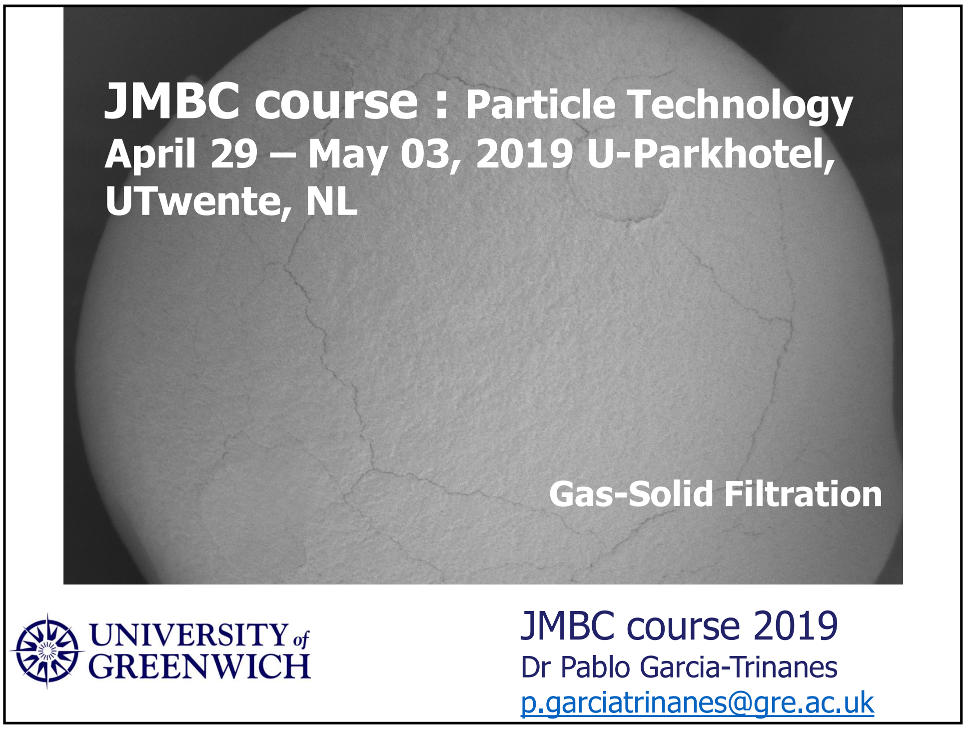

JMBC course : Particle Technology

April 29 – May 03, 2019 U-Parkhotel, UTwente, NL

Gas-Solid Filtration

UNIVERSITY of GREENWICH

JMBC course 2019
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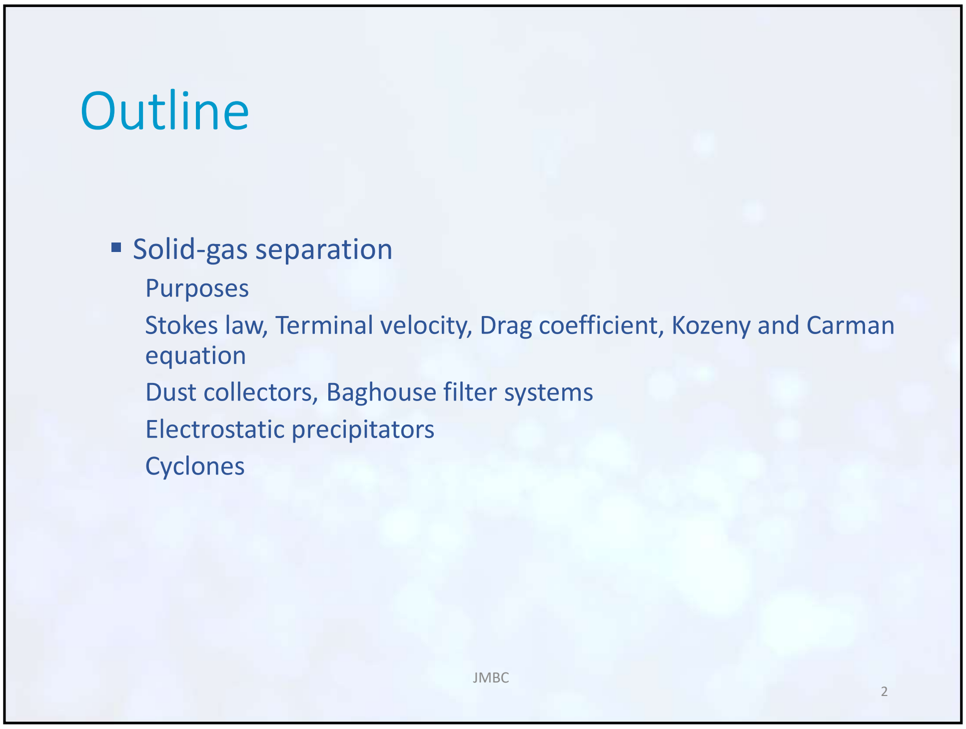
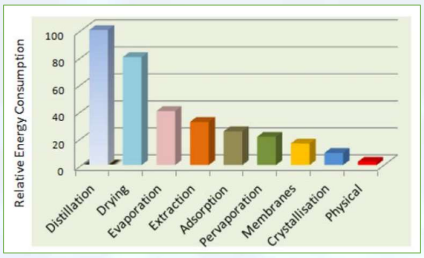


Outline

- Solid-gas separation
  - Purposes
  - Stokes law, Terminal velocity, Drag coefficient, Kozeny and Carman equation
  - Dust collectors, Baghouse filter systems
  - Electrostatic precipitators
  - Cyclones

Solid-gas separation



Solid-gas separation

- **Sedimentation,** in which the solids are allowed to settle by gravity through the fluid
- **Filtration,** in which the solids are collected on a medium, such as a porous material or a layer of fine particles, through which the fluid is pumped.
- **Centrifugal separation,** in which the solids are forced on to the walls of a vessel which is rotated to provide the centrifugal force.

Solid-gas separation: purposes

The need to remove suspended dust and mist from a gas arises not only in the treatment of effluent gas from a plant before it is discharged into the atmosphere but also in processes where solids are carried over in the vapour or gas stream.

In a plant involving a fluidised solid the removal of fine particles is necessary, first to prevent loss of material, and secondly to prevent contamination of the gaseous product.

Solid-gas separation: purposes

- Air-pollution control, as in fly-ash removal from power-plant flue gases.
