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# A Review Study on Gas-Solid Cyclone Separator using Lapple Model

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## Abstract

Cyclone is the most commonly used device to separate dust particles from gas and dust flow. The performance of cyclone separator can be measured in terms of collection efficiency and pressure drop. Parameters like Inlet Flow velocity, the particle size distribution in feed, dimensions of inlet and outlet ducts and cyclone affects the performance of cyclone significantly. Various Mathematical models used for calculation of cut off diameter of separator, flow rate, target efficiency and no. of vortex inside the cyclone to design and study to check the performance of existing cyclone separator. Also new dimensions can be design with help of models. Here, in this study the efficiency achieved with Lapple model cumulatively 86.47%.
**Keywords: Cyclone Separator, Pressure Drop, Collection Efficiency, Lapple Model, Inlet Dimension**

## I. INTRODUCTION

For solid–gas separation of particles, cyclone separator is one of the most commonly used devices. It works by forcing the gaseous suspension to flow spirally within a conical or cylindrical space, so that the particles are throw out toward the walls of the vessel by centrifugal force.

Centrifugal collectors and Cyclone separators are used in the following industries: wood products, rock products, metal working, combustion fly ash, chemical, plastic industry, coal mining and handling, metal melting and metal mining. Usually cyclone separators are uses for the collection of sanding, blending, mixing, grading, for particle collections, crushing, materials handling dust, conveying, buffing, machining.

Tangentially fluid enters into the cyclone. The cyclone induces a spin around and hence, imposes radial speed increase on particles. The densities of particles directly have correlation with separation.

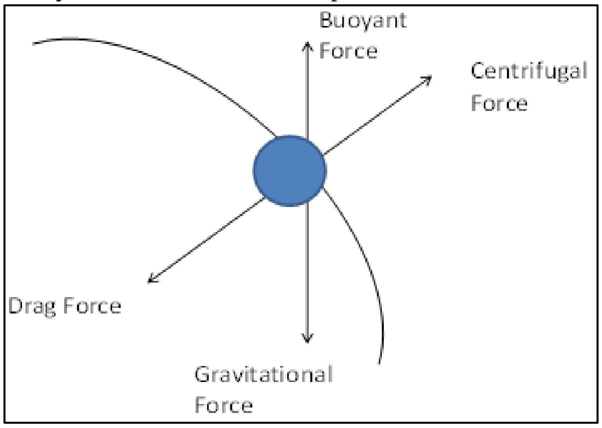

Fig. 1: Forces on Particles of Cyclone Separator

## II. THEORY OF CYCLONE SEPARATOR

Most conventional way of designing a cyclone separator is by determining the cut of diameter of particle that needs to be separated. The basic principle of separation is the higher densities particles have higher inertia and they tend to rotate in larger radius. But, the heavier particles are rotating closed to the wall where they slipped down and removed from conical bottom. Low density particles rotate nearer the center and collected from the center of the cyclone.

Collection efficiency and pressure drop are two most important parameters to determine design and performance of a cyclone separator. Inlet velocity is prime factor effecting the pressure drop and hence the cyclone efficiency. Efficiency increases with increase in velocity as centrifugal force increases but this also increases the pressure drop which is not favorable. Also, decreasing the cyclone diameter increases centrifugal force and hence efficiency. For achieving higher velocity requires the better material which increase the manufacturing cost. At different microscale applications might not permit higher pressure drops.

A two phase particle-fluid system is essential for cyclone, in which particle transport equations and fluid mechanics can be used to define the behavior of a cyclone.

