Air Pollution:

Control of Stationary Sources

Dr. Motasem Saidan

M. Saidan@gmail.com

Control of Stationary Sources

Control of Stationary Sources:

- Particulate Matter
- Gaseous Emissions

Particulate Matter

- Most of the air pollution produced by stationary sources results from the incomplete combustion of fuel or industrial processing

- The types of inorganic and organic air pollutants stationary sources emit are dependent on the specific process operations

Examples: Fossil fuel fired boilers emit ash, sulfur dioxide, nitrogen oxides and mercury, and or vanadium if contained in the fuel. Metallurgical plants can emit a variety of metal dusts, including iron oxides and sometimes fluorides and chlorides. Industrial plants manufacturing inorganic chemicals will emit various waste gases depending on their product. Odorous organic waste gases can also be emitted from organochemical and petrochemical plants.

Industrial pollutant sources

Industrial pollutant sources such as these and others can be categorized into several groups based on their specific process operation:

- **Process Operations:**

  Process operations with incomplete chemical reactions, which include combustion due to unconverted reactants, or a reaction having a final yield that is less than expected theoretical conversion.

- **Atmospheric Releases:**

  Atmospheric releases of process's secondary components or impurities of raw materials.

- **Auxiliary Losses:**

  The auxiliary losses of compounds such as volatile organic solvents from fugitive sources or inorganics such as carbon disulfide and hydrogen sulfide in rayon production and fluorine compounds as in the production of aluminum.

- **Waste Emissions:**

Emissions of malodorous substances or oxidation compounds in the exhaust from oxidation, heating or drying processes.

Releases from these categories can originate from a variety of emission points and may not be centrally collected before entering the atmosphere.

- Air release emission points, from industrial process operations, can be categorized as stack, duct, vent, fugitive and area

- Fugitive emission points are release points, which are unconfined in a stack or duct before reaching the atmosphere.

- ✓ Therefore, whether an emission source is considered a point or fugitive source is dependent on whether the release is confined or unconfined in a stack or duct prior to atmospheric release.

Industrial Process Operation Air Emission Points and Categories	
Process Operation Reactors vents Distillation systems Vacuum systems Combustion stacks Blow molding Spray drying and booths Extrusion machines	**Fugitive Sources** Valves Pump seals Flanges/connectors Compressors Open ended lines Pressure relief devices Equipment cleaning/maintenance
Surface Area Sources Pond evaporation Cooling tower evaporation Wastewater treatment Land disposal	**Handling, Storage, Loading** Storage tank breathing losses Loading/unloading Line venting Packaging and container loading

- Pollution control can be achieved through common sense solutions such as the installation of effective control technology, changes in production processes, and the implementation of pollution prevention techniques.

- Compliance with emission standards and the successful attainment of air quality standards depends in large part on the application of appropriate stationary source control measures.

PM Control Procedures

- Control procedures for stationary sources of pollution include:

  - the use of tall smokestacks,
  - changes in plant operations, and
  - installation of effective control devices

- The control strategy required for an industrial environmental impact is a four step process:

  (1) elimination of the problem source or operation,
  (2) modification of the source operation,
  (3) relocation of the source, and
  (4) selection and application of the appropriate control technology.

Exhaust Stacks

- Exhaust stacks do not reduce emissions from a stationary source; rather they reduce the local effects of the pollution by elevating the exhaust stream to a point where it can be more effectively dispersed.

- High exhaust stacks were an inexpensive solution in the absence of expensive control technology. For years elevated stacks were used with the nearby communities in mind. A belief was widely held that elevated stacks reduced the likelihood that pollutants would have any effect on neighboring populations.

- Utility and smelter operations have traditionally used tall stacks (200m to 400m) in order to reduce the amount of ground-level concentrations of sulfur dioxide (SO2). However, this did not always eliminate the problem, but instead simply transferred it to another location.

- This approach was used for many years, until concern arose over the regional and transboundary spread of harmful toxics. For example, there is great concern over the spread of acid rain from one region to another.

Plant Operations

- Compliance with emission standard may require the use of control technology, but many industrial operations have reduced emissions by **changing operational methods**.

- Some of these changes include **pre-treating process materials**, fuel or material substitution, and changes in the manufacturing process. As an example of how pre-treating raw materials can be an inexpensive solution to pollution control, industry has discovered that significant reductions in particulate matter and sulfur emissions can be achieved by a technique called coal washing. Pre-treating raw materials in this manner not only reduces the amount of fly ash released from coal, but it also reduces the amount of inorganic sulfur released as well.

- Another way to comply with emission standards is to **substitute cleaner fuels** during the refining process. Natural gas and low-sulfur fuel oil are just two examples of fuels that emit less pollution during combustion. However, cleaner fuels can be more expensive and can increase national reliance on foreign fuel sources.

- Reduction in emissions from stationary sources can also be accomplished through increased attention to **plant maintenance**.

- Plants that release significant quantities of pollutants into the environment frequently do so as the result of improperly maintained equipment. This is especially true of combustion equipment.

- **Adequately scheduled maintenance** must be performed to reduce both the exhaust and amount of fugitive emissions released from vats, valves, and transmission lines. **Periodic maintenance** also reduces the likelihood of spill-related accidents by discovering faulty equipment before problems occur.

Control Technology

- A final way to reduce emissions from stationary sources is through the use of advanced, add-on control technology.
- Control devices can destroy or recover gaseous compounds or particulate matter for proper disposal or re-use.
- The pollution control operations used to destroy or capture gases include combustion, adsorption, absorption, and condensation.
- Control devices that implement these processes include thermal incinerators, catalytic incinerators, flares, boilers, process heaters, carbon absorbers, spray towers, and surface condensers.

The most important process parameters for selecting air pollution control equipment are **the exhaust gas characteristics** obtained from emissions tests and **process or site characteristics** obtained from a field survey

Exhaust Gas Characteristics

- Total exhaust gas flow rate
- Exhaust gas temperature
- Required control efficiency
- Particle size distribution
- Particle resistivity
- Composition of emissions
- Corrosiveness of exhaust gas over operating range
- Moisture content
- Stack pressure
- Exhaust gas combustibility and flammability properties

Process or Site Characteristics

- Reuse/recycling of collected emissions
- Availability of space
- Availability of additional electrical power
- Availability of water
- Availability of wastewater treatment facilities
- Frequency of startup and shutdowns
- Environmental conditions
- Anticipated changes in control regulations
- Anticipated changes in raw materials
- Plant type – stationary or mobile

Control Devices for Particulate Emissions

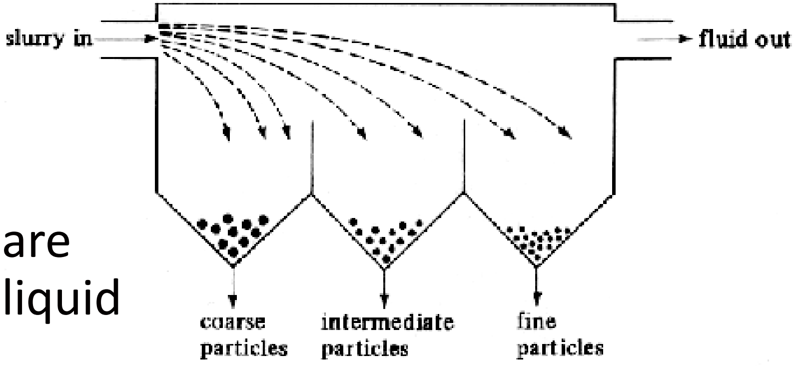
- Technologies used to control particulate matter focus on removing particles from the effluent gas stream.

- Many factors (such as particle size and chemical characteristics) determine the appropriate particulate control device for a process.

- Devices most commonly used devices to control particulate emissions include:

  - Gravity settlers (often referred to as settling chambers)
  - Mechanical collectors (cyclones)
  - Electrostatic precipitators (ESPs)
  - Scrubbers
  - Fabric filters
  - Hybrid systems

- In many cases, a combination of multiple devices yields the best collection efficiency. For example, a settling chamber can be used to remove large particles from the exhaust stream before it enters an electrostatic precipitator where smaller particles are removed.

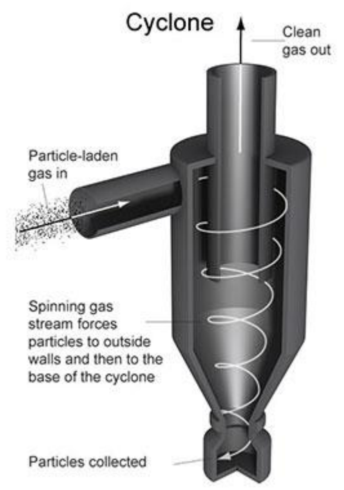


<u>Gravity settlers (often referred to as *settling chambers)*</u>

- Gravity settlers, or gravity settling chambers, are used industrially for the removal of solid and liquid waste materials from gaseous streams.
- Advantages accounting for their use are simple construction, low initial cost and maintenance, low pressure losses, and simple disposal of waste materials.

<u>Mechanical collectors (cyclones)</u>

- Centrifugal separators, commonly referred to as *cyclones,* are widely used in industry for the removal of solid and liquid particles (or particulates) from gas streams.



Fabric filters (bag houses)

- Filtration process may be conducted in many different types of fabric filters.Differences may be related to:
  - Type of fabric
  - Cleaning mechanism
  - Equipment
  - Mode of operation

- Gases to be cleaned can be either "pushed" or "pulled" through the bag house.
- In the pressure system (push through) the gases may enter through the cleanout, hopper in the bottom or through the top of the bags.
- In the suction type (pull through) the dirty gases are usually forced through the inside of the bag and exit through the outside.

