materials. Selection of the fabric material is based primarily on three criteria:

- Maximum gas temperatures of the gas stream
- Corrosive chemical concentrations in the gas stream
- Physical abrasion and fabric flex conditions

The various fabrics differ substantially with respect to their ability to tolerate temperature, chemical attack, and physical abrasion and flex. The temperature and acid-resistant capabilities of some of the commercially available types of fabrics are summarized in Table 7-1. The continuous temperature rating shown in the table is intended only as a general indicator of the fabric's capability. To optimize bag life, the normal operating temperatures should be slightly below this limit. The resistance to acids primarily involves inorganic acids such as sulfuric acid and hydrochloric acid.

The ability to handle temperature surges is a function mainly of the fabric's dimensional stability and protective coatings. For example, the limiting maximum surge temperature for fiberglass fabrics is due, in part, to the need to avoid volatilization of lubricants on the fiber surfaces. These lubricants are necessary to prevent fiber-fiber abrasion during cleaning. Also, the ability of the fabric to withstand short-term temperature spikes depends on the quantity of dust cake present. The dust can absorb some of the heat and thereby moderate the maximum temperature while slightly extending the time period that the fabric is exposed to elevated temperature.

Table 7-1. Temperature and Acid Resistance Characteristics

Generic	Common or	Maximum Temperature, °F		Acid
Name	Trade Name	Continuous	Surges	Resistance
Natural Fiber, Cellulose	Cotton	180	225	Poor
Polyolefin	Polyolefin	190	200	Good to Excellent
Polypropylene	Polypropylene	200	225	Excellent
Polyamide	Nylon®	200	225	Excellent
Acrylic	Orlon®	240	260	Good
Polyester	Dacron®	275	325	Good
Aromatic Polyamide	Nomex®	400	425	Fair
Polyphenylene Sulfide	Ryton®	400	425	Good
Polyimide	P-84®	400	425	Good
Fiberglass	Fiberglass	500	550	Fair
Fluorocarbon	Teflon®	400	500	Excellent
Stainless Steel	Stainless Steel	750	900	Good
Ceramic	Nextel®	1300	1400	Good

The ability of fabrics to withstand physical abrasion and flex is summarized in Table 7-2. Fabrics listed as fair must be cleaned gently, and the bags must be handled carefully during installation. Most of the fabrics have good to excellent capability with respect to abrasion and flex. The three main exceptions are fiberglass, Teflon®, and ceramic fabrics which are often used for moderate-to-high gas temperature applications.

Some of the fabrics are coated to improve their ability to withstand acid attack and abrasion and flex type physical damage. All fiberglass fabrics must have coatings to protect the relatively brittle fibers that can easily be broken by fiber-to-fiber abrasion. Silicone-graphite finishes for fiberglass fabrics have been used for more than 40 years. Other coatings that have been developed and used successfully over the last 20 years include Teflon-B® coating, I-625®, Blue Max®, and Chemflex®. Some of these newer coatings also protect the fabric from acid attack.

Table 7-2. Fabric Resistance to Abrasion and Flex		
Generic Name	**Common or Trade Name**	**Resistance to Abrasion and Flex**
Natural Fiber, Cellulose	Cotton	Good
Polyolefin	Polyolefin	Excellent
Polypropylene	Polypropylene	Excellent
Polyamide	Nylon®	Excellent
Acrylic	Orlon®	Good
Polyester	Dacron®	Excellent
Aromatic Polyamide	Nomex®	Excellent
Polyphenylene Sulfide	Ryton®	Excellent
Polyimide	P-84®	Excellent
Fiberglass	Fiberglass	Fair
Fluorocarbon	Teflon®	Fair
Stainless Steel	Stainless Steel	Excellent
Ceramic	Nextel®	Fair

7.3 Performance Evaluation

Unlike other particle control devices, we do not have mathematical relationships for estimating the collection efficiency of fabric filters. Instead, we evaluate a number of factors to assess whether the device has been properly designed. These factors include:

- Fabric selection
- Air-to-cloth ratio
- Approach velocity
- Bag spacing and length
- Bag accessibility
- Cleaning system design
- Hopper design
- Bypass dampers
- Instrumentation

The cleaning system design parameters were discussed earlier for each type of cleaning system. The remaining evaluation factors will be discussed in this section. A well designed, properly operated, and well maintained fabric filter system should achieve overall collection efficiencies in excess of 99 percent.

Air-to-Cloth Ratio

The air-to-cloth ratio is the main sizing parameter used for fabric filters. Low values of the air-to-cloth ratio indicate that the velocity of gas passing through a given area of the fabric is relatively low. This favors proper particulate matter capture and moderate static pressure drops.

The gross air-to-cloth ratio is defined as the actual gas flow rate at maximum operating conditions divided by the total fabric area in the baghouse. This is summarized in Equation 7-7.

(7-7)

$$(A/C)_{gross} = \frac{Q_{maximum}}{A_{total}}$$

Where:

$(A/C)_{gross}$ = gross air-to-cloth ratio $((ft^3/min)/ft^2)$
$Q_{maximum}$ = maximum actual gas flow rate (ft^3/min)
A_{total} = total fabric area (ft^2)

The net air-to-cloth ratio is often used for multi-compartment fabric filters where one or more of the compartments is isolated from the gas flow due to cleaning or maintenance. This sizing parameter is defined in Equation 7-8.

(7-8)

$$(A/C)_{net} = \frac{Q_{maximum}}{A_{net}}$$

Where:

$(A/C)_{net}$ = net air-to-cloth ratio $((ft^3/min)/ft^2)$
$Q_{maximum}$ = maximum actual gas flow rate (ft^3/min)
A_{net} = fabric area in filtering service (ft^2)

The gross and net air-to-cloth ratios can be calculated using basic information concerning the number of bags, the dimensions of the bags, and the actual gas flow rate at maximum process operating conditions. The bag areas for cylindrical shaker, reverse air and pulse jet bags are calculated with the formula shown in Equation 7-9.