- Equipment-maintenance reduction, as in filtration of engine intake air or pyrites furnace-gas treatment prior to its entry to a contact sulfuric acid plant.
- Safety- or health-hazard elimination, as in collection of siliceous and metallic dusts around grinding and drilling equipment and in some metallurgical operations and flour dusts from milling or bagging operations.
- Product-quality improvement, as in air cleaning in the production of pharmaceutical products and photographic film.
- Recovery of a valuable product, as in collection of dusts from dryers and smelters.
- In all pneumatic conveying plants, some form of separator must be provided at the downstream end.
- In spray drying; and the manufacture of high purity chemical products in granular form.

Solid-gas separation

- Whereas relatively large particles with **settling velocities** greater than about 0.3 m/s readily disengage themselves from a gas stream, fine particles tend to follow the same path as the gas and separation is therefore difficult.
- In practice, **dust particles** may have an average diameter of about 0.01 mm (10 µm) and a settling velocity of about 0.003 m/s, so that a simple gravity settling vessel would be impracticable because of the long time required for settling and the large size of separator which would be required for a given throughput of gas.

Solid-gas separation

Gases are separated from dispersed particles by passing it through a fabric or ceramic **filter “medium”** with a large surface area.

Particles that are not able to penetrate the medium will be retained on its surface, forming the so-called “**filter cake**”.

