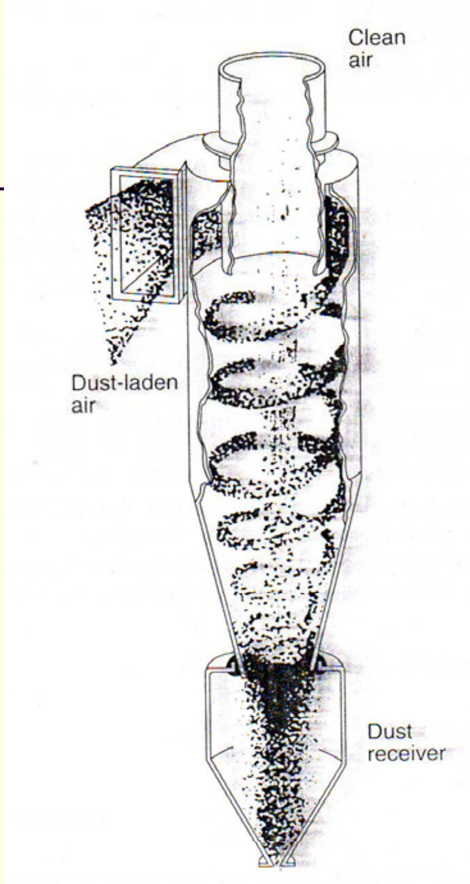
CHAPTER 2

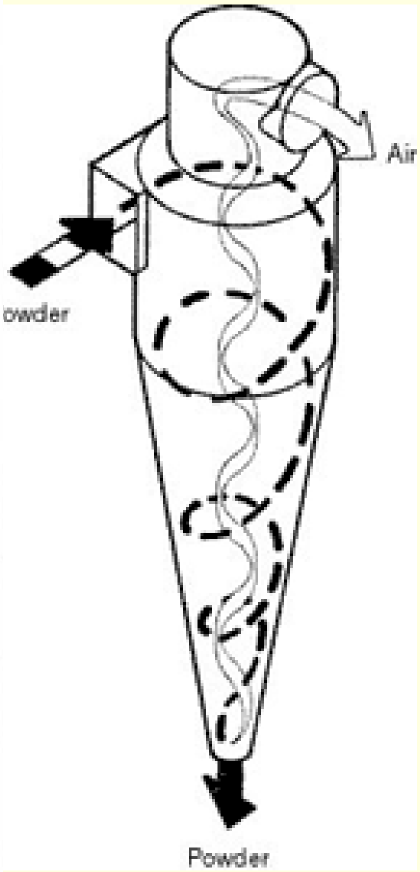
CYCLONES

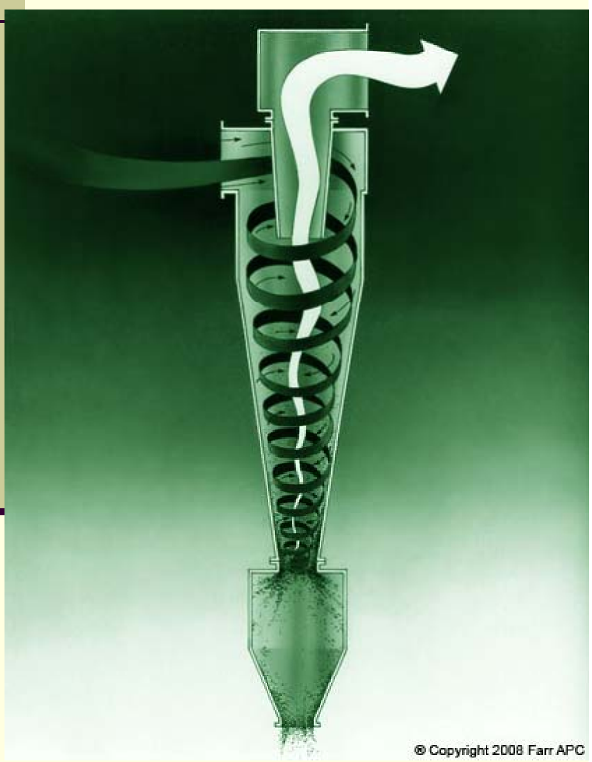
General Structure

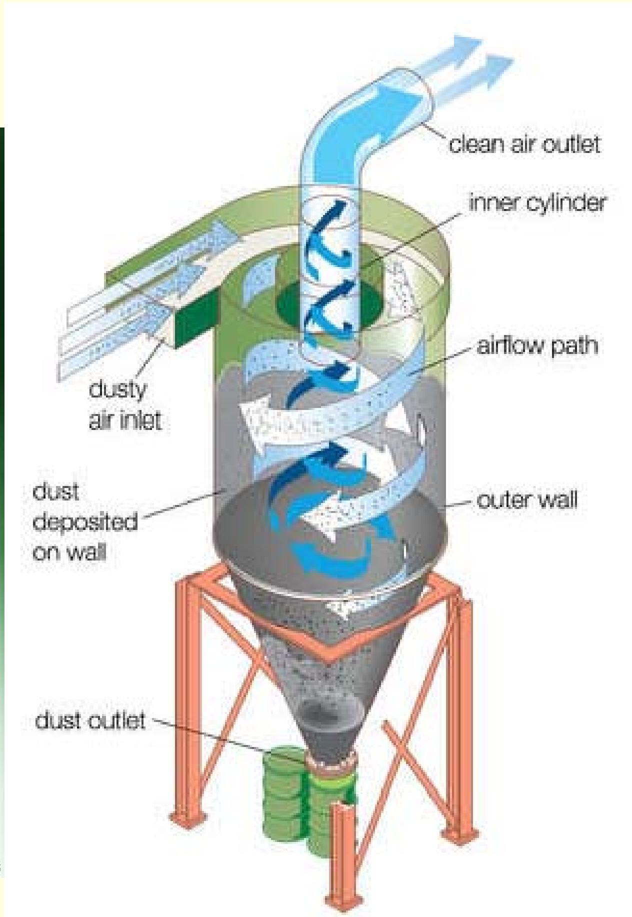


- Moving streamlines for gas and particulates







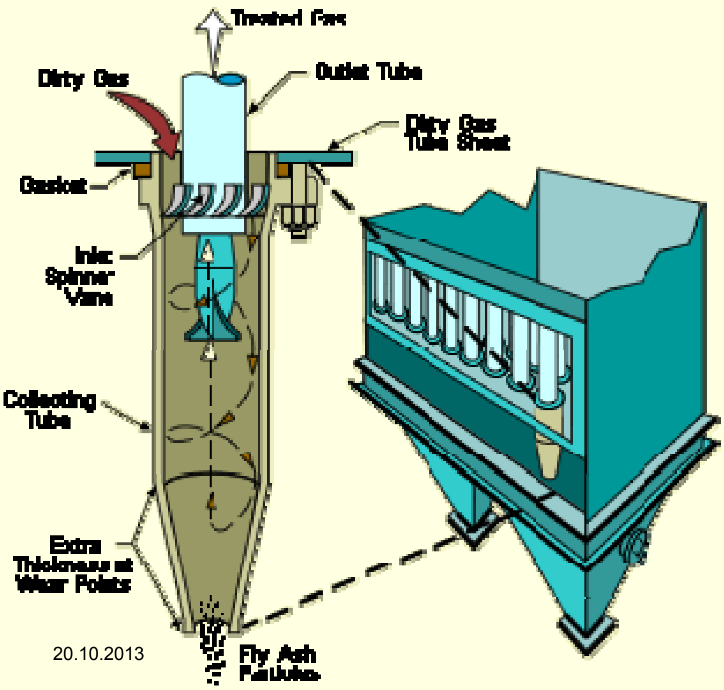


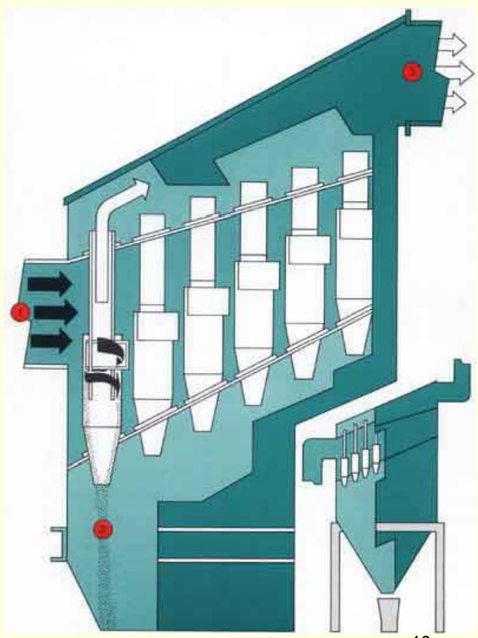
