Fans and air cleaners (2)

Fan Laws

- Fan laws are very useful for finding operating points of a system (condition 1 → 2)
- #1 is starting point; #2 is new point
- 3 basic fan laws in terms of rotation rate (RPM)

$$\frac{Q_2}{Q_1} = \left(\frac{RPM_2}{RPM_1}\right) \qquad \frac{P_{S2}}{P_{S1}} = \left(\frac{RPM_2}{RPM_1}\right)^2 \qquad \frac{BHP_2}{BHP_1} = \left(\frac{RPM_2}{RPM_1}\right)^3$$

- We can derive other system relationships from these:

$$\frac{P_{S2}}{P_{S1}} = \left(\frac{Q_2}{Q_1}\right)^2 \qquad \frac{BHP_2}{BHP_1} = \left(\frac{Q_2}{Q_1}\right)^3$$

Fan P_T and horsepower

- Fan PT is a measure of energy input, so we can use it to estimate horsepower

$$BHP = \left(\frac{P_T, fan \cdot Q}{6356 \cdot \eta}\right) \qquad \eta = efficiency$$

- Typical eta (η) values for fans are ~0.5 - 0.6

Examples

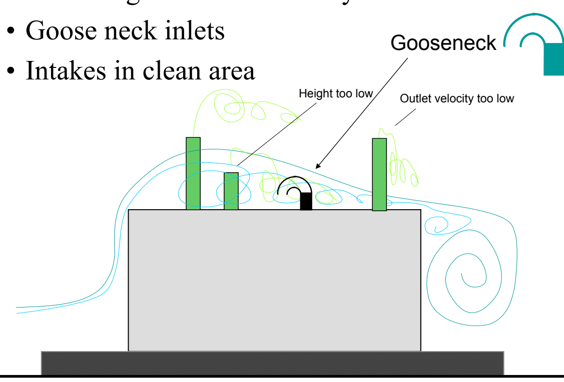
- Fan operating at Q=8000 CFM and Ps=2"$H_2$0 find Ps and RPM for Q=10,000 CFM
- Estimate BHP assuming η=0.55 at 10,000 CFM for a fan P_T of 5" $H_2$0

Examples

- Fan operating at Q=8000 CFM and Ps=2”H_20 find Ps and % RPM change for Q=10,000 CFM
- ANS: P_{s2}=3.125
- RPM_2/RPM_1=1.25 or 25% increase
- Estimate BHP assuming η=0.55 at 10,000 CFM for a fan P_T of 5” H_20
- BHP~ 14.3

Stacks and Intakes

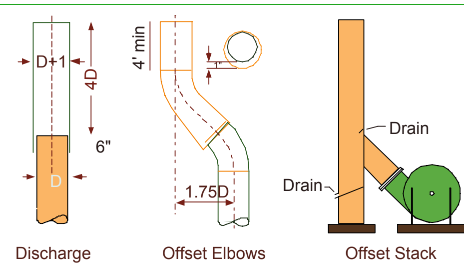
- Need height and exit velocity
- Goose neck inlets
- Intakes in clean area



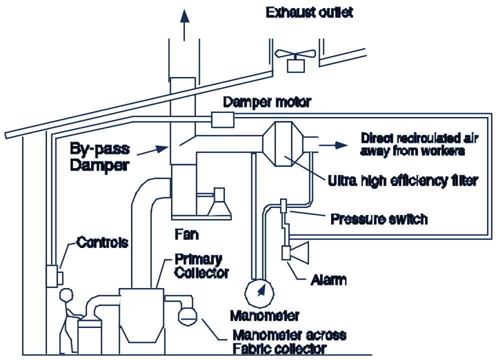
Stacks

- If h=building height
  - Min stack ~ 1.3 h
  - Needed to avoid wake cavity
- Exit velocity
  - Recommended ~ 3000 FPM or 1.8*(WS_{95}) where WS_{95} is the 95%tile of local wind speed

Weather Stacks



Recirculation



Air Cleaners

- Air cleaners often are an important part of the system design
  - Primary air pollution control device
  - Stack emissions must meet permit requirements
- Air Cleaners often have significant pressure drop
  - May be the single biggest loss in the system
  - Need to know how loss scales with Q
  - May alter humidity / density

Reasons for selecting a cleaner

- Toxicity of the material discharged
- Amount of material discharged
- Value of the material discharged
- Abrasive or corrosive material (protect fan!)
- Air quality control requirements

