EVE 402
Air Pollution Generation and Control

Chapter #5 Lectures (Part 6)

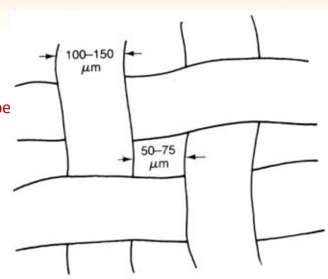
Fabric Filtration

- One of the oldest and most widely-used methods for separating particles from a gas stream
- Particle-laden gas flows through a number of filter bags, leaving the particles retained on the fabric
- Constructed of any material compatible with gas and particulate
- May be cleanable or non-cleanable (discarded after use)

Typical Dimensions

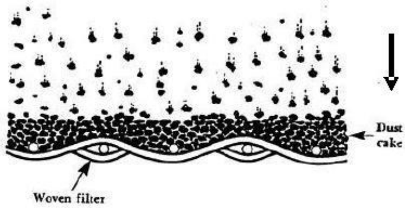
Dirty gas flows into page

Fabric material may be woven, felted, or knitted

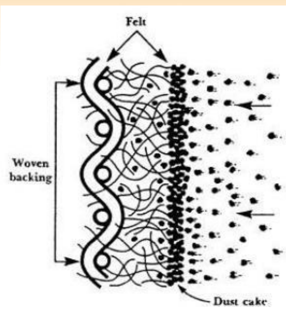


Woven Fabric

- Particles deposit on surface of fabric
- Woven fabric has lower collection efficiency
- Dust layer presents a significant surface for collection



Felt Fabric



- Surface of felt supports dust cake
- Used in pulse jet filters

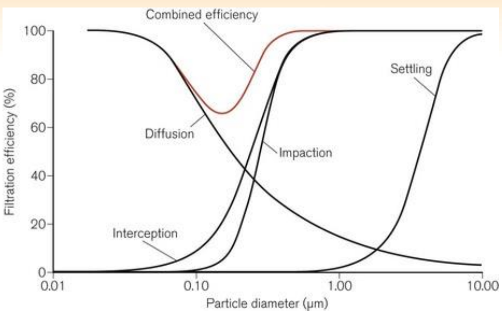
The Pros and Cons

- Pros
  - High collection efficiency even for small particles
  - Can operate on a wide variety of dust types
  - Wide choices of filters depending on application
  - Simultaneous removal of particles and some gases
  - Modular in design (simplifies maintenance)
  - Can operate over an extremely wide range of volumetric flow rates (100 – $5x10^6$ ft^3/m)
  - Requires reasonably low pressure drop
  - Lower capital cost than an electrostatic precipitator (ESP)
- Cons
  - Requires large foot print
  - Fabric can be harmed by high temperatures or corrosive gases
  - Inappropriate for moist environments
  - Potential for fire or explosion from static charge
  - Higher annual cost than an ESP
  - Higher pressure drop compared to an ESP

Baghouse Collection Efficiency

- Collection efficiency is generally *not* a concern in the design of a baghouse
- A well designed, well maintained fabric filter that is operated properly generally collects particles from 0.5 to 100 μm at efficiencies of greater than 99%
- The remaining design involves optimizing filtering velocity to balance capital costs and operating costs

Baghouse Collection Efficiency



Typical Values for Fabric Filtration Units

$$0.1\frac{m^3/min}{m^2} \le \frac{Q}{A_{x\text{-}s}} \le 10\frac{m^3/min}{m^2}$$

$$2 \text{ cm } H_2O_{(l)} \le \Delta P \le 25 \text{ cm } H_2O_{(l)}$$

$$0^\circ C \le T \le 800^\circ C$$

$$10 \text{ cm} \le \text{diameter of filter tube} \le 30 \text{ cm}$$

$$0.5 \text{ m} \le \text{length of fabric tube} \le 10 \text{ m}$$

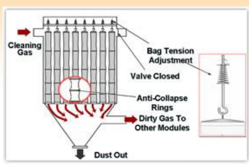
$$1 \le \text{number of compartments} \le 20$$

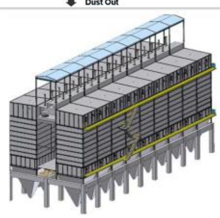
Baghouses are named according to how the dirty bags are cleaned:

- Reverse-air
- Shaker
- Pulse-jet
- Cartridge filter designs

Reverse Air Baghouse

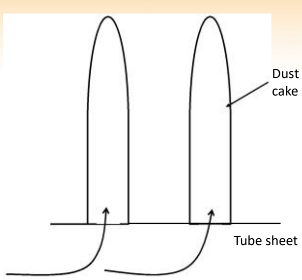
- Uses compartmentalized designs
- Named "reverse air" from the cleaning method
- <u>During cleaning the gas flow through a compartment is stopped</u>, and filtered gas is passed in a reverse direction through the bags
- Bags are hung from top of compartments
- Bags attached by springs on top



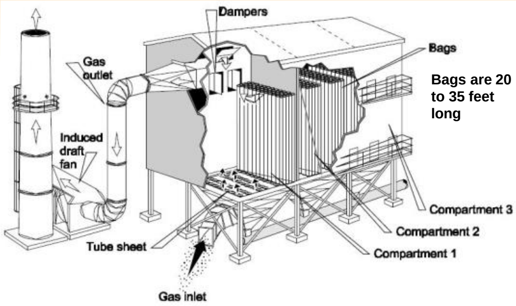


Reverse Air Baghouse

- Bottoms of bags are attached to a plate called tube sheet mounted right above the hopper
- Dirty air enters the inside of each reverse air bag
- The dust cake accumulates on the interior surfaces of the bags
- The dust cake causes most of the filtration



Reverse Air Baghouse

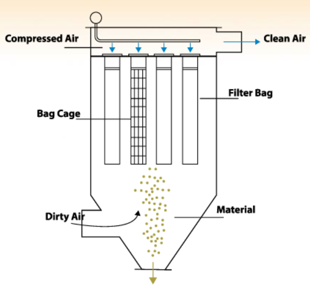


To gauge proper operation the following may be used:

- Double pass transmissometer
  - Measures opacity; source/receiver on same side
- Bag-break monitor
- Pressure gauge
  - Measures overall pressure drop
  - Measures compartment pressure drop
  - Measures pressure of reverse air stream during cleaning
- Inlet and outlet gas thermometers
  - Ensure temperature doesn't exceed fabric rating

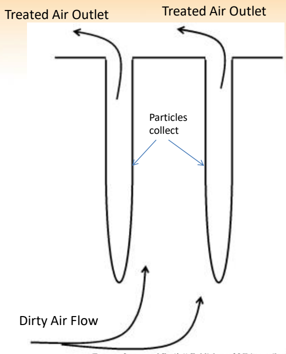
Pulse Jet Baghouse

- Dirty gas enters upper portion of hopper and passes vertically up between the bags during filtering
- Dust accumulates on the outside surfaces of the bags
- Named "pulse jet" because of the cleaning method
- Pulse of compressed air is used for cleaning each of the bags



Pulse Jet Bags

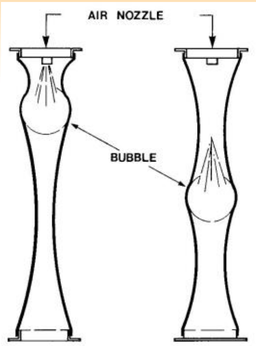
- Cleaned air enters the cylindrical bags and moves upward into the clean gas plenum at the top of the baghouse
- The outlet duct from the plenum takes the cleaned air to the fan and out to the stack



Pulse Jet Baghouse

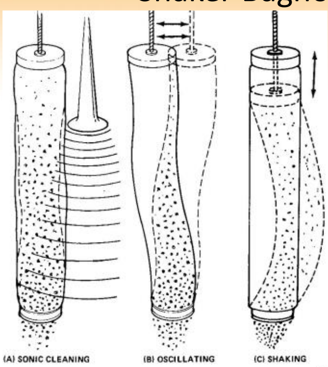
Looking up into an array of bags in a Pulse Jet Baghouse

Pulse Jet Baghouse



- Bags are cleaned by introducing a high-pressure pulse of compressed air at the top of each bag
- Pulse generates a pressure wave that travels down inside the bag
- This cracks the dust cake on the outside of the bags and causes some of the dust to fall into the hopper
- Cleaning is done row by row while baghouse is operating

Shaker Baghouses



- Shaking bag in a simple harmonic or sinusoidal motion on the order of a few inches
- Every 30 sec to few minutes

Bags and Support Structure

Midwesco, Inc.

