10

Fabric Filters

10.1 INTRODUCTION

Fabric filtration is a widely accepted method for particulate emissions control. In fabric filtration, the particle-laden gas flows through a number of filter bags placed in parallel, leaving the dust retained by the fabric. Extended operation of a fabric filter, or baghouse, requires that the dust be periodically cleaned off the cloth surface and removed from the baghouse. After a new fabric goes through a few cycles of use and cleaning, it retains a residual cake of dust that becomes the filter medium. This phenomenon is responsible for the highly efficient filtering of small particles that characterizes baghouses.

The type of cloth fabric limits the temperature of operation of baghouses. Cotton fabric has the least resistance to high temperature (about 355 K), while fiberglass has the most (530 K). In many cases this requires that the waste gas stream be precooled before entering the baghouse. The cooling system then becomes an integral part of the design. Conversely, the temperature of the exhaust gas stream must be well above the dew point of any of its condensable constituents as liquid particles plug the fabric pores quickly.

Most of the energy requirements of the system are to overcome the gas pressure drop across the bags, dustcake, and associated ductwork. Typical values of pressure drop range from 1 to 5 kPa. The most important design parameter is the ratio of the gas volumetric flow rate to fabric area, known as the *gas-to-cloth ratio*. Other important process variables include particle characteristics (such as size distribution and stickiness), gas characteristics (temperature and corrosivity), and fabric properties.

Electric utilities have made significant progress in recent years in designing and operating baghouses for the collection of coal fly ash. Interest in baghouses can be expected to continue increasing as air emission standards become more stringent and concerns over inhalable particles and air toxic emissions increase. In many cases, the relative insensitivity of baghouses to changes in fly ash properties make them more attractive than ESPs

The oldest fly-ash baghouse was commissioned in 1973. By 1990, there were close to 100 baghouses in operation on utility boilers, representing more than 21,000 MW of generating capacity (Cushing et al. 1990).

10.2 TYPES OF FABRIC FILTERS

Your objective in studying this section is to

Describe the operational characteristics of the three most common baghouse designs: (1) shaker; (2) reverse air; and (3) pulse jet.

The most important distinction between fabric filters designs is the method used to clean the dust from the bags between filtration cycles. The distinguishing features of each cleaning method are described subsequently, following Turner et al (1987a).

10.2.1 Shaker Cleaning

For any type of cleaning, enough energy must be imparted to the fabric to overcome the adhesion forces holding the dust to the bags. In shaker cleaning, used with inside-to-outside gas flow, this is accomplished by suspending the bag from a motor-driven hook or framework that oscillates. The motion creates a sine wave along the fabric, which dislodges the previously collected dust. Chunks of agglomerated dust fall into a hopper below the compartment. The compartments operate in sequence so that one compartment at a time is cleaned. Figure 10.1 is a schematic diagram of a shaker baghouse.

Parameters that affect cleaning include the amplitude and frequency of the shaking motion and the tension of the mounted bag. Typical values of the first two parameters are 4 Hz for frequency and 50 to 75 mm for amplitude. The vigorous oscillations tend to stress the bags and require heavier and more durable fabrics. In the United States, woven fabrics are used almost exclusively for shaker cleaning, whereas in Europe felted fabrics are used.

10.2.2 Reverse-Air Cleaning

When fiberglass fabrics were introduced, a gentler means of cleaning the bags was needed to prevent premature bag failure. Reverse-air cleaning was developed as a less intensive way to impart energy to the bags. Gas flow to the bags is stopped in the compartment being cleaned, and a reverse flow of air is directed through the bags. This reversal of flow gently collapses the bags and the shear forces developed remove the dust from the surface of the bags. The reverse air for cleaning comes from a separate fan capable of supplying clean, dry air for one or two compartments at a gas-to-cloth ratio similar to that of the forward gas flow.

Many reverse-air baghouses are installing sonic horns to improve the performance of the cleaning step. Sonic energy using horns during the reverse flow concentrates more cleaning energy at the bag-dust cake interface. The resulting reduction in residual dust cake density reduces the pressure drop by 50% to 60% (Carr and Smith 1984b). Sonic horns operate on compressed air at

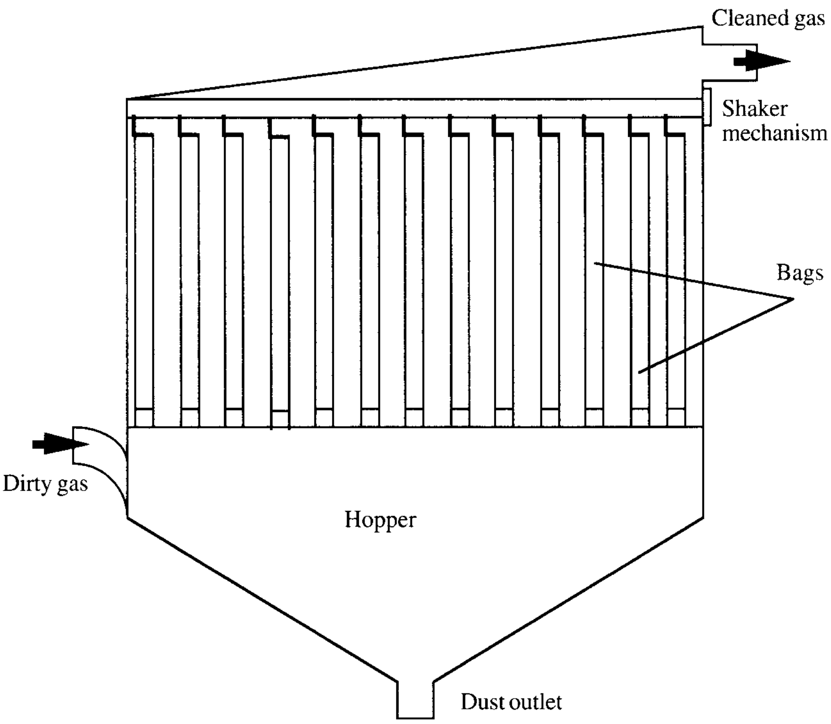

Figure 10.1 Schematic diagram of a shaker baghouse

pressures of about 400 to 900 kPa. It appears that reverse-air cleaning with sonic assistance is the cleaning method of choice for baghouses on pulverized coal-fired boilers (Cushing et al. 1990).

10.2.3 Pulse-Jet Cleaning

This form of cleaning forces a burst of compressed air down through the bag expanding it violently. As with shaker baghouses, the fabric reaches its extension limit and the dust separates from the bag. In pulse jets, however, filtering flows are opposite in direction when compared with shaker or reverse-air designs, with the outside-to-inside gas flow. Bags are mounted on wire cages to prevent collapse while the dusty gas flows through them. The top of the bag and cage assembly is attached to the baghouse structure, whereas the bottom end is loose and tends to move in the turbulent gas flow.

Most pulse-jet baghouses are not compartmented. Bags are cleaned by rows when a timer initiates the burst of cleaning air through a quick-opening valve. Usually 10% of the collector is pulsed at a time by zones. A pipe above each row of bags carries the compressed air. The pipe is pierced above each bag so that cleaning air exits directly downward into the bag. The pulse opposes and interrupts forward gas flow for only fractions of a second. However, the quick resumption of forward flow redeposits most of the dust back on the "clean" bag or on adjacent bags. Pulse jets normally operate at about twice the gas-to-cloth ratio of reverse-air baghouses.

10.3 FABRIC FILTRATION THEORY

Your objectives in studying this section are to

1. Describe, in qualitative terms, the mechanisms of particle penetration through a fabric filter.
2. Estimate the tubesheet pressure drop in baghouses.

The key to designing a baghouse is to determine the gas-to-cloth ratio that produces the optimum balance between pressure drop (operating cost) and baghouse size (capital cost). Although collection efficiency is another important measure of baghouse performance, properly designed and well-run baghouses are highly efficient

10.3.1 Penetration

Design overall efficiencies for fabric filters range from 98% to more than 99.9%. Most units currently in operation meet or exceed their design efficiencies (Cushing et al. 1990). Two basic mechanisms account for the particles that pass through the baghouse. Particles can escape collection through leaks in the ducting, tubesheet, or bag clamps, or through holes, tears, or improperly sewn seams in the bags themselves. The second mechanism for emissions is particle movement through the dustcake and the fabric, also known as *bleed-through*. Bleed-through is primarily a function of baghouse design and particle morphology. Smooth, spherical particles are less cohesive, and can seep through the dustcake and fabric easily, increasing emissions.