As the particles on the cloth build up, they form a cake that acts as a filter, and often is a more effective filter than the fabric or screen.

Parameters

Terminal velocity

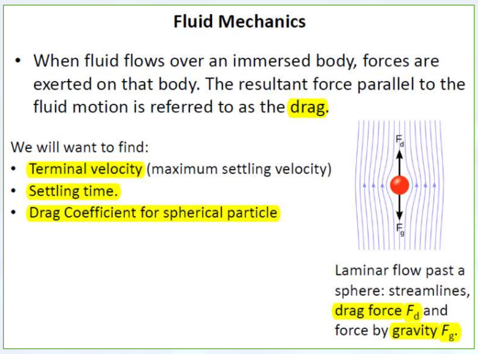
Porosity of the cake

Pressure drop

Allowable gas velocity

Typically the face velocity (= gas flow/filter surface, unit: m/s) also referred to as "air-to-cloth" (A/C) ratio is in the range 0.5 - 5 cm/s.

Parameters

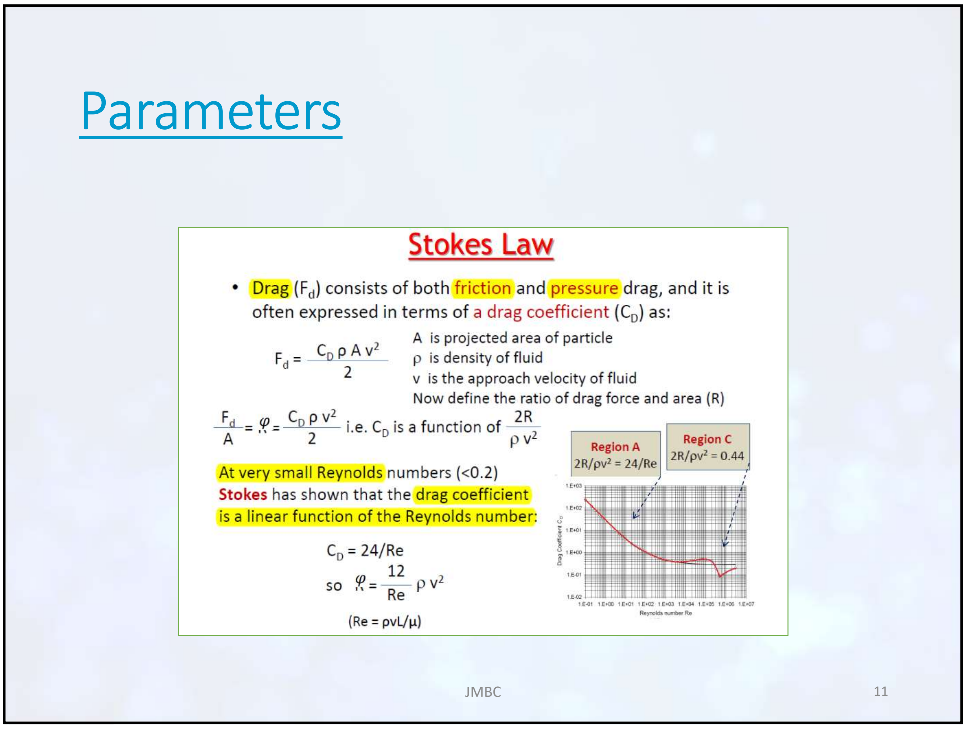


Fluid Mechanics

- When fluid flows over an immersed body, forces are exerted on that body. The resultant force parallel to the fluid motion is referred to as the drag.

We will want to find:
- Terminal velocity (maximum settling velocity)
- Settling time.
- Drag Coefficient for spherical particle

Laminar flow past a sphere: streamlines, drag force F_d and force by gravity F_g.