- $V_i$: inlet velocity tangentially
- r: rotational radius; cyclone's central axis,
- $V_t$: tangential velocity
- $V_r$: radial velocity component

The particle is describing by buoyant, drag and centrifugal forces. Assume Stokes' law, the drag force is opposing the outward velocity on any particle in the inlet stream is:

Table – 1
Theory of Conventional Cyclone Separator

| | | |
|---|---|---|
| ***The DRAG FORCE is:*** | $F_d = -6\pi\mu r_p V_r$ | $r_p = \frac{3}{2}\left[\frac{V_r}{V_t(\rho_p - \rho_f)}\right]$ |
| ***The CENTRIFUGAL FORCE is:*** | $F_c = m\frac{V_t^2}{r}$ | $= \frac{4}{3}\pi\rho_p r_p^3 \frac{V_t^2}{r}$ |
| ***The BUOYANT FORCE is:*** | $F_b = -V_p \rho_f \frac{V_t^2}{r}$ | $= -\frac{4}{3}\pi\rho_f r_p^3 \frac{V_t^2}{r}$ |
| ***Here, $V_p$: particle volume (as opposed to velocity).*** ***By the helpof Newton's second law of motionthe outward radial motion of each particle can bedefine, which is equal to the sum of these forces:*** $m\frac{dV_r}{dt} = F_d + F_c + F_b$ ***If acceleration $\frac{dV_r}{dt}$ : zero than the particle reached terminal velocity; when the radial velocity has caused enough drag force to counter the centrifugal and buoyancy forces.*** | | |
| ***In equation simplification changes:*** | $F_d + F_c + F_b = 0$ | $-6\pi\mu r_p V_r + \frac{4}{3}\pi\rho_p r_p^3 \frac{V_t^2}{r} - \frac{4}{3}\pi\rho_f r_p^3 \frac{V_t^2}{r} = 0$ |
| ***Solving for $V_r$ we have*** | $V_r = \frac{2}{9}\frac{r_p^2}{\mu}\frac{V_t^2}{r}(\rho_p - \rho_f)$ | |
| ***Note: If the density of the fluid >density of the particle, the motion is (-), when the center of rotation and the denser particle, than the fluid motion is (+), away from the center.*** | | |

## III. MODEL USED FOR STUDY CYCLONE SEPARATOR

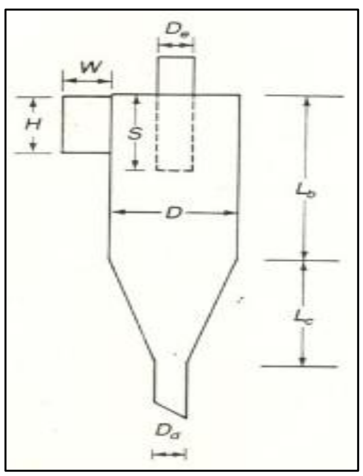


Fig. 2: Standard Cyclone Separator

### *A. Lapple Model*

1) Lapple Model was developed based on force balance without considering the flow resistance. Lapple assumed that a particle entering the cyclone is evenly distributed across the inlet opening. The particle that travels from inlet half width to the wall in the cyclone is collected with 50% efficiency. The semi empirical relationship developed by Lapple to calculate a 50% cut diameter, $d_{pc}$, is

$$d_{p50} = \left[\frac{9\mu W}{2\pi N_e V_g(\rho_p)}\right]^{1/2}$$

$d_{p50}$=Particle cut diameter; μ=Gas viscosity (kg/m. s); W= Width of inlet;

$N_e$=Effective number of turns of the vortex (which ranges between 1 to 10);

$$N_e \cong \frac{1}{H} \; \frac{[L_b + (L_c|2)]}{H}$$

$L_b$=Length of body;
$L_c$= Length of cone; H= height of inlet;
$V_g$=Gas velocity (m/s) [which ranges between 6 to 24 m/s. usually it is taken as 18 m/s];
$\rho_p$=particle density (kg/m$^3$).