Well-developed equations exist in aerosol physics to calculate the fractional penetration of particles on various structures by filtration forces (Crawford 1976; Flagan and Seinfeld 1988). However, each requires detailed knowledge of the geometry of the collection medium. Because the structure of dust cakes is not defined—and, in fact, appears to be system dependent in ways that are now not understood—none can be used to predict fractional penetration.

Figure 10.2 shows actual baghouse penetration data reported by Ensor et al. (1981). Considering the dominant collection mechanisms, diffusion (which decreases with increasing particle size), and impaction and interception (which increase with particle size), the classic theoretical penetration curve exhibits a single maximum in the 0.1- to 0.3-μm range. Thus, additional mechanisms must act to create the bimodal curve of Figure 10.2. A reasonable explanation is to attribute the large-particle penetration mode to bleed-through (Carr and Smith 1984a).

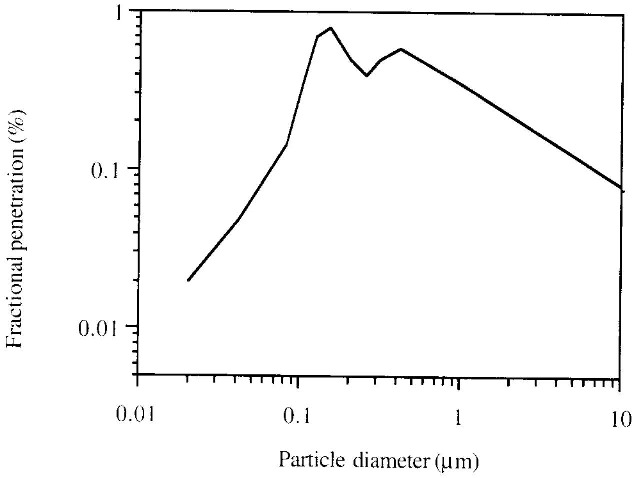

Figure 10.2 Measured baghouse fractional penetration (From Carr, R. C., and Smith, W. B. *JAPCA*, **34**:79, 1984; reprinted with permission from *JAPCA*)

Dennis and Klemm (1979) proposed the following semiempirical overall penetration equation based on the observations that penetration increased with increasing gas-to-cloth ratio and decreased as the dust cake on the fabric grew:

$$Pt = Pt_s + \left(Pt_0 - Pt_s\right)e^{-aW} + Pt_{bt} \tag{10.1}$$

where

Pt = overall penetration

Pt_s = low-level penetration due to pinholes in the cake-fabric structure; increases with the gas-to-cloth ratio

Pt_0 = penetration through a just-cleaned fabric area,

Pt_{bt} = penetration due to bleed-through; a function of particle morphology

W = dust mass per unit bag surface area, also known as areal density, kg/m^2

a = cake penetration decay rate

Viner et al. (1984) found that Eq. (10.1) overpredicts penetration just after a compartment has been cleaned; but, as the dust cake on the filter grows, the discrepancy between predicted and measured values diminishes. All the terms in Eq. (10.1) must be determined empirically for a given fabric-dust cake combination. The following example illustrates typical conditions in a reverse-air filter.

Example 10.1 Time Dependency of Penetration in Baghouse

The waste gases from a coal-fired boiler flow through a reverse-air baghouse for fly-ash removal. The following empirical equation for overall penetration as a function of operation time between cleaning cycles was developed:

$$Pt = 160V^{2.32} + \left[0.10 - 160V^{2.32}\right]\exp\left(-180C_i Vt\right) + \frac{5 \times 10^{-7}}{C_i}$$

where

V = gas-to-cloth ratio, m/s
C_i = inlet dust loading, kg/m3
t = operation time since last cleaning

The baghouse operates at an air-to-cloth ratio of 0.01 m/s and the inlet dust loading is 0.004 kg/m^3. Each compartment is cleaned every 20 min. Plot penetration as a function of time, and calculate the average overall penetration for the cycle.

Solution

Substituting the values of V and C_i in the penetration equation:

$$Pt = 0.0038 + 0.0963\exp\left(-0.432t'\right)$$

where t' is the time in minutes. Figure 10.3 shows the variation in penetration with time. Most of the particle emissions take place shortly after the bags are cleaned. To calculate the average penetration, integrate over a cycle and divide by the length of the cycle.

$$Pt_{av} = \frac{\int_0^{20}\left[0.0038 + 0.0963\exp\left(-0.432t'\right)\right]dt'}{20} = 0.0149$$

Vann Bush et al (1989) derived an expression to quantify the texture or surface morphology of bulk ash samples. Their morphology factor (M) is a dimensionless quantity based on volumetric size distribution data measured with a Coulter Counter (a device that measures particle size by a change in electrolytic resistivity), specific surface area (A), and the true density of the ash particles (ρ), and is defined as

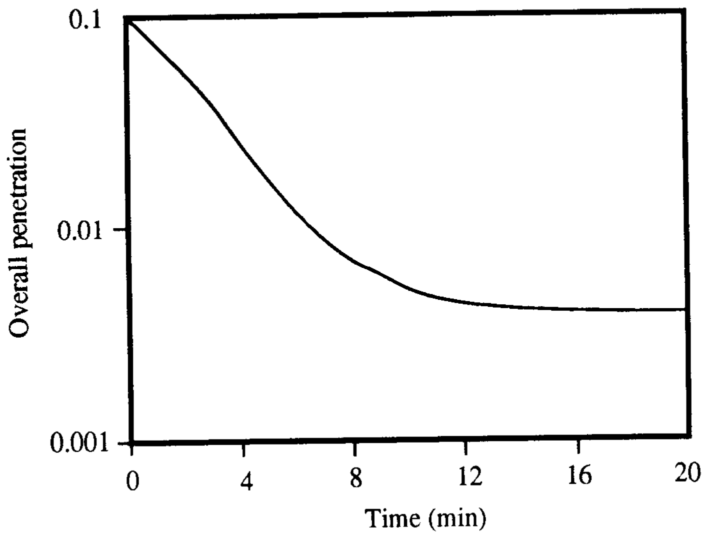

Figure 10.3 Penetration versus time in a reverse-air baghouse.

$$M = \frac{A\rho}{6} \exp\left[\frac{\sum_{i=1}^{N} n_i D_{pi}^3 \ln D_{pi}}{\sum_{i=1}^{N} n_i D_{pi}^3}\right] \tag{10.2}$$

where

n_i = the total number of particles counted in Coulter channel i

D_{pi} = the geometric mean diameter of Coulter channel i, μm

A low value of M indicates that the particles resemble smooth spheres, while a high value indicates that the particles have very irregular shapes and surfaces. For perfect spheres, M = 1.0. Field experience shows that ashes with low values of M (2.0 to 2.7) seep through the fabric, increasing emissions (Felix and Merritt 1986; Miller et al. 1985).

The mechanism of bleed-through is not well understood yet and there is no general theoretical model to predict its effect on particle penetration through baghouses. It is fortunate that fabric filters properly designed based on pressure drop considerations generally exhibit penetrations well below the applicable NSPS.

10.3.2 Pressure drop

There are several contributions to the total pressure drop across a baghouse including the pressure drop from the flow through the inlet and outlet ducts, from flow through the hopper regions, and from flow through the bags. The pressure drop across the bags (also called the *tubesheet pressure drop*) is a complex function of the physical properties of the dust and fabric and the manner in which the baghouse is designed and operated. The duct and hopper losses are constant and can be minimized effectively through proper design.