Baghouse Filter

- similar to conventional home vacuum cleaner
- Efficiency:

  >99.5% for <1 μm diameter

  >99.8% for >5 μm diameter

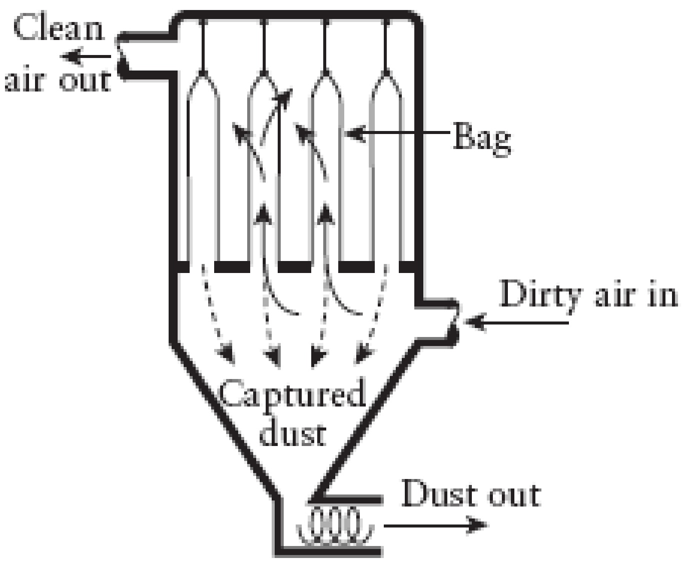
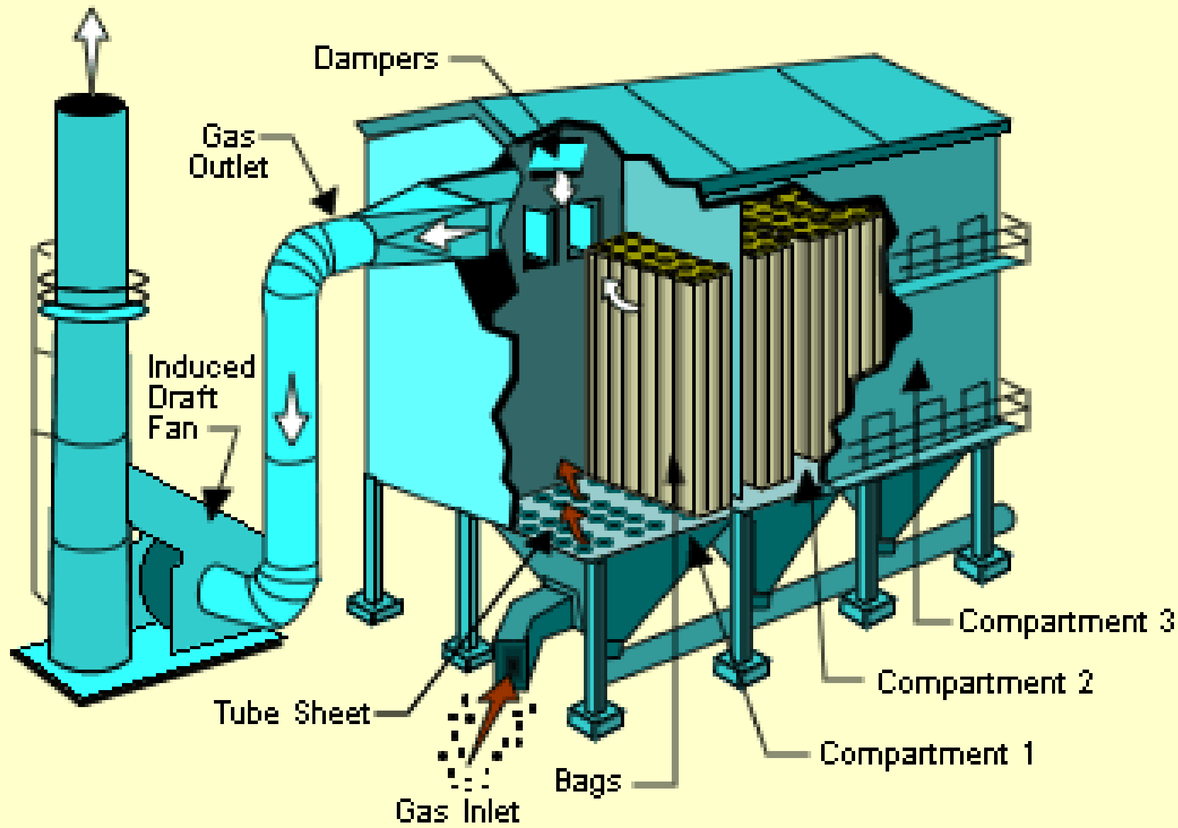


Figure 13. Reverse Air Fabric Filter

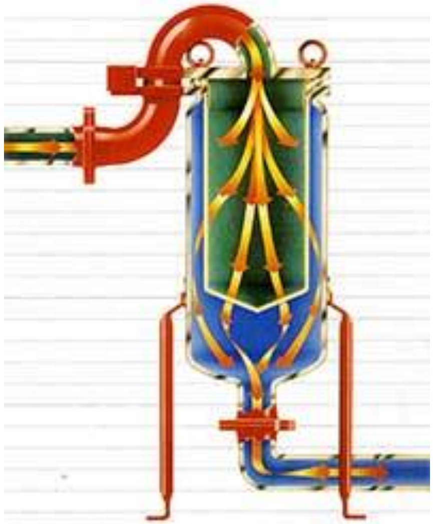


- Fabric filter materials:
  1. Natural fibers (cotton & wool)
     Temperature limit: 80 °C
  2. Synthetics (acetates, acrylics, etc.)
     Temperature limit: 90 °C
  3. Fiberglass
     Temperature limit: 260 °C

- Cannot be used for
  - wet air systems
  - corrosive gases
  - gases above 260oC

- Cleaning:
  1. Shaker
  2. Reverse air
  3. Pulse jet

Fabric filters (bag houses)



- ***Hybrid systems*** are defined as those types of control devices that involve combinations of control mechanisms-for example, fabric filtration combined with electrostatic precipitation.

- Four of the major hybrid systems found in practice today include:
  - Wet electrostatic precipitators,
  - Ionizing wet scrubbers,
  - Dry scrubbers, and
  - Electrostatically augmented fabric filtration.

Cyclones

- ✓ can be used for 50-100 μm size particles and down to 10 μm
- ✓ simple economical unit:
  - no moving parts
  - relies on inertial effects

