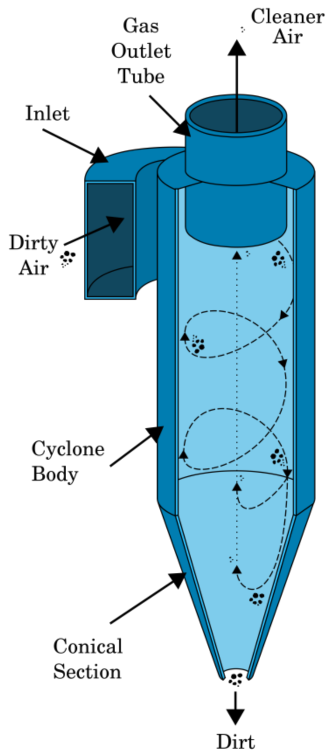
CYCLONES

Operating principles

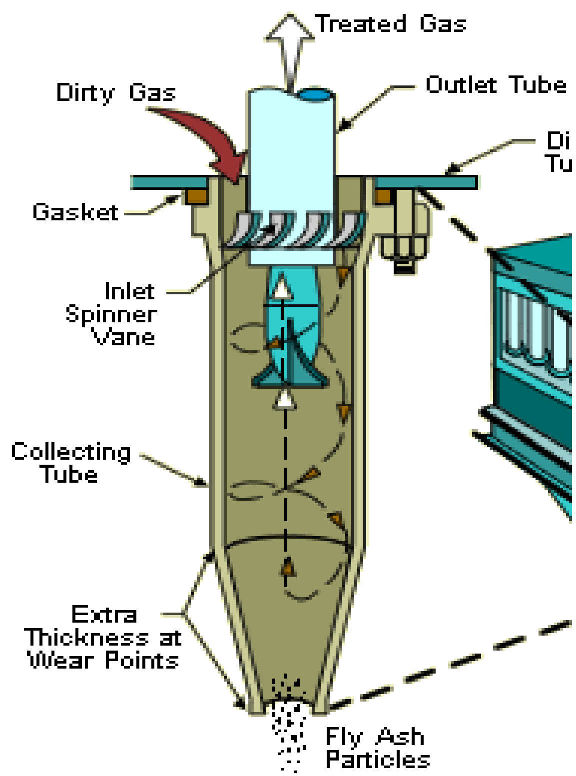
Utilization of **centrifugal force** for particle separation

- centrifugal field developed by the circular motion of gas inside cyclone's body (main vortex)
- vortex created by proper configuration of gas inlet
  - tangential to the circular body (tangential flux)
  - axial to the circular body with proper turning vanes in the inlet section (axial flux)

Tangential flux

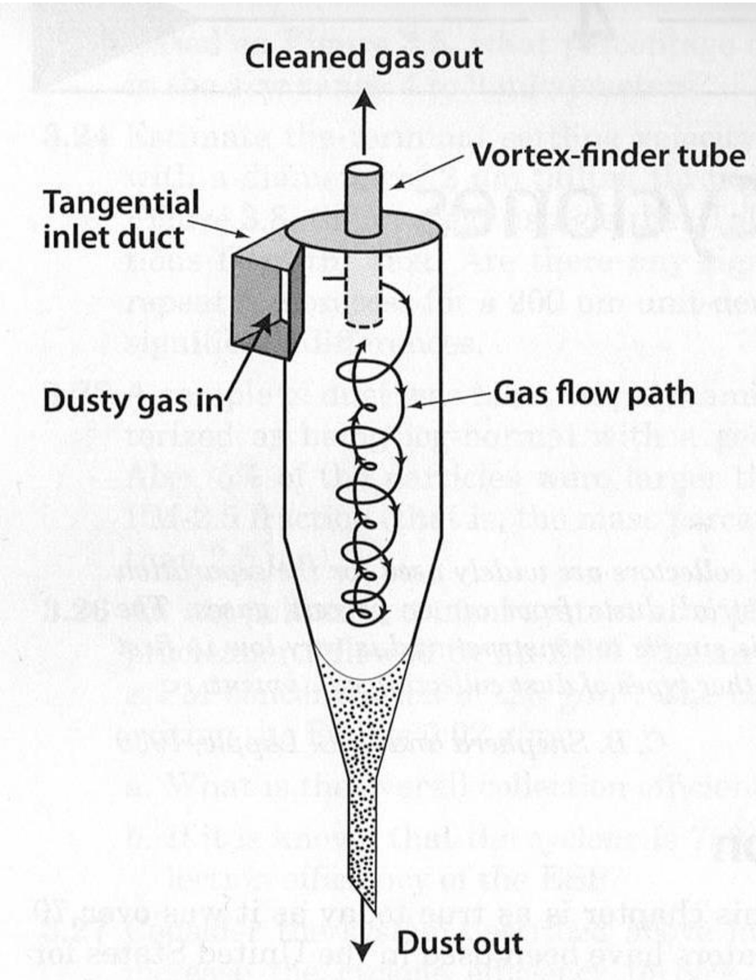


Axial flux



Cyclone configurations

Ciclones separators are probably the most widely used particle collection device in the world



- Typically, they consists of a vertical cilindrical body, with a dust outlet at the conical bottom.
- Generally, the particulate-laden gas **enters tangentially** (the inlet is arranged tangentially to the circular body of the cyclone) near the top of the cyclone.
- Due to the tangential entry and the cyclone's shape, the gas flow **is forced into a downwards spiral path**.
- Near the bottom, the gas **reverses its downwards** spiral and moves upward in a smaller, inner spiral.
- The cleaned gas leave the cyclone through a outlet at the top.
- During the outer spiral of the gas, **the PM are driven by centrifugal forces to the wall**, with whom they collide and slide downward to the bottom of the device.

Cyclone configurations

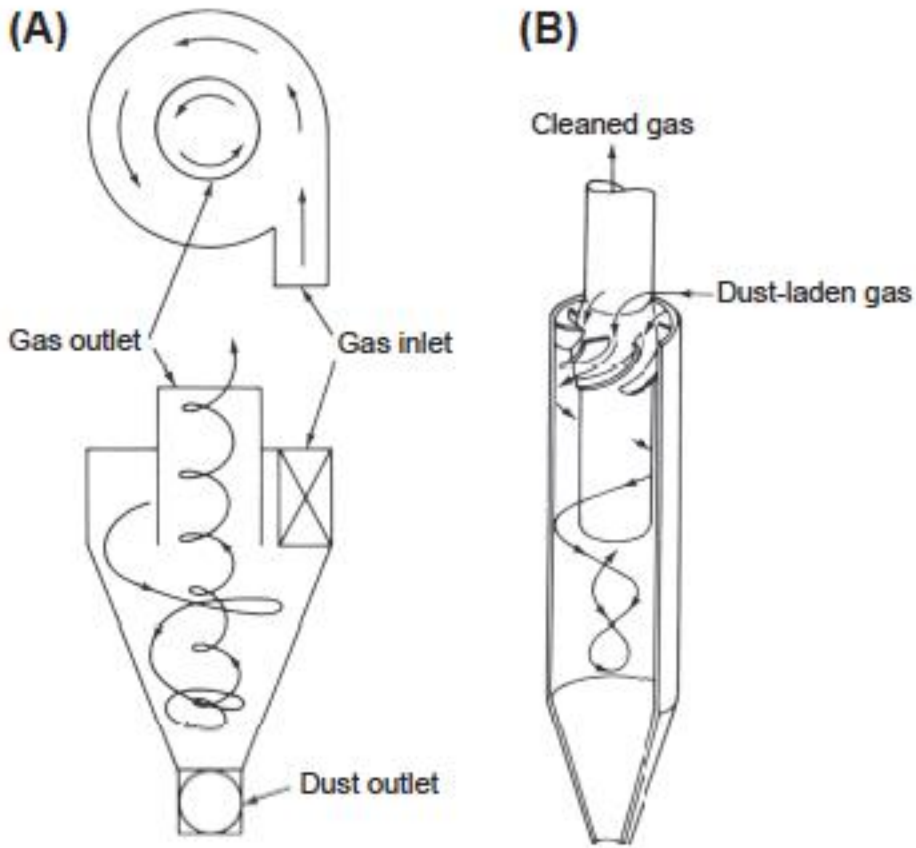


FIGURE 30.8 **Two common cyclone configurations** : (A) tangential inlet and (B) axial inlet. (For color version of this figure, the reader is referred to the online version of this book.)

In actual industrial practice:

- the tangential inlet type is usually a large (1- 5 m in diameter) **single cyclone**,
- while the axial inlet cyclone is relatively small (about 20 cm in diameter and arranged in **parallel units** for the desired capacity).