Parameters

Stokes Law

- Drag (F_d) consists of both friction and pressure drag, and it is often expressed in terms of a drag coefficient (C_D) as:

$$F_d = \frac{C_D \rho A v^2}{2}$$

A is projected area of particle
ρ is density of fluid
v is the approach velocity of fluid
Now define the ratio of drag force and area (R)

$$\frac{F_d}{A} = \mathcal{R} = \frac{C_D \rho v^2}{2} \quad \text{i.e. } C_D \text{ is a function of } \frac{2R}{\rho v^2}$$

At very small Reynolds numbers (<0.2) **Stokes** has shown that the drag coefficient is a linear function of the Reynolds number:

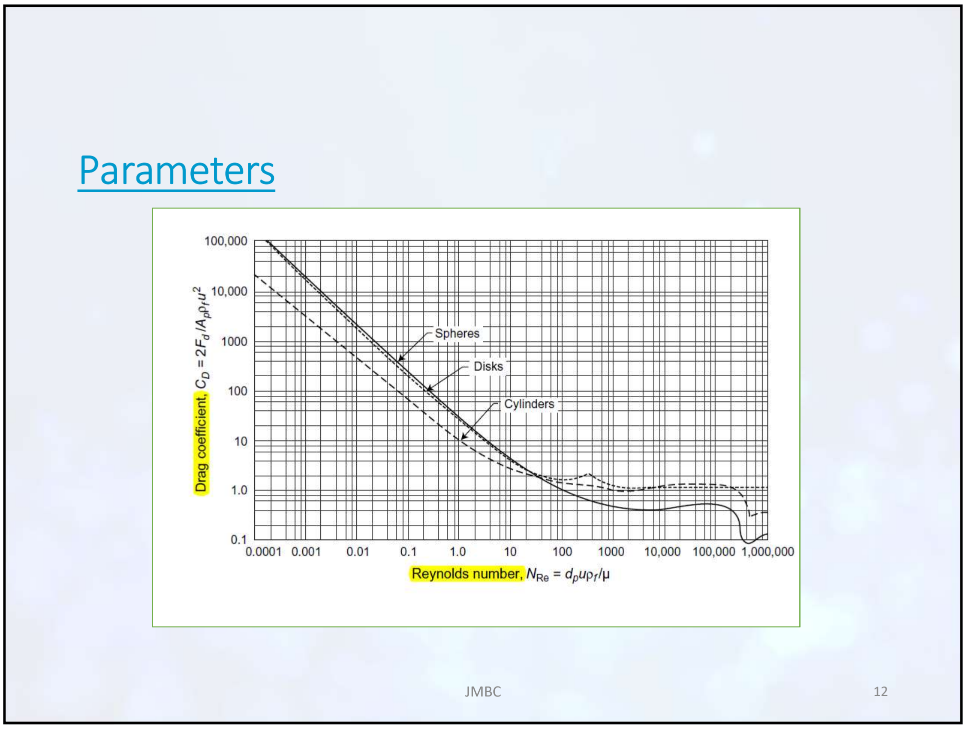
$$C_D = 24/Re$$

$$\text{so} \quad \mathcal{R} = \frac{12}{Re} \rho v^2$$

$(Re = \rho v L/\mu)$

Region A
$2R/\rho v^2 = 24/Re$

Region C
$2R/\rho v^2 = 0.44$



Parameters

Parameters

- Drag coefficients may also be a function of variables not displayed in the plot, which leads to additional correlations and equations. These include:
  - particle velocity history
  - particle shape
  - the effect of walls and collisions with other particles
  - Random Brownian movement, if the particles are very small.

Parameters

- **Terminal velocity** of the particle, u_t, which is defined as the fluid velocity that renders a particle, subject to gravitational force, motionless when suspended unhindered in an upward-flowing fluid stream.
- At that condition, the drag force on the particle plus the buoyant force balance the force of gravity.

$$u_t=\sqrt{\frac{4d_p g(\rho_p-\rho_f)}{3C_D\rho_f}}$$

where: d_p is particle diameter; ρ_p is particle density; ρ_f is fluid density; u_t is terminal velocity (or settling velocity in a quiescent fluid); g is acceleration due to gravity; and C_D is the dimensionless drag coefficient.

