MODULE- IV

AIR POLLUTION CONTROL

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Contents...

Air Pollution control- at source-equipments for control of air pollution-For particulate matter-Settling chambers-Fabric filters-Scrubbers-Cyclones-Electrostatic precipitators, For Gaseous pollutants-control by absorption-adsorption-scrubbers-secondary combustion after burners, Working principles advantages and disadvantages, design criteria and examples

Source correction methods

- Raw material changes
- Process changes
- Equipment modification & replacement

Objectives of control equipment

- Prevention of nuisance
- Prevention of physical damage to property
- Elimination of health hazards to plant personnel
- Recovery of valuable waste product
- Minimization of economic losses
- Improvement of product quality

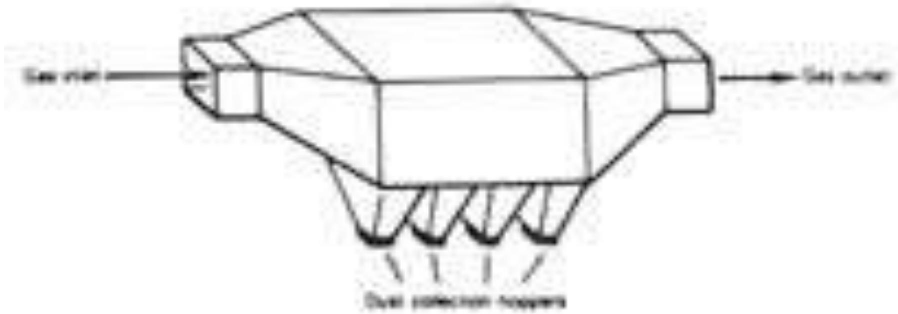
Particulate control equipment

- Gravitational settling chambers
- Fabric filters
- Scrubbers
- Cyclone separator
- Electrostatic precipitators

- Efficiency of a separating device

η= quantity of particulates collected from gas/ quantity of particulates present initially

Gravitational settling chamber



Settling Chamber

- Used to remove particles with size greater than 50 μm.
- Velocity of flue gas reduced in large chamber.
- Particles settle under gravitational force.

$$V_s = hV / L \quad \text{----------- (i)}$$

L= length of chamber

V= horizontal velocity of carrier gas

Vs= settling velocity of particulates

h= height through which particulates travel before settling down

By stokes law

$$\mathbf{Vs= g(\varrho_p - \varrho)D^2/18\mu \text{ --------- (ii)}}$$

D= dia of particle

g= acceleration due to gravity

ϱ_p= density of particle

ϱ = density of gas

μ= viscosity of gas

From eq- i and ii

$$D = [18Vh\mu / Lg\ (\varrho_p - \varrho)]^{1/2}$$

D = is minimum size of particle that can be removed in a settling chamber

Advantages

- Low initial cost.
- Easy to design.
- Low pressure drop.
- Low maintenance cost.
- Dry and continuous disposal of solid particulates.

Disadvantages

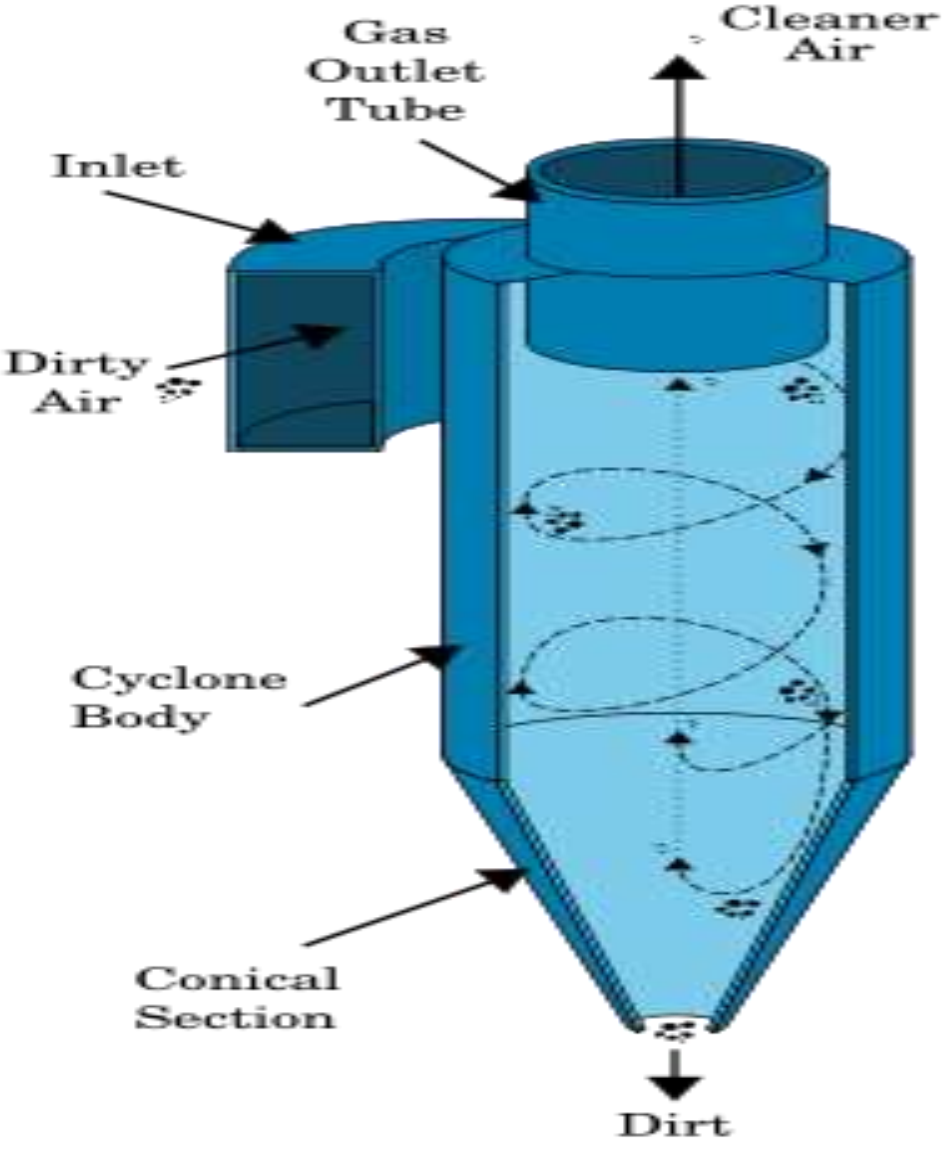
- Require large space.
- Less collection efficiency.
- Only larger size particles can be collected.