Cyclone configurations

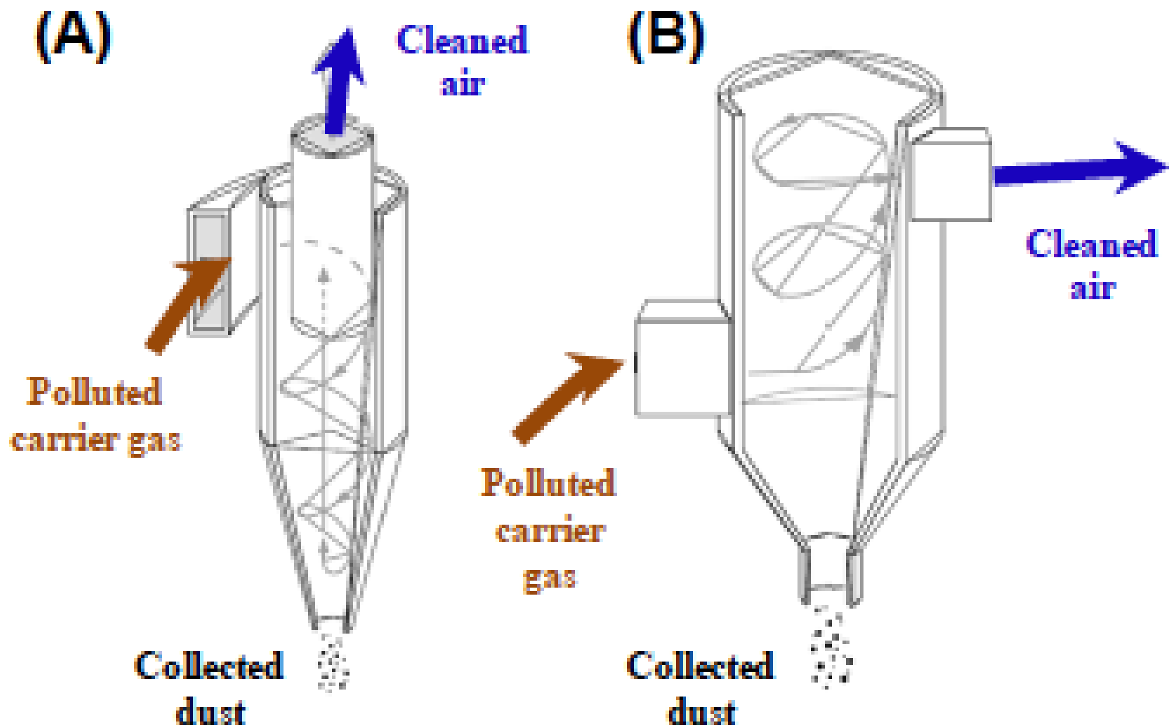


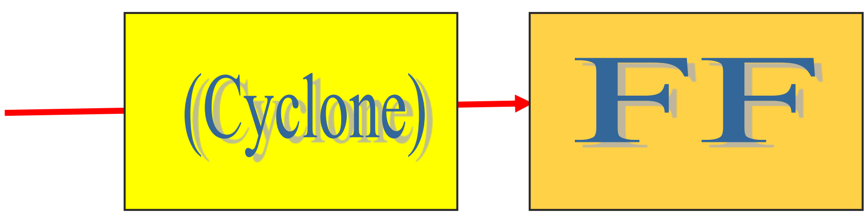
FIGURE 30.9 Schematic of simple cyclone separators: (A) Top inlet type; (B) Bottom inlet type. *Adapted from: U.S. Environmental Protection Agency (2004).* (For color version of this figure, the reader is referred to the online version of this book.) *Air Pollution Control Orientation Course,* *http://www.epa.gov/air/oaqps/eog/course422/ce6.html; accessed November 30, 2013.*

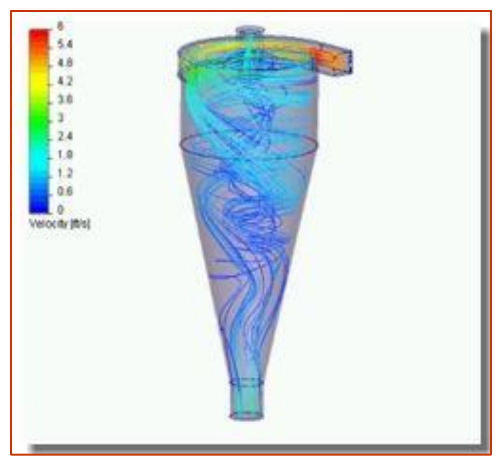
CLEANER AND PLE-CLENEARS

PRE-CLEANERS - example: cyclones

1. **preserve downstream cleaner(s) – (e.g. FF)**
2. **avoid cleaners overload, and a too frequent regeneration**
3. **improve overall dust collection efficiency** (°)
4. **sometimes installed for safety reason** (*e.g. fire prevention of FF, particles still burning in the flue-gas of wood combustion plants)*

(°) low advantages for fine particles!





Advantages and drawbacks of cyclones

❑ Advantages

- low investment and operating costs (contained pressure drops)
- ability to operate at high temperature
- simpler maintenance (no moving equipment or ancillary devices, simple design)
- can handle liquid mists or dry materials
- dry captured particulates discharge
- contained space requirements

❑ Drawbacks

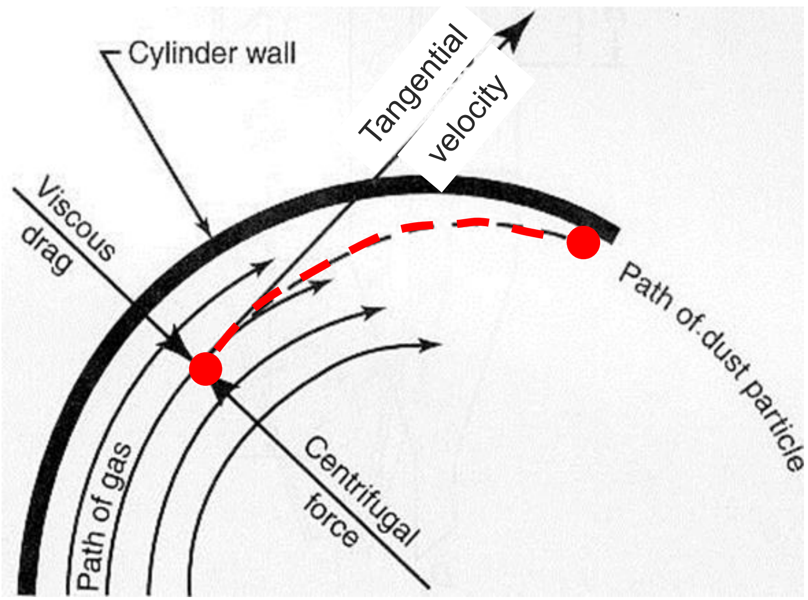
- low capture efficiencies for finer particles
- erosion and/or clogging operating risks
- cyclone has a too low efficiency to be used as a **final** devices (emissions are generally higher than 30 µg dust/Nm^3)

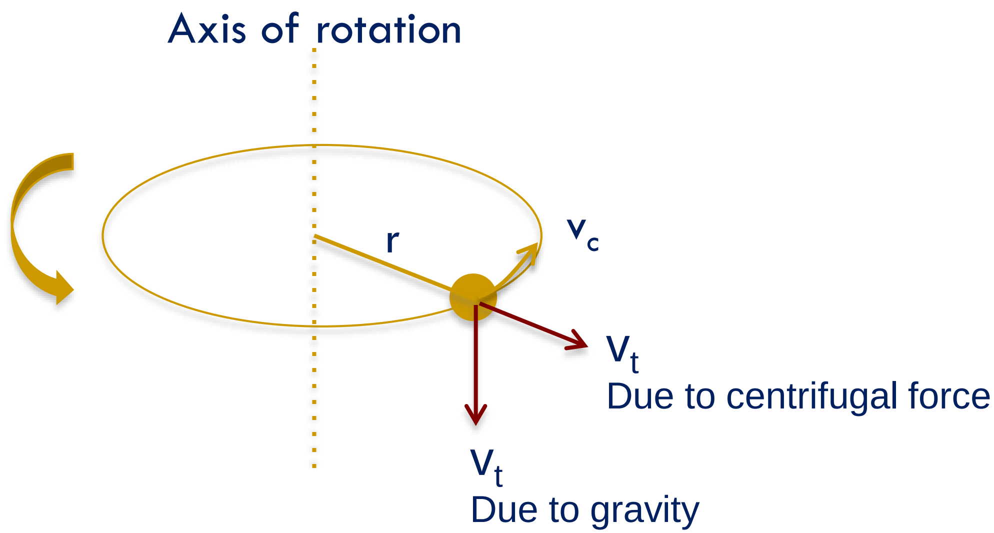
Operating principles: centrifugal force

F_C circular path with radius r, angular velocity ω and tangential velocity v_c along path

$F_C = m\omega^2 r = mv^2_c/r$ (since $\omega = v_c/r$)

Compared with gravity force $F_g \rightarrow F_C/F_g = (mv^2_c/r) / mg = v^2_c/(r \cdot g)$





Example: centrifugal force vs gravity force

Calculate the ratio of centrifugal force to the gravity force acting on a particle travelling in a gas stream with velocity 18 m/s and radius r=0.3048 m.

Gravity force: $F_G = m\,g$

Centrifugal force: $F_c = m\,\frac{v_c^2}{r}$

wooclap

Example: What about buoyancy force?

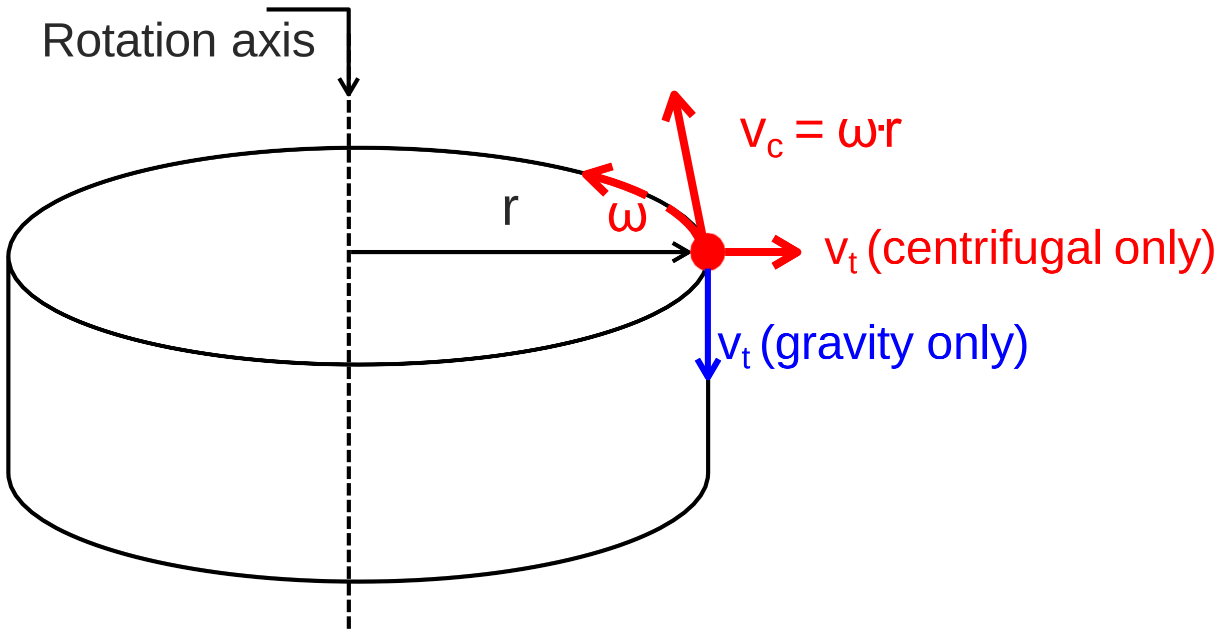
Calculate the ratio of centrifugal force to the gravity force acting on a particle traveling in a gas stream with velocity 18 m/s and radius r=0.3048 m.

