Lesson 7

Industrial Applications of Fabric Filters

Goal

To familiarize you with the typical industrial uses and basic cost estimates of fabric filters.

Objectives

At the end of this lesson, you will be able to do the following:

1. List six process industries that use fabric filters to control particulate emissions
2. Describe the specific uses and design features of fabric filters used in conjunction with acid gas control systems
3. Identify how to use charts and figures to estimate the cost of fabric filters

Introduction

Fabric filters are used for particulate emission reduction for many industrial applications. Fabric filters can be designed to collect particles in the submicrometer range with 99.9% control efficiency. They are occasionally used to remove particles from exhaust air streams generated by industrial processes where the clean air is recirculated back into the plant to help offset space heating needs. Fabric filters are used in the power generation, incineration, chemical, steel, cement, food, pharmaceutical, metal working, aggregate, and carbon black industries. Shaker, reverse-air, and pulse-jet fabric filters are used in a number of industrial applications as shown in Table 7-1.

Table 7-1. Typical industrial applications for baghouses

Shaker	Reverse-air	Pulse-jet
Screening, crushing, and conveying of rock products	Cement kilns	Pharmaceuticals
Low temperature steel applications	Lime kilns	Food industry
Metal working	Electric steel furnaces	Woodworking
Mining operations	Gypsum calcining	Sinter plants
Textiles	Ore smelters and roasters	Metal working
Woodworking processes	Sintering plants	Foundries
Chemical industry	Rock dryers	Textiles
Food industry	Foundries	Chemical industry
Coal-fired boilers	Carbon black	Coal-fired boilers
	Magnesium oxide kilns	Asphalt batch plants
	Coal-fired boilers	Municipal waste incinerators

Fabric filters have been used for filtering fly ash in fossil-fuel fired boilers, municipal and hazardous waste incinerators, and a number of other industrial processes. In many industries fabric filters are becoming as popular as electrostatic precipitators for removing up to 99.9% of the particulate matter from particulate laden exhaust gas streams. The rapid growth in the use of fabric filters for particulate control has been aided by EPA's changing the definition of particulate matter from total particulate matter to that fraction with a mean aerodynamic diameter of 10 micrometers or less (PM10). This is due to the fact that fabric filters are considered to be superior collection devices for fine particulate control. Electrostatic precipitators (ESPs) are also efficient at collecting fine particles. EPA course SI:412B *Electrostatic Precipitator Operation Review* discusses these control devices.

Fossil-fuel Fired Boilers

Utility companies have been using fabric filters on coal-fired boilers since the mid 1970s and because of the advances in their design and operation, fabric filters have become a preferred technology for the control of particulate matter (Cushing 1990). Utility use of fabric filters is expected to increase as emission limits become more stringent and regulatory attention to air toxics increases. Fabric filters can also be integrated with acid gas controls providing an added dimension not possible with some other forms of particulate control.

Based on a survey conducted by the Electric Power Research Institute (EPRI) in 1989, there were 99 fabric filters operating on utility boilers representing 21,359 MW of generating capacity (Cushing 1990). Since the mid 1980s the application of fabric filters downstream of acid gas control equipment has increased substantially. Worldwide, industrial and utility use of fabric filters is even more dramatic as over 300 pulse-jet fabric filters are treating exhaust gas from coal-fired boilers alone (Belba 1992).

Table 7-2 lists some coal-fired boilers that use fabric filters for controlling particulate matter emissions that use either the reverse gas or shake/deflate cleaning method. The fabric most commonly used in the applications depicted on Table 7-2 is woven glass. Fabric coatings used include Teflon, silicon graphite, and other proprietary acid resistant coatings.

Table 7-2. Fabric filter performance data

Plant generating capacity (MW)	Coal type	Coal sulfur content %	Bag cleaning method	Gas temp °F	Flange to flange pressure drop in. H_2O	Tube sheet pressure drop in. H_2O	Gross air/ cloth ratio ft/min	Dustcake density lb/ft^2	Emission rate (lb/MMBtu)	Stack opacity %
Pulverized coal boilers										
150	WS	0.24	RG	325	7.5-8	-	1.95	-	-	-
85	WS	0.37	RG	-	6	-	1.77	-	-	-
223	WS	0.37	RG	270	7	6	1.58	-	0.012	-
223	WS	0.37	RG	282	6	-	1.81	-	-	-
405	WS	0.41	RG	267-305	5-5.5	4.6-4.8	1.65	0.78	-	0.5-2
447	WS	0.43	RG	273-306	3.5-5	2.5-3.5	1.72	0.35	0.0045	-
840	WS	0.43	RG	260-280	5-6	3.8-4.5	1.89	0.24	-	2-3
245	WS	0.47	RG	320	4-5	-	1.46	-	0.01	-
24	WB	0.49	RG	360	6	-	1.65	-	-	-
110	WS	0.52	RG	290	6-7.1	-	1.80	-	0.015	-
150	WS	0.52	RG	283-296	5-5.2	4.2-4.7	1.49	0.86	0.013	3-4
295	WS	0.52	RG	309	4-5	3.5-4.5	1.97	0.35	-	3
30	WS	0.61	RG	290	6-7	-	1.90(D)	-	-	-
565	WS	0.3	RG/S	275	8	5.6-5.8	1.7	0.35	0.03	3-5
565	WS	0.3	RG/S	275	8	-	1.7	0.28	0.023	3-5
254	WS	0.33	RG/S	230	5.5-6.8	4.5-5.5	1.98(D)	0.29	-	1
570	WS	0.45	RG/S	325	5.5-6.5	4-5	1.91	0.19	0.008	1-2
44	WS	0.52	RG/S	290	6.5-8.2	-	2.09(D)	-	0.016	-
100	WS	0.52	RG/S	290	4.2-6	-	1.98(D)	-	-	-
166	WS	0.6	RG/S	315	5.5-6.5	-	2.0 (D)	-	-	-
44	WS	0.61	RG/S	290	6-8	-	1.93(D)	-	-	-
739	WS	0.69	RG/S	240-280	4.8-5.5	4-4.4	1.50	0.64	0.023	-
185	EB	0.85	RG/S	301	5-6.5	2.5-3.5	1.76	0.32	0.029	3
185	EB	0.86	RG/S	305	5.7	2.7	1.87	-	0.018	3-5
185	EB	0.87	RG/S	300	5-6.5	2.5-3.5	1.91	-	0.036	3-5
79	AP	1.79	RG/S	325	6	-	1.71	-	-	-
350	EB	1.83	RG/S	-	5-9	4-8	1.83(D)	-	-	-
191	EB	2.2	RG/S	304	7	-	1.5	-	0.039	-
191	EB	2.4	RG/S	303	7	-	1.5	-	0.125	-
87.5	AP	2.6	RG/S	400	3.5	-	1.89(D)	-	0.085	-
87.5	AP	2.7	RG/S	400	3.5	-	1.89(D)	-	0.085	-
384	WS	0.35	S/D	305	9	8	3.2	0.23	0.03	2-4
384	WS	0.36	S/D	320	7.5	-	2.8	-	0.051	-
593	TL	0.43	S/D	350	9-13	7-11.5	2.6	-	-	-
593	TL	0.49	S/D	350	9-13	7-11.5	2.6	-	-	-
(79)	AP	1.79	S/D	350	6	-	1.9	-	0.01-0.07	-
Pulverized coal boilers with dry FGD systems										
279	WS	0.31	RG	185	4	-	1.58	-	-	-
319	WS	0.36	RG	165	6	-	1.60(D)	0.09	-	-
44	WS	0.52	RG	180	6	-	1.54(D)	-	0.03	-
860	WS	0.6	RG	165	9.8	-	2.00(D)	-	0.024	-
415	NDL	1.08	S/D	200	4-8	-	2.24(D)	-	0.018	-
Fluidized bed combustion boilers										
160	EB	0.33	RG	290	7.2	6.8	1.53	-	< 0.03	-
110	WS	0.39	S/D	294	5-6.5	3.7-5.2	2.4-2.9	0.23	0.0072	-

