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Stationary Source Enforcement Series

ENFORCEMENT WORKSHOP ON PLANT INSPECTION AND EVALUATION PROCEDURES

VOLUME VI
CONTROL EQUIPMENT OPERATION AND MAINTENANCE - FABRIC FILTERS

July 1979

U.S. ENVIRONMENTAL PROTECTION AGENCY
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REFERENCE MATERIAL FOR ENFORCEMENT WORKSHOP

ON PLANT INSPECTION AND EVALUATION PROCEDURES

Volume VI
Operation and Maintenance of
Fabric Filters

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FOREWORD

The following document is a compilation of selected technical information and publications on the evaluation of industrial air pollution control equipment operation and maintenance practices. The reference manual is intended to be an instructional aid for persons attending workshops sponsored by the U.S. Environmental Protection Agency Regional Offices.

TABLE OF CONTENTS

Page No.

Volume VI: Operation and Maintenance of Fabric Filters

VI-1. Fabric Filtration Systems Design, Operation and Maintenance, S.A. Riegel 1-1

VI-2. Baghouses - What to Know Before You Buy, S.A. Riegel, R.P. Bundy, C.D. Doyle, Pollution Engineering, May 1973, pp. 32-34. 2-1

VI-3. The User and Fabric Filtration Equipment, Donald H. Rullman, Journal of the Air Pollution Control Association, Vol. 26, no. 1, January 1976, pp. 15-31. 3-1

VI-4. Ins and Outs of Gas Filter Bags, J.C. Walling, Chemical Engineering, October 19, 1970. 4-1

VI-5. Baghouses: Separating and Collecting Industrial Dusts, Milton N. Krauss, Chemical Engineering, April 9,1979, pp. 94-106 5-1

VI-1.

FABRIC FILTRATION SYSTEMS

DESIGN, OPERATION AND MAINTENANCE

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INTRODUCTION

This report will give you an overview of the design, operation, and maintenance of air pollution control systems using fabric filters (i.e., baghouses) as the control device. Both engineering and cost factors will be discussed.

TYPES OF SYSTEMS

Baghouses are used in two fundamentally different types of systems:

a) Dust control systems which may be described as a system which is not really critical to a plant's continued operation or to the immediate health or wellbeing of workers in the plant or the general public. Dust control is used to collect dust particles from the air, say in a woodworking shop or in material transportation. Dust collectors usually handle low volumes of air. High temperatures, continuous on-line cleaning, long life fabrics, corrosion and other factors usually are not considerations in their design and operation.

b) Process gas systems, on the other hand, are critical to the production process itself. They may be called upon to operate twenty-four hours a day, 365 days a year. They often handle extremely large gas volumes and encounter high temperatures, highly abrasive materials, sub-micron particles, high dust loadings and corrosive agents. The real definition, however, is not necessarily that it is a heavy duty system--rather that if it shuts down, the plant shuts down. For example, in an asphalt plant if the baghouse system is not operating properly, the plant may not be able to achieve adequate production rates. If the baghouse has to be shut down, production also comes to a standstill. Also, where toxic gases are present, operation of the process baghouse is critical. In a plant where lead oxide is generated, for example, there would be a hazard to workers if the baghouse malfunctioned. Because of these factors, process baghouses are maintained in a different manner from dust collectors. They are inspected more frequently--where a dust collector may be inspected once a month, a process baghouse may be inspected once a week. Also, the inspections will be more thorough.

Process baghouses also must normally be more closely monitored, and monitoring equipment may be more sophisticated than on a dust collector. Where a visual check of the stack of a dust collector usually is sufficient, a process gas baghouse may have automatic stack monitors. Pressure gauges usually will be inside the plant, at a monitoring station,

rather than outside, attached to a baghouse leg.

Process gas baghouses also may represent a considerably higher investment than dust collectors, which makes a good maintenance important. However, due to increasing knowledge about the effects of inhaling various particulates in the air, the differences in maintenance of the two systems may be becoming less significant.

TYPES OF BAGHOUSES

No other air pollution control device is subject to as wide a variety of modifications as is the baghouse. Baghouses are classified according to: the type of fabric used; where they collect the dust--either on the inside or outside of the bags; the type of cleaning mechanism used--shaker, reverse air, compressed air or sonic cleaning; or whether they are continuous automatic or intermittant in operation. A baghouse can be a combination of these classifications, such as inside bag collectors, continuous automatic, shaker cleaning on a process gas stream.

Inside Bag vs. Outside Bag Collectors

1. Inside bag collectors

Bag are attached both at the top and at the bottom of inside collectors. See figures 1 and 2. Dust enters the hopper, and the division between the clean and dirty air plenum is near the top of the hopper, with the majority of the housing being clean air side. Air flow is from the inside to the outside of the bags. It is necessary to enter the housing to change bags.

2. Outside bag collectors

Typically, bags are suspended from the top of the housing. Only the top portion of the housing is the clean air plenum, with the major portion of the housing and hopper being on the dirty side. Most outside collectors are designed so bags can be inspected and removed from the top without entering the housing. Since air flows from the outside to the inside of the bags, they must be supported from collapse by cages on the inside of the bag.

Intermittant vs. Continuous/Automatic Baghouses

1. Intermittant baghouses

Intermittant baghouses are used only in applications in which the production machinery is shut down at regular intervals, say

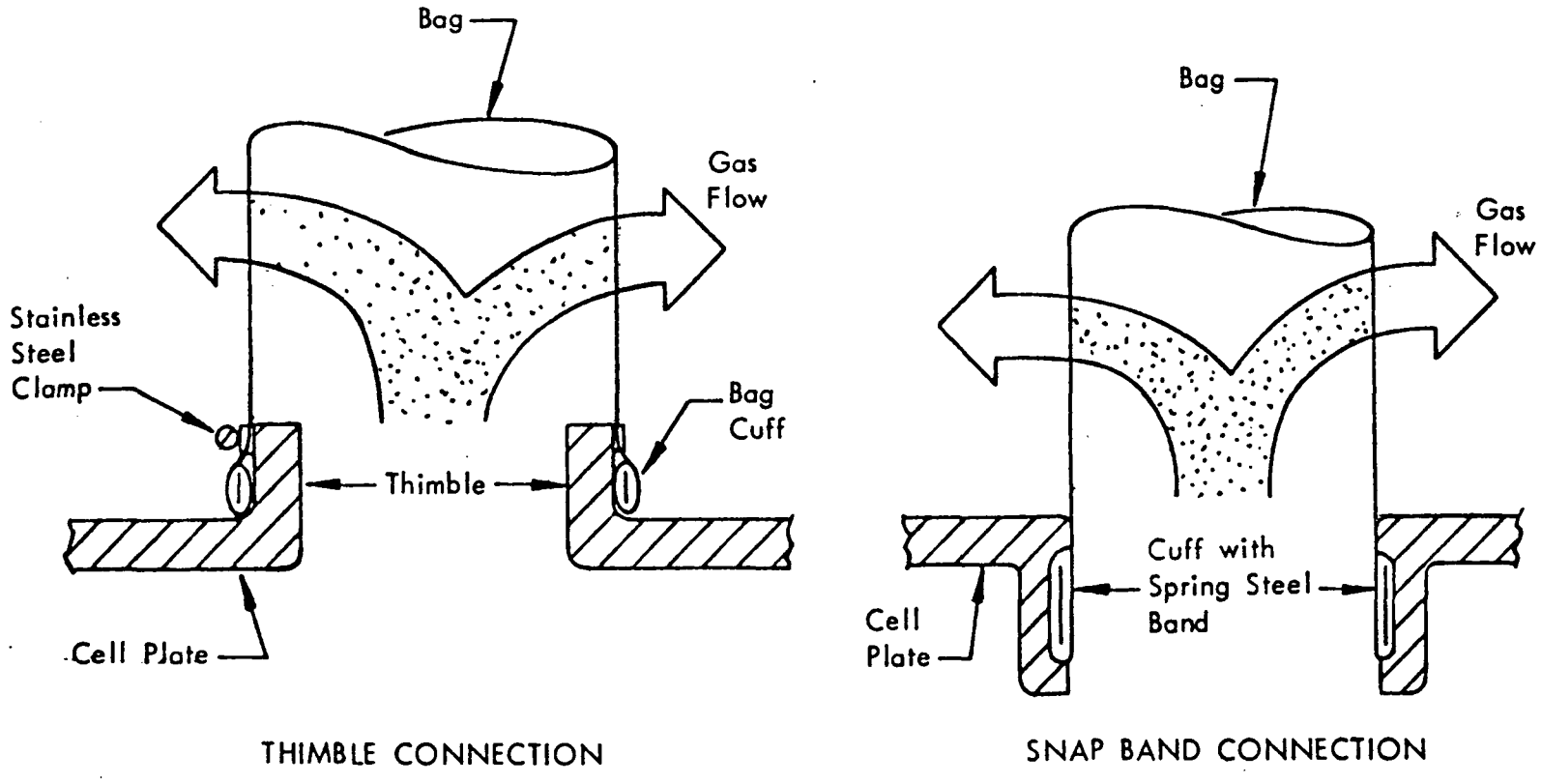


Figure 1 Bag-cell plate attachments

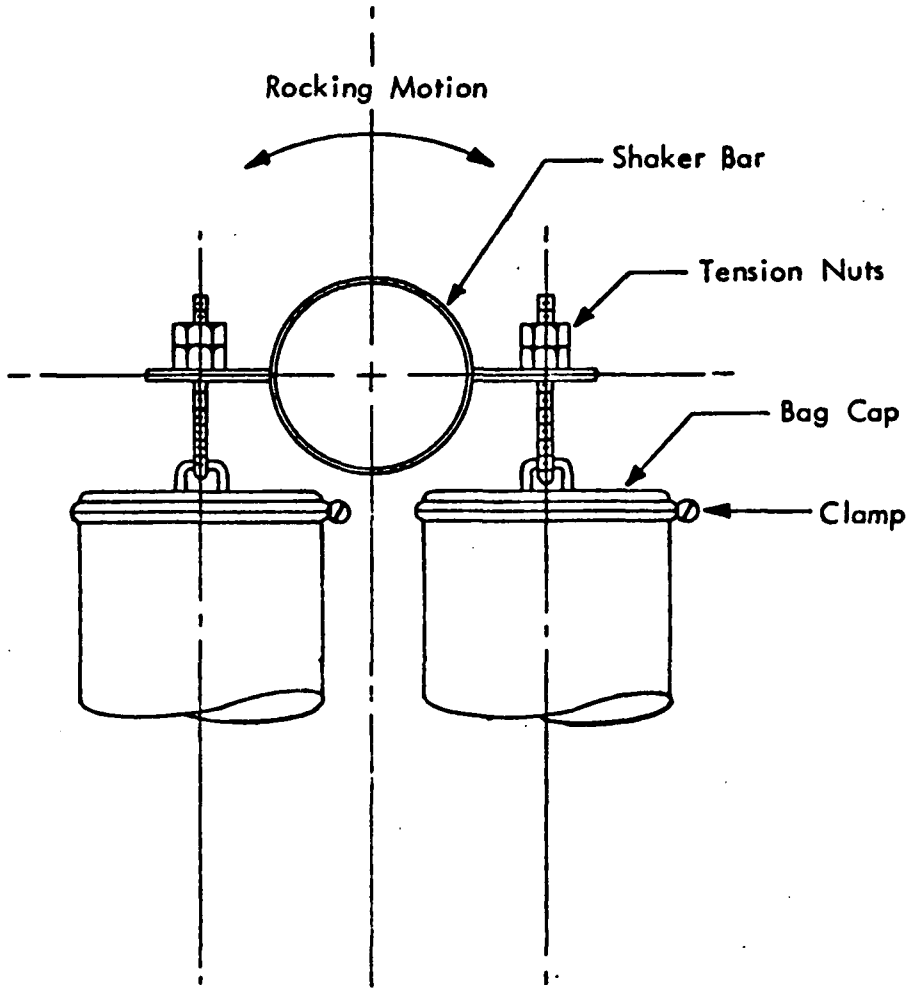


Figure 2. Typical shaker arrangement

during lunch periods, breaks, or at the end of the working shift. The unit must be sized so it can operate without cleaning for the time interval necessary.

2. Continuous automatic baghouses

These are units which clean their bags automatically during operation at pre-set intervals. With the exception of pulse-jet baghouses, continuous cleaning units must be compartmented so a section of the baghouse can be dampered off during the cleaning cycle. In pulse-jet units, the compressed air blast interrupts the air flow through the bag for the instant the bag is being cleaned, and no damper valves or compartmentation is necessary (although the effect is the same).

Types of Cleaning Mechanisms

1. Shaking

The most common type of inside collector is the shaker baghouse. See figure 2. Shakers can range in size from small, intermittant cleaning dust collectors with a few bags that are shaken manually through a hand crank arrangement, to huge compartmented systems with bags up to 40 ft. long and over a million square feet of filtering area. The hopper of a shaker baghouse is covered with a sheet of steel with holes in it called a cell plate. See figure 1. Bags are fastened to the cell plate and, at the top of the housing, to the shaker mechanism. Each row of bags is joined to a rod and each rod to the shaker framework. Each shaker assembly consists of a motor, eccentric, connecting arms and bearings. As the rod rotates, a mechanical shaking is initiated which actually shakes dust off the insides of the bags, where it then falls into the hopper. Shaker baghouses normally utilize woven fabrics and operate at low air-to-cloth ratios.

2. Reverse air

The reverse air baghouse is basically the same in design as the shaker and operates similarly. The sole difference is in the cleaning mechanism. Insteam of mechanical shaking of the bags, a fan is used to reverse the air flow from insie-outward to outside-inward. The result is that clean air is backwashed into the dirty air plenum, through the bags from the clean side to the dirty side, blowing collected particles free. Reverse air cleaning is more gentle than shaking and is used primarily with delicate fabrics. Bag construction is similar to that of shaker systems; however, metal rings must be sewn into the bags to keep them from collapsing during cleaning cycles.

3. Combination reverse air and shaker

Some baghouses may be designed for both shaker and reverse air cleaning. During the cleaning cycle, the bags are first collapsed with the reverse air fan, then gently shaken.

4. Pulse-jet

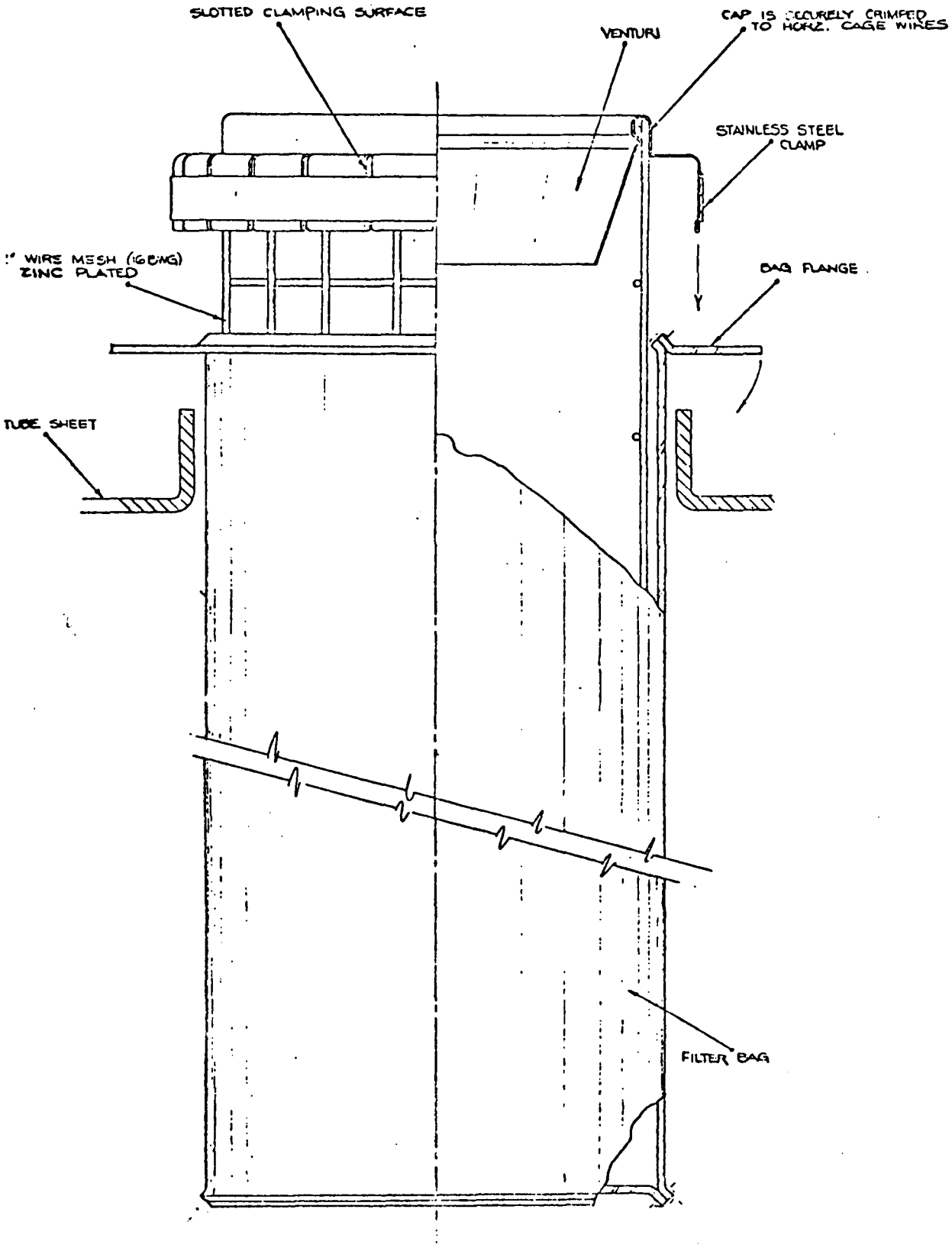
A pulse-jet baghouse uses short bursts of compressed air to clean its bags which are attached only at the top to a tube sheet. See figure 3. Over each row of bags is a compressed air manifold with an orifice directed down toward the top of each bag. During the cleaning cycle, an extremely short burst of compressed air flows from the top to the bottom of each bag, creating a shock wave that pushes the fabric out away from the cage, knocking dust particles loose. Although several rows of bags may be pulsed simultaneously, each bag receives its own individual burst of compressed air.

The cleaning particles from the bag in a pulse-jet collector is not accomplished by the backflow of air through the bag. In fact, a typical pulse puts no more than 0.5 cubic feet of air back through each bag; up to 2 cubic feet with induced air flow from a venturi. Compared to the square feet of cloth area in a typical bag, the effect is negligible. What acutally cleans the bag is the sudden expansion from a shock wave, which moves from the top to the bottom of each bag. Most pulse-jet baghouses are manufactured with some type of venturi over each bag, which most manufacturers consider necessary. However, recent venturi design seems to have become more of a marketing gimmick than a proper engineering design, since tests have shown that all the different configurations manufacturers placed over their bags made little difference in real cleaning action. Moving horns, diffusers, exotic venturi shapes, parabolic velocity stacks, hyperboloid diffusers and even nothing at all have been used over bags.

Although pulse-jet baghouses can be compartmented for certain applications, compartmentation is not normally necessary. Pulse-jet systems use densely felted bag materials to achieve a high level of filtering efficiency. They also operate at air-to-cloth ratios significantly higher than inside bag collectors, so the baghouses are usually much smaller in size for equivalent gas volumes.

Most pulse-jet baghouses are designed with hinged top doors for inspection and maintenance of bags and electrical and pneumatic systems, so there is no need to enter the baghouse itself for routine maintenance.

Figure 3



BAG/CAGE ATTACHMENT DETAIL - ALPHA SERIES (FOJ)

5. Plenum pulse

A variation of the pulse-jet is the plenum pulse baghouse. Basically, it operates in the same manner and also uses compressed air or reverse air to clean the bags. The difference is that the clean air plenum is compartmented into sections. Each of these sections, when isolated by a damper, becomes a semi-compartment and is pulsed all at once during cleaning. ONe large burst of high pressure air, then, cleans several rows of bags.

Plenum pulse baghouses may be equipped either with compressed air or with high pressure blowers.

6. Blow ring

A reverse air variation in which a ring travels up and down the length of the bag blowing air back through the bag as it moves, These are very seldom used anymore although at one time they were popular because they were the only type of baghouse that permitted high air-to-cloth ratios that did not infringe on the pulse-jet patent held by Midro.

TYPES OF BAGS AND BAG MATERIAL

Cloth Construction

1. Woven

Most commonly used with inside bag collectors. Fibers are woven on conventional looms into specified fabrics. The type of weave will vary depending on the application, and also, thread size and type can be altered as necessary.

2. Felted

Most commonly used with outside bag collectors. Normally, a light, loosely woven fabric, called a scrim, is used as a base and fibers are needled into this base to form a dense fabric.

Bag Construction

1. Bag

Common name for all filters, but specifically, means a tube shaped filter. This is the most common type of construction and is used with both inside and outside collectors.

2. Envelope

Flat unit sometimes used with outside bag collectors. These units offer the advantage of the maximum amount of cloth in a

minimum space, but internal velocities are higher.

3. Cartridge

These are relatively new in design and resemble an automotive air filter in that the cloth is pleated to increase filtering area. So far they have been limited in application to low temperature dust collectors.

Cloth Material

At least for process gas systems, the single most important design decision is the cloth material to use. High temperatures, corroosive chemicals, and small abrasive particles combine to make the wrong decision very expensive. Bags that were expected to last for three years may last only three months (or even three weeks) if the wrong decision is made. Table 1 gives the properties of the most commonly used bag materials.

MECHANISMS OF FILTRATION

When a baghouse is started up the first time with brand new clean bags it is a very inefficient device. In fact it leaks like a seive. Clean bags are not good filters. The following mechanisms are important because they make the bags get dirty; these collection mechanisms are only important until the bag builds up a "filter cake" of collected particles. After the bags have been in operation a while and the filter cake has developed the bags are no longer, strictly speaking, the filters. Rather the filter cake of collected materials is itself the actual filter and the bag merely supports it.

1. IMPACTION--the particle carried by an airstream collides with a fiber and has enough inertial force so it doesn't deflect along with the airstream.

2. STRAINING--the particle is larger than the opening between fibers and is trapped between them.

3. DIFFUSION--random movement of fine particulate causes particles to avoid following gas stream lines around the filter.

4. INTERCEPTION--a particle tends to follow airstream lines, but as it passes the fiber, it comes close enough so that one side impacts with the fiber.

5. AGGLOMENTATION--cohesion of one particle to another, and adhesion of particles to fibers so that, in effect, the target size is increased.

6. ELECTROSTATIC ATTRACTION--fiber has an opposite charge from particles.

TABLE 1.

FIBER PHYSICAL PROP.	ACRYLIC* (Homopolymer)	POLYAMIDE*	POLYESTER (Homopolymer)	NOMEX	POLYPROPYLENE	TEFLON*	GLASS	COTTON*	WOOL*
E = Excellent G = Good A = Average F = Fair P = Poor									
Max. Cont. Op. Temp. Of	285	225	275	375	170	450	500	180	200
Abrasion Resistance	A	E	G	G	E	P	P	F	A
Toughness	A	G	E	E	A	F	P	A	E
R = Recommended S = Satisfactory N = Not Recommended O = No Information	CHEMICAL RESISTANCE TO REAGENTS								
MINERAL ACIDS									
Aqua Regia	S	N	S	N	R	R	R	N	N
Chromic	R	N	S	N	S	R	R	N	N
Hydrochloric	R	N	S	S	R	R	R	N	S
Hydrofluoric	R	N	S	N	R	R	N	N	S
	R	N	S	S	S	R	R	N	S
Phosphoric	R	S	S	R	R	R	R	S	S
Sulfuric	S	N	S	N	R	R	R	N	S
ORGANIC ACIDS									
Acetic	R	S	R	S	R	R	R	R	S
Benzoic	R	N	R	S	R	R	R	R	S
Carbolic	R	N	S	N	O	R	R	R	S
Formic	R	S	R	S	R	R	R	R	S
Lactic	R	S	R	S	R	R	R	R	S
Oxalic	R	R	R	N	R	R	R	R	S
Salicylic	R	S	R	S	R	R	R	N	N
BASES									
Ammonium Hydroxide	S	S	N	S	R	R	S	S	N
Calcium Hydroxide	R	R	R	R	R	R	S	R	N
Potassium Hydroxide	S	S	S	S	S	R	N	R	N
Potassium Carbonate	S	R	S	R	R	R	N	R	N
Sodium Hydroxide	S	S	S	S	S	R	N	R	N
Sodium Carbonate	R	R	R	R	R	R	N	R	N

*USED INFREQUENTLY - Glass, Polypropylene, Nomex, and Polyester account for the vast majority of baghouses.

TABLE 1 (continued)

CHEMICAL RESISTANCE TO REAGENTS R = Recommended S = Satisfactory N = Not Recommended O = No Information	ACRYLIC* (Homopolymer)	POLYAMIDE*	POLYESTER (Homopolymer)	NOMEX	POLYPROPYLENE	TEFLON*	GLASS	COTTON*	WOOL*
SALTS									
Calcium Chloride	R	N	R	S	R	R	S	R	S
Ferric Chloride	R	S	R	S	R	R	N	N	N
Sodium Acetate	R	R	R	S	R	R	S	R	S
Sodium Benzoate	R	S	R	S	R	R	S	R	R
Sodium Bisolfite	N	S	R	S	R	R	R	R	S
Sodium Bromide	R	R	R	R	R	R	N	R	S
Sodium Chloride	R	R	R	R	R	R	N	R	R
Sdoium Cyanide	R	S	R	S	R	R	S	R	S
Sodium Nitrate	R	S	R	S	R	R	S	R	S
Zinc Chloride	S	N	R	S	R	R	N	S	N
OXIDIZING AGENTS									
Bromine	S	N	S	O	R	R	R	S	N
Calcium Hypochlorite	R	S	R	O	R	R	R	S	N
Chlorine	S	N	S	O	R	R	R	S	N
Fluorine	S	N	S	O	R	R	N	N	N
Iodine	R	N	R	O	R	R	R	R	N
Ozone	R	O	R	O	S	R	R	O	N
Peracetic Acid	S	S	O	S	R	R	R	O	N
Potassium Chlorite	R	S	R	S	R	R	R	S	N
Postassium Permanganate	N	S	R	O	N	R	R	S	N
Sodium Hypochlorite	S	S	R	O	R	R	R	S	N
Sodium Clorate	O	O	O	O	S	R	R	R	N
Sulfur Trioxide	S	N	R	N	R	R	R	N	N

BAGHOUSE SIZING

Baghouses do not operate according to fractional efficiency curves. In other words, a baghouse cannot be designed to yield a given collection efficiency no matter how much information is available on the process gas flow, particle concentration, particle size distribution, etc. A designer of a baghouse system knows that the collection efficiency of the baghouse will be very high (and the outlet concentration to atmosphere will be very low) but he has no idea precisely what it will be.

Baghouse systems are designed from experience on the same or similar applications. Most often the choice of what particular type of baghouse to use (i.e., inside vs. outside; shake vs. reverse air vs. pulse; etc.) is based on one of the following:

a) The manufacture only builds one kind.
b) Although the manufacturer builds several types, he has had good results with a particular type (conversely, he may have had terrible results with a particular type and will never design it into a system again on this application).
c) The customer specifies a particular type because either he personally has had good results with it or because his industry has, more or less, standardized on it.

The fundamental design parameter around which the baghouse is sized is the air-to-cloth ratio. Size is related to air-to-cloth ratio by the following simple equation.

$$NBS = \frac{Q}{AC} \qquad (1)$$

where:

NBS = Net baghouse size - square feet of filter area.
Q = Gas flow rate through the baghouse - actual cubic feet of gas per minute.
AC = Air-to-cloth-ratio - feet per minute.

The actual baghouse is usually larger than the calculated net for compartmentized baghouses because an extra compartment must be added for cleaning and often an extra is also added for on-line maintenance. The gas flow rate is usually calculated or measured and the air-to-cloth ratio is selected by the designer and depends on the type of baghouse and the application. Air-to-cloth ratio is never calculated, it is selected. The air-to-cloth ratio range commonly used for the various types of baghouses is given below:

1) Outside bag collectors using felted bags - (6 to 12)
2) Outside bag collectors using woven bags - (approx. 4)
3) Shaker - (2 to 3.5)
4) Reverse air - (1.5 to 2.5)
5) Combinations of above vary widely.

OPERATION

The two most important operating parameters for any baghouse are the emission level and the pressure drop.

1. EMISSIONS. A major operating parameter of any baghouse is that of the emission level. Either the system meets emission standards or it doesn't. Generally, a properly operating baghouse, under most conditions, should have no visible emissions (with the exception of steam). Excessive emissions will be caused anytime the integrity of the interface between the clean and dirty air plenum is broken. In other words, damaged or worn out bags, or broken welds or other structural damage to the tubesheet, cell plate or housing.

2. PRESSURE DROP. This is the resistance the gas stream encounters as it flows through the baghouse. The greater the resistance, the more power is required to force the air through the system. If resistance is too great, there will not be enough power to move the air and ventilation at the source will not be adequate. Each baghouse is designed to operate at a certain pressure drop or range of pressure drops. Pressure drop is usually measured in inches of water. The correct pressure drop is whatever it was designed to be; in some cases this may be 2" and in others 10" - 12". During normal operation, if the baghouse is functioning properly, the pressure drop should remain fairly steady. If it begins to rise or drop suddenly, or gradually creeps up during the day, that is an indication of a problem.