(7-9)

$$A = \pi DL$$

Where:

A = bag surface area (ft^2)
D = bag diameter (ft)
L = bag length (ft)

Equation 7-9 is the formula for the area of the side of a cylinder. In using this equation, it is assumed that filtration occurs only on the side of the bag, not on the circular top (shaker and reverse air) or bottom (pulse jet). This is a reasonable approach because reverse air and pulse jet bags usually have a solid cup across the circular area and shaker bags usually taper to a sewn closure.

The formula for calculating the fabric area of a pleated cylindrical cartridge filter (Figure 7-20) is provided in Equation 7-10.

(7-10)

$$A=2ndh$$

Where:

A = cartridge surface area (ft^2)
n = number of pleats
d = depth of pleat (ft)
h = pleat height (ft)

For other types of cartridges, the filter area should be calculated by applying standard geometrical relationships to the shape of the filter surfaces.

Example 7-1 illustrates the calculation of the gross and net air-to-cloth ratios for a reverse air baghouse. Example 7-2 illustrates procedures for calculating the gross and net air-to-cloth ratios for a cartridge baghouse.

Example 7-1 Calculate the gross and net air-to-cloth ratios for a reverse air baghouse with 20 compartments, 360 bags per compartment, a bag length of 30 ft, and a bag diameter of 11 inches. Use an actual gas flow rate of 1.2×10^6 ft^3/min. Assume that two compartments are out of service when calculating the net air-to-cloth ratio.

Solution

$$\text{Bag area} = \pi DL$$

$$\text{Area/bag} = \pi \text{ (11 inches)(ft/12 in.) 30 ft} = 86.35 \text{ ft}^2\text{/bag}$$

The gross air-to-cloth ratio is calculated assuming that all the bags are in service.

Total number of bags = (360 bags/compartment)(20 compartments) = 7,200 bags

Total fabric area = (7,200 bags)(86.35 ft^2/bag) = 621,720 ft^2

$$(A/C)_{gross} = \frac{1.2x10^6 \, ft^3/\min}{621{,}720 \, ft^2} = \frac{1.93 \, ft^3/\min}{ft^2}$$

The net air-to-cloth ratio is calculated by subtracting the compartments that are not in filtering service.

Total number of bags = (360 bags/compartment)(18 compartments) = 6,480 bags

Total fabric area = (6,480 bags)(86.35 ft^2/bag) = 559,548 ft^2

$$(A/C)_{gross} = \frac{1.2x10^6 \; ft^3/\min}{559{,}548 \; ft^2} = \frac{2.14 \; ft^3/\min}{ft^2}$$

Example 7-2 Calculate the gross and net air-to-cloth ratios for a cartridge baghouse with 4 compartments, 16 cartridges per compartment, a cartridge length of 2 ft, and a cartridge diameter of 8 inches. Use a pleat depth of 1.5 inches and a total of 36 pleats in the cartridge. Use an actual gas flow rate of 4,000 ft/min. Assume one compartment is out of service when calculating the net air-to-cloth ratio.

Solution Cartridge area = 2ndh

Area/cartridge = 2(36 pleats)(1.5 in./(12 in. per ft))(2 ft) = 18 ft^2

The gross air-to-cloth ratio is calculated assuming that all the bags are in service.

Total number of cartridges = (16 cartridges/compartment)(4 compartments)
= 64 cartridges

Total fabric area = (64 cartridges)(18 ft2/cartridge) = 1,152 ft2

$$(A/C)_{gross} = \frac{4{,}000 \; ft^3/\min}{1{,}152 \; ft^2} = \frac{3.47 \; ft^3/\min}{ft^2}$$

The net air-to-cloth ratio is calculated by subtracting the compartments that are not in filtering service.

Total number of cartridges = (16 cartridges/compartment)(3 compartments)
= 48 cartridges

Total fabric area = (48 cartridges)(18 ft^2/cartridge) = 864 ft^2

$$(A/C)_{gross} = \frac{4{,}000 \; ft^3/\min}{864 \; ft^2} = \frac{4.62 \; ft^3/\min}{ft^2}$$

The appropriate air-to-cloth ratio for a given application depends on the particle size distribution, fabric characteristics, particulate matter loadings, and gas stream conditions. Low values for a design air-to-cloth ratio are generally used when the particle size distribution includes a significant fraction of submicrometer particulate matter or when the particulate loading is high. The air-to-cloth ratios for cartridge filters are usually maintained at values less than approximately 4 (ft3/min)/ft2. A summary of air-to-cloth ratio values for shaker, reverse air and pulse jet fabric filters in a variety of industries is provided in Table 7-3. Some caution is warranted in reviewing any table of this type, because the design air-to-cloth ratios were gradually decreased over the past 20 years, and there can be significant site-to-site differences in the particle size distributions, particulate loadings, and fabric characteristics. Furthermore, the regulations based on the Clean Air Act Amendments of 1990 place even greater demands on fabric filter performance. Accordingly, historical design data may not be strictly applicable to a specific application.

