



IIT ROORKEE



NPTEL ONLINE
CERTIFICATION COURSE

WASTE TO ENERGY CONVERSION

GAS CLEANUP-1

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Contents

- Typical composition of gas produced through different routes
- Processes for removal of unwanted elements from gas
- Particulates removal
 - Gravity settler
 - ESP
 - Bag filter
 - Cyclone separator
- Gas molecules removal
 - Absorption
 - Adsorption methods
 - Removal of specific gas components like SO_2 , NO_x and CO_2
- Both particulate and gas molecules removal
 - Wet scrubbers



Typical composition of gas produced through different routes

Process	Typical Gas composition	Elements to be removed
Incineration	CO ₂ , H ₂ O, NO _x , SO _x , PM, N ₂	NO _x , SO _x , PM, CO ₂
Gasification	CO, H ₂ , CO ₂ , H ₂ S, COS, PM, CH ₄	CO ₂ , H ₂ S, COS, PM
Pyrolysis of biomass and wastes	Hydrocarbons, CO, CO ₂ , H ₂ ,	CO ₂
Pyrolysis of waste plastics	Hydrocarbons, CO, CO ₂ , H ₂ , HCl, dioxins	CO ₂ , HCl, dioxins
Anaerobic digestion	CH ₄ , CO ₂ , H ₂ S, H ₂ O	CO ₂ , H ₂ S, H ₂ O

Processes for removal of unwanted elements from gas

Particulates

- Gravity settlers
- Cyclones
- ESP
- Filters / Fabric filters

Gas molecules

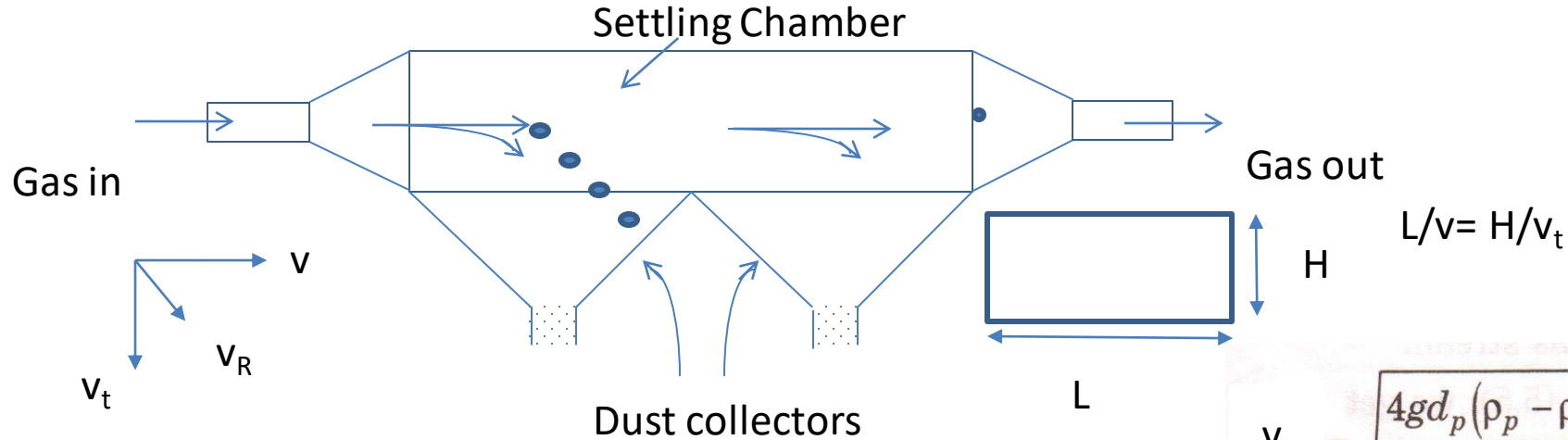
- Wet process : Absorption
- Dry process: Adsorption

Particulates and gas molecules

- Wet Scrubbers

Gravity settlers

Horizontal flow settling chamber



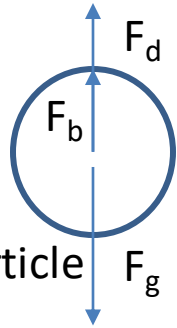
$$v_t = \sqrt{\frac{4gd_p(\rho_p - \rho_g)}{3C_D\rho_g}}$$

$$C_D = \frac{24}{Re_p} \quad \text{for } Re_p < 1$$

$$v_t = \frac{gd_p^2(\rho_p - \rho_g)}{18\mu_g}$$

- To settle large abrasive particles (> 50 micron)
- Low maintenance and low efficiency
- Pre cleaner
- Most simple