Coal Type: WS (Western Subbituminous); WB (Western Bituminous); AP (Anthracite/Petroleum Coke); TL (Texas Lignite); EB (Eastern Bituminous); NDL (North Dakota Lignite).
Cleaning Method: RG (Reverse Gas); RG/S (Reverse Gas with Sonic Assistance); S/D (Shake/Deflate).
(D): Design Air-to-Cloth Ratio.
Source: Cushing 1990.
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Design efficiencies of the fabric filters depicted on Table 7-2 ranged from 98 to 99.9%. The lowest particulate emission rates were found on units using reverse-gas cleaning and ranged from 0.005 to 0.03 lb/MMBtu. Particulate emissions from fabric filters using reverse-gas cleaning with sonic assistance ranged from 0.008 to 0.125 lb/MMBtu. The units using shake/deflate cleaning had particulate emissions of 0.007 to 0.07 lb/MMBtu.

Table 7-3 lists some coal-fired boilers that use fabric filters with pulse-jet cleaning. This table gives you an idea of the different combinations of bag material and A/C ratios that are being used successfully at different sites. Woven glass and felted fabrics are the most common bag materials used. Fabric filters using 16 oz/yd^2 woven fiberglass bags were found to be less efficient in particulate matter collection than fabric filters using 22 oz/yd^2 bags. Fabric filters using 22 oz/yd^2 bags achieved particulate emission levels consistently less than 0.02 lb/MMBtu (Belba 1992).

Table 7-3. Pulse-jet fabric filter performance data

Site No.	Design Volume (Kacfm)	Boiler type	Coal sulfur (%)	Flue gas/ash modifications	Fabric	Design A/C (ft/min)	Actual A/C (ft/min)	Particulate emissions (lb/MMBtu)
1	320	PC	0.35		Dralon T Felt	6.74	6.74	0.0808
2	320	PC	0.35		Dralon T Felt	6.74	6.74	0.0808
3	192	PC	0.48		Ryton Felt	3.71	4.17	
4	178	PC	0.50	SCR:NH3	27 oz WG	3.84	2.71	0.0080
5	96	PC	2.20	DFSDA:Lime	Glass Felt	4.00		0.0849
6	96	PC	1.00	DFSDA:Lime	22 oz WG	4.00		0.0636
7	96	PC	2.20	DFSDA:Lime	Nomex/Ryton Felt	4.00		0.0446
8	132	PC	0.76	DFSDA:Lime/2yrs PC	Ryton Felt	5.52	3.85	
9	82	PC	0.68		16 oz WG	3.66	1.99	0.0534
10	205	PC	0.70		16 oz. WG	3.83	2.83	0.0280
11	60	PC	0.66		22 oz WG	3.70	2.01	
12	50	PC		MC	16 oz WG	3.42		0.0170
13	48	PC	0.82	MC	22 oz WG	2.50	1.56	0.0210
14	84	PC	0.58		16 oz WG	3.23	2.82	0.0159
15	860	PC	0.16	MC	Nomex Felt	6.44	4.04	0.1050
16	530	PC	0.26		Nomex Felt	6.09	3.18	0.0180
17	1017	PC	0.38		Dralon T-Felt	3.94	3.80	0.0050
18	127	PC	0.40		Teflon Felt	4.46	4.40	
19	127	PC	0.40		Teflon Felt	3.35	3.89	0.0695
20	127	PC	0.40		Teflon Felt	3.35	3.95	0.1981
21	127	PC	0.40		Teflon Felt	3.35	3.69	0.0735
22	127	PC	0.40		Teflon Felt	3.35	3.55	0.1263
23	463	PC	0.80	FSI:LS/FUI/ESP	Nomex Felt	5.53	5.53	0.0162
24	220	PC	0.5-0.6	DFSDA:Lime	Nomex Felt	5.15	5.15	0.0032
25	297	PC	0.7-1.5		Dralon T Felt	6.69	2.14	0.0106
26	297	PC	0.7-1.5		Dralon T Felt	6.69		0.0106
27	297	PC	0.7-1.5		Teflon Felt	6.69		0.0127
28	729	PC	0.75	SCR:NH3	Nomex Felt	5.44		0.0269
29	729	PC	0.75	SCR:NH3	Teflon Felt	5.44		0.0269
30	729	PC	0.75	SCR:NH3	Ryton Felt	4.77	2.66	0.0269
31	492	PC	0.60	FSI:LS/DSI:Na/SCR:U	Nomex Felt	5.23	4.10	0.0180
32	320	PC	0.51		Daytex Felt	5.56		0.0230
33	320	PC	0.51	ASI	Daytex Felt	5.56	4.65	0.0230
34	1017	PC	0.38		Dralon T Felt	3.35		
35	180	PC	0.76		Daytex/Ryton Felt	5.30	3.38	0.0920
36	194	PC/WB		ESP/RASDA:Lime	Polyester Felt	4.88	4.13	
37	194	PC/WB			Tefaire Felt	4.88		0.0241
38	194	PC/WB			Glass Felt	4.88		0.0241
39	178	Stoker	0.32	FSI:Dolomite/Cyc	Dralon T Felt	4.92	2.98	0.0062
40	178	Stoker	0.32	FSI:Dolomite/Cyc	Dralon T Felt	4.92	2.98	
41	94	Stoker	1.30	RASDA:Lime	Nomex Felt	2.76		0.0026
42	94	Stoker	1.30	RASDA:Lime	Ryton Felt	2.76	1.80	0.0020

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Table 7-3. *(continued)*
Pulse-jet fabric filter performance data

Site No.	Design Volume (Kacfm)	Boiler type	Coal sulfur (%)	Flue gas/ash modifications	Fabric	Design A/C (ft/min)	Actual A/C (ft/min)	Particulate emissions (lb/MMBtu)
43	133	Stoker	0.40		Teflon Felt	4.33	5.09	0.0024
44	89	Stoker	0.40		Teflon Felt	4.33	5.13	0.0024
45	89	Stoker	0.40		Teflon Felt	4.33	5.13	0.0024
46	110	Stoker	0.51		Ryton Felt	5.73	6.37	
47	91	AFBC	1.19	LS/2ndary MC	16 oz WG	3.16		
48	91	AFBC	1.19	LS/2ndary MC	Nomex Felt	3.16		0.0128
49	91	AFBC	1.19	LS/2ndary MC	Nomex Felt	3.16		0.0168
50	91	AFBC	1.19	LS/2ndary MC	Ryton Felt	3.16	3.56	0.0185
51	146	AFBC	3.11	LS	16 oz WG/G-T	4.52	2.57	
52	59	AFBC	0.90	LS	Nomex Felt	2.82	3.57	0.0041
53	161	AFBC	1.2-3.2	LS/FAR	Nomex Felt	3.57	1.84	0.0095
54	56	AFBC	0.3-0.4	Sand	Ryton Felt	2.97	3.29	0.0057
55	203	CFBC	0.63	LS/NH3/FAR	22 oz WG	3.60	3.98	0.0064
56	182	CFBC	4.28	LS	22 oz WG	3.15	2.68	0.0030
57	182	CFBC	4.28	LS	22 oz WG	3.15		0.0007
58	111	CFBC	0.84	LS	Ryton Felt	4.59		0.0114
59	111	CFBC	0.84	LS	Ryton Felt	4.59	3.40	0.0189
60	165	CFBC		LS	Ryton Felt	3.94	2.37	0.0095
61	165	CFBC		LS	Ryton Felt	3.94		
62	99	CFBC	8.00	LS	Ryton Felt	3.54	3.54	
63	99	CFBC	8.00	LS	P84 Felt	3.54		
64	99	CFBC	8.00	LS	16 oz WG	3.54		0.3200
65	128	CFBC		LS	Nomex Felt	3.12		

Boiler Type: PC (Pulverized Coal); PC/WB (PC w/ Wet Bottom); AFBC (Bubbling Fluidized Bed Combustor); CFBC (Circulating Fluidized Bed Combustor).