Table 7-3. Typical Air-to-Cloth Ratios for Selected Industries

Industry	Shaker	Reverse Air	Pulse Jet
Basic oxygen furnaces	2.5-3.0	1.5-2.0	6-8
Brick manufacturers	2.5-3.2	1.5-2.0	9-10
Coal-fired boilers	1.5-2.5	1.0-2.0	3-5
Electric arc furnaces	2.5-3.0	1.5-2.0	6-8
Ferroalloy plants	2.0	2.0	9
Grey iron foundries	2.5-3.0	1.5-2.0	7-8
Lime kilns	2.5-3.0	1.5-2.0	8-9
Municipal incinerators	1.5-2.5	1.0-2.0	2.5-4.0
Phosphate fertilizer	3.0-3.5	1.8-2.0	8-9
Portland cement kilns	2.0-3.0	1.2-1.5	7-10

Source: EPA 450/3-76-014

Approach Velocity

Gravity settling of dust cake agglomerates, sheets, and particles released during bag cleaning are a critical step in the fabric filtration process. If fine particles with inherently poor terminal settling velocities return to the bag-dust cake surface, there can be adverse effects on both collection efficiency and static pressure drop. This can occur in off-line cleaning systems (shaker and reverse air) if insufficient null time is provided after cleaning to allow the particles to settle. In on-line cleaning systems (pulse jet), gas flow entering into the hopper of the collector, rather than the side, can produce an upward velocity that may prohibit some particles and particle agglomerates from settling. Using a side entry significantly reduces this problem.

In pulse jet units with gas entry into the hopper, the point of maximum velocity is the area around the bottoms of the bags. As shown in Figure 7-24, all the particulate-laden gas to be filtered by the bags must pass through this area in order to reach the bag surfaces, and the dust released during cleaning must fall through this area as it settles by gravity. If the upward velocity of the inlet gas stream exceeds the downward terminal settling velocity, the particles will be caught and returned to the bag surface.

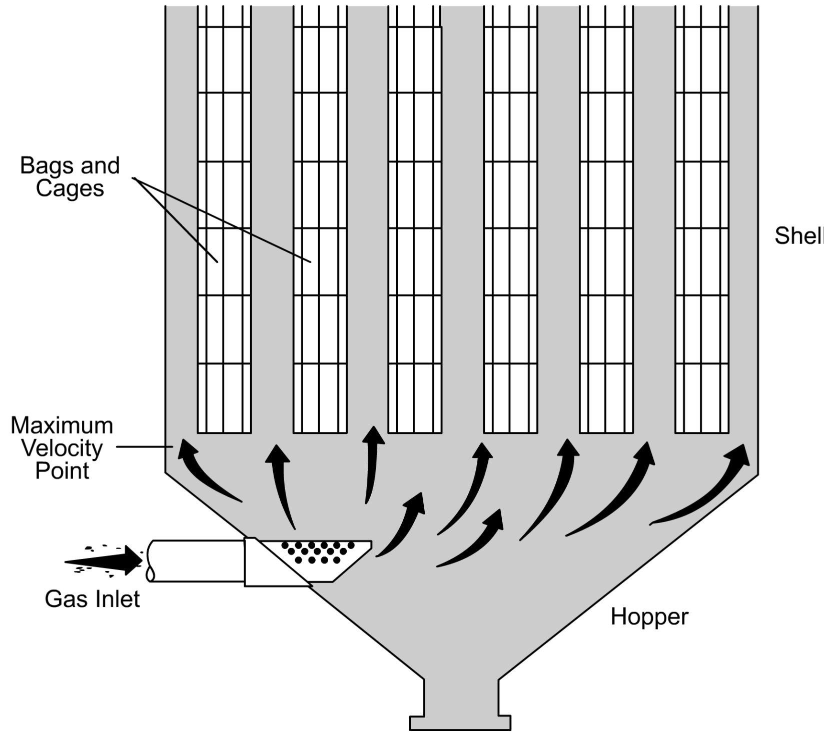
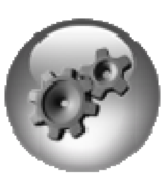


Figure 7-24. Gas approach velocity for pulse jet baghouse

The air-to-cloth ratio is one factor that affects the severity of gravity settling problems in pulse jet fabric filters with hopper entry. The gas approach velocity is directly proportional to the air-to-cloth ratio, as illustrated in Example 7-3. A comparison of the calculated approach velocity indicates that even 100 μm particles released from the dust cake will not settle by gravity. Accordingly, it is important that large dust agglomerates or sheets be released, not small agglomerates or individual particles.

Gravity settling problems can also occur in shaker and reverse air fabric filters. If the compartment isolation damper does not seal properly, settling may be opposed by a modest inlet gas flow into the bags during the cleaning cycle. In reverse air units, small particle removal may not aided by the downward movement of the reverse air if the flow rates are inadequate.



Example 7-3 What is the difference in gas approach velocities for two identical pulse jet fabric filters with the following design characteristics?

Characteristic	Unit A	Unit B
Compartment area, ft^2	130	130
Number of bags	300	300
Bag diameter, in.	6	6
Bag height, ft	10	10
Air-to-cloth ratio, $(ft^3/min)/ft^2$	5	8

Solution The bag area for both units is identical. It is calculated using the circumference of the bag times the length.

Bag area = $\pi DL = \pi(6 \text{ in.})(1 \text{ ft}/12 \text{ in.})(10 \text{ ft}) = 15.7 \text{ ft}^2/\text{bag}$

Total bag area = $(300 \text{ bags})(15.7 \text{ ft}^2/\text{bag}) = 4{,}710 \text{ ft}^2$

$$\text{Total gas flow rate, Unit A} = \frac{5\left(ft^3/\min\right)}{ft^2}\left(4{,}710\ ft^2\right) = 23{,}550\ ft^3/\min$$

$$\text{Total gas flow rate, Unit B} = \frac{8\left(ft^3/\min\right)}{ft^2}\left(4{,}710\ ft^2\right) = 37{,}680\ ft^3/\min$$

The area for gas flow at the bottom of the pulse jet bags is identical in both units.