Application

- Industrial application is limited.
- Used widely for removal of large solid particulates from draft furnace, kilns.
- Sometimes used in process industry, food and metallurgical industry.
- Used as pre-cleaners for high efficiency collectors.

Cyclone separator

- Centrifugal force is utilized to separate the particulate matter.
- It can remove 10 to 50 μm particle size.
- Used mostly in industries.


Gas
Outlet
Tube
Cleaner
Air
Inlet
Dirty
Air
Cyclone
Body
Conical
Section
Dirt

$D_p, min = [9\,\mu\,B / \pi\,V\,N_t(\varrho_p - \varrho)]^{1/2}$

D_p, min= dia of smallest particles that can be removed cm

μ = viscosity of the fluid

B= width of cyclone inlet duct

V= avg. inlet velocity

Nt= no of turns made by gas stream in cyclone

ϱ_p = density of particles

ϱ = density of fluid

- Design factor having greatest effect on collection efficiency is cyclone diameter.
- Smaller dia, higher is efficiency, because centrifugal action increase with decreasing radius of rotation.
- Cyclone efficiencies > 90 % with particle dia of 10 μ
- > 95 % with particle dia 20 μ.

Efficiency

- Conventional efficiency
- High efficiency- smaller body dia to create greater separating force.
- Increase collection efficiency, if increase in dust particle size, dust particle density, gas inlet velocity, inlet dust loading, cyclone body length (no of gas revolutions)
- Decrease collection efficiency due to increase in gas viscosity, cyclone dia, gas outlet dia, inlet width, and inlet area

Operating problems

- Erosion
- Corrosion
- Material build up

Advantages

- Low initial cost.
- Require less floor area.
- Simple construction and maintenance.
- Can handle large volume of gas at high temp.
- No moving parts

Disadvantages

- Requires large head room.
- Less efficiency for smaller particles (<10μm).
- Sensitive to variable dust load and flow rate.

Applications

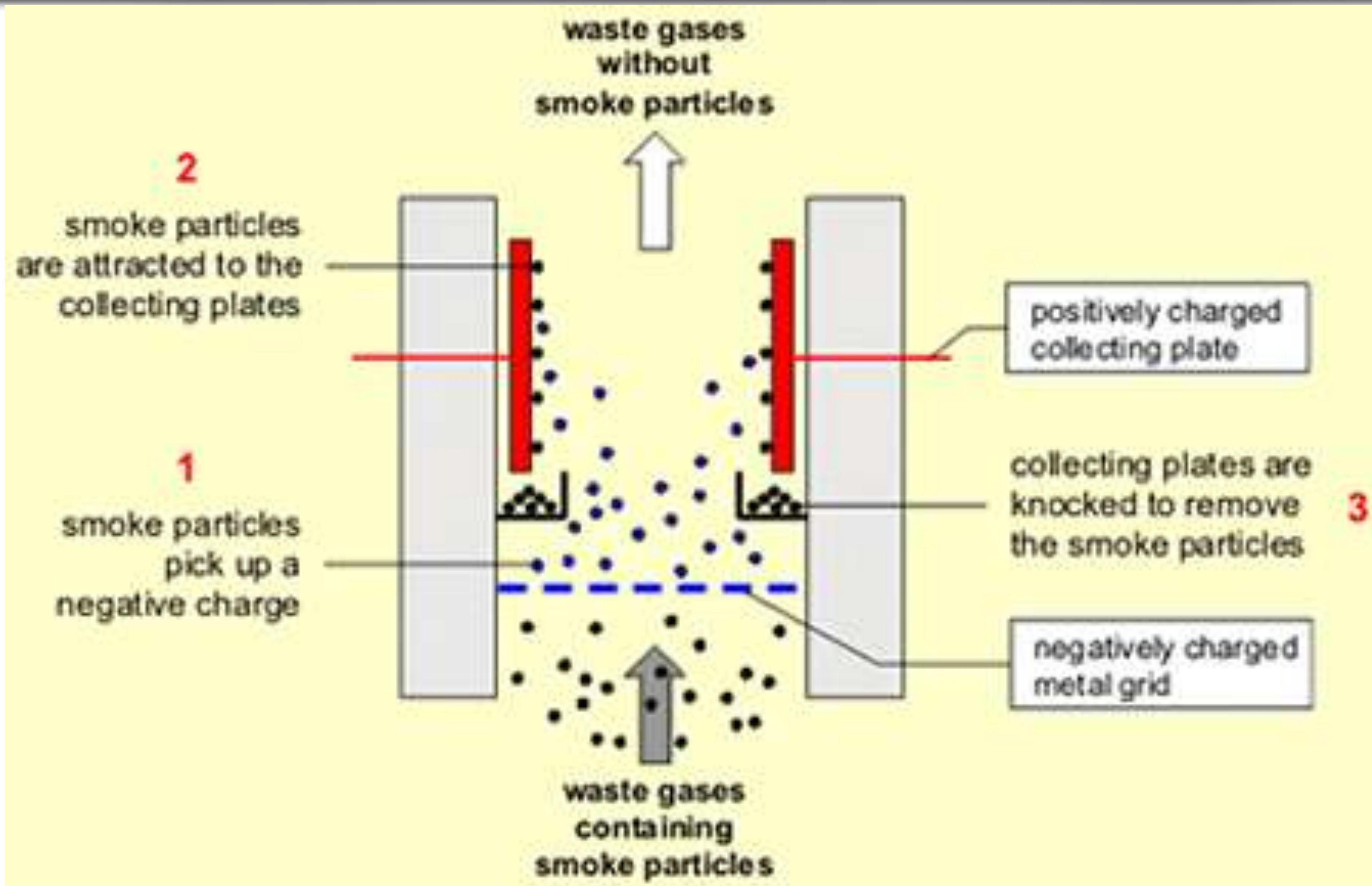
- Control gas borne particulates from industries like cement, feed and grain processing, food and beverage processing, mineral processing, paper and textile industries and wood working industries.
- Used in recovery of catalyst ducts in petroleum industry and reduction of fly ash emission.