Fabric filtration is inherently a batch process that has been adapted to continuous operation through clever engineering. The dust collected on the bags must be removed periodically for continuous operation. Shaker and reverse-air designs are similar in the sense that they both normally use woven fabric bags run at relatively low gas-to-cloth ratios, and the filtration mechanism is cake filtration. The fabric merely serves as a support for the formation of a dust cake, which is the actual filtering medium. Pulse-jet baghouses generally use felt fabrics and run with a high gas-to-cloth ratio. The felt fabric plays a much more active role in the filtration process. The distinction between cake filtration and fabric filtration has important implications for calculating the pressure drop across the filter bags.

The design of a fabric filter begins with a set of specifications including average and maximum pressure drop, total gas flow, and other requirements. Based on these requirements, the designer specifies the maximum face velocity allowed. The standard way to relate tubesheet pressure drop to gas-to-cloth ratio is

$$\Delta P(t) = S(t)V \tag{10.3}$$

where

$\Delta P(t)$ = the pressure drop through the filter, a function of time, t
$S(t)$ = the drag through the fabric and cake, Pa-s/m
V = the average or design gas-to-cloth ratio, m/s

The drag across the fabric and cake is a function of the amount of dust collected on the surface of the bags. Assuming that the filter drag is a linear function of the dust load,

$$S(t) = S_e + K_2 W(t) \tag{10.4}$$

where

S_e = the drag of a dust-free (freshly cleaned) filter bag
K_2 = the dust cake flow resistance, s^{-1}

The dust mass as a function of time is $W = C_i V t$, where C_i is the inlet dust concentration (kg/m^3). Substituting this expression in Eqs. (10.3) and (10.4):

$$\Delta P(t) = S_e V + K_2 C_i V^2 t \tag{10.5}$$

The constants S_e and K_2 depend on the fabric and the nature and size of the dust. The relationship between these constants and the dust and fabric properties are not understood well enough to permit accurate predictions and so must be determined empirically.

Example 10.2 Estimation of Parameters in Filter Drag Model

(a) Estimate the parameters in Eq. (10.4) based on the following data for a freshly cleaned fabric. The gas-to-cloth ratio is 0.0167 m/s and the inlet dust concentration is 0.005 kg/m^3.
(b) Estimate the pressure drop for the same conditions after 70 min of continuous operation.

Test Data

Time (min)	ΔP (Pa)
0	150
5	380
10	505
20	610
30	690
60	990

Solution

(a) Based on the test data, generate a plot of filter drag versus areal density. The following table illustrates the data to be plotted.

$S = \Delta P/V$ (kPa-s/m)	$W = C_i V t$ (kg/m^2)
9.00	0
22.80	0.025
30.30	0.050
36.60	0.100
41.40	0.150
59.40	0.030

Figure 10.4 shows an initial characteristic curvature followed by a linear dependency of filter drag on areal dust density. The nonlinear portion of the curve is due to a non-uniform initial flow through the fabric. The previous cleaning cycle usually dislodges the cake in

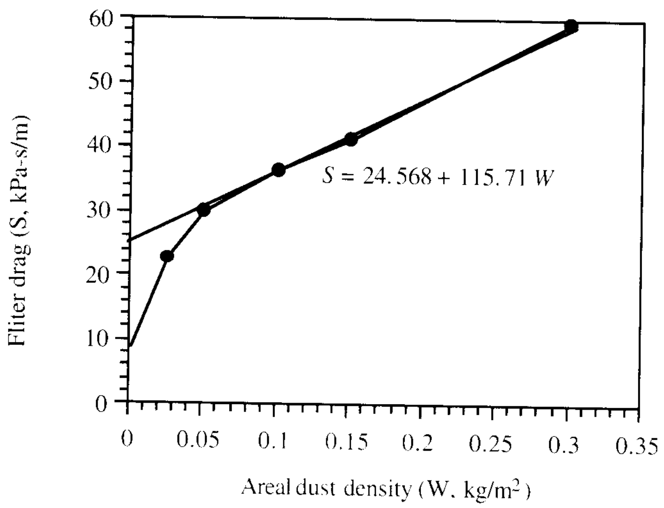

Figure 10.4 Filter drag versus dust areal density for Example 10.2

irregular chunks, leaving some parts of the bag very clean and others still quite dusty, resulting in spatial variations in the initial gas flow. A least-squares fit of the linear portion of the curve yields: S_e = 24.57 kPa-s/m, and K_2 = 115.7 kPa-s-m/kg = 1.16×10^5 s^{-1}.
(b) Equation (10.5) gives the pressure drop after 70 min of continuous operation: ΔP = 24,570(0.0167) + $(1.16 \times 10^5)(0.005)(0.0167)^2(70)(60)$ = 1,090 Pa.

Example 10.3 Cycle time for Reverse-Air Fabric Filter.

A reverse-air fabric filter has 1,000 m^2 of filtering area and treats 10 m^3/s of air carrying a dust concentration of 0.005 kg/m^3. Assume S_e = 20.0 kPa-s/m and $K_2 = 1.0 \times 10^5$ s^{-1}. If the filter must be cleaned when the pressure drop reaches 2.0 kPa, after what period must the cleaning occur?

Solution

The gas-to-cloth ratio is V = 10/1,000 = 0.01 m/s. Solving Eq. (10.5) for the time of operation before the pressure drop exceeds 2,000 Pa, t = [2,000 – (20,000)(0.01)]/[$(10^5)(0.005)(0.01)^2$] = 36,000 s = 10 h.

Pulse-jet baghouses have been designed to operate in a variety of modes. Some remain on line at all times and are cleaned frequently. Others are taken off line for cleaning at relatively long intervals. A complete model of pulse-jet filtration therefore must account for the composite dust-fabric filtration occurring on a relatively clean bag, the cake filtration that result from prolonged periods on line, and the transition period between the two regimes.

If a compartment is taken off line for cleaning, the dust that is removed from the bags falls into the hopper before forward gas flow resumes. If a compartment is cleaned while on line, only a small fraction of the dust removed from the bag falls to the hopper. The remainder of the dislodged dust will be redeposited (i.e., "recycled") on the bag by the forward gas flow. The redeposited dust layer has different pressure drop characteristics than the freshly deposited dust. Dennis and Klemm (1979) proposed the following model of drag across a pulse-jet filter:

$$S = S_e + (K_2)_c W_c + K_2 W_0 \tag{10.6}$$

where

$(K_2)_c$ = specific dust resistance of the recycling dust

W_c = areal density of the recycling dust

K_2 = specific dust resistance of the freshly deposited dust

W_0 = areal density of the freshly deposited dust

This model can easily account for all three regimes of filtration in a pulse-jet baghouse.The pressure drop can thus be expressed as the sum of a relatively constant term and a term that increases with dust buildup.

$$\Delta P = (PE)_{\Delta w} + K_2 W_0 V \tag{10.7}$$

where

$$(PE)_{\Delta w} = \left[S_e + (K_2)_c W_c\right] V \tag{10.8}$$

The disadvantage of the model represented by Eqs. (10.7) and (10.8) is that the constants S_e, K_2, and W_c cannot be predicted at this time. Consequently, correlations of laboratory data must be used to determine the value of $(PE)_{\Delta w}$. For one fabric-dust combination of Dacron felt and coal fly ash, Dennis and Klemm (1980) developed the following correlation:

$$(PE)_{\Delta w} = 1{,}045\, V P_j^{-0.65} \tag{10.9}$$

where

$(PE)_{\Delta w}$ is in kPa

P_j = gauge pressure of the cleaning pulse, in kPa

V = gas-to-cloth ratio, in m/s

Example 10.4 Tubesheet Pressure Drop in Pulse-Jet Baghouse

A pulse-jet baghouse uses Dacron felt bags for the control of fly-ash emissions. The gas-to-cloth ratio is 0.024 m/s and the inlet dust loading is 0.01 kg/m^3. The bags are cleaned at 10-min intervals with pulses of air at 650 kPa gauge. If $K_2 = 1.5 \times 10^5$ s^{-1}, estimate the maximum tubesheet pressure drop.

Solution

The conditions are similar to those for which Eq. (10.9) was developed. Then, $(PE)_{\Delta W}$ = $(1{,}045)(0.024)(650)^{-0.65} = 0.372$ kPa. At the end of the 10-min cycle, $W_0 = (0.01)(0.024)(600) = 0.144$ kg/m^2. Equation (10.7) gives the tubesheet pressure drop: $\Delta P = 0.372 + (1.5 \times 10^5)(0.144)(0.024)/1{,}000 = 0.89$ kPa.