Selecting a cleaner-desirable features

- Clean the air stream to desired levels
- Low costs (tco) and min space
- Constant cleaning efficiency with changes in:
  - Flow rate, age, concentration, etc.
- Low down-time for servicing/cleaning
- Min disposal problem & low employee hazard to maintenance workers

Air cleaner efficiency

- Efficiency defined by contaminant removal
- $\varepsilon = 1 -$ (mass discharge rate/mass input rate)

$$\varepsilon = 1 - \left(\frac{Q_{outlet} \cdot C_{outlet}}{Q_{inlet} \cdot C_{inlet}} \right)$$

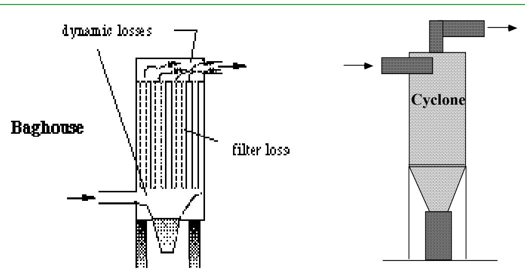
if Q is constant

$$\varepsilon = 1 - \left(\frac{C_{outlet}}{C_{inlet}} \right) = \frac{(C_{inlet} - C_{outlet})}{C_{inlet}} = \frac{removal}{input}$$

COLLECTORS - SELECTION

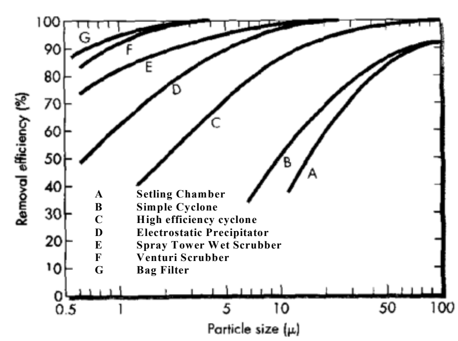
- GASES or PARTICLES?
  - PARTICLE SIZE
  - RECOVERY NEEDS
- WHAT % REMOVAL?
- HIGH TEMPERATURE?
- CORROSIVE /SPECIAL AIRSTREAMS?

Air-Cleaner Losses

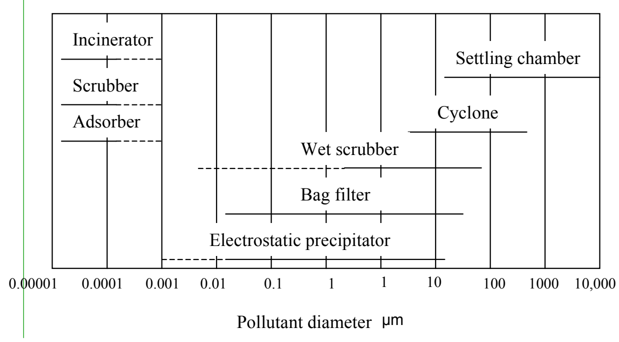


Filter loss linear with Q
Dynamic losses Q squared

Comparison of Air Pollution Control Devices



Effectiveness of Air Pollution Control Devices



Efficiency of Particulate Control Devices

Device	Min.size µm	Efficiency (% mass)	Advantages	Disadvantages
Gravity chamber	>50	< 50%	Low ΔP loss Simple, low cost	Large space needed Low efficiency
Cyclone	5-25	20-90%	Compact, med ΔP Simple, low/med. cost	Sensitive to Q High headroom (tall)
Wet collectors			Both Gas & particle removal, cools & cleans high temp gases, works for corrosive gases/mists, low explosion risk	Corrosion, disposal of wastewater, freezing in cold temp., low efficiency for fine particles, visible plume in some conditions
Spray tower	>10	< 80%		
Cyclonic	>2.5	< 80%		
Cross-flow	>2.5	< 80%		
Venturi	>0.5	< 99%		
Precipitator	>.01	>99%	Removes small particles, wet or dry operation, low ΔP, few moving parts, high temp. operation (300-400C)	High initial cost, sensitive to Q and loading, high voltage safeguards needed
Fabric filter	<1	>99%	Dry collection, decreased performance is noticed, removes small particles	Sensitive to Q, gases must be <450C, affected by condensation & chemical attack

Air Pollution Control Technologies

- Control of Particulate Emission
  - Settling
  - Cyclone separation
  - Wet scrubbing
  - Baghouse filtration
  - Electrostatic precipitation
- Control of Vapor-phase Emissions
  - Wet scrubbing
  - Activated carbon adsorption
  - Incineration