Density gas: 1.2 kg/m^3

Density particulate =2000 kg/m^3

Operating principles

Particles motion: terminal velocity v_t



$\Sigma_i F_i = m_p \cdot dv/dt = 0$

Terminal settling velocity: constant velocity of a free flowing particle when gravity force balances drag forces

- Stokes regime for spherical particles in free flow (F_E = gravity force = $m_p g$)

$$F_E - F_A = m_p \cdot dv/dt \rightarrow v_t = d_p^2 \rho_p g / 18 \mu$$

- Stokes regime for spherical particles in centrifugal flow (F_E = centrifugal force = $m_p v_c^2/r$)

$$F_E - F_A = m_p \cdot dv/dt \rightarrow v_t = d_p^2 \rho_p v_c^2 / 18 \mu r \qquad v_t = u_r$$

Example: centrifugal force vs gravity force

Gravity force

RECALL. Calculate the terminal velocity for a **10** μm particle in air.

DATA: density r_g=1.2 x 10^{-3} g cm^{-3};
viscosity m= 1.8 x 10^{-5} kg $m^{-1}s^{-1}$;
particle density r_p=**1.0** g cm^{-3};
T=20°C.

SOLUTION

$$v_t = \frac{d_p^2 \rho_p \, Cu \, g}{18\mu} = 0.3 \frac{cm}{s}$$

Cu can be assumed equal to 1

Centrifugal force

Terminal settling velocity v_t in presence of a Centrifugal force

Calculate the terminal velocity for a **10** μm particle in air, but in a circular gas flow with velocity v_c=18.29 m/s and radius r=0.3048 m.

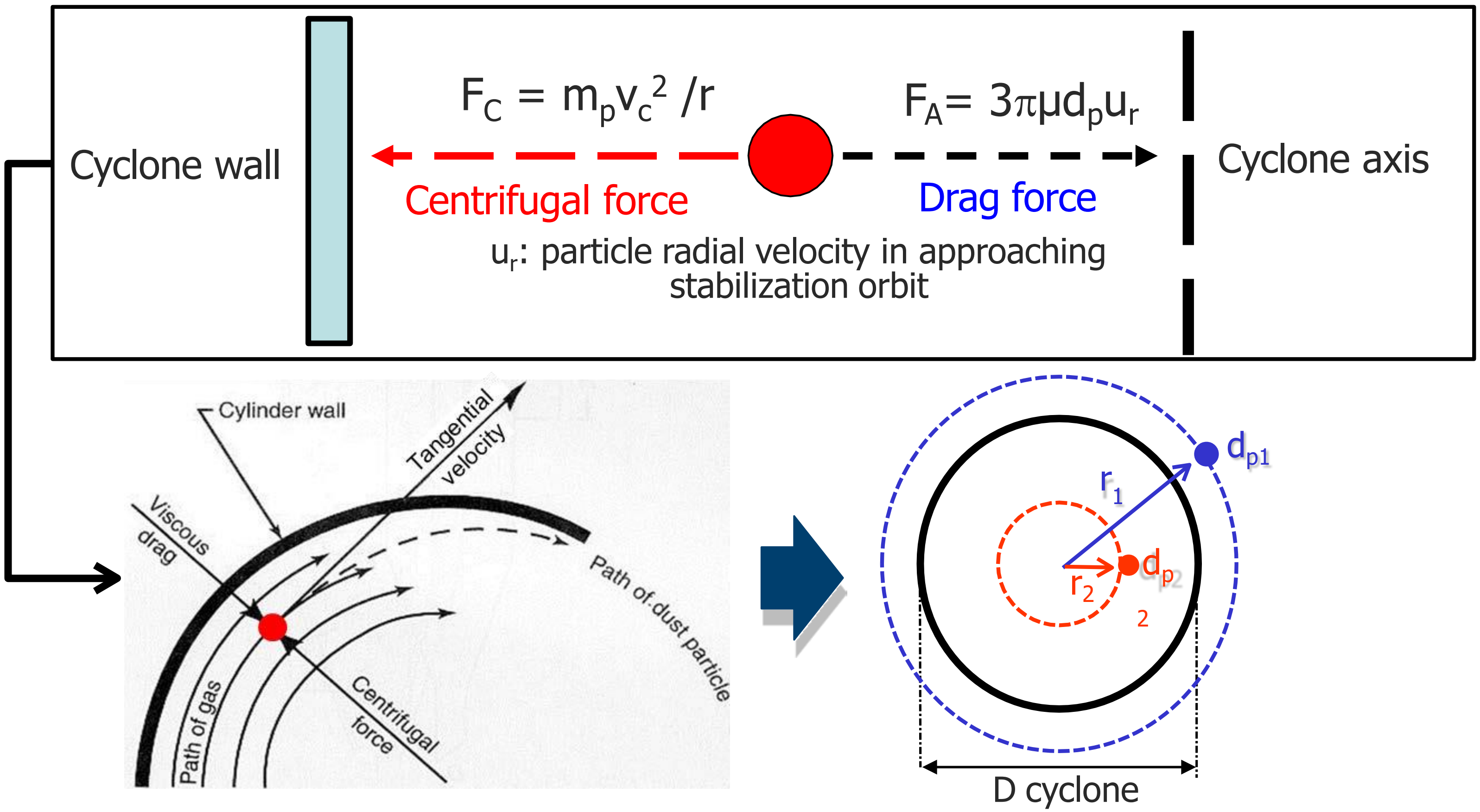
DATA: density r_g=1.2 x 10^{-3} g cm^{-3};
viscosity m= 1.8 x 10^{-5} kg $m^{-1}s^{-1}$;
particle density r_p=**1.0** g cm^{-3};
T=20°C.

$$v_t = \frac{d_p^2 \, \rho_p \, v_c^2}{18\mu r} = \frac{\left(10x10^{-6}\right)^2 [m^2] 1000 \left[\frac{kg}{m^3}\right] (18.29)^2 \left[\frac{m}{s^2}\right]}{18 \cdot 1.8x10^{-5} \left[\frac{kg}{ms}\right] 0.3048[m]} = 0.33 \left[\frac{m}{s}\right] = 33 \left[\frac{cm}{s}\right]$$

This value is **100 times** as large as the previous value indicating that much greater settling velocities can be obtained by applying centrifugal forces.

Operating principles

Particles motion: centrifugal force moves particles towards cyclone walls, with movement hindered by drag forces → net effect of classification on particles by size, whose distribution in cross section results from their stabilisation on orbits with radius dependent on particle diameter **d_p, where centrifugal force is exactly balanced by drag resistance**