2) Shepherd and Lapple found empirically that pressure drop (expressed as the number of inlet velocity heads) depends inversely on exit diameter squared:

$$\Delta P = \frac{1}{2} \; \frac{K \rho_g V_g^2 HW}{D_e^2}$$

$\Delta P$ = Pressure drop (Pa; N/m$^2$); K= An empirical constant [Value: for a tangential inlet cyclone = 16 & for one with an inlet vane= 7.5];
$\rho_p$=particle density (kg/m$^3$);
$V_g$=Gas velocity (m/s) [which ranges between 6 to 24 m/s. usually it is taken as 18 m/s; W= Width of inlet; H= Height of inlet;

3) Lapple's equation has been suits to an algebraic equation by Theodore and De Paola, which makes it more appropriate for compute applications:

$$\eta_j = 1/\left[1 + \left(d_{p50}/d_{pj}\right)^2\right]$$

$d_{p50}$= Diameter of cut particle;
$\eta_j$=Fractional efficiency in range j; $d_{pj}$=Particle diameter in range j;
With the help of these equations we can determine effective collection efficiency and pressure drop for different inlet dimensions with fix range of velocity at different particle diameters.

## IV. RESULT & DISCUSSION

From the literature study standard cyclone dimensions ration was given below in table to be consider for assumption of cyclone design and to find out its collection efficiency with help of finding out pressure drop, too.

Table – 2
Conventional Cyclone Dimension Ratio

| | Cyclone types | | | | | |
|---|---|---|---|---|---|---|
| | Efficiency Higher | | Conventional | | High Throughout | |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| D/D, Diameter of Body | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| H/D, Height of Inlet | 0.5 | 0.44 | 0.5 | 0.5 | 0.75 | 0.8 |
| W/D, Width of Inlet | 0.2 | 0.21 | 0.25 | 0.25 | 0.325 | 0.35 |
| $D_e$/D, Diameter of Gas exist | 0.5 | 0.4 | 0.5 | 0.5 | 0.75 | 0.75 |
| S/D, Vortex Finder's length | 0.5 | 0.5 | 0.625 | 0.6 | 0.875 | 0.85 |
| $L_b$/D, Length of Body | 1.5 | 1.4 | 2.0 | 1.75 | 1.5 | 1.7 |
| $L_c$/D, Length of cone | 2.5 | 2.5 | 2.0 | 2.0 | 2.5 | 2.0 |
| $D_d$/D, Diameter of Dust Outlet | 0.375 | 0.4 | 0.25 | 0.4 | 0.375 | 0.4 |
| Sources: Columns(1) &(5)=Stairmand 1995 ; Column (2),(4) & (6)= Swift,1969 ; Column (3) , Lapple,1951 | | | | | | |

Source: Ref. A.10

From the used data of different literature review the collection efficiency had been find out using Lapple model for different sizes of particles.

Table – 3
Dimension Data of Cyclone Seperator

| Dimensions | | Values | Units |
|---|---|---|---|
| Entry area dimension | H | 0.80 | m |
| | W | 0.96 | m |
| Immersion tube dimensions | S | 2.26 | m |
| | De | 1.50 | m |
| Cylindrical part dimension | $L_B$ | 5.32 | m |
| | D | 2.80 | m |
| conical part | Lc | 3.18 | m |
| discharge dia. | Dd | 0.55 | m |
| Temperature at Cyclone inlet | | 800 | oC |
| Pressure at Cyclone inlet | | -150 | mmWg |
| density of material | | 1500 | kg/m3 |
| density of gases(NTP) | | 1320 | kg/m3 |
| Viscosity of air at temp | | 0.000023 | kg/m s |

| | | | |
|---|---|---|---|
| ***Volume at Cyclone inlet*** | | ***100500*** | ***m3/h*** |
| ***density of the gas*** | | ***331*** | ***kg/m3*** |
| ***Number of turns in Cyclones*** | | ***9.00*** | |
| ***Velocity at inlet*** | | ***36.35*** | ***m/s*** |
| ***Gas residence time in outer vertex*** | | ***2.18*** | ***sec*** |
| ***Cut off size of particle*** | | ***12.82*** | ***microns*** |