Force balance on particle and terminal settling velocity



F_d : drag force = F_R = kinetic force

F_b : buoyancy force

F_g : force of gravity

ρ_f = density of fluid in this case fluid is gas = ρ_g

Resultant force (F) = $F_g - F_b - F_d(F_R) = ma_{\epsilon} = mg - \left(\frac{m}{\rho_p}\right) \rho_f g - F_R$

At steady velocity $mg \left[1 - \frac{\rho_f}{\rho_p}\right] = F_R \left\{ \frac{\pi d_p^3}{6} \right\} \rho_p g \left[1 - \frac{\rho_f}{\rho_p}\right] = F_R$

If particle is assumed to be spherical, then

$$F_R = A K C_D$$

Where C_D is drag coefficient

A = Characteristic area of the system

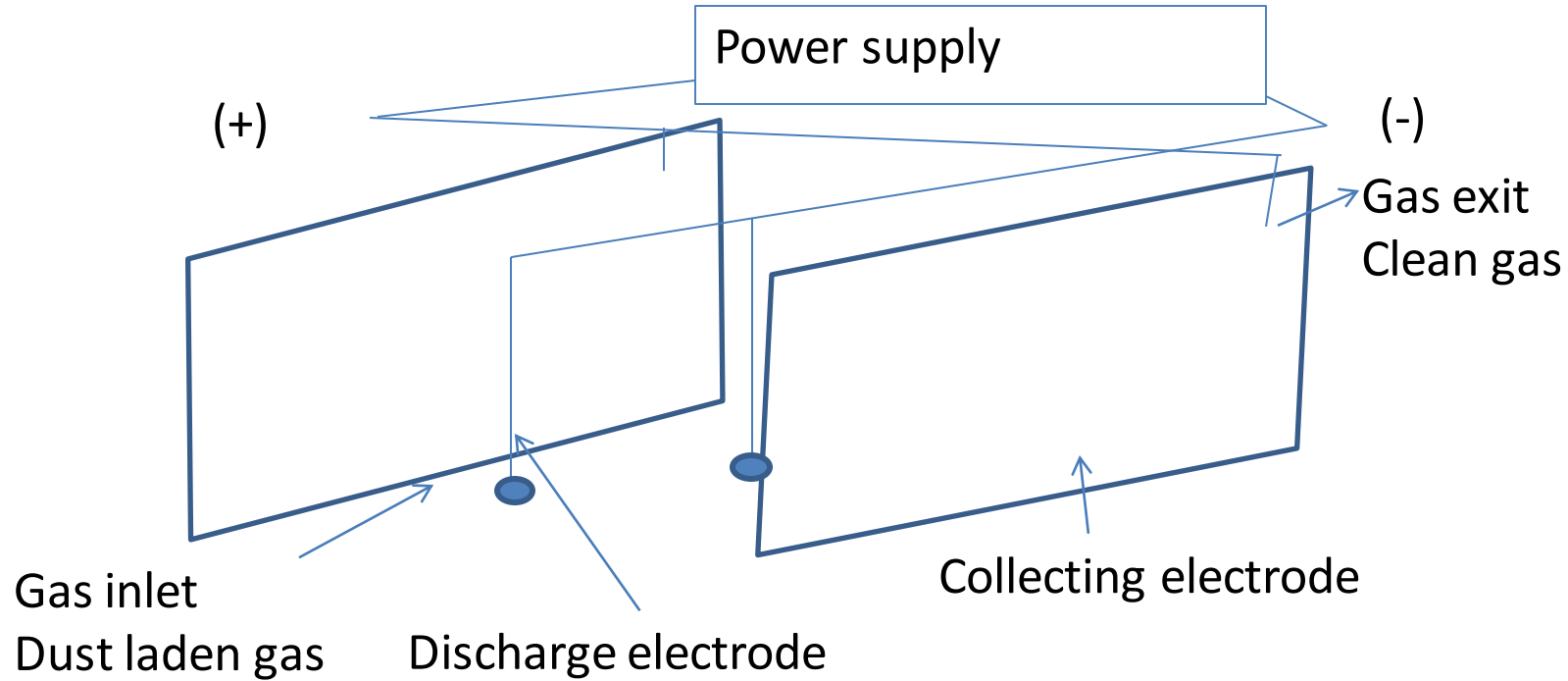
K = Characteristic kinetic energy per unit volume

