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Revision Memo

12/01	Minor editorial changes and minor clarifications to system considerations and process design.
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SCOPE

- ◆ This section covers the major considerations for selecting a gas filtering system for air pollution control to reduce particulate emissions. When applied, fabric filters are the gas filtering system predominantly used in ExxonMobil petroleum refineries and chemical plants for the mitigation of particulate emissions during transport operations. Therefore, this subsection will focus on these devices. As fabric filters are somewhat unusual in the petroleum and petrochemical industry, the terms used are somewhat unusual. Therefore, definition of terms used in this Design Practice is presented in the Glossary at the end of this Design Practice.

The fabric filters are generally configured in the form of cylindrical bags, and a multiplicity of these bags are supported inside a flat-wall enclosure. Hence, fabric filters are also commonly referred to as baghouses. The term fabric filters and baghouses will be used interchangeably in this section.

Three other commonly used, commercially available particulate removal devices are cyclones, wet scrubbers, and electrostatic precipitators (ESP). For more information on these other devices, refer to [Sections A3, A5, and A6](#) of this [Section XVIII](#), respectively.

This subsection has several purposes. One is to provide an understanding of fabric filters to help the designer decide if a fabric filter is the appropriate particulate removal device. Additional purposes are to aid the designer in preparing a duty specification for a fabric filter system and in reviewing equipment suppliers' proposals for a fabric filter system.

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BACKGROUND

Fabric filter design is truly an art, not a science. Due to the simplicity of a fabric filter, there are many equipment suppliers who can provide a fabric filter system. There are a myriad of choices for fabric selection; consequently, fabric material is chosen based on experience from previous or similar services. To assure a suitable, optimum system is being provided, the designer should gather input from a number of equipment suppliers. Selecting the optimum system from various supplier offerings can be exceedingly difficult. In addition, supplier competitiveness may lead to a compromising of design practices and features to gain a cost advantage.

ADVANTAGES / DISADVANTAGES OF FABRIC FILTER SYSTEMS

- ◆ The final choice in a particulate removal application is usually the system that reliably and safely meets regulatory requirements at the lowest annualized cost, primarily defined by the lowest capital investment. To compare control equipment alternatives for an application, the site-specific requirements must be known. However, considering the advantages and disadvantages of each type of particulate removal system may perform a preliminary screening.

In general, fabric filters are among the most efficient means available for removing small particles from dry air or gas streams. The primary advantages of fabric filters include:

- High collection efficiency (95 to 99%).
- Removal of sub-micron particles.
- Collected material is recovered dry for subsequent processing or disposal.
- No liquid waste disposal stream.

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BACKGROUND (Cont)

The primary disadvantages of fabric filters include:

- Gas stream must be above dew point to prevent condensation and below about 550°F (288°C) to use demonstrated fabric materials. (Higher temperatures are potentially achievable with refractory and metallic fibers that are still generally considered in the development phase.)
- Relatively high-maintenance cost, especially for replacement bags.
- Space requirements are large.
- "Sticky" dust (e.g., hygroscopic materials, moisture condensation, tarry adhesive components) may cause blinding of the bags.
- Bag breakage can cause excessive emissions.

EXXONMOBIL APPLICATIONS

Fabric filters have been used in ExxonMobil primarily as part of pneumatic solids transport systems. One example is to remove dust from the effluent from product coke silos for fluid cokers (e.g., Benicia) and FLEXICOKERS (e.g., Rotterdam) to clean the transport media before it is emitted to the atmosphere. Another example is to clean the effluent air from storage silos for fines from ESPs (e.g., Benicia, Augusta). Fabric filters are also used on coal handling systems. These applications would be characterized as small-to-medium capacity, low-temperature services.

ExxonMobil does not have fabric filters on large-capacity systems such as combustion flue gas cleanup for fired heaters and boilers. Fabric filters were considered for a number of larger, utility size oil and coal fired boilers in the early 1980s. However, these units were not built due to changes in ExxonMobil's business needs.