Area for flow = total area – bag projected area
= total area – (number of bags)(circular area of bag at bottom)
$= 130 \text{ ft}^2 - (300)(\pi D^2/4)$
$= 130 \text{ ft}^2 - 58.9 \text{ ft}^2$
$= 71.1 \text{ ft}^2$

$$\text{Gas approach velocity for Unit A} = \frac{23{,}550\ ft^3/\min}{71.1\ ft^2} = 331\ ft/\min$$

$$\text{Gas approach velocity for Unit B} = \frac{37{,}680\,\text{ft}^3/\min}{71.1\,\text{ft}^2} = 530\,\text{ft}/\min$$

Bag Spacing and Length

In pulse jet baghouses, the approach velocity is directly proportional to the length of the bag. For example, an increase in the bag length to 16 ft from 10 ft in Unit B (Example 7-3) would increase the approach velocity to approximately 850 ft/min, as long as the air-to-cloth ratio remained constant. Furthermore, particles and small dust cake agglomerates would have a longer distance to travel with the taller bag. Both factors increase the susceptibility to gravity settling-related problems.

Approach velocities are also a function of bag spacing. Units that crowd the bags close together have high approach velocities because there is very little area between the bags for the inlet gas stream to pass through. For example, the velocities calculated in Example 7-3 were based on a unit having bags on 8-inch centers (8 inches from center of bag to center of adjacent bag). If the bags were spaced on 7-inch centers, the approach velocities for Units A and B would be 571 and 913 ft/min, respectively.

Gravity settling and bag cleaning in general would be significantly more difficult at these higher velocities. It is usually preferable to space the bags far apart to minimize this potential problem. However, there are practical limits to the bag spacing because wide spacing increases the size of the baghouse shell and the area needed for the baghouse.

Pulse jet bag length and spacing are important for other reasons, as well. Bag-to-bag abrasion can occur at the bottoms of the bags because they hang freely from the tube sheet. Slight bows in the pulse jet bag support cages or slight warpage of the supporting tube sheet can cause bag-to-bag contact at the bottom, as illustrated in Figure 7-25. Abrasion damage can occur due to the slight movement of the fabric and cage during each pulse cycle. Holes can develop within several weeks to several months of routine operation, depending on the abrasion sensitivity of the fabric being used. Pulse jet units with relatively short bags are less vulnerable to this mode of bag failure.

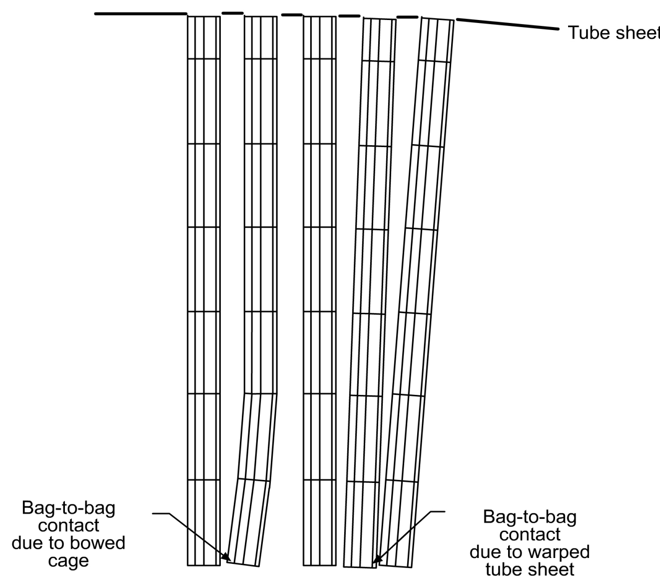


Figure 7-25. Possible problems with tall pulse jet bags

A variety of other practical problems limit bag length. Very tall bags are often difficult to install in a pulse jet baghouse when there is limited overhead clearance to remove the failed bag mounted on the rigid cage. In some cases, failed bags partially fill with solids and, in the case of tall bags, the weight can be substantial. Therefore, relatively short bags of 8 to14 ft are preferable to tall bags, which can be as long as 20 ft.

Bag length and spacing are also important for shaker and reverse air fabric filters. However, the problems with length are less severe because the bags are fixed at both the top and the bottom. Tall reverse air bags are vulnerable to bag tension problems caused by the weight of dust on the bag. This can lead to bag sagging if the support springs become overloaded. Once this happens, bag abrasion can be rapid because the folds of sagging fabric are usually in the direct path of the bag inlet gas stream. Reverse air bags are usually less than 32 ft in length. Shaker bags are usually less than 20 ft long because of the difficulty of maintaining effective shaking movement over longer distances.

Bag Accessibility

Access for bag inspection and replacement is important. In the case of shaker and reverse air baghouses, sufficient space should be allowed so that each bag can be checked visually and either capped off (bag opening sealed) or replaced, if necessary. One measure of the accessibility provided for the maintenance staff is termed the bag reach. This is simply the maximum number of rows of bags from the nearest access walkway. For example, the baghouse compartment shown in Figure 7-26 has a reach of 1-½. Each row of bags in the compartment is no more than 1-½ rows from the nearest walkway. Accordingly, it is possible for plant maintenance staff to find and correct bag problems. Units with less accessible bags are difficult to service. Furthermore, it is possible to damage bags in the outer rows while attempting to work on bags in rows far from the access walkways. There is no single value for bag reach that is considered appropriate for shaker and reverse air baghouses; however, it should certainly be less than one arm's length. Units with a minimum bag reach are easier to maintain.

