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_20 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_20

Examples

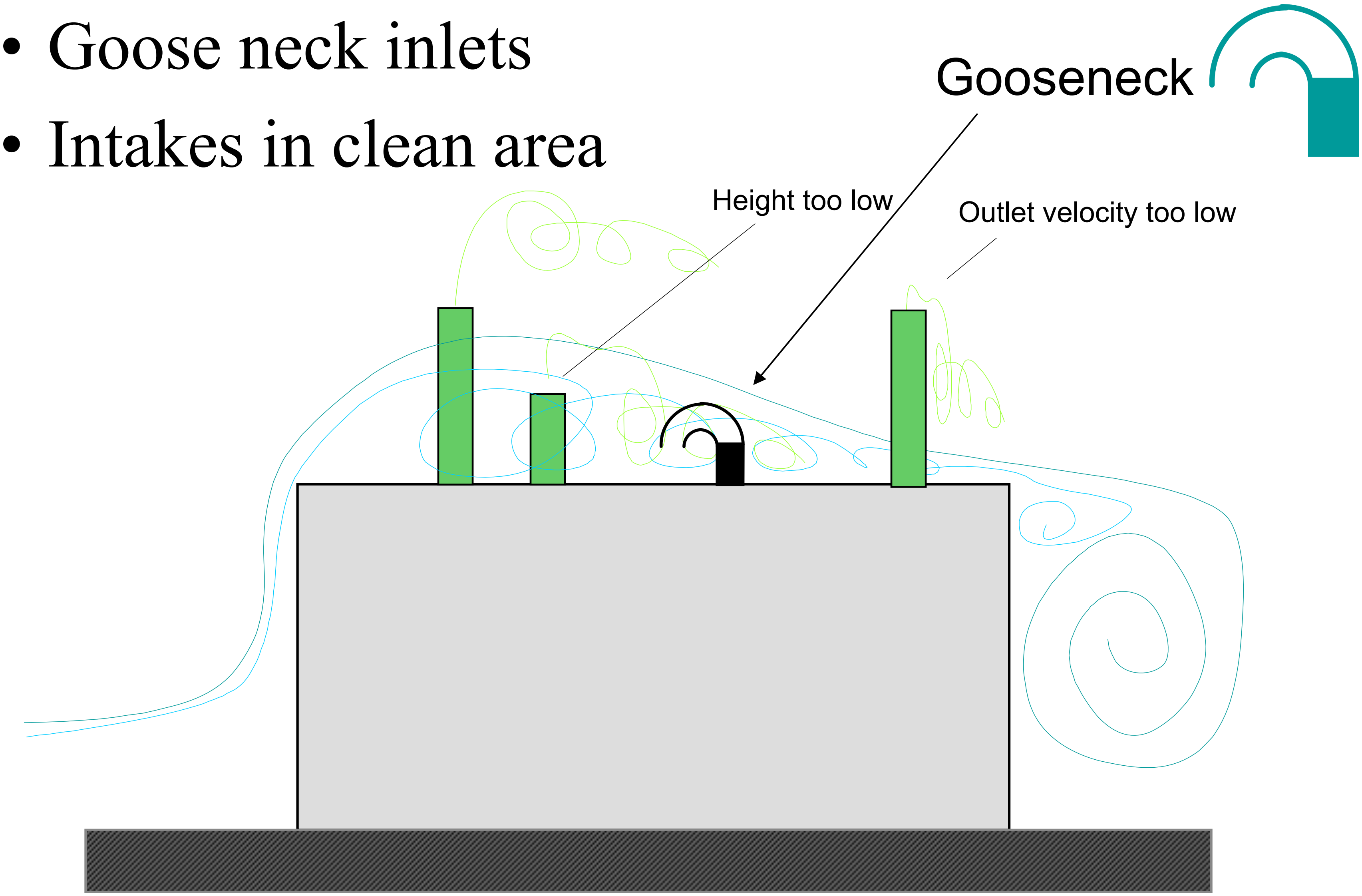
- Fan operating at Q=8000 CFM and Ps=2"H_2O find Ps and % RPM change for Q=10,000 CFM

- 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_2O
- BHP~ 14.3

Stacks and Intakes

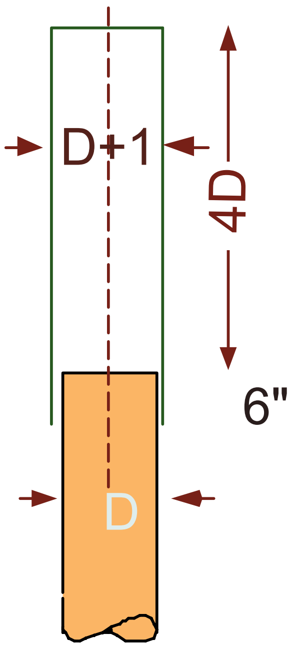
- Need height and exit velocity
- Goose neck inlets
- Intakes in clean area