Example 10.5 Effect of Filter Inhomogeneities on Filter Drag Model (Cooper and Riff 1983)

Knowing the mean of a property, such as dust areal density, may be misleading for predicting the effect of that property. When estimating the specific dust resistance for a filter cake (K_2) from pressure drop data, Eq. (10.7) predicts that $K_2 \propto W^{-1}$. However, in a typical baghouse the areal density is not homogeneous, but changes from bag to bag. For example, Ellenbecker (1979) measured areal densities in a pulse-jet baghouse and found that the data could be fitted by a log-normal distribution with a median of 0.64 kg/m^2 and a geometric standard deviation, σ_g, of 1.15.

In the presence of inhomogeneities, the average value of W should be used for estimating K_2. The proper average to use is the *harmonic mean*, not the arithmetic mean. For a log-normal distribution, the ratio of the harmonic to the reciprocal of the arithmetic mean is

$$\frac{\overline{W^{-1}}}{\overline{W}^{-1}} = \exp\left(\ln^2 \sigma_g\right) \qquad (10.10)$$

where the harmonic average for a log-normal distribution is:

$$\overline{W^{-1}} = W_{50} \exp\left(-0.5 \ln^2 \sigma_g\right)^{-1} \qquad (10.11)$$

where W_{50} is the median.
(a) For Ellenbecker's data, estimate the error introduced in the estimation of K_2 if the arithmetic average of W is used instead of the harmonic average.
(b) Repeat part a for a geometric standard deviation of 2.0.

Solution

(a) Substituting $\sigma_g = 1.15$ in Eq. (10.10), $\overline{W^{-1}} / \overline{W}^{-1} = 1.02$. Therefore, using the arithmetic mean introduces an error of 2% in the estimation of K_2.

(b) For $\sigma_g = 2.0$, $\overline{W^{-1}} / \overline{W}^{-1} = 1.62$, therefore the error is 62%.

10.4 PRACTICAL DESIGN CONSIDERATIONS

Your objectives in studying this section are to

1. Choose a proper filter material for a given baghouse application.
2. Estimate a design gas-to-cloth ratio based on published data.
3. Estimate the net and gross cloth area required.
4. Appraise the potential of a waste heat boiler as a precooler.

10.4.1 Design gas-to-cloth ratio

The design gas-to-cloth ratio is difficult to estimate from theoretical principles. However, shortcut methods of varying complexity allow rapid estimation. One such method is to use gas-to-cloth ratio data available in the literature for similar applications. After a cleaning method and fabric type has been selected, the gas-to-cloth ratio can be estimated from Table 10.1.

Example 10.6 Net Cloth Area of Pulse-Jet Baghouse

A baghouse is required for controlling fly-ash emissions from a coal-fired boiler. The flue gas stream is 23.6 m3/s at 435 K. Estimate the net cloth area of a pulse-jet/Teflon felt baghouse for this application.

Table 1

Dust
Alumina
Asbestos
Cocoa, ch
Cement
Coal
Enamel fr
Feeds, gra
Fertilizer
Flour
Fly ash
Graphite
Gypsum
Iron ore
Iron oxide
Iron sulfa
Leather d
Lime
Limestone
Paint pigm
Paper
Rock dust
Sand
Sawdust
Silica
Soap, dete
Starch
Sugar
Talc
Tobacco
Zinc oxide

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Table 10.1 Gas-to-Cloth Ratios[a] (cm/s)

Dust	Shaker/Woven Reverse-Air/Woven	Pulse-Jet/Felt
Alumina	1.27	4.07
Asbestos	1.52	5.08
Cocoa, chocolate	1.42	6.10
Cement	1.02	4.07
Coal	1.27	4.07
Enamel frit	1.27	4.57
Feeds, grain	1.78	7.11
Fertilizer	1.52	4.07
Flour	1.52	6.10
Fly ash	1.02	2.54
Graphite	1.02	2.54
Gypsum	1.02	5.08
Iron ore	1.52	5.59
Iron oxide	1.27	3.56
Iron sulfate	1.02	3.05
Leather dust	1.78	6.10
Lime	1.27	5.08
Limestone	1.37	4.07
Paint pigments	1.27	3.56
Paper	1.78	5.08
Rock dust	1.52	4.57
Sand	1.27	5.08
Sawdust	1.78	6.10
Silica	1.27	3.56
Soap, detergents	1.02	2.54
Starch	1.52	4.07
Sugar	1.02	3.56
Talc	1.27	5.08
Tobacco	1.78	6.61
Zinc oxide	1.02	2.54

a Generally safe design values. Source: From Turner J. H. et al. JAPCA, 37:749 (1987). Reprinted with permission from JAPCA.

Solution

Table 10.1 gives $V = Q/A_c = 2.54$ cm/s for filtration of fly-ash in pulse-jet filters. Then, the net cloth area is $A_c = (23.6)/(0.0254) = 930$ m2.

For continuously operated shaker and reverse-gas cleaned filters, the area must be increased to allow for shutting down of one or more compartments for cleaning and maintenance. A typical compartment uses bags 0.3 m in diameter and 10.7 m long, with the number of bags per compartment ranging from 40 to 648. Table 10.2 provides a guide for adjusting the net area to the gross area for these two types of baghouses. Because pulse-jet filters are cleaned on line, no additional filtration area is required, and the net and gross cloth areas are equal.

Table 10.2 Guide to Estimate Shaker And Reverse-Air Baghouse Gross Cloth Area

Net Cloth Area (m^2)	Multiply Net Area by
1–370	2
371–1,115	1.5
1,116–2,230	1.25
2,231–3,350	1.17
3,351–4,460	1.125
4,461–5,580	1.11
5,581–6690	1.10
6691–7,810	1.09
7,811–8,920	1.08
8921–10,040	1.07
10,041–12,270	1.06
12,271–16,730	1.05
> 16,730	1.04

Source: From Turner J. H. et al. *JAPCA*, **37**:749 (1987). Reprinted with permission from *JAPCA*.

Example 10.7 Gross Cloth Area of Reverse-Air Baghouse

Estimate the gross cloth area required for the conditions of Example 10.6 if a reverse-air baghouse is specified.

Solution

Table 10.1 gives $V = 1.02$ cm/s for fly-ash filtration in reverse-air baghouses. Then, the net cloth area required is $A_c = (23.6)/(0.0102) = 2{,}314$ m^2. From Table 10.2, the gross cloth area is $(2{,}314)(1.17) = 2{,}710$ m^2.

Comment

Notice that the reverse-air baghouse requires almost three times as much area as the pulse-jet to process the same flue gas flow rate.

10.4.2 Filter media

The type of filter material used in baghouses depends on the specific application in terms of chemical composition of the gas, operating temperature, dust loading, and the physical and chemical characteristics of the particulate. A variety of fabrics, either felted or woven (sometimes knit), is available. The selection of a specific material, weave, finish, or weight is based primarily on past experience. For some difficult applications, Gore-Tex, a polytetrafluoroethylene (PTFE) membrane laminated to a substrate fabric (felt or woven) may be used. Because of the violent action of mechanical shakers, spun or heavy weight staple yarn fabrics are commonly used with this type of cleaning. Lighter-weight filament yarn fabrics are used with reverse-air cleaning.

The type of material will limit the maximum operating gas temperature for the baghouse. Cotton fabric is among the least resistant to high temperatures (about 355 K) while fiberglass is the most resistant (about 530 K). Table 10.3 gives the maximum temperature limits of the leading fabric materials.

Example 10.8 Fabric Filter for Open-Hearth Steel Plant (Licht 1980).

The flue gases from an open-hearth steel plant flow at the rate of 110 m^3/s at 1,000 K and 101.3 kPa with an iron oxides particulate loading of 0.0026 kg/m^3. The water content of the gases is 8%. Design a fabric filter system to reduce the particulate loading of the flue gases to the corresponding NSPS.