ClearVue Cyclones

Shop Vac
Mini Cyclone Video

Multi-cyclones

Figure 2. Small-Diameter Multi-Cyclone Collector



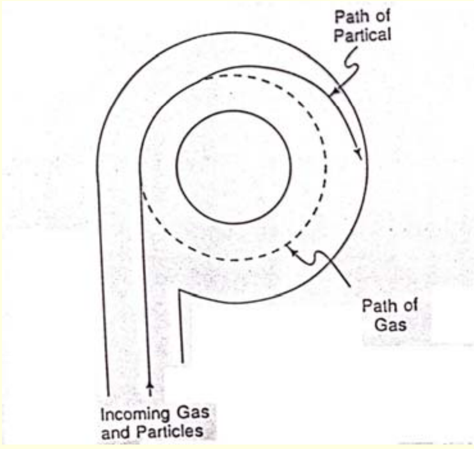


Multi-cyclones

General

A particulate matter control equipment.

The principal collection force: Centrifugal force

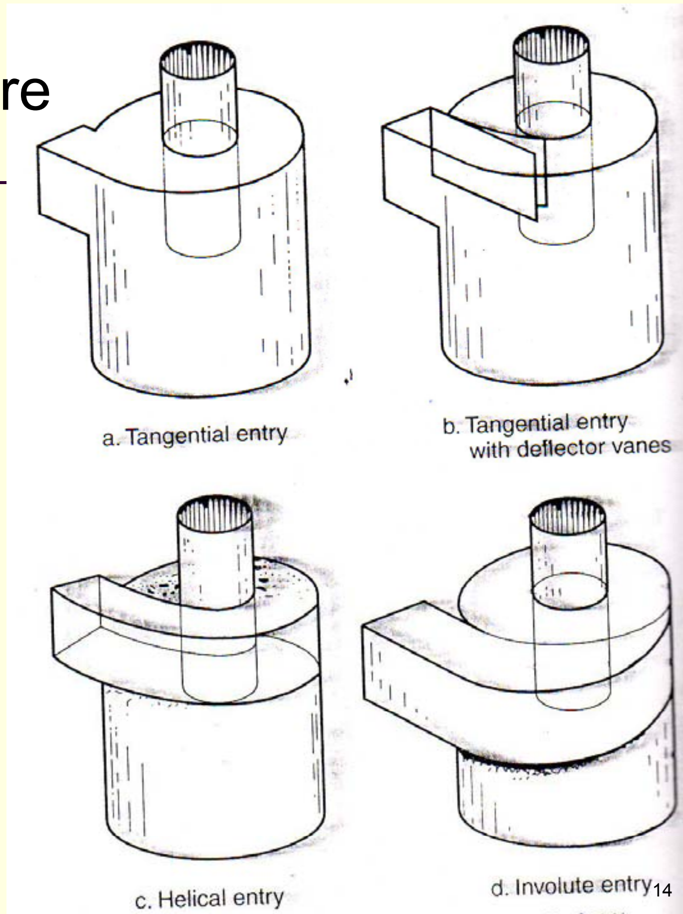


Advantages:
- Low cost equipment
- No moving parts, hence low maintenance costs
- Capable of capturing liquid and solid particulates (noncorrosive particles)
- Harsh operating conditions (high temperatures)
- Proven technology (since 1940s)

Disadvantages:
- Low efficiency for fine particles (dp<10 microns)
- High pressure drop → High operating costs
- Not suitable for adhesive particles