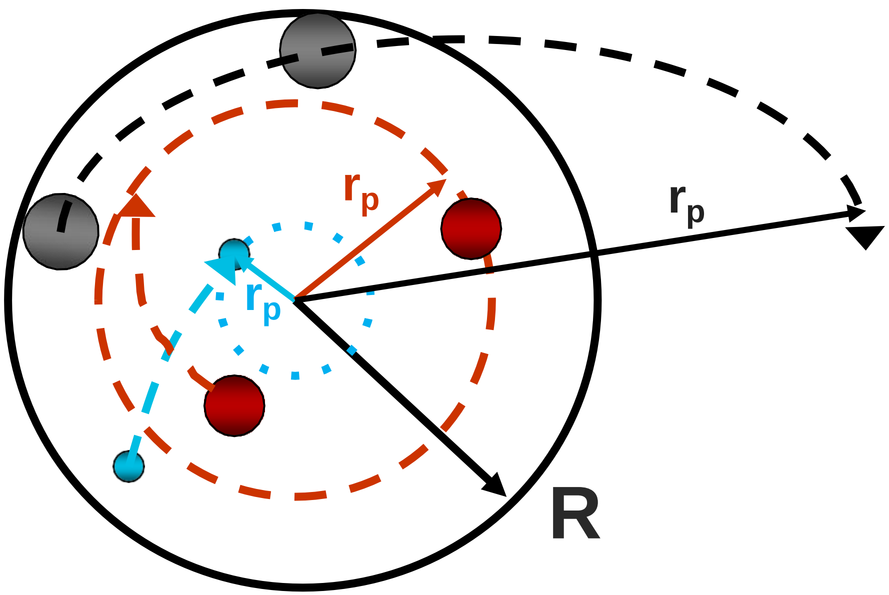
Operating principles

Particle orbit radius r_p

$$\mathbf{F_C = F_A \rightarrow r_p = \rho_p\, d_p^2\, v_C^2/(18\, \mu\, u_r)}$$

v_c = tangential velocity; u_r = radial velocity= vt

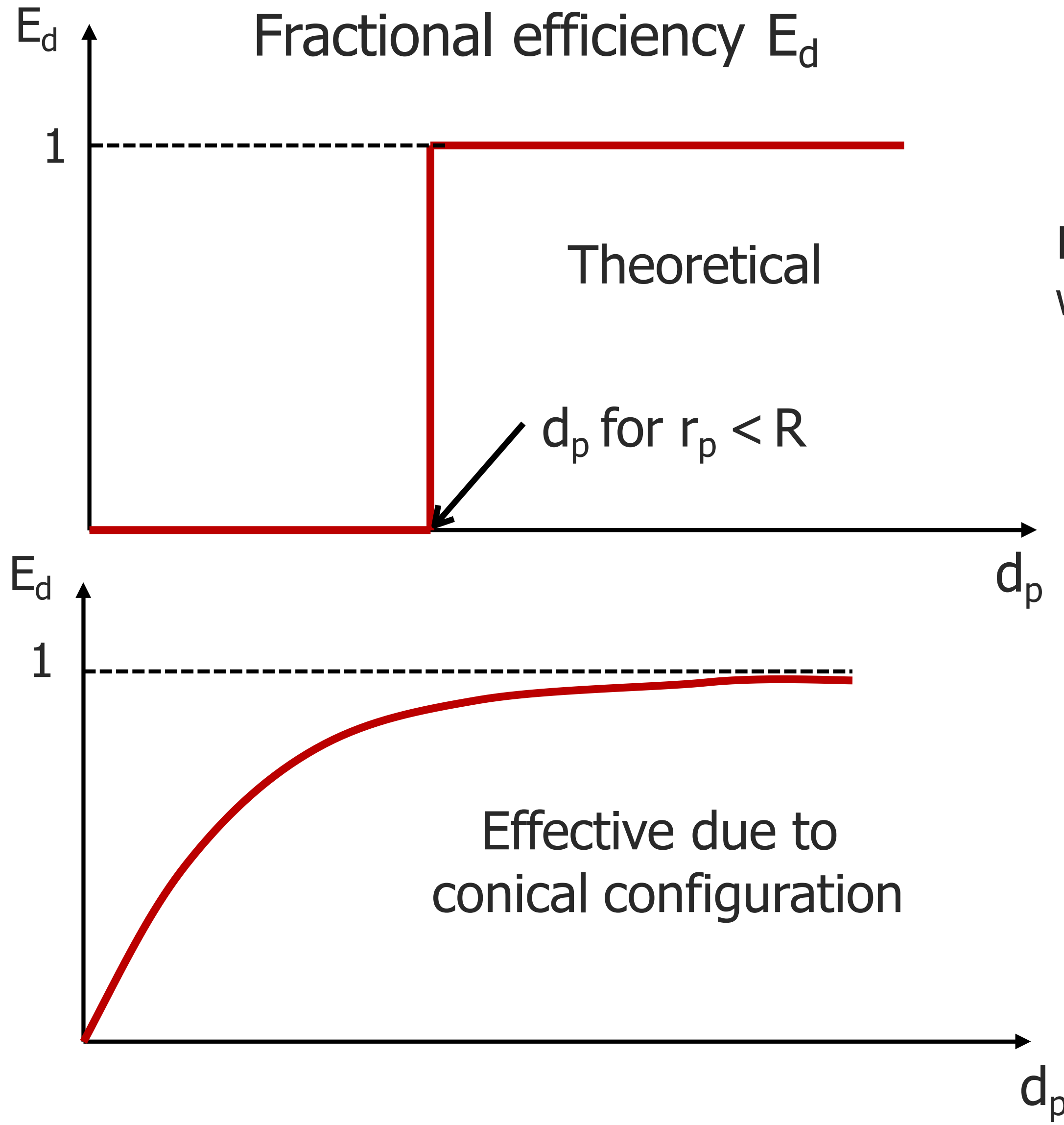
- Particle separated on cyclone wall ($\mathbf{r_p}$>**R**)
- Particle retained in orbit ($r_{inner\ vortex}$<$\mathbf{r_p}$< **R**)
- Particle not retained ($\mathbf{r_p}$<$r_{inner\ vortex}$)



Capture efficiency increase with

- particle mass (d_p, ρ_p)
- tangential velocity (head losses)
- Body diameter: smaller cyclones more efficient →multicyclone configurations

Operating principles

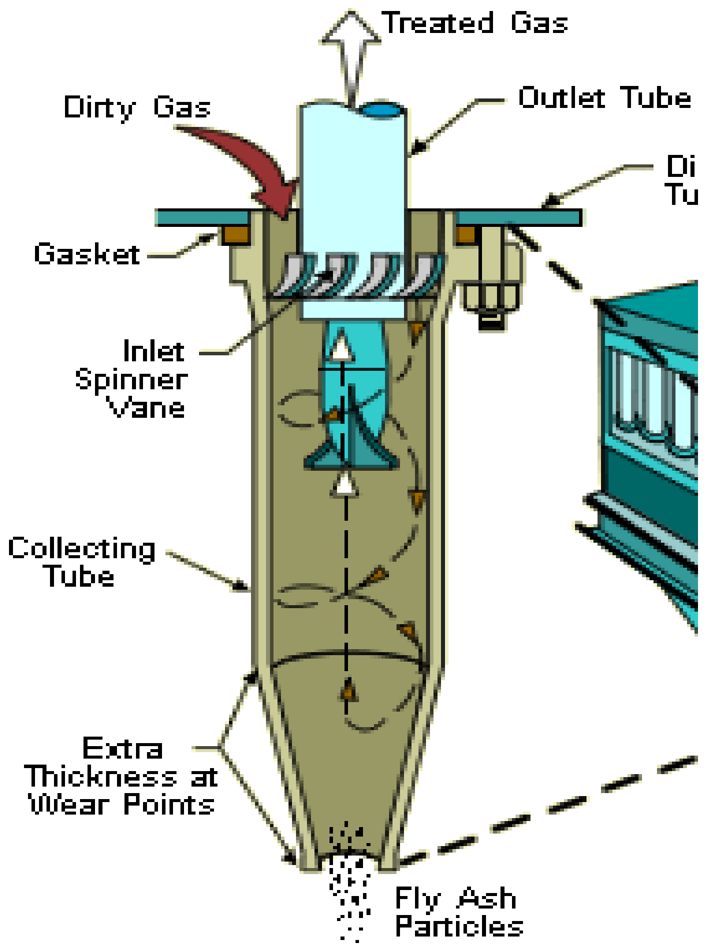


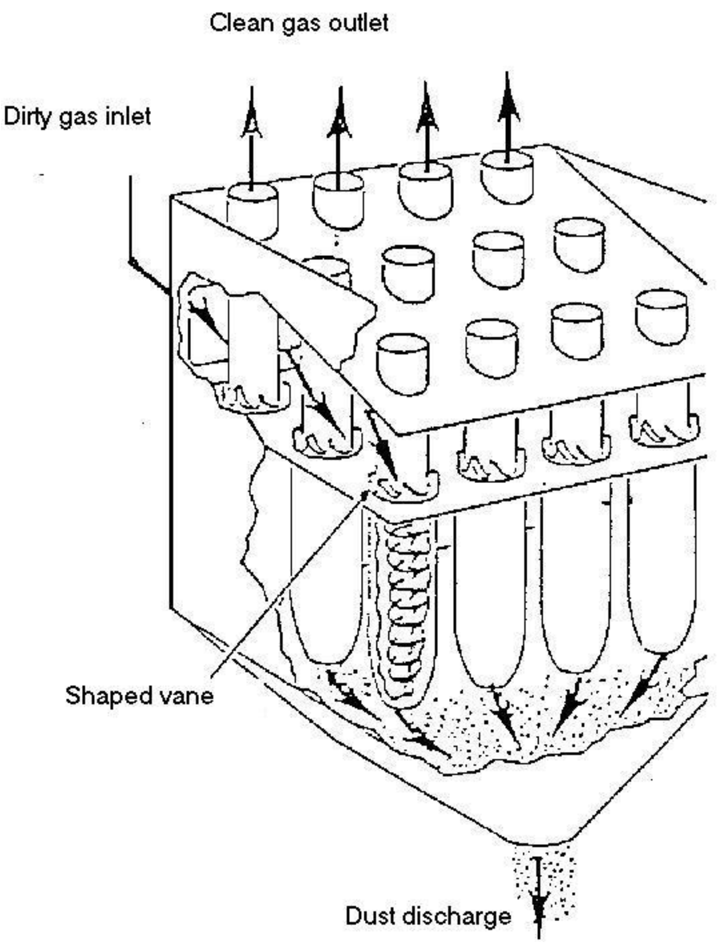
$$r_p = \rho_p \, d_p^2 \, v_C^2 / (18 \, \mu \, u_r)$$

Particle separated on cyclone wall ($r_p > R$)

Design configurations: Multicyclones

- handle large gas flows without excessive cyclone diameters
- removal efficiency increase (smaller units)