Solution

The NSPS for particulate emissions from steel plants is 50 mg/dscm (see Table 1.3). To calculate the overall removal efficiency required, correct the actual particulate loading to dry, standard conditions: $(2{,}600)(1{,}000)/[(0.92)(273)] = 10{,}352$ mg/dscm. The overall efficiency

Table 10.3 Properties of Leading Baghouse Fabric Materials

Fabric	Temp.[a] (K)	Acid resistance	Base resistance
Cotton	355	Poor	Very good
Creslan[b]	395	Good	Very good
Dacron[c]	410	Good	Very good
Dynel[c]	345	Excellent	Fair
Fiberglas[d]	530	Fair-good	Fair-good
Filtron[e]	405	Excellent	Very good
Gore-Tex[f]	Depends on backing	Depends on backing	Depends on backing
Nomex[c]	465	Fair	Excellent
Nylon[c]	365	Fair	Excellent
Orlon[c]	400	Excellent	Fair-good
Polypropylene	365	Excellent	Excellent
Teflon[c]	505	Excellent	Excellent
Wool	365	Very good	Poor

[a] Maximum continuous operating temperature.
[b] American Cyanamid registered trademark.
[c] Du Pont registered trademark.
[d] Owens-Corning Fiberglass registered trademark.
[e] W. W. Criswell Division of Wheelabrator-Fry Inc.
[f] W. L. Gore and Co. registered trademark.
Source: From Turner J. H. et al. *JAPCA,* **37**:749 (1987). Reprinted with permission from *JAPCA.*

is $\eta_M = (10{,}352 - 50)/10{,}352 = 0.9952$ (99.52%). This efficiency is within the limits achievable by a properly designed fabric filter. However, the temperature of the gases is well above the operating limits of available fabric materials. A precooling system is required, but a fabric to operate as hot as possible should be sought.

Table 10.3 shows that fiberglass bags can operate continuously at temperatures up to 530 K. Previous experience shows that fiberglass filters can remove iron oxides dust with efficiencies higher than 99.6% in sonic-assisted, reverse-air baghouses at an air-to-cloth ratio of 1.27 cm/s (Licht 1980). Choose fiberglass bags at an operating temperature of 530 K.

There are, basically, three alternatives for cooling the gases to 530 K: (1) dilution with ambient air; (2) evaporation of a water spray into the gas ; and (3) cooling in a waste heat boiler. Dilution with ambient air will more than triple the filter area required, while evaporative cooling will increase it by about 30% (see Problem 10.10). They both waste the precious thermal energy contained in the gases. A waste heat boiler recovers close to 50% of that energy with no penalty in terms of filtering area required. Figure 10.5 is a schematic diagram of the proposed system.

Assume that the waste gases behave like air (ρ = 0.3524 kg/m^3, C_p = 1.08 kJ/kg-K) and calculate the enthalpy change they experience in going from 1,000 K to 530 K: ΔH_g = (110)(0.3524)(1.08)(530 − 1,000) = −19,677 kJ. The enthalpy change of 1 kg of liquid water at 298 K that is converted to saturated steam at 445 K (830 kPa) is 2,665.4 kJ. Assuming 10% energy losses, the amount of steam produced in the waste heat boiler is (0.9)(19,677) /(2,665.4) = 6.64 kg/s or 23,900 kg/h. To estimate the heat-transfer area, calculate the logarithmic mean temperature difference: LMTD = [(1,000 − 445) − (530 − 298)]/ln (555/232) = 370 K. Assume that the overall heat-transfer coefficient is 300 W/m^2-K. The heat-transfer area is (19,677)/[(0.3)(370)] = 177 m^2.

The gas flow rate entering the baghouse is (110)(530/1,000) = 58.3 m^3/s; the dust loading is (0.0026)(110/58.3) = 0.005 kg/m^3. For a gas-to-cloth ratio of 1.27 cm/s, the net cloth area is 58.3/0.0127 = 4,590 m^2. From Table 10.2, the gross cloth area is (1.11)(4,590) = 5,100 m^2. A reasonable design might use 10 compartments, with 50 bags per compartment each 0.3 m diameter and 10.7 m long.

The length of the filtration time depends on the maximum allowable pressure drop through the fabric-dustcake. Assume that, for this case, the maximum is 2.5 kPa For iron oxides dust on fiberglass, the parameters on the filter drag model— Eq. (10.5)—are S_e = 142 kPa-s/m and K_2 = 1.21 × 10^6 s^{-1} (Licht 1980). Then, 2.5 = (142)(0.0127) + (1.21 × 10^6)(0.005)(0.0127)^{2}t /1,000. Solving, t = 713 s = 12 minutes.

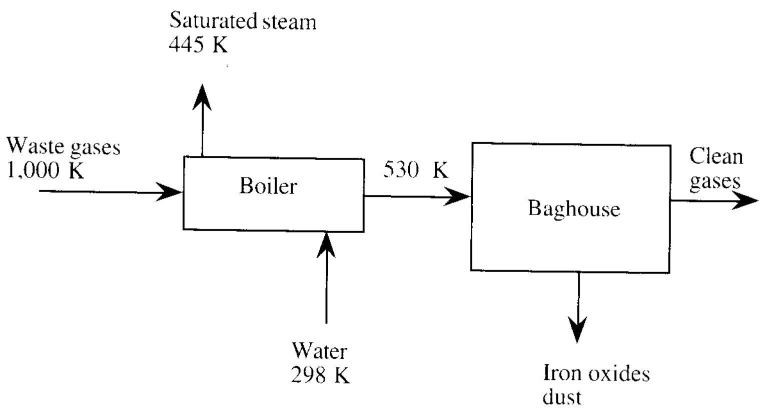

Figure 10.5 Waste-heat boiler of Example 10.8

10.5 COSTS OF FABRIC FILTRATION

Your objectives in studying this section are to

1. Estimate the equipment cost of the most common baghouse types.
2. Estimate the corresponding TCI.
3. Estimate the TAC associated with fabric filtration.

The annualized cost of owning and operating a baghouse can be very high. The capital cost for a fabric filter system can be estimated based on the gross cloth area. The cost also depends on the type of baghouse, whether it is made of stainless or mild steel, and whether or not it is insulated. Furthermore, standardized modular baghouses are less expensive than custom-built units.

10.5.1 Equipment Cost

Baghouse equipment costs consist of two components: the baghouse unit and the bags. Both costs are functions of the gross cloth area, Ac. The baghouse unit cost is, in turn, comprised of the basic baghouse cost and the costs of "add-ons" for stainless steel and insulation. The prices for the basic unit or add-ons are linear functions of the gross cloth area (Vatavuk 1990),

$$EC = a + bA_c \qquad (10.12)$$

where a and b are regression constants listed in Table 10.4. Notice that the parameters in Table 10.4 apply only to certain gross cloth area ranges.

Table 10.5 gives selected bag prices (in $/m^2) for pulse-jet, shaker, and reverse-air baghouses. The pulse-jet bag prices in Table 10.5 do not include the prices of protective cages. Mild steel cages will add approximately $13/m^2 of filter area (June 1990 dollars). Stainless steel cages will cost about $32/m^2.

Example 10.9 Equipment Cost of Reverse-Air Baghouse

Estimate the cost of the reverse-air baghouse of Example 10.8. The baghouse shell material can be mild steel. Insulation is required. The bags should be 0.3-m diameter with sewn-in snap rings.

Table 10.4 Parameters for Fabric Filter Equipment Costs[a]

Baghouse Type	Area Range m²	Component	*a*	*b*
Shaker—intermittent	370–1,500	Basic unit	4,120	84.6
		Stainless steel	14,000	42.9
		Insulation	2,200	5.7
Shaker—continuous	370–5,600	Basic unit	43,800	93.8
		Stainless steel	29,700	61.1
		Insulation	0	4.21
Pulse-jet—common-housing	370–1,500	Basic unit	11,280	69.8
		Stainless steel	12,700	59.1
		Insulation	1,670	11.7
Pulse-jet—modular	370–1,500	Basic unit	55,140	92.0
		Stainless steel	29,300	87.7
		Insulation	3,500	26.1
Reverse-air	930-7,500	Basic unit	34,200	88.0
		Stainless steel	16,500	68.5
		Insulation	1,320	10.0
Custom-built—all types	9,300-37,200	Basic unit	263,000	69.3
		Stainless steel	108,400	28.7
		Insulation	70,200	8.0

[a] Prices updated to June 1990. Source: From Turner J. H. et al. *JAPCA*, **37**:1105 (1987). Reprinted with permission from *JAPCA*.