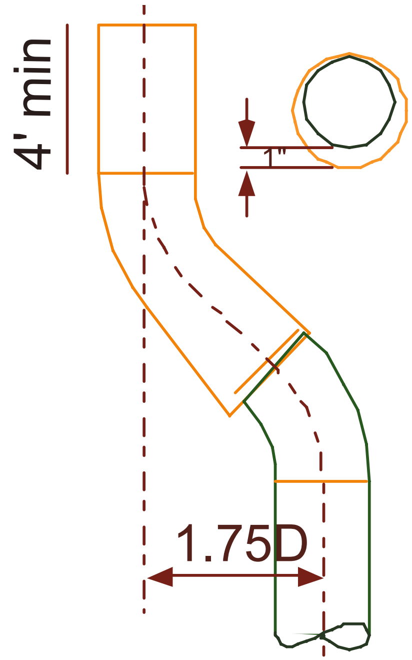
Stacks

- 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

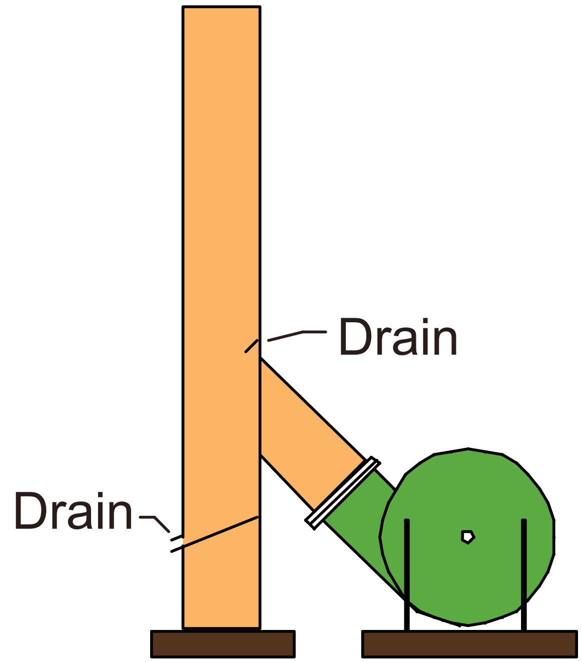
Weather Stacks



Discharge

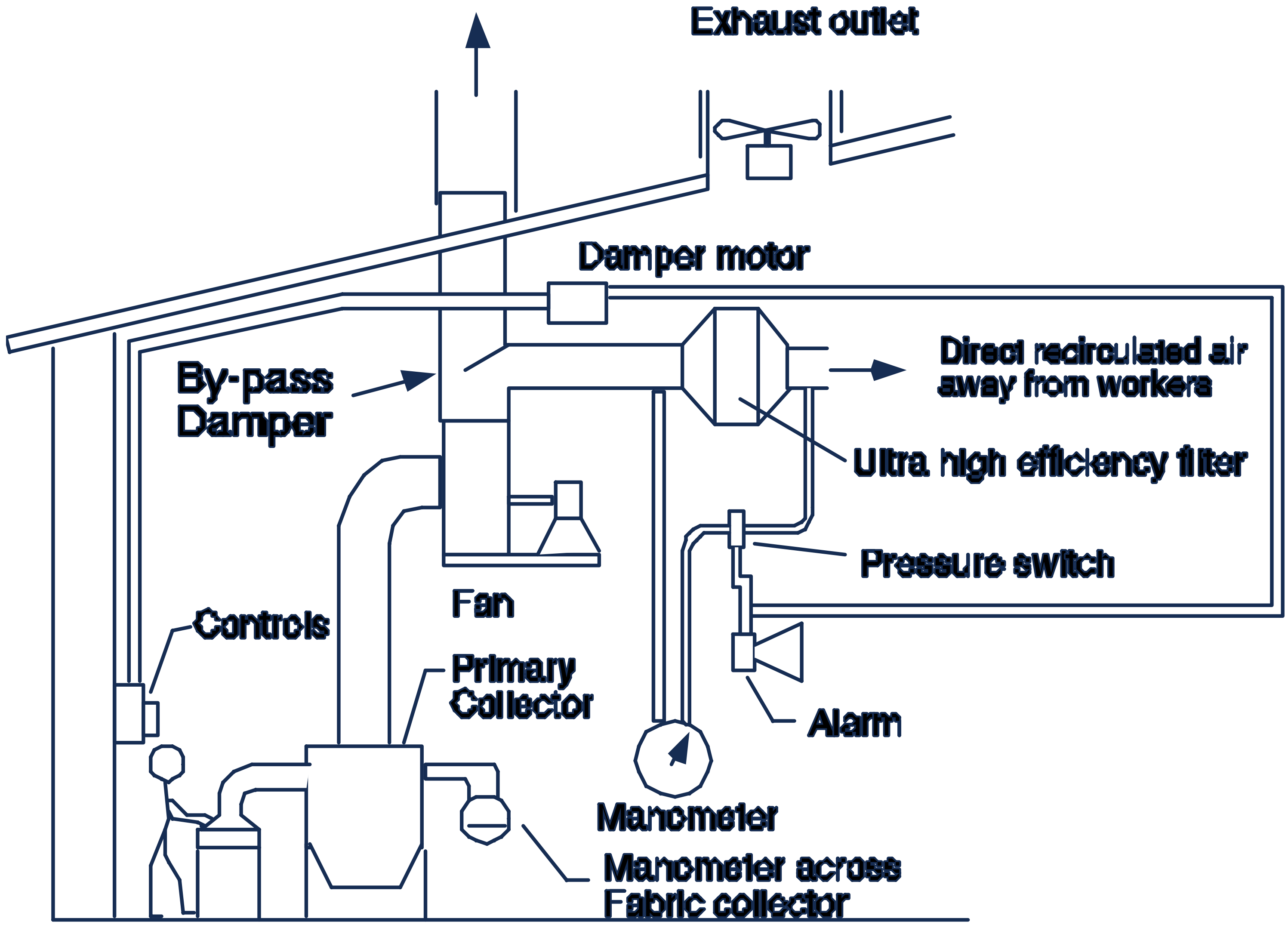


Offset Elbows



Offset Stack

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
- ε = 1 – (mass discharge rate/mass input rate)

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

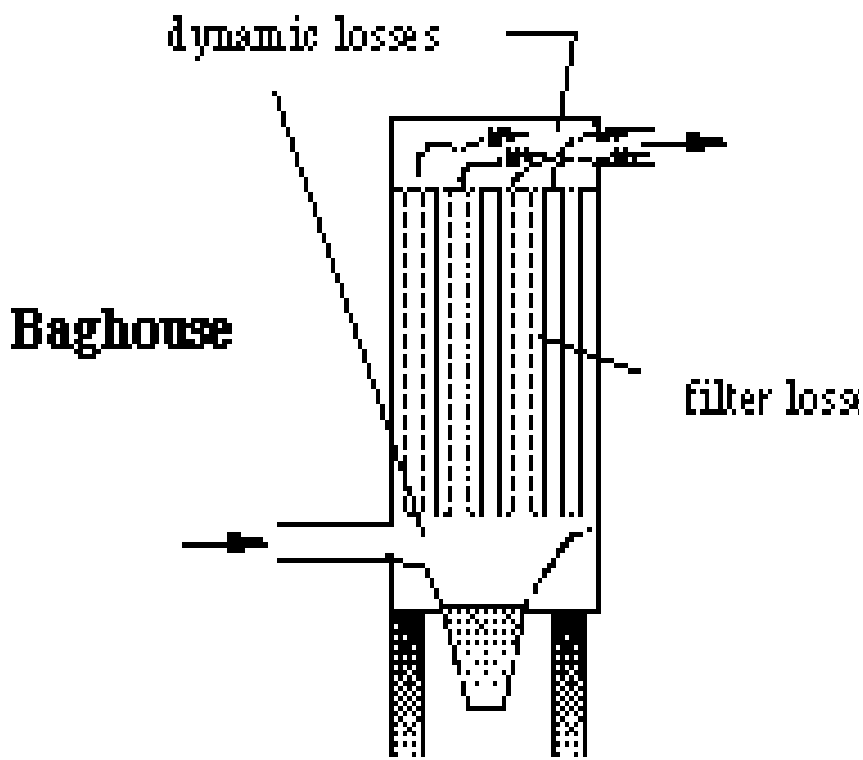
if Q is constant

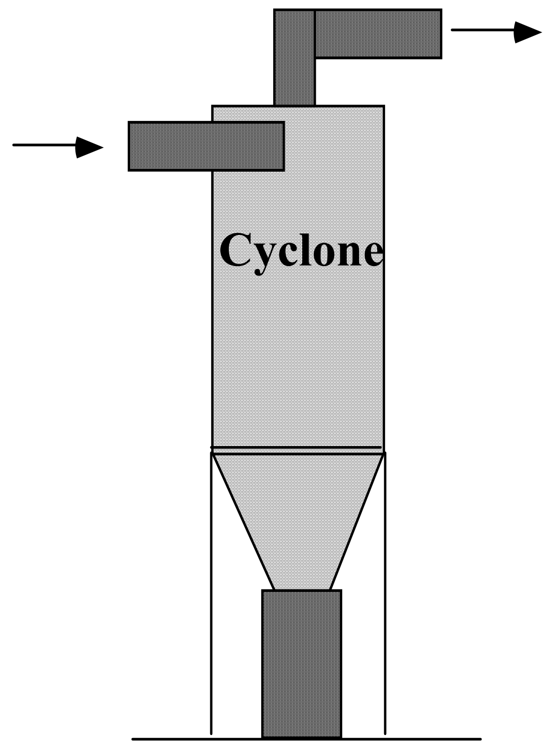
$$\varepsilon = 1 - \left(\frac{C_{outlet}}{C_{inlet}} \right) = \frac{(C_{inlet} - C_{outlet})}{C_{inlet}} = \frac{removal}{input}$$