Flue Gas/Ash Modifications (Upstream of PJFF): ASI (Alcohol & Sludge Incineration); MC (Mechanical Collector); LS (Limestone in FBC Bed or Injected Into Furnace); (Sand in FBC Bed); SCR:NH3 (Selective Catalytic DeNOX w/ Ammonia Injection); FAR (PJFF Fly ash Reinjection into FBC); DFSDA:Lime (Dual Fluid Spray Dryer Absorber w/ Lime sorbent); FSI:LS (Furnace Sorbent Injection of Limestone); FUI (Furnace Urea Injection for NOX Control); ESP (Electrostatic Precipitator); Cyc (Cyclone); RASDA (Rotary Atomizer Spray Dryer Absorber); DSI:Na (Duct Sorbent Injection of Sodium Bicarbonate); SCR:U (SCR DeNOX w/ Urea Injection).

Fabric: 16 oz WG (16 oz/square yard Woven Fiberglass); 22 oz WG (22 oz/square yard Woven Fiberglass); G-T (Gore-Tex Membrane); Nomex/Ryton (Nomex and Ryton Felt Bags).

Source: Belba et al. 1992.
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Dry Sulfur Dioxide (SO_2) Control Systems

One technology for reducing sulfur dioxide (SO_2) emissions from combustion sources that does not generate any liquid sidestreams is **dry flue gas desulfurization** (FGD). This technology is prevalent in treating acid gas emissions from waste incinerators. In dry FGD, the flue gas containing SO_2 is contacted with an alkaline material to produce a dry waste product for disposal. This technology includes the following:

- Injection of an alkaline slurry in a spray dryer with collection of dry particles in a fabric filter or electrostatic precipitator (ESP)
- Dry injection of alkaline material into the flue-gas stream with collection of dry particles in a fabric filter or ESP
- Addition of alkaline material to the fuel prior to or during combustion

These technologies are capable of SO_2 and hydrogen chloride (HCl) emission reduction ranging from 60 to 90% and 70 to 90+% respectively depending on which system is used. Typical reagents used with these technologies include lime, limestone (only in furnace injection), sodium carbonate, sodium bicarbonate, and nahcolite. These technologies have been used on boilers burning low sulfur coal (usually less than 2%), municipal waste incinerators, and hazardous waste incinerators and are attractive alternatives to wet scrubbing technology, particularly in the arid western U.S.

Spray Dryer with a Fabric Filter or ESP

One type of dry FGD installation is a spray dryer (sometimes referred to as a dry scrubber) and can be used on utility boilers and waste incinerators. Alkaline material is injected into a spray dryer with dry particle collection in a fabric filter or ESP. Spray dryers have been used in the chemical, food processing, and mineral preparation industries over the past 40 years. Spray dryers are vessels where hot flue gases are contacted with a finely atomized wet alkaline spray. The high temperatures of the flue gas, 250 to 400°F (121 to 204°C), evaporate the water from the wet alkaline sprays, leaving a dry powdered product. The dry product is collected in a fabric filter or ESP (Figure 7-1).

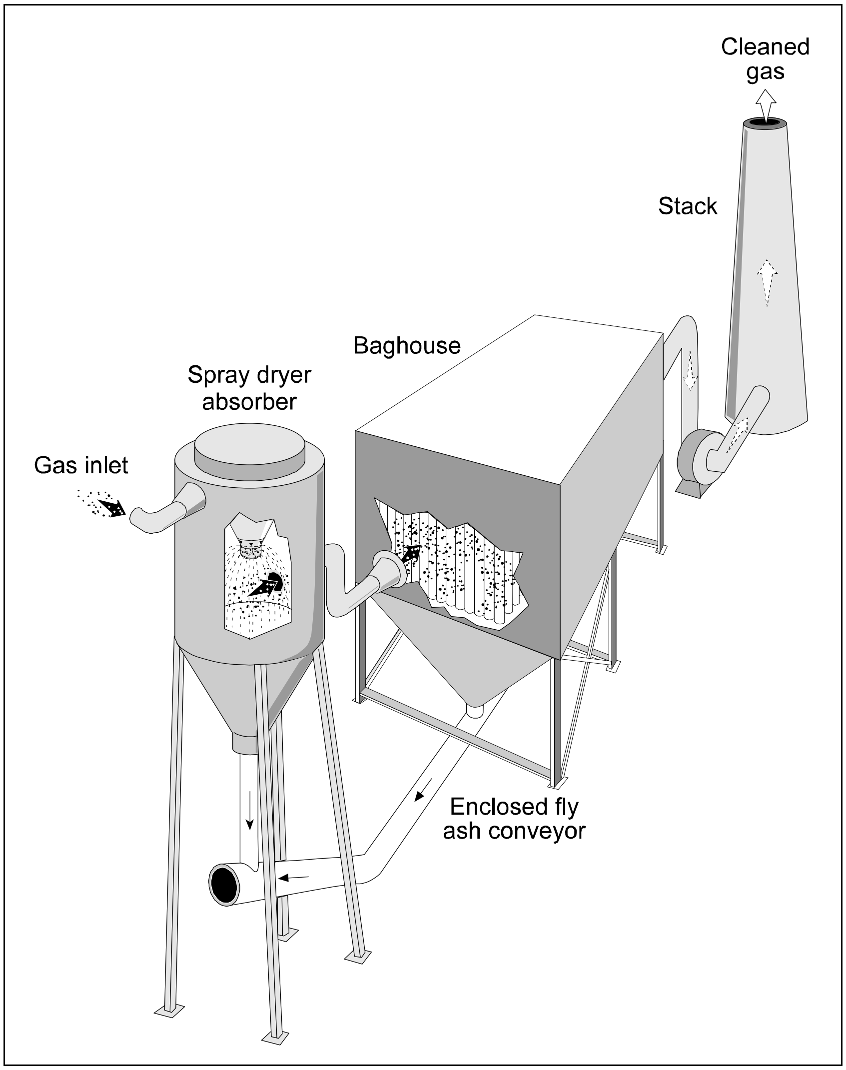

Figure 7-1. Spray dryer absorber and baghouse system

Flue gas enters the top of the spray dryer and is swirled by a fixed vane ring to cause intimate contact with the slurry spray (Figure 7-2). The slurry is atomized into extremely fine droplets by rotary atomizers or spray nozzles. The turbulent mixing of the flue gas with the fine droplets results in rapid SO_2 absorption and evaporation of the moisture. A small portion of the hot flue gas may be added to the spray-dryer-discharge duct to maintain the temperature of the gas above the dew point. Reheat prevents condensation and corrosion in the duct. Reheat also prevents bags in the fabric filter from becoming plugged or caked with moist particles.