Competent operation of a baghouse will, coupled with good maintenance, insure low emissions at an acceptable pressure drop (assuming an adequate system design). Competent operation means proper initial start-up, proper routine start-up, and shut-down, and proper monitoring.

Initial Start-up

When a baghouse system is first installed, it is essential to conduct a pre-start-up inspection, not only of the baghouse itself but of the entire system, including such items as motor rotation, electrical functions, calibration of all indicating equipment, etc. This procedure should be followed even if the unit was factory assembled.

a) Inspect the baghouse interior for debris. Pieces of metal, nuts, bolts, welding rod pieces, etc., can destroy bags, screw conveyors and even fan blades.

b) Inspect baghouse interior for leaks. A baghouse should be air tight. Even pinpoint holes can cause future problems. An easy method for checking leaks, before initial start-up, is to go inside the baghouse, close the doors, extinguish the lights and look for "stars". (NOTE: Always follow recommended safety procedures when entering a baghouse).

c) Check bolted together sections to be sure all bolts are in place and tightened down.

d) Check bag connections for tight clamps.

e) Check bag tensioning on inside collector systems.

f) Check gaskets on all doors.

g) Adjust cleaning mechanism as recommended by manufacturer.

Routine Start-up and Shut-down

On any process other than the most simple dust collection operations, a specific start-up procedure should be provided by the manufacturer. If hot, moist gases are to be filtered, pre-heating will raise the interior temperature above the dewpoint and reduce chances for destructive condensation. A baghouse can be pre-heated either by heaters in each compartment or by recirculating gas through the system and heating it, or by starting a process on some fuel that will not cause dust or acid dewpoint (such as gas or oil firing a boiler before switching over to coal firing). Pre-heating will vary with the application as to both time and temperature necessary to avoid condensation.

After routine shutdown, keep the fan running long enough after the process has been shut down to purge corrosive gases from the system. Also, it may be important to run the cleaning cycle long enough to clean most of the dust from the fabric so that you start with clean bags the next shift. It may also be important not to do this so you start with an adequate filter cake.

Routine Monitoring

As mentioned before, the two major indicators of a baghouse's performance are its collection efficiency and its pressure drop. As long as pressure drop is satisfactory, the proper amount of air is moving through the baghouse; and as long as the air is clean, the system is doing what it is designed to do. Simply speaking, someone needs to visually check the baghouse's pressure gauge and stack at regular intervals. Continuous stack monitors and pressure drop recorders can be used where necessary. Careful monitoring and reporting on a dust collector is not considered as essential as it is on a process baghouse. But the operator should monitor and keep records on any system as if he

were sure that one day he would have a major problem and will have to call the baghouse manufacturer for assistance. If the manufacturer has no idea of the history of the system, it is not uncommon to have to rebag the entire unit and then watch it fail again simply to monitor what happens as it fails so the problem can be corrected. Routine inspection, therefore, should always involve routine recording and accurate record keeping. Special monitoring may be necessary in certain high temperature applications. There are heat sensitive materials, for example, which can be placed on bags and which will change color if the bag is exposed to excessive temperatures.

One good monitoring technique is to draw up a gridwork of the baghouse and plot bag failures on this grid. It should also be noted where, on the bags, failure usually occurs, such as top, bottom, or middle, and the nature of the failure, whether it is, say, a burn, a hole, or a rip. Typical monitoring and indicating devices include:

--Pilot lights to show that the baghouse is operating properly. Pilot lights show what motors are operating, which compartments are off or on-line, which rows of bags are being pulsed, frequency of pulsing, etc.

--Opacity meters which can show even a slight drop in filtering efficiency which would not be detectable by the human eye.

--Pressure drop indicators such as magnehelic gauges or manometers to show any change in pressure drop during operation. Recorders may also be used for a permanent record of pressure drop.

--Temperature indicators and/or records to show when meximum operating temperatures are reached.

--Gas flow meters indicate the amount of air moving through the system.

--Corrosion chips can be placed at strategic points in the dirty air stream. These should be made of the same metal as the baghouse and should be inspected and measured regularly to determine if corrosion is a serious problem.

MAINTENANCE

Here we are concerned with maintenance of the baghouse and several important system components. Bag maintenance, per se, is discussed later.

Routine Maintenance

The key to a good maintenance program is record keeping. The hallmark of a good routine maintenance program is no breakdowns.

1) Establish proper inspection intervals for all moving mechanical assemblies (and bags) based on manufacturer's recommendations. A typical scheme is listed in Table 2.

2) Keep a record of all inspections and maintenance work performed. A typical speciman is shown in Figure 4.

Troubleshooting

The key to good troubleshooting is smart maintenance men and adequate spare parts on hand. The hallmark of good troubleshooting is getting back in production fast after a breakdown. A list of suggested spare parts is given in Table 3 and a troubleshooting guide is shown in Table 4.

BAG MAINTENANCE

Bag maintenance is divided into two distinct categories: 1) location and repair of individual bag failures, and 2) complete bag changeout of an entire unit.

Location and Repair of Individual Failures

On a process baghouse, individual repair requires the most amount of time. In an ideal baghouse, all bags would last their required time and then all would fail on the same day. This, of course, never happens (unless there is a fire in the baghouse). There are variances in fabric quality, in bag manufacturing techniques, tolerances, gas flow distribution inside the baghouse, areas of greater and lesser condensation problems, variations in the bag cleaning mechanism, etc. Any one or any combination of these and other factors can cause bags to fail prematurely.

It is typical to find any baghouse experiencing some small number of failures during the first month or two of operation. These failures generally are due to manufacturing or installation defects. Later on there will be a period of few bag failures until you begin to reach the end of the operating life of a set of bags. Then occasional failures will show up, followed by an increasing rate of failure to the point where it becomes expeditious to change out all of the bags.

The first indication that bag failures have occurred can come through routine inspection or by noticing a visible emission

TABLE 2
PERIODIC MAINTENANCE

Daily

1. Check pressure drop.

2. Observe stack (visual or with opacity meter).

3. Walk through system listening for proper operation (audible leaks, proper fan and motor functions, bag cleaning system, etc.).

4. Note any unusual occurrence in the process being ventilated.

5. Observe all indicators on control panel.

6. Check compressed air pressure.

7. Assure that dust is being removed from system.

Weekly

1. Inspect screw conveyor bearings for lubrication (do not lubricate).

2. Check packing glands.

3. Operate all damper valves (isolation, by-pass, etc.).

4. Check compressed air lines, including line oilers and filters.

5. Check bag cleaning sequence to see that all valves are opening and closing porperly.

6. (Inside bag collectors) Spot check bag tension.

7. (High temperature applications) Verify accuracy of temperature indicating equipment.

8. Check pressure drop indicating equipment for plugged lines.

Monthly

1. (Shaker) Check all shaker mechanism moving parts.

2. Inspect fans(s) for corrosion and material buidl-up.

3. Check all drive belts and chains for wear and tension.

6. Check all hoses and clamps.

TABLE 2 (continued)

7. Check accuracy of all indicating equipment.

8. Inspect housing for corrosion.

Quarterly

1. Inspect baffle plate for wear.

2. Thoroughly inspect bags.

3. Check duct for dust build-up.

4. Observe damper valves for proper seating.

5. Check gaskets on all doors.

6. Inspect paint.

7. Check screw conveyor flighting.

Annually

1. Check all bolts.

2. Check welds.

3. Inspect hopper for wear.

Figure 4

Baghouse Inspection Report

Company _____ Application _____ Date _____ Name _____

Check	Good	Needs Attn.
Serial No. _____		
( ) Structural-Bolts	( )	( )
( ) Ladder Assembly	( )	( )
( ) Airlock	( )	( )
( ) Drive Assembly		
A. Gear Reducer	( )	( )
B. Drive Shaft Align	( )	( )
C. Coupler Shaft	( )	( )
D. Bearings	( )	( )
E. Belts	( )	( )
F. Sheaves	( )	( )
G. Serial No. (Motor) _____		
H. H.P. _____		
I. R.P.M. _____		
J. Sheave Size _____		
( ) Transfer Screw Assy.	( )	( )
( ) Fan		
A. Serial No. _____		
B. Model No. _____		
D. Make _____		
E. Sheaves	( )	( )
F. Sheave Diameter	( )	( )
G. Shaft Diameter	( )	( )
H. Series of Belts _____		
I. Shaft Diameter _____		
J. Make _____		
( ) Water Trap	( )	( )
( ) Air Regulator	( )	( )
( ) Bin Indicator	( )	( )
( ) Magnehelic	( )	( )
( ) Magnehelic Tubing	( )	( )
( ) Baffle Wear	( )	( )

Item	Check	Good	Needs Attn.
15. ( )	Top Door Hold Down Straps	( )	( )
16. ( )	Top Door Leaks	( )	( )
17. ( )	Manifold Pipes Anchored	( )	( )
18. ( )	Manifold Pipes Holes		
19. ( )	Manifold Pipes Center Over Venturi	( )	( )
20. ( )	Venturi Properly Seated	( )	( )
21. ( )	Cages Properly Installed	( )	( )
22. ( )	Bag Clamps	( )	( )
23. ( )	Bags-Visolite R	( )	( )
24. ( )	Bags-General Appear.	( )	( )
25. ( )	Service Module		
	A. Wire Connections Terminal Box	( )	( )
	B. Wire Connections		
	C. Diaphram Valves-Leaks	( )	( )
	D. Solenoid Valves Operating	( )	( )
	E. Hoses & Clamps	( )	( )
	F. Air Pressure-Leak PSI	( )	( )
26. ( )	Pulse Control Panel	( )	( )
27. ( )	Control Panel	( )	( )
28. ( )	Dialatrol	( )	( )
29. ( )	Thermocouple	( )	( )
30. ( )	Thermocouple Wiring	( )	( )

Item	Check	Good	Needs Attn.
31. ( )	Timer Settings		
	A. Duration _____		
	B. Interval _____		
32. ( )	Delta P		
	A. Low _____		
	B. High _____		
	C. Average _____		
33. ( )	P.S.I. at Header		
	A. Low _____		
	B. High _____		
34.	Average Temp. In Baghouse _____		
35.	Visual Stack Emission Clean ____ Dirty ____		
36. ( )	Paint		
	A. Interior	( )	( )
	B. Exterior	( )	( )

NOTES

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TABLE 3
SUGGESTED SPARE PARTS

Following is a list of spare parts that should be kept on hand. Quantities of parts will vary as to manufacturer's suggestion and the type of process.

- Bags
- Bag support cages (reverse pulse and plenum pulse)
- Bag clamps
- Seals and caulking material
- Solenoids
- Diaphragms
- Timer components
- Baffle plates or wear plate sections for baffle
- Bag connecting rods (shaker and reverse flow)
- Tensioning springs (reverse flow)
- Belts for shaker mechanism (shaker)
- Motor for shaker mechanism (shaker)
- Fan belts
- Spare bearings and gasketing for all mechanical components

TABLE 4
TROUBLESHOOTING GUIDE

The following chart lists the most common problems which may be found in a baghouse air pollution control system and offers general solutions to the problems. There are a number of instances in which the solution is to consult the manufacturer. This may not be necessary in plants that have sufficient engineering know-how available.

Where the information applies to a specific type of baghouse, the following code is used:

RP. . . . . Reverse Pulse
PP. . . . . Plenum Pulse
S. . . . . Shaker
RF. . . . . Reverse Flow

Symptom	Cause	Remedy
High Baghouse Pressure Drop	Baghouse undersized	Consult manufacturer Install double bags Add more compartments or modules
	Bag cleaning mechanism not adjusted properly	Increase cleaning frequency Clean for longer duration Clean more virorously
	Compressed air pressure too low (RP,PP)	Increase pressure Decrease duration and/ or frequency Check dryer and clean if necessary Check for obstruction in piping
	Repressuring pressure too low (RF)	Speed up repressuring fan Check for leaks Check damper valve seals
	Shaking not strong enough (S)	Speed up shaker speed
	Isolation damper valves not closing S,RF,PP)	Check linkage Check seals Check air supply on pneumatic operators

TABLE 4 (continued)

Symptom	Cause	Remedy
	Bag tension too loose (S)	Tighten bags
	Pulsing valves failed (RP)	Check diaphragm Check pilot valves
	Cleaning timer failure	Check to see if timer is indexing to all contacts Check output on all terminals
	Not capable of removing dust from bags	Condensation on bags (see below) Send sample of dust to manufacturer Send bag to lab for analysis for blinding Dry clean or replace bags Reduce air flow
	Excessive re-entrainment of dust	Continuously empty hopper Clean rows of bags randomly, instead of sequentially (PP,RP)
	Incorrect pressure reading	Clean out pressure taps Check hoses for leaks Check for proper fluid in manometer Check diaphragm in gauge
Low Fan Motor Amperage/Low Air Volume	High baghouse pressure drop	See above
	Fan and motor sheaves reverse	Check drawings and reverse sheaves
	Ducts plugged with dust	Clean out ducts and check duct velocities
	Fan damper closed	Open damper and lock in position

TABLE 4 (continued)

Symptom	Cause	Remedy
	System static pressure too high	Measure static on both sides of fan and review with design Duct velocity too high Duct design not proper
	Fan not operating per design	Check fan inlet configuration and be sure even air flow exists
	Belts slipping	Check tension and adjust
Dust Escaping At Source	Low air volume	See above
	Ducts leaking	Patch leaks so air does not by-pass source
	Improper hood design	Close open areas around dust source Check for cross drafts that overcome suction Check for dust being thrown away from hood by belt, etc.
Dirty Discharge At Stack	Bags leaking	Replace bags Tie off bags and replace at later date Isolate leaking compartment if allowable without upsetting system
	Bags clamps not sealing	Check and tighten clamps Smooth out cloth under clamp and re-clamp
	Failure of seals in joints at clean/dirty air connection	Caulk or weld seams
	Insufficient filter cake	Allow more dust to build up on bags by cleaning less frequently Use a pre-coating of dust on bags (S,RF)

TABLE 4 (continued)

Symptom	Cause	Remedy
	Bags too porous	Send bag in for permeability test and review with manufacturer
Excessive Fan Wear	Fan handling too much dust	See above
	Improper fan	Check with fan manufacturer to see if fan is correct for application
	Fan speed too high	Check with manufacturer
Excessive Fan	Build-up of dust on blades	Clean off and check to see if fan is handling too much dust (see above) Do not allow any water in fan (check cap, look for condensation, etc.)
	Wrong fan wheel for application	Check with manufacturer
	Sheaves not balanced	Have sheaves dynamically balanced
	Bearings worn	Replace bearings
High Compressed Air Consumption (RP,PP)	Cleaning cycle too frequent	Reduce cleaning cycle if possible
	Pulse too long	Reduce duration (after initial shock all other compressed air is wasted)
	Pressure too high	Reduce supply pressure if possible
	Damper valves not sealing (PP)	Check linkage Check seals
	Diaphragm valve failure	Check diaphragms and springs Check pilot valve

TABLE 4 (continued)

Symptom	Cause	Remedy
Reduced Compressed Air Pressure (RP,PP)	Compressed air consumption too high	See above
	Restrictions in piping	Check piping
	Dryer plugged	Replace dessicant or by-pass dryer if allowed
	Supply line too small	Consult design
	Compressor worn	Replace rings
Premature Bag Failure - Decomposition	Bag material improper for chemical composition of gas or dust	Analyze gas and dust and check with manufacturer Treat with neutralizer before baghouse
	Operating below acid dew-point	Increase gas temperature By-pass and start-up
Moisture in Baghouse	Insufficient pre-heating	Run system with hot air only before starting process gas flow
	System not purged after shut-down	Keep fan running for 5-10 minutes after process is shut down
	Wall temperature below dew-point	Raise gas temperature Insulate unit Lower dew-point by keeping moisture out of system
	Cold spots through insulation	Eliminate direct metal lines through insulation
	Compressed air introducing water (RP,PP)	Check automatic drains Install aftercooler Install dryer
	Repressuring air causing condensation (RF,PP)	Pre-heat repressuring air Use process gas as source of repressuring air

TABLE 4 (continued)

Symptom	Cause	Remedy
High Screw Conveyor Wear	Screw conveyor under-sized	Measure hourly collection of dust and consult manufacturer
	Conveyor speed too high	Slow down speek
High Airlock Wear	Airlock undersized	Measure hourly collection of dust and consult manufacturer
	Thermal expansion	Consult manufacturer to see if design allowed for thermal expansion
	Speed too high	Slow down
Material Bridging in Hopper	Moisture in baghouse	See above
	Dust being stored in hopper	Remove dust continuously
	Hopper slope insufficient	Re-work or replace hoppers
	Conveyor opening too small	Use a wide flared trough
Frequent Screw Conveyor/Airlock Failure	Equipment undersized	Consult manufacturer
	Screw conveyor misaligned	Align conveyor
	Overloading components	Check sizing to see that each component is capable of handling a 100% de-livery from the previous item
High Pneumatic Conveyor Wear	Pneumatic blower to fast	Slow down blower
	Piping undersized	Review design and slow blower or increase pipe size

TABLE 4 (continued)

Symptom	Cause	Remedy
	Elbows too short radius	Replace with long radius elbows
Pneumatic Conveyor Pipes Plugging	Overloading pneumatic conveyor	Review design
	Slug loading of dust	Meter dust in gradually
	Moisture in dust	See above
Fan Motor Overloading	Air volume too high	See below
	Motor not sized for cold start	Dampen fan at start-up Reduce fan speed Provide heat faster Replace motor
Air Volume Too High	Ducts leaking	Patch leaks
	Insufficient static pressure	Close damper valve Slow down fan
Reduced Compressed Air Consumption (RP,PP)	Pulsing valves not working	Check diaphragms Check springs Check pilot valves
	Timer failed	Check terminal outputs
High Bag Failure-Wearing Out	Baffle plate worn out	Replace baffle plate
	Too much dust	Install primary collector
	Cleaning cycle too frequent	Slow down cleaning
	Inlet air not properly baffled from bags	Consult manufacturer
	Shaking too violent (S)	Slow down shaking mechanism

TABLE 4 (continued)

Symptom	Cause	Remedy
	Repressuring pressure too high (RF)	Reduce pressure
	Pulsing pressure too high (RP,PP)	Reduce pressure
	Cages have barbs (RP,PP)	Remove and smooth out barbs
High Bag Failure-Burning	Stratification of hot and cold gases	Force turbulence in duct with baffles
	Sparks entering baghouse	Install spark arrestor
	Thermocouple failed	Replace and determine cause of failure
	Failure of cooling device	Review design and work with manufacturer

or an increased reading on a stack monitoring device. At this time, it is necessary to inspect for bag failure.

In a compartmented baghouse, it is possible to monitor the stack while isolating one compartment at a time. Through this technique, any compartment which has experienced significant bag failures can be discovered easily because stack emissions will be reduced when the compartment in question is turned off.

In non-compartmented baghouses, or if no single compartment is responsible for the majority of emissions, it may be necessary to check the entire unit for failed bags. There are no different approaches used to locate failed bags - the major difference being in whether it is necessary to enter the unit to look for failed bags.

There are three basic ways to search for leaking bags: 1) hunt for the hole itself, 2) hunt for an accumulation of dust which can be related to a nearby hole, and 3) use some detecting device.

Inside collectors experience their most frequent bag failure near the bottoms of the bags. If this is the case, an accumulation of dust on the cell plate or near the failure sometimes will be visible and relatively easy to spot, provided the failure is near the walkway. If the failure is higher up on the bag, it will be more difficult to find because dust will be distributed over a wide area of the cell plate. In this case, it is necessary to inspect the entire circumference and length of every bag.

With top bag access on outside collectors, it is normally very difficult to see the exact failure; however, in many applications a dust accumulation on the tubesheet or on the blow pipe running over a failed bag will be readily noticeable.

The difficulty in finding a failed bag will vary with the application and type of material being filtered.

One of the newest and most effective techniques that has been found to locate failed bags is to inject a quantity of florescent or phosphorescent dust into the baghouse and then inspect the clean air plenum with a black light. The dust from even very small leaks is easily visible as it glows under the black light.

On inside collectors it is necessary to scan the entire length of the bag with the black light to pinpoint the failure. On outside collection units the florescent powder will be drawn through the hole in the bag and will be easily visible either on the venturi or around the blow pipe over the venturi.

Use of this florescent powder technique is also effective in spotting broken welds or other leaks in the baghouse tubesheet, cell plate or housing.

In the past it was considered good maintenance procedure to immediately replace a failed bag with a new one. Recently, however, it has been found that a new bag in the vicinity of old ones will be forced to take a higher percentage of the dust loading because the resistance is lower than that of the "seasoned" bags. It was not uncommon to replace a bag one month and then the next month to find the very same bag once again needing replacement.

Also, individual one at a time bag replacement is quite costly in man-hours on a per bag basis. More recently, it has become an accepted technique to simply seal off the failed bag until a significant number of bags have been sealed that the pressure drop increase, at which time all the sealed off bags are replaced simultaneously. In most cases, 2% to 3% of the bags (sometimes even up to 10% or more) can be plugged before noticing a change in pressure drop.

On inside collectors if the failure has not occurred too close to the cell plate, the bad bag can be cut, tied in a knot and stuffed inside the cell plate. If the failure is too close to the cell plate, it is advisable to plug the hole. In top access outside collection baghouses, a plug is simply placed over the failed bag.

There are commercially available plugs, although a plate of steel with gasketing material will also work. The gasketing material should be made out of the same type of material as the bag. When using homemade plugs, it should be noted that they must be heavy enough to resist the pressure differential, otherwise the seal will be knocked out of place.

It is important on inside collectors to replace a plug failed bags as soon as possible because of the "domino effect" in which a hole in one bag will cause one to appear in an adjacent bag and then that bag will cause a hole to appear in another bag and so forth.

It is important to keep track of the rate of failure of individual bags. As the rate of failure begins to rise, it is possible to predict the end of bag life and schedule complete changeout of all bags at a convenient time. This is less costly than changing individual bags, say month by month.

Complete Bag Changeout

1. Baglife

Depending upon a variety of factors, sooner or later, probably within two to five years, the original bags will wear out. At that time a complete changeout is required.

If inadequate bag life is obtained through no fault of the operator, it may be possible to charge the manufacturer due to either an express or implied warranty.

a) Express warranty. Several years ago baghouse manufacturers uniformly refused to give express bag life warranties. Now the opposite is true and virtually all manufacturers will give at least a pro-rated warranty.

b) The UCC, which is law in every state (with the possible exception of Louisiana) will give the operator the benefit of the implied warranties of "merchantibility" and "fitness for a particular purpose" unless they are specifically disclaimed by the manufacturer in writing. "Merchantibility" means that the baghouse is of good quality and "fitness for a particular purpose" means that if the operator makes his intended use of the baghouse known to the manufacturer and relies on his expertise, the manufacturer must supply a baghouse "fit" for that "purpose".

2. Changeout

When bag replacement is necessary, first de-bag the collector and save all the useable parts such as cages, venturis, and clamps. It may be desirable to vacuum out the baghouse to provide a more comfortable and safer working environment. Care should be taken when installing new bags to avoid tears, punctures and rips in the bags. Also, all clamps, seals, gaskets, etc., should be checked after rebagging. When putting bags on cages, the bags should not be twisted, as damage could occur.

If bolt-on clamps are used to hold bags in place, it should be noted that pneumatic wrenches are available in the $100 to $200 price range. One pneumatic wrench will pay for itself not only in time saved during the first bag changeout, but in assuring that all clamps are properly tightened down.

There are new mechanized bag changeout procedures today whereby an entire compartment of bags can be withdrawn all at once and a new pre-bagged cartridge installed through the use of a crane, usually mounted on top of the system. The old cartridge is removed to a remote location where it can later be re-bagged at a convenient scheduled time and held in readiness for use on another compartment of the system as the need arises.

COST

What is the total cost of owning, operating, and maintaining

a baghouse system? Figure 5 attempts to give a breakdown of an answer to this question that would satisfy both an engineer and an accountant (if such a thing is possible).

Some equations are presented below that predict (probably within plus or minus 25%) the annual cost of operating and maintaining a typical large baghouse system using a reverse flow baghouse. The annual operating cost a reverse flow baghouse is composed of:

1. Main fan power cost.
2. Reverse flow fan power cost.
3. Dust handling system power.
4. Direct operating labor.

ID Fan Power Cost

Te ID fan power cost for a baghouse is given by Equation 2.

$$FPC_B = 1.17 \cdot \frac{10^{-4} \cdot Q \cdot \Delta P \cdot AH \cdot PC}{E_f} \qquad (2)$$

where:

FPC_B = Fan power cost attributable to baghouse, 1978 dollars/year,
Q = Gas, flow rate, acfm,
ΔP = Operating pressure drop, kn. (probably about 6" W.G.),
AH = Annual hours of operation, hr/year
PC = Local cost of electrical power, dollars/kWh (see Table 3), and
E_f = Efficiency of ID fan, fraction,
= 0.6 approximately.

Reverse Flow Fan Power Cost

The annual cost incurred to clean bags via the reverse flow fan is given by Equation 3.

$$BCP_R = 1.1 \cdot 10^{-4} \cdot \frac{GCA \cdot \Delta P \cdot AH \cdot PC}{(N_{CN} + 2)} \qquad (3)$$

where:

BCR_R = Annual bag cleaning cost for reverse flow baghouse, 1978 dollars/year,
GCA = Gross cloth area, ft^2,
ΔP = Operating pressure drop, in WG (probably about 6" W.G.),
AH = Annual operating hours, hr/year,
PC = Local power cost, 1978 dollars/kWh, and

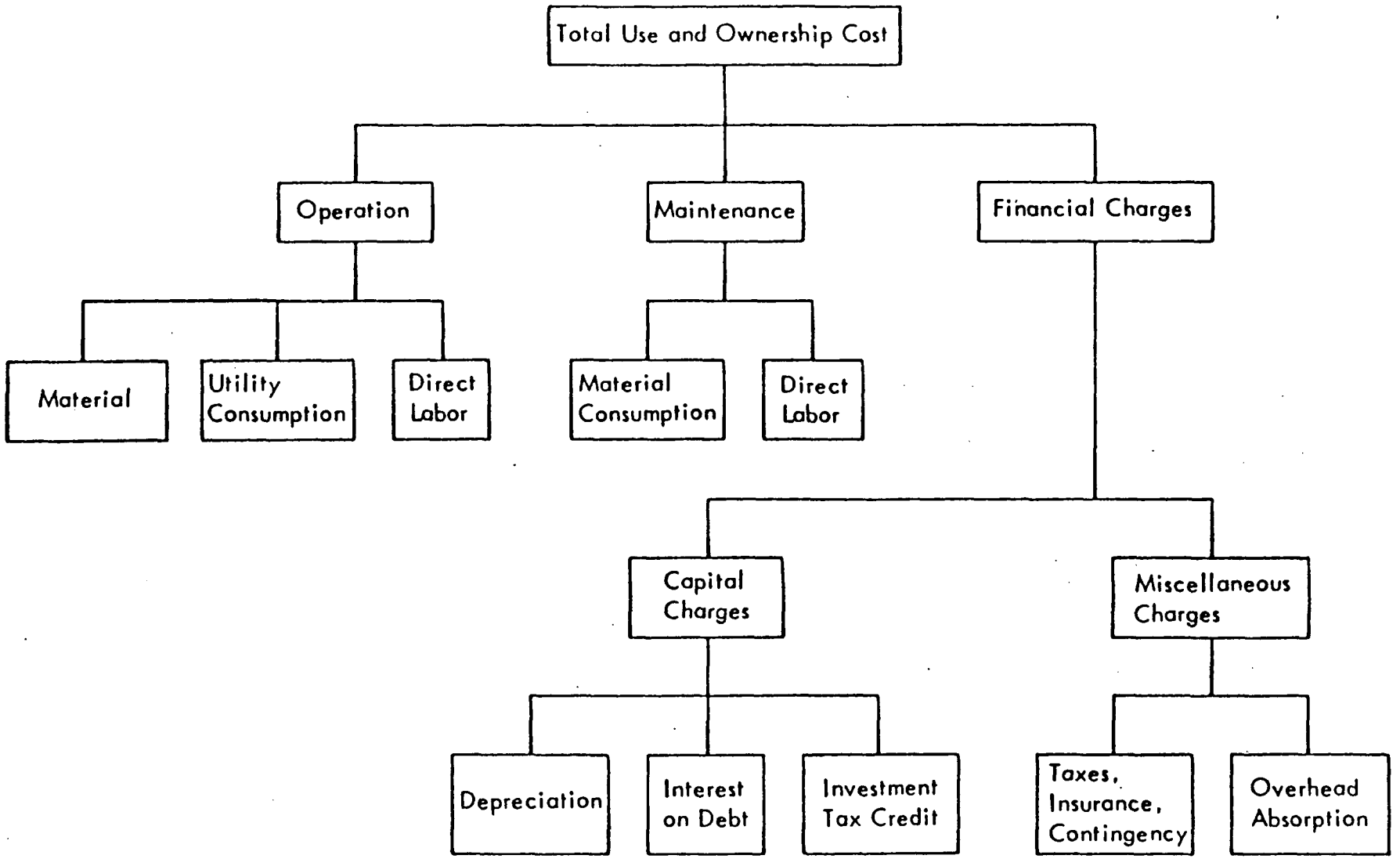

Figure 5- Cost Breakdown

N_{CN} = Net number of baghouse compartments (total number of compartments less one for cleaning and one for maintenance).