FILTRATION MECHANISMS

Fabric filters remove particulates, often referred to as dust, from a gas stream by passing the stream through a porous fabric. When the fabric is new, the dust forms a porous cake on the surface of the fabric. It is this cake which thereafter actually does the filtration. Bags are sometimes pre-coated, particularly if the dusts are fine or the dust loading is low, with an appropriate material to accelerate this cake-forming stage.

The effective filtration does not begin until the dust particles accumulate within and upon the surface of the filter. The dust builds up with time; and at some point, the filter medium must be partially cleaned to remove part, but not all, of the dust cake. The filter medium, with some residual dust on it, is then returned to service. This regeneration of the cleaning surface is a feature that distinguishes fabric filters from most other filters (e.g., plate filters, where the dirty filter is replaced).

The selection of design parameters is crucial to the optimum performance of the fabric filter system. The manner in which the dust is removed from the fabric is one of the essential design parameters. If the dust cake is not adequately removed, the pressure drop across the system will increase to an unacceptably high value. This may lead to a high-operating cost and possible bag breakage. If too much cake is removed, excessive dust leakage will occur while fresh cake develops. The cleaning interval is also important with a short interval resulting in excessive leakage and/or reduced bag life.

Several particle collection mechanisms are responsible for filter effectiveness. Some of these mechanisms probably predominate during both initial cake formation and cake rebuilding. These mechanisms are based on the capture of single particles by single fibers and include interception, inertial impaction, and diffusion. Theoretical equations are available in the literature for describing these mechanisms. Electrostatic attraction and gravitational settling are other forces that can also contribute to fiber filtration.

Once the dust cake has formed or reformed after cleaning, sieving is probably the dominant mechanism. For the operating fabric filter, the fabric is covered with a dust cake of varying thickness. As particles approach the porous mass of dust that comprises the cake, they either strike one or more surface particles or enter a pore. If the particle is larger than the pore it enters, it will be sieved out. If the particle is smaller than the pore it enters, it will continue traveling through the pore until it touches the pore wall and adheres. The pore dimensions may narrow until the pore is smaller than the particle and again the particle is sieved out. In some locations the particle passes completely through the cake pore and the fabric pore and exits on the clean-gas side of the filter. Ordinarily, only one out of 1000, or even 10,000 particles, finds its way through the filter pore.

Experimentation has shown that particle size distribution changes only slightly between gas entering and leaving the fabric filter. This lack of change in particle size from the inlet to outlet of the filter results from the manner in which most particles pass through the filter. Most particles that transit the filter do so by a leakage process. These leakage points, due to variability in the fabric or defects, are the relatively few pores that are too large and cannot be bridged as the cake builds up. These points may also be the result in the fabrics (e.g., tears, rips, etc.) that allow particles to pass through uncollected.

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BAGHOUSE SYSTEM

A typical baghouse system is shown in **Figure 1**. The principle components in the system include:

1. Inlet ductwork to carry dirty gas to the baghouse.
2. Baghouse inlet and internals to distribute the gas and dust throughout the baghouse.
3. Tube sheet to separate the dirty and clean areas of the baghouse and to provide connections/supports for the filter bags.
4. Bag plenum(s) to support and house filter bags.
5. Bag-cleaning components, dampers and controls to clean the dirty filter bags.
6. Hopper(s) to collect the dust cleaned from the filter bags and discharge it for disposal.
7. Dust removal system.
8. Outlet ductwork to collect the filtered gas and deliver it to the fan.
9. Fan, if it is needed, to move the gas through the system.
10. Stack or vent to discharge the cleaned gas to the atmosphere.
11. Bypass to protect the baghouse from damage during process system upsets.

SYSTEM CONSIDERATIONS

There are a number of considerations that will impact the design and specification of a fabric filter, as described in the subsequent sections. These considerations would have to be addressed and defined in the preliminary stages of a baghouse selection and layout.