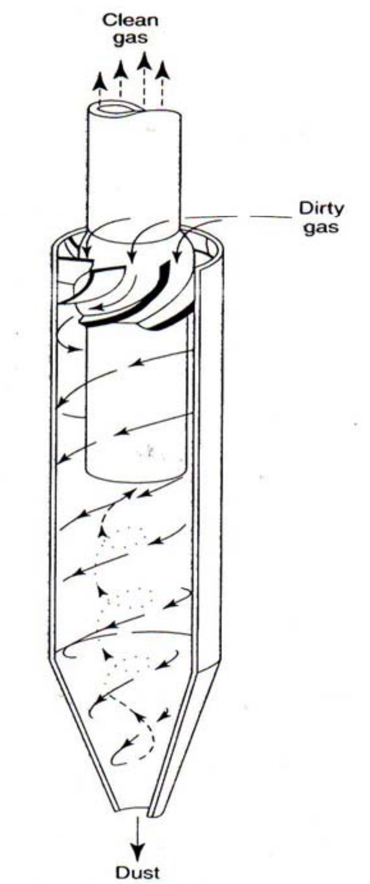
Entrance structure

Tangential entarnce structures

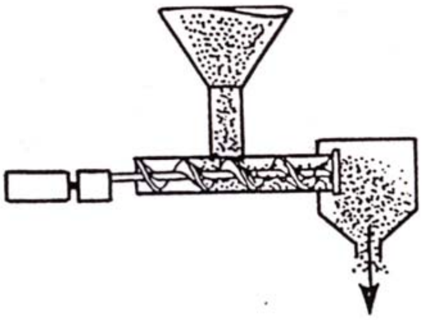


Entrance structure

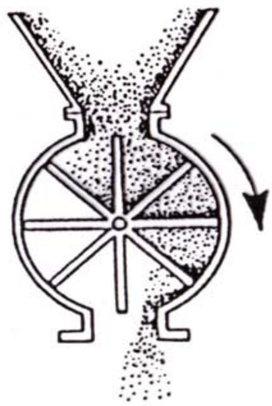
Axial entrance structure



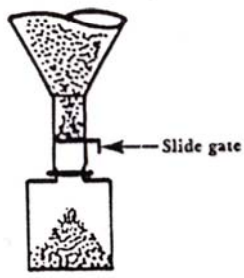
Dust collection mechanisms



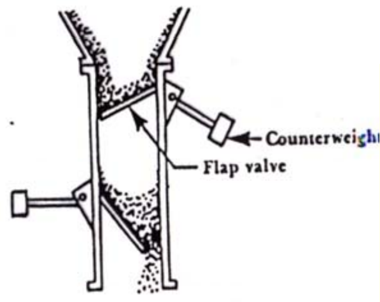
c. Discharge screw feeder



b. Rotary valve



a. Simple manual slide gate



d. Automatic flap valve

Pressure Drops in a cyclone

- Total Pressure Drop (ΔP),between entrance and exit of a cyclone is composed of the following factors:

- 1. Frictional losses in the entrance duct,
- 2. Pressure drop due to sudden expansion in the entrance of cylindrical body
- 3. Frictional losses on the inside wall of the cyclone
- 4. Pressure drop and kinetic energy losses due to turbulence inside the cyclone (**the most important**)
- 5. Pressure drop due to sudden contraction in the entrance of exit duct
- 6. Static pressure drop due to head difference between entrance and exit
- 7. Frictional losses in the exit duct

Design Criteria

- **<u>Two important design criteria</u>**

- **1. Optimum Diameter**
  - High rotational velocity for high efficiency
    Decrease cyclone body diameter in order to increase rotational (tangential) velocity
    But, **saltation** occurs as velocity increases...
    Therefore, velocity should have an **optimum** value…
    Cyclone body diameter is increased to decrease rotational velocity…