Dust Handling System Power

The annual power cost to run the dust handling system is given by Equation 4.

$$ASH_P = 0.435 \cdot PC \cdot DB \cdot AH \quad (4)$$

where:

ASH_P = Annual power cost to run system, 1978 dollars/year,
PC = Local power cost, 1978 dollars/kWh,
DB = Dust burden, ton/hr, and
AH = Annual hours of operation, hrs/year.

Annual Operating Labor

The annual labor and maintenance cost, other than bag replacement cost, is given by Equation 5.

$$OL_{RB} = AWF\ (0.249\ GCA^{0.966} + 0.089\ GCA + 5.850) \quad (5)$$

where:

OL_{RB} = Annual direct operating labor, 1978 dollars/year,
AWF = Area wage factor (see Table 3), unitless, and
GCA = Gross cloth area, ft^2.

Maintenance Costs

The cost of maintaining a baghouse is divided into:

1. Direct labor (other than replacing bags).
2. Parts and materials (other than replacement bags).
3. Direct labor to replace bags.
4. Bag cost.

Direct Labor (other than replacing bags)

$$ML_B = 0.04 \cdot GCA \cdot AWF \quad (6)$$

where:

ML_B = Annual direct maintenance labor (other than bag replacement), 1978 dollars/year,
GCA = Gross cloth area, ft^2, and
AWF = Area wage factor, unitless.

Parts and Materials (other than replacement bags)

$$MMB = 0.04 \cdot GCA \quad (7)$$

where:

MMB = Baghouse annual maintenance material cost, 1978 dollars/year (other than bags), and
GCA = Gross cloth area, ft^2.

Bag Replacement

Bags represent a substantial portion of the total baghouse system investment and they must be replaced periodically as they wear out. This section deals with the cost of bag replacement and focuses on:

1. Material cost, i.e., the cost of the replacement bags themsleves.

2. Labor cost, i.e., the direct labor necessary to install the replacement bags.

3. Frequency, i.e., the number of times the bags must be replaced over 30 years or, in other words, in-service bag life.

Material Cost

The cost of a set of replacement bags is given by Equation 8.

$$RBC_R = 0.78 \cdot GCA \quad (8)$$

where:

RBC_R = The cost of a set of replacement bags, 1978 dollars/year, and
GCA = Gross cloth area, ft^2.

Equation 8 is based on one foot diameter by 35 ft. long fiberglass bags. The equation can be used for other bag materials by biasing with information contained in Table 5.

Labor

The labor required to change a set of bags in a reverse flow baghouse is given by Equation 9.

$$BRL_R = 0.021 \cdot GCA \cdot AWF \quad (9)$$

where:

BRL_R = Bag replacement labor, 1978 dollars,
GCA = Gross cloth area, ft^2, and
AWF = Area wage factor, unitless.

TABLE 5
APPROXIMATE COST OF REPLACEMENT BAGS

Material	1977 Cost (dollars)
Nylon (5.3 oz/yd^2)	0.64/ft^2
Sewn in ring	2.00 each
Polyester (7 oz/yd^2)	0.31/ft^2
Sewn in ring	1.30 each
Fiberglass (silicon/graphite finish; 9 oz/yd^2)	0.26/ft^2
Sewn in ring	1.25 each
Fiberglass (10% PTFE finish; 9 oz/yd^2)	0.42/ft^2
Sewn in ring	1.50 each
Top caps (mild steel, 12 in. dia.)	2.80 each
Stainless steel clamps	1.75 each

TABLE 6
COSTS THAT VARY WITH LOCATION

State	$/kWh	Area Wage Factor
Alabama	0.0322	0.89
Alaska	0.0354	1.79
Arizona	0.0451	1.00
Arkansas	0.0315	0.78
California	0.0371	1.06
Colorado	0.0346	1.03
Connecticut	0.0450	1.01
Delaware	0.0529	1.11
Florida	0.0433	0.84
Georgia	0.0457	0.81
Hawaii	0.0489	1.00
Idaho	0.0232	1.03
Illinois	0.0460	1.12
Indiana	0.0320	1.19
Iowa	0.0435	1.15
Kansas	0.0382	0.96
Kentucky	0.0281	1.01
Louisiana	0.0356	1.06
Maine	0.0335	0.81
Maryland	0.0470	1.08
Massachusetts	0.0479	0.93
Michigan	0.0475	1.33
Minnesota	0.0349	1.07
Mississippi	0.0445	0.76
Missouri	0.0381	1.02
Montana	0.0194	1.27
Nebraska	0.0297	0.97
Nevada	0.0330	1.05
New Hampshire	0.0387	0.82
New Jersey	0.0564	1.04
New Mexico	0.0366	0.80
New York	0.0783	1.02
North Carolina	0.0326	0.74
North Dakota	0.0371	0.92
Ohio	0.0435	1.20
Oklahoma	0.0314	0.95
Oregon	0.0209	1.13
Pennsylvania	0.0461	1.05
Rhode Island	0.0458	0.80
South Carolina	0.0332	0.77
South Dakota	0.0326	0.87
Tennessee	0.0270	0.85

TABLE 6 (continued)

State	$ / kWh	Area Wage Factor
Texas	0.0364	0.99
Utah	0.0277	0.93
Vermont	0.0362	0.84
Virginia	0.0432	0.85
Washington	0.0143	N/AVAIL
West Virginia	0.0342	1.10
Wisconsin	0.0358	1.11
Wyoming	0.0221	1.03

VI-2.

BAGHOUSES
WHAT TO KNOW BEFORE YOU BUY

by

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Standard Havens, Inc.

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Baghouses – What to Know Before You Buy

By S. A. REIGEL, R. P. BUNDY and C. D. DOYLE, Standard Havens Inc., Glasgow, Mo.

With the advent of stricter emission standards designed to produce the national quality standard of 75μg/m³ of particulate, only the most efficient removal devices will be suitable. The baghouse traditionally yields high removal efficiences (99.9 + percent).

A baghouse is a large metal box divided into two functional areas. The first of these, the dirty air plenum, may be a part of the baghouse proper or it may take the form of a distribution manifold. The function of the dirty air plenum is to distribute the fouled gas evenly to the filtering elements or bags. The baghouse hopper, which is the receptacle for collected material, is part of the dirty air plenum. The clean air plenum is that part of the baghouse where recombination of the air circuits from each of the individual bags takes place. The interface separating the clean air and dirty air plenums is the filtering media or bags.

There are three important mechanisms involved in removing particles from a flowing gas stream using filter media: impaction, interception, and diffusion. These three mechanisms which are responsible for collision of a particle on a target, are of paramount importance when the baghouse is first brought on line and the bags are clean. After a short time, however, the bags become caked with a layer of dust and this dust cake actually becomes the filtering medium. No matter how vigorously the bags are shaken, collapsed, or pulsed, a residual dust cake is retained after each on-line cleaning. The bags act primarily as a matrix to support the dust cake.

Baghouse Types

All baghouses operate in basically the same way: dirty gas is ducted to the unit where it is filtered by cloth tubes or bags. This filtering action is extremely efficient and results in virtually 100 percent of the entrained particulate remaining in the unit on the bags. The bags must be periodically purged of this collected material. The method used for this cleaning characterizes one type of baghouse from another.

All baghouses are either *intermittent* or *continuous automatic*. Intermittent baghouses are designed to be cleaned after the unit has ceased filtering, say at the end of the work day. Intermittent baghouses cannot be cleaned while on line, and thus are limited to low dust loadings or infrequent operation. They have the distinct advantage of being low priced. Continuous automatic baghouses, on the other hand, are more expensive but are able to operate 24 hours a day without rest and can handle high dust loadings.

Baghouses are characterized and identified according to the method used to remove collected material from the bags. This is accomplished in a variety of ways, including shaking the bags, reversing the direction of air flow through the bags, blowing a jet of air on the bags from a reciprocating manifold, or rapidly expanding the bags by a pulse of compressed air.

The bags in **shaker-type baghouses** are supported by a structural framework. The structural framework is free to oscillate when driven by a small electric motor, Fig. 1. Periodically, on a timed basis, a damper isolates a compartment of the shaker baghouse so that no air flows. The bags in that compartment are then shaken for approximately a minute during which time the collected dust cake is dislodged from the bags. The dust falls into the hopper for subsequent removal.

Reverse flow baghouses are equipped with an auxiliary fan that forces air through the bags in the direction opposite to filtration. This backwash action collapses the bag and fractures the dustcake. When the bag is reinflated by being brought back on-line, the fractured dustcake is dislodged into the hopper. If the unit operates under suction (the main fan is located on the "clean" side of the baghouse) reducing pressure in the baghouse may elimate the need for an auxiliary fan.

Reverse jet baghouses incorporate a jet case or manifold that surrounds each bag. The manifold travels the length of the bag in a constantly repeating cycle. As it passes over the surface of the bags, a jet of high pressure air issues from orifices in the manifold and blows the dust cake off the bags.

In recent years **reverse pulse baghouses**, Fig. 2, have enjoyed a rapidly increasing use. This design utilizes a short (usually less than 100 milliseconds) pulse of compressed air through a venturi, or diffuser, directed from the top to the bottom of the bag, Fig. 3. This primary pulse of air aspirates secondary air as it passes through the venturi. The resulting air mass violently expands the bag and casts off the collected dust cake. A modification of this technique is the *pressurized plenum type* of cleaning. In this case an isolated compartment above several rows of bags is supplied with pressurized air. The change in pressure differential across the bags when the damper is operated causes the bags to flex and cast off the dust cake.

The fundamental criterion used in applying any baghouse to any application is the "air-to-cloth ratio," defined as the ratio of actual volumetric air flow rate to net cloth area.

$$AC = \frac{Q}{A}$$

where: AC = Air to cloth ratio, fpm
Q = Volumetric air flow, acfm
A = Net cloth area, sq. ft

AC is equal to the superficial face velocity of the air as it passes through the cloth. Shaker and reverse air baghouses normally operate at an air-to-cloth ratio of from 1 to 3, while reverse pulse baghouses operate at about 3 to 6 times this range. Units which are cleaned with a compartment off-line must be outfitted with an extra compartment in order to keep a minimum net cloth area on line at all times. In extreme cases, this can double the size of the baghouse.

A second important operating characteristic is the "filter drag" given by:

$$S = \frac{\Delta P}{V}$$

where: S = Filter drag, in. H_2O/fpm
ΔP = Pressure drop across filter, in. H_2O
V = Superficial face velocity, fpm

As this equation indicates, baghouses do not obey the fan law, which states that the pressure drop varies as the square of the volumetric air flow. Virtually all other devices obey this law. Figure 4 shows the variation of filter drag during a cycle varying from "just cleaned" to "just before cleaning."

Filtering Bags

The most important components of any baghouses are the filtering elements, or bags. Perhaps less is known about predicting their in-service performance than about any other component. In general, bags are either woven or felted. Woven bags are used in shaker and reverse air baghouses; felted bags are used in reverse pulse, plenum pulse, and jet case baghouses.

Woven bags are usually furnished with a weight of 5 to 10 oz per sq yd and a permeability (acfm passing through one sq ft of cloth with pressure differential of 0.5 in. H_2O) of approximately 10 to 30 acfm. Felted bags are heavier and much fuzzier, weighing 10 to 20 oz per sq yd. They also have a permeability of approximately 10 to 30 acfm.

A common problem with many man-made fibers is their tendency to elongate under load and shrink at higher temperature. This lack of dimensional stability may cause a reduction in cleaning efficiency or premature mechanical failure of the bags. To avoid or minimize these problems, many fabrics are *heat-set*. Spun fabrics may also be singed or sheared for reducing the surface hairs in order to present a smooth surface to the dust cake, thus making it easier for the dust cake to dislodge during the cleaning cycle. Many other surface finishes and mechanical operations may be performed on the cloth to accomplish specific aims. Resin finishes provide a smoother surface; graphite finishes may be of value in eliminating build-ups of static charge; napping a fabric may help improve collection efficiency. Resins or graphite are used to improve abrasion resistance.

Limitations

Although baghouses operate at the highest collection efficiency level (99.9 + percent) all is not perfect. For a given application baghouses will probably be one of the more expensive solutions and will probably require the most space for installation (see Table). The cost of maintaining such facilities as settling ponds or providing chemical additives in wet systems may, however, offset this price disadvantage. Baghouses will generally require much less power to achieve high efficiency operation than water scrubbers and, of course, have no water requirements.

The highest maintenance component of a baghouse is the bags. The bags represent 20 to 40 percent of the equipment cost and probably have an average life of 18 to 36 months. This means that the unit will be rebagged from three to seven times assuming a 10 year amortization of the unit.

There are several causes for bag failure—blinding, caking, burning, abrasion, chemical attack, and aging. The circumstances that can cause the above to occur are varied—some due to normal operation, and some due to misapplication or improper operation. Blinding occurs when dust is captured within the bag material and the cleaning mechanism is unable to dislodge it. Either the cleaning mechanism is not powerful enough, or the nature of the dust is such that it can readily enter the fabric. Obviously blinding is the result of either misoperation (the cleaning mechanism is not powerful enough) or misapplication (the nature of the dust is at fault).

Caking is the formation of a solid mat of self-adhering dust on the dirty air side of the bag which cannot be removed by the normal cleaning mechanism of the dust collector. The most common cause of caking is the presence of water droplets in the gas stream which causes mud to form on the bags. This later dries into a hard cake. The water droplets can be caused by the

Fig. 1 Installation of shaker mechanism in shaker-type baghouse.

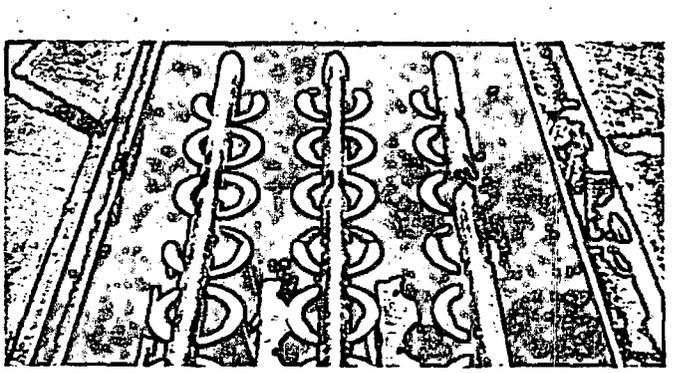

Fig. 2 Venturi and manifold in reverse pulse-type baghouse.

Rule-of-Thumb Costs of Typical Collectors of Standard Mild Steel Construction

Type of collector	Dollars per cubic feet per minute: Equipment cost	Erection cost	Yearly maintenance and repair cost
Mechanical collector	0.07-0.25	0.03-0.12	0.005-0.02
Electrostatic precipitator	0.25-1.00	0.12-0.50	0.01-0.025
Fabric filter	0.35-1.25	0.25-0.50	0.02-0.08
Wet scrubber	0.10-0.40	0.04-0.16	0.02-0.05

malfunction of water spray cooling equipment, or more commonly, from condensation.

Water, in the form of condensate, is a common cause of malfunction. If the temperature of the hot humid gas falls below the dew point temperature in the baghouse, water will condense, combine with the collected dust and blind the bags with mud. The gross gas temperature does not have to reach the dew point for this phenomenon to occur: only the metal skin of the baghouse need be below this temperature. For this reason many baghouses are insulated to retard heat transfer and maintain skin temperature above the dew point.

Two types of *burning* can destroy bags. Baghouses have a rather low temperature limitation ranging from 180 to 550 F. Consequently, on those applications generating high temperature off-gas, there is a practical limitation of using those fabrics able to withstand at least 400 F. Even then, a very reliable means of gas cooling, such as evaporative cooling, is required, (POLLUTION ENGINEERING, Nov./Dec. 1970). Even when the gas temperature is closely controlled, there is the possibility of a hot spark reaching the bags and burning a hole.

Abrasion is a natural phenomenon resulting from handling dust-laden gases. Some wear on bags occurs from direct impaction, but wear is greatly increased when dust strikes a bag tangentially. Elimination of abrasion is impossible, but proper design of a baghouse will retard this cause of bag failure by channeling the air in the least destructive way, and/or by holding gas velocity to a minimum.

The destruction of a bag by chemical attack is generally due to misapplication or misoperation. Processes which generate gases at elevated temperature frequently produce water vapor and acid radicals which, at a given temperature (the acid dew point), will react and form an acid vapor. The acid dew point is dependent upon the concentrations of the constituent in the gas, and is therefore very difficult to predict.

Bags also tend to wear out from aging. After hundreds of thousands of cleaning cycles, the fabric weakens and will ultimately fail. The occurrence is as unavoidable as human deterioration, but, like humans, the better the bag is cared for, and the better the original equipment design, the longer it will last.

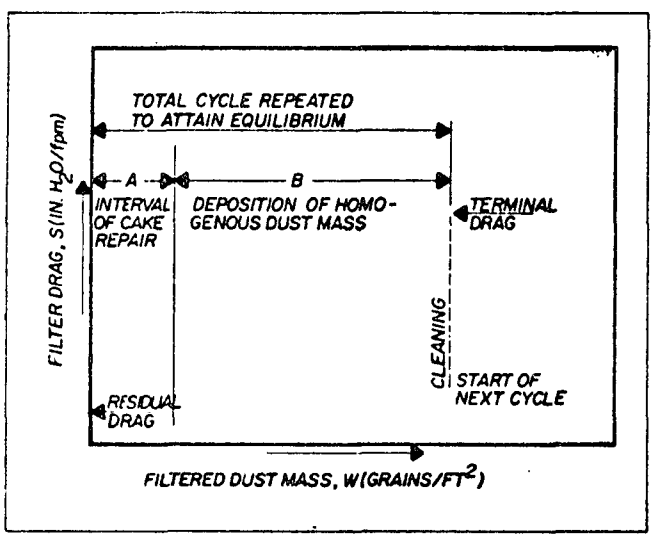

Fig. 3 Filter drag cycle.

How to Buy a Baghouse

If you have an air pollution or dust control problem in your plant and are considering purchasing a baghouse, here are some do's and don'ts:

DO: Write specifications that include volume, temperature, dust and water content of the gas stream. Specifications should clearly state the application.

DON'T: Specify crucial parameters such as air-to-cloth ratio. No one knows the manufacturer's equipment like the manufacturer. Trust him to make the correct decisions based on experience and require a performance guarantee.

DO: State the applicable code requirements and performance expected.

DON'T: Request a bag-life guarantee; most manufacturers won't give one.

DO: Spell out peripheral equipment you want quoted with baghouse; i.e., fan, motor, screw conveyor, etc. If you want a turnkey job, require that the equipment price be broken out separately from the erection price.

DON'T: Require detailed proposal if "budget" figures will do.

DO: Expect the manufacturer to explain his features and evaluate them as they pertain to your application and plant operations.

DON'T: Arbitrarily request changes to standard design. "Specials" cost much more and require fantastic lead time.

DO: Check with the manufacturer's customers—they know his ability to perform.

DON'T: Expect to visit an installation identical to the one you're considering. No two operations are alike. Also, improvements are being made daily that may make what you buy better than what is in the field.

DO: Require factory assembly and prebagging if at all possible. This will be less expensive and cause fewer headaches than doing it at your plant.

VI-3. THE USER

AND

FABRIC FILTRATION EQUIPMENT

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That fabric filters offer unmatched opportunities for attaining optimum control of particulate emissions is generally conceded. It is also accepted, however, that difficulties arise in predicting and achieving consistency of performance when seemingly insignificant changes occur in processing conditions, in baghouse design, in maintenance, or in operation.

The following package of information draws on field experience to address this unpredictability and to examine specific causes of success and failure. Several papers, and portions of papers, were selected from those presented at the second APCA specialty conference on The User and Fabric Filtration Equipment, held in Buffalo, New York in October 1975. The papers which follow are authored by baghouse "users" in various categories of industry; the one exception is a condensed version of the keynote paper by a "manufacturer" which was designed to bridge the gap between the first and second conferences. The entire second conference will be reported in a Proceedings whose availability will be announced in *JAPCA*.

Baghouse Technology: A Perspective

Donald H. Rullman
American Air Filter of Canada, Ltd., Montreal, Quebec

As presented at the Second Conference on The User and Fabric Filtration Equipment, this keynote address served to bridge the two year period between the first and second conferences. In this condensation, the author discusses the current state of the industry, and points out some of the user's responsibilities to the goal of achieving regulation compliance in a cost-effective manner.

The dialog of the First Conference on The User and Fabric Filtration Equipment, held in Buffalo in 1973, and this Second Conference two years later comes down to two basic elements:

—proper design of system and equipment
—living with the results.

The Clean Air Act Amendments of 1970 provided three methods for mandating air pollution control for stationary sources.

1) Setting of primary and secondary air quality standards,
2) Setting standards for hazardous air pollutants, and
3) Setting new source performance standards.

Ambient air quality standards have been established for six pollutants.

1) Sulfur dioxide
2) Particulate matter
3) CO
4) Photochemical oxidants
5) Hydrocarbons
6) Nitrogen dioxide

Of these, primarily particulate matter is controllable by bag filtration. However, in 1973, of the 23 industries for which new source performance standards had been set or were under consideration, 17 had a particulate matter standard.

Updating, as of June 1975, the Environmental Protection Agency has promulgated 22 new source performance standards. An additional 16 have been proposed and 55 are currently being developed. A spokesman from EPA informed me recently that their objective is to issue 22 standards per year.

What the EPA tells us, essentially, is that they have determined, fairly accurately, the scope of the problem by industry and by process, and are continuing to apply research emphasis in measurement and filtration of fine particulates. They have expressed an opinion that there is substantial evidence that fine particulate can be controlled in a cost effective manner. That of course is why we are here. How do we design the process, the system and the baghouse to be compliant in a cost effective manner?

Throughout these presentations it will be evident that there is still—and perhaps always will be—a mixture of art and science in the application and performance of fabric collectors. Let's review briefly where we stand today. What is happening in this "arty science" of fabric filtration?

On the large collector scale there is considerable activity in yet another major production area of the integrated steel mill. That is in "hot metal operations," or those operations involved in moving, tapping and handling molten iron from the blast furnace to the basic oxygen furnace shop. Specific applications include:

—cast house
—torpedo car reladling
—desulfurization, in the ladle or in a torpedo car by several processes
—BOF secondary ventilation which involves fugitive emissions control at the BOF during charging and tapping.

Japanese steel producers have the bulk of experience in these areas—particularly cast house ventilation. Their major installations, including BOF secondary emission control, are virtually all structural, reverse air collectors with polyester fabric and 12 in. diameter bags. Two such collectors will also be installed soon in England. Several BOF secondary ventilation collectors have been installed in the United States. These are shaker collectors. A similar installation is also being installed in Mexico and the first such unit will be installed in Canada within a year.

We are well aware that the metric system is being increasingly used in North America. If you travel into Canada now, the reported temperature is given in degrees Celsius. In fact, snow depths in Canada this year will be reported in centimeters. Having lived in Montreal for a year it would seem to me that the kilometer might be a better unit of measure for snow fall.

In the metric system the 5 in. diameter bag becomes 125 mm, the 8 in. bag becomes 200 mm and the 12 in. bag becomes 300 mm. For the most part these bags are interchangeable with their North American counterparts.

While this is a North American conference, there is no doubt that the European and Japanese producers can teach us a thing or two with respect to certain applications, for instance, ferroalloy applications. In North America two basic collectors have been applied successfully on ferroalloy and electrometallurgical processes. These are the glass or Nomex fabric reverse air unit and the Nomex equipped shaker collector. In Europe the predominant baghouse in use on these applications is a glass reverse air collector, and I understand they are going a step further. Other than for ferrosilicon furnaces, many ferroalloy furnaces can be virtually completely enclosed extracting a relatively small gas

TROUBLE SHOOTING GUIDE*

Trouble	Possible cause	Remedy
Loss of Air Flow	Fan stopped	Check motor interlock circuit or for tripped overload. Check for broken or slipping belts.
Insufficient air flow, lack of dryer capacity or puffing at burner	1) Cleaning cycle too long	Decrease cycle time and cycle timer.
	2) Low compressor pressure	Check comp., if ok, check blast time.
	3) Low compressor pressure	Check for sticking blast valves or broken lines.
	4) Excessive dust load	Reduce feed rate or use cleaner aggregated.
	5) Excessive firing rate	Check moisture removed vs cap. chart and reduce feed rate.
	6) Mud plugging	Clean bags, maintain internal collector temperature above dew pt.
	7) Oil or carbon coating	Clean bags, clean burner and check for proper air/fuel ratio.
	8) Damper closed	Check damper position.
	9) Duct leaks	Weld and repair.
	10) Fines system leaks	Check airlock seals and housing discharge.
	11) Plugged precleaner or duct	Clean out build-up.
	12) Plenum bypassed (reverse air or plenum pulse types).	Check plenum valves and bypass switches.
Excessive air flow, poor fuel consumption or low temp.	1) Cleaning cycle too short	Increase cycle timer.
	2) Damper open	Check damper position.
	3) Inadequate firing rate	Check burner, if ok, reduce feed rate.
Dusty Stack	1) Holes in bags	Replace or repair.
	2) Poor bag seating	Repair bag mounting device.
	3) Housing leaks	Repair leaks between bag section and clean air plenum.
	4) Bleed through	Replace or repair worn bags, increase cleaning cycle. Also reduce air flow to minimum to reduce operating air/cloth ratio.

* "Special Problems with Fabric Filters on Hot Mix Asphalt Plant Dryers," W. Con Proctor, Rea Construction Company, Charlotte, NC.

volume off the process. Whereas this application had predominantly used scrubbers, the idea now is to use a combustion chamber followed by a heat exchanger—with or without heat recovery—and a relatively small reverse air glass collector.

There are also municipal and commercial incinerator installations in Switzerland which have proved that the baghouse is a viable option to the precipitator in this application. Virtually every form of bag cleaning is in use in this application with apparently no significant data indicating one achieves better results than another. Since in most instances incinerators actually discharge relatively low sulfur levels Nomex can be used. Chlorides are the big problem; therefore these units are well insulated. Also, considerable attention has been given to material handling systems on such collectors.

In the cement and rock products industry, the fabric collector continues to be an alternative to the precipitator in certain applications previously considered as exclusively belonging to ESP. The increased use of direct reduced pellets in steel producing arc furnaces should augment lime consumption, and there is an increasing number of successful lime kiln fabric collector installations.

We should also say a word or two about collector construction. In our 1973 conference, several manufacturers discussed the merits of modular versus structural collector construction. I do not intend to repeat those discussions but I do wish to stress that both methods are widely accepted today. One has not eclipsed the other and will not. Both techniques can give equivalent years of suitable enclosure for the filtering system. Two years ago it would have appeared that the modular unit would soon displace the structural design for all small and medium range collector sizes. But then the cost of fabricated steel started moving higher and higher. Already having a weight disadvantage the fabrication cost of modular units soon began to outweigh the remaining erection cost advantage.

Under certain conditions the modular collector has a higher equipment cost (than a structural unit) but a more than compensating lower field erection cost. However, the cost of fabricated plate can in certain cases destroy that advantage. Thus, responsible manufacturers today do, and must, investigate more than just the technical factors we have reviewed before making a final decision on whether to recommend modular or structural.

Recent advances in fabric filtering technology involve making the selected fabric collector more dependable, conceivably more efficient, and easier to maintain as this device is applied to an increasing number of applications. However, as the baghouse is in each case simply a compo-

nent of a system—albeit the major component—advance in system design technique is truly important to the success of a baghouse installation.

The User's Responsibility

Before I close I would like to discuss briefly a serious matter—the user's or purchaser's responsibility toward proper analysis of process, proper specification of system and collector, and ultimate selection of manufacturer.

To the user's accounting department, purchase of an air pollution control system undoubtedly represents a major, non-return, capital expenditure except where there is significant reclaim value in the collected material.

To the user's management, this situation also represents a high capital outlay with increased operating costs. But it also represents far more—risk. Risk that the equipment will not perform, and perform dependably, and risk that the letter of the law will not be met.

To the engineering and operating department of a company contemplating purchase of pollution control equipment, the assignment to select the proper system and equipment still occasionally represents a very real dilemma. Unless a portion of the engineering department is specifically assigned continued responsibility for air and water pollution control, too often involvement in these problems presents new technologies with new jargons, and there is inevitably the pressure of a tight time schedule.

This is normally the right situation to choose a qualified consultant. However, with or without this consultant, the baghouse manufacturer has a serious responsibility to determine what he can about the process and to inform the user. The user has the responsibility to listen, to study, to inspect installations, and to confer with other users of such equipment.

With some fear of being misunderstood we can say that the primary purpose of the steel envelope, shell, or building around the filtering system (by which we mean bags, bag suspension members, bag cleaning devices, instruments, dampers, and material handling) is simply to provide an optimal working environment to allow this filtering system to function properly. Design of collector housings entail normal building design disciplines considering wind, snow loads, seismic conditions, and the like. But occasionally it is difficult for a manufacturer to get a potential user to mentally open the door of such a structure and fully and equally analyze the filtering system—that portion of the structure that has entailed far more design research and years of practical engineering. In such cases, final analysis can too easily dwindle to cost per ton of fabricated steel.

