Pollution Control Devices — Concepts

Particulate Control

The important force acting on the particle which needs to overcome for removing particle from the gas stream is the drag force (F_d)

$$F_d = 3\pi \mu d_p v$$

$\mu \rightarrow$ Viscosity, $d_p \rightarrow$ diameter of particle, $v \rightarrow$ velocity of particle

- Simplest device is Gravitational settling chambers using gravitational force. Assume that Stokes law is valid, the terminal settling velocity v_t is

$$v_t = \frac{g}{18} \frac{(\rho_p - \rho_{air}) d_p^2}{\mu} \qquad (1)$$

Example $d_p = 1 \mu m$, $\mu = 1.8 \times 10^{-5}$ kg/m-s

ρ_p = 2000 kg/m³ (density of particle); ρ_{air} = 1.2 kg/m³ (density of air)

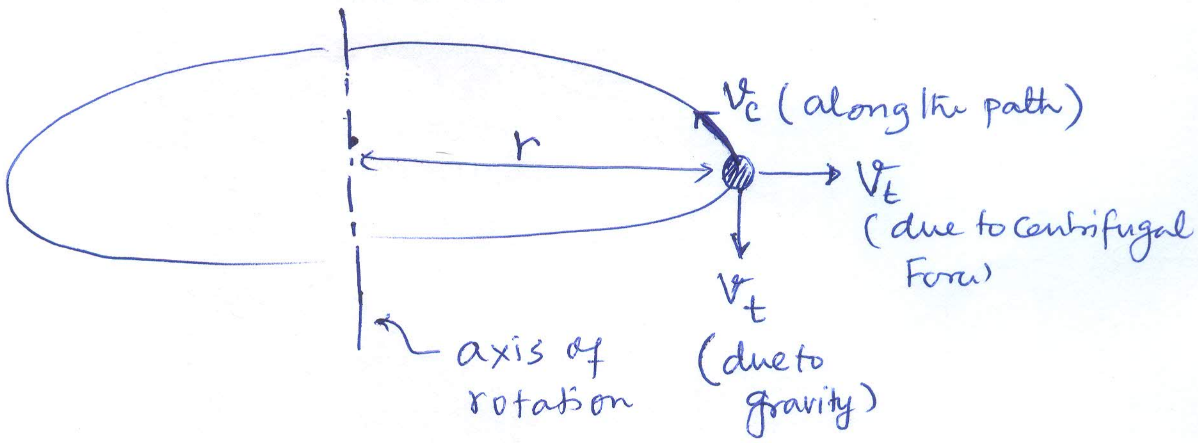
v_t = 0.0065 cm/s

This velocity is very small and we will require large volume of chamber and detention time. Thus we rarely use gravitational chamber for air pollution control. Let us also examine this by force point of view. The driving force to overcome the drag force F_d is Gravitational force

$F_g = mg$ for unit mass $F_g = 9.81$ N

Let us now consider another method or principle to remove the particle, Centrifugal Force or Centrifugal separators

Centrifugal Force is a pseudoforce which is result of body's inertia carrying it straight while some other force makes it move in a curved path.



Recall – If you had tied the body with rope the outward Centrifugal force is balanced by Centripetal force which acts inward and particle follow the circular path with v_c. However if Centripetal force is not there the particle (body) will move outward due to inertia and we take advantage of this.

$$\text{Centrifugal force} = \frac{m v_c^2}{r} = m \omega^2 r \quad \text{——— (2)}$$

ω = angular velocity ($= v_c/r$)

Example – Ratio of Centrifugal Force to Gravitational force for Unit mass $v_c = 18$ m/s, $r = 0.304$ m

$$\frac{\text{Centrifugal Force}}{\text{Gravitational force}} = \frac{m v_c^2/r}{m.g} \simeq \underline{112}$$