  Hence, **<u>Optimum body diameter</u>** is considered

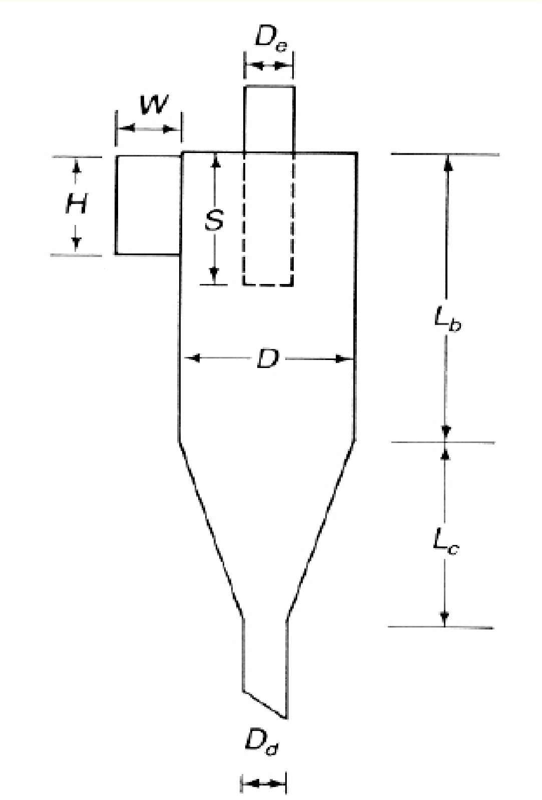
- **2. Check for Pressure Drop…**

Optimum cyclone body diameter

$$D = 0.0502 \left[\frac{Q\,\rho_f^2}{\mu\,\rho_p} \frac{(1 - b/D)}{(a/D)\,(b/D)^{2.2}} \right]^{0.454}$$

(Birimler: ft.,lb.,sn)

Standard Cyclone Dimensions



Standard Cyclone Types

- 1. High Efficiency Cyclones
  - 2 standard geometries
- 2. High Througput cyclones
  - 2 standard geometries
- 3. Conventional Cyclones
  - 2 standard geometries
- A total of 6 standard geometries

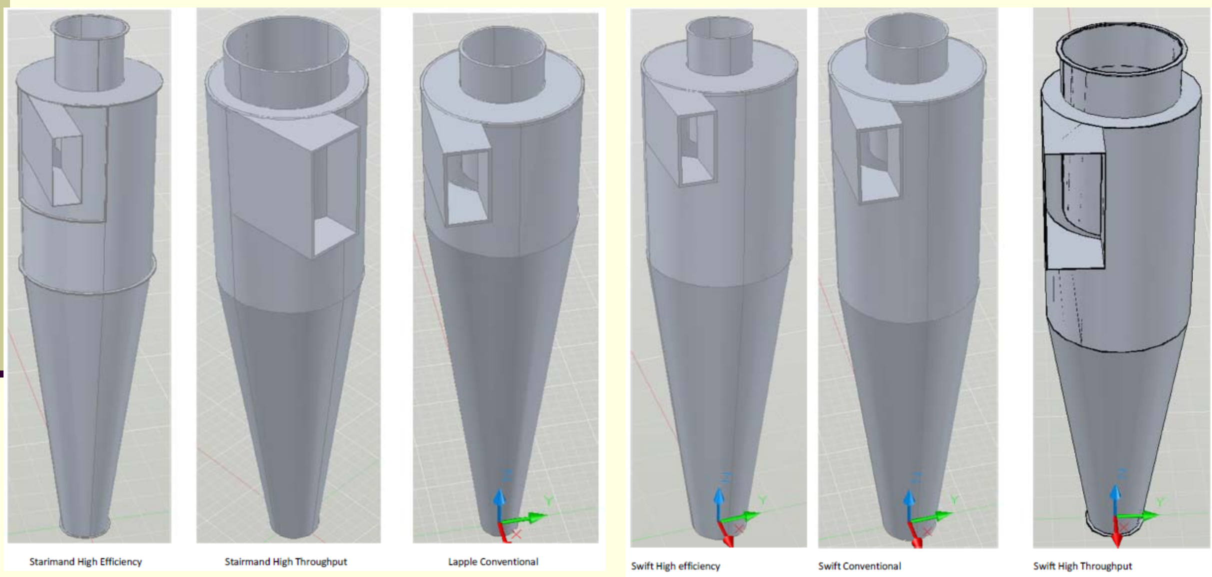
Standard Cyclone Dimesions

Table 1 Standard cyclone dimensions

	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, D/D	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, H/D	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, W/D	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder, S/D	0.5	0.5	0.625	0.6	0.875	0.85
Length of Body, L_b/D	1.5	1.4	2.0	1.75	1.5	1.7
Length of Cone, L_c/D	2.5	2.5	2.0	2.0	2.5	2.0
Diameter of Dust Outlet, D_d/D	0.375	0.4	0.25	0.4	0.375	0.4

SOURCES: Columns (1) and (5) = Stairmand, 1951; columns (2), (4) and (6) = Swift, 1969; columns (3) = Lapple, 1951.