v_t = relative velocity between the particle & liquid (terminal settling velocity)

$$A = \frac{\pi d_p^2}{4} \quad K = \left(\frac{1}{2}\right) v_t^2 \rho_g$$

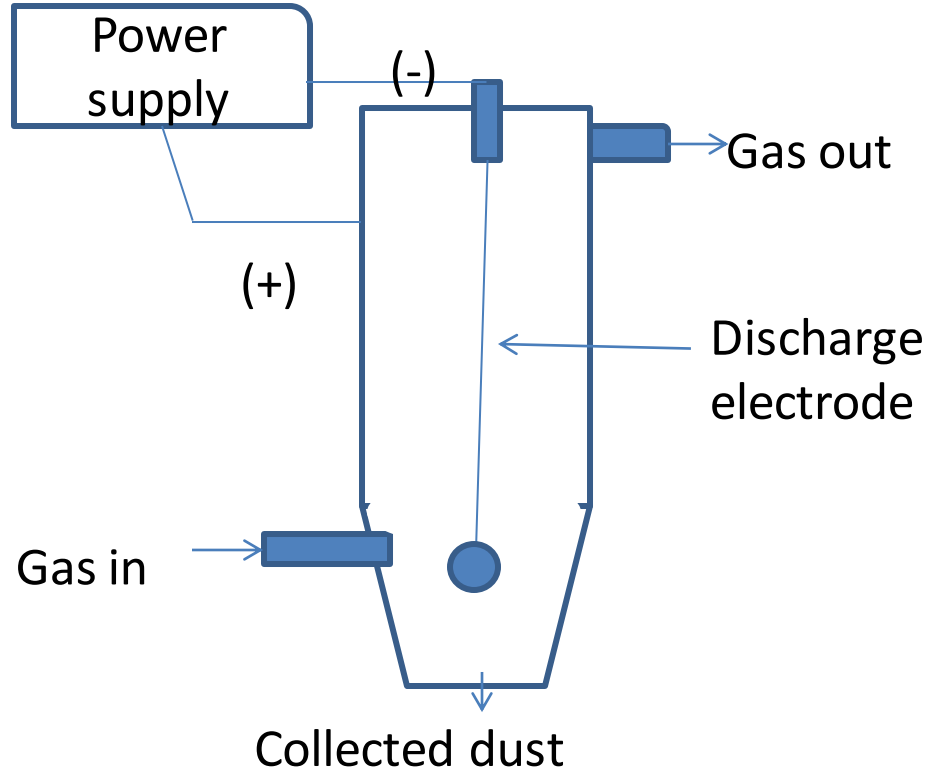
$$v_t = \sqrt{\frac{4gd_p(\rho_p - \rho_g)}{3C_D\rho_g}}$$

ESP



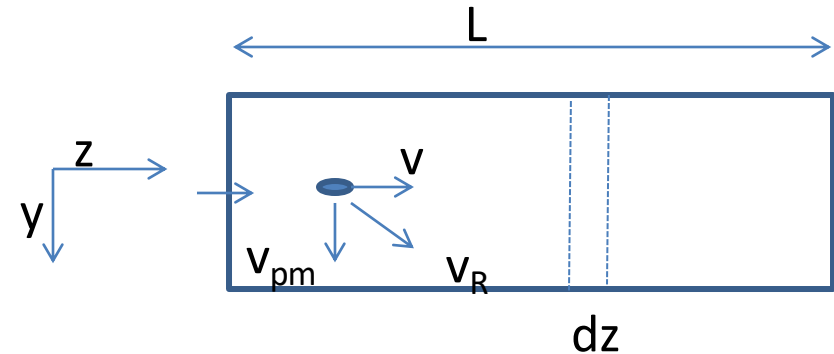
Schematic diagram of a parallel-plate precipitator

ESP Types



Important Two types are:

- Parallel plate precipitator
- Wire and pipe precipitator



Schematic diagram of a wire and pipe precipitator

Efficiency of ESP

Efficiency , $\eta = 1 - \exp\left(-\frac{v_{pm}A_c}{Q}\right)$

Or $\eta = 1 - \exp\left(-\frac{v_{pm}}{v} \frac{A_c L}{V}\right)$

Where v = Gas velocity

V = Volume of the precipitator

L = Length of precipitator

For tubular type precipitator

$$A_c/V = 4/D_c$$

D_c = Diameter of the collector

Where v_{pm} = drift velocity

A_c = Collector surface area

Q = Volumetric flow rate

$$Q * L/v = V$$

For plate type

$$A_c/V = 2/S$$

S = Distance between two plates



Now v_{pm} can be replaced as
$$v_{pm} = \frac{q_p E_c C}{3\pi\mu_g d_p}$$

Thus,
$$\eta = 1 - \exp\left(-\frac{q_p E_c C}{3\pi\mu_g d_p} \frac{A_c}{Q}\right)$$

Where, E_c = Electric field strength

d_p = Particle size

μ_g = Gas viscosity

q_p = Particle charge

C = Cunningham correlation factor

q_p = Particle charge

C can be written as

$$C = 1 + \frac{2\lambda}{d_p} \left(1.257 + 0.4e^{-0.55d_p/\lambda} \right)$$

where, λ = Mean free path of gas molecules

A MSW based power plant is emitting 45,000 m³/h flue gas. It is proposed to install an ESP with a collection efficiency of 96.8%. Calculate the total area of the collection electrodes. If the collection efficiency is 99.5%, how much additional collection electrode area would be needed? Drift velocity of the particles has been determined experimentally as 0.13 m/s.

Ans.

$$Q = 45000 / 3600 = 12.5 \text{ m}^3/\text{s}$$

$$\text{Efficiency} = 1 - e^{-v_{pm} A_c / Q}$$

For the first case

$$0.968 = 1 - e^{-0.13 A_c / 12.5}$$

$$A_c = 330.96 \text{ m}^2$$

Similarly for 99.5 % efficiency

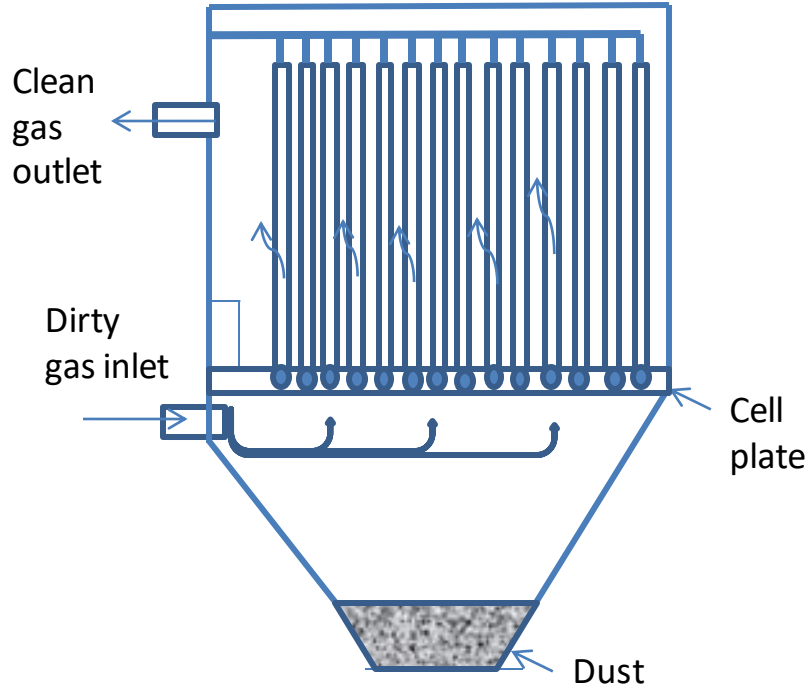
$$A_c = 509.45 \text{ m}^2$$

$$\text{Additional area: } 509.45 - 330.96$$

$$= 178.49 \text{ m}^2$$



Fabric filters



Salient features

- Eff – $> 99.9\%$;
- Particles $> 0.01\text{-}1$ micron;
- Low pressure drop;
- Cannot operate in moist environment
- Large & Expensive;
- Competitive with ESP;
- Process temp. below 285°C
- Woven fabric or felt cloth made of cotton, nylon, polyester, fiberglass, asbestos, etc.

Mechanism of separation

- Inertial collection - Dust particles strike the fibers placed perpendicular to the gas-flow direction instead of changing direction with the gas stream.
- Interception - Particles that do not cross the fluid streamlines come in contact with fibers because of the fiber size.
- Brownian Movement - Sub micrometre particles are diffused, increasing the probability of contact between the particles and collecting surfaces.
- Electrostatic forces - The presence of an electrostatic charge on the particles and the filter can increase dust capture.

