Module 13: Cyclone

Lecture 41: Equipment, theoretical cut diameter, efficieny

Cyclone (Centrifugal settler)

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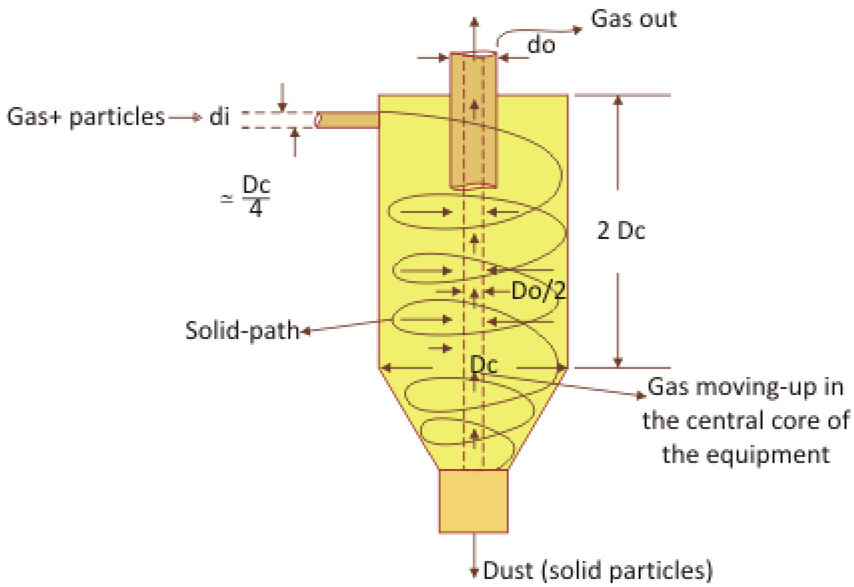
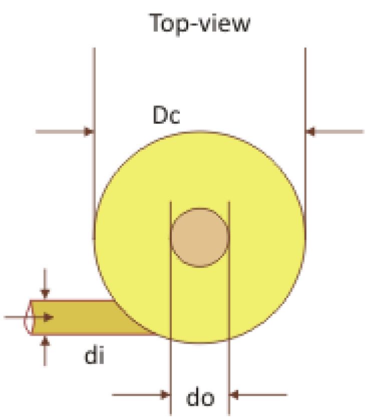
Cyclone (Centrifugal settler)

- The equipment separates solid particles from a gas (eg. dust laden flue gas), based on the principle of centrifugal force, which is much stronger than gravitational force. Cyclone works relatively more efficiently at high gas flow rates.
- The equipment requires large flow rates/velocity to create a swirling movement inside the column. Cyclone, as such, does not have moving parts but may require a blower upstream to impart KE to the gas laden with particles.



(Fig. 41a)



(Fig. 41b)

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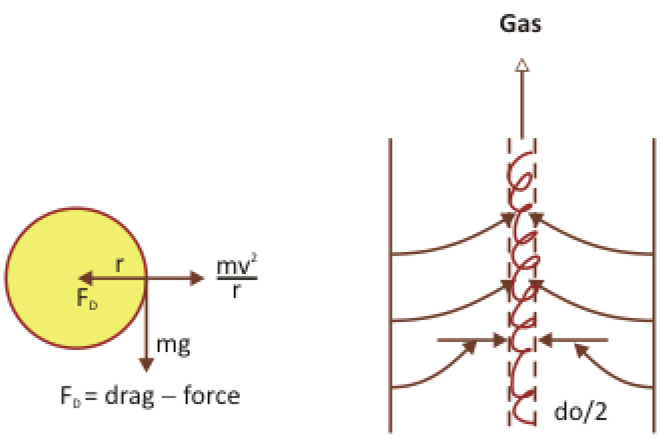
a. The real trajectory of gas and particles is difficult to analyze. The particles laden gas enters the cyclone from the sideway (see top view) at a high flow rate and moves downward in a swirling/ spiral path.
b. Solid particles are thrown outward radially due to centrifugal force. They strike the walls of cyclone and settle down. Gas, on the other hand, will move radially inward, then upward through the least hydrodynamically resistance – path to the exit.
c. Gas moving in spiral reaches the apex of the cone, then moves upward in a smaller spiral ($\sim do/2$) path to the exit at the top, as the opening at the bottom is filled with solid particles. For the gas, the least resistance – path is the exit at the top. For the particles, the least resistance- path is the exit at the bottom.
d. Mechanistically, if the centrifugal force acting on the particles is larger than the drag (inward) by the gas, the particles will strike the walls and settle down, else they will move inward alongwith the gas. At a radius r, where these two forces are equal, particle will rotate in equilibrium and move downward till they hit the slant walls and are collected. Gas on the other hand has a very high upward flow rate at the center, typically in the core-diameter of $do/_{2}$. Any particle in the zone will be carried upward.