PURPOSE

The baghouse is most likely to be used as a piece of process equipment or as an environmental control device to reduce particulate emissions.

In either case, information should be provided to the equipment supplier on current rate, future rate (if a rate increase is anticipated), operating mode (batch versus continuous), on-stream requirement (permissibility of bypassing), retrofit versus grass roots installation, and physical constraints (space availability).

- ◆ In addition, if the baghouse will serve as an environmental control device, the particulate emission requirement needs to be identified. The emission target could be a specific percent collection efficiency, an effluent particulate concentration, or opacity. Also, the regulation could require control of the effluent particle size distribution, especially the percentage of fine particulate (< 2.5 micron). It should be noted that most baghouse vendors typically prefer to guarantee only the outlet loading of solids via test methods that exclude non-particulate matter (e.g., US EPA Test Method 5F)

INLET CONDITIONS

There are a number of inlet conditions that must be specified to allow an effective and reliable fabric to be provided by the equipment supplier. These conditions, which cover the gas and solid characteristics, are covered below.

Flow Volume

The gas flow volume in actual ft³ per minute (ACFM) or cubic meters per hour establishes the size of the fabric filter. Testing may be required to obtain an accurate definition of the process inlet flow. Any variations in flow, especially those that cause an increase above design, must be identified. The baghouse should be designed for the maximum anticipated rate because higher-than-anticipated gas flow rates will result in greater baghouse pressure drop, higher cleaning frequencies, shorter bag life, and potentially higher emissions.

Static Pressure

- ◆ Most baghouses are flat-sided boxes and excessive high pressure or vacuum can result in permanent distortion of the box, which in turn may result in leaks or other equipment malfunctions, or increased emissions. The standard fabric filters used in pressure or vacuum service are usually operated within ± 25 in. of water (1 psi, 0.07 kg/cm²). However, for special applications, high-pressure shells can be built, but these are generally used for small gas flows due to their cost.

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SYSTEM CONSIDERATIONS (Cont)

Temperature

The inlet temperature impacts the size of the baghouse and the fabric selected. As the temperature increases, the gas flow volume increases which in turn results in a larger baghouse.

The gas inlet temperature is a key parameter in selecting the type of fabric used for the bags. The maximum gas temperature encountered by the filter fabric is the primary parameter that sets or limits fabric alternatives. If the gas is too hot for the fabric, the fabric may burn or melt leading to a catastrophic failure. The chosen fabric must be able to tolerate both the continuous and anticipated upset conditions of the system with a margin of safety (see page 15 for recommended margin).

The minimum gas temperature is an important consideration, as well, since most fabrics cannot operate below the moisture or acid dew points. When this happens, condensation occurs on the fabric, and hydrolysis of the fabric (reaction with water) or acid attack of the fabric may occur. Condensation can also "blind" the fabric.

Moisture Content

Moisture content of the inlet gases is important for several reasons. First, the collected dust cake depending on the hygroscopic nature of the dust may absorb the moisture. This can result in the cake sticking together or sticking to the fabric, thereby increasing cleaning difficulty. If the dust is not adequately removed from the bags during the cleaning cycle, the bags could become permanently blinded.

Moisture condensation on the fabric can allow strong acids or alkaline solutions to form that may attack the fiber, degrade the fabric construction properties, and lead to bag failures.

Another effect of inlet moisture is the possibility of condensation of moisture on the walls of the baghouse, hopper, or downstream ducting. This condensation will result in corrosion and shortening the life of the baghouse. Corrosion on the hopper walls will retard the discharging of collected dust and may lead to bridging and hopper plugging.

Chemical Contaminants

The presence of acid gases will influence the selection of the filtration fabric, including both the fiber and the finish used. Acid gases include sulfur oxides (SO_2 , SO_3), nitrogen oxide (NO_x), and hydrogen chloride (HCl). Their impact will depend on the amount of acid gases present and the amount of condensation that occurs. Some fabrics are also sensitive to the presence of alkalis (e.g., sodium, potassium) in the gas stream which can also degrade the fabric.