Parameters

- The **drag coefficient** C_D is related to the **drag force** $\mathbf{F_d}$ on the projected area, A_p, of a spherical particle by

$$F_D = C_D\left(\frac{\pi d_p^2}{4}\right)\left(\frac{u_t^2}{2}\right)\rho_f$$

where: d_p is particle diameter; ρ_f is fluid density; u_t is terminal velocity (or settling velocity in a quiescent fluid) and C_D is the dimensionless drag coefficient.

Parameters

- Stokes' law, $F_d = 3\pi\mu u d_p$, which applies at Re < 2, gives $C_D = 24/Re$. Substitution gives the settling velocity for a spherical particle of diameter d_p as

$$u_t = \frac{g d_p^2\,(\rho_p - \rho_f)}{18\mu}$$

Parameters

- **Porosity**

$$\varepsilon = 1 - \frac{W}{\rho_p L}$$

where W is the mass of powder deposited on the filtering medium per unit of area.

ρ_p is the particle density and L represents the thickness of the dust cake.

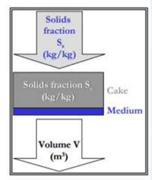
Parameters

- **Kozeny and Carman** derived a semi-empirical equation that represents the dust cake as a series of parallel capillaries or channels whose total volume equals the void volume of the cake and whose surface area equals the surface area of the particles constituting the cake.
- The specific dust cake resistance coefficient is defined as a function of the dust cake porosity Ɛ.

$$K = \frac{18\mu}{\rho_p D_{vs}^2 C} \frac{2k(1-\varepsilon)}{\varepsilon^3}$$

- Where the empirical constant k is equal to 4.8 for spherical particles and 5 for irregular particles and D_{vs} is the volume-surface mean diameter (or Sauter diameter).

Parameters



Fluid flow influenced by pressure differential across the filter

$$\boxed{Rate\ of\ filtration = \frac{Driving\ force}{Resistance}}$$

For a filter cake with porosity ε, specific cake resistance α (m/kg) can be defined as:

$$\alpha = \frac{1}{K(1-\varepsilon)\rho_p}$$

Parameters

- When the deposited cake has a mass w (kg/m^2) per unit filter surface, Ruth's equation gives (for filtration along x axis), with medium resistance R (1/m).

$$dw = (1 - \boldsymbol{\varepsilon})\rho_{solid}\, dx$$

$$u = \frac{1}{\alpha(1-\varepsilon)\rho_p}\frac{\Delta P}{L\mu_f} = \frac{\Delta P}{(\alpha w + R)\mu_f}$$

Parameters

- The cake mass, w, in kg/m² filter surface, depends on the volume V (m/s) of fluid that has been filtered per unit area, the density of fluid (kg/m^3) of the fluid, and the fractions S_s and Sc (kg/kg) of solids in the incoming fluid and the cake, respectively. A mass balance gives

$$w = \left(\rho_f V + \frac{w}{S_c}(1 - S_c)\right)\left(\frac{S_s}{(1 - S_s)}\right)$$