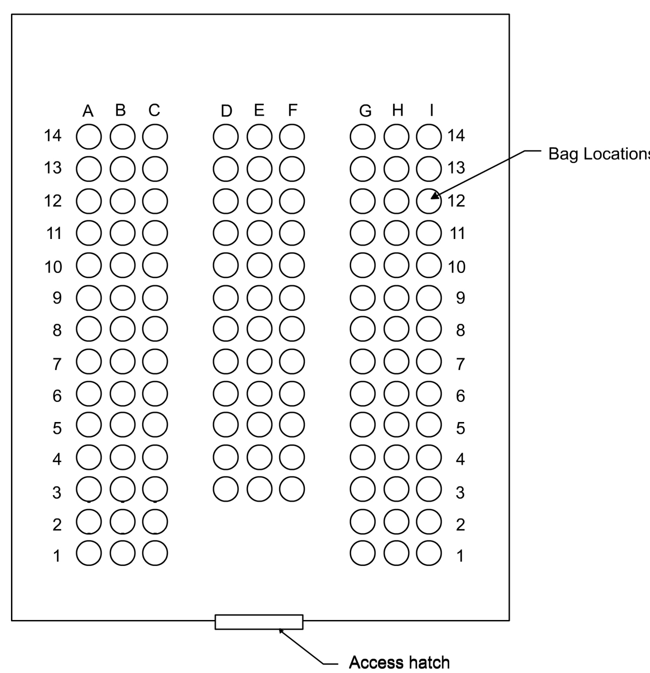


Figure 7-26. Baghouse plan view

Hopper Design

A variety of solids-handling systems are used to empty hoppers and transport the solids. Large shaker and reverse air baghouses usually have either pneumatic or pressurized solids-handling systems, both of which empty one hopper at a time. The solids-handling system often cycles continuously between the hoppers in order to minimize solids build-up problems. Smaller baghouses often have screw conveyors with either rotary discharge valves or double flapper valves to prevent air infiltration. As discussed in Chapter 6, rotary valves use either metal blades or flexible wipers on metal blades to maintain an air seal, while the sections of the double flapper valve move in an alternating fashion so that one is always in place to provide an air seal.

Hoppers must be designed to facilitate proper solids discharge. High solids levels due to blockage in the baghouse hoppers are very undesirable. The solids can be reentrained by the inlet gas stream and contribute to abrasion damage at the lower portions of both pulse jet and shaker and reverse air bags. Additionally, the inlets of shaker and reverse air bags can be blocked as the solids levels increase. As discussed in Chapter 6, several hopper design features are used to minimize solids overflow. Some of these features are shown in Figure 7-27 and include:

- Properly sealing solids discharge valve
- Adequately sized hopper throat
- Adequately sloped hopper walls
- Strike plates or vibrators
- Thermal insulation

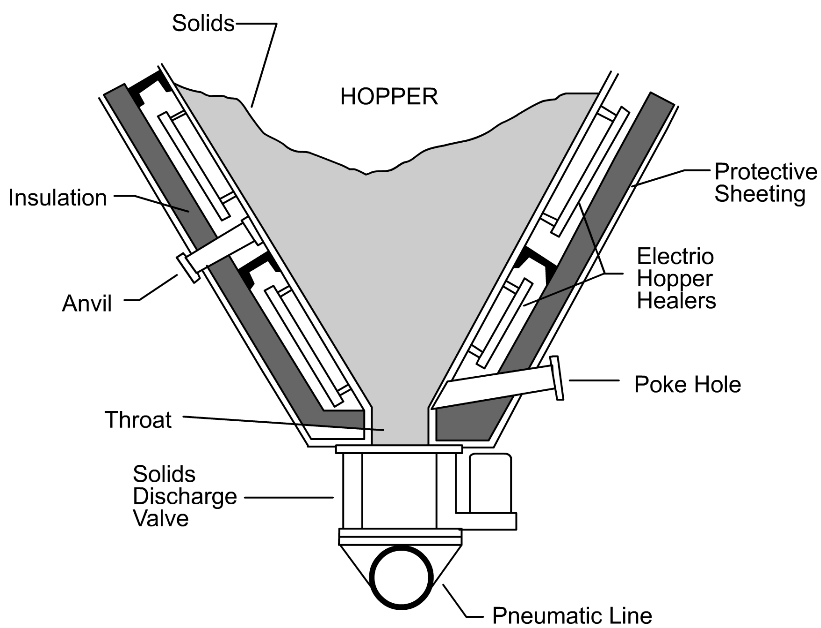


Figure 7-27. Hopper design features

Bypass Dampers

Bypass dampers are sometimes mounted in short connecting ductwork that leads from the baghouse inlet duct to the outlet duct. These dampers provide important protection for the baghouse during periods of adverse gas temperatures or other conditions that could severely damage the bags. For example, dampers are usually open during start-up and shut down of solid-fuel combustion processes because the gas stream temperature is below the acid dew point and the particulate matter can be sticky, prompting bag blinding.

During routine operation, it is important that these dampers seal tightly. They are subjected to a static pressure differential that is equivalent to the overall static pressure drop across the entire baghouse. Slight gaps in the poppet or louvered dampers can allow relatively large quantities of unfiltered air to short circuit around the baghouse. This problem is often indicated by a constant opacity of several percent.

Instrumentation

Fabric filters are sophisticated devices that are often applied to sources generating small diameter particulate matter. Instrumentation useful to evaluating their performance includes:

- Static pressure drop gauges
- Inlet and outlet gas temperature gauges
- Opacity monitors

Static Pressure Drop Gauges

Many of the problems that can occur during the operation of a fabric filter system usually result in a change in the static pressure drop. If the baghouse static pressure drop is high, undercleaning may be occurring and gas flow rates through the system may have decreased because of high flow resistance. This can result in fugitive emissions from the process. If the baghouse static pressure drop is low, overcleaning could be occurring, resulting in increased stack emissions. Accordingly, it is important to have static pressure drop gauges to monitor the overall resistance across the entire fabric filter.

For shaker and reverse air collectors, and any other collector that cleans off line, there is a normal cycle in the static pressure drop of individual compartments. In order to evaluate isolation during off-line cleaning and the effectiveness of reverse air flow, static pressure drop gauges are also needed on individual compartments.