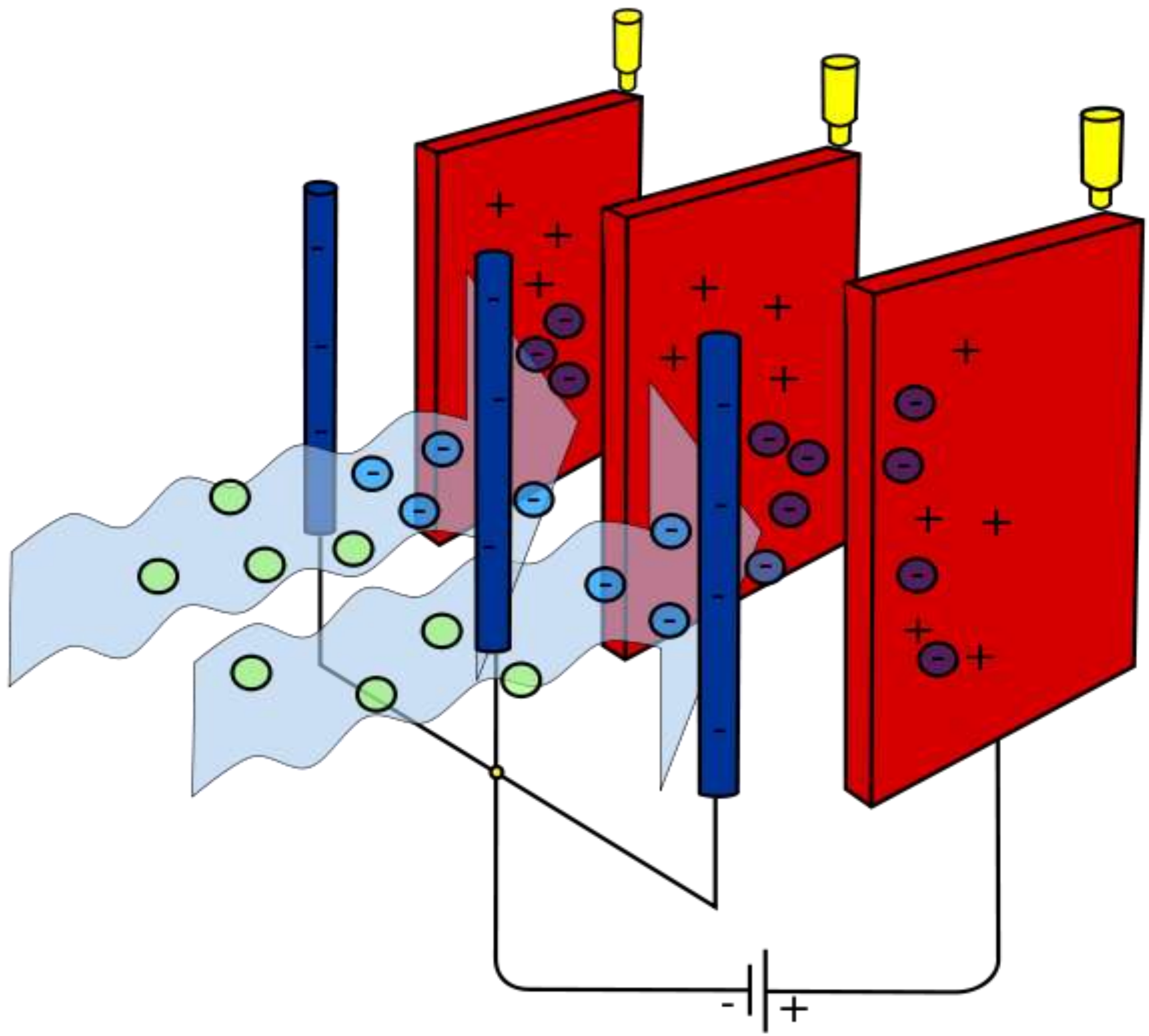
Electrostatic precipitators

- Works on the principle of electrical charging of particulate Matter (-ve) and collecting it in a (+ve) charged surface.
- 99% efficiency.
- Can remove particle size range of 0.1 μm to 1 μm.

Six major components

- A source of high voltage
- Discharge electrodes and collecting electrodes
- Inlet and outlet for gas
- A hopper for disposal of collected material
- An electronic cleaning system
- An outer casing to form an enclosure around electrodes


waste gases without smoke particles
2
smoke particles are attracted to the collecting plates
positively charged collecting plate
1
smoke particles pick up a negative charge
collecting plates are knocked to remove the smoke particles
3
negatively charged metal grid
waste gases containing smoke particles



Principles

- Gas stream passed two electrodes.
- High potential difference is maintained.
- Out of two electrodes, one is discharging other collecting.
- Potentials of 100 kv are used.
- Ionization creates active glow zone called “corona”.
- Gas ionization is dissociation of gas molecules into free ions.

- As particulates pass through field, they get charged and migrate to oppositely charged electrode.

- Particles deposited on collecting electrodes, lose charge and removed mechanically by rapping., vibration or washing to a hopper.

Single stage and two stage precipitators

- Single stage gas ionization and particulate collection in a single stage.
- Two stage, particle ionized in first chamber and collected in second chamber.
- Industrial precipitators single stage design.
- Two stage used for lightly loaded gases.
- Single stage for more heavily loaded gas streams.

Efficiency

- General collection efficiency is high, nearly 100%
- Installations operate 98 and 99% efficiency.
- Acid mist and catalyst recovery efficiencies in excess of 99%.
- Carbon black, because of agglomeration tendency collection efficiency less than 35%.

$$E = 1 - e^{-U_t f}$$

E= collection efficiency

f= specific collecting area of precipitator, expressed as sq m of collecting electrode area per cubic m of gas handled per s.

U_t= migration velocity of particle towards collection electrode

e= napierian log base

Design parameter

- Volumetric flow rate
- Composition
- Temperature
- Dew point
- Dust particle conc.
- Size of particle
- Bulk density
- Tendency of allgomorate

Advantages

- High collection efficiency.
- Particles may be collected dry or wet.
- Can be operated at high temp. (300-450˚c).
- Maintenance is normal.
- Few moving parts.