Figure 7-2. Spray dryer

Sodium carbonate solutions and lime slurries are the most common absorbents used. A sodium carbonate solution will generally achieve a higher level of SO_2 removal than lime slurries (EPA 1980). When sodium carbonate is used, SO_2 removal efficiencies are approximately 75 to 90%, lime removal efficiencies are 70 to 85% (EPA 1980). However, vendors of dry scrubbing systems claim that their units are capable of achieving 90% SO_2 reduction using a lime slurry in a spray dryer. Lime is very popular for two reasons: (1) it is less expensive than sodium carbonate and (2) sodium carbonate and SO_2 form sodium sulfite and sodium sulfate, which are very soluble causing leaching problems when landfilled.

Some of the evaporated alkaline spray will fall into the bottom of the spray dryer. In coal-fired units where appreciable quantities of HCl do not exist, this material can be recycled. In municipal and hazardous waste incinerators, this spray dryer product is not recycled due to the presence of calcium chloride. Calcium chloride is formed when HCl in the flue gas reacts with calcium hydroxide (lime slurry). Calcium chloride is very hygroscopic and can plug bags, hoppers and conveyors if the material is not kept dry and the exhaust gas stream conveying this material is not kept well above the dew point. The majority of the spray reacts with SO_2 in the flue gas to form powdered sulfates and sulfites. These particles, along with fly ash in the flue gas, are then collected in a fabric filter or ESP. Fabric filters have an advantage because unreacted alkaline material collected on the bags can react with any remaining SO_2 in the flue gas. Some process developers have reported SO_2 removal on bag surfaces on the order of 10% (Kaplan and Felsvang 1979). However, since bags are sensitive to wetting, a 35 to 50°F (2.5 to 10°C) margin above the saturation temperature of the flue gas must be maintained in coal-fired installations (EPA 1980). With waste incineration facilities this margin must be increased to around 100°F (38°C) due to the presence of calcium chloride. ESPs have the advantage of not being as sensitive to moisture as fabric filters. However, SO_2 removal is not quite as efficient when using ESPs.

In a spray dryer, finely atomized alkaline droplets are contacted with flue gas, which is at air preheater outlet temperatures of 250 to 400°F (121 to 204°C). The flue gas is humidified to within 50 to 100°F (28 to 56°C) of its saturation temperature by the moisture evaporating from the alkaline slurry. Reaction of SO_2 with the alkaline material proceeds both during and following the drying process. However, sodium-based sorbents are more reactive in the dry state than calcium-based sorbents are. Since the flue gas temperature and humidity are set by air preheater outlet conditions, the amount of moisture that can be evaporated into the flue gas is also set. This means that the amount of alkaline slurry that can be evaporated in the dryer is limited by flue gas conditions. Alkaline slurry sprayed into the dryer must be carefully controlled to avoid moisture in the flue gas from condensing in the ducting, particulate emission control equipment, or the stack.

Many spray dryer systems have been installed on industrial and utility boilers. Some are listed in Table 7-4. Additional experience in using FGD systems in combination with pulse-jet fabric filters is noted on Table 7-3 (see column “Flue Gas/Ash Modifications”). Permit reviewers should review the EPA BACT Clearinghouse for additional information on spray dryers and baghouse systems. Spray dryers will be particularly useful in meeting New Source Performance Standards (NSPS) for utility boilers burning low sulfur coal that require only 70% SO_2 scrubbing in addition to achieving the requirements of the acid rain provisions included in Title IV of the 1990 Clean Air Act Amendments.

Table 7-4. Commercial spray dryer FGD systems using a baghouse or an ESP

Station or plant	Size (MW)	Installation date	System description	Sorbent	Coal sulfur content (%)	SO_2 emission removal efficiency (%)
Otter Tail Power Company: Coyote Station No. 1, Beulah, ND	410	6/81	Rockwell/ Wheelabrator-Frye system: four spray towers in parallel with 3 atomizers in each: reverse-air-shaker baghouse with Dacron bags	Soda ash (sodium carbonate)	0.78	70
Basin Electric: Laramie River Station No. 3, Wheatland, WY	500	Spring 1982	Babcock and Wilcox: four spray reactors with 12 "Y-jet" nozzles in each: electrostatic precipitator	Lime	0.54-0.81	85-90
Strathmore Paper Co.: Woronco, MA	14	12/79	Mikropul: spray dryer and pulse-jet baghouse	Lime	2-2.5	75
Celanese Corp.: Cumberland, MD	31	2/80	Rockwell/ Wheelabrator-Frye: one spray tower followed by a baghouse	Lime	1-2	85

Source: EPA February 1980.

Dry Injection

In dry injection systems, a dry alkaline material is injected into a flue gas stream. This is accomplished by pneumatically injecting the dry sorbent into a flue gas duct, or by precoating or continuously feeding sorbent onto a fabric filter surface. Most dry injection systems use pneumatic injection of dry alkaline material in the boiler furnace area or in the duct that precedes the ESP or baghouse. Sodium-based sorbents are used more frequently than lime for coal-fired installations but hydrated lime is prevalent in waste burning incinerators. Many dry injection systems have used nahcolite, a naturally occurring mineral which is 80% sodium bicarbonate found in large reserves in Colorado. Sodium carbonate (soda ash) is also used but is not as reactive as sodium bicarbonate (EPA 1980). The major problem of using nahcolite is that it is not presently being mined on a commercial scale. Large investments must be made before it will be mined commercially. Other natural minerals such as raw trona have been tested; trona contains sodium bicarbonate and sodium carbonate.

Municipal Waste Incinerators

Spray dryers followed by fabric filters have become the control option of choice for municipal waste incineration facilities. A survey conducted in 1990 by the Institute of Resource Recovery (IRR) reported that of 158 municipal waste combustion facilities, 47 used fabric filters for particulate control. Almost all of these were preceded by a spray dryer. In fact spray dryers followed by fabric filters are typically considered best available control technology for municipal waste incinerators since this equipment is effective in removing acid gases, particulate matter, and a number of hazardous air pollutants.

Modern municipal waste incinerators recover waste heat by using boilers to generate steam and electricity. After passing through the heat recovery equipment, the flue gas typically enters the air pollution control system at 350 to 400°F (177 to 204°C). Emission controls typically consist of a spray dryer absorber to remove acid gases followed by a fabric filter to remove particulate matter, which includes acid gas reaction products, unreacted reagent, fly ash, and trace metals. A survey of spray dryer applications on municipal waste incinerators in the U.S. shows that lime is used exclusively as the reagent. Onsite lime slaking systems are typically used to prepare the lime slurry.

A calcium hydroxide [$Ca(OH)_2$] slurry, frequently referred to as lime slurry, is injected into the spray dryer reaction vessel as a finely atomized spray. Acid gases (mainly HCl and SO_2) are absorbed into the atomized lime slurry. The hot flue gas causes the water in the droplets to evaporate and leave behind dry reaction products (calcium salts).

Spray dryers must be operated at flue gas temperatures adequate to produce a dry reactant product. Spray dryers are typically designed to operate with an inlet (flue gas) temperature of approximately 350 to 400°F (177 to 204°C) and outlet temperature of 260 to 300°F (127 to 149°C). Some major benefits can be realized when operating at these temperatures, including increased boiler efficiency, lime utilization, and trace metal and organic removal efficiency.

Potential operating problems can occur when handling the reaction products that contain calcium chloride ($CaCl_2$). This material is hygroscopic, and can cause caked deposits on reactor walls, bag plugging or blinding problems in the baghouse, and/or caking and plugging problems in the fly ash removal equipment. The spray dryer and fabric filter must be operated within the above specified design temperature limits, be well insulated, and be designed to minimize air inleakage to prevent these potential problems from occurring.