Particulate Loading

The amount of dust in the entering gas produces the increase in baghouse pressure-drop between cleaning cycles, thus establishing the frequency with which the baghouse must be cleaned. The particulate loading is also important in defining the amount of dust to be removed from the hoppers and in setting the hopper evacuation schedule. The variability of the dust loading needs to be considered to define the degree of flexibility the baghouse will require.

Particulate Characteristics

Both particle size and the size distribution will affect pressure drop across the cake. In general, smaller particles result in a greater pressure drop for a given dust loading and gas flow rate. Also in general, a wider particle size distribution packs tighter and will give a higher-pressure drop than a narrow distribution, which packs more loosely. In both cases, the fine particles fill in the flow passages between the larger particles to give the greater pressure drop.

Particle shape can also impact baghouse performance. Very spherical and hard particles can be expected to flow readily and ease dust handling system problems. Sharp, ragged particles that do not flow as easily and may increase fabric wear. The sharp particles may also become embedded in the fabric and cut the fibers as the fabric is flexed. Finally, flat particles can pack together, resulting in higher-pressure drop than would be anticipated for the particle size and size distribution.

Particles stickiness is another characteristic to be considered. Adhering particles, such as oily residues, can blind the fabric. Fabric materials and possibly pre-coats may have to be selected that provide good release of sticky particles.

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SYSTEM CONSIDERATIONS (Cont)

Particle Chemistry

Consideration should be given to chemical reactions that may occur among the various constituents of the dust cake during the time interval between cleaning cycles, or in the part of the cake that remains after cleaning. A baghouse collecting fly ash from a coal-fired boiler is an example of an application where the particulate chemistry must be considered. Coal fly ash includes the basic constituents of cement (i.e., lime, silica, alumina, and iron oxides). When present as fine particles, these constituents can react to form the complex silicates, aluminates, and alumina ferrites characteristic of cements, especially if the dust becomes wet. The result may be a hard, fused cake that cannot be removed by any normal cleaning technique.

Chemical reactions in the dust cake may be beneficial. For example, the reaction of alkaline constituents in the dust with acid gases can produce solid reaction products that are removed with the dust thereby removing the acid gas from the gas stream.

- Currently, for most typical petroleum and petrochemical baghouse applications these particle chemical reactions are not present, but this review must be made for every installation.

PROCESS DESIGN

GAS-TO-CLOTH RATIO

The most important parameter in any baghouse design is the air-to-cloth ratio, A/C, or the gas-to-cloth ratio, G/C. This ratio is the measure of the volume of gas passing through the baghouse fabric surface area. The parameter defines how much filter cloth is required within the baghouse and thus how large and costly the system will be. The A/C is calculated as the gas volume (ft³/min or m³/min) divided by the fabric area (ft² or m²).

There are different methods for defining and calculating the A/C. The frequently used A/C ratios are the Gross A/C and the Net A/C. The Gross A/C is based on the total inlet gas volume divided by the total filter cloth in the collector. The Net A/C is based on the total volume passing through the active bags divided by the on stream cloth area, where the total volume is the sum of the inlet gas plus any volume that is added for on-stream cleaning of the bags plus any air that leaks into the baghouse. The total active area is the on-stream cloth area. When calculating the active area, the area out of service for cleaning must be subtracted from the total cloth area.

- A typical A/C is 2 to 10 ft³/min/ft² (0.6 to 3.0 m³/min/m²) for industrial applications. The A/C depends on a number of factors. These include the cleaning method, filter media, dust material, dust size, dust density, dust loading, gas temperature and others. **Consequently, selecting the A/C is an art rather than a science and requires input from the baghouse supplier or previous experience with baghouses in the exact or similar services.**

The A/C reduces to length/time and, therefore, can also be considered a superficial gas velocity referred to as the filtration velocity, V_f , reported as feet per minute or meters per minute. This is not the actual velocity through the pores in the fabric, but rather the apparent velocity of the gas approaching the cloth. The actual gas velocities within the openings in the dust cake and the pores and interstices of the fabric can be an order of magnitude or more greater than the computed filtration velocity.