Fortunately such situations are becoming increasingly rare. Often the deliberate, technical approach taken by users and consultants in our work is impressive and highly respected. The continuation of conferences such as this, play a large part in allowing each of us, from our own perspective, to establish that necessary technical dialog.

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Innovations in Ferroalloy Baghouse System Design

R. Neil Payton
Airco Alloys, Niagara Falls, New York

System design used by a typical ferroalloy producer is reviewed, with special emphasis on shaker cleaning of Nomex fabric in large structural baghouses. The use of air curtains at the furnace hoods, duct size venturi for flow measurement, and other techniques are described to permit evaluation of individual bags as well as complete compartments of bags. A unique hook-up of magnehelic gauges provides an instant assessment of the performance of each compartment to assist operators in achieving optimum operation. A critique on waste heat recovery, gas coolers, and induced draft fans on dirty gas service is included.

Airco Alloys, a Division of Airco, Inc., is the second largest producer of ferroalloys in the United States. This paper deals with the application of large filter fabric collectors to collect fume from submerged arc electric smelting, open-hooded furnaces. At the present time, Airco has three baghouse systems controlling five furnaces, with an additional three systems under construction for six other furnaces. There are also two submerged arc furnaces equipped with electrostatic precipitators, and one covered furnace with a wet scrubber. This paper will describe the philosophy of, and experience with, the components of the air pollution systems which are in use or under construction. Following

this, we will go into the evolution of some of the unique features of our systems which are at the heart of filter operation, and the reason for the title of this paper.

Ferroalloy furnaces producing fume considered most difficult to collect are from silicon metal, 50% to 75% ferrosilicon, and ferrochrome silicon. These fumes are largely silicon dioxide, in submicron sizes, reported to average less than 0.3 microns. It is the collection of these fumes that will be discussed.

Thus far, we have used only two shaker type cleaning methods; namely, fiberglass with deflation air and gentle shake, and combination Nomex with deflation air and vigorous shake. Another popular cleaning method which is used in our industry, both here and abroad, is reverse air through ringed glass bags. Although glass filter media have advantages of a 500°F plus operating temperature and lower capital cost, the air-to-cloth ratio is limited to 2 to 1 or less. Thus far, Airco Alloys has elected to use the combination Nomex filter cloth and shaker mechanisms that permit a 2.75 to 1 ratio at equivalent bag pressures. Bag pressures up to 16 to 18 in. WG on this type of application are not uncommon. All bags are a standard 11½ in. diameter by 30 ft-6 in. high. In order to cool gas from 500°F or more down to 375°–400°F, we use forced convection, tubular, air-to-gas cooling. We prefer to put an investment in coolers instead of more bags. Our experience with glass and Nomex has shown good bag life but fewer bag failures with Nomex. Perhaps the most significant difference is the increasing filter drag of glass using gentle shake, compared with the stable filter drag of Nomex.

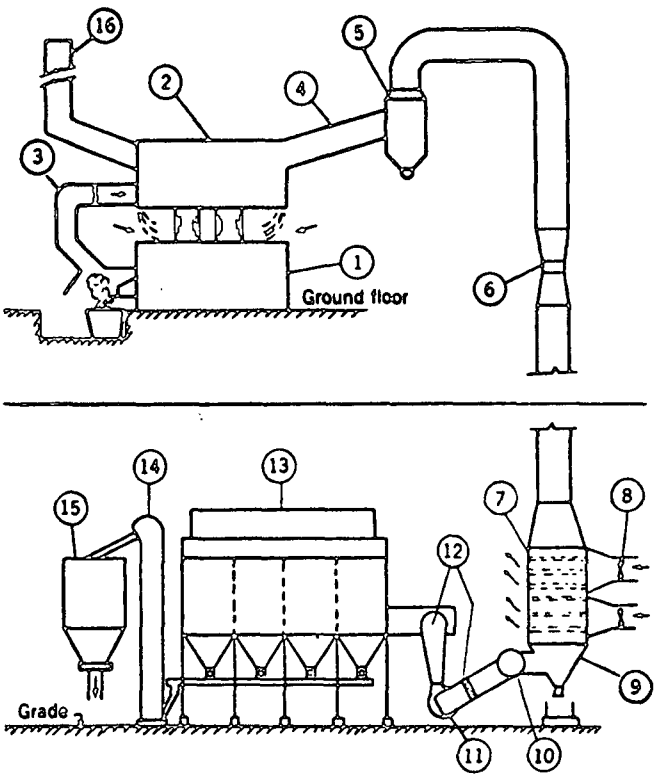
Our experience with conventional dust handling by screw conveyors, bucket elevator, and live-bottom storage hopper has been satisfactory. We did have an initial bad application of a vertical screw conveyor which taught us the value of a dependable dust removal system. The collected fume is being slurried in concrete mixers and hauled away as land fill. One mixer truck has been able to keep up with about 20 tons/day of fume, hauling a distance of one mile, and washing out the bowl after each load and scouring out with crushed stone or slag at least once a day.

Fume Hood Ventilation

The type of hood venting used on our ferroalloy furnaces is an open hood approximately the same diameter as the furnace, with a 5 ft vertical opening between the furnace and hood to allow charging and stoking equipment to go right up to the furnace. Thus, the hoods are upward of 30 ft in diameter and about 10 ft high, with one or more offtake ducts leading to stacks, and then to air pollution control systems. (See Figure 1.) Sufficient ventilation must be provided to prevent an outflow of gases from over the furnace into the furnace building. Starting in 1971, Airco Alloys has used air curtains to help seal in the gases and to complement the use of vertical sliding doors in some cases. Although the primary object at that time was to eliminate the use of doors to reduce the required ventilation flow into the furnace, the full evaluation of this technique has been difficult without accurate and continuous flow measurements. What has been accomplished, unquestionably, is an economical way to dispose of furnace taphole fumes amounting to approximately 50,000 cfm, depending on the size of the furnace. Building drafts make open hood ventilation difficult, requiring a face velocity through the ventilation space of at least 250 ft/min. In principle, the air curtain jets blow downward and inward to the furnace, eliminating inflow for 2 to 3 ft below the bottom of the hood skirt. If the jet velocities are carefully controlled, the induced secondary flow of room air is minimal, and any recirculation outward from the air curtain is immediately reentrained into the horizontal inflow entering the furnace.

INDUSTRIAL & UTILITY BOILER APPLICATION

As a measure of our confidence in the air curtain technique, Airco has built these devices around the hoods of three furnaces and is building three more in both new and existing furnaces. Another ferroalloy producer has built one unit with the likelihood of adding three more on existing furnaces. Low capital cost is possible, since the device is an annular duct or ducts built either inside or outside the hood skirt and requires only an additional ⅛ in. static pressure, over and above the hood and duct losses. The flow can be provided by in-duct vane axial fans.



1. Furnace
2. Hood
3. Tap
4. Offtake
5. Fallout
6. Flow venturi
7. Coolers
8. Cooling air
9. Fallout
10. Suction manifold
11. I.D. fans
12. Dampers
13. Baghouse
14. Dust elevator
15. Dust silo
16. Emergency damper

Figure 1. Fabric filter system.

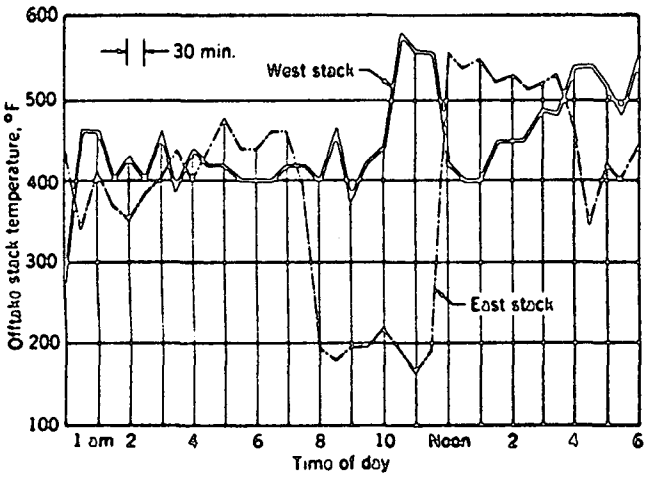


Figure 2. Variation in dual stack temperatures.

Ductwork

In our recently designed offtake ductwork from the hood, we are using at least two offtakes with fall-out chambers in which a change of direction and a reduction in velocity are incorporated. Since the offtake gas temperatures will be of the order of 600° to 700°F, we are using automatic control dampers to limit large excursions of temperature in the ductwork. An indication of temperature fluctuations in two equal ducts under a single fan suction is shown in Figure 2. In the latest design, we use a single damper, controlled by ratio control, in an effort to keep both offtake temperatures equal in value. This avoids the complication involved in having separate temperature control dampers in each offtake, since upon furnace shut down, the dampers will close and transfer fan pressure from the bags to the suction side of the baghouse, inviting a disastrous duct collapse.

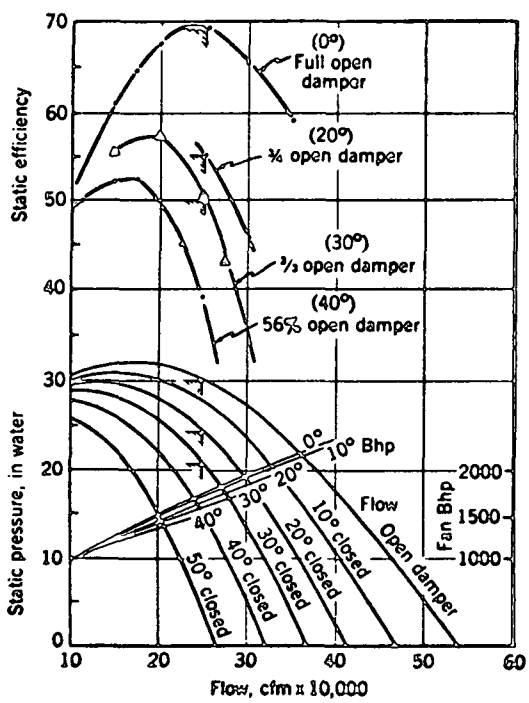


Figure 3. Effect of inlet damper on fan efficiency.

Fan Abrasion

On a dual single inlet fan installation, severe fan wear occurred on blade wear plates and at the junction of the blades with the back and side plates. The fan wheels did not originally have weldments or wear plates on the back and side plates. On the scroll, which was originally ¼ in. thick, up to ⅜ in. wear had occurred. It was necessary to make costly wheel replacements on both fans. For future installations on dirty gas service, these wear points should be adequately protected and backed up by regular inspections for wear.

Fan Characteristics

I.D. fans in this industry are usually controlled by inlet box dampers. In selecting fans, we have found that serious losses of static efficiency occur when the fan system pressures are overestimated. We have also found that fan manufacturers sometimes use overly optimistic factors for estimating fan brake horsepower, based on percent of full load volume. With radial tip fan wheels, we find that the promised horsepower savings are not achieved.

Figure 3 illustrates that the static efficiency at the rated capacity can drop from 69% to 55% if the system pressure changes from 30 in. to 24 in. In this example, 4 fans rated at 30 in. SP would cost $150,000 more per year in power costs than if properly rated in 24 in. SP. From our experience with several manufacturers, we would recommend that prospective purchasers of industrial fans should ask for performance curves at various inlet damper positions, and *not* accept the customary horsepower reduction factors given by the fan manufacturer.

Heat Recovery and Gas Cooling

Waste heat recovery from ferroalloy furnaces is not practiced to date in the U.S. To recover waste heat, the furnace must be closely hooded to restrict excess room air from tempering the combustion gas temperatures. We have continued to use open-hooded furnaces for several reasons, including easier stoking, safer operation, and the ability to change products to meet market demands. To be economically feasible, waste heat recovery requires that a user of steam, hot water, or warm air is close by and can use the heat throughout the year.

Studies made by Airco Alloys in 1972 indicated that furnace offgas temperatures of at least 1000°F (538°C), would be required to generate up to 150,000 lb/hr of steam at 400 psig and 650°F from two of our largest furnaces located at Calvert City, KY. Steam turbines would drive two large I.D. fans and exhaust 100 psig steam for use in a nearby chemical plant. In subsequent tests on one of these furnaces, offgas temperatures up to 800°F were obtained, but ventilation was marginal and the existing air-cooled hood would not withstand these temperatures. The furnace construction also made such high operating temperatures too risky, and so a maximum offtake temperature of 650°F (343°C), was arbitrarily selected. It was decided to build forced convection coolers, of a type first used in 1971, as this design fitted into the available site, was self-cleaning, required little maintenance, and had only 2 in. of pressure drop. The cooling air fans were selected for 100°F ambient temperature, and have inlet louver dampers controlled by cooler outlet temperatures. Two fans in parallel are used for each pair of coolers.

Elsewhere in the industry, radiation-convection *trombone* type coolers are being used and are reported to be of

less expensive construction. We believe that this design has more pressure drop, requires greater site space, and lacks outlet temperature control to the extent that it could overcool in winter and undercool in summer.

Similarly, evaporative cooling was rejected because of possible acid dewpoint corrosion in the ductwork and baghouse, requiring adequate insulation of these parts. Finally, the possibility of sulfuric acid dewpoint in the Nomex bags would make glass filter media a better selection, but this requires lower air-to-cloth ratio and, thus, more filter bags. As previously stated, we prefer an investment in coolers to reduce baghouse size, and the number of operating parts.

Baghouse Maintenance

Contrary to our original expectations, bag replacement cost is not the major maintenance cost in our structural baghouses. Rather, it is the dust handling from compartment hoppers through to the trucking of the mixed paste. Plugups in the conveyor to elevator transfer point are common, and there are periodic replacement of conveyor bearings and seals around dampers and conveyor drives. We prefer to use poppet type dampers for their tight closing characteristics, and prefer not to use them in horizontal positions due to failure of supporting rollers. Next, we have sought better access to the dampers, and this required a new structural design of the baghouse substructure. Finally, we have gone to extra large compartments in order to limit the number of compartments to 12 on new systems. We have found that the larger compartments not only reduced the number of operating valves, conveyors, and rotary valves to be maintained, but there also was a 10% reduction in cost. There should also be less danger of re-entrainment of dust from the hopper when inlet and deflation dampers open.

Gas Flow Measurements and Bag Evaluation

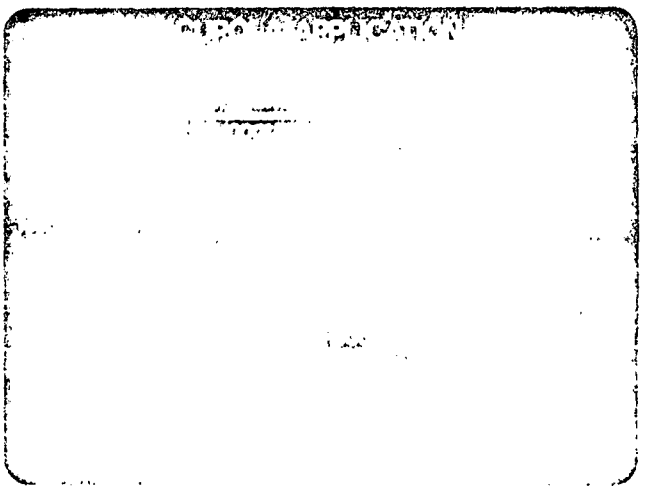
The primary variable in the dirty air side of baghouses is flow. There must be sufficient ventilation to capture the particulate. This aspect of air flow measurements has been lacking, and in the past, there has been a substitution of temperature and pressure values, which are of secondary use in indicating baghouse performance. We will be measuring flows in the following manner in our latest baghouse project.

Total System Flow

Main gas flow will be measured by a duct size venturi with a design ΔP of 1.5 in. WG and a pressure loss of 0.25 in. WG. The flow differential will be transmitted to a 30-day strip chart.

Bag Flow Measurement

Individual bags in a single compartment can be compared by a simple test apparatus, with results as shown in Figure 4. These are multiple venturi tubes, which are mounted within the dust compartment and aligned with the test bags and directly below the tube sheet. We have been using a 4 bag cluster, of which at least one is a standard service bag identical to those used in the other compartments. The calculation of flow through test bags, as determined from the velocity head measurements, can be compared with the calculated flow through the standard bag or bags, which in turn can be compared with the total flow to the baghouse passing through X compartments of bags identical to the standard test bags.



Compartment Flow Measurement

By measuring the pressure drop across the inlets of each compartment in a baghouse, and knowing the total flow from a flowmeter or velocity traverses, the changing and relative flows into each compartment at any time can be calculated. This permits a ready tool for evaluating the effect of changes in bags from one compartment to another, different shaker cycles per minute, or malfunction in any compartment which may be seriously affecting the flow capability of that compartment. Bag filter drag coefficients from a furnace operation on a certain product can be used to estimate system pressures in a future installation. Bag pressures are the major pressure components in the calculation of system losses for I.D. fan selection.

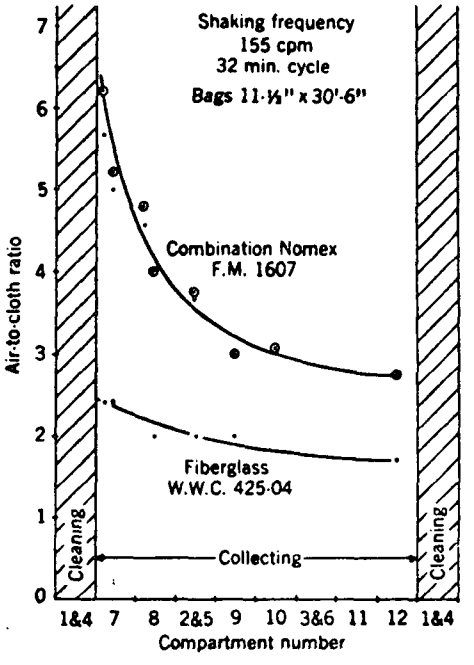


Figure 4. Test bag performance.

Compartment Monitoring

By connecting the manometer or differential pressure gauges, as shown in Figure 5, the effectiveness of each compartment can instantly be monitored. This is quite important when you consider that an operator rarely can afford to spend an hour or so watching all compartments isolate, clean, and return to service. The causes of the assumed loss in flows may be: inoperative inlet, reverse air or reinflation dampers, leaky dampers or loss of shaking and/or reverse air flow. Defective compartments have been known to stay on-line for weeks at a time because the deficiency was never detected during casual daily inspections.

Automatic Air Purging

In an effort to maintain the operation of the compartment flow monitors by preventing dust plugging of the measuring lines, we are installing automatic purging valves between the manometers and the measuring points. These small valves are cam driven, and isolate each gauge for a few seconds while they apply a 50 psig air supply pressure to the measuring line. The purge timer starts the purge cycle after a preset interval, and the cycle is stopped by a limit switch on the camshaft.

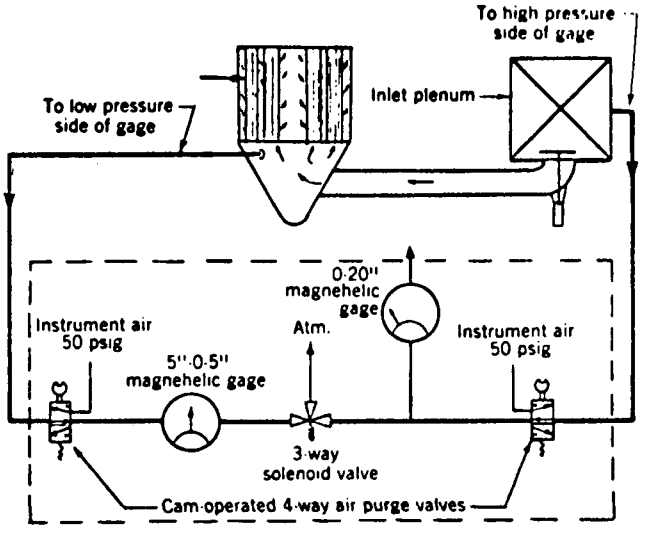


Figure 5. Typical compartment monitoring system.

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Review of Baghouse Systems for Boiler Plants

M. J. Hobson
Acres American Incorporated, Buffalo, New York

The principle of fabric filtration has only recently been accepted for fossil fuel fired boiler particulate emissions control. Information on design criteria is, therefore, limited. The paper provides data on the few installations where baghouses have been installed and successfully operated. The general conclusion is that a strong relationship exists between air to cloth ratio and bag life.

Fabric filtration is accepted as a standard method for particulate removal from the majority of industrial process emissions. One application that is just beginning to achieve commercial acceptance is the control of fossil-fueled boiler emissions.

Until now, the reasons for choosing other emission control systems for boilers have been:

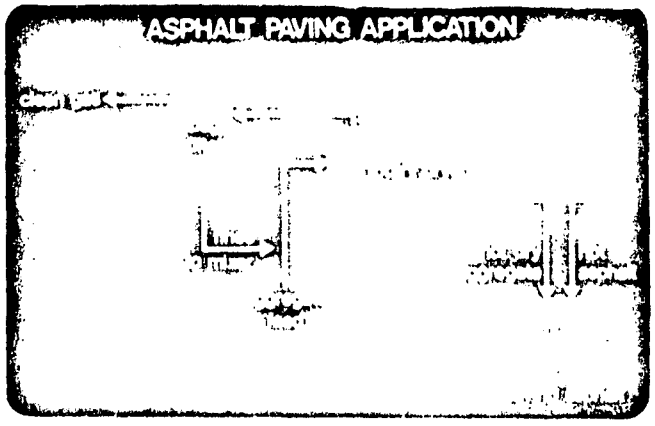
- High cost compared to less efficient, but acceptable, control methods;
- High flue gas pressure loss compared to other control methods;
- Acid attack problems;
- Unacceptably short bag life;
- High totalized costs compared to switching to a cleaner fuel;
- Possibility of high temperature excursions and flammable gas ignition.

In recent years, particulate emission regulations for both industrial and utility size boilers have tightened to the point that fabric filtration is now a serious competitor to

electrostatic precipitation and wet scrubbing on most installations. The alternative of switching to a cleaner fuel is, in most cases, no longer viable due to high price and allocation priorities.

It is important, therefore, to reexamine the application of fabric filtration to boilers and determine whether those remaining potential problems have been solved by recent developments.

This paper was prepared to document the experience of those few experimental and commercial installations of boiler plant baghouses.



Boiler Flue Gas Characteristics

Flue gas characteristics, such as gas composition and temperature, depend on the capacity of the boiler unit, the type and extent of heat recovery equipment, the type of fuel firing equipment and the fuel analysis. The flue gas from industrial installations fired by spreader stokers is usually in the temperature range 300°–400°F with high excess air and large particulate size.

Large industrial and utility installations are pulverized coal fired with flue gas temperatures in the range 250°–350°F and particle size distribution ranging from 50 to 0.5 μm, with the bulk of the fly ash between 2 and 16 μm.

Plant operation can vary considerably. Many small industrial boilers shut down in the summer or operate at a low load. Larger industrial and utility units usually operate continuously at a fairly high capacity factor.

As many designers and operators are aware, acid attack on the gas side of flue gas systems is often proportional to the frequency of unit shutdowns and the extent of low load operation.

Pilot Studies

A considerable number of fabric filter pilot tests have been performed on various boiler flue gas systems. These results have been documented in previous technical papers and I do not propose to recapitulate the results in detail.

The pilot tests showed that bulk woven fiberglass and Teflon felt fabrics can provide the performance required on most boiler fly ash removal applications. Both fabrics are resistant to acid attack and abrasion and are sufficiently impervious to give satisfactory dust removal efficiency.

Woven fiberglass was found to operate well at air to cloth ratios between 2 and 4. When using Teflon felt air to cloth ratios can be higher.

Commercial Installations

Data were collected from 10 installations of baghouses on boilers. Four of these are power utility plants, the remainder are industrial boiler plants supplying steam for process and heating. One of the power utility plants burns heavy fuel oil, all the remainder burn solid fuel.

Each baghouse installation will be reviewed for design data and operating experience. This information is given in brief tabular form in Tables I, II, and III.

Southern California Edison, Alamitos Unit 3

Number 3 boiler at Alamitos Plant is an oil- and gas-fired unit of 2,305,000 lb/hr capacity. For 6 months of the year, residual oil is fired which, until 1965, caused a visible stack plume. A program of pilot tests showed that fabric filtration could be utilized for heavy oil-fired boiler stack

Table I. Boiler data.

Case no.	Plant and location	Fuel	Fuel firing equipment	Plant capacity on baghouses
1	Alamitos, CA	No. 6 Oil 1.5–1.7% S	Tangential tilting return flow burners	2,305,000 lb/hr
2	Sunbury Shamokin, PA	0.8% S anthracite and up to 6% S petroleum coke (75/25 mixture)		175 Mw
3	Carborundum Niagara Falls, NY	Bituminous coal 7% ash 2.3% S	Spreader	75,000 lb/hr
4	Amal. Sugar NYSSA, OR	Coal	Spreader	200,000 lb/hr
5	Amal. Sugar Nampa, ID	Coal		150,000 lb/hr
6	Colorado UTE	0.6–1.9% S coal 12% ash	Spreader	3 units each 132,000 lb/hr
7	Holtwood, PA	Anthracite, fines and petroleum coke	Pulverized coal	50% of 80 Mw unit
8	Winston-Salem, NC	0.8% S Coal	Spreader	75,000 lb/hr
9	Winston-Salem, NC	0.8% S Coal	Spreader	40,000 lb/hr
10	du Pont	Coal	Spreader	
11	du Pont	Coal	Spreader	

Table II. Baghouse design data.

Case no.	Flue gas temp. °F	Gas flow acfm	gr/scf entering baghouse	Air/cloth ratio cfm/ft²	Cloth cleaning method	Suction or pressurized	Fabric type
1	258	820,000		6.5	Deflation & reverse air	P	Fiberglass 601ST
2	325	220,000	2.0	2.0	Deflation & reverse air	S	Fiberglass Teflon coated
3	350			3.5	Reverse air	S	Fiberglass
4	310	191,800		3.56	Deflation & shake	S	Fiberglass
5		145,000[a]		2.36	Deflation & reverse air	S	Fiberglass
6	310	86,000	1.53	3.35	Deflation & shake	S	Fiberglass
7		200,000			Deflation & shake	S	Fiberglass
8	300–350	38,000	0.6	8.5	Reverse air	S	26-oz fiberglass
9	300–350	23,000	0.3	8.3	Reverse air	S	26-oz fiberglass
10				4.48	Pulse-jet		Teflon felt
11				2.32	Reverse air		Fiberglass Teflon coated

[a] in 8 modules.

gases provided that an alkali is injected ahead of the baghouse to neutralize SO_3. In 1965, a large horseshoe shaped baghouse was installed at the base of the stack of No. 3 Unit at the Alamitos Station.

The air to cloth ratio is 6.5:1 when one compartment is out for cleaning. The outside diameter of the baghouse is 90 ft, the height 80 ft and the depth 23 ft.

The alkali additive is injected at the outlet of the air heaters. Flue gas temperature is 258°F and the bags are cleaned about once per hour by deflation and reverse air.

The baghouse equipment has passed through five phases of modification. Operation of the baghouse has steadily improved due to the many equipment modifications made. Bag failures are now reduced to less than 1% over a 5 month period. The stack plume is clear.

Sunbury, Pennsylvania (P.P.&L.)

Each of the two boiler units at the Sunbury Station have two baghouses installed. The two boiler units generate a total of 175 Mw and are fired with a mixture of anthracite and petroleum coke. The anthracite has a sulfur content of 0.8% and the coke sulfur content can be as high as 6%.

The gas flow to each baghouse is 220,000 acfm and the dust burden is 2 gr/ft³ at a temperature of 325°F. The baghouses were supplied by Western Precipitation and have an air to cloth ratio of 2. Bag cleaning is by deflation and reverse air and the I.D. fan is located on the dirty side. The original mechanical collectors were retained ahead of the baghouses. The mechanicals were modified to reduce the pressure drop.

Of the 5040 bags, only 50 were replaced after over 2 yr of operation and many of these failures were caused by improper installation. The pressure drop for the baghouse and ductwork is less than 5 in. water gauge. It is planned to replace the bags every 2 yr.

Discharge loadings from the baghouse were measured to be 0.017 gr/acf.

Carborundum Company, Niagara Falls, New York

The boiler plant is fired with coal and oil. One of the coal fired units was fitted with a baghouse 6 yr ago and it has operated for 9 mo/yr ever since. Numerous modifications have been made to the baghouse and the boiler firing equipment has also received attention. The last 18 months of operation have been very successful from the viewpoint of bag life.

The 75,000 lb/hr boiler is fired with 7% ash, bituminous coal with a sulfur content of 2.3%. The firing equipment is a spreader stoker. No mechanical collectors are installed ahead of the baghouse. The gas temperature entering the baghouse is 350°F. The bags are fiberglass with an air to cloth ratio of 3.5. The bag cleaning method is reverse air and the baghouse is operated at negative pressure. The cloth resistance is 6 in. maximum and the bag failures expressed as a percent per year of operation amount to 0.3%.