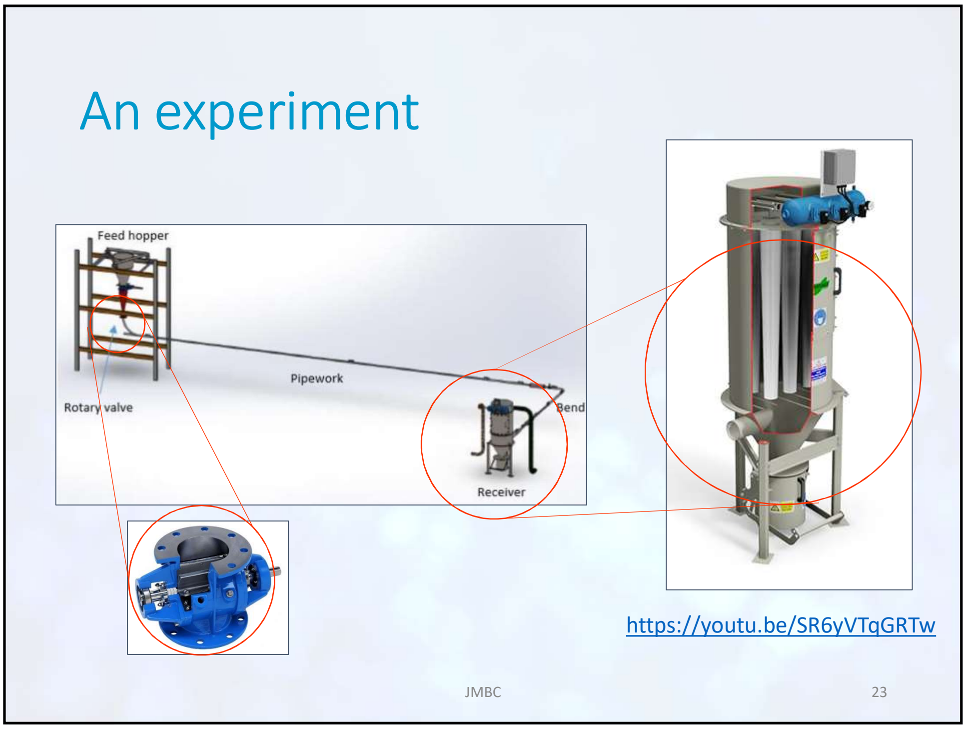
$$w = V f(\rho_f, S_c, S_s)$$

Parameters

With the function f defined as:

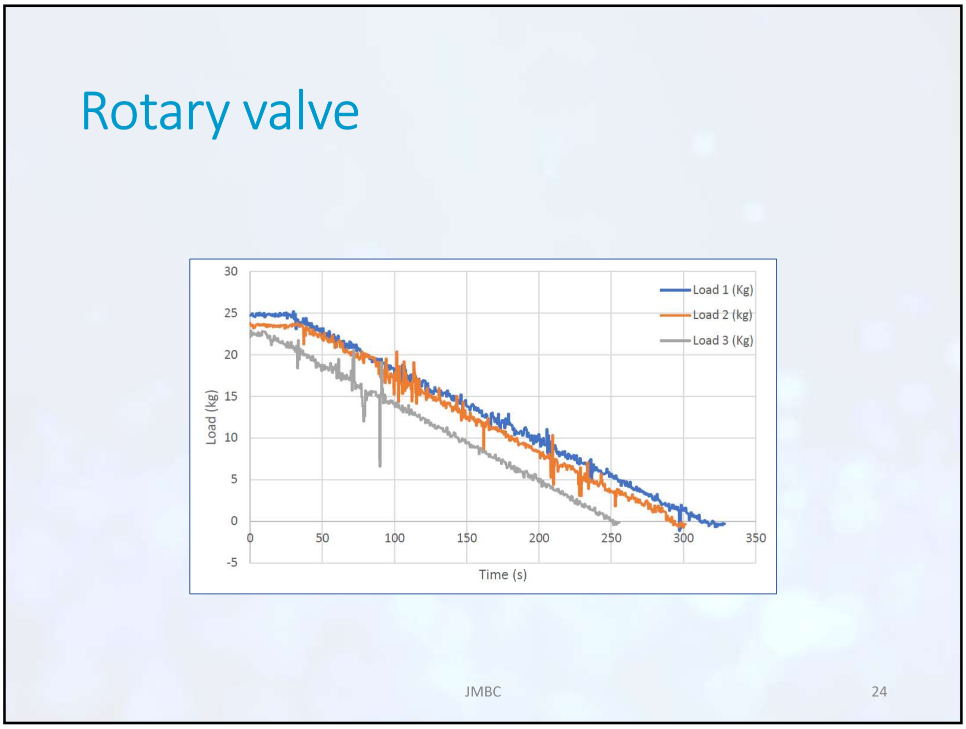
$$f(\rho_{fluid}, S_c, S_s) = \left(\frac{\rho_{fluid}}{(\frac{1 - S_s}{S_s}) - (\frac{1 - S_c}{S_c})}\right)$$