(Fig. 41c)

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- Theoretical 'cut-size' of a cyclone is the particle size above which all particles will be collected. A theoretical expression considering drag and centrifugal forces on a particle, has been obtained to estimate the 'cut size' of cyclone. The calculation takes into account the experimental observation that the equilibrium rotation-radius of all captured particles in cyclone is $\geq \frac{1}{2}\left(\frac{do}{2}\right)$ or 0.25 do, where do is the diameter of the nozzle at the top of the cyclone though which the gas exits.
- The settling velocity of captured particles,

$$v_o = \frac{0.25\ do\ G\ g}{\pi\ ZD_C\rho_f U_{to}^2}$$

where,

do = diameter of the gas exit nozzle, m

G = gas flow rate, kg/m^3

g = gravity (m/s^2)

Z = height of cyclone, m

D_c = diameter of cyclone, m

ρ_f = density of gas, kg/m^3

$U_{to} = G/\rho A_i$, m/s

$A_i = \frac{\pi}{4} d_i^2$, m^2

d_i = diameter of inlet pipe, m

Form v_o, the theoretical cut–diameter, d_p is determined from the settling velocity equation:

$$v_o = \frac{{d_p}^2 g(\rho_s - \rho_f)}{18\ \mu_f}$$

(Note that it is assumed that particles settle in Stoke's regime)

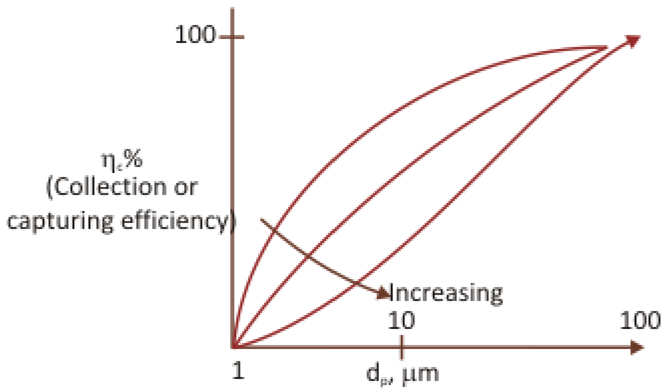
- All particles having diameter $< d_p$ will have equilibrium radius within 0.5 do so that they will be carried away with the gas.
  All particles having diameter $> d_p$ will be captured in cyclone.
- Cyclones are very effective in removing particles from gas. Disadvantages are large flow rate required and large pressure–drop because of the tortuous path of the gas.
- $\Delta p \simeq 8\, \rho_f \frac{v_c^2}{2}$, where $v_c =$ gas velocity at the inlet
- Separation factor of a cyclone, s is defined as

$$s = \frac{F_c}{F_g} = \frac{mv^2/r}{mg} = \frac{v^2}{rg}$$

- Cyclones are effective typically for particle size $> 5\mu m$
- Efficiency (capturing) of cyclone, η_c

$$\eta_c = \frac{\text{mass of collected particles of diameter, } d_p}{\text{mass of particles of diameter } d_p \text{ in the incoming gas}}$$

Design graphs are available to calculate the efficiency.



(Fig. 41d)

End

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