Amalgamated Sugar

At one plant of Amalgamated Sugar in Oregon, a 200,000 lb/hr coal fired spreader stoker has operated since 1973 with a fiberglass baghouse. The gas flow to the baghouse is 191,800 acfm at 310°F. The air to cloth ratio is 3.56. The bag cleaning method is deflation and shake. The baghouse is operated at a suction. No significant operating data were available on operating experience from this installation.

Amalgamated Sugar

At another plant of Amalgamated Sugar, an 8-module baghouse of Western Precipitation design is installed on a 150,000 lb/hr boiler. The gas flow is 145,000 acfm and the air to cloth ratio is 2.36. The bags are fiberglass cleaned by deflation and reverse air. The baghouse is operated under suction.

Colorado UTE

The Colorado UTE Electric Association has three 13 Mw boilers, each with maximum evaporative capacity of 132,000 lb/hr. The boilers are fired by spreader stokers consuming low sulfur coal with 12% ash.

Wheelabrator-Frye baghouses were installed on all boilers. The first unit commenced operation in early 1974. The flue gas temperature is 310°F and dust burden at the baghouse inlet is 1.53 gr/scf. Fiberglass fabric bags are in-

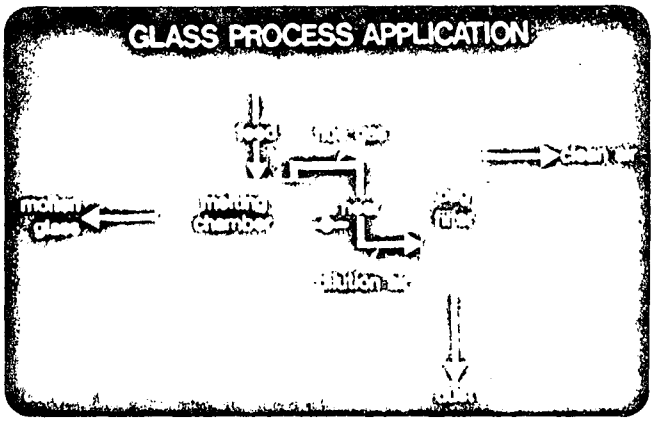
stalled with an air to cloth ratio of 3.35 when five of the six compartments are in operation (i.e., when one compartment is cleaning or down for maintenance).

Pressure drop across the collector (headers, house, and fabric) is maintained at 4.2 in. water gauge by initiation of the cleaning cycle. Cleaning normally occurs every 3–4 hr.

To inhibit SO_3 corrosion, a heating system is installed which circulates hot gas when the baghouse is down, during startup and during low load conditions.

The dust collection efficiency is high; discharge concentrations are less than 0.003 gr/acf on all three units.

After some initial problems relating to bulk density of the fly ash, frequency of emptying the hoppers, and flue gas distribution, bag life is exceeding 1 yr of operation and 2 yr plus are expected.



Holtwood Station (P.P.&L.)

The boiler plant at the Holtwood Station is a 75 Mw unit fired with anthracite fines and petroleum coke. The fuel is pulverized and 50% of the flue gases discharge to a Wheelabrator-Frye baghouse. The other 50% pass through a wet scrubber.

The gas flow to the baghouse is 200,000 acfm at full load. The dust burden entering the baghouse is not available, but it is estimated to be approximately 4 gr/acf. The bags are fiberglass with deflation and mechanical shake cleaning.

Little operational data are available but the discharge concentration was measured at 0.007 gr/acf.

Hanes, Winston-Salem

The boiler plant consists of two spreader stoker-fired boilers; 1—75,000 lb/hr, 1—40,000 lb/hr. The fuel fired is low sulfur coal and the dust burden entering the baghouses is 0.6 gr/acf for the 75,000 unit and 0.3 for the 40,000 unit. These concentrations are low because the original mechanical collectors were retained in service.

Two Dustex baghouses were installed after a program of pilot testing. The baghouses were provided with I.D. fans and stacks and a draft control system to allow the existing equipment to function without modification.

High air to cloth ratios of 8.5 and 8.3 were selected for 26 oz woven fiberglass fabric bags. The gas temperature entering the baghouses is maintained between 300° and 350°F by bypass and control dampers.

Bag life on the 40,000 unit was poor due to abrasion at the cage wire contact points. It was better for the 75,000 unit, possibly due to the coarser particle size distribution, which resulted in a lower cloth resistance.

Gas cleaning performance was high. A discharge concentration of 0.006 gr/scf was obtained in tests. Woven Teflon and Gore Tex (microporous PTFE membrane on a woven teflon grid) bags are now under test in this installation.

du Pont Plant

Four baghouses were installed at a 6 unit boiler plant of E. I. du Pont de Nemours and Company, Incorporated to arrive at source emission compliance for the overall plant. Both pulse-jet and reverse air cleaning systems were selected to compare performance. The pulse-jet design was fitted with Teflon felt bags; the reverse air design was fitted with Teflon coated fiberglass bags. The original mechanical collectors were retained ahead of the baghouses. Air to cloth ratios are 4.48 for the pulse jet and 2.32 for the reverse air.

During 12 mo of operation, only one bag failed in the pulse jet units and that is reported to be due to contact with the wall. The baghouse efficiency is 98.4%. In series with the mechanical collector, the overall efficiency is 99.8%. The fiberglass bags have a life of 1–1/2 to 2 yr.

Table III. Baghouse operation experience.

Case no.	Months of operation	% Bag failures/year	Cloth[a] resistance in. W.G.	gr/scf leaving baghouse	Comments
1	23	2.2[b]	5.7	Clear Stack	System extensively modified in five phases over 3 yr. Alkali injection ahead of baghouse
2	30	1.25	5[c]	0.017	Mechanicals ahead of baghouse
3	54	0.3	6.0	N.A.	No mechanicals in series
4	14		5.0	N.A.	No mechanicals ahead of baghouse
5					
6	20		4.2	0.003[d]	Heating and hot gas circulation during shutdown
7	4			0.007[d]	
8	9	150	8.0		
9	9	800	9.0	0.006	Bags fail at cage wire contact
10	12	0.03			Mechanicals ahead of baghouse
11					Mechanicals ahead of baghouse

[a] Maximum at full load.
[b] In last two phases.
[c] Including ductwork.
[d] gr/acf.

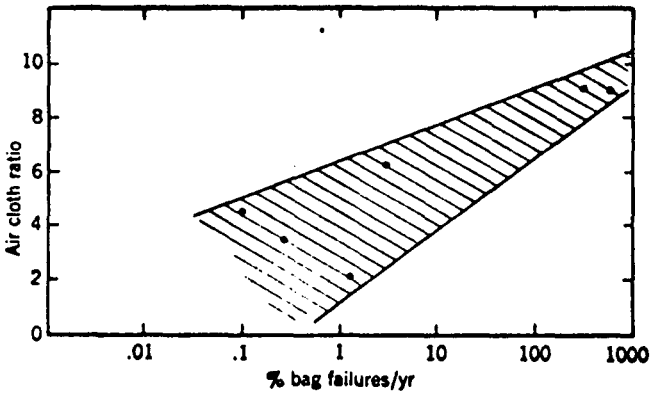


Figure 1. The relationship between air to cloth ratio and bag failures.

Conclusions

Although the data available on boiler plant baghouses are scant, the information reviewed above indicates that satisfactory results can be obtained with careful design and intelligent boiler operation.

The relationship between air to cloth ratio, cloth resistance and bag replacement rate is also evident even though these factors are strongly influenced by the large variation in boiler equipment, flue gas systems, fuel characteristics and operating conditions.

Mr. Hobson is with Acres American Incorporated, Buffalo, NY.

Glass Bag Filters for Lime Kiln Exhaust

James R. Gage
Bethlehem Steel Corporation, Bethlehem, Pennsylvania

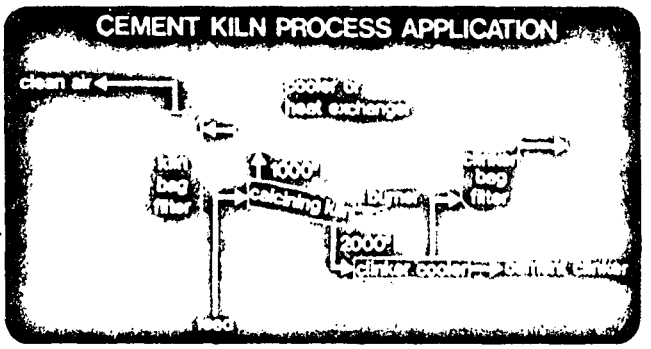
The information presented in this paper is directed toward those concerned with specifying and operating larger size fiberglass bag filter houses. Information on emissions, bag life, instrumentation, and maintenance is presented from an operating installation. The solutions to particular problems of short bag life, one due to erratic start-up and the other due to coarse dust are presented and discussed. The bag filter collectors are satisfactory for these applications and a bag life of 22 to 34 months is being realized. Proper hopper inlet arrangement, hydraulic dampers, and reverse air draft control are believed to be partially responsible for the good operation and bag life.

Many press releases announcing the installation of an industrial fabric filter dust collector will describe its function as similar to an ordinary household vacuum cleaner. Well, some bag filters do serve such cosmetic needs but others are not that simple. The purpose of this paper is to explore the inner workings of a large baghouse as it operates to control the particulate emissions of a lime kiln exhaust. Useful information is presented on cleaning cycles, extending bag life and avoiding operating problems.

Background

In 1969 it became necessary to abandon efforts to collect our lime kiln exhaust particulates with a low energy wet scrubber. An estimated 125 tpd of dust was then being emitted from one kiln of which 40 tpd was high quality burned lime dust. This dust was highly reactive with water and produced a lime mortarlike deposit on all equipment interiors. In addition, the high alkalinity of the scrubber water would have required the added installation of a large acid gas neutralizing system. Electrostatic precipitators were seriously considered as a solution but the high calcium dust was too resistive to collect without excessive collector size and electrical power costs. Therefore, a fiberglass type baghouse was selected for both installations, one for a single large 650 tpd lime kiln, the other a common baghouse for four smaller lime kilns of 700 tpd total pro-

duction. The characteristics of the gas stream for these two applications are shown in Table I. The large kiln emits 180 tpd of baghouse dust, the four kilns emit a total of 150 tpd. The presence of sulfur trioxide in the four kiln baghouse exhaust is due to different kiln combustion controls and internal heat exchangers, which create a less reactive dust than at the large kiln. All the kilns use the same coal. Also the stone feed is the same chemical analysis with some kilns burning a finer size. The single kiln baghouse operates continuously except for minor kiln repairs every 6 to 12 months. The four kiln baghouse runs continuously except for repairs to the main I.D. fan every 12 to 15 months.



Baghouse Construction Features

These baghouses were viewed as a part of the kiln process equipment, therefore specifications were developed to emphasize good operation and reliability. Plant visits and literature searches were made to develop background knowledge in writing the purchase specifications. Figure 1 shows the cross section of the baghouses purchased. The large kiln baghouse has 14 modules, the four kiln unit has 16. The lower exterior steel siding prevents chilling of the screw conveyors and hoppers which are not insulated. Both systems include I.D. fans with inlet box dampers to provide automatic draft control for the kilns. Both systems were provided with generously sized fans and baghouses to eliminate the process restrictions due to inadequate draft.

System Controls

As special features to maintain proper and continuous operation, the specifications included an inlet pressure recorder, a hydraulic control system for the dampers and a reverse air fan draft control system.

Inlet Pressure Recorder

This provides a visible record of the internal functioning of the baghouse. A pressure tap located on the I.D. fan outlet duct senses baghouse inlet pressure which is transmitted to a continuous strip chart recorder at the baghouse control panel. With all compartments working well, the pressure trace is a regular series of evenly sized vertical lines showing the normal rise and fall caused by the cleaning cycle as shown in Figure 2. The pressure trace will thus show if the baghouse is operating well without a tedious inspection. However, if there are missing lines or noticeably shorter vertical lines as in Figure 3, the corresponding compartment is not doing its share of the filtering. A direct check on that compartment can be made by observing the pressure trace on its next cleaning cycle. The inlet valve, while closing, should cause a pressure rise as the flow increases to the remaining compartments. Next the reverse air (or collapse air) valve should open and remove hot dusty air from the compartment hopper, collapsing the bags. This further volume is delivered to the filtering areas through the inlet duct causing an additional pressure rise. A typical cycle is illustrated in Figure 4. By watching this pressure trace, the general area of the trouble can usually be discovered for the compartment being observed. The action of the tipping valves is also a good indicator of the actual dust removal during the cleaning cycle. A rising pressure trace with regular lines would indicate a change in the process volume as shown in Figure 5. It is necessary to service the pressure tap weekly by disconnecting the hose to the pressure transmitter and blowing compressed air back through the piping to the duct. Otherwise the tap will clog, giving an erratic trace as shown in Figure 6. The information from the pressure rise can be used to estimate the flows in the compartments. Table II shows the typical results of the 14 compartment baghouse filtering 160,000 acfm with bags 8 months old.

Table I. Gas stream characteristics.

	4 Kilns	Large kiln
Inlet temperature	460° F	490° F
Inlet dust loading	8 gr/acf	10 gr/acf
Dew point	130° F	145° F
SO_3 in outlet	15 ppm	None
SO_2 in outlet	225 ppm	25 ppm
Inlet volume	158,000 acfm	160,000 acfm
Outlet temperature	340° F	380° F

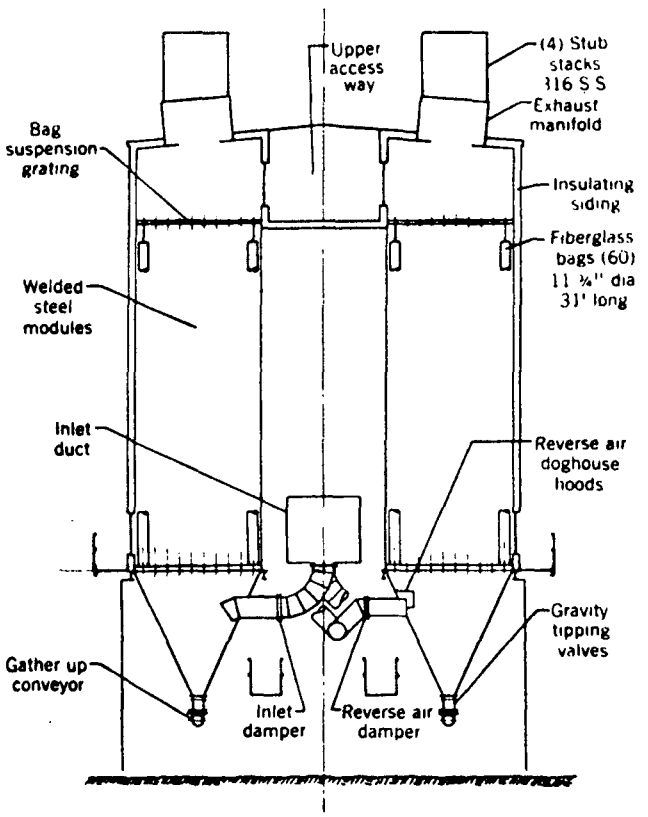


Figure 1. Fiberglass baghouse cross section.

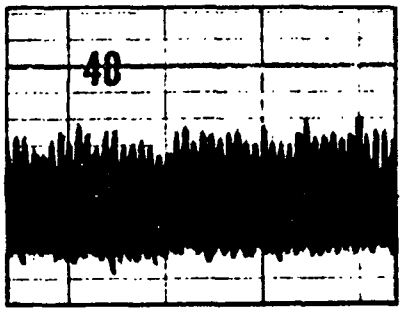


Figure 2. Normal pressure trace with all compartments functioning.

There are serious consequences for ignoring a problem compartment. Eventually a module of bags which are on line but are not being cleaned will fill up with a dust load until the hanger springs fail dropping the bags. Their filtering load is also transferred to the remaining compartments, shortening the overall bag life. If the total cleaning mode fails, the baghouse will build up pressure drop until it interferes with the process. At this point the bags are well loaded with dust. If either the main I.D. fan is shut down or one compartment is cleaned normally, following the restoration of the cleaning cycle, the whole baghouse dust load will drop into the screw conveyors. This should be anticipated in the dust removal system design. If not, the handling equipment may stall or flood causing further problems.

Hydraulic Control System

An hydraulic damper control system was chosen to provide repeatable damper motions at controlled speeds. The hydraulic power-pack was located next door to the baghouse control panel. Copper instrument tubing bundles each with eight ⅜ in. tubes were run thru an 8 in. underground conduit pipe to the baghouse interior. The system includes a variable volume 5 gpm 500 psig pump, a volume control valve and ¼ in. direct solenoid operated hydraulic valves. The cylinders (2 in. dia × 8 in. stroke) are located along an interior walkway and drive through a pipe extension of the rod to the damper arms overhead. All cylinder rods are retracted when the compartment is on line.

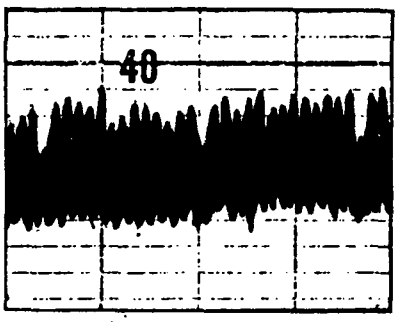


Figure 3. 14 compartment baghouse with one compartment malfunctioning.

The volume control valve provides a 10 sec stroking time for all the cylinders without resorting to any individual cylinder speed control valves. An additional volume control valve would be helpful, one for the reverse air dampers and the other for the inlet air dampers. These central controls allow a fine degree of cleaning cycle tuning which would not be practical using individual damper controls.

The slow damper stroking minimizes the rate of volume change in the process during the cleaning cycle and prevents the bags from reinflating too rapidly after their collapse. This helps the I.D. fan to maintain control of the firing hood draft which is important in providing the proper kiln combustion atmosphere. This hydraulic feature for control is thus some compensation for the baghouse being a variable draft loss device in contrast to the steady state operation of either precipitators or scrubbers.

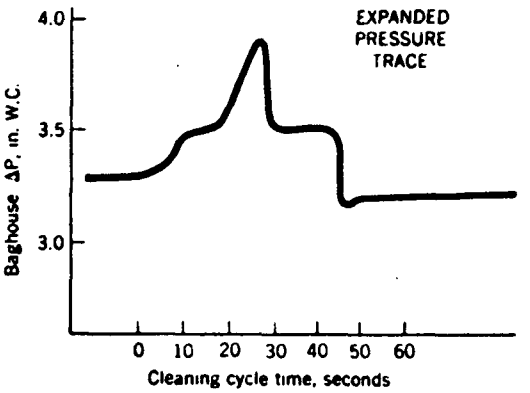


Figure 4. Variation of baghouse inlet pressure during cleaning cycle.

Reverse Air Draft Control System

This system adjusts the reverse air manifold draft by damping the fan performance to suit the variable pressures to be expected at the baghouse inlet. Draft is maintained at 2.5 in. of water using a control damper in the duct operated by a 25 sec/100° rotary actuator. The control instrument is on the baghouse panel where the draft fluctuation can be observed during the cleaning cycle. A fan ammeter is also helpful in discovering any reverse air damper malfunctions. For convenience, the dedusting line from the dust elevator and storage bin is connected upstream of this control damper. This provides some flow to prevent controller wind-up should the reverse air dampers be unusually gas tight.

One aim of the system is to prevent the collapsed bags from enduring the full reverse air fan suction if damper timing or operations are maladjusted. It also provides for a constant cleaning effort even though the baghouse inlet pressure may be rising or falling requiring more or less fan static pressure to effect the cleaning.

The draft pickup tap on the manifold rarely plugs in contrast to the baghouse inlet pressure tap.

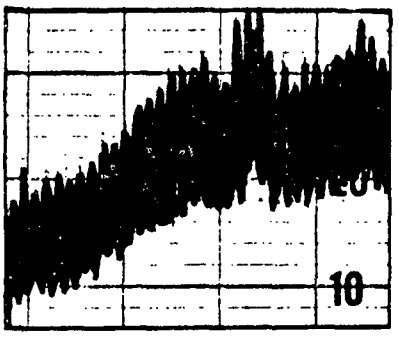


Figure 5. Pressure trace with changing process volume.

Bag Collapse Adjustment

The baghouse cleaning cycle has been adjusted to provide a very gentle bag collapse. Primarily the reverse air action is interrupted at a time when the bag is nearly collapsed but well before the bag is drawn into the full star shape and drawn tightly down towards the tube sheet collar. This type of cleaning cycle is successful both due to the precision of the hydraulically-operated dampers and to the controlled supply of reverse air volume. It is noteworthy that this type of cycle has been in use for the past 9 months and spanned the end of the life of one set of bags and the start of the new set of replacements.

This operation was instituted to try to correct two of the worst problems in fiberglass bag life under reverse air cleaning.

1. The severe stresses that occur at the bottom of a fully collapsed bag causing premature failure at the maximum flexure points.
2. Overcleaning of the bottom few feet of the bag during the maximum collapse of the cleaning cycle.

Operating the baghouse under this type of cleaning action should provide benefits for any type or style of bags, and allow the maximum possible bag life based on failure due to flexure.

Baghouse Performance

Figure 7 shows emission concentrations versus bag service life based on emission tests conducted on the exhaust stacks of both baghouses. As expected, it indicates an increase in emissions over the life of the bags.

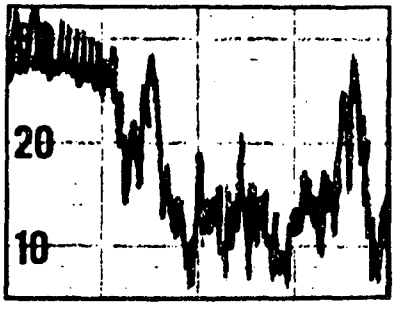


Figure 6. Pressure trace with plugged sensing tap.

Bag Life

Figure 8 shows that there is some correlation between lower filter rate and longer bag life. The net air quantity as used here includes an estimated 10,000 acfm of reverse air volume. Bag life is the point in the life cycle where bag failures become so numerous that it is more economical to rebag the whole baghouse. No attempt was made to keep track of individual bags and their average life. The baghouse with the longer life enjoyed a normal 2 to 3 in. water pressure drop whereas the other was normally 4 to 5 in. water. However, the first set of bags for the large kiln were not included in the data as they were replaced after 6 months of operation. This is an unusually short life and a result of a combination of start up problems. The following corrective measures were taken and a resultant improvement to a 22 mo life was realized.

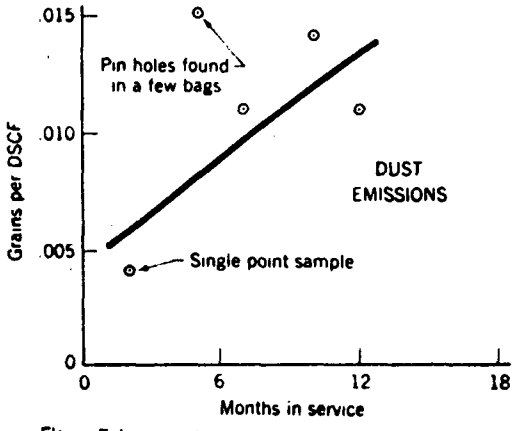


Figure 7. Increase in dust emissions with service life.

1. The cooling tower outlet temp was reduced from 550° to 510°F and the shutdown interlocks reset from 600° to 550°F.
2. The cooling tower water spray atomization system was improved to reduce and later eliminate the bleed in air cooling which had been inflating the total volume.
3. Doghouse hoods were installed over the reverse air connections at the hoppers in order to reduce clogging of the reverse air ducts. Figure 1.
4. The cleaning program system was revised to give damper operations in sequence. This insured that the cleaning cycle could function properly even if there were small amounts of dust in the ducts slowing down the damper strokes, which were also adjusted to 10 sec, to give maximum power and minimum bag popping during reinflation.
5. The slipping damper operator arms, which caused damper malfunctioning, were corrected.
6. The system was adjusted to provide a gentle collapse of the bags.

Table II. Cleaning cycle description.

	Baghouse	Volume
Start of cycle	3.3 in. W.C.	9,000 acfm
Inlet valve closes	3.5 in. W.C.	None
Rev. valve opens	3.8 in. W.C.	(−)14,000 acfm
Rev. valve closes	3.5 in. W.C.	None
Inlet valve opens	3.2 in. W.C.	13,700 acfm
Initial drag	2.1 in. W.C./fpm	
Final drag	1.3 in. W.C./fpm	

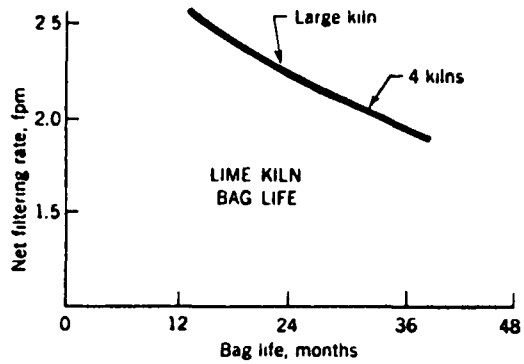


Figure 8. Effect of net filter rate on bag life.

Moisture and Corrosion

After 3 years of operation, the extended walls have prevented dust or mud buildup in the screw conveyors or baghouse hoppers, even though these portions are not insulated, and there are no vibrators on the hoppers. The side wall insulation has prevented any stiffness or acid salting in the bags near the exterior walls. The baghouse modules interior steel is scale free and in good condition. The 316 stainless steel outlet stacks and H.R.S. manifolds are also in good condition. The ground level access doors have been removed and a louvre installed above the inlet duct to provide some air circulation for cooling.

Cyclone Precleaners

The coarseness of the dust has not caused wear on the fiberglass bags even though precleaners were not incorporated, although a dropout effect is obtained in the down flow cooling tower. However, precleaning is a problem at one of the two other Bethlehem Lime Plants and at a preheater type lime kiln plant in Nevada.[1] At the latter, two kilns each with 10 ft dia cyclone precleaners provided very good bag life after 18 months of operation. A third kiln, with a multitube precleaner converted to a dropout box, experienced unusually bad bag life during the same period. Plans were to reinstall the multitubes at the earliest opportunity.

Bethlehem's problem occurred in collecting dust from the lime cooler portion of a rotary hearth (or doughnut shaped) kiln at one of two different locations. The first installation is a quite successful reverse pulse type cleaner operated at 4 fpm, 5 to 6 in. water, 240°F while the second, a modular shaker type unit was spectacularly unsuccessful when operating at a net 2.5 fpm, at 2 to 3 in. water, 200°F. Table III shows the dust size for all three type units. The dust from the fiberglass baghouse is as coarse as the hopper sample from the shaker. The dust from the successful pulse collector is coarser than the shaker sample collected at the tube sheet after passing through the broken bags. The coarse material found on the tube sheet was blamed for the bag failures and was removed by installing a retrofit cyclone precleaner. The shaker baghouse had, by then, operated 12 months with daily bag replacements totaling $10,000/mo in direct bag and labor costs. The bag life has been good since the cyclone installation.

However, it should also be noted that both the successful fiberglass baghouses and the successful reverse pulse baghouse have an inlet arrangement conducive to good dust settling in the hopper. They have an overhead duct with round 90° elbows from the duct into the upper portions of the hopper. The down comer elbows promote dust migration to the outside or bottom of the elbow where it can drop into the hopper without being swept upward with the air flow into the bags. The unsuccessful modular shaker and the fiberglass baghouse in Nevada do not have this same feature and instead must rely on precleaners. The shaker has an opposite mounted inlet duct with side outlets coming directly into the hoppers at a point too low in the hopper as it was chosen to clear the cross bracing. The manufacturer's literature for the Nevada fiberglass baghouse shows a square tee connection feeding opposite compartments which would also be a very turbulent and non-segre-

Table III. Dust size comparison.

Unit	Fiber glass	Reverse pulse	Shaker		Cyclone and shaker
Source	Hopper	Hopper	Tube sheet	Hopper	Hopper
Topsize	20 Mesh	16 Mesh	10 Mesh	100 Mesh	325 Mesh
−100 Mesh	99%	28%	27%	98%	All
−200 Mesh	88%	6%	17%	83%	All
−325 Mesh	10%	N.A.	11%	63%	1%
−5 micron	N.A.	N.A.	N.A.	15%	72%
Baglife, mo	22−34	18+		0−2	11+

14 TIPS FOR FIRE PROTECTION OF FABRIC COLLECTORS*

Recommendations for Safeguarding Fabric Collectors**

1. Lightning protection for collectors located outdoors.
2. Positive choke devices in material discharge outlets from collectors.
3. Collectors constructed to be electrically conductive, with all parts bonded to prevent a build-up of static electricity.
4. Exhaust air from the collector arranged to discharge outside the building unless safe provision is made to recirculate exhaust air back into the airveying system.
5. Electrical equipment designed to conform to the National Electrical Code Article 500.
6. Use of only noncombustible materials in construction of the collector.
7. Fabric filters should be of low hazard materials. Where combustible media must be used, flame retardant treatment must be provided.
8. Fabric filters should be in metal enclosures with provision made for cleaning the filters.
9. Collectors should be constructed so as to eliminate ledges or other points of dust accumulation. Hopper bottoms should be sloped and the discharge system designed to handle maximum flow.
10. The collector should be designed to handle the maximum possible operating pressure to which it might be subjected.
11. Clean-out doors or panels should be provided for interior cleaning of collectors.
12. Explosion relief venting should be provided.
13. Collectors should be located outside of buildings unless the interior room has an exterior wall that incorporates explosion relief venting, with other walls, floor and ceiling designed to withstand a pressure of 1½ psi. The room should be equipped with automatic sprinkler protection.
14. To protect against damage, in addition to explosion relief venting or design of a collector to withstand maximum peak explosion pressure, the following features should be provided:
    a. Explosion suppression system.