Solution

For a reverse-air baghouse with 930 $<A_c<$ 7,500 m², Table 10.4 gives the following equipment costs:

Basic unit: 34,200 + (88)(5,100) = $483,000

Insulation add-on: 1,320 + (10)(5,100) = $52,320

For 0.3-m diameter Fiberglass bags with rings, Table 10.5 gives

Bags cost: (12.2)(5,100) = $62,220

Table 10.5 Selected Bag Prices ($ in June 1990/m²)

	Pulse Jet		Shaker		Reverse Air	
Material[a]	TR[b]	BBR[c]	Strap[d]	Loop[e]	w/Rings[f]	w/o Rings
PE	5.4–7.3	4.0–4.6	5.6	5.4	5.7–5.8	4.0
PP	5.5–7.5	4.1–4.9	5.9	5.6	NA[g]	NA
NO	19.2–23.1	14.6–16.9	15.7	14.5	20.7–21.2	14.3–14.8
FG	13.3–15.9	11.7–15.3	NA	NA	9.3–12.2	6.5–8.5
TF	83.8–111	82.7–108	NA	NA	NA	NA
CO	NA	NA	5.5	4.8	NA	NA

[a] Materials: PE = polyester; PP = polypropylene; NO = Nomex; FG = Fiberglass with 10% Teflon; TF = Teflon felt; CO = cotton. [b,c] Bag removal method: TR = top bag removal; BBR = bottom bag removal. [d,e] Bag top design. [f] Prices are given for bags with and without sewn-in snap rings. [g] Not applicable. Ranges shown reflect different bag diameters. Pulse-jet bag diameters: 0.1–0.2 m; reverse air: 0.2–0.3 m; shaker: 0.13 m. Source: From Turner J. H. et al. *JAPCA*, **37**:1105 (1987). Reprinted with permission from *JAPCA*.

Example 10.9 Continuation

The equipment cost is EC = 483,000 + 52,320 + 62,220 = $598,000 in June 1990.

Example 10.10 Cost of Pulse-Jet Baghouse for Municipal Solid Waste (MSW) Incinerator

The air pollution control system of a MSW incinerator consists of a spray dryer followed by a pulse-jet fabric filter (Frame 1988). The flue gas entering the baghouse flows at the rate of 35 m^3/s at 500 K and 1 atm and contains significant amounts of HCl. A design gas-to-cloth ratio of 0.025 m/s is specified when using Teflon felt bags, which are extremely resistant to the harsh environment prevailing in the baghouse. Estimate the fabric filter equipment cost.

Solution

The net filtration area is (35)/(0.025) = 1,400 m^2. Assuming that the cleaning is done on-line, the gross filtration area is also 1,400 m^2 and a common housing design is appropriate. Because of the corrosive conditions and high temperature, stainless steel construction and insulation are required. The diameter of the bags is 0.1 m, and they are of the top removal type. Stainless steel cages are also required. The following table summarizes the disbursements that comprise the equipment cost for this system.

Item	Cost ($ in June 1990)
Basic unit	108,580
Stainless steel add-on	95,440
Insulation add-on	18,050
Teflon felt bags	117,320
Stainless steel cages	44,800
Equipment cost	384,190

10.5.2 TCI

The total capital investment is estimated from a series of factors applied to the purchased equipment cost to obtain direct and indirect costs of installation. The TCI is the sum of these three costs. Table 10.6 gives the required factors.

Example 10.11 TCI for Reverse-Air Baghouse

Estimate the total capital investment for the baghouse of Examples 10.8 and 10.9. Assume that no special site preparation or buildings are needed. The cost of auxiliary equipment, excluding the waste heat boiler, is $150,000.

Solution

From Example 10.9, the equipment cost for the baghouse—including the bags—is $598,000. The cost of the waste heat boiler to produce 23,900 kg/h of steam saturated at 445 K (830 kPa) must be estimated. Based on data published by Peters and Timmerhaus (1991), the cost of the boiler for steam pressures up to 1,800 kPa can be estimated from:

Table 10.6 Capital Cost Factors for Fabric Filters.

Costs	Factor
Direct costs	
Purchased equipment cost	
Fabric filter, plus bags, plus auxiliary equipment	A
Instruments and controls	$0.10\,A$
Taxes and freight	$0.08\,A$
Total purchased equipment cost (B)	$1.18\,A$
Installation direct costs	$0.72\,B$ + SP[a] + Bldg[b]
Total direct costs	$1.72\,B$ + SP + Bldg
Indirect costs	$0.45\,B$
Total capital investment	$2.17\,B$ + SP + Bldg

[a] SP = site preparation.. [b] Bldg = buildings. Source: From Turner J. H. et al. *JAPCA*, **37**:1105 (1987). Reprinted with permission from *JAPCA*.

$$EC = 40(\dot{m})^{0.84} \qquad 1{,}400 < \dot{m},\ kg/h < 180{,}000 \tag{10.13}$$

where

EC = cost of the boiler, in June 1990
$\dot{m}$ = rate of steam generation, kg/h

The cost calculated with Eq. (10.13) is for a complete package boiler plant, which includes feed-water deaerator, boiler feed pumps, chemical injection system, and stack. For a rate of steam production of 23,900 kg/h, Eq. (10.13) gives a boiler cost of \$190,500. From Table 10.6, A = 598,000 + 190,500 + 150,000 = \$938,500. The purchased equipment cost is B = 1.18 A = \$1,107,400. TCI = 2.17 B = \$2,403,000 (in June 1990).

10.5.3 TAC

Direct annual costs include operating and supervisory labor, replacement bags, maintenance labor and materials, utilities, and dust disposal. Indirect annual costs include capital recovery, property tax, insurance, administrative costs, and overhead.

Typical operating labor requirements are 2 to 4 h per shift for a wide range of filter sizes. Supervisory labor is taken as 15% of operating labor. Maintenance labor varies from 1 to 2 h per shift. Maintenance materials costs are assumed to be equal to maintenance labor costs (Vatavuk and Neveril 1980). The major replacement part items are filter bags, which have a typical operating life of 2 yr. The bag replacement labor is approximately \$2.00/m^2 of bag area (Turner et al. 1987b).

Electric power is required to operate system fans and cleaning equipment. The pressure drop through the system is the sum of the pressure drop through the baghouse structure and ductwork and the tubesheet pressure drop. The contribution of the baghouse structure and ductwork is approximately 2 kPa. The tubesheet pressure drop is estimated with Eq. (10.3) when the filter drag coefficients are known. Cleaning energy for reverse-air systems can be calculated from the number of compartments to be cleaned at one time (usually one, sometimes two), and the reverse gas-to-cloth ratio (from one to two times the forward gas-to-cloth ratio). Reverse-air pressure drop is about 1.7 kPa. The reverse-air fan generally runs continuously. Typical energy consumption for a shaker cleaning system can be estimated from (Turner et al. 1984b):

$$W_s = 6.5 \times 10^{-5} A_c \tag{10.14}$$

where

W_s = power, in kW

A_c = gross cloth area, in m^2

Cooling process gases to acceptable temperatures by water evaporation or in a waste heat boiler require plant water. Pulse-jet filters use compressed air at pressures of about 500 to 800 kPa. Typical consumption is about 2 standard m^3/1,000 actual m^3. If the collected dust can not be recycled or sold, the costs for final disposal must be included. Disposal costs are site specific, but they are typically about \$30 to \$50/metric ton including transportation.

Capital recovery costs are based on the total depreciable investment less the cost of replacing the bags. The lifetime of the fabric filter system is typically 20 yr. Property taxes, insurance, and administrative charges are about 4% of the TCI. The overhead is calculated as 60% of the sum of all labor and the maintenance materials.