COLLECTORS - SELECTION

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

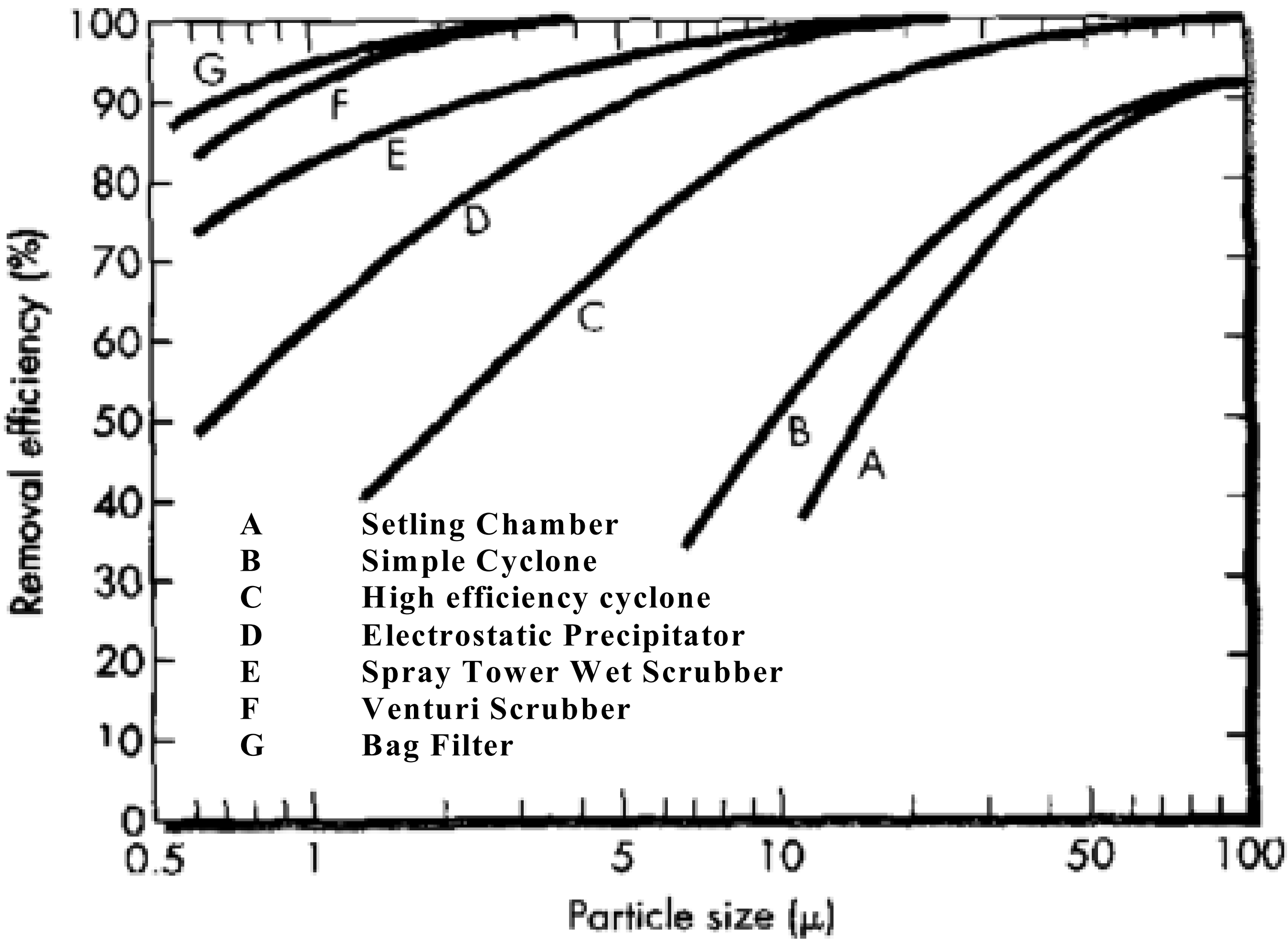
Air-Cleaner Losses





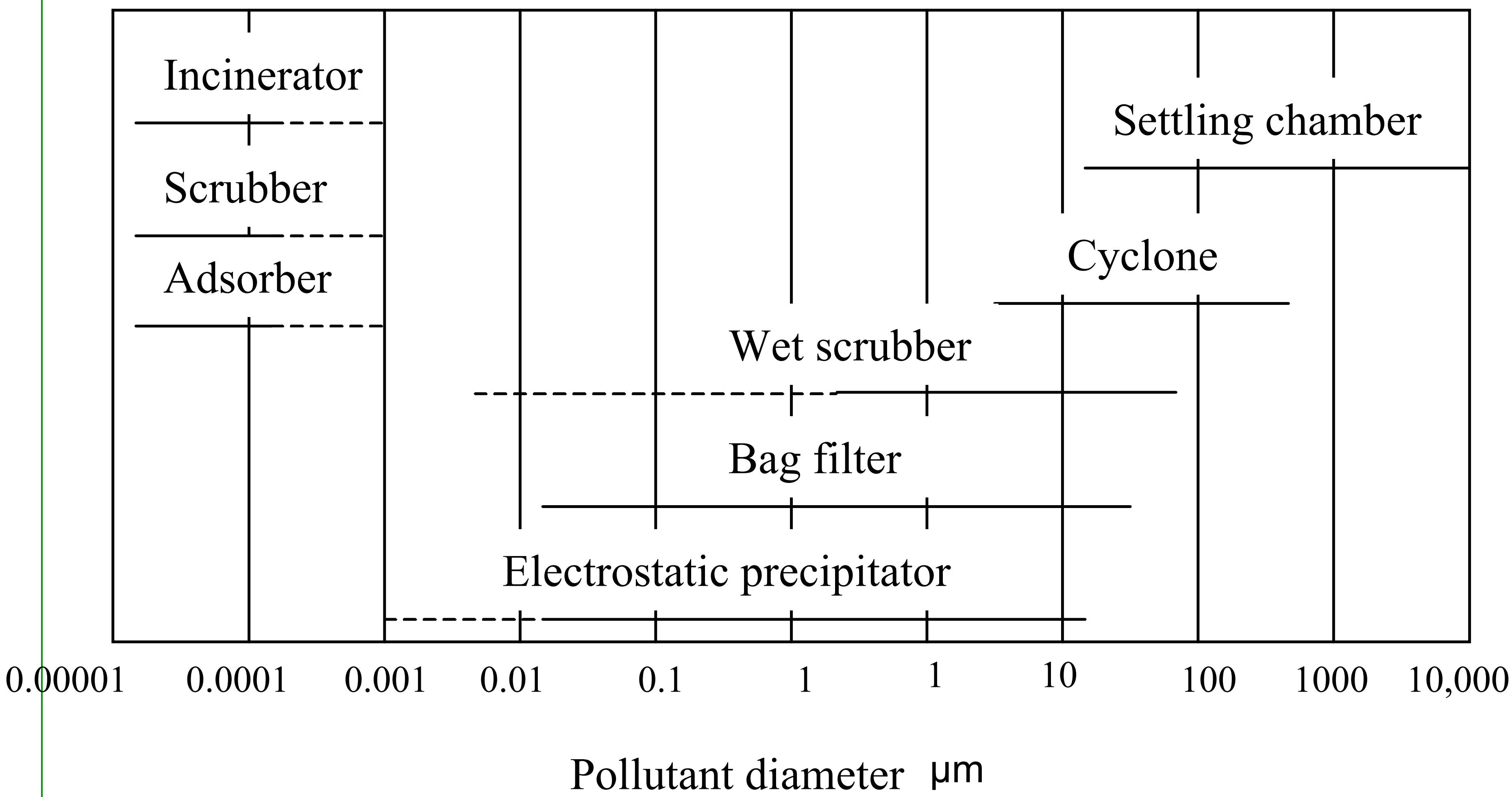
Filter loss linear with Q
Dynamic losses Q squared

Comparison of Air Pollution Control Devices



A Setling Chamber
B Simple Cyclone
C High efficiency cyclone
D Electrostatic Precipitator
E Spray Tower Wet Scrubber
F Venturi Scrubber
G Bag Filter

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

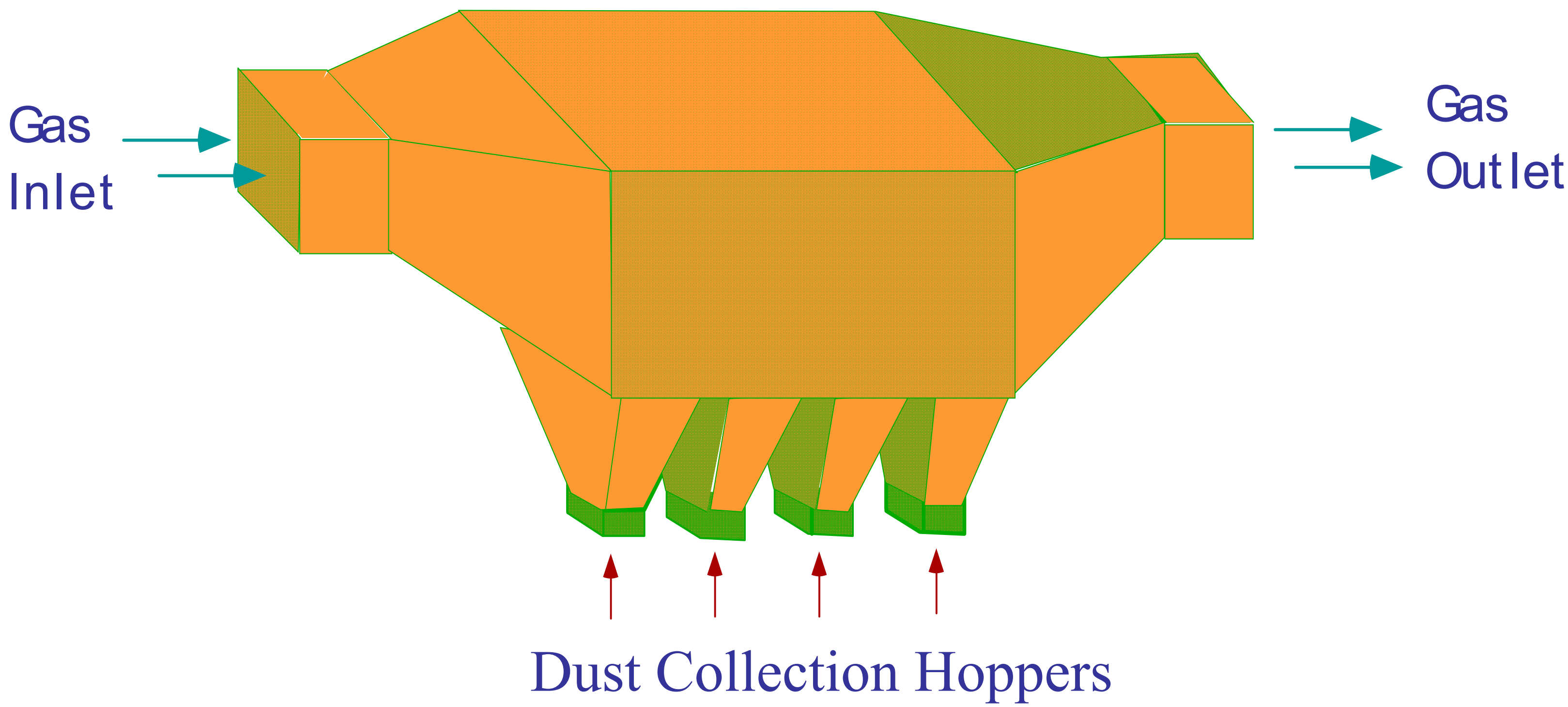
d = particle diameter

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

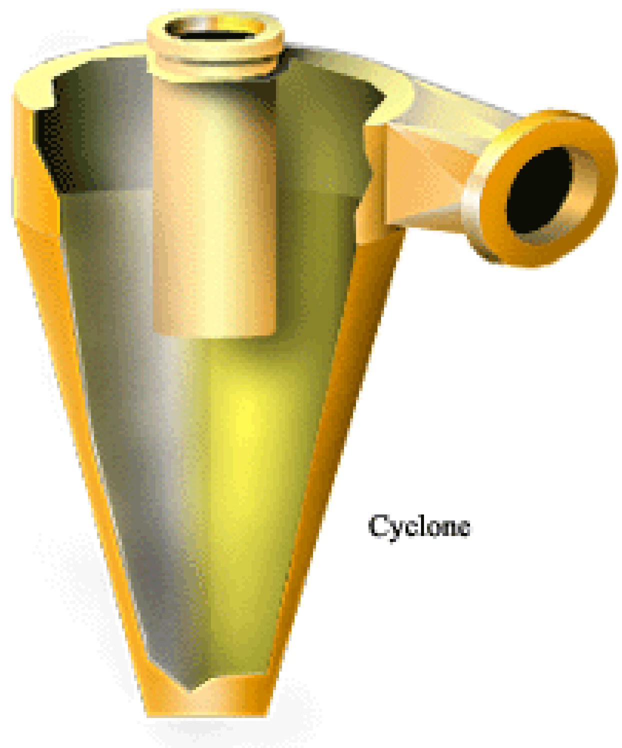
Horizontal Settling Chamber



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

CYCLONES

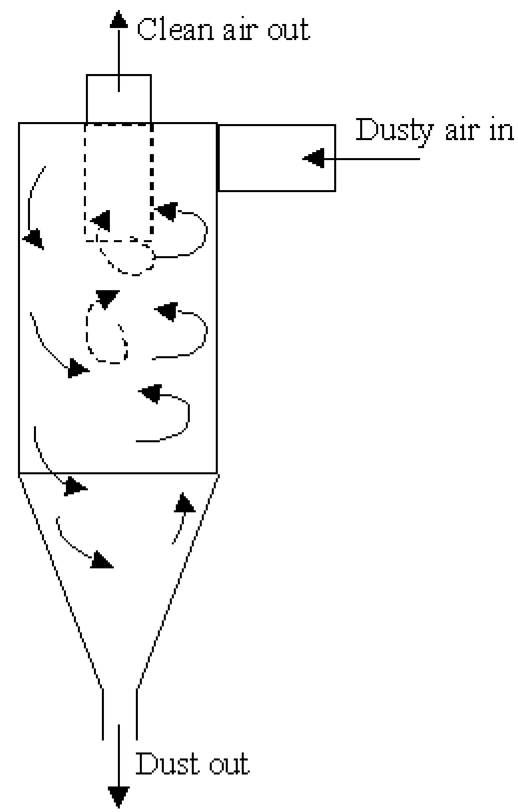
Cyclone cut-off



•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:

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

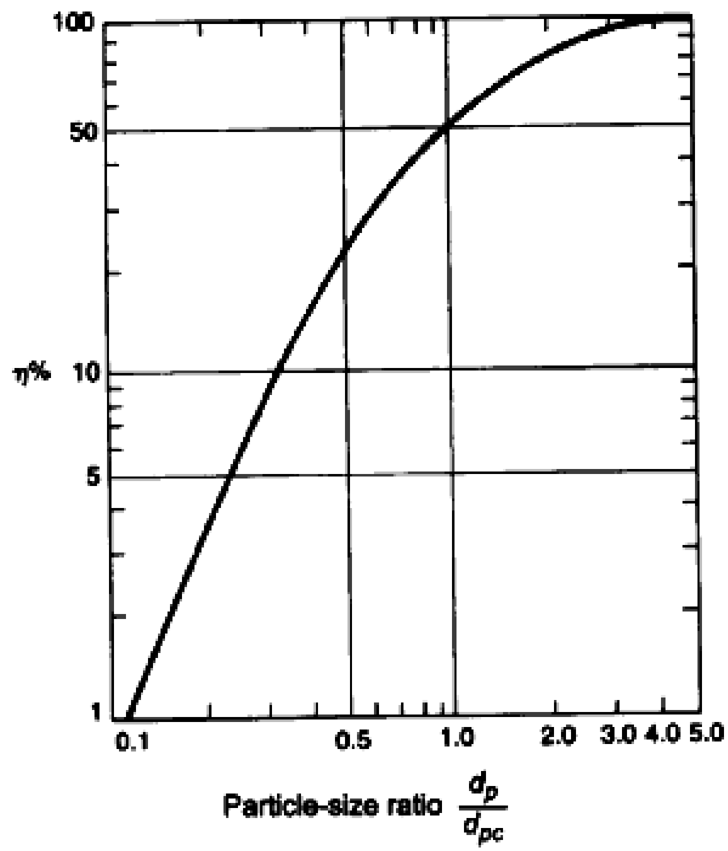
- The overall efficiency is:

$$h_0=\Sigma h_j m_j$$

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

Standard Cyclone Efficiency

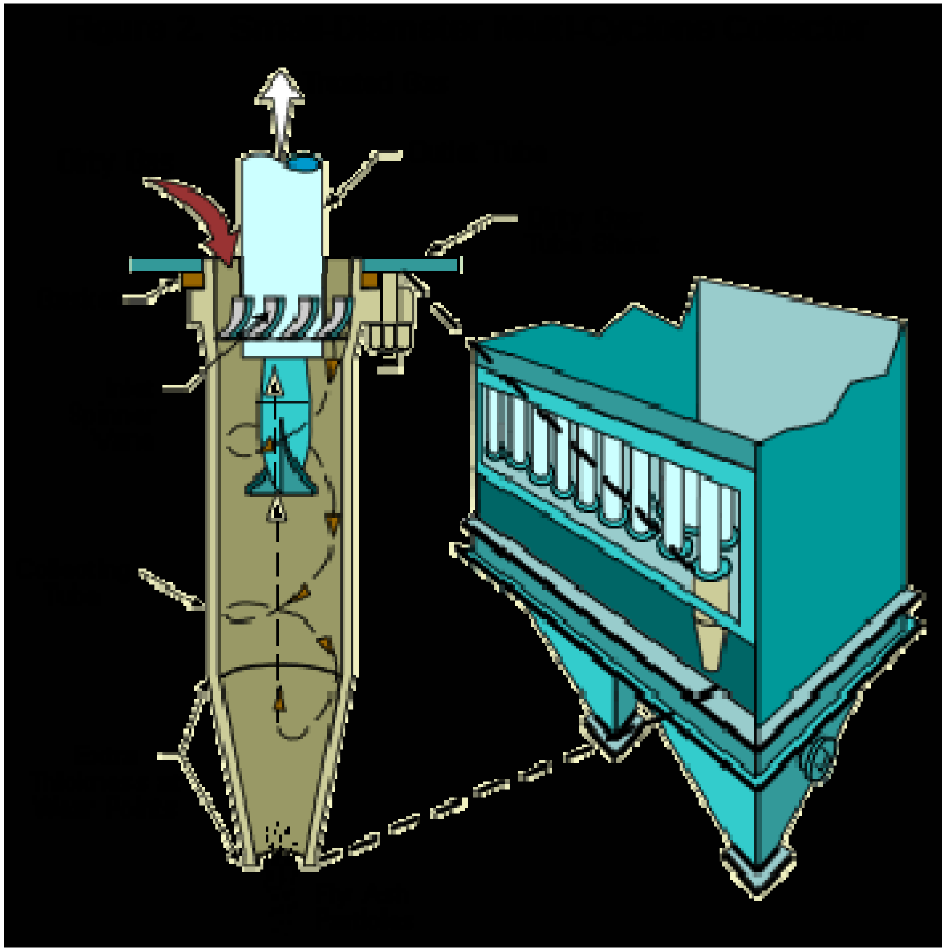
If d_{pc} is 6.3 um , the cyclone will collect particles of ~32 um with 100 % efficiency; But those of 10 um with only about 60% efficiency; and PM2.5 with about 10% efficiency



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 (~HW/D_{entry}^2)