    OR

    b. Collector should be designed to operate using an inert or oxygen deficient gas as an operating medium.

    OR

    c. Collectors containing combustible parts should be equipped with automatic sprinklers.

* "Fire Protection for Fabric Collectors," Richard A. Gross, Factory Insurance Association, Buffalo, NY.

** ***Recommendations to protect collectors can be derived from loss experience. Also, NFPA Pamphlet #66 contains valuable guidance regarding collectors used in air conveying systems which can be applied to collectors used in other applications.***

gating arrangement. We are now more aware of this important feature and intend to review carefully the manufacturers' design of this function in the future. The buyer should be especially aware of standardized modular units built for a variety of applications for the lowest cost, for a precleaning cyclone retrofit is an expensive correction.

Conclusions

The fiberglass baghouse has proven to be a satisfactory dust collector for the exhaust of these lime kilns. We expect to continue or to improve upon the bag lives experienced to date. Above all, the units have provided good collection of the dust satisfying state emission limits. Interruptions to the kiln operations have been nominal and the extra draft provided has improved production on all the kilns to the limit of other equipment in the kiln system.

References

1. David J. Krohn, "U.S. Lime Division's dust abatement efforts whip pollution problem," *Pit & Quarry* (May 1974).

Mr. Gage is in the Mining Division of Bethlehem Steel Corporation, Bethlehem, PA.

VI-4

INS AND OUTS OF GAS FILTER BAGS

by

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Joy Manufacturing Co.

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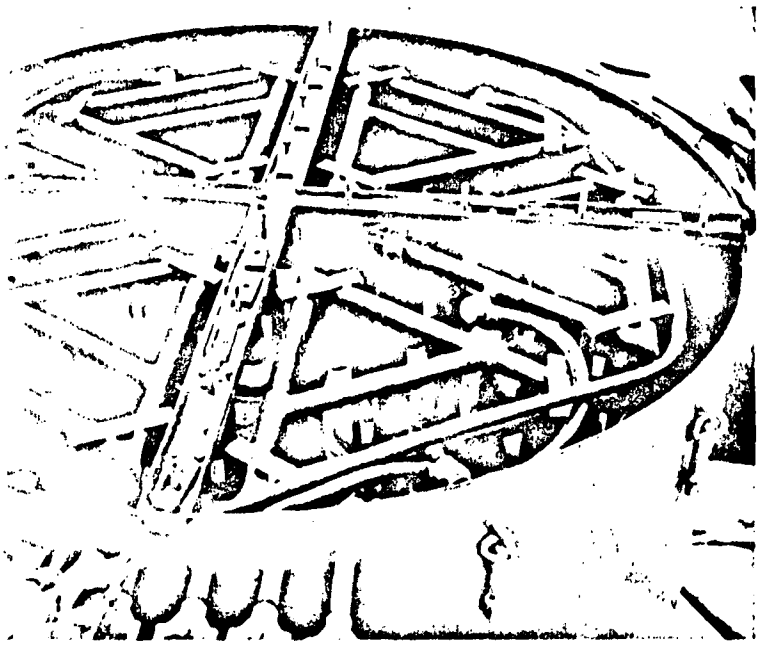


Ins and Outs Of Gas Filter Bags

Here is a guide to selecting the synthetic-fiber bag cloth and the bag-cleaning technique that could most efficiently and economically handle your gas-filtering problems.

JOHN C. WALLING, Joy Manufacturing Co.

Until recently, the so-called natural fabrics—cotton, wool and silk—were all that were available for gas filtration, despite their limitations with respect to resistance to temperature, chemical attack, abrasion and wear. The development of glass-fiber cloth capable of withstanding continuous temperatures up to 600 F. made cloth practical in gas filtration applications from which it was once precluded.

Synthetic Fibers for Dust and Fume Control

Acrylics—Synthetic fibers for filter cloth are made from materials having a molecular structure that is naturally, or which can be made crystalline. The proper orientation of this crystalline structure during the extrusion process gives the fiber the necessary tensile strength. The most suitable member of the acrylic family of plastics with regard to crystallinity is acrylonitrile, which yields an oriented fiber having a tensile strength in the neighborhood of 40,000 psi.

An acrylic fiber by definition is one containing a minimum of 85% acryonitrile. Acrylic fibers are available in the U.S. under such names as Creslan (American Cyanamid Co.), Orlon (Du Pont Co.), and Acrylan (Chemstrand, div. Monsanto Co.). The maximum recommended gas temperature is about 275 F. Fibers of 100% acrylonitrile resist a somewhat higher temperature. Acrylic fibers exhibit excellent resistance to hot, acid atmospheres.

Polyamides (nylon)—Polyamide resins are naturally crystalline materials that can be quenched and cold worked to yield a tough, oriented fiber having a tensile strength of about 80,000 psi. Nylon fiber is available from American Enka Corp., Allied Chemical Corp. and Firestone Tire & Rubber Co. (Nylon 6), Celanese Corp., Du Pont Co. and Chemstrand (Nylon 6.6). It is suitable for gas temperatures to about 250 F. This is lower than that for many of the other synthetics. However, the excellent abrasion resistance of nylon makes it very suitable for filtering abrasive dusts when temperature is not a factor. It resistance to alkalis is good under most conditions, but its resistance to mineral acids is poor.

Nomex (nylon)—A special nylon capable of continuous service in gas temperatures as high as 450 F., Nomex's (Du Pont) resistance to fluorides makes

Properties of Synthetic Fibers for Gas Filtration

Material	Acrylic	Nylon	Nomex	Teflon	Polypropylene	Polyester
Maximum temperature (dry), °F	275	250	450	500	225	275
Abrasion resistance	Good	Excellent	Good	Poor	Good	Good
Resistance to acids	Good	Fair	Good	Excellent	Good	Good
Resistance to alkalis	Fair	Good	Good	Excellent	Fair	Good
Tensile strength, psi	40,000	80,000	80,000	20,000	110,000	80,000
Cost/sq. ft. of surface	Moderate	Moderate	High	High	Low	Moderate

it superior to glass in many high temperature applications. It resists acids and alkalis better than conventional nylon. It is, incidentally, the material used in the Apollo space suits.

Fluorocarbons (Teflon)—Fluorocarbon resins have unique properties because of the presence of fluorine atoms in the molecular structure. They are practically inert to chemical attack. In addition, the temperature resistance of the fluorine-carbon bond is such that fluorocarbons retain their properties at temperatures higher than any other carbon-chain plastic. Fluorocarbons are crystalline in nature, and suitable for fiber applications. Teflon is produced in multifilament and monofilament form. The multifilament material can be used continuously in gas stream temperatures up to 500 F. Its main disadvantages are its high price and poor resistance to abrasion.

Polypropylene—A polymeric resin of the polyolefin family, polypropylene's qualities are similar to polyethylene except that its heat resistance is higher. The action of the catalyst induces a crystalline structure that makes polypropylene very suitable in the fiber form. Its tensile strength is in the neighborhood of 110,000 psi.

Polypropylene fiber offers the combination of low price with high resistance to acid and alkali attack. However, it should not be exposed continuously to gas temperatures higher than 225 F. Its abrasion resistance is good.

Polyesters—Certain of the long-chain polyester resins can be converted to fiber form by cold working after extrusion to produce an enforced crystalline structure. Their tensile strength averages about 80,000 psi.

Polyester fibers (Dacron, Fortrel, Vycron, etc.) are a popular synthetic filter material having good all-around resistance to chemical and abrasive attack, combined with gas temperature tolerance up to 275 F.

Manufacturers of synthetic cloth filters can suggest finishing techniques—such as heat setting, scouring, resin treating, calendering and napping—appropriate to the application that will improve bag life, dimensional stability, permeability and ease of cleaning.

Evaluating Cleaning Methods

A comparison of the gas-cleaning efficiencies of bag filter cloths is not basically important, because almost all commercial filter materials remove 99+% of the dust and fume from gas streams. All else being equal, the greatest variety in design is found in the technique by which the filter bags are cleaned. This is an important factor because it not only affects the size of the baghouse, but also its cost, maintenance requirements and dependability.

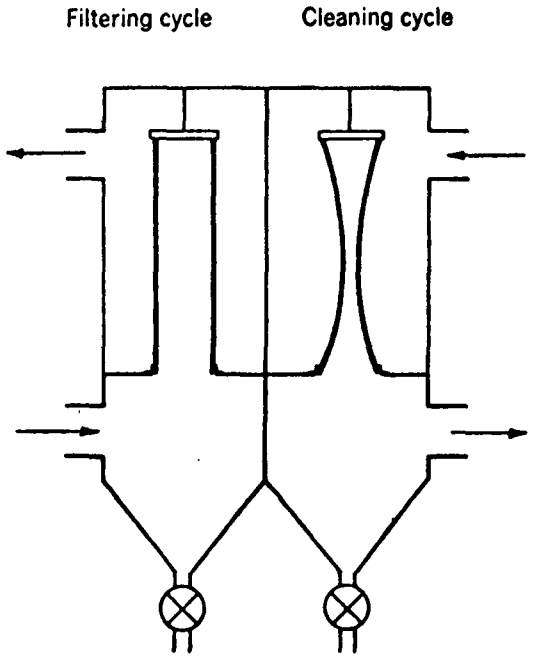
For a specific filter material, the size and cost of a bag filter depends primarily on the area of filter surface required and the amount of space available for filtration within the filter housing. The basic parameter of baghouse size vs. capacity is the air-to-cloth ratio, i.e., the total cu. ft./min. of gas filtered divided by the total sq. ft. of filter cloth in the filter.

Most of the factors that affect the air-to-cloth ratio are linked to application, such as gas temperature, dust loading, filter cloth material and dust characteristics. However, a factor that bears directly on the ratio is the percentage of bags out of service for cleaning at any one time. Another is the amount of flexing and creasing imposed on the filter cloth by the cleaning mechanism.

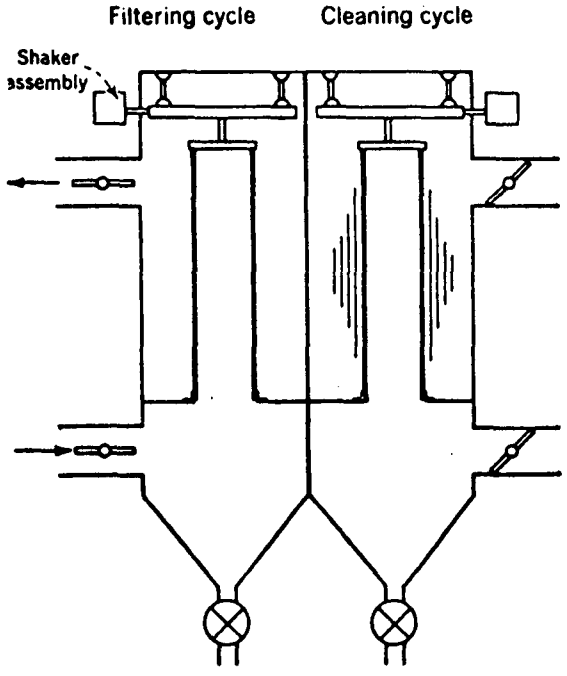
In recent years, new filter-cleaning techniques have been developed that allow significant increases in the air-to-cloth ratio without affecting the life of the filter cloth, filter dependability, or maintenance requirements. These advances allow a corresponding decrease in filter area and filter space requirements for the same application and capacity. In the case of some of the new high-performance synthetic fabrics (which are costly on a square-yard basis) high air-to-cloth ratios are essential if first cost is to remain low enough to make their use economically practical.

Popular Cleaning Methods

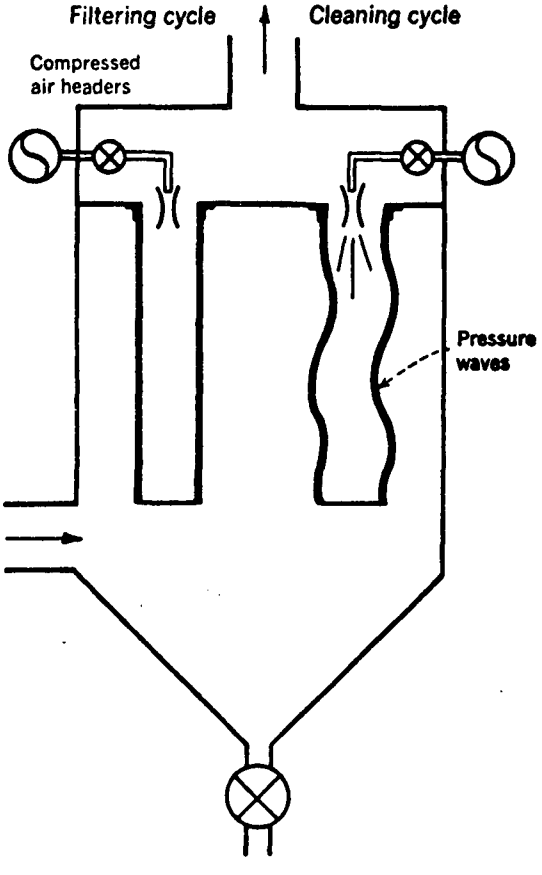
Backwash (Fig. 1)—The principle of removing collected material from a filter medium by backwashing is probably as old as filtration itself. In



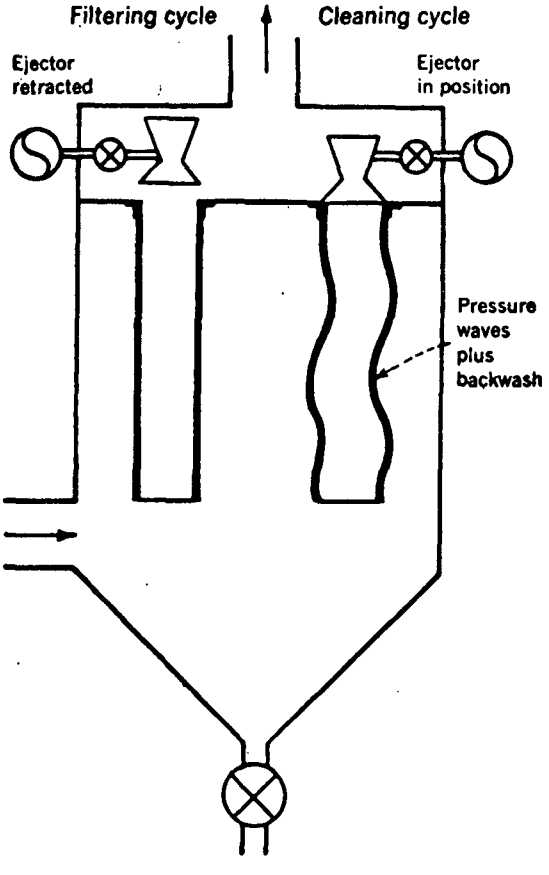
BACKWASHING removes dust by collapsing bags—Fig. 1



SHAKER cleaning requires isolation of bags—Fig. 2



EJECTOR *cleans bags with a short burst of air—Fig. 3*



IMPROVED EJECTOR *(patented) also backwashes—Fig. 4*

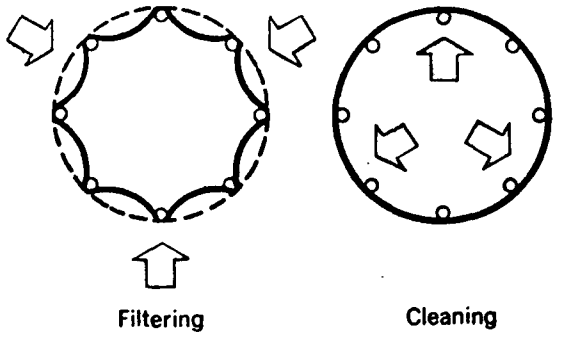
the case of bag-type industrial gas filters, filter cake is discharged partially or completely by collapsing the bags during the backwash cycle. The resulting flexing and creasing of the filter material is the major cause of bag deterioration in this design. In addition, the section of the housing containing the bags being backwashed is necessarily out of service during this cycle. These two factors limit the air-to-cloth ratio of backwash-type filters to from 1:1 to 3:1, depending on the severity of the application.

Shaker (Fig. 2)—In some applications, the filter cake can be discharged by simply isolating the bag from the gas stream and shaking it, either manually or automatically. This method reduces bag flexing and extends bag life, compared to the backwashing technique. In some cases, both backwashing and shaking are used simultaneously. Air-to-cloth ratios for shaker-type bag filters range from as low as 1:1 to as high as 5:1.

Ejector (Fig. 3)—Both backwash- and shaker-type bag filters suffer from the same limitations: (1) frequent cleaning cycles that cause rapid deterioration of the filter material, and (2) a large proportion of the filter must be removed from service during the cleaning cycle. The ejector principle is a recent development that is suitable for many applications, and is capable of operating at air-to-cloth ratios up to 15:1 with reasonable material life.

Contrary to the conventional backwash or shaker arrangement, gas flows from the outside to the inside, and the bag shape is maintained by means of a wire frame (Fig. 5). A compressed air nozzle, usually augmented with an ejector tube, is positioned above each bag outlet. A short burst of compressed air creates a pressure wave that travels down the bag and pneumatically inflates it as it passes. This action discharges the filter cake from the bag.

Gas flow through the bag effectively stops during the period this pressure wave exists, even though the bag is "onstream" as far as the system is concerned. There is therefore no need to isolate sections of the filter for cleaning. Theoretically, each bag can be blown individually. As a practical matter, however, each row of bags is usually piped to the same compressed air header, and blown simultaneously.



FRAME retains bag shape in ejector cleaning—Fig. 5

Improved Ejector (Fig. 4)—The conventional ejector design depends on a controlled flexing of the filter cake to break and dislodge it from the filter cloth. In many cases, this is inadequate for proper cleaning. Unforeseen conditions—such as moisture condensation on the filter surface, electrostatic attraction between the cloth and the filtered material—will cause the filter cake to "ride" with the cloth as it flexes, in which case the ejectors are ineffectual and the filter must be taken out of service.

The improved design mechanically seals off each bag as it is blown and causes a positive backwashing action that, in addition to the flexing action of the pressure wave, thoroughly removes hard-to-dislodge filter cakes. This development greatly extends the application range and reliability of the ejector-type filter, while retaining its other advantages.

Maintenance and Access

The failure of even a small proportion of the filter bags in an industrial gas filter seriously compromises its efficiency. Present day concern for pollution makes it imperative that broken filter bags be replaced promptly. A well designed filter must therefore allow quick and easy access for the removal and replacement of individual bags.

Conventional filters depend on walkways within the filter housing for access to individual bags. These walkways take up valuable filter space. In addition, manhandling filter bags into place within the restricted confines of the housing is expensive and time consuming.

This problem can be resolved by an arrangement in which the bags and bag cages can be inspected and removed from outside the filter housing. Bag replacement becomes a simple matter of (1) pushing aside the ejector, (2) releasing three hold-down bolts, (3) lifting the old bag out, (4) dropping the new bag in, (5) refitting the the hold-down bolts and (6) repositioning the ejector.

A complete filter can be rebagged by this method in a fraction of the time formerly required, and access walkways within the housing are also eliminated. ■

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VI-5.

BAGHOUSES: SEPARATING AND COLLECTING INDUSTRIAL DUSTS

by

Milton N. Krauss

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Baghouses: separating and collecting industrial dusts

The selection and operation of baghouse collectors is mainly an art. Here is practical information on filter fabrics and cleaning; baghouse design, operation and servicing; and methods for protecting the system from fire and explosion.

Milton N. Kraus

☐ The separation of dusts from industrial-gas streams may often be done by using filters made of natural or synthetic fibers. These filter elements are bag-shaped, and placed in structural enclosures called baghouses.

In addition to supporting the filter elements, the baghouses contain baffles for directing airflow into or out of these elements, equipment for cleaning the fabric, and a hopper for collecting and discharging the dust.

Baghouses are used to control dust nuisance whenever dust-laden air must be discharged to the atmosphere, or to recover valuable dust from a process venting system. Sizes may range from small bin-venting filters to large multicompartment filters that receive dust from an extensive system of exhaust ducts.

Dust filtration and collection is an art. The sizing and selection of dust filters are based on (a) past experience and (b) actual tests that use specific fabrics at specific dust-to-air loadings. Because of the many types of collectors and filter fabrics, combined with numerous material properties that affect filtration, the selection of a filter should be made by actual test at the design load, using the least-costly fabric for the requirements.

Separation principle for filters

Dust filtration in baghouses is accomplished by passing the dust-laden air through a filter fabric that is formed into cylindrical tubes or oblong bags. As the air passes through the fabric, the dust is retained on the surface and in the interstices of the yarn strands, building up a filter cake that also acts as a filter medium. In order to reduce the resistance to airflow (so as not to affect the flowrate), the filter cake must be periodically dislodged. The method of cleaning the fabric is the basic difference between various filters.

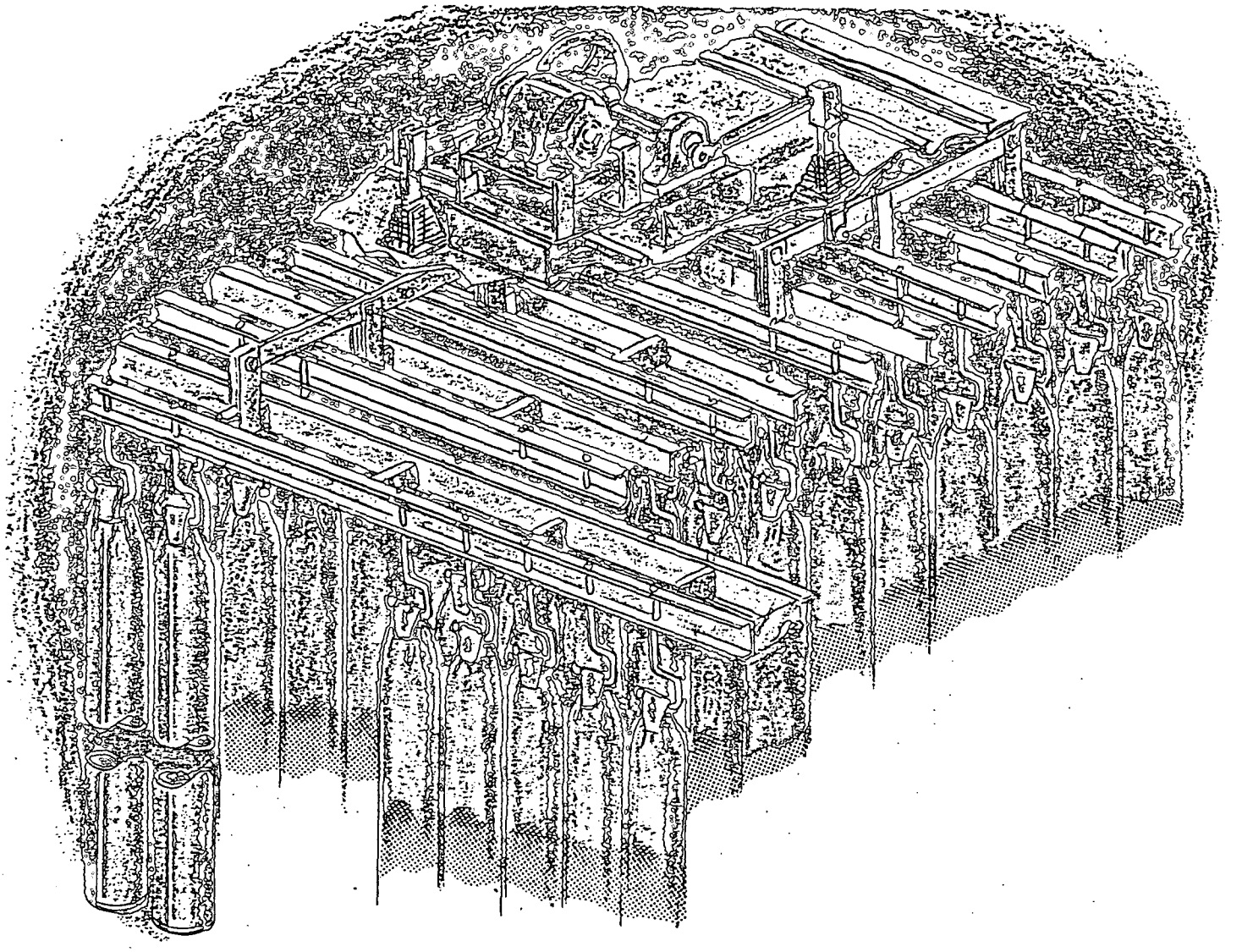
The greater the area of filter cloth provided for a given dust loading on a specific baghouse, the longer it takes for a filter cake to build up that will affect the airflow. In comparing the area of filter fabric offered by different vendors, we should consider the different methods of cleaning the fabric. The criterion should be a constant pressure drop across the fabric for a specified airflow rate and a specified dust loading, rather than the term "air-to-cloth ratio."

If checked dimensionally, this term is the face velocity of the air (ft/min) through the effective area of the fabric for a given type of filter. The air-to-cloth ratio only has significance when comparing the performance of a particular manufacturer's line of baghouses when handling different materials. The cleaning method establishes whether a baghouse is suitable for continuous or intermittent service.

Properties of filter fabrics

In order to function properly, a filter fabric must have the following properties:

Permeability—The fabric must be sufficiently porous to



permit a satisfactory flow of air. The permeability of a fabric is generally stated as the clean airflow in $(ft^3/min)/ft^2$ of fabric, at a pressure differential of 0.50 in. water column, as determined by the Frazier test.* However, the Frazier permeability alone is no guide to fabric selection because materials having the same permeability may not have the other characteristics required to successfully filter a specific material. Also, the filter cake formed on the fabric surface will reduce airflow.

Mechanical strength—The fabric must resist the tensile forces caused by the operating pressure differentials, by mechanical shaking during cleaning, and by pulsing during reverse airflow. It must withstand abrasion where it is clamped to tubesheet ferrules, where it is supported on metal grids or retainers, and where it is subjected to the impact of the filtered materials.

Solids retention—Fabric construction must be open enough to prevent the accumulation of fines in the interstices of the yarn, yet tight enough to prevent fines from blowing through the fabric. This may seem anomalous, but the filter cake on the surface of the fabric also acts as a filter medium and narrows the interstices.

Corrosion resistance—The fabric must resist attack and weakening due to chemical action between the fibers and the filtered materials, especially if moisture is present due to condensation.

Heat resistance—From some processes, the fabric must resist high-temperature exhaust gases. Each fabric has a definite temperature limit beyond which it will tend to disintegrate.

Cleanability—The fabric must have a surface texture that is conducive to rapid release of the filter cake during cleaning. This, too, may seem anomalous, since the surface must also retain the cake. However, the forces involved during cleaning are usually the airflow in the opposite direction to normal airflow, and mechanical flexing of the fabric. The fabric should have a high rate of electrostatic-charge dissipation so as to shed charged dust particles.

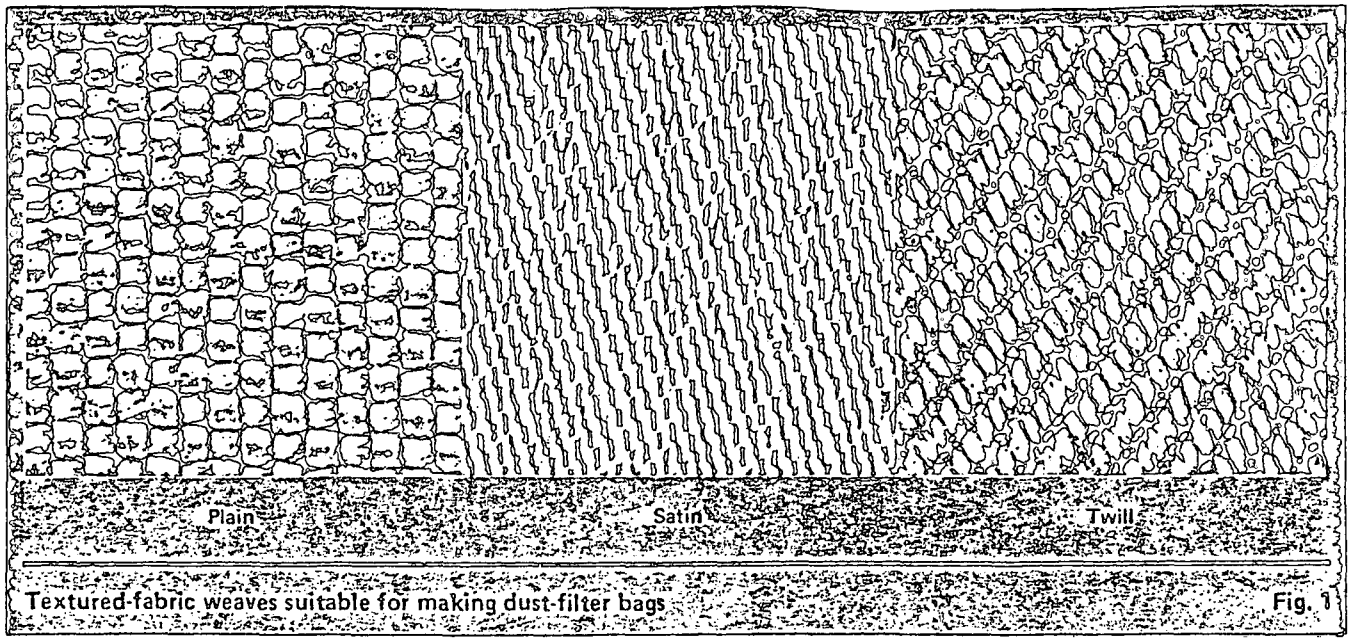
Dimensional stability—The fabric must resist stretching or shrinking that would affect its permeability. Many untreated fabrics tend to increase in permeability after laundering.