A fabric filter is used downstream from the spray dryer to collect reactant products, unreacted sorbent, and fly ash. Fabric filters applied to incinerators often use woven fiberglass bags to remove particulate matter from the flue gas stream. Fabric filters can act as secondary acid gas collectors because the dust cake that builds on the bags contains some unreacted sorbent that provides a surface to neutralize some of the acid gases passing through the cake. Many recent fabric filter designs applied to municipal waste incinerators use pulse-jet cleaning and have easily achieved the NSPS of 0.015 gr/dscf corrected to 7% O_2 (Pompelia and Beachler 1991). Use of fabric filters on municipal waste incinerators is also effective in removing heavy metals and organics (Brna and Kilgroe 1990).

Performance of this equipment has been studied in depth since the mid 1980s in support of revising the NSPS for Municipal Waste Combustors (58 FR 5488). Typically, use of a spray dryer followed by a fabric filter has shown to remove 75 to 85% of SO_2 and 90 to 95% of HCl. Higher removal efficiencies have been achieved when calculating removal efficiencies over long term time periods (i.e. long term averages) (EPA 1989; Beachler and Joseph 1992).

Other Fabric Filter Applications

Examples of typical baghouse installations are given in Table 7-5. This table lists the industry, exhaust gas temperature, dust concentration, baghouse cleaning method, fabrics, and air-to-cloth ratios. This list is by no means inclusive of the industries using baghouses for controlling particulate emissions. Typical air-to-cloth ratios of shaker, reverse-air, and pulse-jet baghouses for various industries are also given in Table 5-2.

Table 7-5. Typical baghouse installations

Industry	Process dust concentration (gr/ft^3)	Baghouse cleaning method	Fabrics	Temperature (°F)	Air-to-cloth ratio (cfm/ft^2)
Aluminum					
furnaces	6 to 20	Shaker	Nomex, Orlon	250 to 375	2 to 2.5:1
scrap conveyor		Pulse-jet	Polyester	100	7 to 8:1
Asphalt batch plants		Pulse-jet	Nomex	250	4 to 6:1
Coal-fired boilers (1.5% sulfur coal)		Reverse-air Pulse-jet	Glass Felt/Glass	350 to 450 300 to 450	2:1 2 to 5:1
Coal processing					
pulverizing mill		Pulse-jet	Nomex felt	240	4 to 6:1
dryer		Pulse-jet	Nomex felt	400	5 to 7:1
roller mill		Pulse-jet	Polyester felt	225	6:1
crusher		Pulse-jet	Polypropylene felt	100	7 to 8:1
Carbon black		Reverse-air	Glass-Teflon (treated) or Teflon		1.5:1
Cement					
clinker cooler		Pulse-jet	Nomex felt		5:1
crusher venting		Reverse-air and shake	Polyester felt, Gore-tex		5:1
kiln	10 to 12	Reverse-air	Glass	400 to 500	2:1
Clay					
calcining kiln or dryers	25	Pulse-jet	Glass felt, Nomex	300 to 400	6:1
Copper smelter	< 2	Shaker	Dacron, Teflon	130	
Cupola furnace (gray iron)	1 to 2	Reverse-air shaker	Glass-Teflon treated Nomex	550	1.9:1
Chemical					
polyvinyl chloride (PVC) spray dryer		Reverse-air	Acrylic, Gore-tex	350-425	2 to 3.6:1
Food					
sugar storage bin		Pulse-jet	Polyester, Gore-tex		10:1
Ferro alloy plant					
silicon metal electric arc furnace	< 1.0	Reverse-air with shaker assist	Nomex	350	
Foundry					
sand casting operation	5 to 10	Pulse-jet	Polyester felt	275	6 to 7:1
Glass melting furnaces		Reverse-air Reverse-air and shake	Glass Nomex	400 to 500 375 to 400	< 2:1
Gypsum building materials		Pulse-jet	Nomex		
Lead smelting (battery lead)		Pulse-jet	Nomex, Teflon	320 to 325	
Lime calcining		Pulse-jet	Nomex	280	
Metals					
lead oxide processing		Shaker	Dacron, Gore-tex		1.5 to 3:1
Municipal incinerators	0.5 to 5.0	Reverse-air Pulse-jet	Glass Glass, Teflon	300 300	2:1 2 to 3:1
Steel					
electric arc furnace	0.1 to 0.5	Shaker	Dacron	275	
canopy hood over steel	0.1 to 0.5	Reverse-air	Dacron	125 to 250	
furnace	1.0 or less	Pulse-jet	Polyester felt	250	8:1
Secondary copper and brass rotary kiln		Shaker	Nomex	350	
Woodworking					
furniture manufacturing		Pulse-jet	Polyester		10:1
Zinc refining					
coker (zinc oxide)		Pulse-jet	Glass felt, Nomex	350 to 450	4 to 6:1

Capital and Operating Cost Estimation

This section contains generalized cost data for baghouse systems described throughout this manual. These data should be used only as an estimate to determine systems costs. In some cases the cost of the control device may represent only a very small portion (< 20%) of the total installed cost; in other cases it may represent the total cost. Variations in the total cost can be attributed to a number of variable factors such as cost of auxiliary equipment, new or retrofitted installation, local labor costs, engineering overhead, location and accessibility of plant site, and installation procedure (factory or field assembled).

These cost estimation data are from an EPA publication, *OAQPS Cost Control Manual*, (EPA 1990). Refer to this publication for additional information concerning this subject. These estimations represent equipment costs based on a reference date of third quarter, 1986.

Total Capital Costs

Total capital costs include costs for the baghouse structure, the initial complement of bags, auxiliary equipment, and the usual direct and indirect costs associated with installing or erecting new structures. These costs are described below, and may be escalated if desired. See EPA's *OAQPS Cost Control Manual* (EPA 1990) for escalation techniques.

Structure Cost

A guide to estimate the structural costs of six types of bare fabric filter systems (EPA 1990), is provided in Table 7-6.

Table 7-6. Guide to estimate costs of bare fabric filter systems

Operation	Cleaning Mechanism	Figure
Preassembled Units		
Intermittent	Shaker	7-3
Continuous	Shaker	7-4
Continuous	Pulse-jet (common housing)	7-5
Continuous	Pulse-jet (modular)	7-6
Continuous	Reverse-air	7-7
Field-assembled units		
Continuous	Any method	7-8

Table 7-6 associates a figure (found later in this lesson) with each of the six types of fabric filters listed. Each figure consists of a graph that plots the following three structural costs as a function of gross cloth area:

1. Cost of the filter structure (without bags)
2. Additional cost for 304 stainless steel construction
3. Additional cost for insulation

Extrapolation of these lines is not recommended. All units include unit and exhaust manifolds, supports, platforms, handrails, and hopper discharge devices. The indicated prices are flange-to-flange. Note that the scales on axes differ.

The 304 stainless steel add-on cost is used when stainless steel is necessary to prevent the exhaust stream from corroding the interior of the baghouse. Stainless steel is substituted for all metal surfaces that are in contact with the exhaust gas stream.

Insulation costs are for 3 inches of shop-installed glass fiber encased in a metal skin. One exception is the custom baghouse, which has field-installed insulation. Costs for insulation include only the flange-to-flange baghouse structure on the outside of all areas in contact with the exhaust gas stream. Insulation for ductwork, fan casings, and stacks must be calculated separately.

The costs for intermittent service, mechanical shaker baghouses (including the shaker mechanism) as a function of gross cloth area are presented in Figure 7-3. Because intermittent service baghouses do not require an extra compartment for cleaning, gross and net fabric areas are the same.