- There are two basic approaches for selecting the A/C that are routinely employed. The first approach and the one most often applied, is to collect all of the empirical data available in the industry (for example, petroleum refining) for the source being considered. If there is none within the industry, examine a similar industry using baghouses and determine the A/C range being successfully applied. The risk with this approach is that subtle but potentially significant differences between the two industries may prevent selection of an optimum A/C. Baghouse manufacturers have developed procedures that allow rapid estimation of the A/C. These procedures comprise nomographs, charts, tables of factors, and equations. Some of these can be found in the literature and references cited herein. It should be noted that depending on the vendor or author's experiences the stated ratios might vary widely for the same application.
- The second approach is to operate a pilot unit on a slipstream of the actual process and vary the A/C. This approach may well provide a more optimized design but is generally more costly and time consuming. The new full-scale unit is designed based on the A/C that appeared to give the best results. The pilot unit should be run for a period long enough, typically several weeks to several months, to obtain sufficient data representative of the long-term, full-scale operation. One drawback to this approach is that a slipstream of the particulate laden stream may not be available if the baghouse will be employed in a new process. Another concern could be the potential cost for the testing, especially if the baghouse will be a small capacity unit.



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PROCESS DESIGN (Cont)

FILTER AREA

The physical size of the baghouse depends on the filter cloth area. The required filter cloth area is determined by dividing the gas or air stream flow volume, Q , by the filtration velocity of V_f . As indicated above, V_f has the same numerical value as the A/C. In equation form, this relationship would be expressed as:

$$\text{Filter Area} = \frac{Q}{V_f} = \frac{Q}{A/C}$$

The computed filter area must be adjusted depending on whether the A/C was gross or net ratio. The final area selected will be derived from an interactive process that allows for an optimum number of compartments, additional compartments (if required) for both on-line cleaning and off-line maintenance, modular construction, and standardized design features.

PRESSURE DROP

The baghouse pressure drop from its inlet flange to its outlet flange consists of the mechanical pressure drop and the bag pressure drop (also referred to as the tube sheet pressure drop). The mechanical pressure drop consists of the drop through ductwork and dampers, and the tube sheet pressure drop consists of the drop across the fabric and dust cake. As might be expected, the tube sheet pressure drop is variable with time and depends on a number of factors associated with the fabric and particles being collected.

Mathematically, the total baghouse pressure drop can be expressed as follows:

$$\Delta P_{fl-fl} = \Delta P_m + \Delta P_{ts}$$

where:

ΔP_{fl-fl}	=	Total pressure drop from flange to flange
ΔP_m	=	Mechanical pressure drop
ΔP_{ts}	=	Tube sheet pressure drop

The mechanical pressure drop is established by the size and configuration of the ductwork and dampers and will vary approximately as the square of the gas volume as follows:

$$\Delta P_m = K_m Q^2$$

where:

K_m	=	Mechanical component flow coefficient (varies with baghouse type, size, etc.)
Q	=	Gas volume

The tube sheet pressure drop consists of two components, with one component associated with the fabric and residual dust cake after cleaning and the second component associated with the new dust cake that accumulates since the last cleaning. The tube sheet pressure drop can be expressed as follows:

$$\Delta P_{ts} = K_1 V_f + K_2 C_i V_f^2 t$$

where:

V_f	=	Filtration velocity or A/C
K_1	=	Residual flow coefficient of the fabric and residual dust cake
K_2	=	Newly deposited dust flow coefficient
C_i	=	Inlet dust loading
t	=	Elapsed time since cleaning

The value of K_1 and K_2 cover an extremely broad range and must be determined experimentally for a given filter system.