Inlet and Outlet Gas Temperature Gauges

Filter bags are not tolerant of either very high or very low gas temperatures. Short term excursions of more than approximately 25oF above the filter media temperature limits can cause volatilization of protective coatings, yarn degradation, fabric shrinkage, or fabric stretching. All these conditions lead to premature bag failure. Acid attack occurs when the gas temperature drops below the acid vapor dew point, also resulting in yarn degradation and premature bag failure.

Air infiltration into fabric filters may cause damage because of localized temperatures that are below the acid or moisture dew points. It may also reduce the air flow at the source, contribution to fugitive emission losses. One of the most useful ways to evaluate air infiltration into negative pressure collectors is to compare the difference between the inlet and outlet gas temperatures to the baseline difference. If the temperature difference is significantly higher than during the baseline condition, excessive air infiltration may be occurring. If baseline data are not available, excessive air infiltration may be indicated by an inlet and outlet temperature difference that is greater than about 25°F.

Opacity Monitors

Some fabric filter systems have bag break indicator systems to provide an early warning of increased particulate emissions. Instruments used for bag break monitoring include Triboflow®, single pass light scattering, and scintillation instruments.

The Triboflow® instrument (Figure 7-28) uses a probe inserted in the outlet duct of a compartment or of the overall fabric filter. The transfer of electrical charge from the particulate emitted from the fabric filter to the probe provides an indication of the particulate matter concentration in the outlet gas stream. An increase in the instrument signal provides a qualitative indication of increased emissions.

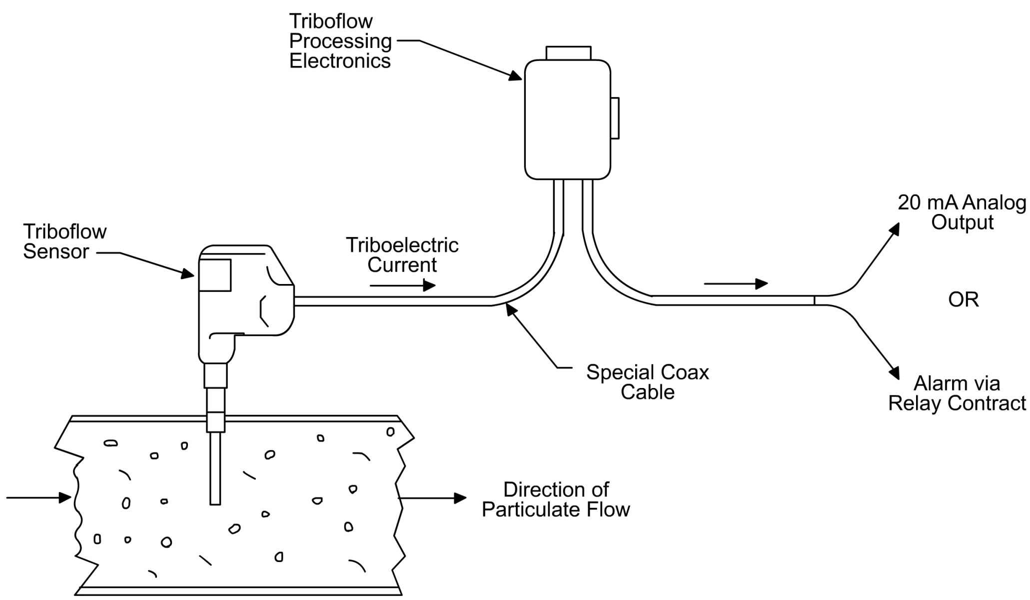


Figure 7-28. Triboflow® bag break detector

In the single pass light scattering detectors, a visible light source is mounted on one side of the outlet duct, and a light detector is mounted on the opposite side. A decrease in light intensity due to the presence of particulate matter in the gas stream provides an indication of a failed bag. These instruments often have an output scale expressed in terms of opacity. However, these instruments do not satisfy a number of the performance specifications applying to opacity monitors, and the output value is intended to be qualitative.

A scintillation type bag break indicator is also a light scattering, cross-stack monitor. The frequency of the light is varied to provide a means to evaluate the particulate mass concentration. This instrument provides data in the form of mass concentration values rather than opacity; however, these data are considered qualitative.

On large fabric filter systems, a double-pass transmissometer is often used to monitor the effluent gas stream opacity continuously. These systems use visible light that is projected across the stack, reflected off the surface of a mirror, and returned to a detector. The loss in light due to absorption and scattering during this double pass across the stack is measured as percent transmittance and is mathematically converted to opacity. These instruments are designed and installed in accordance with U.S. EPA Performance Specification 1 (40 CFR Part 60, Appendix A). They are usually located in either an outlet duct or the stack serving the fabric filter system.

Advantages and Disadvantages

Advantages

- High Collection Efficiency (>99%)
- Effective for a Wide Range of Dust Types
- Modules Can be Factory Assembled
- Operates Over Wide Range of Gas Flow Rates
- Reasonably Low Pressure Drop
- Good Efficiency for Small Particles
- Dry Collection and Disposal

Disadvantages

- Large Footprint
- Temperature Limitations
- Requires Dry Environment
- Fire or Explosion Potential
- High Maintenance Cost

Review Questions

1. What types of fabric filter systems collect the dust cake on the exterior surface of the filter media? Select all that apply.
a. Pulse jet
b. Cartridge
c. Reverse air

2. What is the purpose of using offline cleaning in a multi-compartment pulse jet collector? Select all that apply.
a. Minimize solids build-up problems in hoppers
b. Minimize gravity settling problems during cleaning of the bags
c. Minimize high static pressure drop problems
d. Minimize variability of the overall static pressure drop across the baghouse during the cleaning cycle