Disadvantages

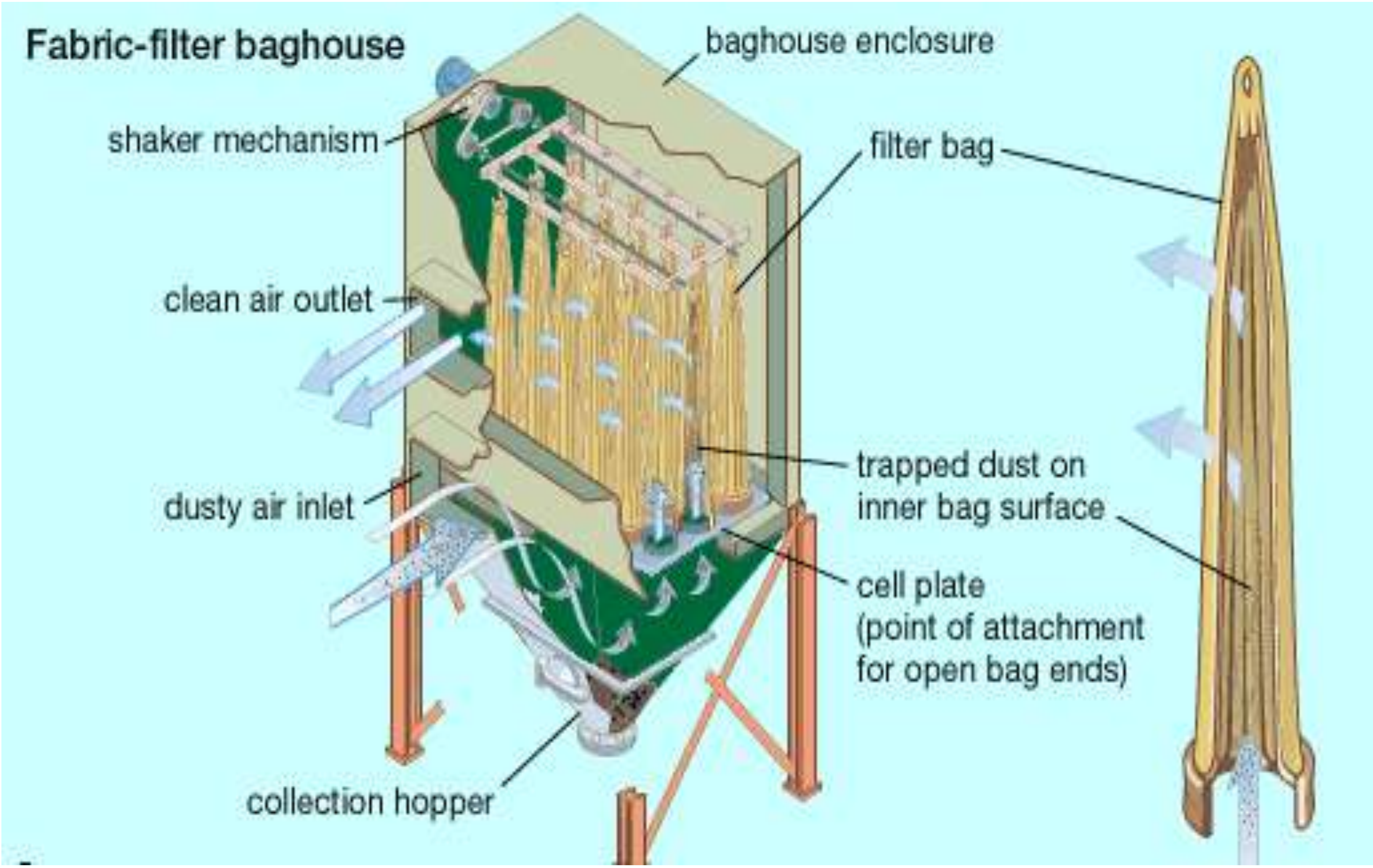
- High initial cost.
- Require high voltage.
- Collection efficiency reduce with time.
- Space requirement is more.
- Possible of explosion during collection of combustible gases or particulates.