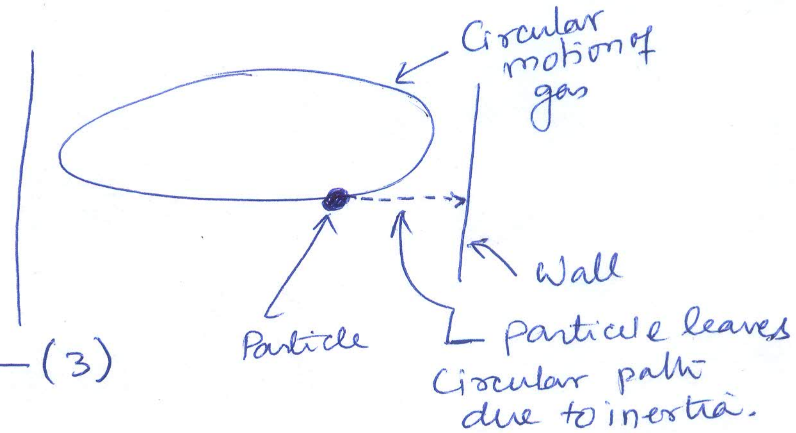
big advantage in using the Centrifugal force

In a sense to get equivalent terminal velocity for Centrifugal force, one can replace g in (1) with acceleration cause by centrifugal force i.e. v_c^2/r and taking the ratio of two terminal velocities for example above; we say —

$$\frac{V_t \text{ (due to Centrifugal)}}{V_t \text{ (due to gravity force)}} = \frac{v_c^2/r}{g} = \frac{18^2/0.3}{9.81} = \underline{110.1}$$

This is helpful to make a device which can use Centrifugal force – in other words we should provide cyclonic motion to gas stream laden with particles (See Figure ~~below~~ 1).

How is the separation –



The efficiency of a cyclone is given by

$$\eta = \frac{\pi N V_c d_p^2 \cdot \rho_{part}}{9 W_i \mu} \qquad (3)$$

$N \rightarrow$ Number of turns in the cyclone for the gas.

$W_i \rightarrow$ Width at the inlet

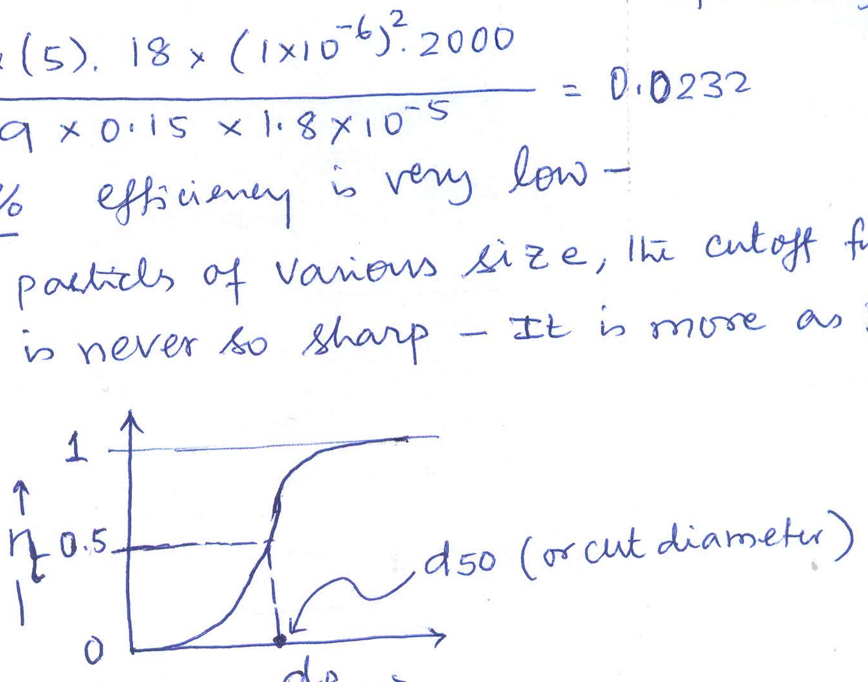
Example

$W_i = 0.15\,m$, $V_c = 18\,m/s$, $d_p = 1\,\mu m$, $\mu = 1.8 \times 10^{-5}\,kg/m\text{-}s$, $N = 5$, $\rho_p = 2000\,kg/m^3$