The same costs for a continuously operated baghouse cleaned by mechanical shaker as a function of the gross cloth area are presented in Figure 7-4. As in Figure 7-3, the units are modular in construction. Costs for these units, on a square foot basis, are higher because of increased complexity and generally heavier construction.

Costs of common-housing pulse-jet units and modular pulse-jet units are presented in Figures 7-5 and 7-6. Modular units are constructed of separate modules that may be arranged for off-line cleaning, while common-housing units have all bags within one housing. The cleaning system compressor is not included. Because the common housing is relatively inexpensive, the stainless steel add-on is proportionately higher than for modular units. Added material costs and set-up and labor charges associated with the less workable stainless steel account for most of the added expense.

The costs for the reverse-air baghouses are shown in Figure 7-7. The construction is modular and the reverse-air fan is included. Costs for custom baghouses which must be field assembled because of their large size are given in Figure 7-8. These units often are used on power plants, steel mills, or other applications too large for the factory-assembled baghouses.

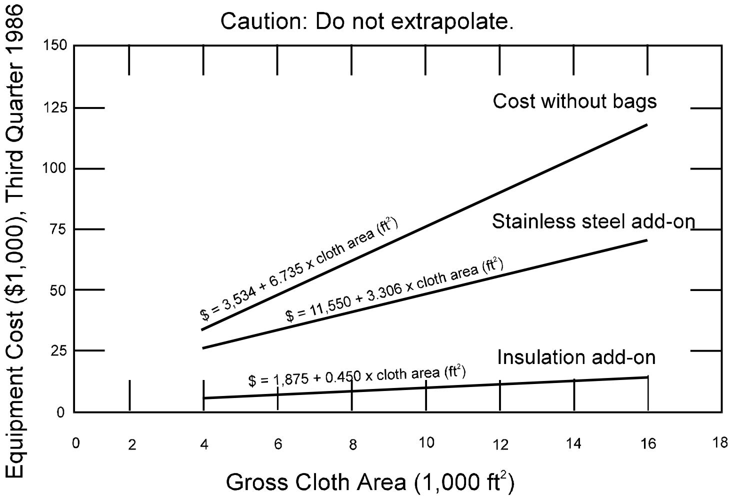

Figure 7-3. Structure costs for intermittent shaker filters

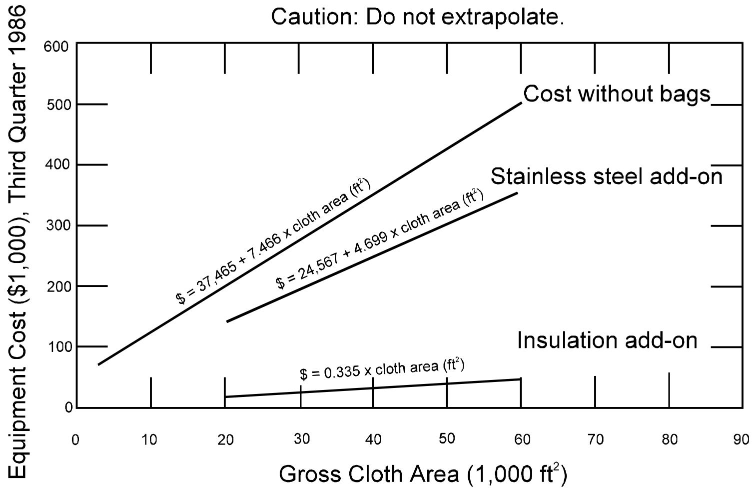

Figure 7-4. Structure costs for continuous shaker filters

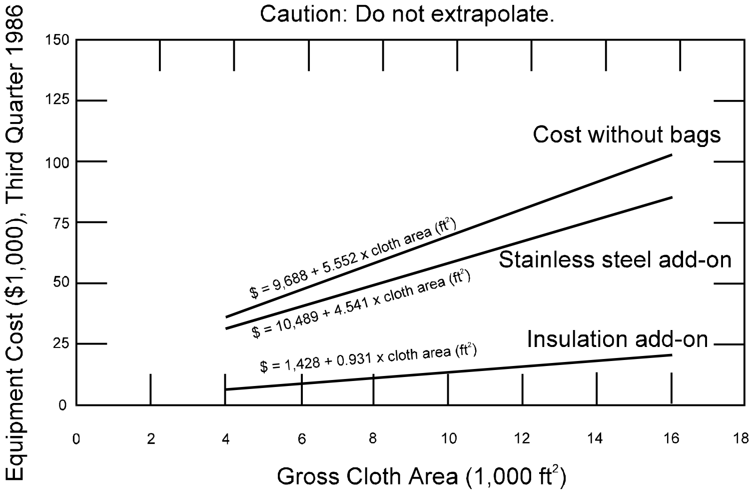

Figure 7-5. Structure costs for pulse-jet filters (common housing)

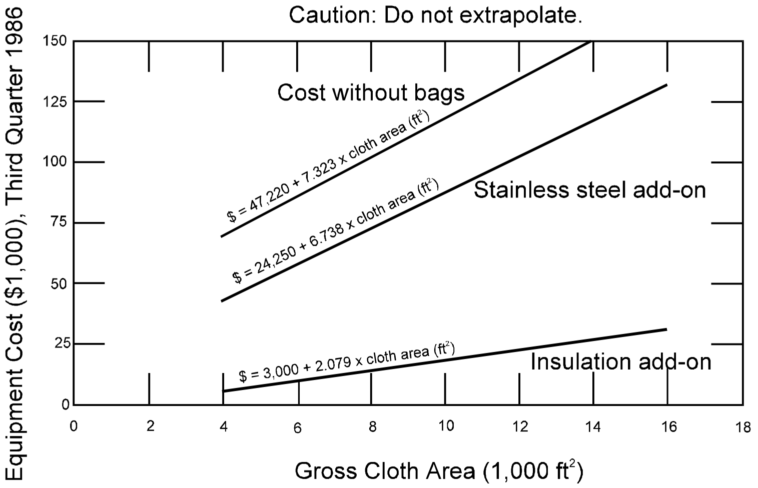

Figure 7-6. Structure costs for pulse-jet filters (modular)