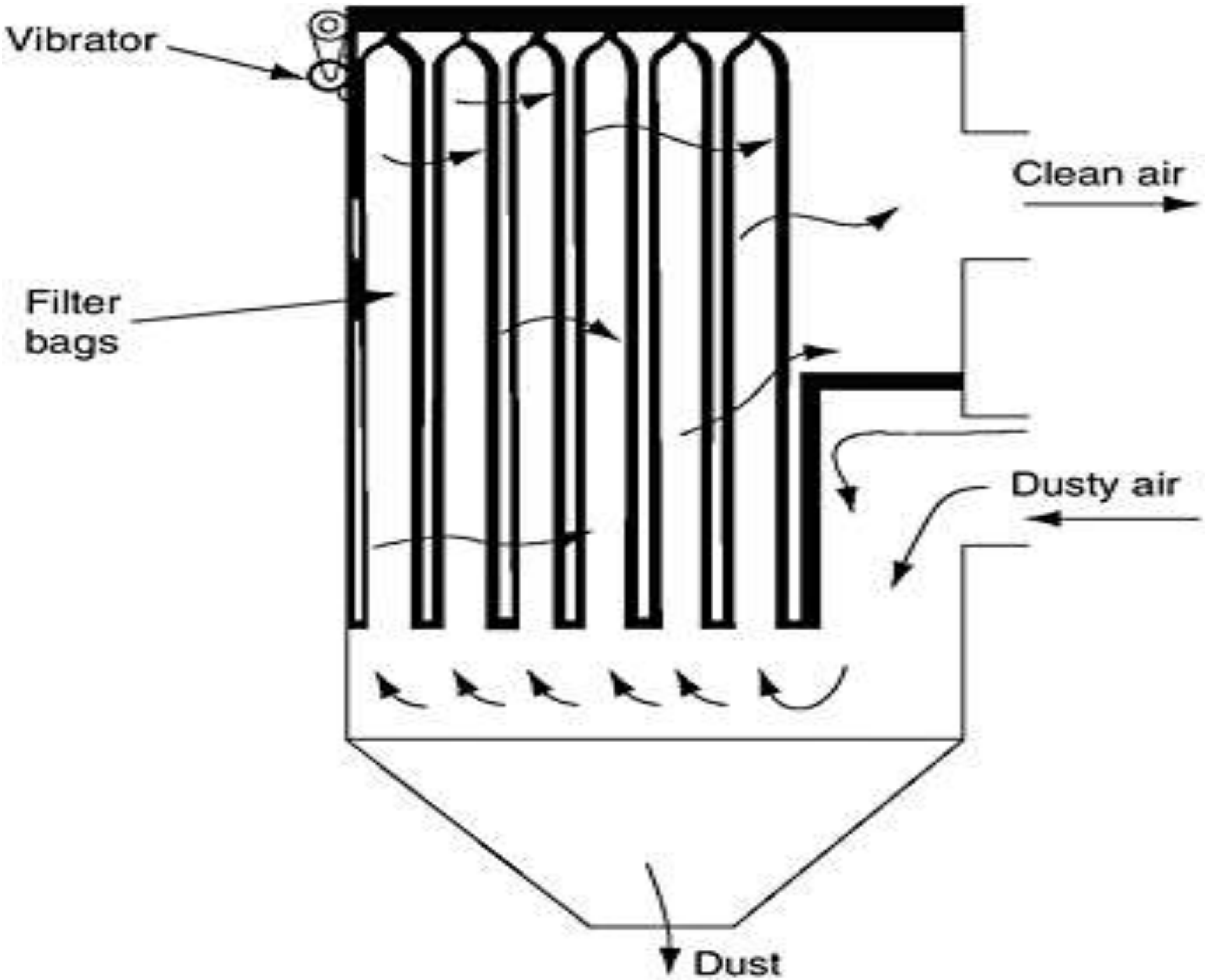
Application

- Cement factories
- Pulp and paper mills
- Steel plants
- Non- ferrous metal industry
- Chemical industry
- Petroleum industry
- Carbon black industry
- Electric power industry

Fabric filters or cloth filters

- Flue gas is allowed to pass through a woven fabric, which filters out particulate matter.
- Small particles are retained on the fabric.
- Consists of numerous vertical bags 120-400 mm dia and 2-10 m long.
- Remove particles up to 1 μm.
- Its efficiency up to 99%.


Fabric-filter baghouse
baghouse enclosure
shaker mechanism
filter bag
clean air outlet
trapped dust on
inner bag surface
dusty air inlet
cell plate
(point of attachment
for open bag ends)
collection hopper



Vibrator
Filter bags
Clean air
Dusty air
Dust

Factors affecting efficiency

Efficiency decrease due to

- Excessive filter ratio:- ratio of carrier gas vs gross filter area

- Improper selection of filter media:- temp. resistance, resistance to chemical attack and abrasion resistance taken into consideration.

Operating problems

- Cleaning
- Rupture of cloth
- Temperature
- Bleeding
- Humidity
- Chemical attack

Filter cleaning

- Rapping
- Shaking
- Back wash
- Pulse jet

Filter medium

- Carrier gas temp.
- Carrier gas composition
- Gas flow rate
- Size and shape of dust particles

Fabric	Max. operating temp. (° C)	Acid resistance	Alkali resistance	Abrasion resistance	Tensile strength Kg/cm^2
Cotton	82	Poor	Good	Very good	4920
Wool	93	Very good	Poor	Fair to good	1755
Nylon	93	Poor to fair	Excellent	Excellent	5625
Dacron	135	Good	Good	Very good	5625
Polypropylene	93	Excellent	Excellent	Excellent	7730
Fiber glass	290	Fair to good	Fair to good	Fair	14,060

Physical properties of bag filters

Advantages

- Higher collection efficiency for smaller than 10 μm particle size.
- Performance decrease becomes visible, giving prewarning.
- Normal power consumption.

Disadvantages

- High temp. gases need to be cooled.
- High maintenance and fabric replacement cost.
- Large size equipment.
- Fabric is liable to chemical attack.

Application

- Metallurgical industry
- Foundries
- Cement industry
- Chalk and lime
- Brick works
- Ceramic industry
- Flour mills

Scrubbers or wet collectors

- Particulate matters are incorporated into liquid droplets and removed from the gas stream.
- Flue gas made to push up against a down falling water current.
- Particulate matter mix up with water thus falls down and gets removed.