  ΔP ~ proportional to Q^2

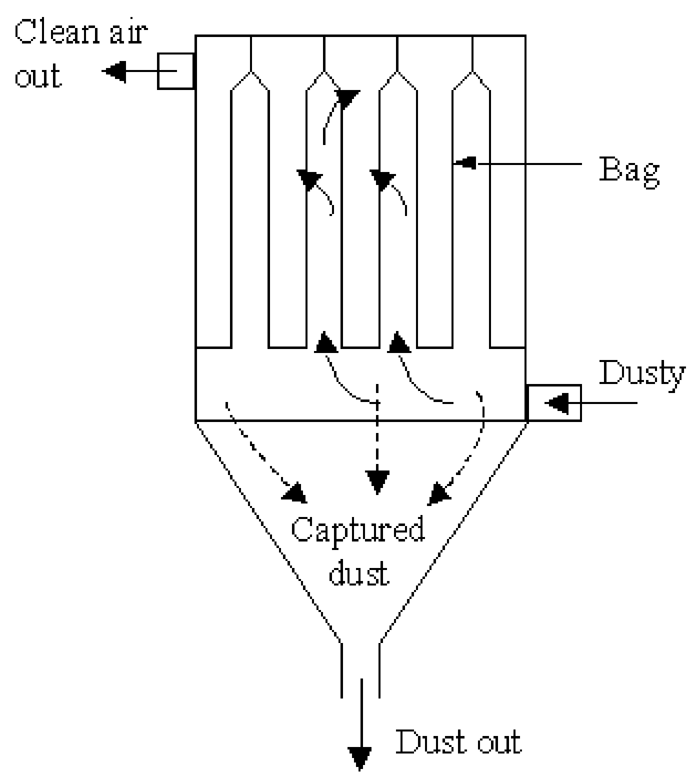
  ε changes with Q

- 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

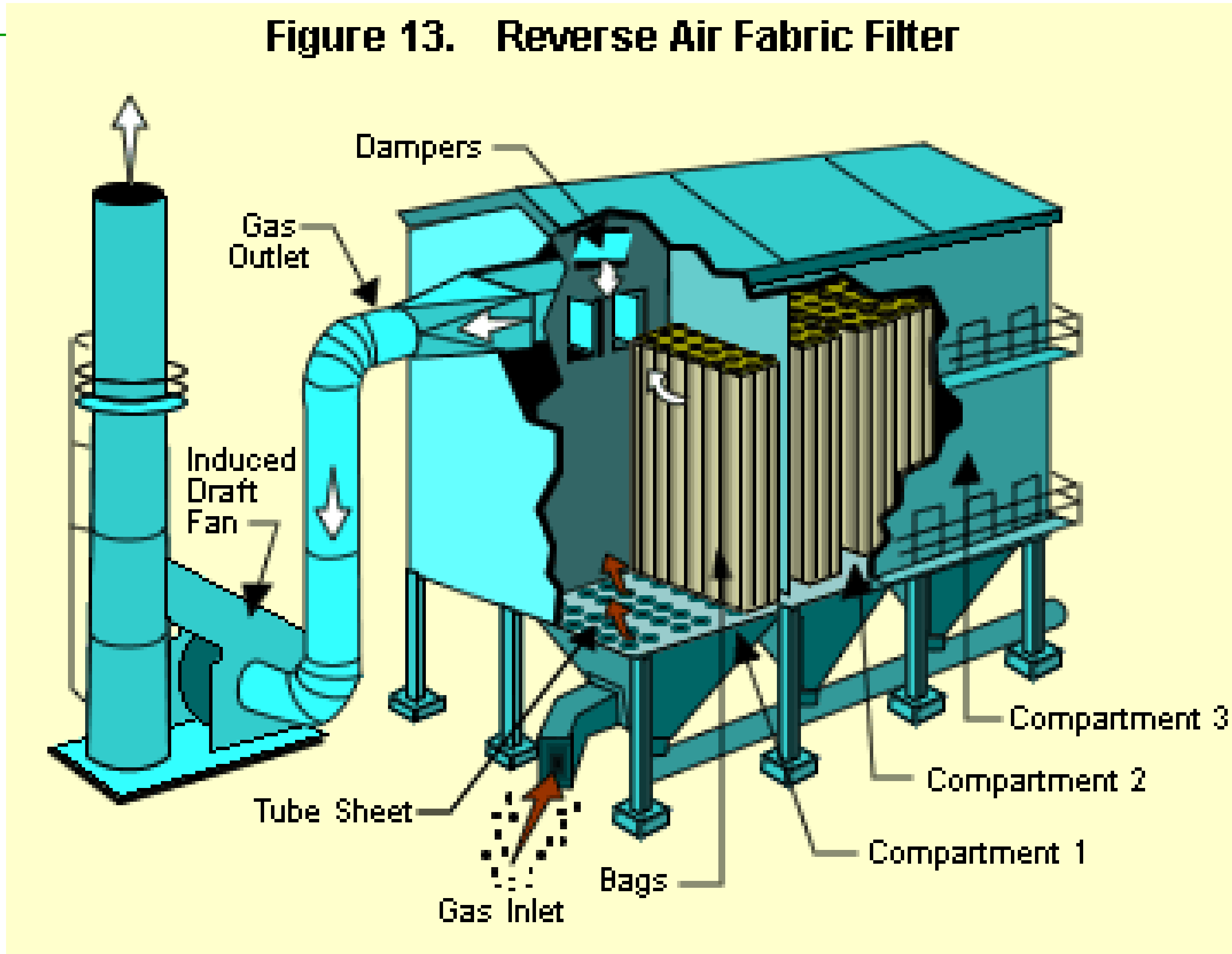
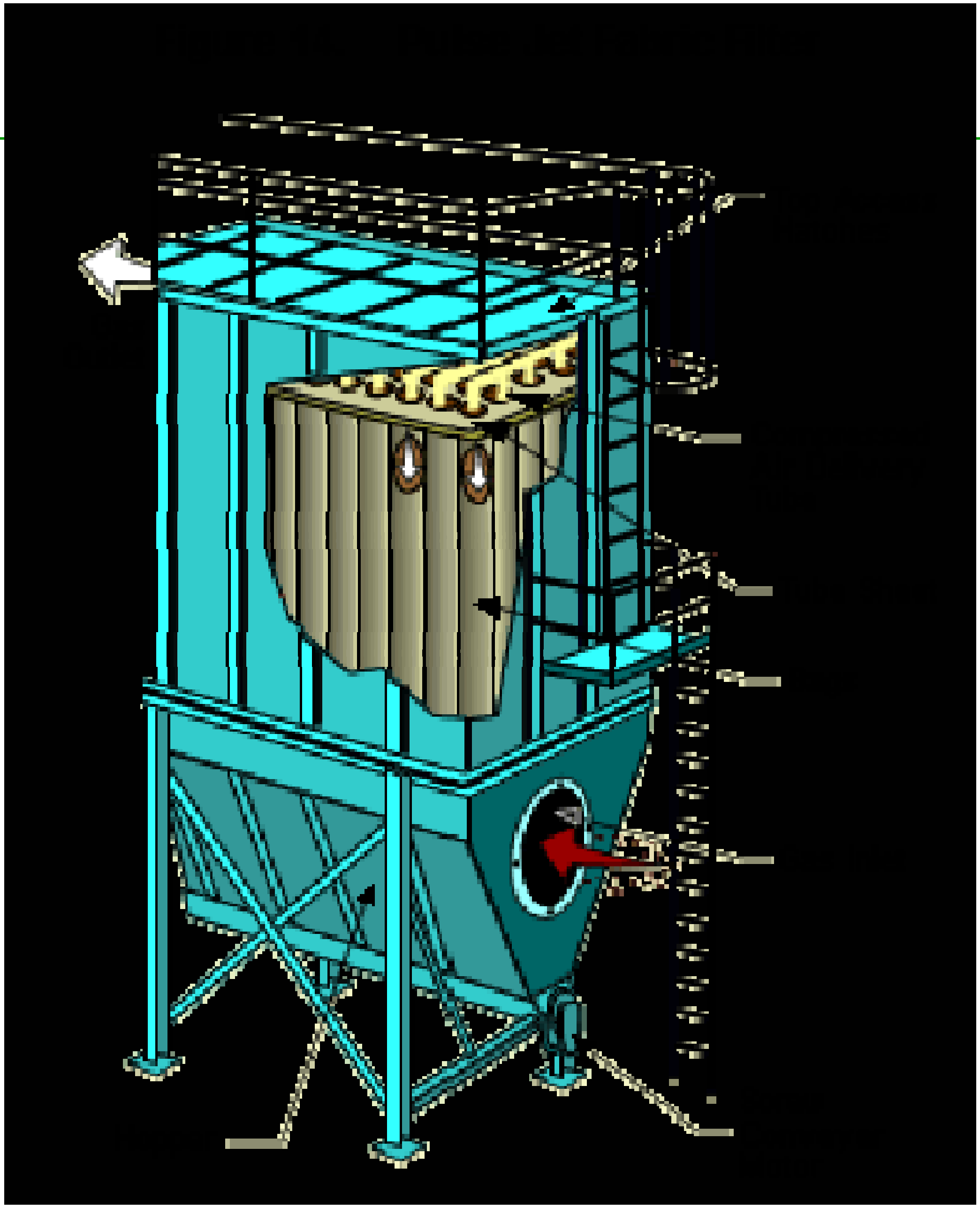


Figure 13. Reverse Air Fabric Filter
Dampers
Gas Outlet
Induced Draft Fan
Tube Sheet
Gas Inlet
Bags
Compartment 1
Compartment 2
Compartment 3