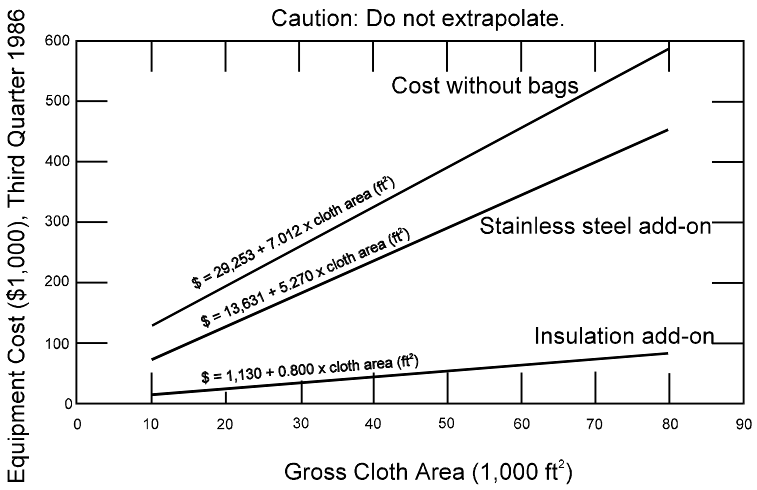

Figure 7-7. Structure costs for reverse-air filters

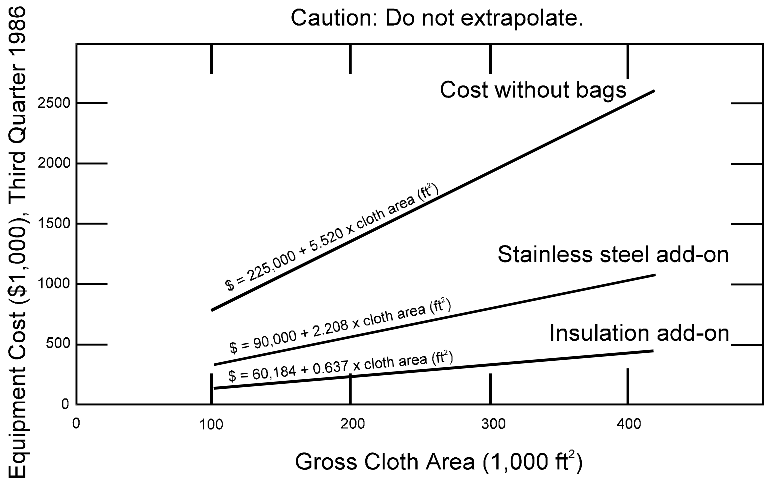

Figure 7-8. Structure costs for custom-built filters

Bag Costs/C_B

The price per square foot (in 3rd quarter 1986 dollars) of bags by type of fabric and type of cleaning system used is given in Table 7-7. The prices represent about a 10 percent range. In calculating the cost, use the gross area as determined from Table 7-8. Gore-Tex fabric costs are a combination of the base fabric cost and a premium for the PTFE laminate and its application. As fiber market conditions change, the costs of fabrics relative to each other also change. The bag prices are based on typical fabric weights, in ounces/square yard, for the fabric being priced. Sewn-in snap rings are included in the price, but other mounting hardware, such as clamps or cages, is an added cost. See the notes on Table 7-7 for these costs. EPA's *OAQPS Cost Control Manual* can be used to obtain additional information on the cost (EPA 1990).

Table 7-7. Bag prices (3rd quarter 1986 $/ft^2)

		Type of Materials[1]						
Type of Cleaning	**Bag Diameter (Inches)**	**PE**	**PP**	**NO**	**HA**	**FG**	**CO**	**TF**
Pulse-jet, TR[2]	4-1/2 to 5-1/8	0.59	0.61	1.88	0.92	1.29	NA	9.05
	6 to 8	0.43	0.44	1.56	0.71	1.08	NA	6.80
Pulse-jet, BBR	4-1/2 to 5-1/8	0.37	0.40	1.37	0.66	1.24	NA	8.78
	6 to 8	0.32	0.33	1.18	0.58	0.95	NA	6.71
Shaker								
Strap top	5	0.45	0.48	1.28	0.75	NA	0.44	NA
Loop top	5	0.43	0.45	1.17	0.66	NA	0.39	NA
Reverse-air with rings	8	0.46	NA	1.72	NA	0.99	NA	NA
Reverse-air w/o rings[3]	8	0.32	NA	1.20	NA	0.69	NA	NA
	11-1/2	0.32	NA	1.16	NA	0.53	NA	NA

NA = Not applicable.

1. Materials:
   - PE = 16-oz polyester
   - PP = 16-oz polypropylene
   - NO = 14-oz Nomex
   - HA = 16-oz homopolymer acrylic
   - FG = 16-oz fiberglass with 10% Teflon
   - CO = 9-oz cotton
   - TF = 22-oz Teflon felt
2. Bag removal methods:
   - TR = Top bag removal (snap in)
   - BBR= Bottom bag removal
3. Identified as reverse-air bags, but used in low pressure pulse applications.

Note: For pulse-jet baghouses, all bags are felts except for the fiberglass, which is woven. For bottom access pulse-jets, the mild steel cage price for one cage can be calculated from the single-bag fabric area using:

$\$ = 4.941 + 0.163\ \text{ft}^2$ in 50 cage lots
$\$ = 4.441 + 0.163\ \text{ft}^2$ in 100 cage lots
$\$ = 3.941 + 0.163\ \text{ft}^2$ in 500 cage lots

These costs apply to 4-1/2-in. or 5-5/8-in. diameter, 8-ft and 10-ft cages made of 11 gauge mild steel and having 10 vertical wires and "Roll Band" tops. For flanged tops, add $1 per cage. If flow control venturis are used (as they are in about half of the pulse-jet manufacturers' designs), add $5 per cage. For stainless steel cages use:

$\$ = 23.335 + 0.280\ \text{ft}^2$ in 50 cage lots
$\$ = 21.791 + 0.263\ \text{ft}^2$ in 100 cage lots
$\$ = 20.564 + 0.248\ \text{ft}^2$ in 500 cage lots

For shakers and reverse-air baghouses, all bags are woven. All prices are for finished bags, and prices can vary from one supplier to another. For Gore-Tex bag prices, multiply base fabric price by factors of 3 to 4.5.

Source: EPA 1990.

Table 7-8. Factors to obtain gross cloth area from net cloth area

Net Cloth Area, A_{nc} (ft^2)	Factor to Obtain Gross Cloth Area, A_{tc} (ft^2)
1 - 4,000	Multiply by 2
4,001 - 12,000	Multiply by 1.5
12,001 - 24,000	Multiply by 1.25
24,001 - 36,000	Multiply by 1.17
36,001 - 48,000	Multiply by 1.125
48,001 - 60,000	Multiply by 1.11
60,001 - 72,000	Multiply by 1.10
72,001 - 84,000	Multiply by 1.09
84,001 - 96,000	Multiply by 1.08
96,001 - 108,000	Multiply by 1.07
108,001 - 132,000	Multiply by 1.06
132,001 - 180,000	Multiply by 1.05

Source: EPA 1990.

Purchased Equipment Cost (PEC) and Total Capital Costs (TCC)

The purchased equipment cost (PEC) of the fabric filter system is the sum of the costs of the baghouse, bags, auxiliary equipment, instruments and controls, taxes, and freight costs. The factors necessary to estimate these costs are presented in Table 7-9. The factors necessary to estimate the remaining direct and indirect capital costs to obtain total capital costs are also provided in Table 7-9. EPA's *OAQPS Cost Control Manual* can be used to estimate the cost of auxiliary equipment (EPA 1990).

Table 7-9. Capital cost factors for fabric filters

	Factor
Direct Costs	
Purchased Equipment Costs:	
Fabric Filter	As estimated
Bags	As estimated
Auxiliary equipment	As estimated
	EC = Sum of estimated values
Instruments & controls	0.10 EC
Taxes	0.03 EC
Freight	0.05 EC
Purchased Equipment Cost, PEC	PEC = 1.18 EC
Installation Direct Costs	
Foundation & supports	0.04 PEC
Erection & handling	0.50 PEC
Electrical	0.08 PEC
Piping	0.01 PEC
Insulation for ductwork[1]	0.07 PEC
Painting[2]	0.02 PEC
Site preparation	SP (as required)
Buildings	Bldg. (as required)
	0.72 PEC + SP + Bldg.
Total Direct Costs, DC	1.72 PEC + SP + Bldg.
Indirect Costs	
Engineering and supervision	0.10 PEC
Construction and field expense	0.20 PEC
Construction fee	0.10 PEC
Start-up fees	0.01 PEC
Performance test	0.01 PEC
Contingencies	0.03 PEC
Total Indirect Costs, IC	0.45 PEC
Total Capital Cost (TCC) = DC + IC	2.17 PEC + SP + Bldg.

1. If ductwork dimensions have been established, cost may be established based on $\$10$ to $\$12/\text{ft}^2$ of surface for field application. Fan housings and stacks may also be insulated.
2. The increased use of special coatings may increase this factor to 0.06 PEC or higher.