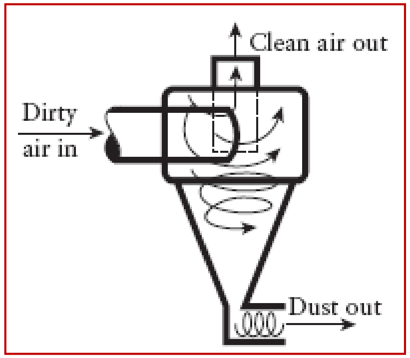
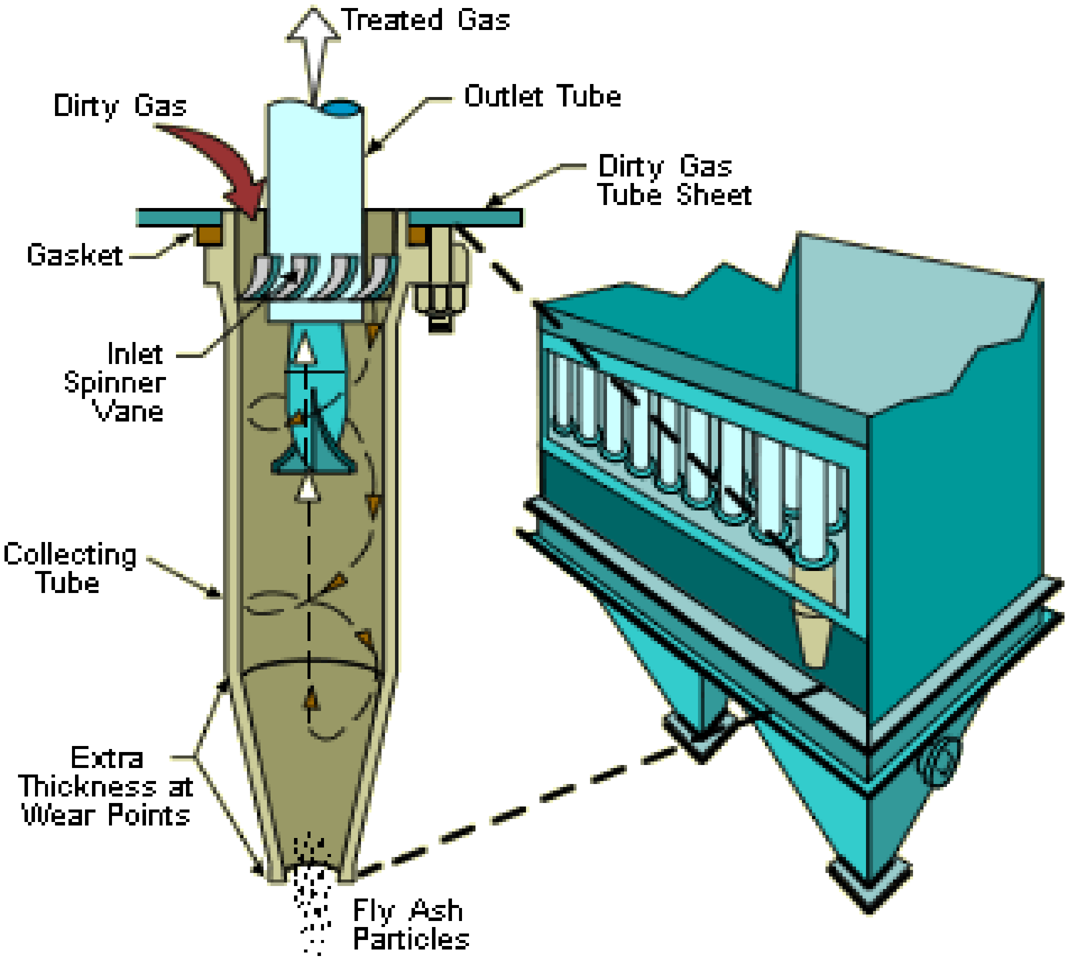
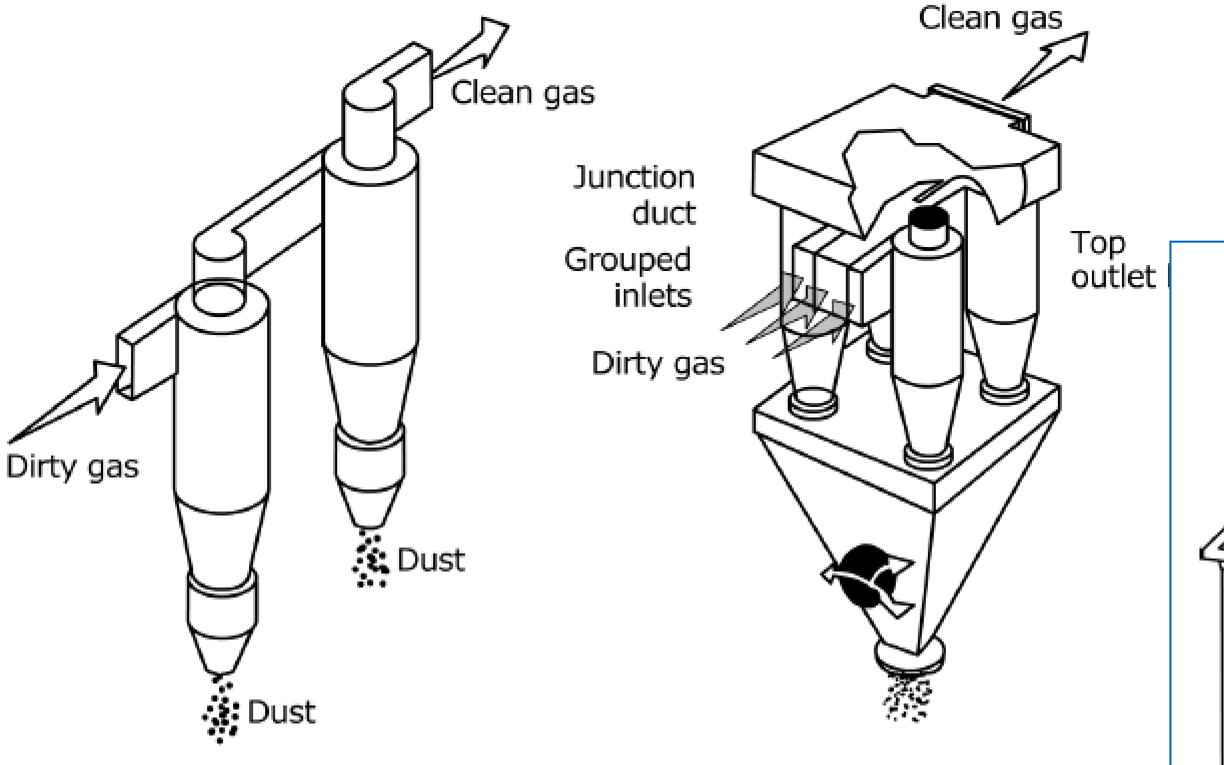


Figure 2. Small-Diameter Multi-Cyclone Collector





A. two cyclones in series

B. Four cyclones in parallel

For particle sizes greater than about 10 µm in diameter, the collector of choice is the cyclone