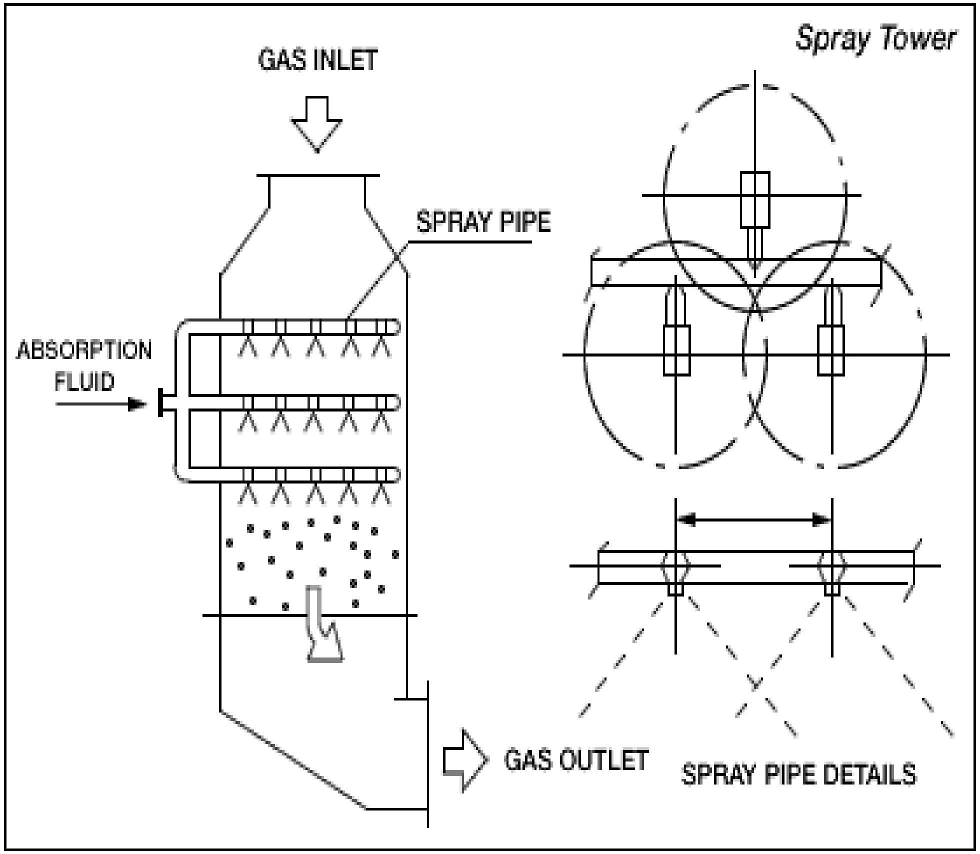
Collection mechanism

- Impingement
- Interception
- Diffusion
- Condensation

Types of scrubbers

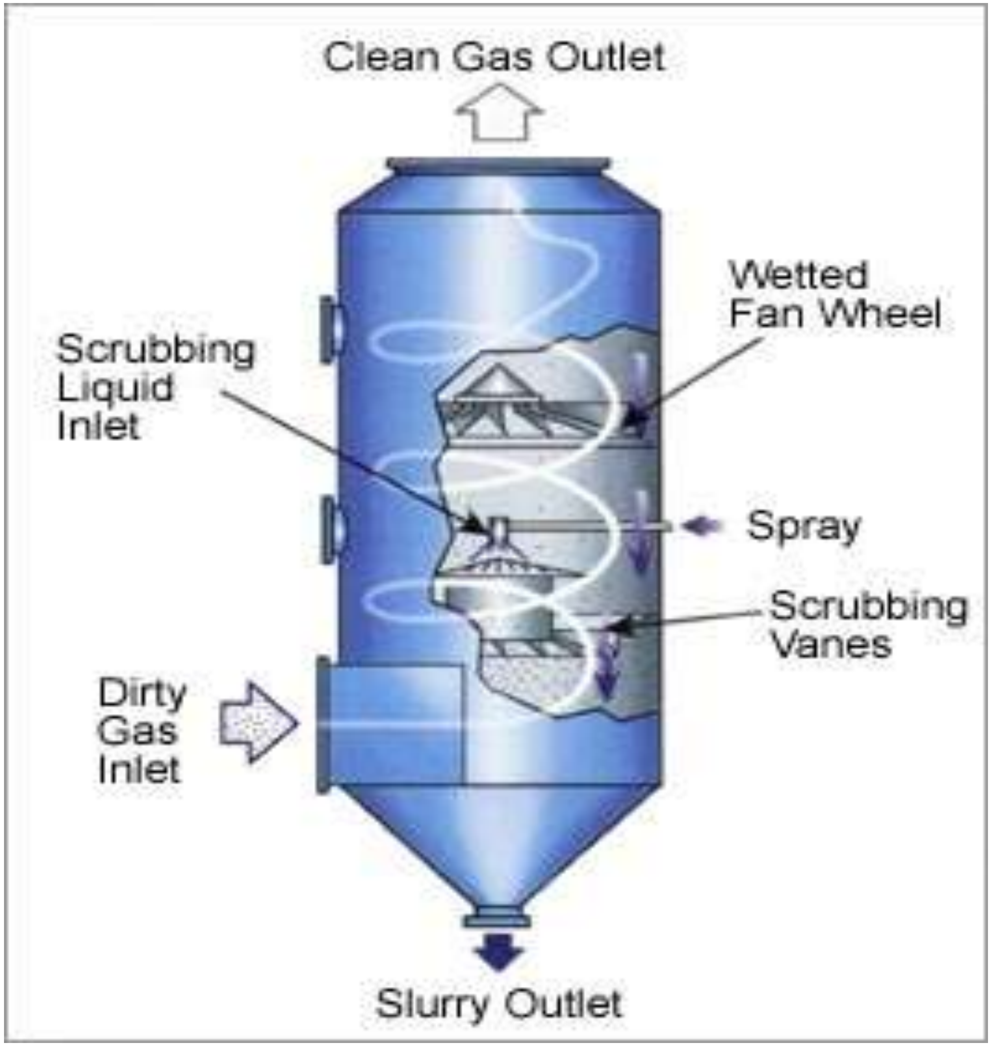
- Spray towers
- Venturi scrubbers
- Cyclone scrubbers
- Packed scrubbers
- Mechanical scrubbers