Example 10.12 TAC for Reverse-Air Baghouse

Estimate the TAC for the baghouse of Example 10.11. The system operates 8,640 h/yr. The operating labor rate is \$12/h, the maintenance labor rate is \$15/h. The cost of electricity is \$0.06/kW-h, process water costs \$0.26/metric ton. The dust recovered can be returned to the process at no additional cost. The recovery credit for the waste-heat steam is \$2/metric ton. The pressure drop through the waste heat boiler is 2 kPa. The minimum attractive rate of return is 12%/yr; the system lifetime is 20 years. The mechanical efficiency of the fans is 65%.

Solution

Table 10.7 gives the direct and indirect annual costs as calculated from factors given previously. To calculate the annualized cost of replacing the bags, the total cost of replacement, including labor, taxes, and freight must be estimated. The cost of purchasing the bags is multiplied by a factor of 1.08 to account for taxes and freight. The cost of replacement labor is estimated at a rate of $2/m^2 of filtering area. The capital recovery factor for a 2-yr lifetime and $i = 0.12$/yr is 0.592.

To calculate the electricity cost to operate the main fan, the total pressure drop through the system must be estimated. From Example 10.8, the maximum tubesheet pressure drop is 2.5 kPa. The total pressure drop including the waste heat boiler, is 6.5 kPa. Assuming that the fan is located at the entrance of the baghouse, the gas flow rate through the fan is 58.3 m^3/s. Therefore, the power to operate it is (58.3)(6.5)/(0.65) = 583 kW. A reverse-air fan will operate continuously to clean one (out of 10) compartment at a time. The reverse gas-to-cloth ratio is equal to the forward gas-to-cloth ratio: 0.0127 m/s. The reverse air flow is (5,100)(0.1)(0.0127) = 6.48 m^3/s. The corresponding pressure drop is 1.7 kPa, therefore, the power to operate the reverse-air fan is (6.48)(1.7)/(0.65) = 17 kW.

The capital recovery factor (0.134) for the depreciable investment corresponds to a lifetime of 20 yr and a minimum attractive rate of return of 12 %/yr. As usual when calculating the capital recovery cost, the total cost of replacing the bags is subtracted from the total depreciable investment to avoid double accounting. Because the recovered dust can be returned to the process at no additional cost, there is no cost associated with final disposition of the solid residue. There is a substantial recovery credit for the waste heat steam, which helps to partially offset the annual costs. The total annual cost for the system is $504,800. The total amount of particulate removed is (0.0026)(110)(3,600) (8,640)/(1,000) = 8,900 metric ton/yr. Therefore, the cost effectiveness of the system is $56.7/metric ton of dust collected.

10.6 CONCLUSION

Fabric filtration is rapidly becoming an accepted and frequently preferred particulate matter control technology. Interest in baghouses will continue increasing as air emissions standards become more stringent and concerns over fine particulates increase. They are gaining acceptance for use downstream of dry FGD systems and fluidized bed boilers. The baghouse provides additional SO_2 removal, and particulate collection is not affected by the high alkali content of the products of dry SO_2 removal. The relative insensitivity of fabric filters to variations in dust electric resistivity makes them more attractive than ESPs in many applications. *Electrically enhanced fabric filters,* an emerging technology, operate at higher gas-to-cloth ratios than conventional baghouses, and at greatly reduced pressure drops.

Table 10.7 Annual Costs for the Fabric Filter of Example 10.12

DAC	
Operating labor: 6 × 360 × \$12 =	\$25,900
Supervisory labor: 0.15 × 25,900 =	3,900
Maintenance	
Labor: 3 × 360 × \$15 =	16,200
Materials	16,200
Replacement parts, bags: (\$62,200 × 1.08 + \$2 × 5,100) × 0.592 =	45,810
Utilities	
Electricity: (583 + 17) × 8,640 × \$0.06 =	311,000
Process water for boiler: 23.9 × 8,640 × \$0.26 =	53,700
Total DAC	\$472,700
IAC	
Overhead: (25,900 + 3,900 + 2 × 16,200) × 0.60 =	37,300
Property tax, insurance, administration: 0.04 × \$2,403,000 =	96,120
Capital recovery cost	
(\$2,403,000 − \$2 × 5,100 − \$62,200 × 1.08) × 0.134 =	311,640
Total IAC	\$445,100
Recovery credit for waste heat steam: 23.9 × 8,640 × \$2 =	\$413,000
TAC	\$504,800

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PROBLEMS

The problems at the end of each chapter have been grouped into four classes (designated by a superscript after the problem number)

Class a: Illustrates direct numerical application of the formulas in the text.
Class b: Requires elementary analysis of physical situations, based on the subject material in the chapter.
Class c: Requires somewhat more mature analysis.
Class d: Requires computer solution.

10.1^a. Effect of the gas-to-cloth ratio on penetration

If the gas-to-cloth ratio of Example 10.1 increases to 0.015 m/s, calculate the average overall penetration for a 20-min cycle.

Answer: 1.65%

10.2^b. Effect of operation cycle length on penetration

Determine the operation cycle length that reduces the average overall penetration of Example 10.1 to 1.0%.

Answer: 36 min

10.3^c. Penetration and pressure drop through a fabric filter

The filter drag parameters for the fly-ash and fabric combination of Example 10.1 are $S_e = 100$ kPa-s/m and $K_2 = 10^6$ s^{-1}. Choose a gas-to-cloth ratio and operation time such that the average overall penetration for the cycle does not exceed 1.0% and the pressure drop does not exceed 2.5 kPa.

10.4[c]. Alternative form of the morphology factor

(a)Show that an alternative expression for the morphology factor defined by Eq. (10.2) is

$$M = \frac{A\rho}{6}\prod_{i=1}^{N} D_{pi}^{x_i} = \frac{A\rho}{6}\ \mathrm{MGD}$$

where

x_i is the mass fraction collected in chanel i

MGD = mass-weighted geometric mean diameter

(b)The Monticello Generating Station is a coal-fired power plant operated by the Texas Utilities Generating Company (Felix et al. 1986). Part of the flue gases go to a 36-compartment shaker baghouse for particle removal. The baghouse experienced higher-than-expected pressure drops and large penetration spikes, even though it operated at reasonably low gas-to-cloth ratios. In an effort to find an explanation to these unexpected operational problems, samples of the fly ash were analyzed. The specific surface area was measured at 0.85 m^2/g and the true particle density at 2,420 kg/m^3 (Vann Bush et al. 1989). The following table gives a typical size distribution analysis.

Dpi **(μm)**	**Mass Fraction**	***Dpi*** **(μm)**	**Mass Fraction**
0.02	5×10^{-5}	0.80	0.0503
0.05	2×10^{-4}	2.00	0.0600
0.08	1.6×10^{-3}	5.00	0.1500
0.10	0.0010	7.00	0.3540
0.20	0.0008	10.0	0.2640
0.30	0.0010	20.0	0.1020
0.40	0.0070	50.0	0.0010
0.60	0.0100	70.0	8×10^{-5}

Estimate the value of the morphology factor for the Monticello fly-ash and discuss whether the operational problems experienced can be explained in terms of the particle's morphology.

Answer: M = *2.22*

10.5[a]. Morphology of particles from atmospheric fluidized-bed combustor (AFBC)

The TVA atmospheric fluidized-bed combustor is a 20 MW power plant, which burns eastern bituminous coal. The flue gases flow through a reverse-air baghouse for particle removal. The fly-ash has the following properties: true density, 2,620 kg/m^3; specific surface area, 14.44 m^2/g; mass geometric mean diameter, 5.0 μm. Estimate the morphology factor for this fly-ash (see Problem 10.4). Do you expect penetration problems owing to bleed-through?

Answer: 31.5

10.6[b]. Filter drag model parameters estimation

Estimate the parameters in Eq. (10.4) based on the following test data.

Gas-to-cloth ratio = 0.013 m/s

Inlet dust loading = 0.005 kg/m^3

Time (min)	5	10	15	20	25	30
ΔP (kPa)	0.33	0.49	0.55	0.60	0.64	0.70

Answer: $K_2 = 1.96 \times 10^5\ s^{-1}$

10.7[a]. Maximum and average tubesheet pressure drops

The fabric filter of Problem 10.6 operates with an inlet dust loading of 0.01 kg/m^3. The filtration time is 1 h. Estimate the maximum and average tubesheet pressure drops during the filtration time.