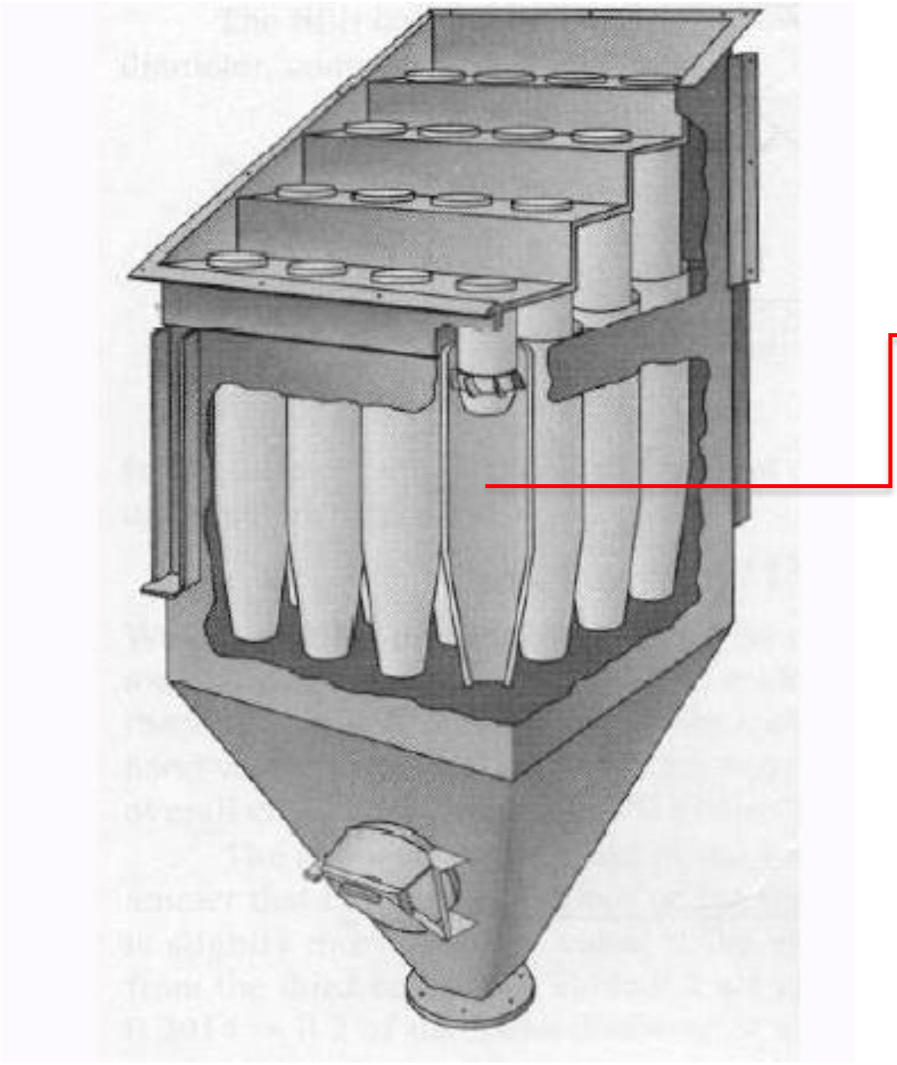
Design configurations

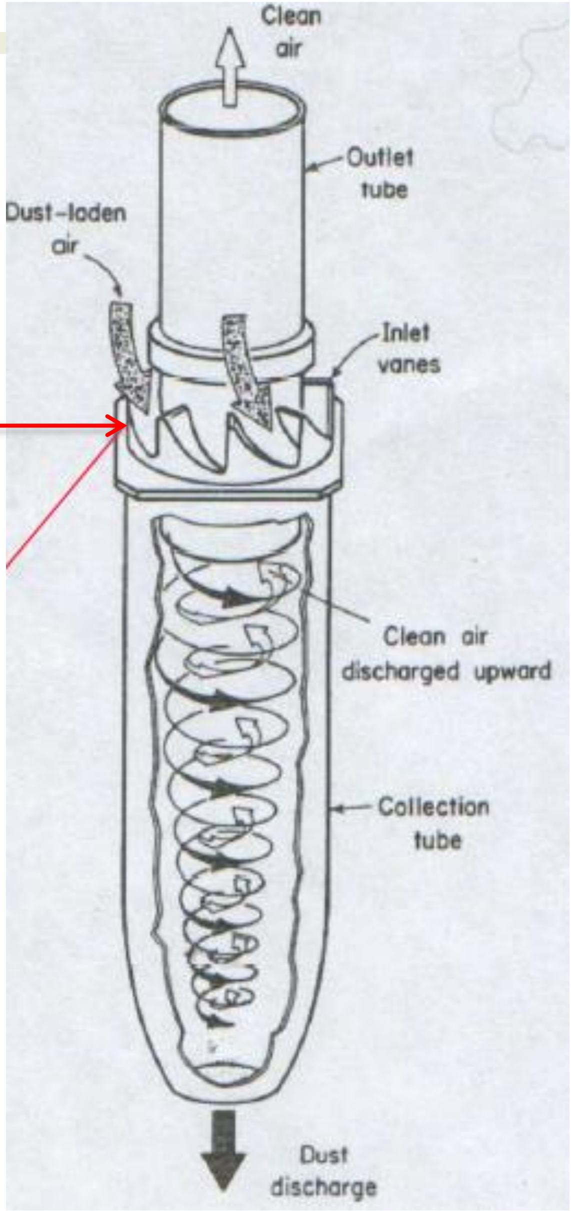
Low-pressure drop cyclone
at Rochester Asphalt Plant
(Victor, NY)

A cyclone used in a woodshop
(Lebanon, NH)

Design configurations: Multicyclones

Design configurations: Multicyclones

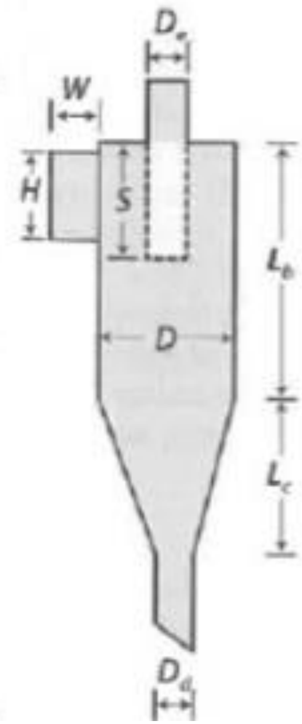




Design configurations of classical cyclone

- Standard configurations: derived from full scale devices with design optimized for efficiency and pressure drop
- geometric and performance parameters defined in terms of cyclone diameter or **body diameter**

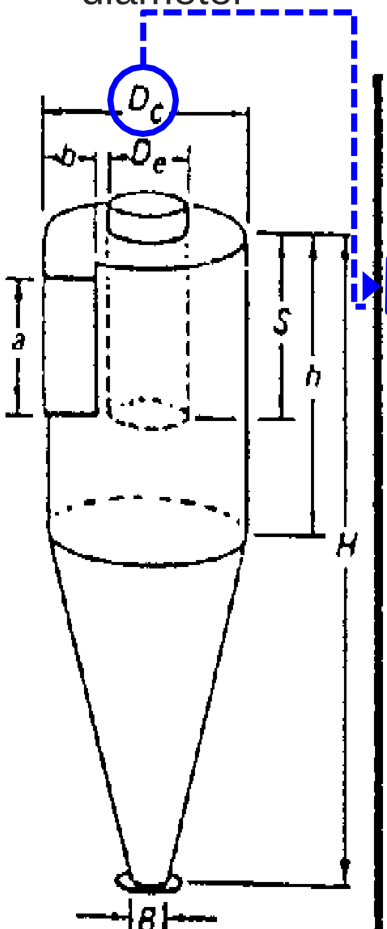
	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, D/D	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, H/D	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, W/D	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, D_e/D	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex 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



Columns 1) and 5) adapted from Stairmand, 1951; column 2), 4) and 6) adapted from Swift, 1969; column 3) adapted from Lapple, 1951 (Reference: Air Pollution Control: A Design Approach, 4th Ed, by C. David Cooper and F. C. Alley, Waveland Press, Inc)

Design configurations of classical cyclone

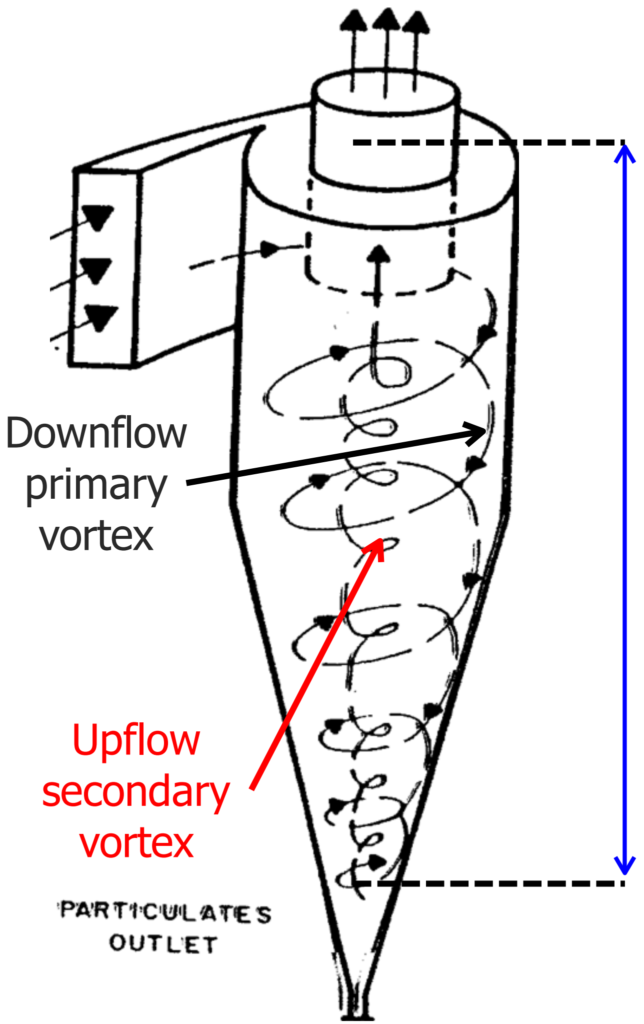
- Standard configurations: derived from full scale devices with design optimized for efficiency and pressure drop
- geometric and performance parameters defined in terms of cyclone diameter or body diameter



$$\text{Natural length } Z = 2.3D_e\left[\frac{D_c^{\,2}}{a \cdot b}\right]^{1/3}$$

Nomenclature		High-efficiency: Stairmand	High-efficiency: Swift	General-purpose: Lapple	General-purpose: Swift	General-purpose: Peterson & Whitby
D_c	body dia.	1.0	1.0	1.0	1.0	1.0
a	inlet height	0.5	0.44	0.5	0.5	0.583
b	inlet width	0.2	0.21	0.25	0.25	0.208
S	outlet length	0.5	0.5	0.625	0.6	0.583
D_e	outlet dia.	0.5	0.4	0.5	0.5	0.5
h	cylinder height	1.5	1.4	2.0	1.75	1.333
H	overall height	4.0	3.9	4.0	3.75	3.17
B	dust outlet dia.	0.375	0.4	0.25	0.4	0.5
Z	natural length	2.48	2.04	2.30	2.30	1.8
$K = 8\,K_c/K_a^2\,K_b^2$		551.3	699.2	402.9	381.8	324.8
$N_H = 16\,ab/D_e^2$		6.40	9.24	8.0	8.0	7.76
K/N_H		86.14	75.67	50.36	47.7	41.86