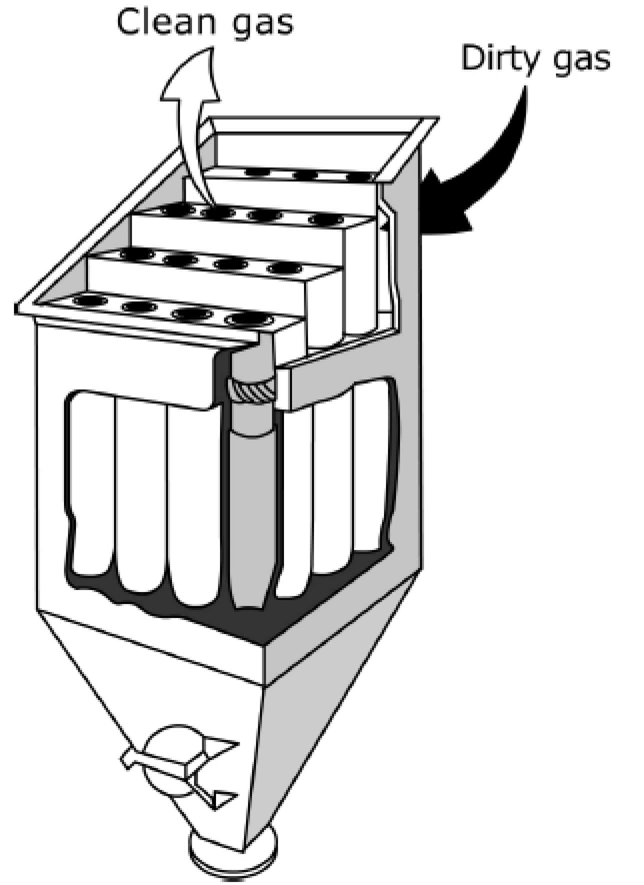


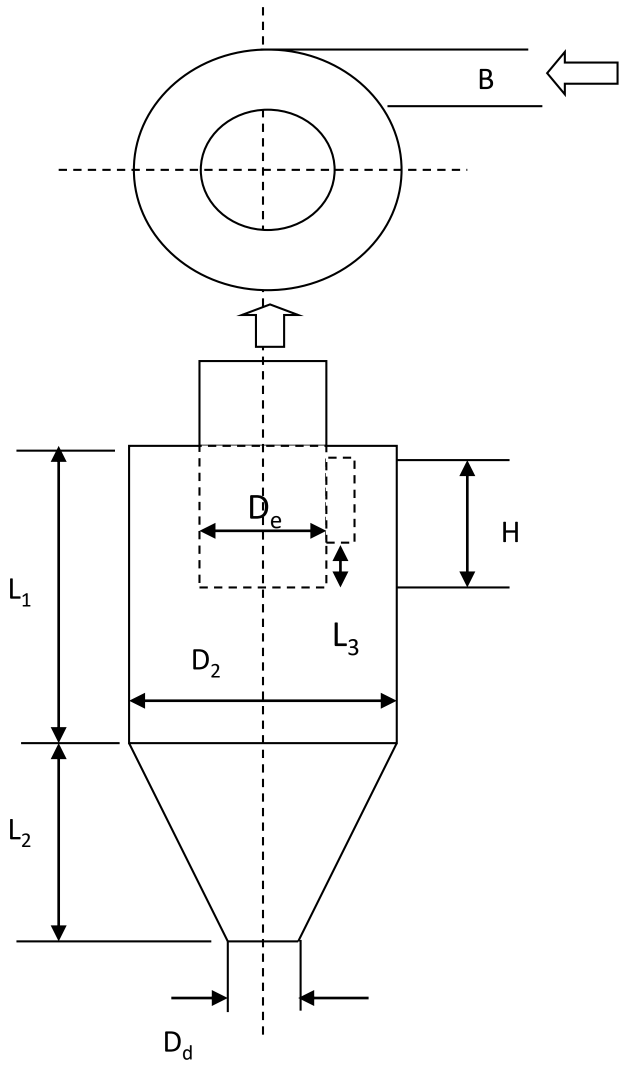
Figure 6-7. Multi-cyclone collector

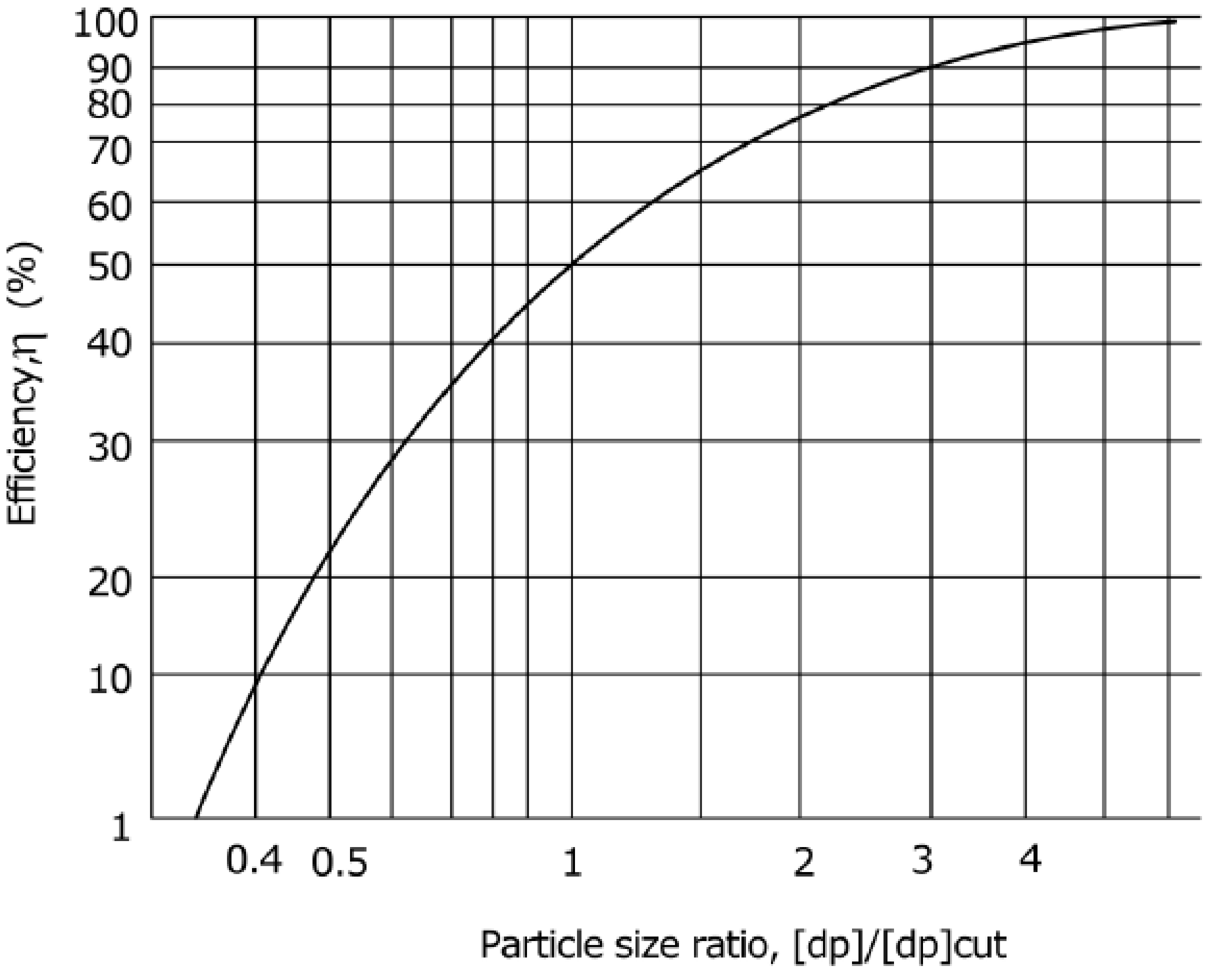
The particle size collected with 50% efficiency, termed the cut diameter:

$$d_{0.5} = \left[\frac{9 \mu B^2 H}{\rho_p Q_g \theta} \right]^{1/2}$$

$$\theta = \frac{\pi}{H} \left(2L_1 + L_2 \right)$$

$d_{0.5}$ = cut diameter at 50% removal
μ = dynamic viscosity of gas, Pa-s
B = width, m
H = height, m
ρ_p = particle density, kg/m3
Q_g = gas flow rate, m3/s
θ = effective number of turns





100
90
80
70
60
50
40
30
20
10
1
Efficiency,η (%)
0.4
0.5
1
2
3
4
Particle size ratio, [dp]/[dp]cut

Example

Given:

$D_2 = 0.5$ m

$Q_g = 4\ m^3/s$

T = 25 °C

$\rho_p = 800\ kg/m^3$

For standard Cyclone:

$B = 0.25\ D_2 = 0.13$ m

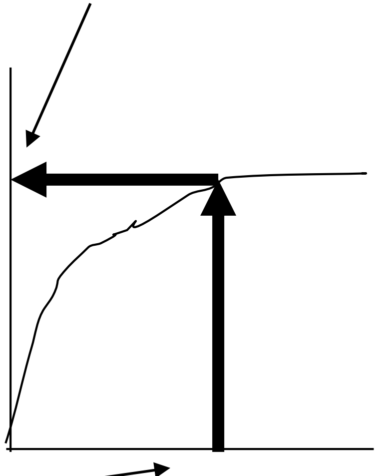
$H = 0.5\ D_2 = 0.25$ m

$L_1 = L_2 = 2\ D_2 = 1$ m

$$\theta = \frac{\pi}{0.25}\left(2(1)+1\right) = 37.7$$

Q = What is the removal efficiency for particles with ave diameter of 10 μm?

$\eta = 0.95$



$$d_{0.5} = \left[\frac{9(18.5x10^{-6})(0.13)^2(0.25)}{(800)(4)(37.7)}\right]^{0.5} = 2.41x10^{-6}$$

$$= 2.41(\mu m)$$

@ d =10 μm

$$\frac{d}{d_{0.5}} = \frac{10}{2.41} = 4.15$$

Electrostatic Precipitator (ESP)

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

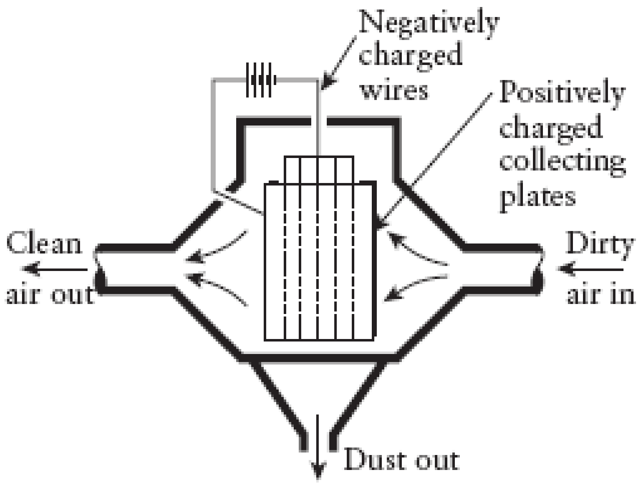
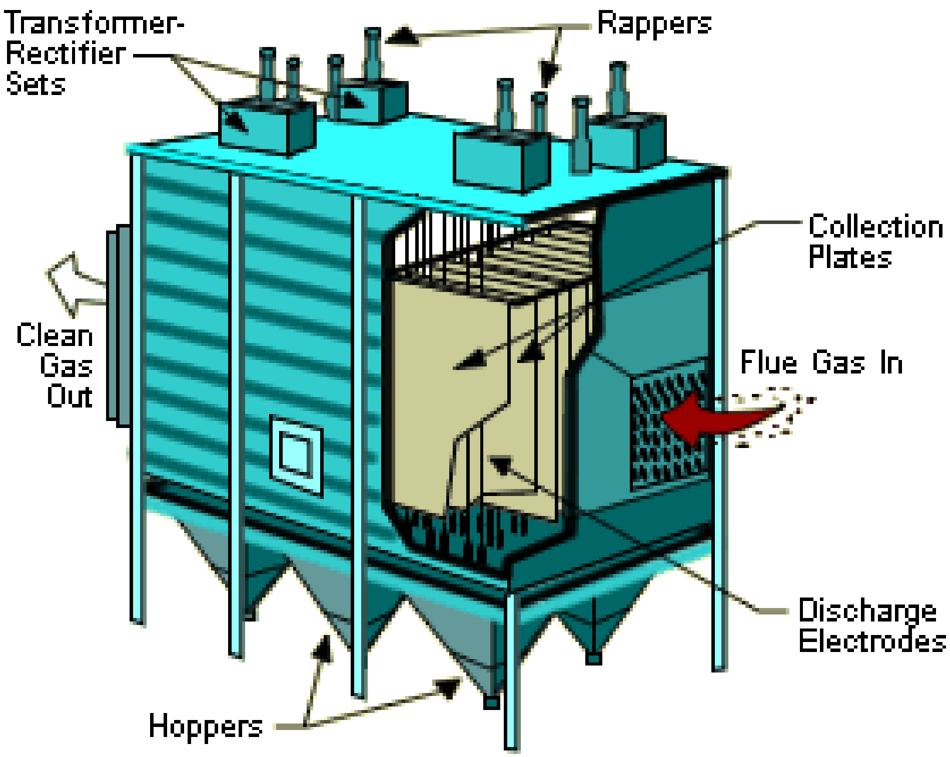
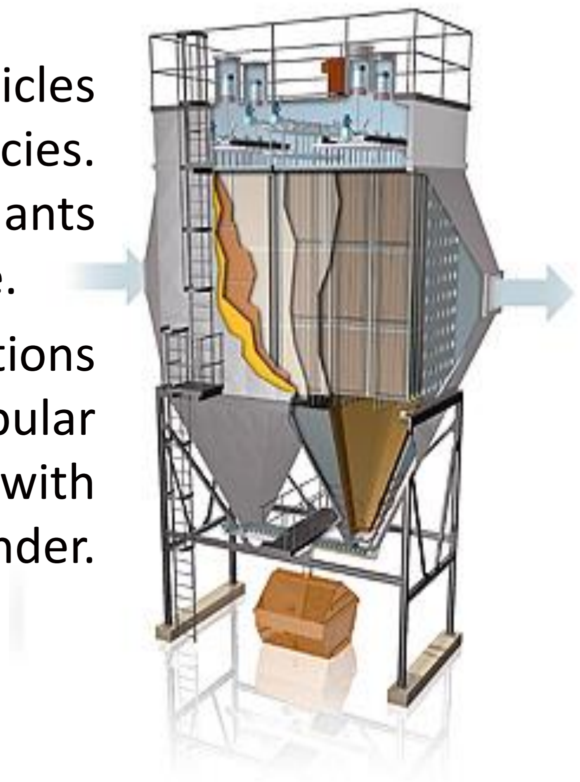