Note : u and V per m² surface, A ! Throughput Q (m³/s) = uA



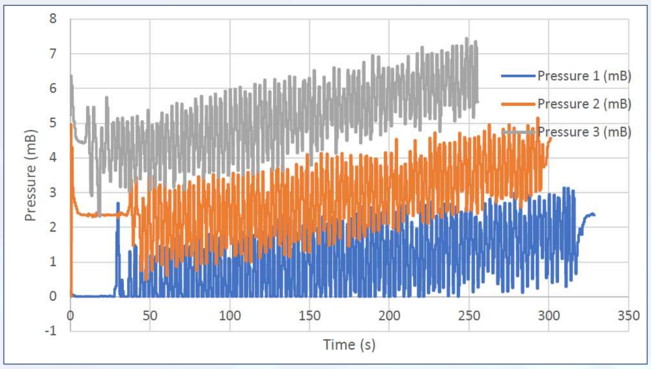
An experiment

https://youtu.be/SR6yVTqGRTw



Rotary valve

Pressure on the filtering system

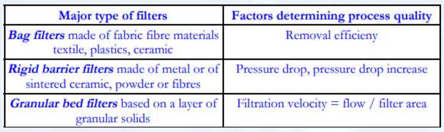


Industrial applications

- A very common industrial filtration device is a fabric dust collector.
- In industry, multiple collectors are housed in enclosures called baghouses.
- Capable of capturing particles down to 0.05 µm.
- Particles are collected on the outside of a fabric-encased, porous, cylindrical candle.
- The device has a vibratory or compressed-air blowback system to remove the particles trapped on the outside of the filter element.

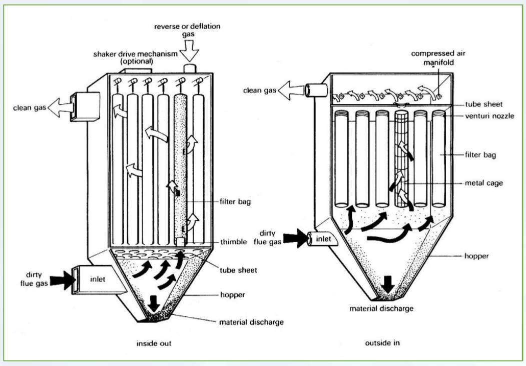
Gas filters

Medium properties: chemical and physical stability
Filter clean-up and capacity for regeneration



Major type of filters	Factors determining process quality
Bag filters made of fabric fibre materials textile, plastics, ceramic	Removal efficieny
Rigid barrier filters made of metal or of sintered ceramic, powder or fibres	Pressure drop, pressure drop increase
Granular bed filters based on a layer of granular solids	Filtration velocity = flow / filter area

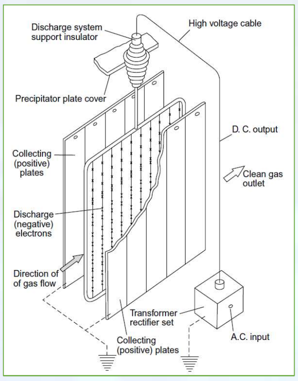
Baghouse filter systems



Electrostatic precipitators

- Electrostatic precipitators are best suited for the collection of fine mists and submicron particles.
- The first practical application was fashioned by Cottrell in 1907 for abating sulfuric acid mists.
- Particle suspended in an ionized gas stream within an electrostatic field will become charged and migrate to a collecting surface.
- To obtain ionization, the voltage must be high enough to initiate a corona discharge, but not so high as to cause sparking.

Electrostatic precipitators



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