Real Scales of Standard Cyclones



An Empirical Formula For Pressure Drop

- **$\Delta P = 0.0033\ \rho_f'\ u_T^2\ N_H$** ….(English Units)
- $\rho_f' = \rho_f + c\ (\rho_p - \rho_f)$: lb/ft^3
  - c : particle volume / gas volume
- ΔP : pressure drop in inches of water (in. H_2O)
- ---
- **$\Delta P = 5.12\ \rho_f'\ u_T^2\ N_H$** ………(SI Units)
- $\rho_f' = \rho_f + c\ (\rho_p - \rho_f)$: gr/cm^3
  - c : particle volume / gas volume
- ΔP : pressure drop in cm of water (cm H_2O)

Design Procedure

- 1. Choose a standard cyclone geometry according to the data available and required efficiency
- 2. Calculate optimum body diameter
- 3. Check for Pressure Drop
- 4. If Pressure Drop is Acceptable, then Design is OK.
- 5. If Pressure Drop is NOT Acceptable, then
  - -Choose alternative geometry and repeat calculations for acceptable pressure drop, or
  - -Divide gas flow into suitable parts and repeat calculations for acceptable pressure drop.

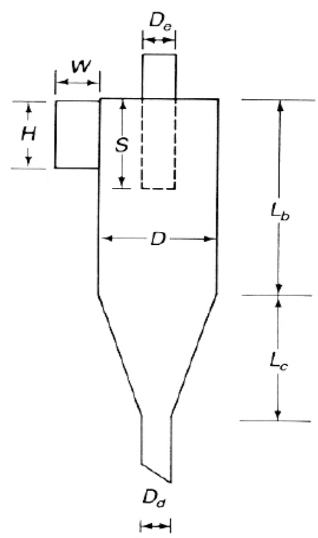
6. When dimensional design is OK, go on for Efficiency calculation

Efficiency Calculation

- The distance gas travels inside the cyclone

(Length of outer vortex in which PM capturing occurs)

$$N_e = \frac{1}{H}\left(L_b + \frac{L_c}{2}\right)$$



N_e = number of effective turns
H = height of inlet duct (m or ft)
L_b = length of cyclone body (m or ft)
L_c = length (vertical) of cyclone cone (m or ft).

Efficiency Calculation

- Residence time of gas on the outer vortex

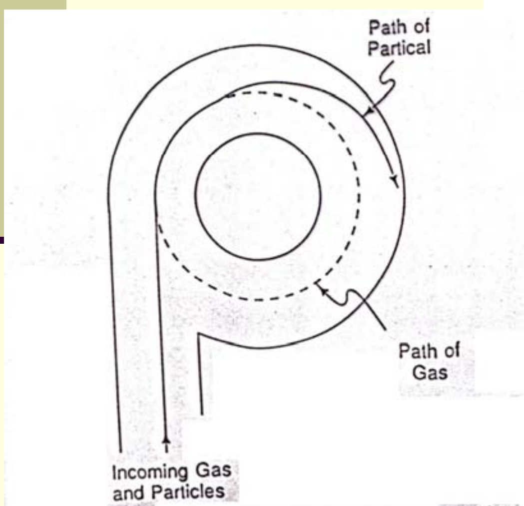
$$\Delta t = \pi D N_e / V_i$$

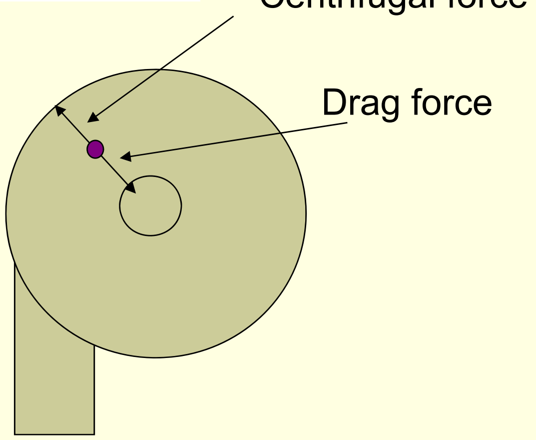
Δt = time spent by gas during spiraling descent (sec)
D = cyclone body diameter (m or ft)
V_i = gas inlet velocity (m/s or ft/s) = Q/WH
Q = volumetric inflow (m^3/s or ft^3/s)
W = width of inlet (m or ft).