Spray towers

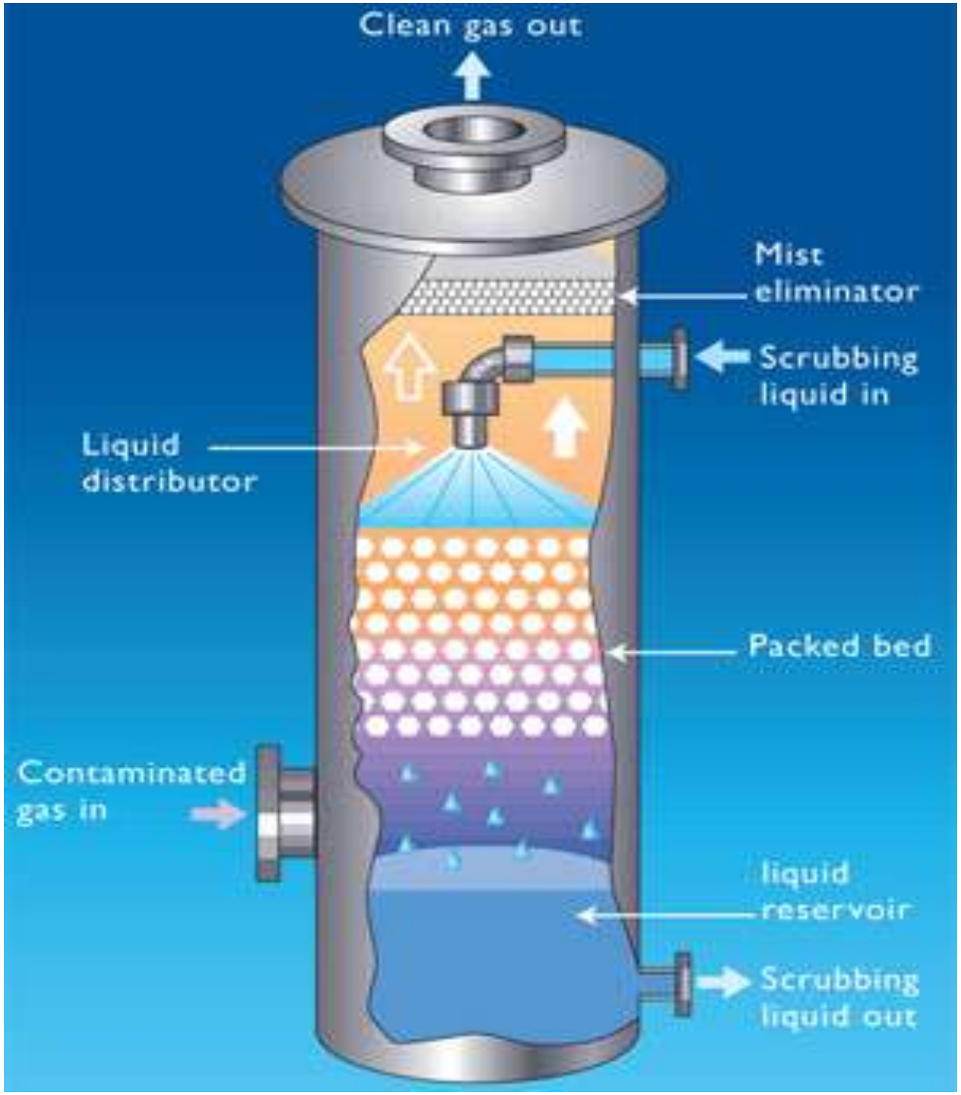


Venturi scrubber

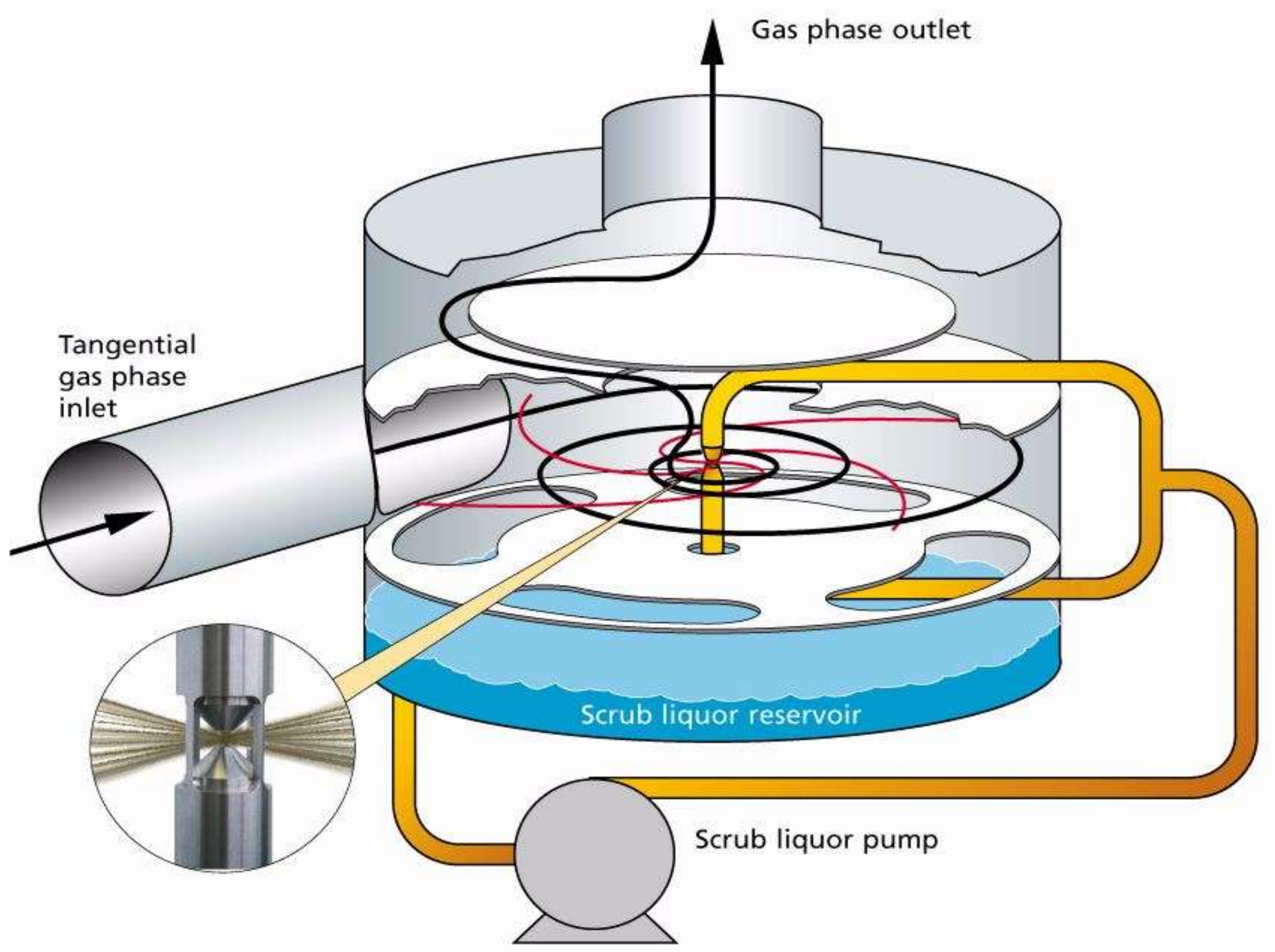
Cyclone scrubber



Packed scrubbers



Mechanical scrubbers



Advantages

- Simultaneously remove particulates and gaseous pollutants.
- Hot gases can be cooled down.
- Corrosive gases can be recovered and neutralize.

Disadvantages

- Lot of waste waters produced.
- Poses freezing problem in cold countries.
- Maintenance cost is high when corrosive materials are collected.

Choice of equipment

1. Particulate size
2. Particulate loading
3. Efficiency required
4. Properties of carrier gas
    1. Composition
    2. Temp.
    3. Pressure
    4. Viscosity
    5. Density
    6. Humidity
    7. Combustibility
    8. Reactivity
    9. Toxicity
    10. Electrical property

5. Flow characteristics of carrier gas

1. Flow rate
2. Variation in flow rate

6. Specific property of contaminant

1. Composition
2. Contaminant phase
3. Solubility characteristics
4. Combustibility
5. Reactivity
6. Toxicity
7. Hygroscopicity
8. Agglomerating
9. Electrical and sonic properties
10. Catalyst poisoning

7. Allowable pressure drop

8. Contaminate disposal

9. Capital and operating cost of equipment

10. Ease of maintenance and reliability

Economical aspects

1. Cyclones:- cheap to install, power consumption moderate, maintenance cost normal.
2. Filters:- expensive to install, power consumption moderate. Maintenance cost high.
3. Electrostatic precipitators:- most expensive regarding installation, power consumption moderate to low as pressure drops. Maintenance cost moderate
4. Scrubbers :- installation cost moderate, maintenance cost not high, high rate of power consumption.