The properties of commonly used filter fabrics are shown in Table I.

Fabric construction

A knowledge of the construction of filter fabrics will indicate how well the preceding property requirements can be met. However, final selection should be made by test and by an economic study that weighs first cost against probable maintenance expense. All fabrics will

*ASTM Standard D-737, Standard Method of Test for Air Permeability of Textile Fabrics, American Soc. for Testing and Materials, Philadelphia, Pa.



Textured-fabric weaves suitable for making dust-filter bags

Fig. 1

West Point Pepperell

eventually blind when handling fine materials, or materials that crystallize or polymerize when embedded in the fabric. It is better to replace all cloth in a filter at regular intervals (as determined by experience or by periodic permeability tests) than to operate the unit until airflow is drastically reduced and other problems are created.

Filter fabrics may be felted or woven. Felted fabrics are composed of fibers that are compressed under high pressure and are relatively thick. The pressure enmeshes the fibers, and in so doing forms a strongly bonded sheet of material having complex labyrinthine interstices through which air can pass in three directions. Synthetic monofilament fibers cannot form a strong bond between themselves and are usually pressed over a woven sheet of scrim fabric for strength. Wool fibers are naturally barbed and have a stronger bond than synthetics. Most felts can absorb moisture due to capillary action between the fibers—even though the fibers themselves are moisture resistant.

Properties of common filter fabrics — Table I

Fabric	Temperature limitation, °F	Chemical resistance: Acids	Chemical resistance: Alkalis
Cotton	180	Poor	Good
Wool	200	Good	Poor
Nylon	200	Poor	Good
Polypropylene	200	Excellent	Excellent
Orlon	260	Good	Fair
Dacron	275	Good	Fair
Dynel	160	Good	Good
Glass	550	Excellent	Poor
Nomex	400	Fair	Good
Polyethylene	165	Good	Good
Teflon	400	Excellent	Excellent

Relative ratings: Excellent, Good, Fair, Poor

Source: Publications of the Industrial Gas Cleaning Institute, Inc., Alameda

A simple test for relative absorption of moisture is to stand equal lengths of fabric on edge in a jar containing a shallow layer of water. After several minutes, the samples should be withdrawn and the height to which the water has risen in each sample noted.

The thickness of felt provides for maximum dust impingement. The many changes in direction due to lateral airflow traps the finest particles. Inspection (a) by ultraviolet light of the cross-section of felt fabrics that have handled dust containing fluorescent materials, and (b) by microscopic examination of the cross-section of felts handling other types of dust, shows that the particles rarely penetrate through more than one third of the felt thickness. While there is a reduction in air permeability, this is not as much as would occur in a woven fabric having the same quantity of trapped dust per square inch of filter area.

Felted fabrics are used for maximum product recovery where filtered air is recirculated or discharged into a work space. Felts are primarily used in collectors having a high face velocity for airflow (i.e., high air-to-cloth ratio).

Woven fabrics are composed of twisted yarns that are woven into geometric patterns having various spacings between the yarns, and with a specific surface finish that is designed to retain or shed a filter cake, depending upon the application. The permeability of these fabrics depends on the type of fiber, the tightness of twist and the size of the yarn, the type of weave (geometric pattern), the tightness of weave (thread count), and the type of surface finish. Correct coordination of all these factors for a successful filter application cannot be done by abstract analysis. The fabric must be tested in a dust collector considered suitable for a particular application on the basis of operational and economic factors. Woven fabrics have a low ratio of weave openings to yarn area and require a surface filter cake to retain the dust. This limits the face velocity for airflow

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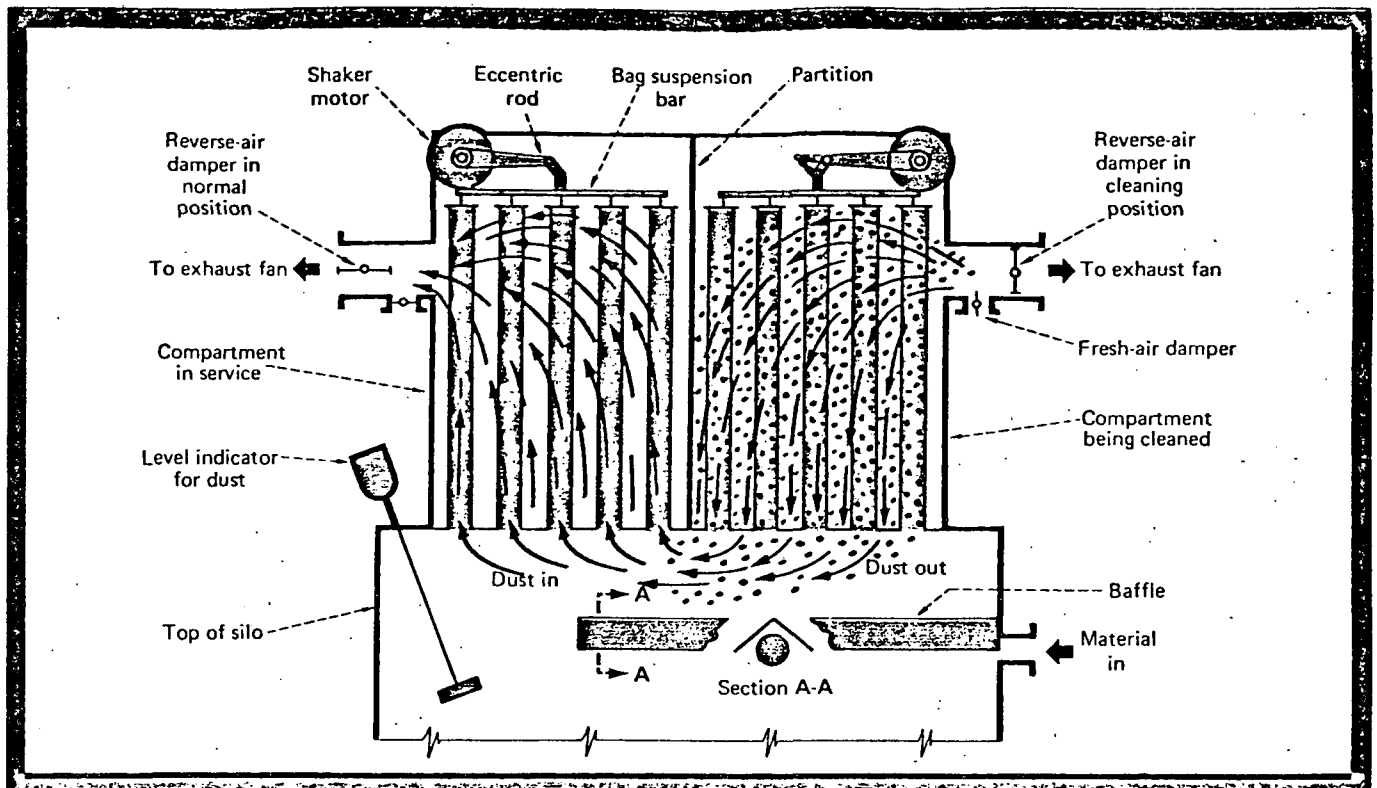


Bag shaking and reverse-air flow cleans dust collector Fig. 2

to low values [1.5 to 3 (ft^3/min)/ft^2] in order to prevent dust from blowing through the openings and destroying the filter cake.

The permeability of woven fabric is very dependent on its construction. A review of textile terminology will prove useful in understanding the effects of yarn design and fabric weaving on permeability. The yarn may be made from:

1. Staple—the term for short fibers of cotton or synthetic material—drawn into parallel strands and twisted into yarn by spinning.
2. Continuous filaments of synthetic material, made by extruding a solution through a finely perforated nozzle and then spinning the filaments into yarn.

The degree of twist of the yarn affects permeability. A tight twist resists penetration by dust particles, and a loose twist permits retention of dust, or "blinding" of the yarn. Filament yarns are stronger than staple ones. Spun yarns have more flexibility than filament yarns and more resistance to repeated flexing.

Weaving is the interlacing, at right angles, of a series of yarns to form a textured fabric. The basic weaves are plain, twill and satin (Fig. 1). In the plain weave, each crosswise or filling yarn passes alternately over and under one warp or lengthwise yarn. Each warp yarn passes alternately over and under each filling yarn. This type of construction makes the tightest weave; by varying the thread count, the weave may be made as open and porous as required.

In the twill weave, the filling yarn passes under one warp yarn, then over two or more warp yarns. In each succeeding row, the filling thread moves one warp either left or right, forming the diagonal lines that identify a twill weave. Twills have fewer interlacings than plain weave and, depending on the thread count, greater permeability.

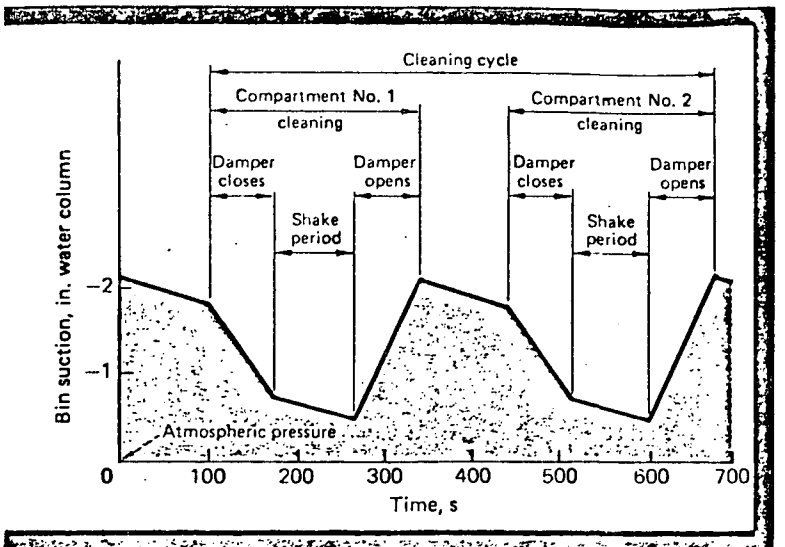
In the satin weave, the filling yarn passes over one and under four or more warp yarns in the next row. This weave has few interlacings, spaced widely but regularly. It has a smooth surface and greater permeability than the other weaves. Cotton fabric in this weave is known as cotton sateen. Regardless of weave, the size of yarn and the number of warp and filling yarns per inch (thread count) greatly affect permeability. A low thread count will permit higher airflow rates at low pressure drop, whereas a high count will trap more fine particles and produce a higher pressure drop.

The woven fabric may have various finishes. Cotton fabrics may be preshrunk to maintain dimensional stability. They may also be napped in order to hold a filter cake. (Napping is the process of scratching the cloth surface to raise the fibers and form a soft pile.) Synthetic fabrics may be heat-set to obtain dimensional stability and a smoother surface with uniform permeability. All fabrics may be silicone-sprayed to obtain abrasion resistance, improved cake release, or low moisture absorbency.

Many other fabrics are available for special applications. Selection of these should be made only after determining that the common fabrics are not suitable for the proposed service, and after discussing the application with specialists in filter-media firms.

Example of performance

The following example illustrates the unpredictability of fabric performance. Specifications for the original



Changes in bin pressure during cleaning of two-compartment filter. Fig. 3

bag material as furnished by a filter manufacturer are compared to a replacement material supplied six years later by the same manufacturer for the same filter and the same service.

	Original	Replacement
Fabric manufacturer	ABC Co.	XYZ Co.
Material	Orlon filament	Orlon staple
Thread dia., in.	0.0085	0.024
Thread count, yarns/in.	70 x 68	90 x 60
Weave	Twill	Satin
Permeability, $(ft^3/min)/ft^2$ (Frazier)	20 to 25	43

Despite the apparent dissimilarity of these fabrics, they gave the same performance. In this case, filtration and pressure drop were evidently a function of the type of filter cake built up on the fabric during service rather than a function of the fabric.

The fabrics are formed into filter bags having configurations to suit the collector. The bags may be cylindrical tubes open at both ends for attachment to top and bottom tubesheets using band clamps or snap rings, and fitted with anticollapse spreader rings to permit the released dust to fall out. Or, the bags may be cylindrical tubes closed at the top to permit suspension from a system of shaker bars, and open at the bottom for fastening to a tubesheet. Or, they may be cylindrical tubes closed at the bottom and open at the top for installation over a wire retaining-cage suspended from a tubesheet.

The bags may be oblong—in one version, closed at one end, open at the other for slipping over a retaining cage (like a pillowcase); in another version, closed at one end for top suspension, with several cylindrical openings at the lower end for clamping to a tubesheet.

In any bag design, the following details should be considered:

Thread used to sew the bag should be of the same material as the bag, or compatible with it. The open ends of the bag, which are attached to tubesheet ferrules by clamps or snap rings, should have a reinforced cuff. All hems and seams should have two rows of stitches, with edges folded or treated to prevent fraying. Spreader rings should be enclosed in a pocket that is doubly reinforced inside and outside the bag.

The suspension end of hung bags should be doubly reinforced and folded over to form a loop for hanging on a wide suspension hook, or fitted with a metal grommet if hung from an eye bolt or hook bolt. Cuffs of oblong bags that are hooked over support pins should be fitted with metal grommets at the hook locations. Where bags must be grounded, a copper wire should be sewn the full length of the bag, with sufficient lead to clamp to a tube ferrule.

Filter cleaning

The shape of the filter element, its method of support and the normal direction of airflow through the filter will determine the method of cleaning. Normal airflow will hold the dust cake against the fabric. Stopping the flow of air will tend to release the dust cake. Simultaneously flexing the element, or reversing the airflow, will ensure release of the cake so that it can drop into a hopper.

Flexing can be induced (1) mechanically, by motor-driven crank mechanisms that oscillate closed-end tube elements, or (2) pneumatically, by reverse airflow for flow-through or closed-end tube elements.

On flow-through elements that collect dust on the inside surface, spreader rings may be used to form nodes for more-effective reverse-air flexing and to prevent collapse of the elements. (A collapsed element would prevent the dust from falling into the hopper.) On closed-end tubular elements that collect dust on the inside surface, a top-suspension tensioning device is depended upon to prevent collapse of the elements during cleaning and to hold their surfaces taut to form the dust cake during normal airflow.

Envelope, oblong or tubular elements that collect dust on their external surfaces are generally placed over metal retaining cages or grids that keep the fabric taut so as to retain the dust cake and maintain the internal open area required for clean-air flow. During cleaning, reverse airflow flexes the fabric away from the retainer grids; restoring normal airflow whips the fabric against it.

On collectors where normal airflow through the fabric is not stopped, an extra-high reverse airflow is needed to dislodge the dust cake. This may be done by using high-pressure air jets or separate air-reversal blowers.

Cleaning methods for baghouses

Commercial baghouses use one or more of the cleaning methods previously discussed. These methods may be further described as follows:

Shaking only is used on unit filters having woven bags where service can be interrupted long enough for cleaning—usually 3 to 4 min. The bags may be (1) envelope type, mounted over a metal spacer, with the closed end connected to a motor-driven shaker grid and tensioning bar, and the open end fastened to a clean-air plenum wall; or (2) tubular type, with the closed end suspended

from motor-driven shaker bars, and the open bottom end fastened to a tubesheet for the entry of dust-laden air. The cleaning cycle may be initiated by (a) a timer set for a specific cleaning period, (b) a pressure-differential sensor, or (c) a manual stop-button connected to a time-delay relay. In this method, the exhaust fan stops, allowing the internal pressure to reach atmospheric, and the shaker motor operates for a preset interval. After cleaning, operation of the dust collector may be restored automatically or manually, depending upon the service.

Shaking with reverse airflow is used with either type of bag described for unit filters. However, for continuous service, the filter elements must be distributed among two or more compartments, and the exhaust fan must remain in operation during the cleaning cycle. Each compartment is fitted with its own shaker mechanism and a set of reverse-air dampers. Each set comprises an outlet damper, ducted to the exhaust fan, and a smaller damper opening directly to atmosphere. A program timer permits cleaning the bags in each compartment successively, with the time interval between cleanings adjusted to suit the service.

During cleaning, the timer activates the reverse-air damper drive to close the clean-air outlet damper to the fan, and simultaneously opens the atmospheric-air inlet damper. Suction from the active compartments draws air through the bags in the reverse direction. Limit switches make sure the dampers are correctly positioned and start the shaker mechanism. After the shake period, the reverse-air damper drive opens the clean-air outlet damper and closes the atmospheric-air inlet damper, reactivating the compartment. During the cleaning cycle, a certain amount of dust is picked up by the reverse airflow and deposited on the bags in the active compartments.

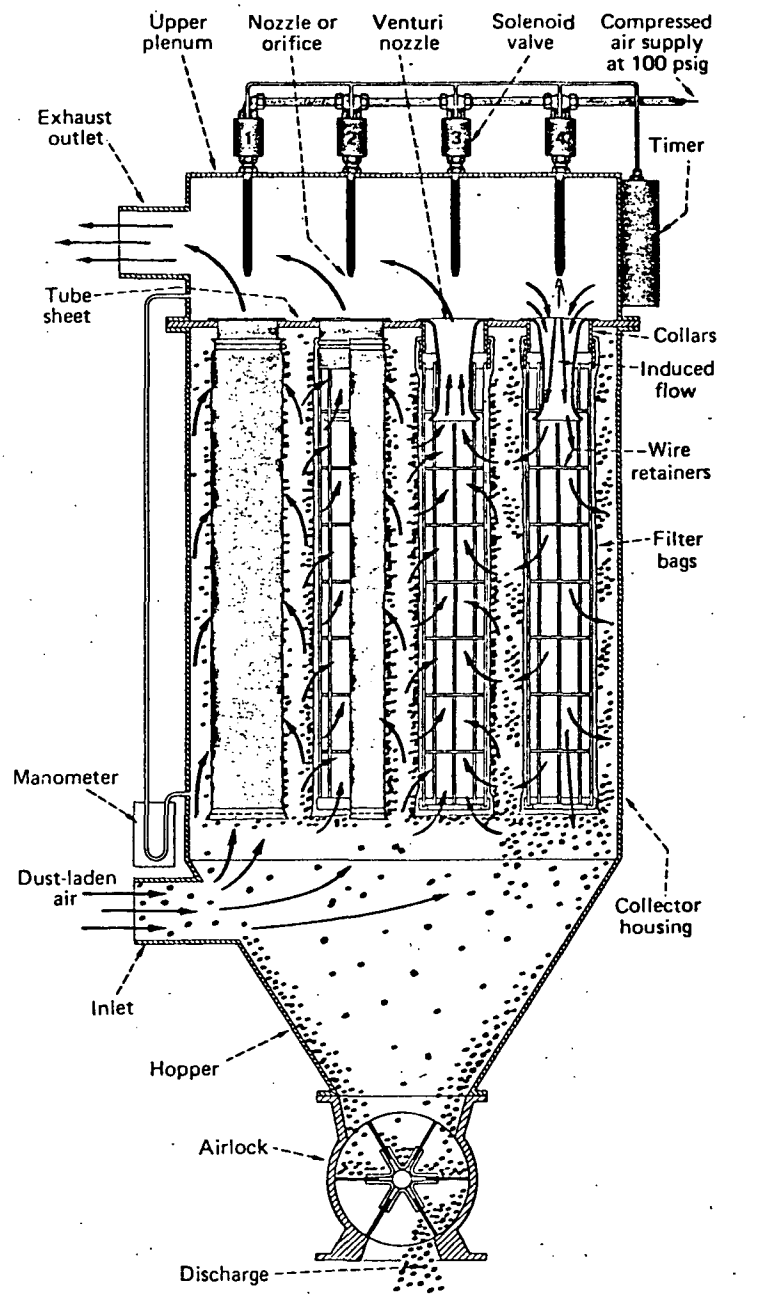
Fig. 2 shows a two-compartment filter used for venting a silo receiving material from a pneumatic conveying system. Fig. 3 shows the variation in bin pressure during the cleaning cycle for this collector.

Reverse-airflow cleaning is used for all types of filter elements (tubular or envelope, woven or felt materials, dust inside or outside of the bag, elements distributed between several compartments or all in one housing). There are many arrangements for creating reverse airflow—all intended to enable continuous service. Several common arrangements are:

1. A compressed-air nozzle at the clean-air discharge of each bag injects high-pressure air into the tube in the reverse direction from normal airflow in pulses of short duration (1/10 to 1/25 s) for systems having closed-end tubular bags supported on metal retainer cages suspended from the clean-air plenum tubesheet. The pulses are controlled by external timers that operate special air-supply solenoid valves, each of which serves a group of bags. The time between pulses is adjustable, but is factory-set for the intended service. See Fig. 4.

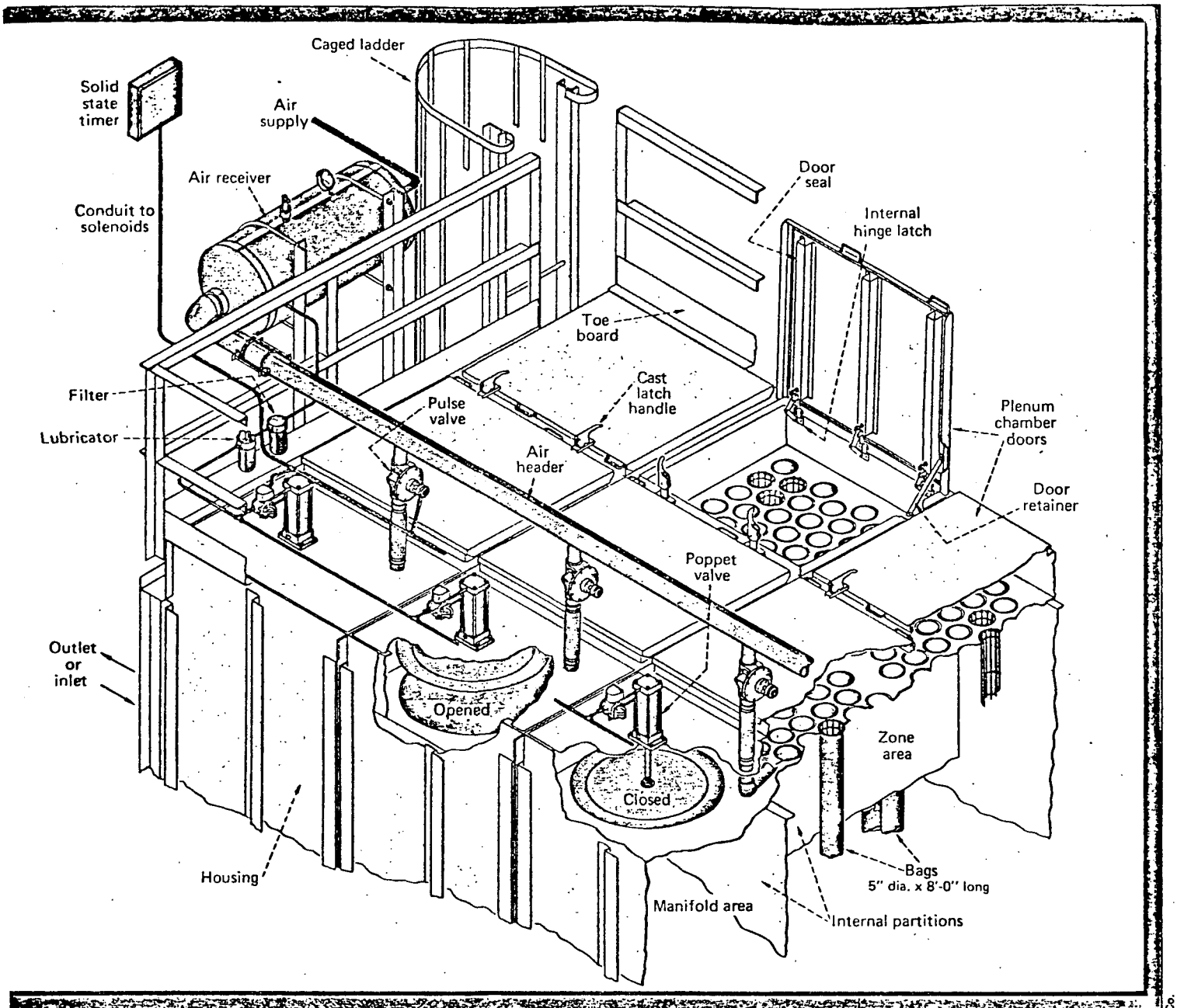
2. A variation of this method is to divide groups of bags (including the clean-air plenum) into zones by means of internal partitions. The clean-air plenums are manifolded into an outlet duct via poppet valves. Each zone is equipped with a single pulse valve that supplies compressed air to the group of bags. During the cleaning cycle, the poppet valve in the zone to be cleaned closes, stopping airflow through the zone. The pulse valve opens for 0.1 s, admitting a burst of air into the plenum to clean the bags. The poppet valve then automatically reopens, putting the cleaned zone back onstream. This operation is repeated in each successive zone until all bags in the collector have been cleaned. See Fig. 5.

3. A motor-driven plenum chamber receiving air from a separate blower delivers reverse air to closed-end oblong bags that are supported as in the previous arrangement but not zoned. The plenum rotates and blows reverse air into the clean-air discharge end of each bag as its nozzles travel over the bags. Timing is



Mikropul Corp.

High-pressure reverse-air blast cleans bags Fig. 4



Partitioned collector uses a pulse valve to admit reverse air for cleaning all bags in zone Fig. 5

Fuller Co.

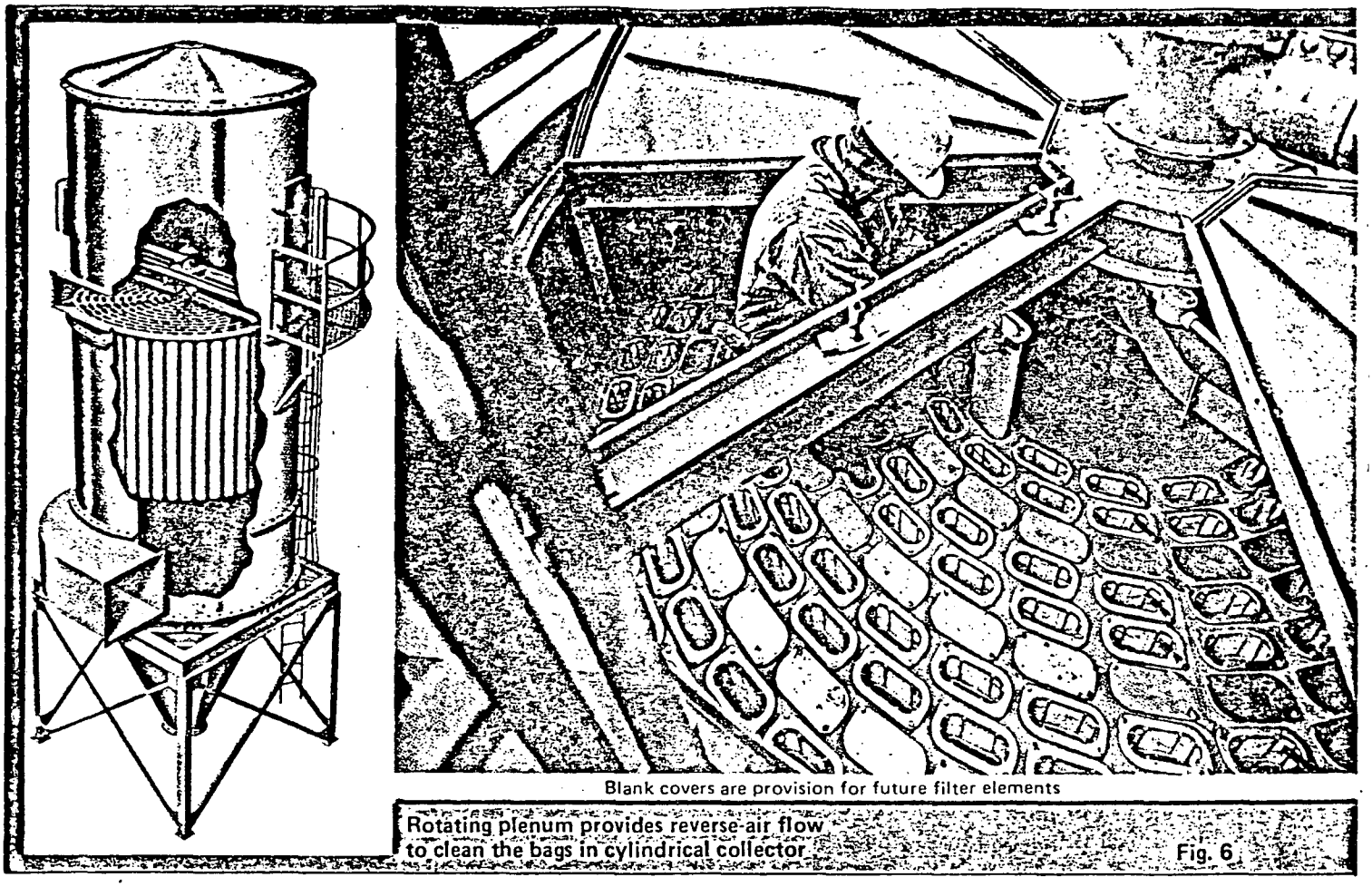
determined by the speed of rotation of the plenum chamber. See Fig. 6.