❑ Baghouses are classified by the cleaning method used. The three most common types of baghouses are **mechanical shakers, reverse gas, and pulse jet**

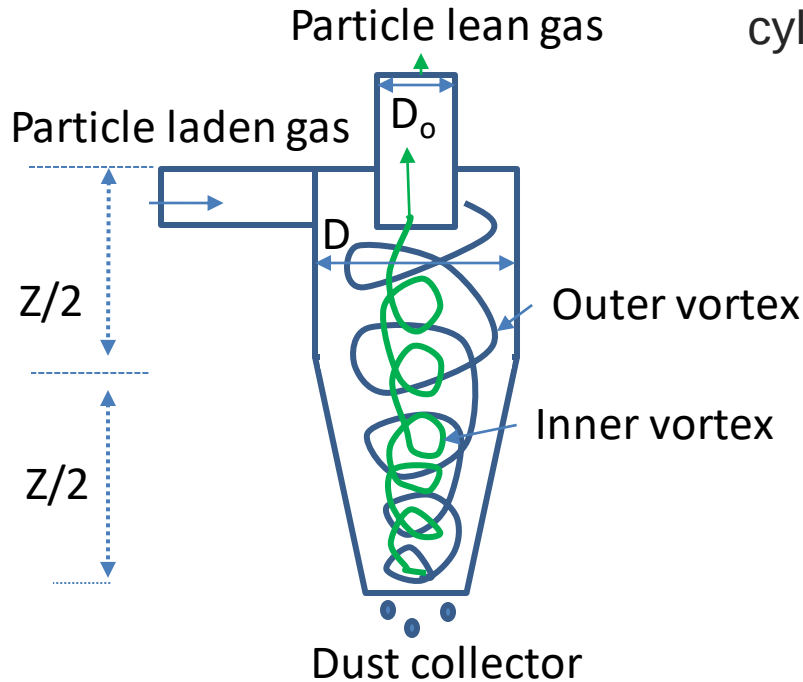


Air to cloth ratio for different types of bag houses

Cleaning by Shaking	2-6 (ft ³ /min)/ft ²
Cleaning by reverse air	1-3 (ft ³ /min)/ft ²
Cleaning by pulse jet	5-15 (ft ³ /min)/ft ²



Cyclone separator



- A high speed rotating gas flow is established within a cylindrical or conical container called a **cyclone**.
- In a conical system, as the rotating flow moves towards the narrow end of the cyclone, the rotational radius of the stream is reduced, thus separating smaller and smaller particles.
- The cyclone geometry, together with flow rate, defines the *cut point* of the cyclone. This is the size of particle that will be removed from the stream with a 50% efficiency.

- For the separation of a particle, its radius must be equal or more than $0.2D_o$, where D_o is the dia. of the top outlet

Force balance and characteristics equations

$$\text{Centrifugal force (outward)} = mV_{gt}^2/r$$

Where m = mass of the particle
 r = radius of the particle

$$\text{Drag force (inward)} = 3 \pi \mu_g D_p V_r$$

Where D_p = diameter of the particle
 V_r = radial component of the velocity of gas
 μ_g = viscosity of the gas

$$\text{Laminar gravitational free settling velocity } (V_t) = (\rho_s - \rho_g)gD_p^2/18\mu_g$$

Minimum size of particle for separation in cyclone separator

$$(D_p)_{\min} = \left[\frac{3.6 A_i^2 D_o \rho_g \mu_g}{\pi Z D \rho_s G} \right]^{1/2}$$

G = mass flow rate of gas
 A_i = area of cross section of gas inlet
 D_o = is the dia. of the top outlet

Comparison of different PM removal equipment

Equipment type	Typical particle size	Typical removal efficiency	Remark
Gravity settler	$> 50 \mu\text{m}$	$< 50 \%$	Need large space, Low pressure loss
ESP	$> 1 \mu\text{m}$	$> 98 \%$	High initial cost Sensitive to variable dust loading or flow rates
Fabric filter	$> 0.01 \mu\text{m}$	$> 99 \%$	Filters are susceptible to chemical attack
Cyclone separator	$> 5 \mu\text{m}$	$> 90 \%$	Inexpensive and less maintenance

Thanks...