Answer: $\Delta P_{max} = 1.58\ kPa$

10.8[a] Tubesheet pressure drop in a pulse-jet baghouse

A pulse-jet baghouse uses Dacron felt bags for the control of fly ash emissions. The gas-to-cloth ratio is 0.030 m/s and the inlet dust loading is 0.02 kg/m^3. The bags are cleaned at 10-min intervals with pulses of air at 690 kPa gauge. If $K_2 = 2.0 \times 10^5\ s^{-1}$, estimate the maximum tubesheet pressure drop.

Answer: 2.61 kPa

10.9^b. Areal density distribution in a baghouse

(a)The following areal density distribution data were measured in a baghouse:

Areal density (W, kg/m^2)	Cumulative percent less than W
0.56	1
0.77	5
1.10	20
1.60	50
2.40	80
4.10	98

Show that these data follow a log-normal distribution and estimate the median and geometric standard deviation

(b) Estimate the ratio of the harmonic mean to the reciprocal of the arithmetic mean.

Answer: 1.18

(c) Estimate the arithmetic mean of the distribution

Answer: 1.74 kg/m^2

10.10^b. Precooling of waste gases upstream of fabric filters

(a) If the waste gases of Example 10.8 are precooled by dilution with ambient air at 298 K, estimate the volumetric flow rate of the gases at the baghouse inlet. Assume that the mean heat capacity of air in the range 298 to 530 K is 1.02 kJ/kg-K. Neglect the effect of heat losses.

Answer: 183 m^3/s

(b) Estimate the flow rate of the waste gases at the baghouse inlet if they are precooled by evaporation of water at 298 K.

Answer: 74.8 m^3/s

10.11^b. Baghouse heat exchanger

The J. E. Baker Company of York, Pennsylvania processes dolomitic limestone into a variety of agricultural and industrial products (Krout, B., and Kilheffer, J. *JAPCA*,

31:293, 1984). They operate two rotary coal and coke-fired kilns. In 1978, they fitted Numer One kiln with a fiberglass reverse-air baghouse for particulate matter control. The system included a heat exchanger to lower the exhaust gas temperature from 756 K to 533 K before entering the baghouse. The cooling fluid is ambient air which enters the heat exchanger at 300 K and leaves at 590 K. The unit has a heat-transfer area of 1,374 m^2 for an inlet flow rate of 56.7 m^3/s. Estimate the overall heat-transfer coefficient for the unit. Assume that the exhaust gases behave like air.

Answer: 23 W/m²-K

10.12[a]. Gross cloth area for a reverse-air fabric filter

Estimate the gross cloth area for the reverse-air baghouse of Problem 10.11. The particles coming out of the kiln are a mixture of lime dust and fly-ash.

Answer: 4,400 m²

10.13[a]. Cloth area for a pulse-jet baghouse

The exhaust gases from a cement plant flow at the rate of 130 m^3/s at 500 K. Calculate the net cloth area for a pulse-jet baghouse to remove the cement dust. Assume on-line cleaning of the bags.

Answer: 3,190 m²

10.14[a]. Reverse-air baghouse for a coal-fired power plant

Consider the coal-fired power plant of Example 5.1. The plant will consist of two, 150-MW boilers. Design a reverse-air fabric filter for each boiler to remove at least 99 percent of the fly ash in the flue gases. The bags are 0.3 m in diameter and 10.7 m long. There are 120 bags per compartment. Specify the gross cloth area and the number of compartments for each baghouse.

Answer: 22 compartments/unit

10.15[b]. Gas-to-cloth ratios for pulse-jet baghouses

A correlation was presented to estimate the gas-to-cloth ratios for process gas filtration with pulse-jet fabric filters as a function of the temperature, particle size, dust load, and material filtered (Turner et al. 1987a):

$$V = F\left(T - 256\right)^{-0.2335}\left(C_i\right)^{-0.06021}\left(0.7471 + 0.0853 \ln \text{MMD}\right)$$

where

V = gas-to-cloth ratio, m/s

T = temperature, K (between 285 and 410 K); for temperatures above 410 K, use $T = 410$ K

C_i = inlet mass loading, kg/m^3 (between 0.0001 and 0.23)

MMD = inlet aerosol mass median diameter, μm (between 3 and 100)

F = material factor given in the following table

		F		
1061	0.0849	0.0707	0.0636	0.0424
ur	Asbestos	Cement	Fly-ash	Activated carbon
acco	Lime (hydrated)	Coal	Metal oxides	Detergents
n	Talc	Limestone	Dyes	Soaps
dust	Gypsum	Silica	Silicates	Milk powder

Estimate the gross cloth area for a pulse-jet filter to process the gases from the -hearth steel plant of Example 10.8 The MMD of the iron oxides dust is 5 μm (Licht

Answer: 2440 m²

10.16[b]. Profit from a baghouse heat exchanger

The cooling air of Problem 10.11 (leaving the heat exchanger at 590 K) is used for purposes in the plant, reducing the fuel required for the calcination process. The fuel savings are approximately \$100,000/yr. The annual operation and maintenance expenses of the heat exchanger are \$20,000/yr. Estimate the profitability index for the capital invested in the heat exchanger. Assume that the useful life of the unit is 15 yr with no salvage value. The following equation can be used to estimate the cost of heat exchangers (Vatavuk, W. M. and Neveril, R. B. *Chemical Engineering*, p.129, July 12, 1982):

$$EC = 14{,}814\, A^{-0.12} \exp\left[0.0672\,(\ln A)^2\right]$$

where

EC = cost in 1978 dollars

A = heat-transfer area, m^2

Assume that TCI = 2.34 EC.

10.17[a]. TCI for a fabric filter system

Estimate the total capital investment for the fabric filter system of Problem 10.14. Because the fabric filters will be located upstream of the FGD system, the flue gases are acidic at this point, which mandates stainless steel fabrication. At the temperaure of operation (530 K) insulation is required and the bags must be made of Fiberglass. The cost of auxiliary equipment for each baghouse is \$300,000.

Answer: TCI = \$19.9 millions in June 1990

10.18[b]. TAC of a reverse-gas baghouse

Estimate the total annual costs and the cost effectiveness (\$/metric ton) for the baghouse system of Problem 10.17. The system operates 8,640 h/yr. The operating labor rate is \$25/h, the maintenance labor rate is \$28/h. The cost of electricity is \$0.06/kW-h; the total pressure drop through the system is 5 kPa. The cost of final fly-ash disposal is \$20/metric ton. The minimum attractive rate of return is 12%/yr; the system lifetime is 20 yr. The mechanical efficiency of the fans is 65 percent.

Answer: \$77/metric ton

10.19[a]. TCI for a MSW incinerator pulse-jet baghouse

Estimate the total capital investment for the baghouse of Example 10.10. Assume that the cost of the auxiliary equipment is $90,000. No buildings or special site preparation is needed.

Answer: $1,214,000 in June 1990

10.20[c] Design of a pulse-jet filter for a Portland cement kiln

In Problem 8.17, a multiple cyclone system was designed as a precleaner for the control of particulate emissions from a Portland cement kiln. For each of the alternatives considered in that problem, design a pulse-jet fabric filter such that the combined system is capable of satisfying the particulate NSPS for the source. Use the correlation of Problem 10.15 to estimate the gas-to-cloth-ratio for each alternative. Assume that the tubesheet pressure drop can be calculated from Eqs. (10.7) to (10.9), with $K_2 = 1.5 \times 10^5$ s^{-1} and a cleaning interval of 10 min. The lifetimes of the bags and system are 2 yr and 20 yr, respectively, with no salvage value. Operating and maintenance labor rates are $15/h and $20/h, respectively. The dust collected in both devices can be recycled to the process at no additional cost. Compressed air (dried and filtered) is available at $7.00/1,000 standard m^3. For each alternative, specify the following:

(a) Total filtration area

(b) Filter media, number and dimensions of the bags

(c) TCI and TAC of the combined multiple cyclone–fabric filter system.

Choose between the three alternatives suggested based on the EUAC measure of merit. Compare your results to those of Problem 9.22.