Compartments



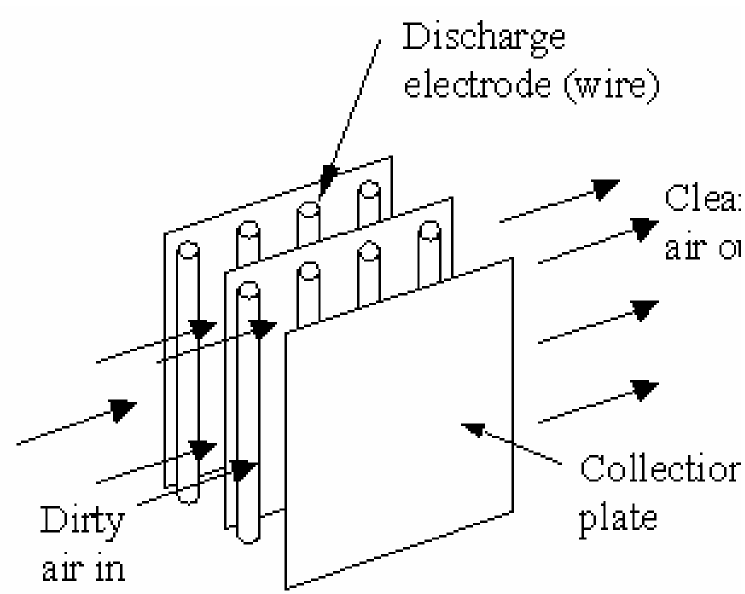
Fabric Filters - Baghouses

Fabric Filters - Baghouses

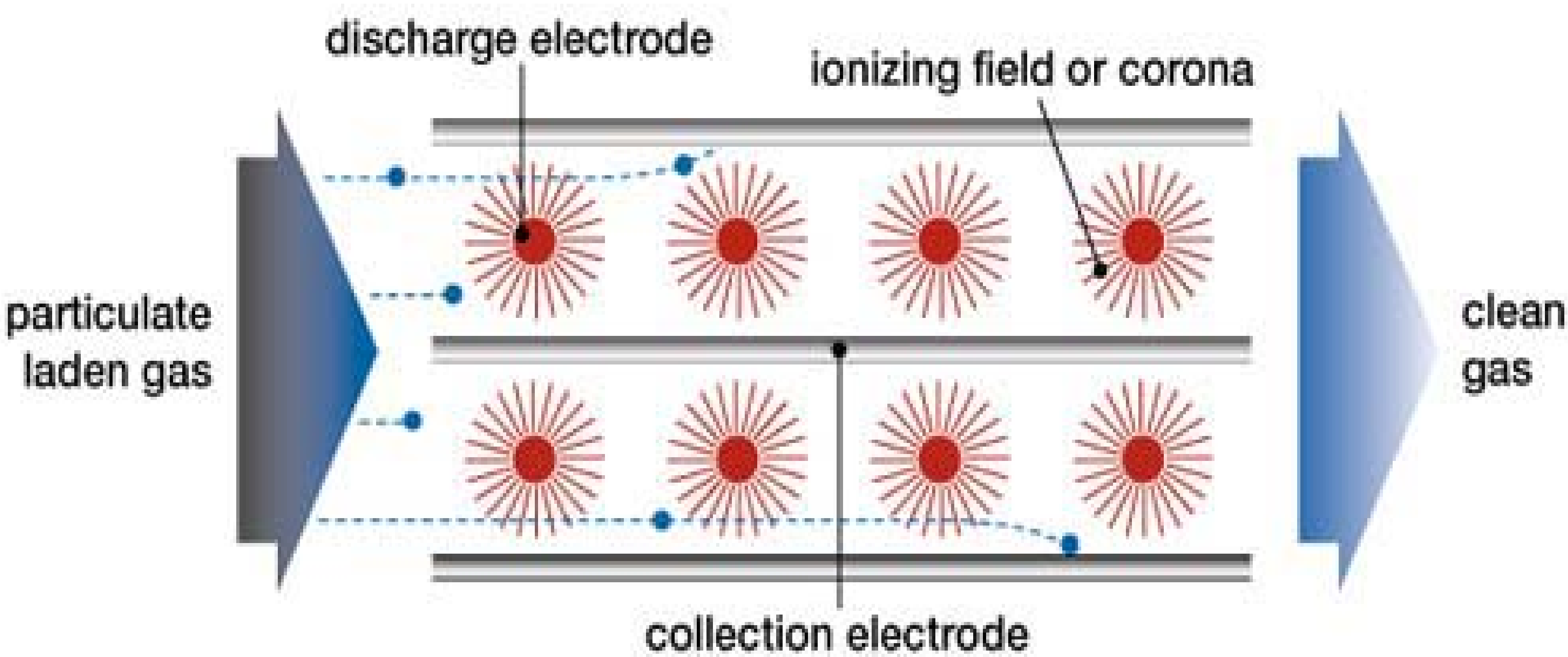
PRECIPITATORS

Particulate Control: ESP

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



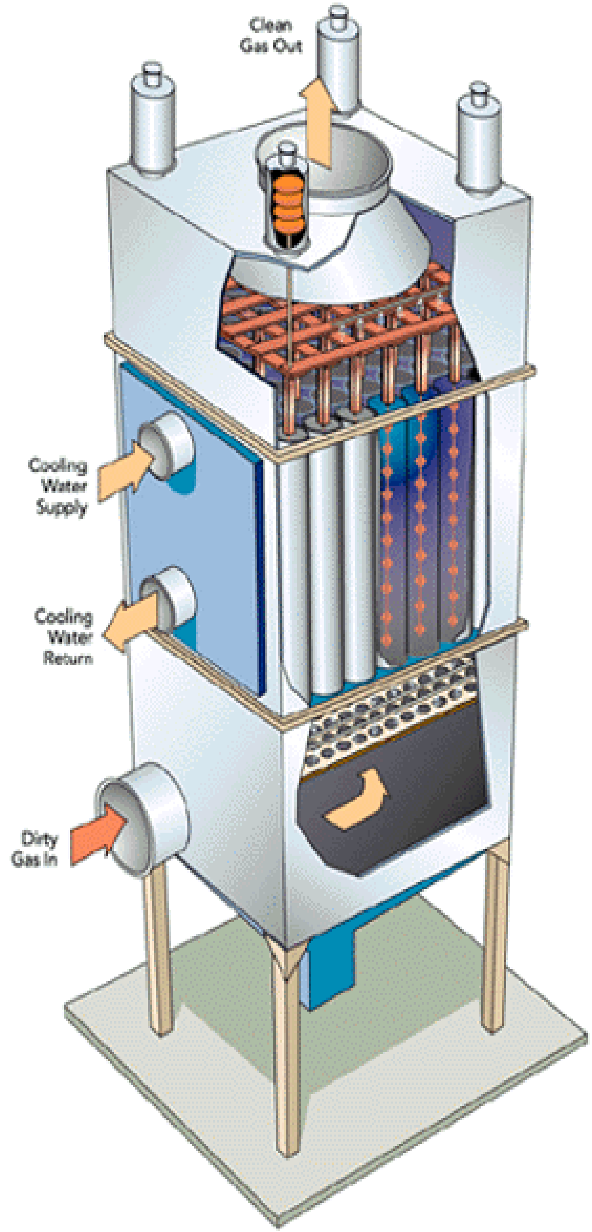
Principle of ESP Operation



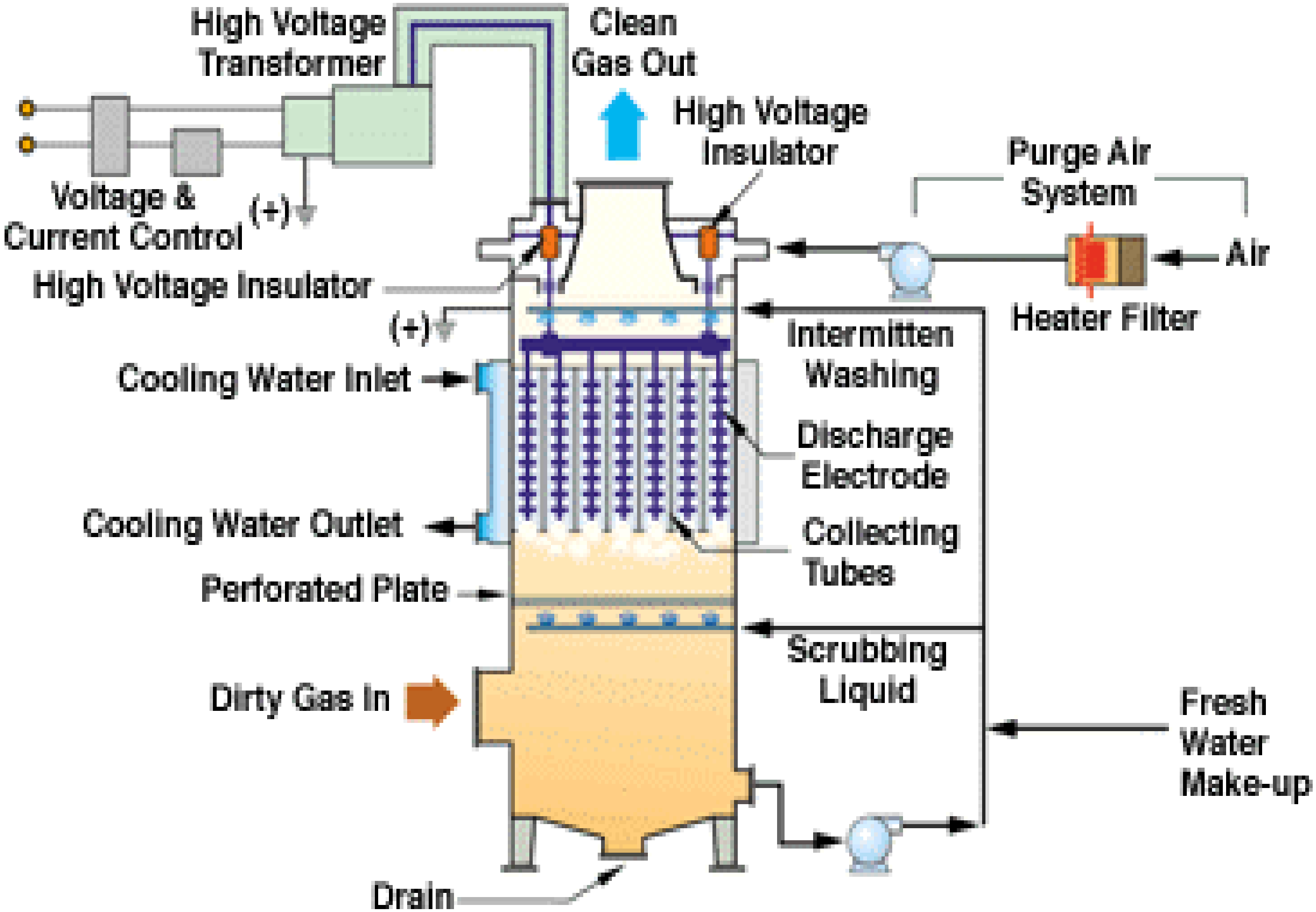
Electrostatic Precipitators

Electrostatic Precipitators

Wet ESP


Clean
Gas Out
Cooling
Water
Supply
Cooling
Water
Return
Dirty
Gas In

Wet ESP

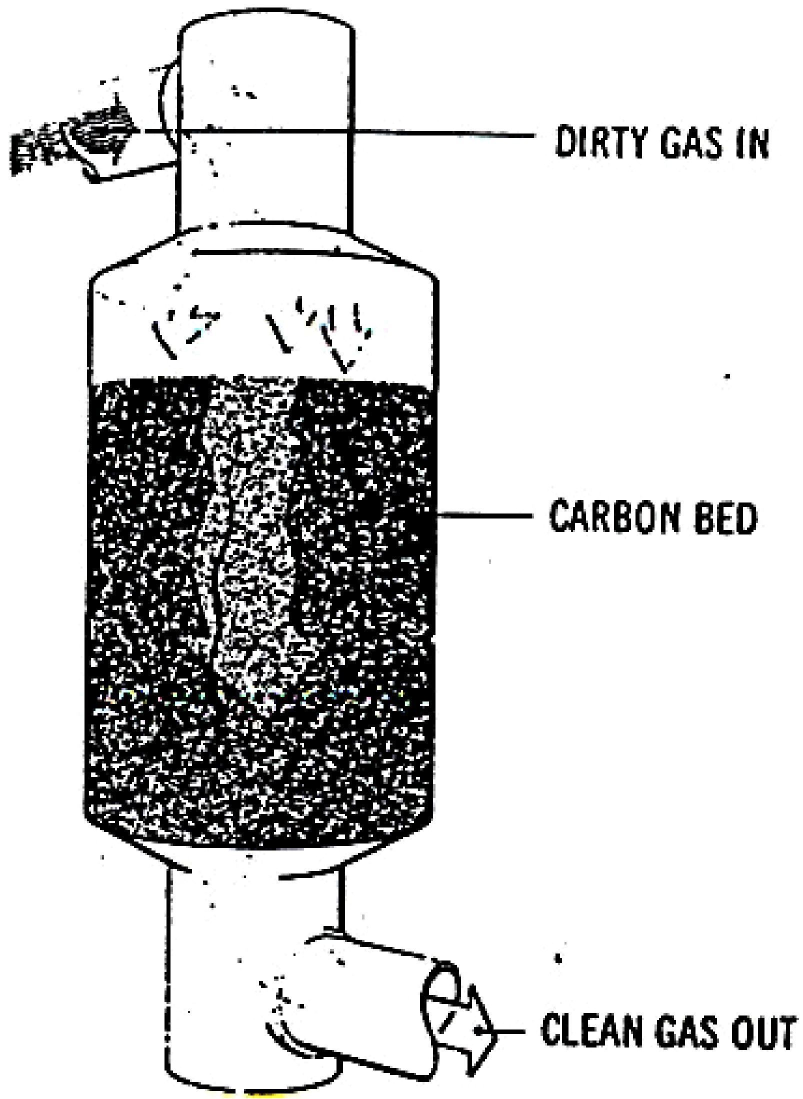


High Voltage Transformer
Clean Gas Out
High Voltage Insulator