The residual pressure drop flow coefficient, K_1 , is determined by the fabric type, its cake release properties; the size, shape and chemical content of the collected particulate; the gas properties; the cleaning system's energy level, frequency and effectiveness; bag tensioning (where applied); and the age of the bags. Normally, this coefficient and thus the residual pressure drop of the system increases as the bag set gets older. Generally, it will rise relatively rapidly over the first few hours to months of operation, remain stable for several years, and then begin to rise again near the end of the bag sets' life.

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PROCESS DESIGN (Cont)

The pressure drop rise after cleaning is due to build up of newly collected dust and increases with time. The new dust flow coefficient (also referred to as specific cake coefficient), K_2 , depends on a number of factors characteristic of the gas and dust. Experimental measurements have shown that K_2 depends on particle size, shape, composition, and concentration; fabric structure; gas velocity; and electrical field condition (if applicable) in the vicinity of the cake and fabric. Small, smooth particles tend to have higher K_2 values; while rough, large particles form more permeable dust cakes and have lower K_2 values. Gas characteristics that promote adhesion of particles to each other tend to have lower K_2 values, as long as they do not become too sticky and inhibit their removal during cleaning.

Combining the pressure drop components together, the total overall pressure drop becomes:

$$\Delta P_{fl-fl} = K_m Q^2 + K_1 V_f + K_2 C_i V_f^2 t$$

As can be seen from this equation, the filtration velocity or A/C is an important factor. For a given application with given gas and dust characteristics, the A/C is a primary factor at the designer's control to determine the overall system pressure drop.

Typically, the total pressure drop for a baghouse would be 5 to 10 in. (125 to 250 mm) of water. About 2 to 4 in. (50 to 100 mm) of H_2O can be expected for the mechanical component. About 3 to 6 in. (75 to 150 mm) of H_2O is reasonable across the bags, with the residual pressure drop contributing 1 to 4 in. (25 to 100 mm) and the newly deposited cake producing a pressure drop rise of about 2 in. (50 mm) with time.

The baghouse incorporates many parallel bag filters with each operating with its own filtration characteristics. At any given time, some bags are processing higher or lower gas volumes, depending on the time since the bags were cleaned; the effectiveness of that cleaning; and the amount and characteristics of the dust arriving at each bag. The more uniform the gas flow within each of the bags in the baghouse, the lower the pressure drop and emissions will be, and the longer the bag life.

EFFICIENCY

Efficiency is a measure of the effectiveness of a particulate removal device, and it is defined as:

$$\text{Eff} = \frac{C_i - C_o}{C_i} \times 100\%$$

where: C_o = Outlet concentration
 C_i = Inlet concentration

Another measure of performance is penetration where:

$$\text{Penetration (\%)} = 100 - \text{Efficiency (\%)}$$

- ◆ Efficiency and penetration can be determined by measuring particle concentration via standard source testing methods. There is no satisfactory set of published equations that allows a designer to calculate the expected efficiency for a proposed baghouse. Efficiency could be estimated if experience was available from an existing baghouse operating in similar service to the proposed baghouse. The actual efficiency must be determined from the baghouse after it has been in service.
- ◆ Efficiency for a baghouse is less meaningful than for other particulate control devices because it is generally very high (99% and greater is typical). Regardless of the inlet loading, a well designed and operated baghouse is capable of reducing overall particulate emissions to values less than 0.010 gr/dscf (grains/dry standard ft³) (22.8 mg/dNm³). In some cases, emissions as low as 0.001 - 0.005 gr/dscf have been reported. It must be noted that deficiencies in the design, or operation, or general aging of the baghouse system can result in emissions be significantly higher than stated above.

FABRIC FILTER CATEGORIES

There are six categories that describe baghouse design features. They are: capacity, operating temperature, operating duty, cleaning methods, filter media, and filtering mode. The first three categories depend on the needs of the specific application and the second three are options available. Each category is defined briefly below and several are expanded on further in subsequent sections.