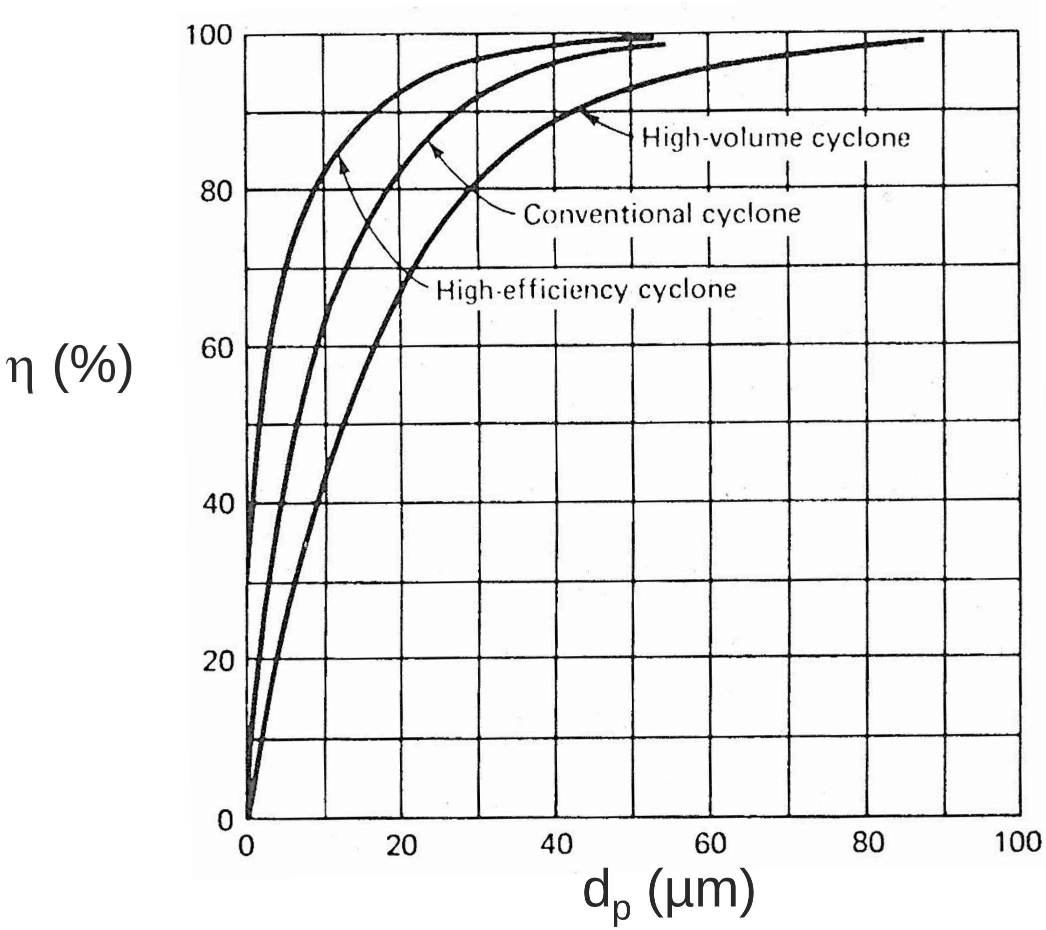
CYCLONES - Design configurations



Natural length Z

height of inversion in the direction of main flux (vortex). Dependent only on geometric parameters

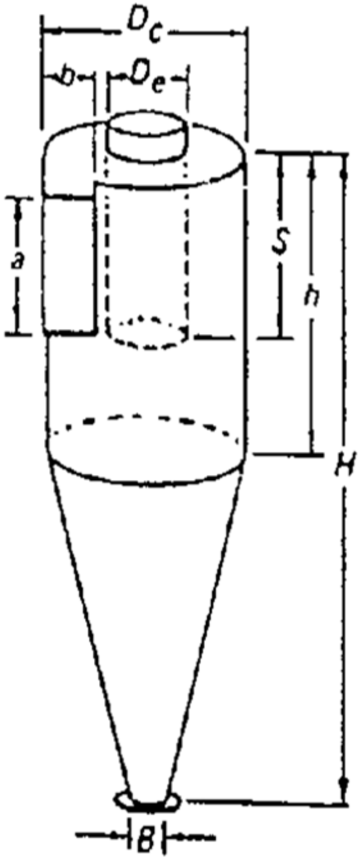
CYCLONES – General efficiencies



General relationship of collection efficiency versus particle size for cyclones

Empirical method (Lapple)

Cut diameter d_{pc} is the diameter of particles collected with 50% efficiency



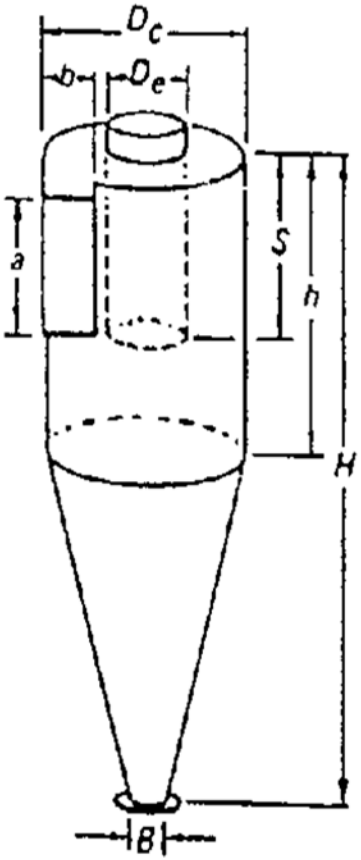
$$d_{pc} = \left(\frac{9 * \mu * b}{2 * \pi * N_e * (\rho_p - \rho_g) * u_{in}} \right)^{1/2}$$

Where:

- μ: gas viscosity
- b (or W): inlet width
- a (or H): inlet height
- N_e : number of gas revolutions in outer vortex
  = [h + (H - h)/2]/a
- u_{in} = flue gas inlet velocity = Q/(a*b)
- h: cylinder height
- H: overall height

Empirical method (Lapple)

Cut diameter d_{pc}

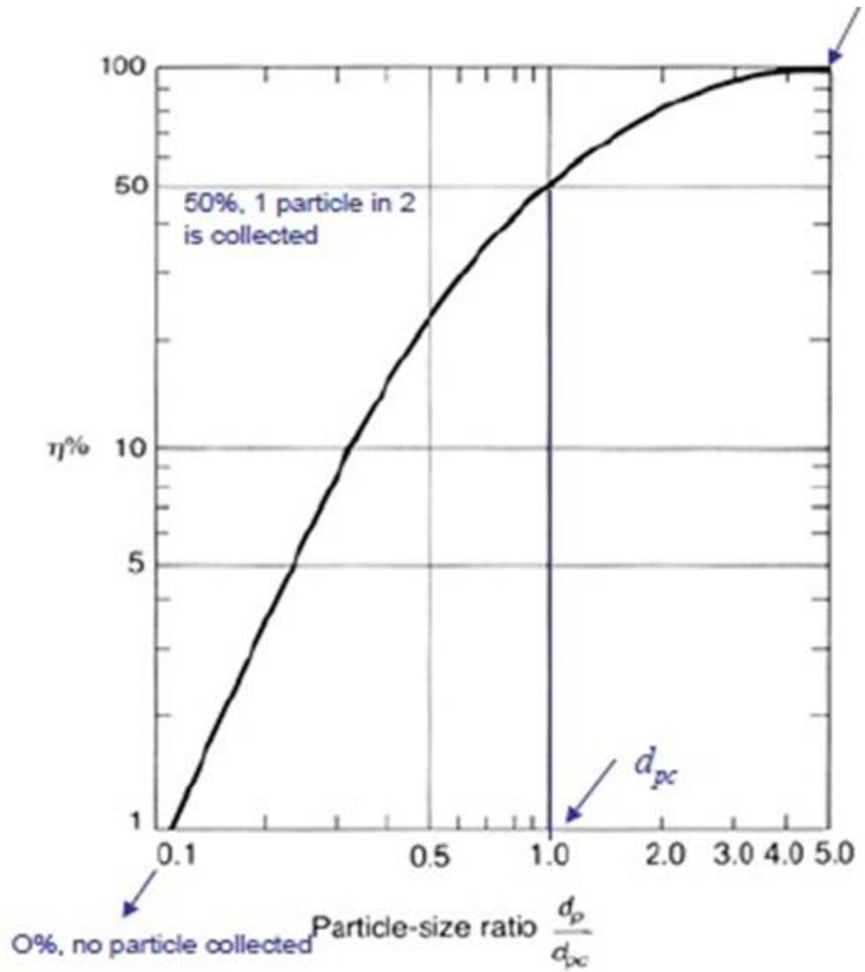


$$E(d_{p,i}) = \eta(d_{p,i}) = \frac{1}{1 + (\frac{d_{pc}}{d_{p,i}})^2}$$

η_T (total efficiency) from inlet size distribution and device configuration geometry

$$E_T = \eta_T = \sum m_i * E_{p,i}$$

Empirical method (Lapple): particle collection efficiency versus particle size ratio for standard conventional cyclones



Lapple then developed a general curve for standard conventional cyclones to predict the collection efficiency for any particle size (see side figure).

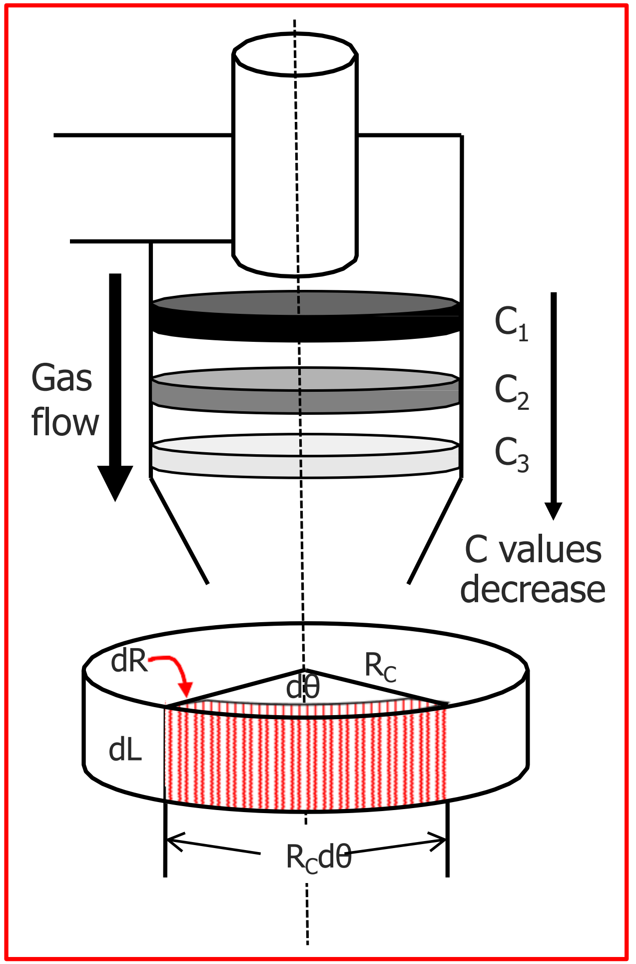
If the size distribution of particles is known, the overall collection efficiency of a cyclone can be predicted by using the figure.