Purge Air System
Air
Heater Filter
Voltage & Current Control
(+)
High Voltage Insulator
(+)
Intermitten Washing
Cooling Water Inlet
Discharge Electrode
Cooling Water Outlet
Collecting Tubes
Perforated Plate
Scrubbing Liquid
Dirty Gas In
Fresh Water Make-up
Drain

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

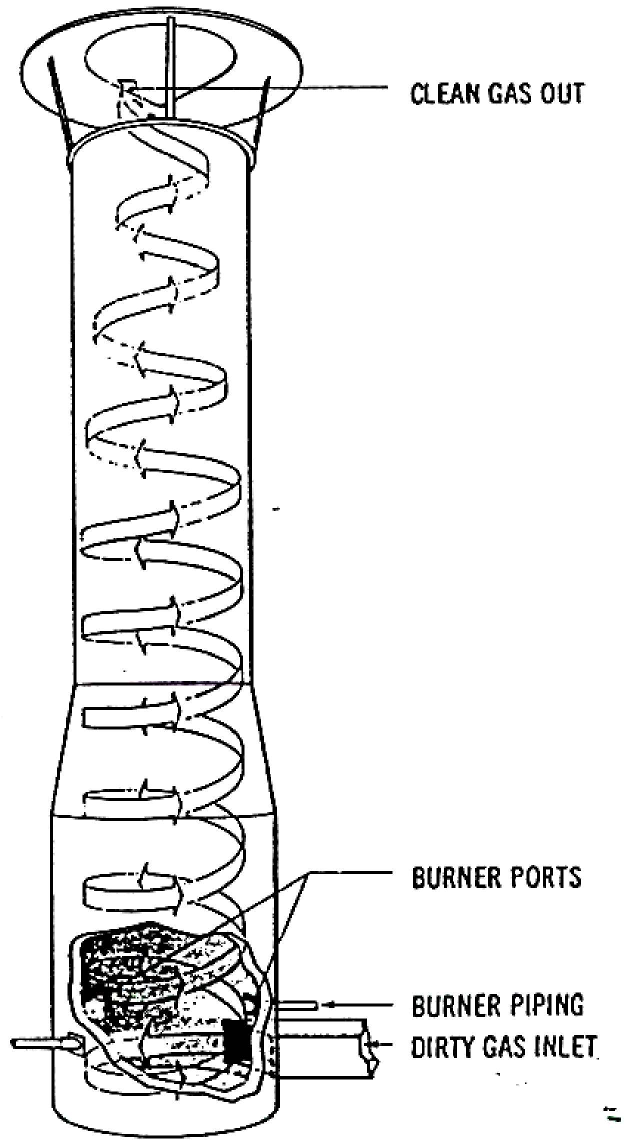


Gas Removal

- 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

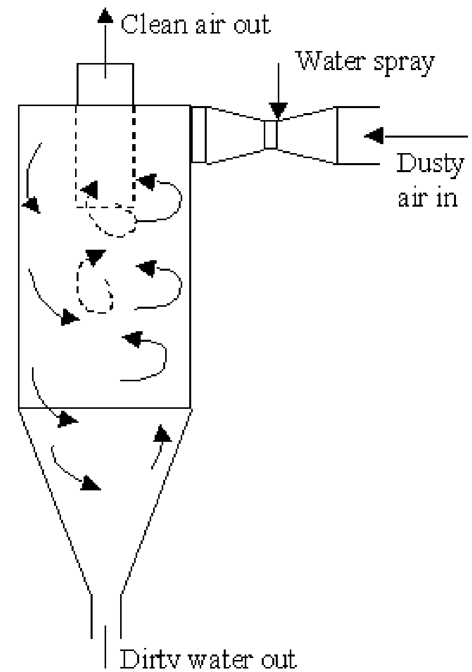
Incinerator



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

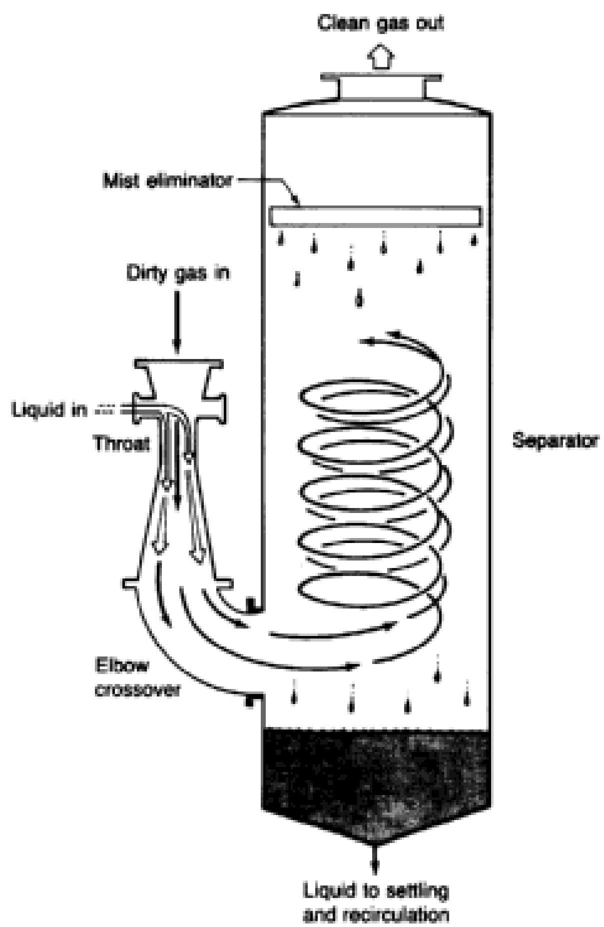
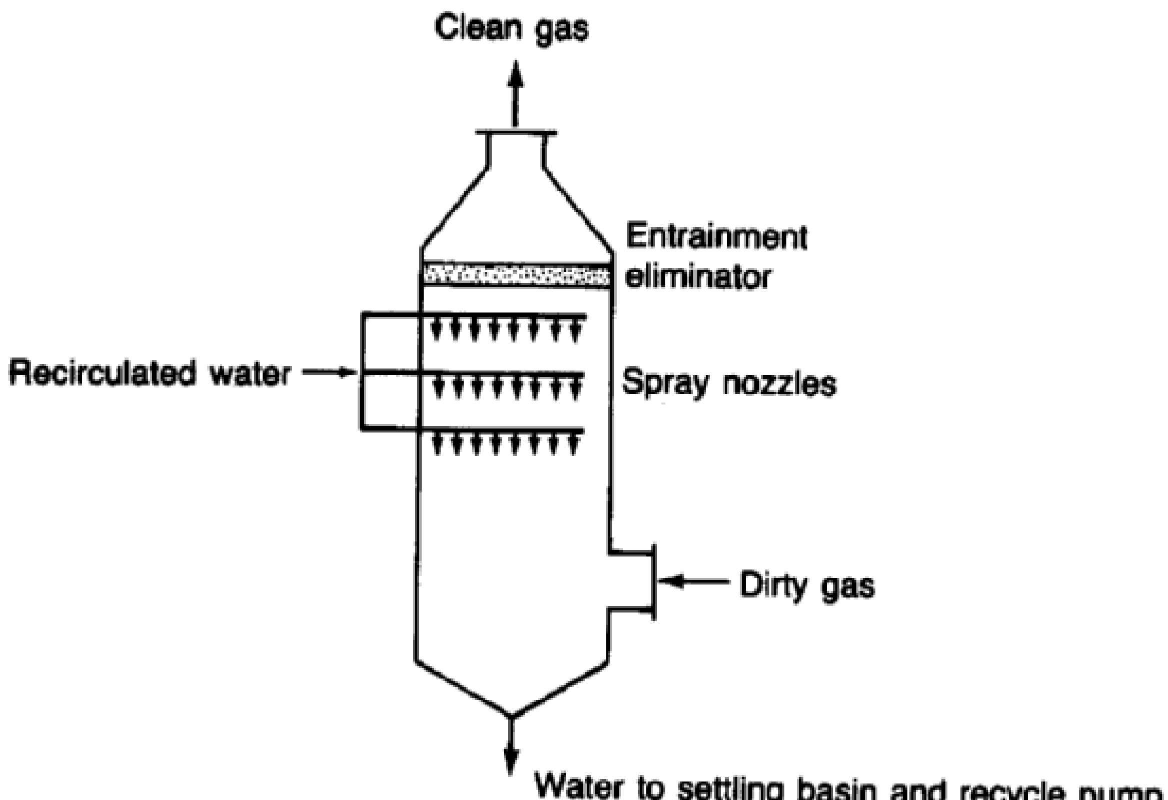