Figure 9. Conventional Electrostatic Precipitator

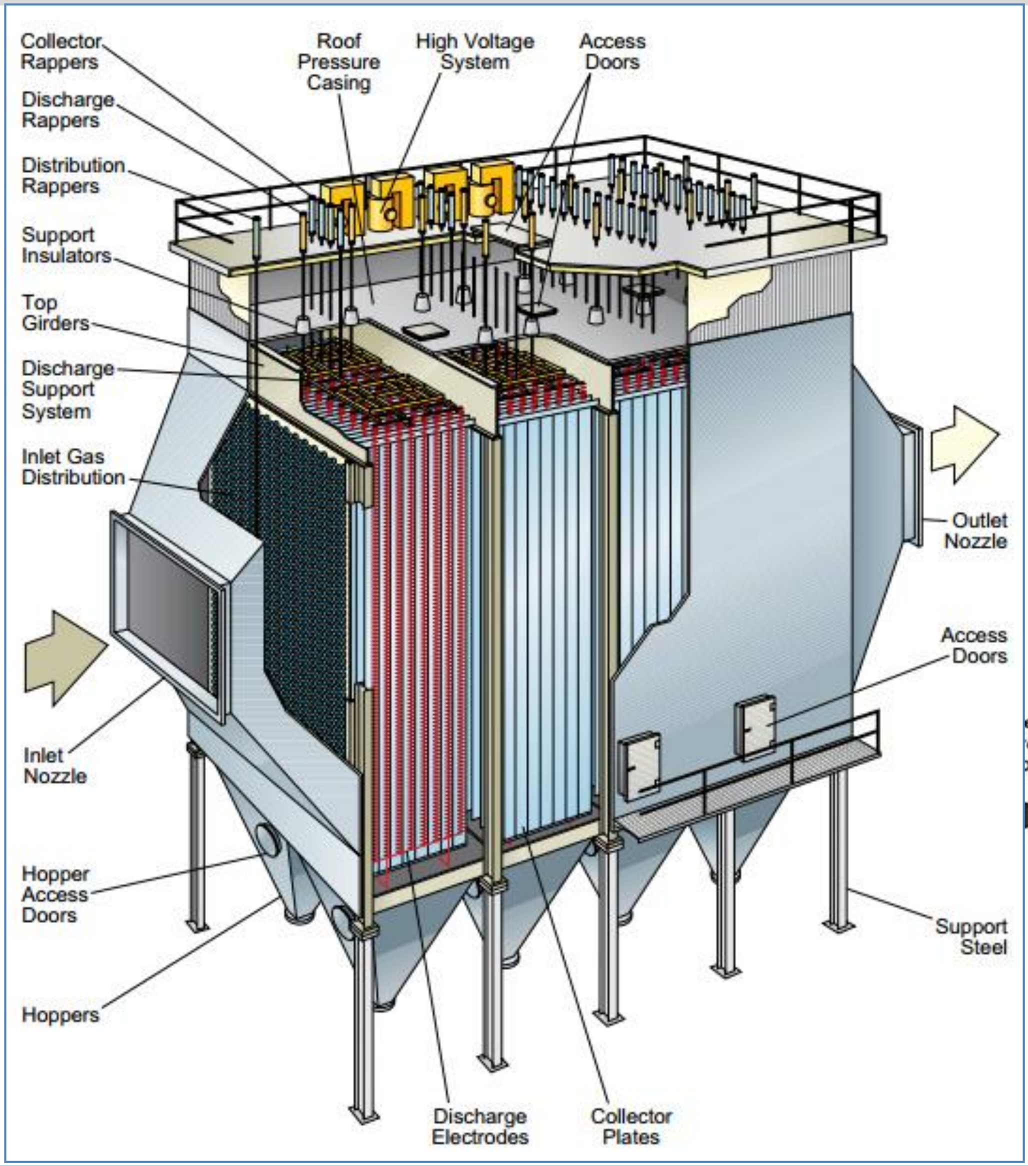


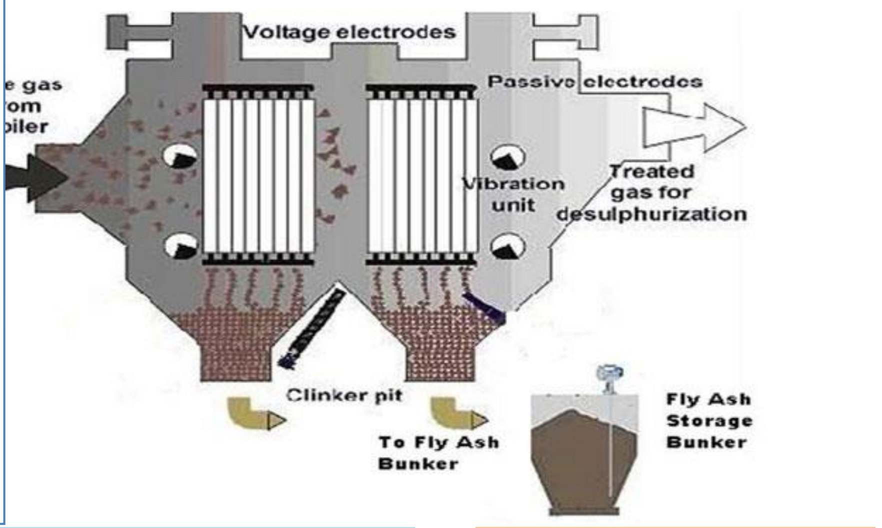
Electrostatic precipitators (ESPs)

- They are satisfactory devices for removing small particles from moving gas streams at high collection efficiencies. They have been used almost universally in power plants for removing fly ash from the gases prior to discharge.
- Two major types of high-voltage ESP configurations currently used are tubular and plate. Tubular precipitators consist of cylindrical collection tubes with discharge electrodes located on the axis of the cylinder. Vast majority of ESPs installed are of the plate type.
- Collected particles are usually removed by rapping.



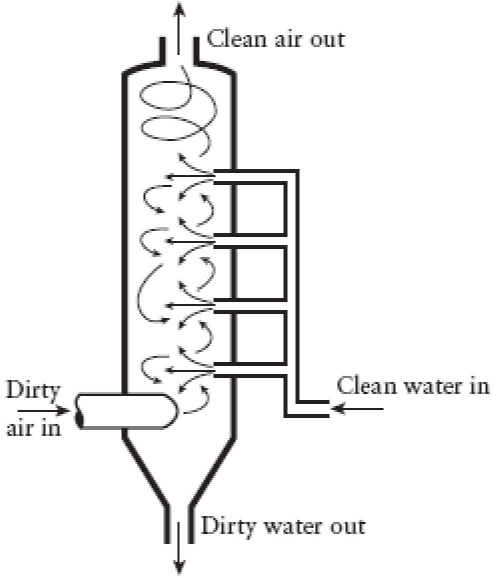
Electrostatic precipitators (ESPs)