3. What fabrics have a long term temperature limitation above 400°F? Select all that apply.
a. Fiberglass
b. Cellulose
c. Nomex
d. P84
e. Stainless steel
f. Ceramic
g. Teflon

4. A static pressure drop gauge is mounted on the side wall of a pulse jet baghouse. One side of the gauge is connected to the side wall of the baghouse at a location just below the tube sheet. The other side of the gauge is located just above the tube sheet. The data provided by this instrument is termed the _____.
a. Overall baghouse static pressure drop
b. Filter media static pressure drop
c. Compressor discharge static pressure
d. Compressor header static pressure

5. What types of contaminants can be present in untreated compressed air used to clean pulse jet fabric filters and cartridge fabric filters? Select all that apply.
a. Condensed water droplets
b. Sulfur dioxide
c. Carbon monoxide
d. Condensed oil droplets

6. What problem or problems are created if a pulse jet bag does not seal

properly to the tube sheet? Select all that apply.
a. Unfiltered gas could leak around the bag into the clean gas plenum
b. The bags could fall into the hoppers due to inadequate support
c. The filter media static pressure drop would decrease

7. A reverse bag constructed of fiberglass has very low tension and is sagging severely at the connection to the tube sheet thimble. What problem or problems could be created by this condition? Select all that apply.
a. The bag could develop holes due to its vulnerability to flex failure
b. The bag could be abraded by the high velocity inlet gas stream
c. The sagging bag could choke off flow of unfiltered air into the bag

8. What forces are used to remove particles in woven and felted bags? Select all that apply.
a. Inertial impaction
b. Brownian diffusion
c. Electrostatic attraction
d. Sieving

9. What forces are used to remove particles in a membrane bag? Select all that apply.
a. Inertial impaction
b. Brownian diffusion
c. Electrostatic attraction
d. Sieving

10. What problem occurs at excessive air-to-cloth ratios?
a. Accelerated bag failure
b. Decreased static pressure drop
c. Increased particulate emissions through the filter media
d. All of the above

Review Question Answers

1. What types of fabric filter systems collect the dust cake on the exterior surface of the filter media? Select all that apply.

a. Pulse jet
b. Cartridge

2. What is the purpose of using offline cleaning in a multi-compartment pulse jet collector? Select all that apply.

b. Minimize gravity settling problems during cleaning of the bags
c. Minimize high static pressure drop problems

3. What fabrics have a long term temperature limitation above 400°F? Select all that apply.

a. Fiberglass
e. Stainless steel
f. Ceramic

4. A static pressure drop gauge is mounted on the side wall of a pulse jet baghouse. One side of the gauge is connected to the side wall of the baghouse at a location just below the tube sheet. The other side of the gauge is located just above the tube sheet. The data provided by this instrument is termed the _____.

b. Filter media static pressure drop

5. What types of contaminants can be present in untreated compressed air used to clean pulse jet fabric filters and cartridge fabric filters? Select all that apply.

a. Condensed water droplets
d. Condensed oil droplets

6. What problem or problems are created if a pulse jet bag does not seal properly to the tube sheet? Select all that apply.

a. Unfiltered gas could leak around the bag into the clean gas plenum

7. A reverse bag constructed of fiberglass has very low tension and is sagging severely at the connection to the tube sheet thimble. What problem or problems could be created by this condition? Select all that apply.

a. The bag could develop holes due to its vulnerability to flex failure
b. The bag could be abraded by the high velocity inlet gas stream
c. The sagging bag could choke off flow of unfiltered air into the bag

8. What forces are used to remove particles in woven and felted bags? Select all that apply.

a. Inertial impaction
b. Brownian diffusion
c. Electrostatic attraction

9. What forces are used to remove particles in a membrane bag? Select all that apply.

a. Inertial impaction
b. Brownian diffusion
c. Electrostatic attraction
d. Sieving (But the best answer is sieving.)

10. What problem occurs at excessive air-to-cloth ratios?

c. Increased particulate emissions through the filter media

Review Problems

1. Calculate the net air-to-cloth ratio for a reverse air baghouse with 12 compartments containing 276 bags each. The diameter of each bag is 11 in, and the bag height is 28 ft. One of the compartments is always off-line for cleaning, and another is off-line for maintenance. Use a gas flow rate of 350,000 acfm.

2. Calculate the gas approach velocity for a pulse jet baghouse having a single compartment, 60 rows of bags with 10 bags each, and a bag diameter of 6 in. Assume that the internal dimensions of the compartment are 6.5 ft x 40 ft. Use a gas flow rate of 66,000 acfm.

3. Would a 150 μm size particle or particle agglomerate successfully settle by gravity in the pulse jet baghouse described in Problem 2? Assume a temperature of 20°C, a particle density of 1.0 g/cm3, and that the transitional region terminal settling velocity equation is appropriate for this particle size.

4. Calculate the static pressure difference between the clean gas plenum of a top access type pulse jet baghouse and the ambient air. Assume that the inlet static pressure to the baghouse is - 4 in WC and the static pressure drop across the baghouse is 5 in WC.

5. It is proposed to install a pulse jet fabric filter with an air-to-cloth ratio of 2.5 ft/min to clean a 10,000 scfm air stream at 250°F. Determine the filtering area required for this operation and, using the information below, choose an appropriate filter bag and determine how many will be needed.

Filter bag	A	B	C	D
Tensile strength	Excellent	Very good	Fair	Excellent
Maximum temperature (°F)	260	275	260	220
Relative cost per bag	2.6	3.8	1.0	2.0
Size	4¾" x 10'	6" x 10'	6" x 14'	6" x 14'

Review Problem Solutions

1. Calculate the net air-to-cloth ratio for a reverse air baghouse with 12 compartments containing 276 bags each. The diameter of each bag is 11 in, and the bag height is 28 ft. One of the compartments is always off-line for cleaning, and another is off-line for maintenance. Use a gas flow rate of 350,000 acfm.