Figure 7.4
Typical venturi scrubber with a cyclone separator configuration.

Vertical Spray Chamber

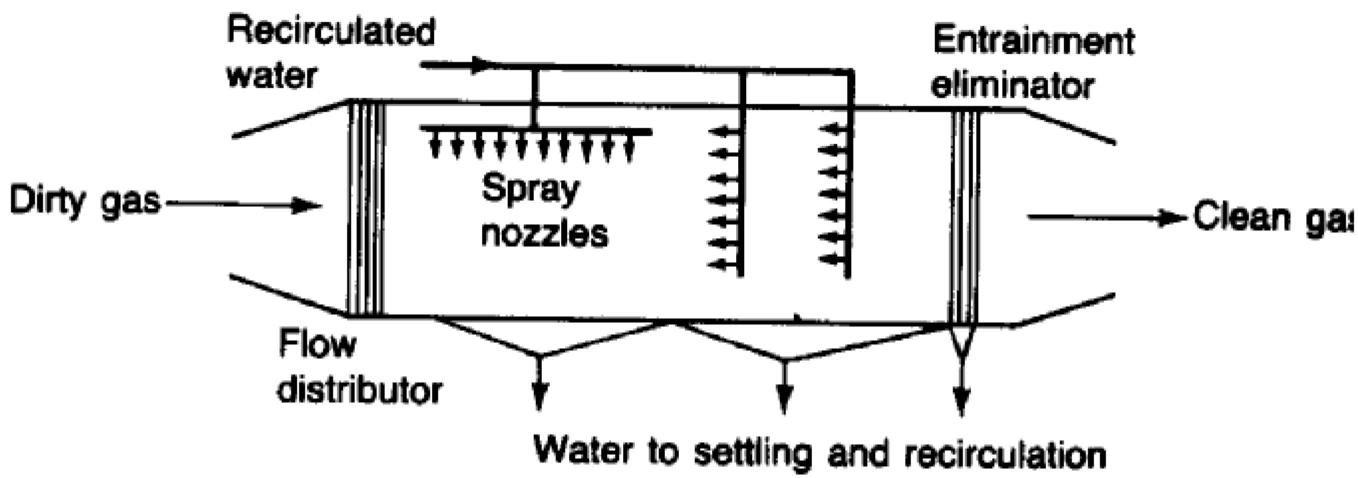
Vertical Spray Chamber



(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

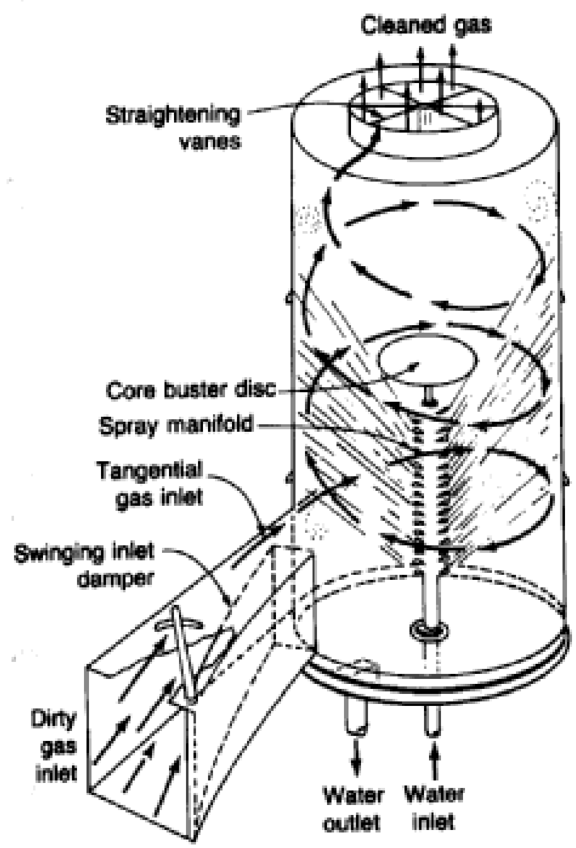
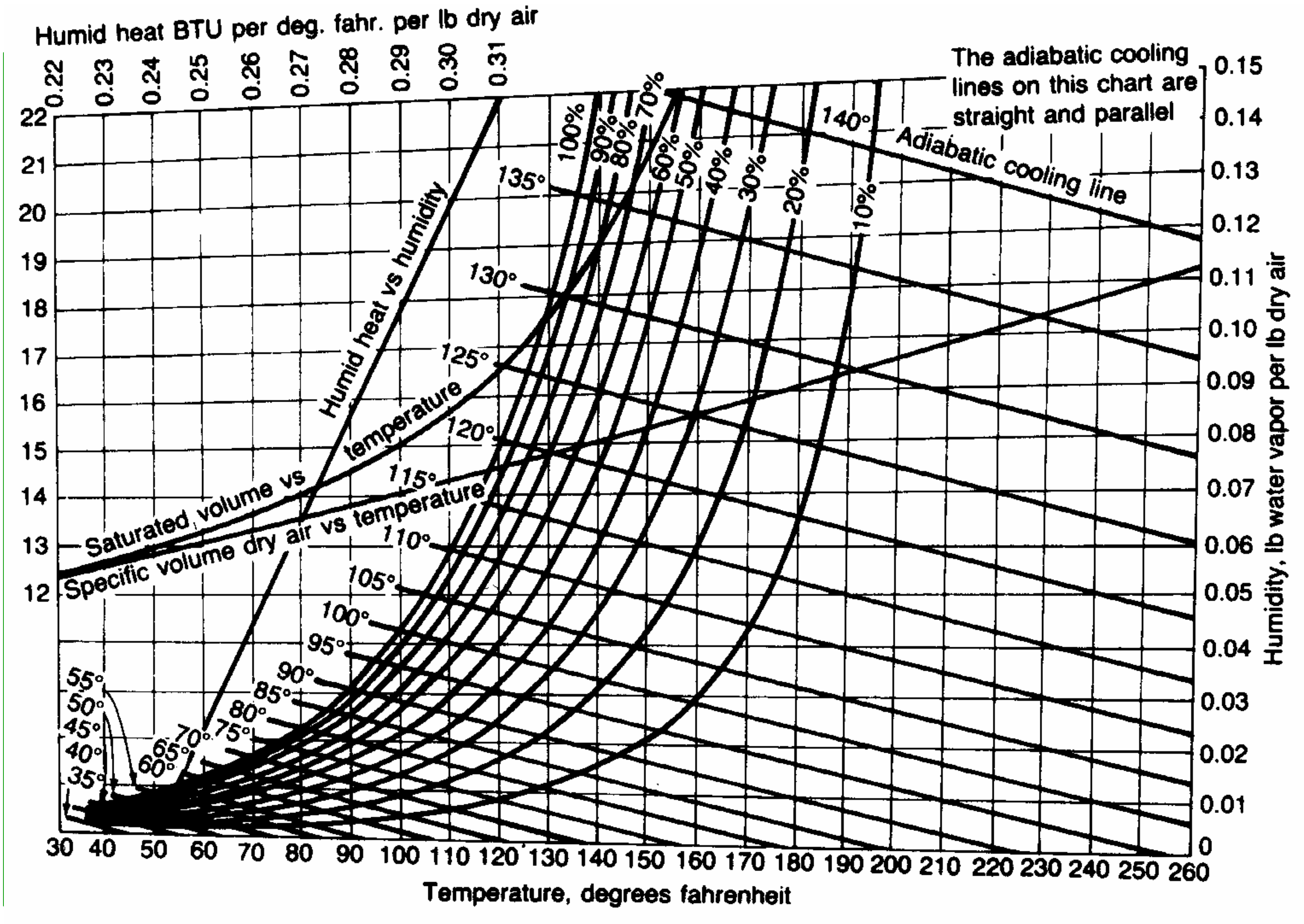


Figure 7.2
Cyclone spray chamber.
(Adapted from *Air Pollution Manual—Part II*, 1968.)

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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