Efficiency Calculation

- The minimum velocity (terminal velocity) for particles to be captured…)

$$V_t = W / \Delta t$$





Efficiency Calculation

- Forces acting on particle:
  - **$F_{centrifugal} – F_{drag} + F_{bouyancy} = F_{net} = m\ a$**

$$F_{centrifugal} - 3\pi\mu d_p v + m_p \frac{\rho_f}{\rho_p} g = m \frac{dv}{dt}$$

$$F_{centrifugal} = \frac{mV_i^2}{R}$$

$$\frac{dv}{dt} + \frac{18\mu}{\rho d_p^2} v = \frac{V_i^2}{R}$$

Efficiency Calculation

- Re-arranging the force equilibrium…

$$V_t = \frac{d_p^2 \rho_p V_i^2}{18\mu R} = \frac{W}{\Delta t}$$

- Diameter of the minimum particle to be captured

$$d_p = \left[\frac{9\mu W}{\pi N_e V_i \rho_p}\right]^{1/2}$$

Efficiency Calculation

- This equation says that,,
- Particles having diameter greater than dp will be captured at 100% efficiency
- which is NOT correct in reality…

- Then,

  Only theory is NOT sufficient to calculate the real efficiency…☹

Efficiency Calculation

- Lapple (1950) defined a semi-empirical term called **“50% CUT DIAMETER”** …

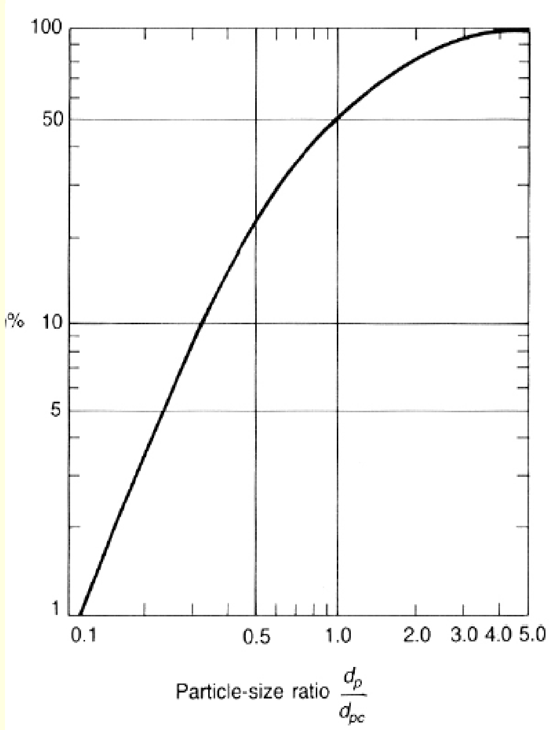
- **<u>Cut diameter</u>**
  - *Use 0,5 for Efficiency term and solve for d_p*

$$d_{pc} = \left[\frac{9 \mu W}{2\pi N_e V_i (\rho_p - \rho_g)} \right]^{1/2}$$

- d_{pc}: diameter of particles captured with 50% efficiency

Efficiency Calculation

- A semi-empirical **individual removal efficiency** for particles having **diameter d_{pj}**:
- $$\eta_j = \frac{1}{1+\left(d_{pc}/d_{pj}\right)^2}$$
- η_j: individual removal efficiency for particles
- d_{pj}: characteristic diameter of particles j



Efficiency Calculation

- Overall removal efficiency:

$$\eta = \frac{\sum \eta_j m_j}{M}$$

η = overall collection efficiency ($0 < \eta < 1$)
m_j = mass of particles in the jth size range
M = total mass of particles.

- You know that $m_j / M = g_j$