Source: Ref. A.5

Table – 4
Different Mesh Size Particles with Studied Efficiency

| ***Minimum sieve (microns)*** | ***maximum sieve (microns)*** | ***mean micron size*** | ***% of retained*** | ***efficiency %*** | ***cummulative efficiency %*** |
|---|---|---|---|---|---|
| ***212*** | ***300*** | ***256*** | ***3.0*** | ***1.0*** | ***2.99*** |
| ***150*** | ***212*** | ***181*** | ***1.0*** | ***1.0*** | ***1.0*** |
| ***90*** | ***150*** | ***120*** | ***15.0*** | ***0.99*** | ***14.83*** |
| ***45*** | ***90*** | ***68*** | ***39.0*** | ***0.97*** | ***37.64*** |
| ***20*** | ***45*** | ***33*** | ***29.0*** | ***0.87*** | ***25.09*** |
| ***0*** | ***20*** | ***10*** | ***13.0*** | ***0.38*** | ***4.92*** |
| ***EFFICIENCY OF COLLECTION*** | | ***86.47%*** | | | |

Source: Ref. A.5

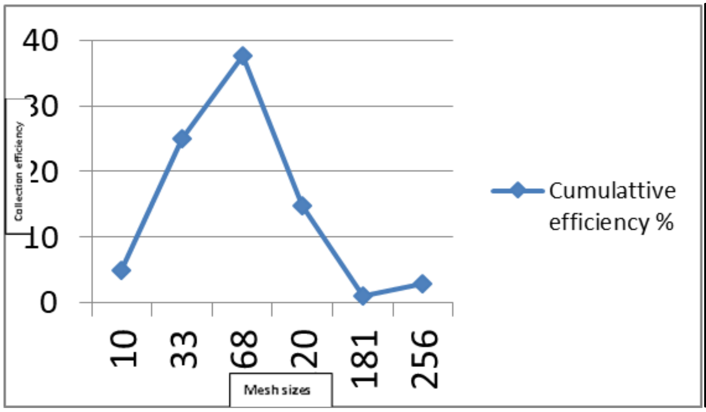


Fig. 3: Curve of Mesh Sizes vs Efficiency

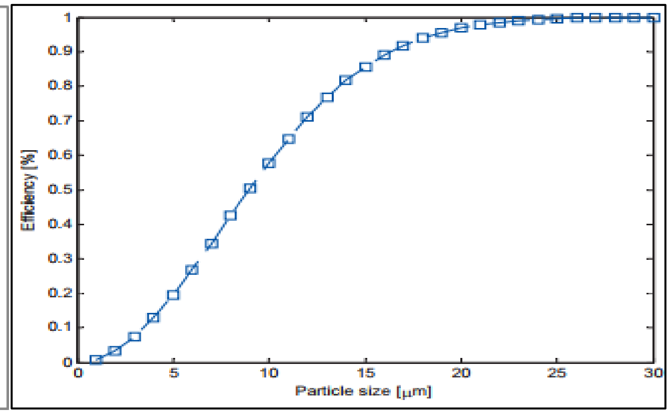


Fig. 4: Curve of Particles Size from 30μm- 10μm

Source: Ref. A.10

## V. Conclusion

Effect of collection efficiency and pressure drop on the cyclone performance was studied using the developed Lapple Model. Decreasing the smaller particle size gives less numbers of efficiency of separation particles. It was concluded that for smaller size particle from the range 60 μm – 10μm very less collection efficiency achieved. The model prediction was in good agreement with Lapple model with study theoretical literature survey with other author's findings which increases the creatibility of the method. For achieving good results between theoretical assumption and experimental data the Lapple theory and its containing parameter has good procedure to follow. In the Leith-Litch theory data was not match with the theoretical fractional efficiency curves. Leith-Licht and Barth theories worked better for staimand high-efficiency cyclone, but when dimensions changes due to gas flow patterns in the cyclone separator, and theoretical assumptions that work well for one design may not be valid for another. The theories need to be modified for a different range of cyclone designs and operating conditions.

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