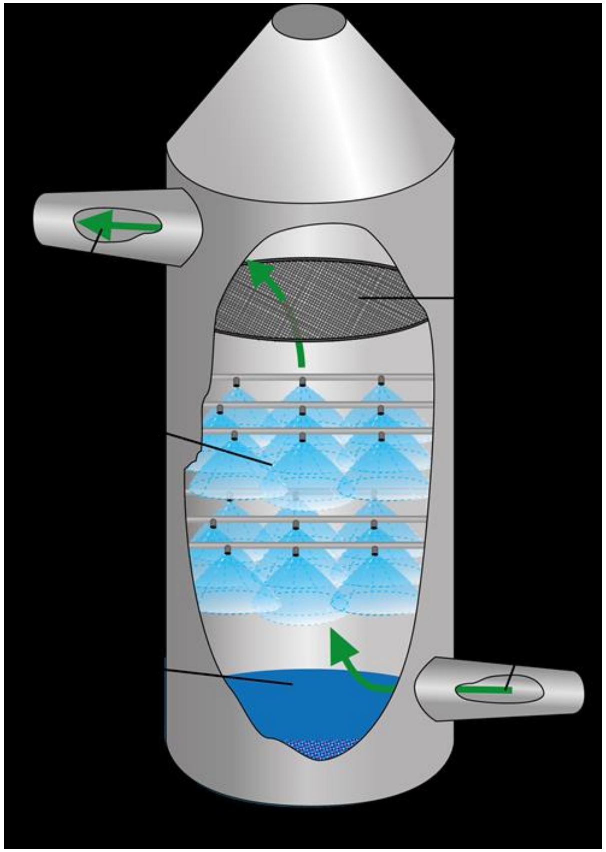
Wet Scrubber

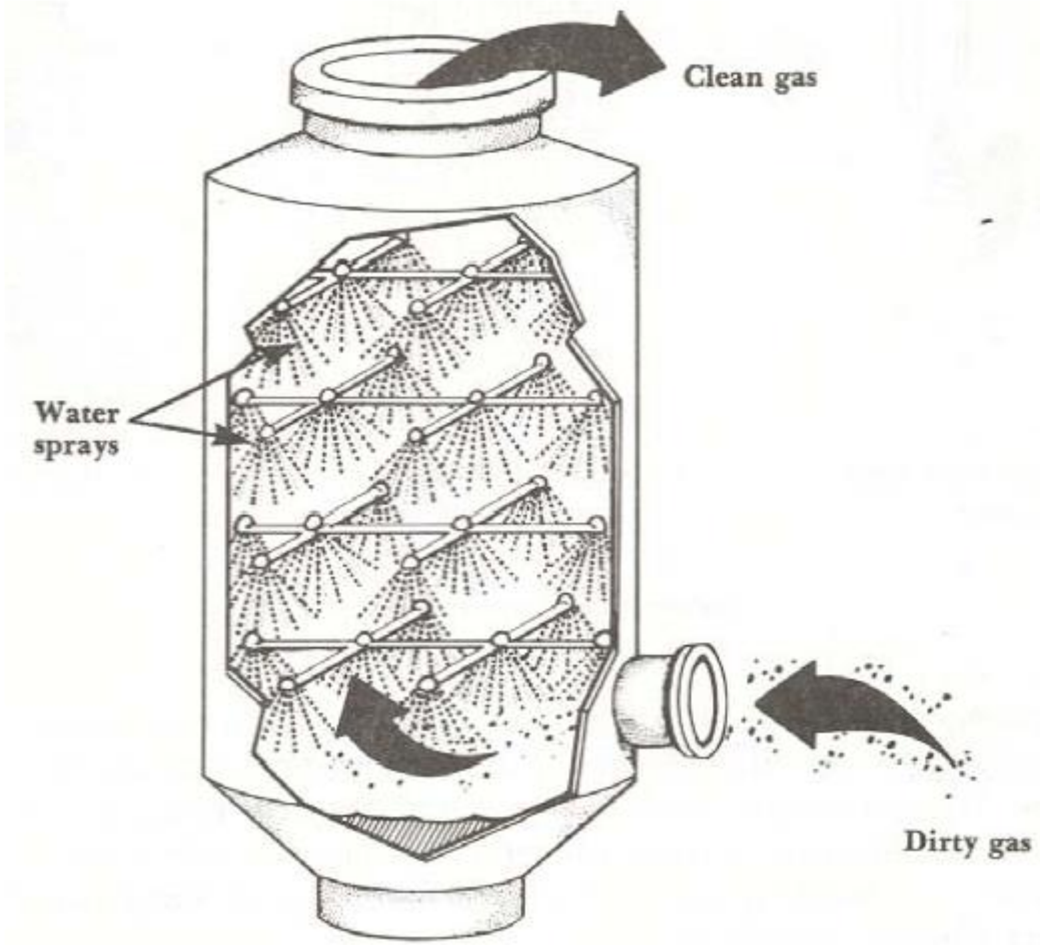
- can be used where
  - ✓ air is wet
  - ✓ corrosive
  - ✓ hot
  - ✓ where baghouses can not be used
  - ✓ for even higher efficiencies, a combination of a venturi scrubber and cyclone and can be used



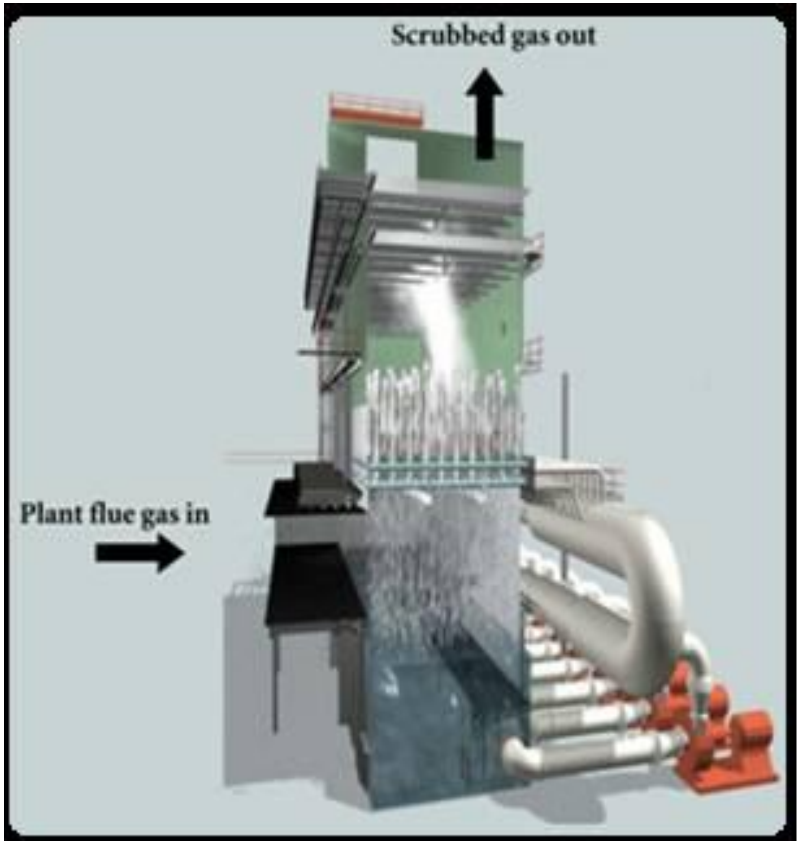
Scrubbers (venturi scrubbers)

- Wet scrubbing involves the technique of bringing a contaminated gas stream into intimate contact with a liquid.
- Wet scrubbers include all the various types of gas absorption equipment.
- The term "scrubber" will be restricted to those systems which utilize a liquid, usually water, to achieve or assist in the removal of particulate matter from a carrier gas stream.