Solution

$$\text{Individual bag area} = \pi Dh = \pi\left[11\text{in}\left(\frac{1\text{ft}}{12\text{in}}\right)\right](28\text{ft}) = 80.6\ \text{ft}/\text{bag}$$

$$\text{total net bag area} = 80.6\ \text{ft}^2/\text{bag}\left(276\frac{\text{bags}}{\text{compartment}}\right)(10\text{compartments}) = 222{,}456\text{ft}^2$$

$$\text{Net air-to-cloth ratio} = \frac{Q}{A} = \frac{350{,}000\ \text{ft}^3/\text{min}}{222{,}456\text{ft}^2} = 1.57\ \text{ft}/\text{min}$$

2. Calculate the gas approach velocity for a pulse jet baghouse having a single compartment, 60 rows of bags with 10 bags each, and a bag diameter of 6 in. Assume that the internal dimensions of the compartment are 6.5 ft x 40 ft. Use a gas flow rate of 66,000 acfm.

Solution

Total baghouse shell area = (6.5 ft)(40 ft) = 260 ft2

$$\text{Bottom area of bag} = \frac{\pi D^2}{4} = \frac{\pi\left[6\text{in}\left(\frac{1\text{ft}}{12\text{in}}\right)\right]^2}{4} = 0.196\ \text{ft}^2/\text{bag}$$

$$\text{Total bottom area} = 0.196\ \text{ft}^2/\text{bag}\left(10\frac{\text{bags}}{\text{row}}\right)(60\text{rows}) = 118\text{ft}^2$$

Open area = total shell area – total bottom area = 260 ft2 – 118 ft^2 = 142 ft^2

$$\text{Gas approach velocity} = \frac{Q}{A} = \frac{66{,}000\ \text{ft}^3/\text{min}}{142\text{ft}^2} = 465\ \text{ft}/\text{min} = 7.75\ \text{ft}/\text{sec}$$

3. Would a 150 μm size particle or particle agglomerate successfully settle by gravity in the pulse jet baghouse described in Problem 2? Assume a temperature of 20°C, a particle density of 1.0 g/cm3, and that the transitional region terminal settling velocity equation is appropriate for this particle size.

Solution

$$v_t = \frac{0.153 g^{0.71} \rho_p^{0.71} d_p^{1.14}}{\mu_g^{0.43} \rho_g^{0.29}} =$$

$$\frac{0.153\left(980\,{}^{cm}/_{sec^2}\right)^{0.71}\left(1\,{}^{g}/_{cm^3}\right)^{0.71}\left(150x10^{-4}\,cm\right)^{1.14}}{\left(1.8x10^{-4}\,{}^{g}/_{cm \cdot sec}\right)^{0.43}\left(1.2x10^{-3}\,{}^{g}/_{cm^3}\right)^{0.29}} = 48.58\,{}^{cm}/_{sec} = 1.59\,{}^{ft}/_{sec}$$

The 150 μm particle will not settle. The upward velocity of the gas stream is much higher than the terminal settling velocity.

4. Calculate the static pressure difference between the clean gas plenum of a top access type pulse jet baghouse and the ambient air. Assume that the inlet static pressure to the baghouse is - 4 in WC and the static pressure drop across the baghouse is 5 in WC.

Solution

Static pressure in the clean gas plenum = -4 in WC – (5 in WC) = -9 in WC

Since the ambient gauge pressure is 0 in WC, the static pressure difference between the clean gas plenum and the ambient air in 9 in WC.

5. It is proposed to install a pulse jet fabric filter with an air-to-cloth ratio of 2.5 ft/min to clean a 10,000 scfm air stream at 250°F. Determine the filtering area required for this operation and, using the information below, choose an appropriate filter bag and determine how many will be needed.

Filter bag	A	B	C	D
Tensile strength	Excellent	Very good	Fair	Excellent
Maximum temperature (°F)	260	275	260	220
Relative cost per bag	2.6	3.8	1.0	2.0
Size	4¾" x 10'	6" x 10'	6" x 14'	6" x 14'

Solution

Calculate actual flow rate:

$$Q = 10{,}000\, {ft^3}/{min}\left(\frac{250°F + 460}{68°F + 460}\right) = 13{,}447\, {ft^3}/{min}$$

Calculate filtering area:

$$\text{Filter area} = \frac{Q}{\text{A/C Ratio}} = \frac{\dfrac{13{,}447\, {ft^3}/{min}}{min}}{2.5\, {ft}/{min}} = 5{,}379 ft^2$$

Bag D can be eliminated because its maximum temperature is too low. Bag C can be eliminated because it has only fair tensile strength. Only Bags A and B will be considered further.

For Bag A:

$$\text{Bag area} = \pi Dh = \pi\left[4.75in\left(\frac{1ft}{12in}\right)\right](10ft) = 12.44\, {ft^2}/{bag}$$

$$\text{Number of bags} = \frac{5{,}379 ft^2}{12.44\, {ft^2}/{bag}} = 432\, bags$$

$$\text{Relative cost} = \left(\frac{2.6}{bag}\right)432\, bags = 1{,}123$$

For Bag B:

$$\text{Bag area} = \pi Dh = \pi 6\left[4.75in\left(\frac{1ft}{12in}\right)\right](10ft) = 15.71\, {ft^2}/{bag}$$

$$\text{Number of bags} = \frac{5{,}379 ft^2}{15.71\, {ft^2}/{bag}} = 342\, bags$$

$$\text{Relative cost} = \left(\frac{3.8}{bag}\right)342\, bags = 1{,}300$$

Bag A should be chosen because of its lower relative cost.

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