Control of gaseous contaminants

Methods of control include:

- Absorption
- Adsorption
- Secondary combustion

Absorption

- Effluent gas passed through absorbers (scrubbers), which contain liquid absorbent.
- Efficiency depends on
  1. Amount of surface contact between gas and liquid
  2. Contact time
  3. Conc. of absorbing medium
  4. Speed of reaction between the absorbent and gases
- Absorbents used to remove SO_2, H_2S, SO_3, F and oxides of nitrogen.

Equipments using principles of absorption for removal of gaseous pollutants

- Packed tower
- Plate tower
- Bubble cap plate tower
- Spray tower
- Liquid jet scrubber absorbers

Gaseous pollutants	Common absorbents used in solution form
SO_2	Dimethylaniline, ammonium sulphite, ammonium sulphate, sodium sulphide, calcium sulphite, alkaline water,
H_2S	NaOH and phenol mix (3:2), tripottasium phosphate, sodium alamine, sodium thioarsenate, soda ash
HF	Water, NaOH
NOX	Water, aqueous nitric acid

Adsorption

- Surface phenomenon, require large solid surface
- Adsorption towers use adsorbents to remove the impurities from the gas stream.
- The impurities bind either physically or chemically to the adsorbing material.
- The impurities can be recovered by regenerating the adsorbent.
- Adsorption towers can remove low concentrations of impurities from the flue gas stream.

Construction and Operation

- Adsorption towers consist of cylinders packed with the adsorbent.
- The adsorbent is supported on a heavy screen
- Since adsorption is temperature dependent, the flue gas is temperature conditioned.
- Vapor monitors are provided to detect for large concentrations in the effluent. Large concentrations of the pollutant in the effluent indicate that the adsorbent needs to be regenerated.

Advantages of Adsorption Towers

- Very low concentrations of pollutants can be removed.
- Energy consumption is low.
- Do not need much maintenance.
- Economically valuable material can be recovered during regeneration.

Gaseous pollutants	Adsorbents used in solid form
SO_2	Pulverized limestone or dolomite, alkalized alumina
H_2S	Iron oxide
HF	Lump limestone, porous sodium fluoride pellets
NOX	Silica gel
Organic solvent vapours	Activated carbon

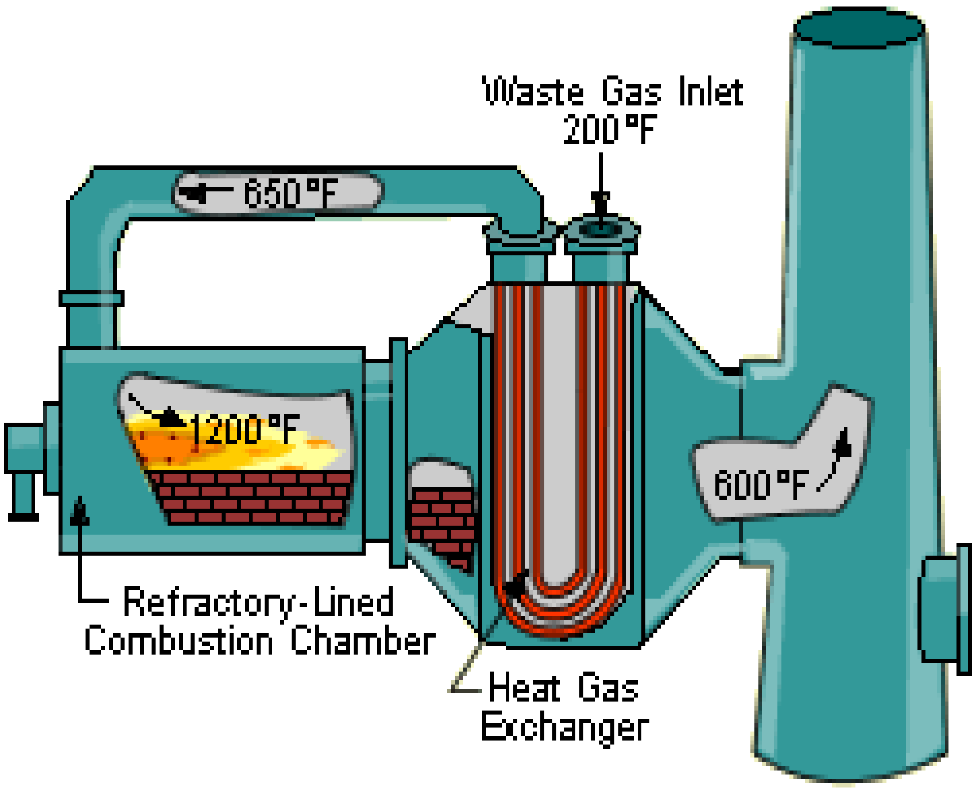
Secondary combustion

- Flame or catalytic combustion can be utilized when gases or vapors to be controlled.

- Fume and vapor incinerators
- After burners
- Flares, either with steam injection or venturi flare

- After burners on incinerators met with varying success depending on kind of after burner used and type of incinerator.
- Flare design for smokeless combustion gases of variable composition and wide range of flow rates.
- Venturi flares, mix air with gases in proper ratio prior to ignition to achieve smokeless burning.

Figure 1. Thermal Oxidizer with Recuperative Heat Exchanger



Fume incinerators

- When conc. of combustible portion of gas stream below flammable range, catalytic combustion process used.

- Used to control effluent gases, fumes and odors from refineries, burning waste, cracking gases, chemical plants, paint and enamel ovens.

Method is expensive when

1. Fuel values of gaseous discharge low

2. Moisture content of discharge is high

3. Exhaust volume is extremely large

Factors considered in design of incinerators are

1. Sufficient air for combustion reaction
2. Adequate temp.
3. Adequate retention time

- Incineration equipment, single combustion chamber.
- Combustion chamber proportioned that gas velocity, gas flow patterns, established produce adequate retention time.
- Avg. retention time 0.2-0.3 s at temp. 650 ˚C and higher.

Thank u all…