PARTICLE SIZE VS COLLECTOR CHOICE

SIZE	METHOD
~ 100	settling
> 1	impact fabric
< 0.5	diffusion
0.01 - 5	electrostatic

Stokes' Law for Particle Settling

$$v = \sqrt{\frac{4}{3} g \frac{\rho_p d}{C_d \rho_a}}$$

$$d = \frac{0.75 C_D Q^2 \rho_a}{g L^2 W^2 \rho_p}$$

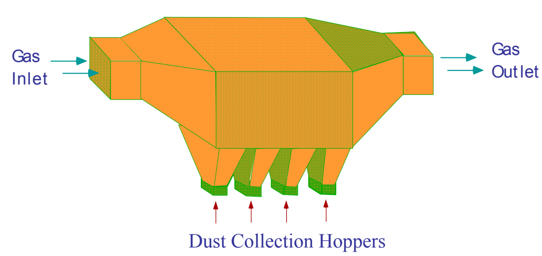
V = terminal settling velocity
g = gravitational acceleration
ρ_p= particle density
ρ_a= air density
C_d= drag coefficient
d = particle diameter

Can be used for > 50-100 µm size particles

Controlling Particulates

- Can use several types of treatment
  - settling chambers
    - based on Stokes' Law
    - practical lower limit is 50-100 um
  - cyclones
    - lower limit = 10 um
  - bag house filter
    - removes very small particles
  - scrubber
  - electrostatic precipitator

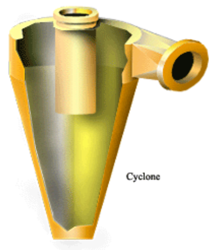
Horizontal Settling Chamber



- Cut diameter ~ 100 um
- Much blows across if no impaction plate
- Suitable for product removal, gross dust pre-cleaning

CYCLONES

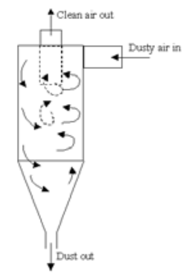
Cyclone cut-off



•Advantages & Disadvantages

Particulate Control: Cyclones

- can be used for ~5-100 µm size particles
- simple economical unit
  - no moving parts
  - relies on inertial effects



Cyclones Efficiency

- d_{pc} is the diameter of the particle collected with 50% efficiency
- The efficiency of collection for particle j with diameter d_{pj} is:

$$h=1/[1+(d_{pc}/d_{pj})^2]$$

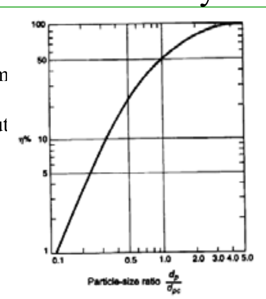
- The overall efficiency is:

$$h_0=\Sigma h_j m_j$$

- H_j is the mass fraction of particles in the *j*th size range

Standard Cyclone Efficiency

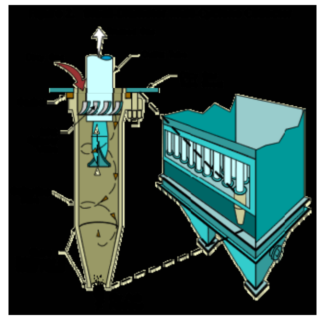
If d_{pc} is 6.3 um , the cyclone will collect particles of ~32 um with 100 % efficiency; But those of 10 um with only about 60% efficiency; and PM2.5 with about 10% efficiency



Particle collection efficiency vs size for conventional cyclones

Cyclone

Multi-Cyclones



Multiple Cyclones

Pressure Drop and Costs

- Pressure drop important consideration, increases with with the ratio of inlet to outlet area ($\sim HW/D_{entry}^2$)

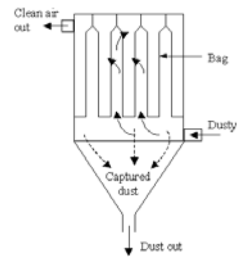
  $\Delta P \sim$ proportional to Q^2

  ε changes with Q
- Cyclone costs can be estimated by inlet area

FILTERS

Particulate Control: Baghouse Filter

- particle size smaller that 10µm
- similar to conventional home vacuum cleaner
- cannot be used for
  - wet air systems
  - corrosive gases
  - gases above 260^{o}C