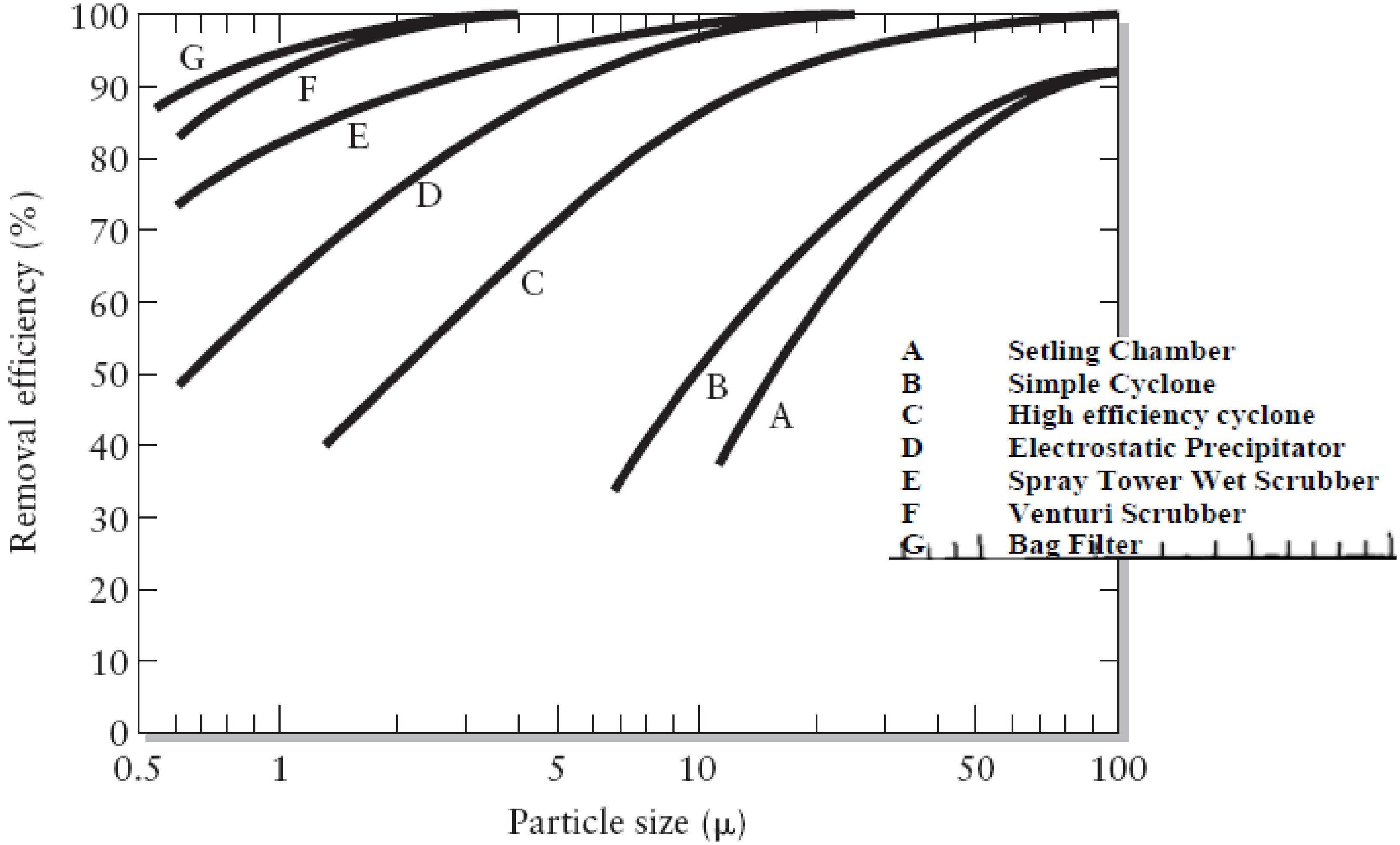



Clean gas
Water
sprays
Dirty gas

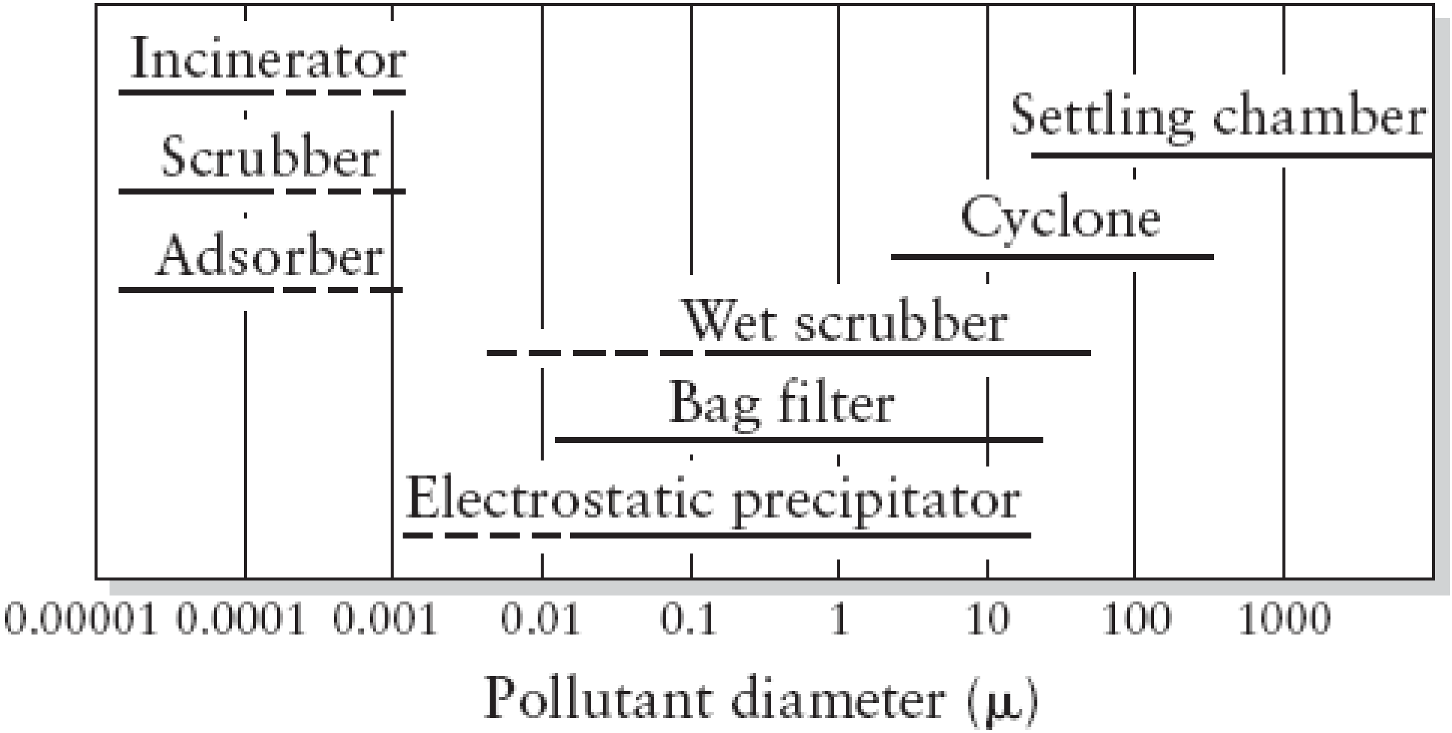
Scrubbers



Comparison of Air Pollution Control Devices



Effectiveness of Air Pollution Control Devices



Gaseous Emissions

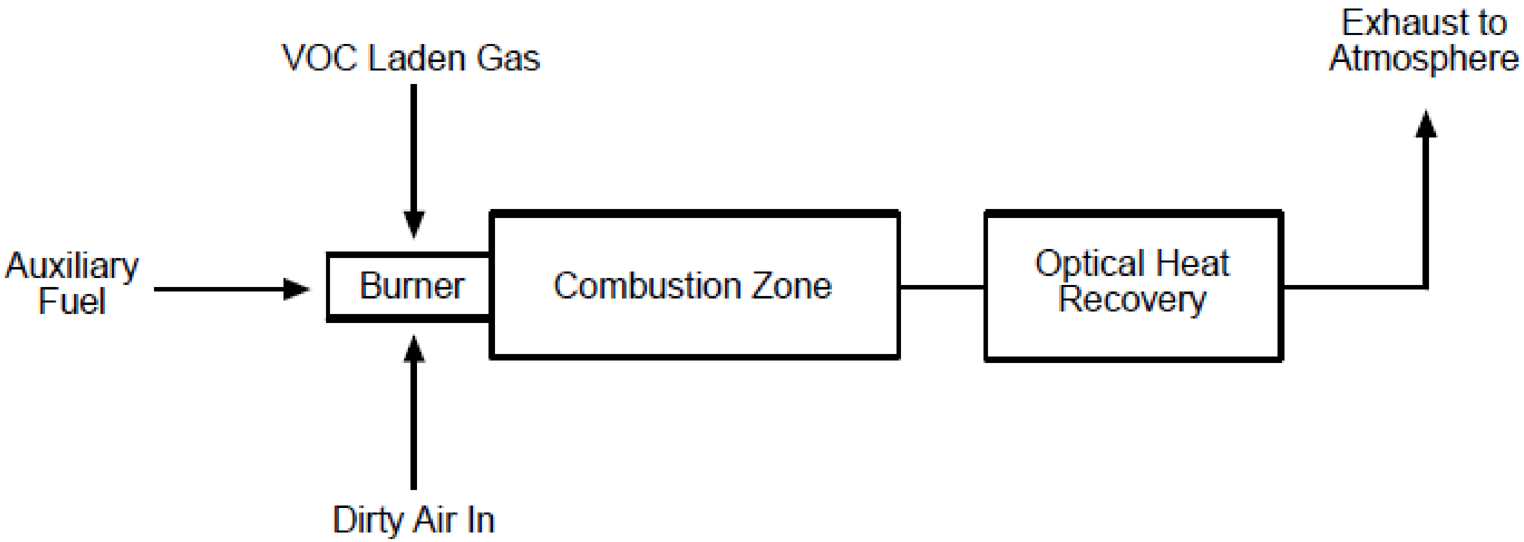
- The preferred method for controlling gaseous pollutants is with add-on control devices used to destroy or recover the pollutant.

Control Equipment for Gaseous Emissions:

  - *Thermal Incinerators*
  - *Catalytic Incinerators*
  - *Flares*
  - *Boilers and Process Heaters*
  - *Carbon Adsorbers*
  - *Absorbers*
  - *Condensers*

Thermal Incinerator

- Thermal incinerators are commonly used to destroy volatile organic compounds (VOCs).
- In general, incineration involves the destruction of liquid, solid, or gaseous waste by a controlled burn at high temperatures.
- Incinerators are one of the most positive and proven methods for destroying VOC, with efficiencies up to 99.9% possible.



- **Applicable Pollutants:** Primarily volatile organic compounds (VOC). Some particulate matter (PM), commonly composed as soot (particles formed as a result of incomplete combustion of hydrocarbons (HC), coke, or carbon residue) will also be destroyed in various degrees.

- VOC destruction efficiency depends upon design criteria (i.e., chamber temperature, residence time, inlet VOC concentration, compound type, and degree of mixing) (EPA, 1992).

- Most thermal units are designed to provide no more than 1 second of residence time to the waste gas with typical temperatures of 650° to 1100 °C (1200° to 2000 °F).

- Studies based on actual field test data, show that commercial incinerators should generally be run at 870°C (1600°F) with a nominal residence time of 0.75 seconds to ensure 98% destruction of non-halogenated organics (EPA, 1992).

Theoretical Reactor Temperatures Required for 99.99 Percent Destruction by Thermal Incineration for a 1-Second Residence Time

Compound	Temperature, °F
acrylonitrile	1,344
allyl chloride	1,276
benzene	1,350
chlorobenzene	1,407
1,2-dichloroethane	1,368
methyl chloride	1,596
toluene	1,341
vinyl chloride	1,369

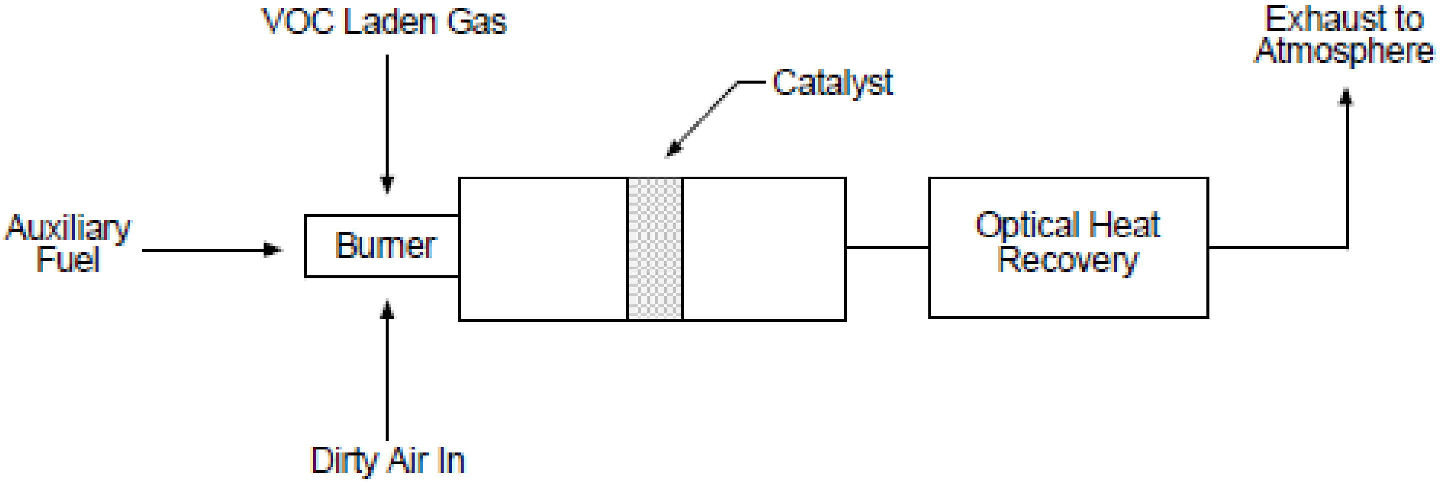
Thermal Incinerator PM10 Destruction Efficiencies by Industry (EPA, 1996):