Bagsandcages.com

With pulse-jet cleaning, no bags have to be taken out of service (astecinc.com)

Baghouse cage
4.5” x 48”
$60.00

Aget Dust Collection Bag House $800
Model # FT-40
33" x 51" x 120" tall bag house
40 @ 5" dia. x 88" long bags
13" dia. air intake
240v or 460v 3 ph. shaker motor
37" x 58" x 72" welded steel stand
No blower or cyclone

Filter Characteristics

- Filter medium serves as a structural support rather than impaction surface
- Packing Density

$$\alpha = \frac{\text{fiber volume}}{\text{total volume}} = 1 - \text{porosity}$$

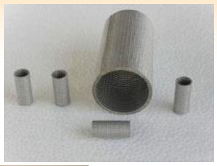
For fiber filter, $\alpha < 0.1$
For woven filter, $\alpha \sim 0.3$

Filter Materials

- Woven fabric
  - Interlaced yarn type
- Felted fabric
  - Randomly oriented fibers
- Membranes
  - PTFE laminated to a woven fabric or felt
- Sintered metal fibers
  - Small metal fibers randomly oriented on a cylinder
- Ceramic cartridges
  - Fabricated on honeycomb or cylinder

Filter Materials

PTFE laminated



Sintered metal

Ceramic

Material Characteristics

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

Stop

Pressure Drops

- Pressure drop across the baghouse is given as

$$\Delta P = \Delta P_F + \Delta P_C + \Delta P_S \qquad \text{Eq. 5 − 89, p. 253}$$

where:

ΔP_F = pressure drop across fabric

ΔP_C = pressure drop across particle (or cake)layer

ΔP_S = pressure drop across the structure (negligible)

- The flow through the filter and cake layer is assumed to be viscous (i.e., μ_g is important)
  - Thus ΔP may be represented by Darcy's equation:

$$\Delta P = \Delta P_F + \Delta P_C = \frac{\mu_g x_F V}{K_F} + \frac{\mu_g x_C V}{K_C}$$

Pressure Drops (2)

$$\Delta P = \Delta P_F + \Delta P_C = \frac{\mu_g x_F V}{K_F} + \frac{\mu_g x_C V}{K_C}$$

where
μ_g = gas viscosity
x_F, x_C = filter and cake layer thicknesses, respectively
K_F, K_C = filter and cake layer permeabilities, respectively
V = superficial filtering velocity (air-to-cloth ratio)

Air-to-Cloth Ratio

Superficial filtration velocity (average velocity) also known as the air-to-cloth ratio

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

Q = volumetric gas flow rate, m^3/min

A = cloth area, m^2

Typical Air-to-Cloth Ratios

Baghouse Cleaning Method	Air-to-Cloth Ratio
Shaking	2 – 6 $(ft^3/min)/ft^2$
Reverse air	1 – 3 $(ft^3/min)/ft^2$
Pulse jet	5 – 15 $(ft^3/min)/ft^2$

Dust Cake Growth

- Over time, the depth of the dust layer (dust cake) increases

$$\chi_c = \frac{C_i V t}{\rho_c} \qquad \text{Eqn}(5\text{-}91),\ \text{p. } 254$$

where:

C_i = dust loading, kg/m^3

V = filtration velocity, m/s

t = time of operation, min

ρ_c = bulk density of the particulate layer, kg/m^3

$\rho_c = \rho_p c$

c = packing density

Pressure Drop

$\Delta P = \Delta P_R + \Delta P_c \left(+\Delta P_s\right)$ Pressure drop through the baghouse

$\Delta P = K_1 V + K_2 \left(C_i V t\right) V$ C_i = dust loading, kg/m^3

Areal Dust Density $W = C_i V t$

Filter drag

$S = \frac{\Delta P}{V} \Rightarrow S = K_1 + K_2 W$ in Pa-min/m

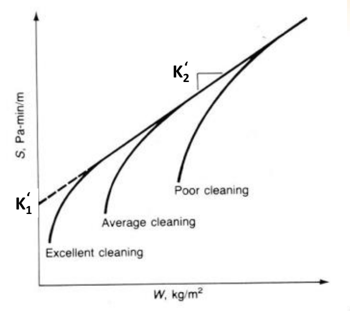
K_1 and K_2 to be determined empirically (resistance factor)

ΔP_R = fabric pressure drop

ΔP_c = particle cake layer pressure drop

ΔP_s = structure pressure drop

Typical filter drag, **S, vs. areal dust density** curves for various degrees of cleaning