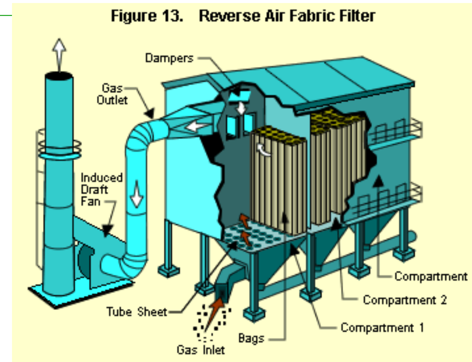


Types and Principles

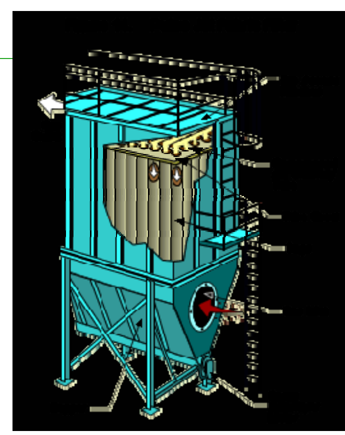
- Vacuum Cleaner Principle
- Types: By Direction of Flow; By Cleaning Mechanism
- Advantages: Efficiency, Applications, Pressure loss relatively low
- Disadvantages: Foot Print, Type of Gas effect on Fabric, Gas Conditions Effects on Fabric, Fire or Explosion Hazard, Effect of Gas Moisture

Design Considerations

- Selection of Fabrics
- Bag Arrangement
- Fan Location
- Costs: Case/Enclosure a function of size (cloth area) and Metallurgy
- Typical Costs for Baghouses by type



Compartments



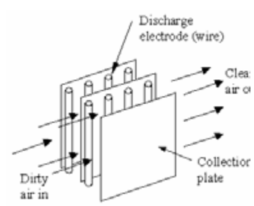
Fabric Filters - Baghouses

Fabric Filters - Baghouses

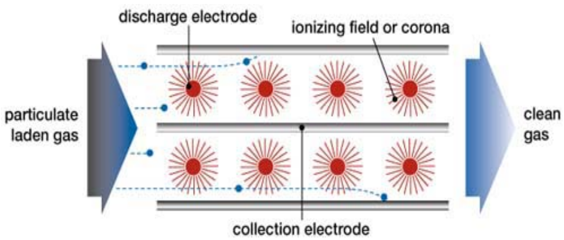
PRECIPITATORS

Particulate Control: ESP

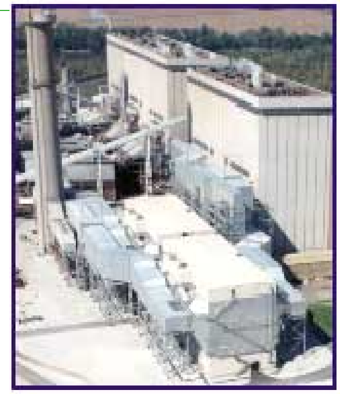
- high efficiency, dry collector of particulates
- high electrical direct current current potential (30-75 kV)



Principle of ESP Operation

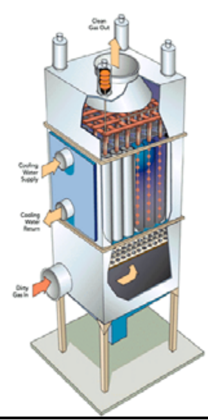


Electrostatic Precipitators

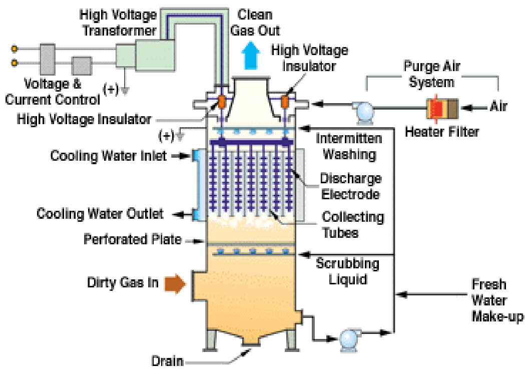


Electrostatic Precipitators

Wet ESP



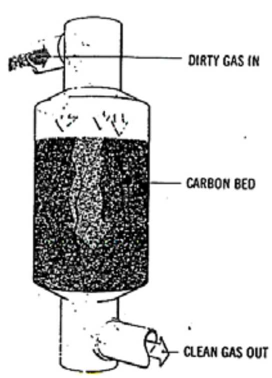
Wet ESP



Gas Removal

- Adsorption Systems
  - consist of a bed of adsorbing material
    - activated carbon
  - adsorbing material is housed within a pressure vessel through which the contaminated air passes
  - pollutants are transferred from air to adsorber