Theodore and DePaola (1980) then fitted an algebraic equation to the curve, which makes Lapple's approach more precise and more convenient for application to computers. The efficiency of collection of any size of particle is given by

Semiempirical approach

ASSUMPTION

- Complete radial mixing → uniform concentration of uncollected dust in any horizontal cross section (C constant with R)
- Gravity force is neglected
- U_T*R^n= constant (U_T= tangential gas velocity; n= vortex exponent)
- Residence time t: average value, resulting from geometry of standard configurations K_C (non dimensional parameter), cyclone diameter D and flue gas flow rate Q → $t = K_C D^3/Q$



PROCEDURE

- Apply a mass balance
- In time interval dt, within the volume sector bounded by dθ, dL and R_C:
  - all particles travel a vertical distance dL and a tangential distance $R_C d\theta$
  - simultaneously, particles within a certain distance dR from cyclone wall are removed

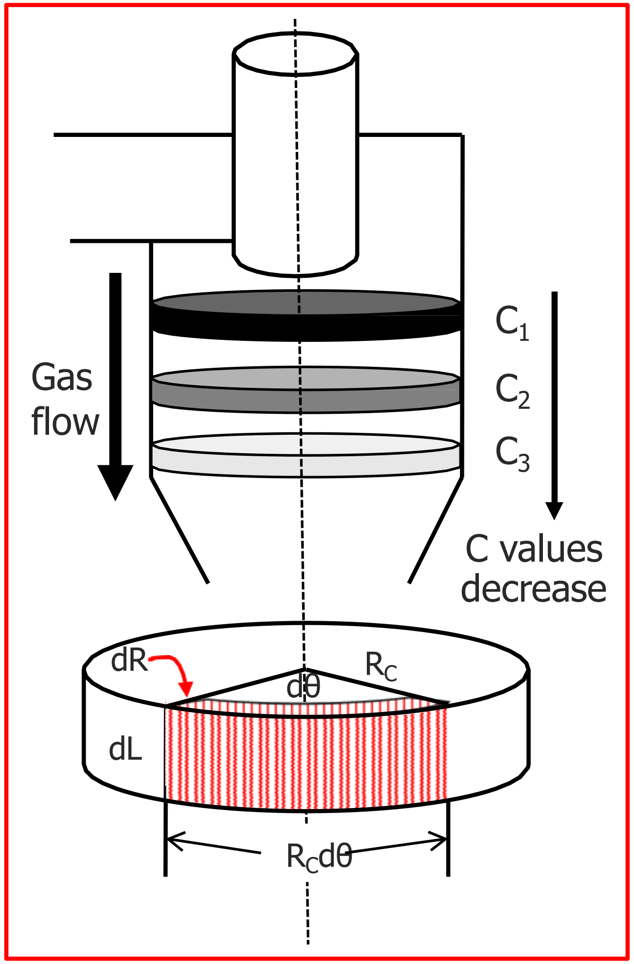
Semiempirical approach

Radial mixing model → collection efficiency

Complete radial mixing → uniform concentration of uncollected dust in any horizontal cross section (C constant with R)

In time interval dt, within the volume sector bounded by dθ, dL and R_C:

- all particles travel a vertical distance dL and a tangential distance $R_C d\theta$
- simultaneously, particles within a certain distance dR from cyclone wall are removed



Semiempirical approach

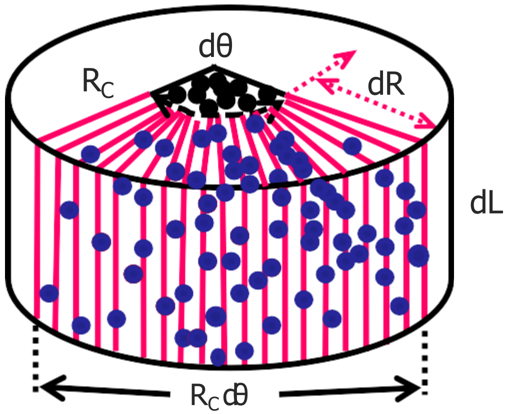
- total particles present in sector over dt:

  $m_{tot} = (R_C^2 \cdot d\theta/2 \cdot dL) \cdot C$

removed

⇩

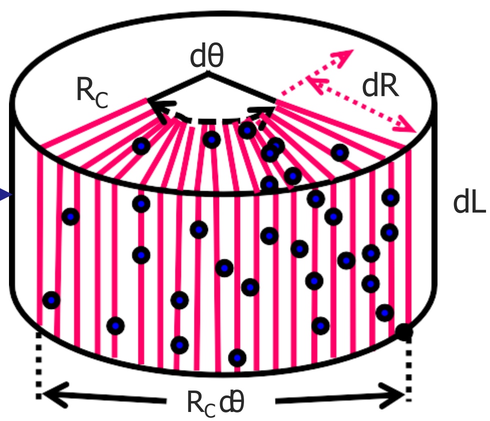
present within dR



- mass of particles removed over dt:

  removed = total - present in $(R_C - dR)$

  removed $= [R_C^{\,2} - (R_C - dR)^2] \cdot d\theta/2 \cdot dL \cdot C$



Radial mixing model: mass balance

Collection efficiency E_d along dt:

$E_d = dm/m$

where $dm = m_{t+dt} - m_t = -$ removed

$E_d = dm/m = -$ removed/total

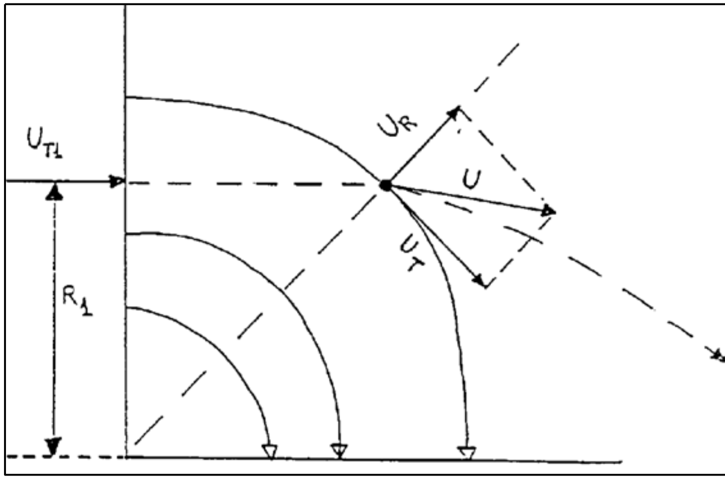
$E_d = -2dR/R_C$ **(1)**

(excluding second order differential dR^2)

Need to insert relationship of R with residence time

Semiempirical approach: Particle dynamics in fluid with circular motion

1. Particle velocity components (neglecting gravity)
   - tangential U_T = tangential gas velocity V_T
   - radial $U_R = dR/dt$



2. Momentum balance on particle (radial direction)

$$F_E - F_A = m_p \cdot dU_R/dt$$

$$m_p dU_R/dt = m_p U^2_T/R - 3\pi\mu d_p U_R \qquad (2)$$

3. From experimental tests,

   $U_T R^n$ = constant (n = vortex exponent, see later) (3)

4. Utilizing (3), momentum balance on spherical particle (2) becomes: $d^2R/dt^2 = U^2_{T0}R_0^{2n}/R^{2n+1} - [18\mu/(\rho_p d_p^{\ 2})](dR/dt)$

with R_0 is the innermost radial position and U_{T0} the corresponding tangential velocity. Neglecting 2nd order terms:

$$dR/dt = U^2_{T0}R_0^{2n}\tau/R^{2n+1}, \qquad \text{with } \tau = \rho\, d_p^{\ 2}/18\mu \text{ (relaxing time)}$$

By integration between t=0 (R_0) and t (R):

$$t = R_0^2[(R/R_0)^{2n+2}-1]/[2(n+1)\tau U^2_{T0}] \qquad (4)$$

From (3), $U_{T0}R_0^n = U_{TC}R_C^{\ n}$: equation (4) becomes

$$t = R_C^{\ 2}[(R/R_C)^{2n+2} - (R_0/R_C)^{2n+2}]/[2(n+1)\tau U^2_{TC}$$

with R_C = cyclone radius, U_{TC} = outermost tangential velocity

Semiempirical approach: Fluid particle dynamics in circular motion

5. Since $R_0 = 0$, solving for R and deriving with respect to time t:

$$\frac{dR}{dt} = \tau \frac{U_{TC}^2}{R_C}\left[2(n+1)\,\tau\left(\frac{U_{TC}}{R_C}\right)^2 \cdot t\right]^{-\frac{2n+1}{2n+2}}$$

representing the required relationship between R and t.

6. From mass balance [see **(1)**], integrating over residence time t:

$$E_d = -\int_{m_0}^{m}\frac{dm}{m} = 2\int_0^R \frac{dR}{R_C} = 2\tau\left(\frac{U_{TC}}{R_C}\right)^2\left[2(n+1)\tau\cdot\left(\frac{U_{TC}}{R_C}\right)^2\right]^{-(2n+1)/(2n+2)}\int_0^t t^{-(2n+1)/(2n+2)}dt =$$

$$= 2\left[2(n+1)\tau\cdot\left(\frac{U_{TC}}{R_C}\right)^2\cdot t\right]^{1/(2n+2)}$$

$$\text{Since } E_d = -\int_{m_0}^{m}\frac{dm}{m} = \ln\frac{m_0}{m} \Rightarrow \frac{m}{m_0} = \exp\int_{m_0}^{m}\frac{dm}{m} \text{ and } E_d = \frac{m_0 - m}{m_0} = 1 - \frac{m}{m_0}, \text{ then}$$

$$E_d = 1 - \frac{m}{m_0} = 1 - \exp\int_{m_0}^{m}\frac{dm}{m} = 1 - \exp - 2\left[2(n+1)\tau\left(\frac{U_{TC}}{R_C}\right)^2 t\right]^{\frac{1}{(2n+2)}}$$

Semiempirical approach: Fluid particle dynamics in circular motion

7. Residence time t: average value, resulting from geometry of standard configurations (K_C: non dimensional parameter), cyclone diameter D and flue gas flow rate Q:

$$t = K_C D^3/Q$$

8. Assuming U_{TC} equal to gas inlet velocity Q/(ab):

$$E_d = 1 - \exp - 2\left[\frac{(n+1)\tau Q}{D^3}\,\frac{8K_C D^4}{(ab)^2}\right]^{1/(2n+2)}$$