Variation of ΔP with Time

$t_f = N(t_r + t_c) - t_c$

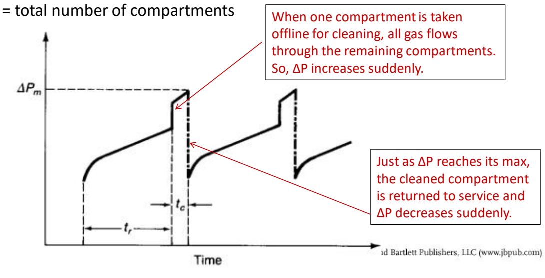
where,

t_f = filtration time (the elapsed time a compartment runs between cleanings)

t_r = run time (the time elapsed between cleanings of any two compartments)

t_c = cleaning time (the time required to clean one compartment)

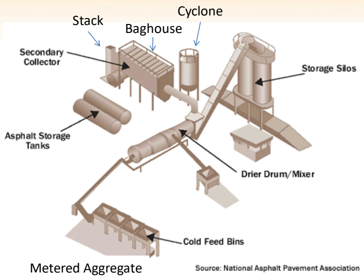
N = total number of compartments



Applications

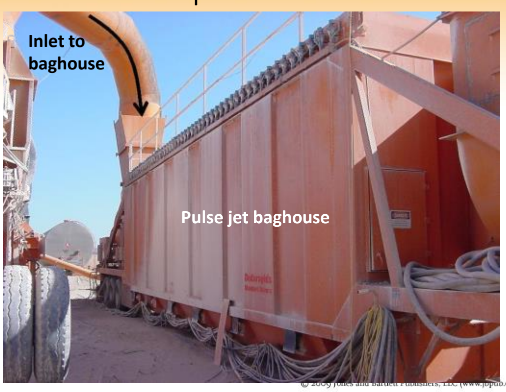
- A baghouse for a 250 MW utility boiler may have 5,000 separate bags with a total fabric area approaching 500,000 square feet
- Most cement plants have between 40 and 80 separate fabric filter control systems ranging in size from 30 actual cubic meters per minute capacity to more than 100,000 actual cubic meters per minute capacity
- Typical asphalt plants use either stationary or portable baghouses that are capable of handling 300 to 2,200 cubic meters per minute at 300 - 400˚F. Material collected is aggregate dust from an asphalt drum mix or batch plant drying process

Hot-Mix Asphalt Plant

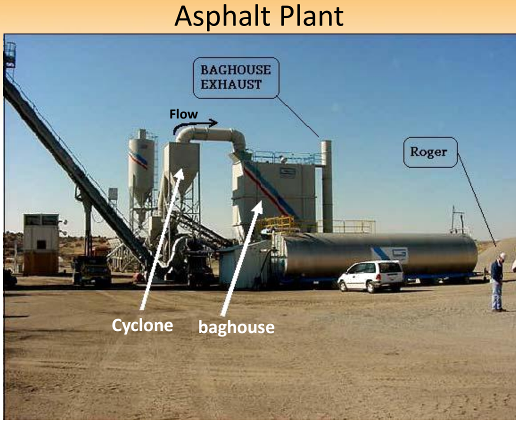


Asphalt Plant

Asphalt Plant



Asphalt Plant



Baghouse Explosions

7 February, 2009: Imperial Sugar Refinery, Port Wentworth, GA (14 workers killed)

Baghouse Explosions

29 January, 2003: West Pharmaceutical Services Plant, Kinston, NC (6 deaths)

Example (Fabric Filtration)

A fabric filter will be used downstream of a spray dryer to remove particulate material from a gas stream. Actual concentration of particulate matter is 10 g m^{-3} upstream of the fabric filter. A pilot plant was built and operated downstream of the spray dryer to characterize the behavior of the filter cake and fabric under actual conditions. Pilot plant data are presented.

Filter Drag (s) [cm $H_2O_{(l)}$ cm^{-1} sec]	Areal Dust Loading (w) [g m^{-2}]
8.0	0.0
13.2	0.5
15.3	1.0
16.8	1.5
18.3	2.0
19.9	2.5
21.4	3.0
22.9	3.5
24.5	4.0

a. Determine the value of the effective residual filter drag (K_1) with units of cm $H_20_{(l)}$ cm^{-1} sec.
b. Determine the value of the filter cake resistance factor (K_2) with units of ((cm $H_2O_{(l)}$/(cm/sec))/(g/m^2)).