Industry/Types of Sources	PM_{10} Control Efficiency (%)
Petroleum and Coal Products Asphalt roofing processes (blowing, felt, saturation); mineral calcining; petroleum refinery processes (asphalt blowing, catalytic cracking, coke calcining, sludge converter); sulfur mfg.	25 – 99.9%
Chemical and Allied Products Carbon black manufacturing (mfg); charcoal mfg; liquid waste disposal; miscellaneous chemical mfg processes; pesticide mfg; phthalic anhydride mfg (xylene oxidation); plastics/ synthetic organic fiber mfg; solid waste incineration (industrial)	50 – 99.9%
Primary Metals Industries By-product coke processes (coal unloading, oven charging and pushing, quenching); gray iron cupola and other miscellaneous processes; secondary aluminum processes (burning/drying, smelting furnace); secondary copper processes (scrap drying, scrap cupola and miscellaneous processes); steel foundry miscellaneous processes; surface coating oven	70 – 99.9%
Electronic and Other Electric Equipment Chemical mfg miscellaneous processes; electrical equipment bake furnace; fixed roof tank; mineral production miscellaneous processes; secondary aluminum roll/draw extruding; solid waste incineration (industrial)	70 – 99.9%
Electric, Gas, and Sanitary Services Internal combustion engines; solid waste incineration (industrial, commercial/ institutional)	90 – 98%
Stone, Clay, and Glass Products Barium processing kiln; coal cleaning thermal dryer; fabricated plastics machinery; wool mfg.	50 – 95%
Food and Kindred Products charcoal processing, miscellaneous; corn processing, miscellaneous, fugitive processing, miscellaneous; soybean processing, miscellaneous	70 - 98
Mining asphalt concrete rotary dryer; organic chemical air oxidation units, sulfur production	70 - 99.6
National Security and International Affairs solid waste incineration (commercial/institutional and municipal)	70
Textile Mill Products plastics/synthetic organic fiber (miscellaneous processes)	88 - 95
Industrial Machinery and Equipment secondary aluminum processes (burning/drying, smelt furnace)	88 -98
Lumber and Wood Products solid waste incineration (industrial)	70
Transportation Equipment solid waste incineration (industrial)	70 - 95

Catalytic Incinerators

- Catalytic incinerators operate very similar to thermal incinerators. The primary difference is that the gas, after passing through the flame area, passes through a catalyst bed to destroy essentially any oxidizable compound in an air stream.

- The catalyst has the effect of increasing the oxidation reaction rate, enabling conversion at lower reaction temperatures than in thermal incinerator units. Therefore, catalysts also allow for smaller incinerator size. Catalysts typically used for VOC incineration include platinum and palladium. Other formulations include metal oxides, which are used for gas streams containing chlorinated compounds EPA, 1998).



- The waste stream must be preheated to a temperature sufficiently high (usually from 300 to 900ºF) to initiate the oxidation reactions.

- Catalyst Temperatures Required for Oxidizing 80% of Inlet VOC to CO2, ºF for Two Catalysts

Compound	Temperature, ºF	
	CO_3O_4	Pt - Honeycomb
acrolein	382	294
n-butanol	413	440
n-propylamine	460	489
toluene	476	373
n-butyric acid	517	451
1, 1, 1-trichloroethane	661	>661
dimethyl sulfide	-	512

Flares

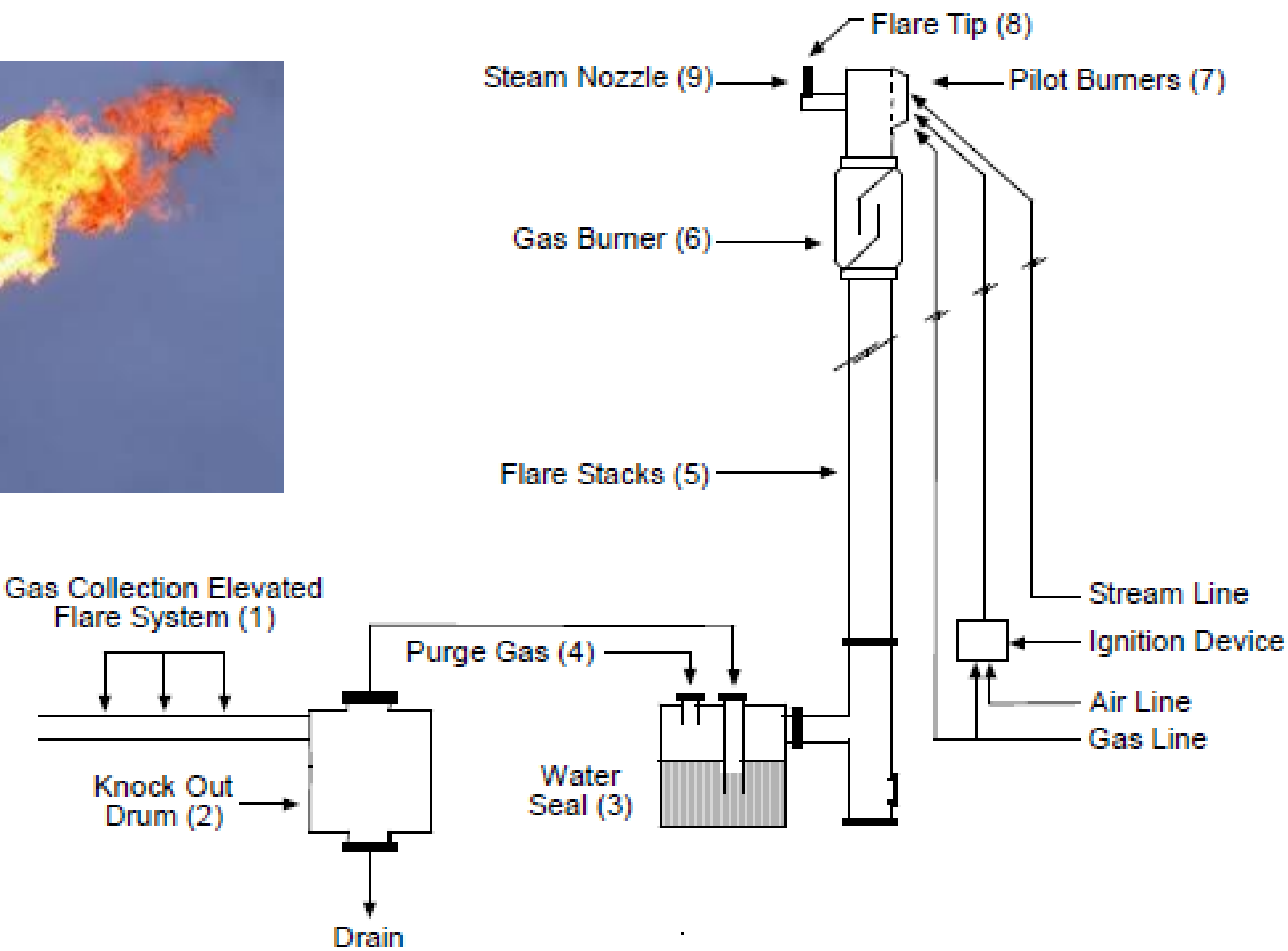
- Flaring is a VOC combustion control process in which the VOCs are piped to a remote, usually elevated, location and burned in an open flame in the open air using a specially designed burner tip, auxiliary fuel, and steam or air to promote mixing for nearly complete (>98%) VOC destruction.

- Flares are typically used as a last resort to dispose of gases that are of little recyclable value or are not easily combustible.

- Gases flared from refineries, petroleum production, and the chemical industry are composed largely of low molecular weight VOC and have high heating values.

- As in all combustion processes, an adequate air supply and good mixing are required to complete combustion and minimize smoke. The various flare designs differ primarily by their ability to mix air with the combustibles.

Steam-assisted Elevated Flare System



- The non-assisted flare consists of a flare tip without any auxiliary provision for enhancing the mixing of air into its flame. Its use is limited to gas streams that have low heat content and low carbon/hydrogen ratio that burn readily without producing smoke. These streams require less air for complete combustion have lower combustion temperatures.

Boilers and Process Heaters

- Boilers and process heaters are commonly used by production facilities to generate heat and power.

- Although their primary purpose to contribute to plant operations, they can also be used quite effectively as a pollution control device by recycling the pollutant for fuel.

- However, the only pollutants that can be used for fuel are those that do not affect the performance of the burner unit. For example, an exhaust stream can be used as supplementary fuel, but only if its fuel value is sufficient to maintain the combustion process. All volatile organic compounds (VOCs) have different heating values. If the pollutant stream is large and the heating value is high, the exhaust can be a primary source of fuel for the plant.