Source: EPA 1990.

Example Case

This problem will show you how to calculate the total capital cost of a baghouse using the figures and tables in this lesson.

Problem:

A facility is proposing to build a reverse-air baghouse that will operate with a net air-to-cloth ratio of 2.5:1 $(ft^3/min)/ft^2$ and an exhaust gas flow rate of 110,000 acfm. Eight-inch diameter fiberglass bags with Teflon backing and rings are proposed. The structure requires stainless steel add-on and insulation. Auxiliary equipment is estimated to cost $10,000. Calculate the total capital cost of the baghouse.

Solution:

1. **Calculate the total net cloth area** using a variation of equation 3-6 (lesson 3).

$$v_f = \frac{Q}{A_{nc}}$$

$$A_{nc} = \frac{Q}{v_f}$$

Where: A_{nc} = net cloth area, ft^2
Q = process exhaust rate, acfm
v_f = filtration velocity, ft/min

Since the filtration velocity (v_f) equals the air-to-cloth ratio:

$$v_f = 2.5(ft^3/min)/ft^2 = 2.5\ ft/min$$

$$A_{nc} = \frac{110{,}000\ acfm}{2.5\ ft/min} = 44{,}000\ ft^2$$

2. **Calculate the total gross cloth area**. Use Table 7-8 to find the factor needed to convert the total net cloth area to the total gross cloth area. For a net cloth area of 44,000 ft^2, the factor is 1.125.

$$A_{tc} = A_{nc} \times 1.125$$
$$= 44{,}000\ ft^2 \times 1.125 = 49{,}500\ ft^2$$

3. **Calculate the structure cost of the baghouse**. Knowing that the total cloth area is 49,500 ft^2 and using Figure 7-7 (structure costs for reverse-air filters), you can calculate the structure cost as follows:

Base cost	$ 380,000
Stainless steel add-on	270,000
Insulation add-on	+ 40,000
Structure cost	$ 690,000

4. **Calculate the total bag cost (C_B).** From Table 7-7 (Bag Prices), the cost of fiberglass bags for a reverse-air baghouse with rings is \$0.99/ft^2.

$$\text{Total bag cost} = \$\ 0.99/\text{ft}^2 \times 49{,}500\ \text{ft}^2$$
$$= \$\ 49{,}000$$

5. **Calculate the total capital cost of the baghouse**. Based on the above information, the equipment cost (EC) can be calculated to be \$749,000. See Table 7-10.

   Use the factors given in Table 7-9 to calculate the following:

   1. Purchased equipment costs (PEC)
   2. Installation direct costs
   3. Indirect costs
   4. Total capital cost (TCC)

   A summary of these costs is provided in Table 7-10.

Table 7-10. Example case capital costs[1]

	Factor	Cost(s)
Direct Costs		
Purchased Equipment Costs:		
Fabric Filter	As estimated	$690,000
Bags	As estimated	49,000
Auxiliary equipment	As estimated	10,000
	EC = Sum of estimated values	$749,000
Instruments & controls	0.10 EC	$74,900
Taxes	0.03 EC	22,500
Freight	0.05 EC	37,500
Purchased Equipment Cost, PEC	PEC = 1.18 EC	$883,900
Installation Direct Costs		
Foundation & supports	0.04 PEC	$35,400
Erection & handling	0.50 PEC	442,000
Electrical	0.08 PEC	70,700
Piping	0.01 PEC	8,840
Insulation for ductwork[1]	0.07 PEC	61,900
Painting[2]	0.02 PEC	17,700
Site preparation	SP (as required)	_
Buildings	Bldg. (as required)	_
	0.72 PEC + SP + Bldg.	$636,540
Total Direct Costs, DC	1.72 PEC + SP + Bldg.	$1,520,440
Indirect Costs		
Engineering and supervision	0.10 PEC	$88,400
Construction and field expense	0.20 PEC	177,000
Construction fee	0.10 PEC	88,400
Start-up fees	0.01 PEC	8,840
Performance test	0.01 PEC	8,840
Contingencies	0.03 PEC	26,500
Total Indirect Costs, IC	0.45 PEC	$397,980
Total Capital Cost (TCC) = DC + IC	2.17 PEC + SP + Bldg.	$1,918,420

1. If ductwork dimensions have been established, cost may be established based on \$10 to \$12/ft^2 of surface for field application. Fan housings and stacks may also be insulated.
2. The increased use of special coatings may increase this factor to 0.06 PEC or higher.

Review Exercise

1. True or False? Fabric filters cannot be used for the collection of fly ash from coal-fired boilers since the flue gas deteriorates the bags.
2. For fabric filters used on coal-fired boilers, the bags are usually made of:
   a. Cotton
   b. Glass
   c. Wool
3. One technology for reducing both SO_2 gas and particulate emissions involves the injection of a(an) ____________________ slurry in a spray _____________________ with dry particle collection in a baghouse.
4. True or False? Fabric filters preceded by spray dryers are commonly applied to municipal waste incinerators.
5. In a spray dryer, moisture is _____________________ from the wet alkaline sprays, leaving a(an) _____________________ powdered product.
6. Which one of the following materials is hygroscopic and can cause bag plugging or blinding problems?
   a. Calcium carbonate
   b. Calcium chloride
   c. Calcium sulfate
7. True or False? Dry FGD systems using lime injected in a spray dryer and a baghouse for dry particle collection are capable of 70% SO_2 reduction and 99+% particulate matter removal efficiency.
8. In dry sulfur dioxide control systems for coal-fired boilers using a spray dryer, the most common alkaline absorbents used are:
   a. Sodium citrate and magnesium oxide
   b. Sodium carbonate and lime
   c. Sodium bisulfate and sodium hydroxide
9. Fabric filters with bags made of woven glass usually have air-to-cloth ratios:
   a. Greater than 6:1
   b. Approximately 7.5:1
   c. Less than 4:1
10. True or False? Pulse-jet fabric filters with polyester felt bags cannot be used to collect iron oxide dusts from steel furnaces.
11. True or False? Fabric filters have been used for filtering dust-laden gas from cement kilns, clinker coolers, and crushing operations.

Review Answers

1. **False**
   Fabric filters can be used to collect fly ash from coal-fired boilers.

2. **b. Glass**
   For fabric filters used on coal-fired boilers, the bags are usually made of glass.

3. **Alkaline**
   Dryer
   One technology for reducing both SO_2 gas and particulate emissions involves the injection of an alkaline slurry in a spray dryer with dry particle collection in a baghouse.

4. **True**
   Fabric filters preceded by spray dryers are commonly applied to municipal waste incinerators.

5. **Evaporated**
   Dry
   In a spray dryer, moisture is evaporated from the wet alkaline sprays, leaving a dry powdered product.

6. **b. Calcium chloride**
   Calcium chloride is hygroscopic and can cause bag plugging or blinding problems.

7. **True**
   Dry FGD systems using lime injected in a spray dryer and a baghouse for dry particle collection are capable of 70% SO_2 reduction and 99+% particulate matter removal efficiency.

8. **b. Sodium carbonate and lime**
   In dry sulfur dioxide control systems for coal-fired boilers using a spray dryer, the most common alkaline absorbents used are sodium carbonate and lime.

9. **c. Less than 4:1**
   Fabric filters with bags made of woven glass usually have air-to-cloth ratios less than 4:1.

10. **False**
    Pulse-jet fabric filters with polyester felt bags can be used to collect iron oxide dusts from steel furnaces (see Table 7-5).

11. **True**
    Fabric filters have been used for filtering dust-laden gas from cement kilns, clinker coolers, and crushing operations (see Table 7-5).

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