4. A counterweighted frame carries a series of blow-rings that encircle each filter tube. The frame is driven slowly up and down by chains supported from overhead shafts and sprockets. Air is continuously supplied to the blow-rings by an external blower or fan connected by a hose, or a specially designed air-supply connection to a manifold mounted on the blow-ring carriage. See Fig. 7.

5. A traveling air-plenum, moving horizontally, is positioned over the clean-air discharge of each vertical line of envelope-type filter bags. Diaphragms on the traveling plenum seal off adjacent rows of bags. Reverse air may be supplied in two ways: (a) atmospheric air may be drawn through the filter bag in the reverse direction from normal airflow by the operating suction of the exhaust fan, or (b) clean air may be blown back into the bags from a separate blower mounted on the traveling plenum. See Fig. 8.

Design requirements for filters

Manufacturers offer standard designs for baghouses. However, such designs may have to be radically modified to suit the user's requirements. These may be fixed by the characteristics of the material entering the baghouse, and by the operational needs of the duct system to which the baghouse is connected. Before preparing a specification for a baghouse, consideration must be given to design details such as: housing construction, physical location, servicing provisions, method of operation, and protection from fire and explosion.



Rotating plenum provides reverse-air flow to clean the bags in cylindrical collector Fig. 6

CEA—Carter-Day

Housing construction

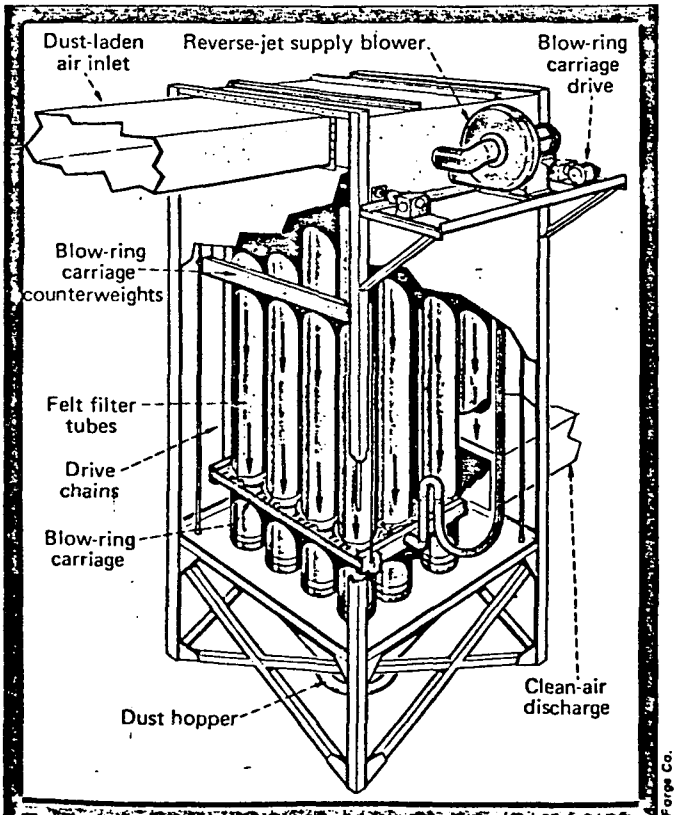
Baghouses may operate under positive or negative pressures. Baghouses that receive air from a fluidized-bed process or from a positive-pressure pneumatic conveying system generally operate under positive pressure. The pressure is limited by the pressure drop across the bags because discharge is directly to atmosphere.

Most baghouses operate under negative pressure, which imposes stringent design requirements for the bag enclosure walls.

Although the pressure drop across a baghouse may be 3 to 6 in. water column, the negative pressure imposed by the exhaust fan is determined by the duct-system requirements that may be five to ten times those of the pressure drop. If the air inlets to the baghouse are blocked by powder or closed inlet dampers, the suction may increase to values well above the normal operating level. The user must determine the maximum suction that may be imposed on the baghouse, and seek a unit that is rated for this condition.

If the dust-air mixture can become explosive, the baghouse walls must also resist a positive pressure that is determined from dust-explosion tests. These fix the vent area in the walls, so as to limit pressure buildup. The user must specify the allowable positive pressure for baghouse design.

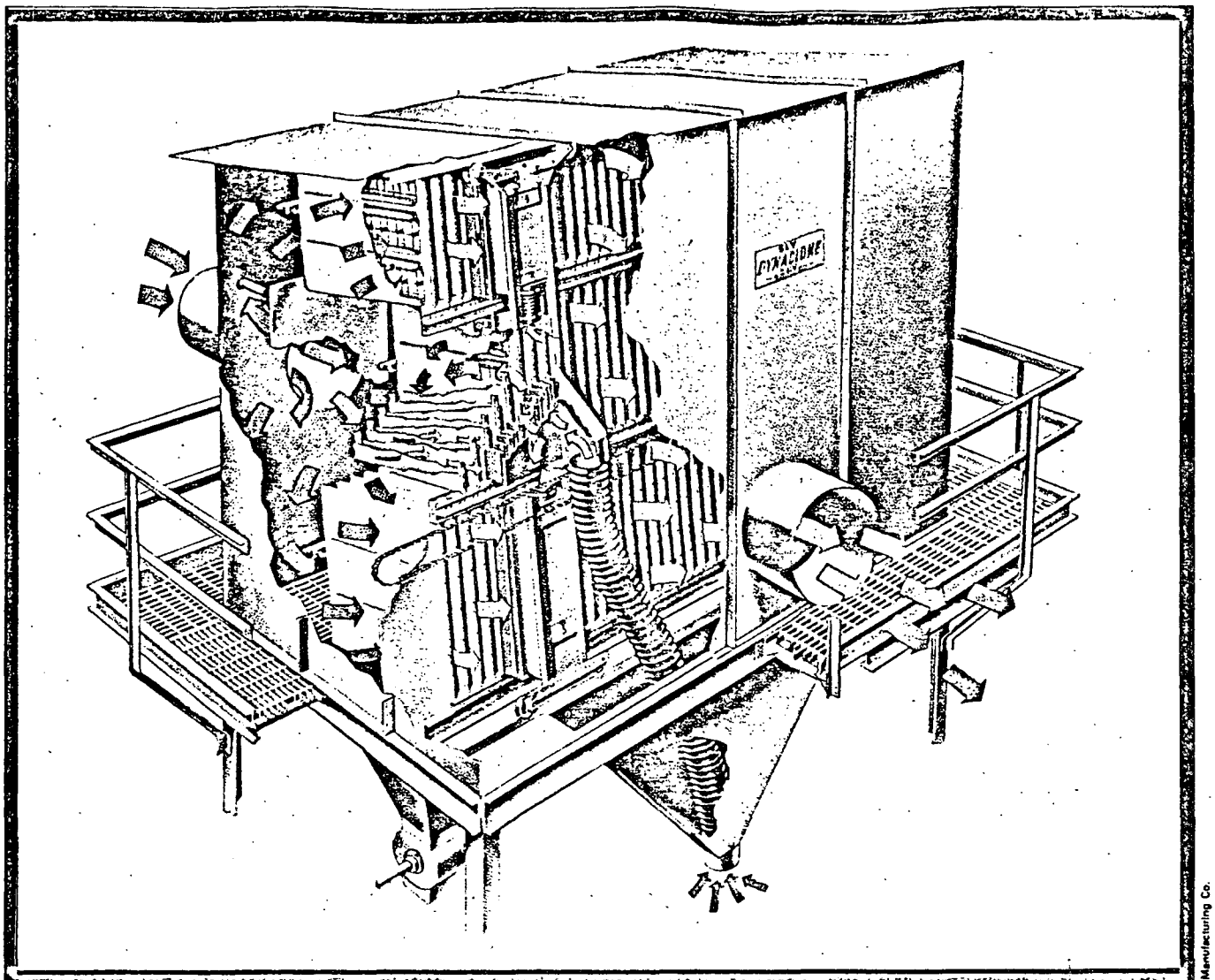
Cylindrical baghouses are simpler to design for high suction or high pressure than are flat-sided enclosures.



Traveling blow-rings remove dust from collector tubes Fig. 7

Buffalo Forge Co.

5-8



Traveling plenum moves horizontally to remove dust from envelope-type bags Fig. 8

W.W. Sly Manufacturing Co.

Standard suction ratings for cylindrical units range from 15 to 160 in. water column, depending on diameter. Rectangular or square baghouses have ratings that range from 15 to 30 in. water column. These units require external battens and cross-bracing to stiffen them. Multicompartmented units have interior walls that require special bracing to resist differential pressures and stress reversal during cleaning operations. Tubesheets are usually made of heavier plate than are the walls, and are fitted or formed with stiffeners because the tubesheets not only serve to support the bags and retainers but also act as walkways during tube replacement. Distortion of tubesheets can cause top-suspended bag retainers to touch each other and retain dust. Some baghouses are only available as cylindrical units; others may be square, rectangular or cylindrical, depending on size and application.

Fabrication of baghouses

The enclosures for housing and supporting the bags may be made in several ways:

1. Modular design—A complete, factory-assembled unit consisting of bolted or welded components may include the dust hopper, supporting legs, cleaning accessories, timer, internal baffles, bags, etc. Installation only requires rigging into location atop a base to hold down the legs before connecting to the inlet and exhaust systems, and utilities. A group of parallel-connected units may be used to get additional capacity. The parallel connections may be internal, using common clean-air or dusty-air plenums; or external, using ductwork manifolds attached to inlet and outlet connections on each module. Module sizes are limited to those that can be transported over the road. The largest (12 to 14 ft square in cross-section) would require a low-bed trailer.

2. Factory-welded subassemblies—The bag housing, inlet and outlet plenum chambers, dust hoppers, etc., are separately fabricated to form the largest subassemblies that can be shipped over the road. Connections to adjacent components may be prepared for bolting or welding at the jobsite. The method of assembly depends on the materials of construction and location of the baghouse. Field welding is precluded where bags are

5-9

already installed in the subassembly. The bag enclosures may contain all the bags attached to their retainers, and may have cleaning accessories factory-piped and factory-wired.

3. Knocked down—All structural components are fabricated as separate panels, with formed flanges for assembly in the field by bolting or by welding. This type of construction is limited to very large baghouses fabricated of special materials or located at jobsites where access by crane is not possible. The flanged joints also serve as stiffeners on the flat surfaces of hoppers, plenum chambers, tubesheets and bag enclosures.

Materials of construction and unit size

The materials of construction and the sheer size of some units may preclude complete factory assembly, which is preferred in order to eliminate leakage and fix responsibility.

Baghouses requiring hot-dipped galvanized surfaces or internal linings of rubber, polyurethane or other plastics for resisting corrosion or abrasion will need bolted and gasketed joints because welding will destroy the coating. Hot-dipped galvanized sections are limited to sizes large enough to fit into available dip tanks.

Welding of galvanized surfaces is possible, but special joint preparation and field coating the weld with compatible materials are required in order to maintain corrosion resistance. Larger galvanized sections may be welded by using lower-cost electrogalvanized sheet steel instead of hot-dipped, in order to avoid the size limitation imposed by dip tanks. However, special welding preparation and coating of the weld will be required.

The weight of the zinc coating on electrogalvanized sheets should equal that normally specified for hot-dipped galvanizing (a coating of not less than 1 oz/ft^2 on each surface). Complicated surfaces such as tubesheets on baghouses requiring interior coatings may have to be stainless steel or Hastelloy because coating these surfaces may not be possible. All bolted joints will require gasketing or the application of a sealing compound to the mating surfaces. These materials should be compatible with the interior coating and the dust entering the collector.

The large size of a unit may require fabrication and shipment knocked-down in order to erect the baghouse in areas inaccessible to a crane. Such areas could be (a) building interiors, (b) yards surrounded by high buildings, or (c) roofs loaded with other equipment. In many cases, a crane could lift the components to a peripheral location, from where they could be trolleyed on a cable to the final position.

Access for servicing

The location of access doors is principally determined by the method of grouping the bags and attaching them to their supports. The closed-end tubular bag and its metal retainer suspended from the clean-air plenum tubesheet is the most common design because it permits the closest grouping of bags in a given space. Access is through hinged doors located entirely across the clean-air plenum, atop the collector. The bag and its retainer are simply dropped through the tubesheet and fastened to it by clamps, snap rings or twist locks, using the bag material as a gasket. Internal air-nozzle piping is made to swing out of the way or to be easily disconnected. Or, the clean-air plenum is subdivided and valved so that each subdivision can be isolated and pulsed by a single solenoid valve.

Where the bags must be serviced regardless of weather conditions, the clean-air plenum can be designed as a walk-in housing requiring only one door, but only on collectors fitted with an air nozzle over each bag. Where bags and retainers are clamped from below the tubesheet, the doors must be located on the side walls of the unit so that bags are within 30 in. of the opening to allow proper takeup of clamps.

If adjacent walls or equipment interfere with proper location of a side door, the available doors must be used, necessitating the removal of a group of bags in order to reach those furthest from the door.

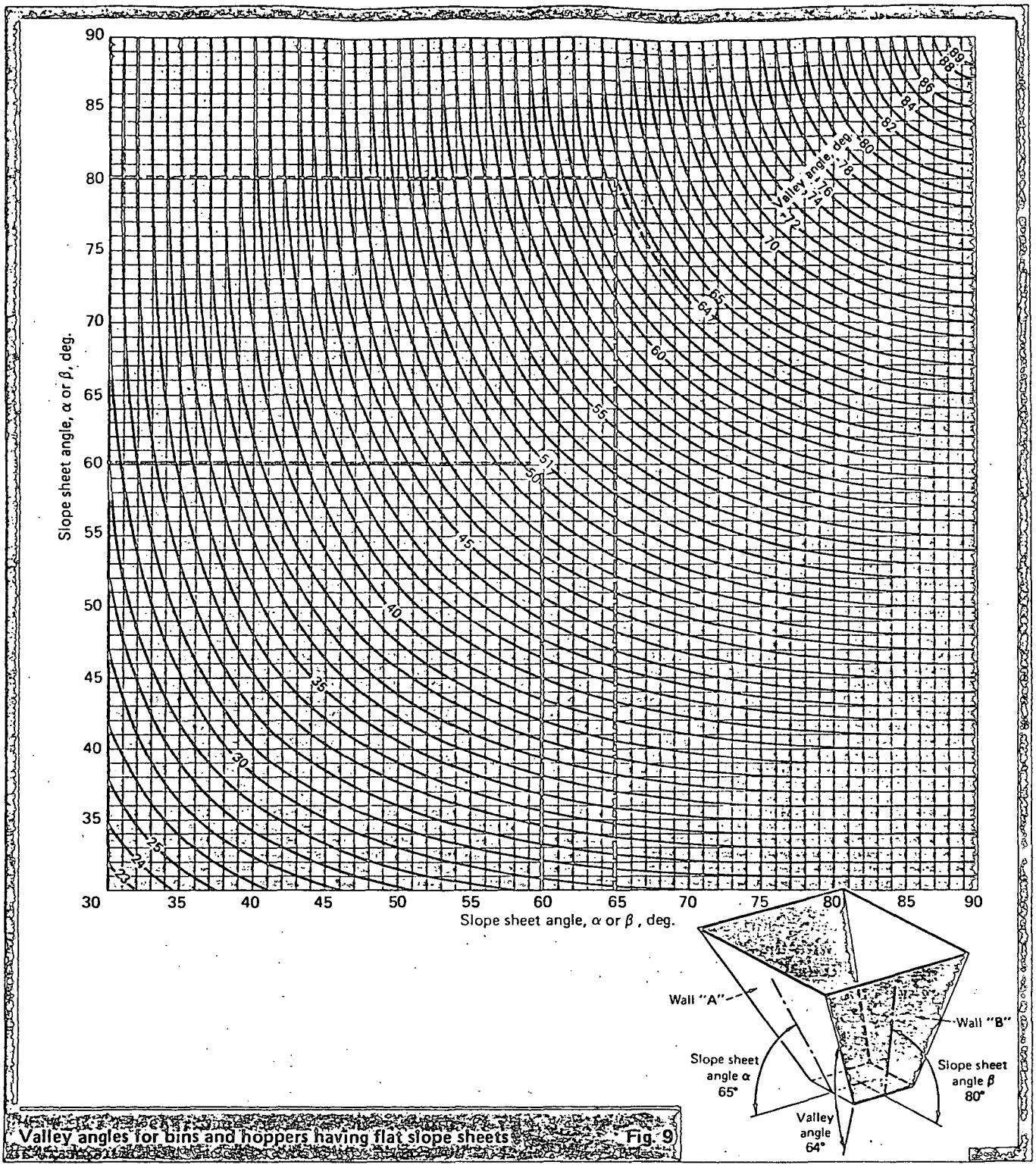
Bags suspended from shaking bars, with their open ends fastened to a bottom tubesheet, are usually grouped on each side of a narrow walkway within the clean-air compartment that is reached through a single door in the wall. During rebagging, the most remote bags must be attached and tensioned. Then, work must progress toward the walkway.

Envelope-type bags on metal spacer frames are installed in horizontal rows, with their open ends clipped to the vertical slots of a clean-air plenum, and their closed ends hooked to a support frame. Several rows of bags are located in tiers, one above the other. All bags in a compartment are accessible from two doors—one leading to the clean-air plenum, the other leading onto a walkway in the dusty-air chamber.

Long, large-diameter bags that are open at both ends are usually fastened to a bottom tubesheet that is accessible through a side door at the bottom of each compartment, and to the top tubesheet that is accessible through one or more doors in the roof of the dusty-air inlet plenum. The side doors lead to walkways between the bags. Some designs limit the number of rows of bags on either side of the walkway in order to improve access for clamping and to avoid damage to the bags.

All doors should be loosely hinged, and clamped or latched in such a manner that all surfaces of the gasket are sealed airtight. Gaskets should be closed-pore sponge rubber (40 Durometer hardness) that is cemented into a confining recess around the door or around its frame. The rubber and its cement should be compatible with each other and with the dust to which they are exposed. Latches or clamps should be so designed that they can be opened manually by operators without using a wrench or special tool. The frames of all doors should extend beyond any external insulation so that they can be flashed properly. The inside surface of vertical or sloping doors on the dusty side of the collector should be flush with adjacent walls in order to prevent dust buildup on ledges.

Platforms, railings and ladders should be furnished for reaching all elevated equipment and all access doors. These should be built in accordance with applicable safety codes. Rooftop equipment should be accessible for servicing from within the peripheral handrailing. Ladders should have safety cages starting 7 ft above floors or platforms, and should be equipped with



Valley angles for bins and hoppers having flat slope sheets Fig. 9

grab rails and, for greater safety, with narrow, nonskid treads in place of rungs. Platforms should be made from serrated grating so that dust cannot accumulate and slipping is prevented.

Dust hoppers and dust discharge

The material removed from the bags may be dropped directly into a bin or silo if the baghouse is used for venting that bin or silo. Otherwise, the material is dropped into a collecting hopper that is shaped to direct the flow to the dust outlet usually fitted with an airlock-type discharge valve.

On multicompartment units, each compartment should be fitted with its own dust hopper, to permit its isolation during cleaning or maintenance. To eliminate a multiplicity of airlock discharge valves, the bag compartments may discharge into a common V-shaped hopper equipped with a screw conveyor that delivers the dust to a single discharge valve. Such a screw conveyor must operate at the baghouse pressure. Therefore,

the conveyor must be equipped with effective seals at the ends of the trough and at the bearings, which should be outboard of the hopper. The conveyor must also be able to handle the collected dust at the proper rate.

The flow properties of the collected dust should be known, since they may be quite different than the properties of the material from which they originated. The slope angles of the dust hopper may have to be steeper than those of the storage silos of the original material because (1) fine dusts tend to pack more readily than coarse materials, (2) the dust may contain moisture picked up in the conveying air or formed by condensation within the collector, (3) collected material should be removed as rapidly as it is deposited on the hopper walls. Steep slope angles increase the overall height of the baghouse and may limit the space available for installing a discharge valve. However, failure to provide the proper slope will create problems after installation.

A conical hopper attached to a cylindrical baghouse presents no problem other than the increase in height required to obtain a steep slope. Attachment of a square, rectangular or conical hopper to a square or rectangular baghouse requires study—especially of the valley angles formed by the slope sheets of inverted pyramidal hoppers, or by transitions to conical hoppers. These valley angles should be at the minimum value required to obtain material flow. If the wall-slope angles to the horizontal are known, the valley angles may be obtained from Fig. 9, or from the formula from which the chart is derived:

$$\cot^2\theta = \cot^2\alpha + \cot^2\beta$$

where θ is the valley angle, and α and β are the slope angles between the horizontal and Wall A and Wall B of the hopper, respectively, as shown in the sketch in Fig. 9.

Provision of the proper valley angle at an intersection does not ensure material flow, because moist materials can bridge across the intersection. To minimize bridging, the intersection should be formed to as large a radius as possible when joining the flat slope-sheets internally.

On baghouses cleaned by reverse-air blast (using compressed air), the slope-sheet angles can be reduced by a few degrees because the air blast helps to propel the collected powder down the slope.

Materials may still hang up even though the proper slope angles are provided on dust hoppers, because of process upsets, changes in moisture content, etc. To ensure flow, mounting pads should be installed on the slope-sheets for attaching mechanical or pneumatic vibrators for inducing flow. The vibrators should be placed at the centroid of each surface. The flow inducers should be operated only when needed. Cylindrical hoppers require only one pad, located at the centroid of the projected surface.

The dust hopper and its supports should be designed on the basis that it could become full of material and may also have to support a surcharge. This situation may arise if the baghouse becomes full of material because of a broken bag, a malfunction of the dust-discharge valve, or stoppage of a downstream dust conveyor.

Outdoor installations

Since many exhaust systems draw air from within warm buildings, or handle hot materials from processes or handle materials containing moisture, condensation is a possibility within the baghouse. This can occur on baghouses located indoors or outdoors, particularly in winter. Some manufacturers' guarantees are automatically voided if condensation occurs inside the unit.

In such situations (especially outdoors), the baghouse should be insulated. Insulation should be of sufficient thickness to prevent condensation at the lowest outdoor temperature recorded in a given location. All doors, dust hoppers and projecting stiffeners should also be insulated. Outdoor insulation should be protected with aluminum or stainless-steel jacketing, applied so as to shed water. Flashings of the same material should be formed and fitted around all access openings. In some cases, removable covers containing the insulation may be fitted over doors to permit easy access.

If a baghouse does not require a separate enclosure, a watertight housing should be provided around dust hoppers, dust-discharge valves, and other dust-recovery equipment located below the baghouse to permit access for servicing during bad weather. Hinged or easily removable weathertight hoods should be furnished to protect all external operating mechanisms.

All electrical conduit to timers and actuators mounted on the baghouse should be watertight. Pneumatic actuators, solenoid valves, shaking mechanisms, and air piping to them, must also be insulated or traced, to prevent condensation of moisture and its subsequent freezing, which will prevent operation of the accessories.

If baghouses handling hot gases are shut down for the weekend, they become especially susceptible to condensation problems that prevent startup. Such units should be equipped with an independent heater and a pressurizing fan designed to maintain the normal operating temperature within the unit during shutdown. A gravity-closed damper on the discharge of the main exhaust fan will permit retention of the heated air. Baghouses operating under pressure should have a weathertight cover or an automatic backdraft damper at the air outlet to prevent intake of cold air during shutdowns.

Protection against fire

When hazardous materials are handled, protection must be provided to eliminate or minimize hazards. Some materials may only require fire protection; others, fire and explosion protection.

The best procedure for determining the hazards in handling a particular dust with unknown characteristics is to submit test samples to the fire-insurance underwriter's laboratory or to a commercial testing laboratory that has facilities for conducting:

1. Combustion test—Ignition by match flame or Bunsen burner to determine whether the material is self-extinguishing, or whether the flame will spread.

2. Spontaneous-combustion test—Exposing material to high temperature for a prolonged period (several hours). The material is contained in a crucible im-

mersed in a hot salt bath. Moist materials should be tested at their usual moisture content, and again after drying.

3. *Autoignition-temperature test*—Same as the preceding test, but raising the temperature continuously to determine the temperature at which ignition occurs. Evaporation of water from a moist sample may exclude air, so that the autoignition point could be on the high side.

4. *Dust-explosion test*—Material is placed in a bomb having a variable vent opening, mixed with compressed air, and then ignited by an electric spark. The pressure developed is measured and reported for two conditions—(a) unvented, and (b) for a specific ratio of vent area to bomb volume. Materials known to be explosive should also be tested for rate of pressure rise in addition to the pressure developed from an explosion.

Where possible, any baghouse subject to fire or explosion should be located outdoors, and away from important equipment.

Fire protection may be provided by a built-in sprinkler system. The sprinkler heads would be rated about 25° (F) below the temperature limit of the bags if no other protection were available; and 100° (F) above this limit, if early-warning protection were installed. The sprinklers would be connected to a building sprinkler system. The heads are usually located where they can cover most of the bag area. Additional heads may be needed to cover the dust hoppers. Because of difficulty in placing heads in some baghouses, assistance of the fire underwriter's engineering department should be obtained.

Opening of the sprinklers would be indicated by the water-flow detector and alarm on the building sprinkler system. However, a local alarm to warn system operators may also be required. The local alarm would be a fire detector within the baghouse—the detector being set at the same temperature as the sprinkler head. Provision must be made to dispose of the water released by the sprinklers. When the baghouse is outdoors, a nonfreeze sprinkler system will be needed. A dry system, using air in the sprinkler lines, is expensive and requires considerable maintenance. A system filled with a nonfreeze solution may foul the bags when the heads are released. Hence, the bags may require replacement even if they are not burned.

Several alternatives are available for sprinklers:

1. An inert-gas (Halon) injection system may be installed. When actuated, it will exclude or reduce the oxygen content in the baghouse so that combustion cannot be sustained. The sensor is a rate-of-rise temperature detector, set at the temperature limit of the bags, that operates a control unit to electro-explosively rupture a diaphragm to release the inert gas into the baghouse. The gas storage vessels are located outside the collector. If the system is actuated, there is no mess to clean up except char from the fire. The control unit can also initiate other functions such as closing dampers, stopping fans and sounding alarms.

2. A steam-smothering or a water-deluge system that is actuated manually or by a rate-of-rise temperature detector uses open nozzles, located in the same manner as sprinkler heads.

3. A manually operated deluge system can be devised for collectors having reverse-jet air manifolds by connecting a water header to the air manifold pipes at the ends opposite the air header. When water is turned on, the air pulses speed up wetting of the bags. The timer can be temporarily switched to pulse all nozzles simultaneously, and pulse time could be increased to obtain faster water distribution.

Protection against explosion

Explosion protection may be provided by installing an inert-gas suppression system or explosion doors.

The suppression system is similar to that for fire protection, except that a highly sensitive pressure detector initiates action of the control unit. The pressure setting is determined from data for the rate of pressure rise obtained during the bomb test. The baghouse may be isolated so as to contain the inert gas without loss by the use of fast-acting inlet and outlet dampers, or by shutting down the exhaust fan and rapidly closing an outlet damper.

The inert-gas suppression system detects the pressure rise caused by an explosion, and acts in milliseconds to stop pressures from reaching values that would rupture the bag housing. Because of the short duration of an explosion, and the dependence on proper functioning of all control equipment, a backup system of explosion doors may be desirable.

Explosion doors are generally installed in baghouse walls on the dusty-air side. They may be hinged doors with special, spring-loaded, quick-releasing latches. They may be rupture panels made of frangible materials such as aluminum foil, lead sheets, polyethylene or Teflon. They may be laminates of metal and plastic designed to rupture along prescored lines to obtain full opening of the panel. They may be loose doors held in place by their own weight or by suction.

Latched or loose explosion doors on outdoor baghouses must have rain hoods built around them. Weighted doors, unattached by any other means, should have chains connected to them, which are fastened to an internal structural member, so that the doors do not become missiles when blown open.

Every explosion is rapidly followed by an implosion that can be as damaging to the structure as the explosion. Explosion doors that are pivoted or hinged should be designed to prevent automatic reclosing. Such doors should be reclosed manually.

The concluding installment of this two-part series on baghouse collectors, to appear in the issue of Apr. 23, will deal with the selection and testing of filters, measuring performance, and acceptance testing of baghouses. A reprint notice for both parts will be carried at the end of the article in that issue.

Steven Danatos, Editor.

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