Activated Carbon Adsorber

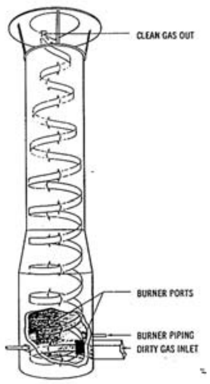


Gas Removal

- Incineration or flaring
  - used to oxidize:
    - carbon monoxide
    - organic air pollutants
    - organics containing chlorine, sulfur, and nitrogen

  to carbon dioxide and water
  - direct flame combustion and catalytic combustion

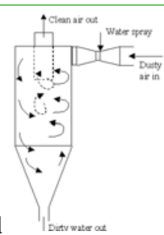
Incinerator



Gas Removal

- Wet Scrubbers
  - transfer pollutants from air to water phase
  - further treatment may be necessary
  - pollutants must be highly soluble in water
  - for less soluble materials, a chemical may be injected in the water
    - flue gas desulfurization
      - SO_2 in the flue gas may be removed by reacting it with a solution of lime or lime stone in water

Particulate Control: Scrubber



- can be used where
  - air is wet
  - corrosive
  - hot
  - where baghouses can not be used
  - for even higher efficiencies, a combination of a venturi scrubber and cyclone and can be used

Theory

- Advantages: Can handle flammable Gases, simultaneous gas and particle removal, neutralization, cools and humidifies
- Disadvantages: corrosion problems, liquid waste (problems: recovery, disposal), in cold weather freezing protection needed

Design Equations

- Based on Penetration, i.e. complement of removal
- Spray Chamber Equations
- Venturi Scrubber Equations
- Pressure loss
- Efficiency and Energy Expenditure: Contacting Power
- Mist Elimination
- Costs a function of capacity and type

Ventury Scrubber

Ventury Scrubber

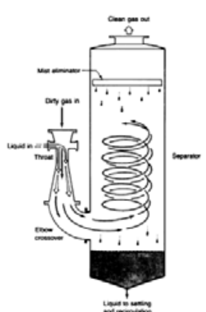
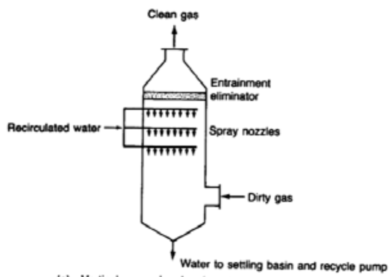


Figure 7.4
Typical venturi scrubber with a cyclone separator configuration.

Vertical Spray Chamber

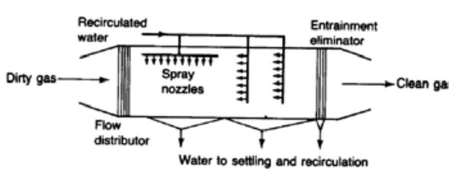
Vertical Spray Chamber



(a) Vertical spray chamber (countercurrent flow)

Horizontal Cross Flow Scrubber

Horizontal Cross Flow Scrubber



(b) Horizontal spray chamber (cross-flow)

Figure 7.1
Typical spray chamber arrangements.

Cyclone Spray Chamber

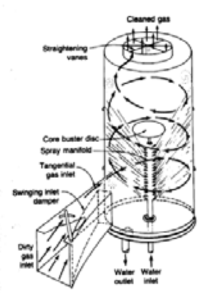
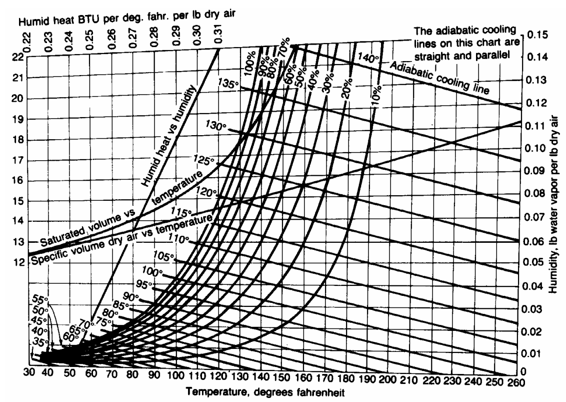


Figure 7.2
Cyclone spray chamber.
(Adapted from *Air Pollution Manual—Part II*, 1968.)

Humidification

- Example: A stream of 100,000 acfm at 150F, 1 atm and 20% humidity is scrubbed. Estimate temperature, flowrate of the scrubbed gas and make up water.

Psychrometric Chart



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