$$\eta = \frac{3.14 \times (5) \cdot 18 \times (1 \times 10^{-6})^2 \cdot 2000}{9 \times 0.15 \times 1.8 \times 10^{-5}} = 0.0232$$

or $\underline{2.3\%}$ efficiency is very low –

In a mixed of particles of various size, the cutoff for particles for efficiency is never so sharp – It is more as per the Figure below



Most of the cyclones are rated for efficiency against d_{50}.

$$d_{50} = \left(\frac{9 W_i \mu}{2 \pi N v_c \rho_{particle}} \right)^{1/2}$$

Example estimate cut diameter for a cyclone for $W_i = 0.15$ m $v_c = 18$ m/s $N = 5$

$d_{50} \simeq 5\ \mu m$ (generally written as just 5μ).

Examine eq (3), to increase efficiency η, there are two options increase v_c or decrease W_i. Increasing W_i is a smarter idea. Remember pressure drop across any system is proportional to v^2. Pressure drop is energy and thus recurring cost.

<u>Example Pressure drop</u>

$$\Delta P = K . (\rho_g . v_c^2)/2$$

$K = 8$ for cyclones (depends on bands, expansion contraction etc)

$v_c = 18$ m/s $\quad \Delta P = 8\ (1.2 \times 18 \times 18)/2 = 1.555$ k. Pa

or <u>15.86 cm of water column</u>

If W_i is reduced, the cyclone become smaller (see Figure 1) and can not handle the full flow. The idea is to have many small cyclones in parallel receiving same flow so that pressure drop at each cyclone is the same. Such a system is called multicyclone or simply multiclones (See Figure-2). If <u>flow in each cyclone and pressure drop across each cyclone is not same the system of multiclones will fail.</u>

ESP For removing small particles-

General

Resisting Force from eq 1 $\propto d$

driving force for gravity or inertia device] $\propto m \propto d^3$ (for a given density)

$$\frac{\text{driving force}}{\text{resisting force}} \propto d^3/d (= d^2)$$

for submicron 0.5 μm
$d^2 = 0.25$

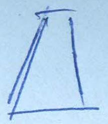
smaller is the particle more difficult to remove.

If we use electric force or charge the particles, the driving force will proportional d^2 (as charge depends on surface). For electric force

$$\frac{\text{driving force}}{\text{resisting force}} \propto d^2/d (= d)$$

for submicron particle ~~0.25~~ 0.5 μm
the ratio is 0.5 μm.

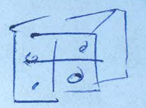
This the idea to have a system called electrostatic Precipitator or commonly called <u>ESP</u>. (Figure 3). More notes on ESP ~~or~~ are being sent.

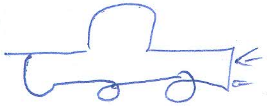


S_j · $j = 1$

a_{ij}

S_1





$j = 2$

a_{ij}

S_j

$j = 3$

a_{ij}

$k = 1$

$$C_{ik} = \sum_{j=1}^{m} a_{ij} \cdot S_j$$

Simplify

$C_{1k} = a_{11} S_1 + a_{12} S_2 + a_{13} S_3 + \cdots$

$C_{2k} = a_{21} S_1 + a_{22} S_2 + \cdots$

$\vdots$

$C_{nk} = a_{n1} S_1 + a_{n2} S_2 + \cdots a_n S_m$

Mostly over determined system

$$[C]_{i \times 1} = [a_{ij}]_{i \times j} [S_j]_{j \times 1}$$

$n > m$

$\det [a_{ij}] \neq 0.$