Inertial parameter ψ_d (gas/particle characteristics)

Geometric parameter K (standard configuration geometry)

n = vortex exponent; From experimental tests, $U_T R^n$ = constant ; normally included between 0.5 - 0.9

$n = 1 - (1 - 0{,}67\ D^{0,15})\ (T/283)^{0,3}$ [Alexander empirical formula]

Where: T = temperature (K); D = cyclone diameter (m)

τ = relaxing time = $\rho\, d_p^{\,2}/18\mu$

Kc non dimensional parameter used to estimate the resident time

Cyclone design: Semiempirical approach

$$E_d = 1 - \exp - 2\left[\frac{(n+1)\tau Q}{D^3}\frac{8K_C D^4}{(ab)^2}\right]^{1/(2n+2)}$$

$$E_d = 1\text{-}\exp\left(-2(\psi_d K)^{1/(2n+2)}\right)$$

In terms of d_p:

τ = relaxing time = $\rho\, d_p{}^2/18\mu$

$$E_d = 1\text{-}\exp\text{-}(M * d_p{}^N)$$

$$M = 2\left[(n+1)\frac{QK\rho_p}{18\mu D^3}\right]^{1/(2n+2)}$$

$$N = 1/(n+1)$$

Cyclone design: Semiempirical approach – Effect of D (size) on Ed (collection efficiency)

$$E_d = 1\text{-}\exp\text{-}(M{*}d_p^N)$$

$$E_d \approx 1 - \exp - \left[\frac{k}{\left(D^3\right)^{1/(2n+2)}} \right]$$

With:

- k = numerical constant
- n = vortex exponent; normally included between 0.5 - 0.9

D **increase** → $\exp - \left[\frac{k}{\left(D^3\right)^{1/(2n+2)}} \right]$ **increase** → Ed **decrease**

smaller diameters, larger efficiencies → *multicyclones*

Cyclone design: Semiempirical approach- Collection efficiency

Factors not considered (approximations of E_d)

- agglomeration of finer particles by collisions inside vortex → coarser particles → efficiency increase → conservative approach (OK)
- re-entrainment phenomena of removed particles for higher gas velocities and/or smaller diameters → efficiency decrease → overestimation (NO GOOD)

Empirical equation for correct estimation of cyclone diameter D [Karen-Zenz]

$$D = 0.029 \left[\frac{Q\rho_g^2}{\mu\rho_p} \frac{(1 - \frac{b}{D})}{\left(\frac{a}{D}\right)\left(\frac{b}{D}\right)^{2.2}} \right]^{0.454}$$

with Q, ρ_p, ρ_g and μ in SI units (kg, m, sec) and D in m

Pressure drop

- Main phenomena involved: expansion/compression losses at outlet/inlet, wall friction losses, kinetic losses from turbulence (most significant)

- Normally expressed in terms of inlet velocity heads ($u^2/2g$)

$$\Delta P = \frac{1}{2} * \rho_g * u^2 * H_v$$

Where:

- ΔP: pressure drop (N/m^2 or Pa)
- ρ_g: gas density (kg/m^3)
- u: gas inlet velocity (m/s)

Optimum design conditions for:

- u → 15 - 30 m/sec
- Δp → 8 - 20 cm H_2O (784.48 -1961.2 Pa)

$$H_v = K * \frac{a * b}{De^2}$$

- K: a constant that depends on cyclone configuration and operating condition; for air pollution work with standard tangential-entry cyclones, values of K are in the range of 12 to 18. A value of 16 is commonly set
- «a» (or H) and «b» (or W): are inlet height and inlet width (m) respectively
- D_e: Outlet diameter (m)

General field of applications

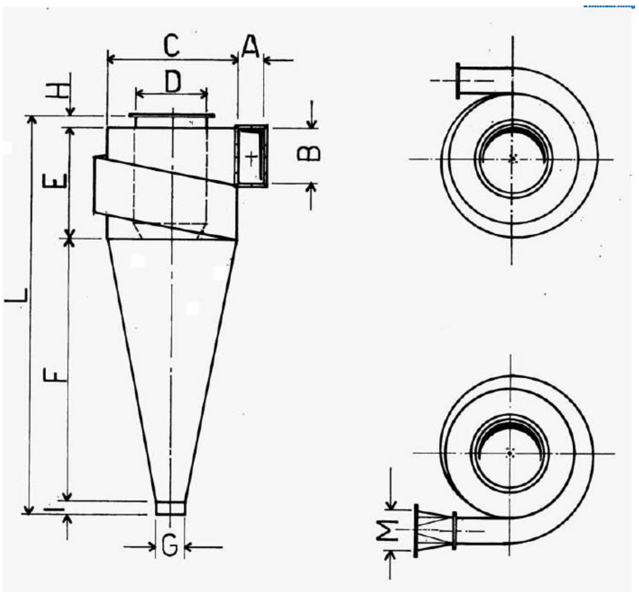
- For particle sizes under 5 µm, capture efficiencies rarely over 80%

general application as pretreatment, upstream of more efficient devices, unless for coarse particulate emissions ($d_p \geq 20 - 30$ µm)

- General performance and operating parameters

Parameter	Conventional design	High efficiency design (multicyclones)
Grade efficiency		
< 5 µm	< 50%	50%-80%
5-20 µm	50%-80%	80%-95%
20-50 µm	80%-95%	95%-99%
>50 µm	95%-99%	95%-99%
Operating parameters		
Pressure loss (kPa)	0.5-1	1-5
Cyclone diameter (m)	1-10	0.15-0.3
Inlet gas velocity (m/sec)	5-15	20-30
Energy consumption (kWh/1000 m^3)	0.15-0.3	0.6-1.5

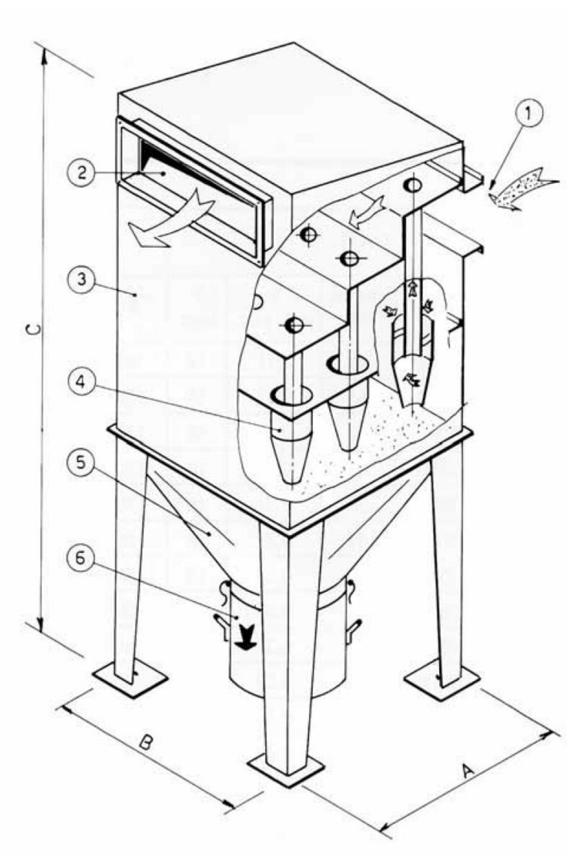
Commercial design criteria for cyclone



DATI / *DATA*					DIMENSIONI / *DIMENSIONS*										
Tipo *Type*	Q m^3/h *Q m3/h*	mm c.a. HS *mm w.g. HS*	Ø min. part. *Ø min. part.*	V ingr. *V inlet.*	A	B	C	D	E	F	G	H	I	L	M
1	1000	68	0.11	18	80	200	350	250	400	800	100	30	80	1310	130
1.5	1500	65	0.13	18	100	230	480	300	460	1100	130	30	80	1670	150
2	2000	62	0.16	18	130	250	600	320	500	1400	150	50	100	2050	180
2.5	2500	62	0.19	18	130	300	650	350	600	1500	150	50	130	2280	180
3	3000	58	0.21	18	150	320	700	380	640	1650	180	50	130	2520	200
4	4000	57	0.22	18	150	430	750	420	860	1800	200	80	150	2890	230
4.5	4500	57	0.23	18	150	450	800	480	900	1900	230	80	150	3060	250
5.5	5600	56	0.25	18	150	550	950	550	1100	2150	250	80	150	3530	280
8	8000	52	0.27	19	180	700	1100	580	1400	2200	280	80	180	3900	300
9.5	9500	51	0.28	18	200	750	1200	720	1500	2400	300	80	180	4250	380
11	11000	50	0.32	19	200	800	1250	750	1600	2600	380	80	200	4550	380
13	13000	50	0.40	20	220	820	1300	780	1640	2700	350	100	200	4640	400
16	16000	49	0.45	21	240	850	1450	850	1700	2800	380	100	220	4870	450
20	20000	48	0.48	25	250	880	1650	950	1760	2900	380	100	220	4980	500

Reference: Air cleaning technical and practical Handbook by Ventilazione Industriale srl

Commercial design criteria for multicyclone



DIMENSIONI MULTICICLONICO - B *DIMENSIONS MULTICYCLONE - B*				
PORTATA m3/h *FLOW RATE m3/h*	N. ELEMENTI *N° OF ELEMENTS*	A *A*	B *B*	C *C*
900	3 (1x3)	250	500	2800
1800	6 (2x3)	350	500	2800
2400	8 (2x4)	350	650	2800
3600	12 (3x4)	500	650	3200
4800	16 (4x4)	650	650	3200
6000	20 (4x5)	650	850	3200
7200	24 (4x6)	650	950	3200
7200	24 (3x8)	500	1250	3200
8400	28 (4x7)	650	1100	3200
9600	32 (4x8)	650	1250	3200
10800	36 (4x9)	650	1400	3200
10800	36 (3x12)	500	1500	3200
12000	40 (4x10)	650	1550	3200
13200	44(4x11)	650	1700	3500
14400	48 (4x12)	650	2000	3500 (*)
15600	52(4x13)	650	2100	3500(*)
16800	56(4x14)	650	2200	3500(*)
18000	60 (6x10)	950	1550	3500
18000	60(5x12)	850	2000	3500(*)

Reference: Air cleaning technical and practical Handbook by Ventilazione Industriale srl