DESIGN & FABRICATION OF A CYCLONE SEPARATOR FOR REMOVAL OF PARTICULATE MATTER

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ABSTRACT

Emissions from industries & air pollution from these emissions adversely affects the environment and public health. In air pollution dust & particulate matter plays a major factor and to separate them from air is tedious task. But from a social and control point of view separation of this particulate matter is mandatory. Particulate matter is the sum of all solid & liquid particles suspended in air many of which are hazardous. This complex mixture includes both organic or inorganic particles such as dust, pollen, soot, smoke and liquid droplets. These particles vary greatly in size, composition and origin. Cyclone Separators are essential component of gas cleaning systems and are extensively used in different industries. It is the most commonly used device, to separate dust particles from gas and dust flow. They are used as a primary abatement devices. To design a cyclone abatement system for particulate control, it is necessary to accurately estimate cyclone performance. This project presents the details of the design, fabrication and removal of particulate matter present in the atmospheric air. The cyclone was proportioned and designed using the Shepherd & Lapple (1939) and a Classical Cyclone Design (CCD) models.

Keyword: - *Air pollution1 , Particulate matter2, Cyclone Separator3, Classical Cyclone Design4, Shepherd & Lapple model5.*

1. INTRODUCTION

Air is considered to be polluted when it contains certain substances in concentrations high enough and for durations long enough to cause harm or undesirable effects. These include adverse effects on human health, property, and atmospheric visibility. The atmosphere is susceptible to pollution from natural sources as well as from human activities. Most air contaminants originate from combustion processes. During the Middle Ages the burning of coal for fuel caused recurrent air pollution problems. Beginning in the 19th century, in the wake of the Industrial Revolution, increasing use of fossil fuels intensified the severity and frequency of air pollution episodes. The advent of mobile sources of air pollution i.e., gasoline-powered highway vehicles had a tremendous impact on air quality problems in cities.

The primary focus of air pollution regulation in industrialized countries has been on protecting ambient, or outdoor, air quality. This involves the control of a small number of specific “criteria” pollutants known to contribute to urban smog and chronic public health problems. The criteria pollutants include fine particulates, carbon monoxide, sulfur dioxide, nitrogen dioxide, ozone, and lead. Since the end of the 20th century, there also has been a recognition of the hazardous effects of trace amounts of many other air pollutants called “air toxics.” Most air toxics are organic chemicals, comprising molecules that contain carbon, hydrogen, and other atoms. Specific emission regulations have been implemented against those pollutants. In addition, the long-term and far-reaching effects of the “greenhouse gases” on atmospheric chemistry and climate have been observed, and cooperative international efforts have been undertaken to control those pollutants. The greenhouse gases include carbon dioxide, chlorofluorocarbons (CFCs), methane, nitrous oxide, and ozone.

The best way to protect air quality is to reduce the emission of pollutants by changing to cleaner fuels and processes. Pollutants not eliminated in this way must be collected or trapped by appropriate air-cleaning devices as they are generated and before they can escape into the atmosphere. The emphasis of this project work is air pollution control technology with the help of cyclone separator as it is designed to remove particulate and gaseous pollutants from the emissions of stationary sources, including power plants and industrial facilities.

1.1 CYCLONE SEPARATOR

Cyclone separators provide a method of removing particulate matter from air or other gas streams at low cost and low maintenance. Cyclones are basically centrifugal separators, consists of an upper cylindrical part referred to as the barrel and a lower conical part referred to as cone. They simply transform the inertia force of gas particle flows to a centrifugal force by means of a vortex generated in the cyclone body. The particle laden air stream enters tangentially at the top of the barrel and travels downward into the cone forming an outer vortex. The increasing air velocity in the outer vortex results in a centrifugal force on the particles separating them from the air stream. When the air reaches the bottom of the cone, it begins to flow radially inwards and out the top as clean air/gas while the particulates fall into the dust collection chamber attached to the bottom of the cyclone.

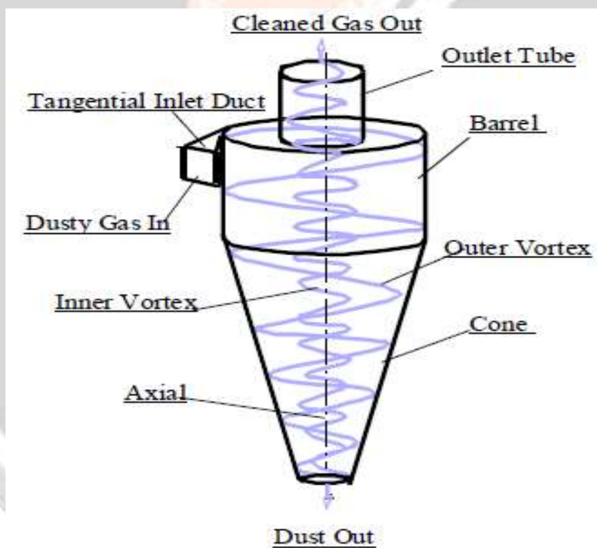

FIGURE 1-Schematic flow diagram of a cyclone.

1.2 DIFFERENT TYPES OF CYCLONE SEPARATORS

In various industries, 2D2D (Shepherd and Lapple, 1939) and 1D3D (Parnell and Davis, 1979) cyclone designs are the most commonly used abatement devices for particulate matter control.

The D’s in the 2D2D designation refer to the barrel diameter of the cyclone. The numbers preceding the D’s relate to the length of the barrel and cone sections, respectively. A 2D2D cyclone has barrel and cone lengths of two times the barrel diameter, whereas the 1D3D cyclone has a barrel length equal to the barrel diameter and a cone length of three times the barrel diameter. The models of these two cyclone designs are shown in Figure 2.

Simpson and Parnell (1995) introduced a new low-pressure cyclone, called the 1D2D cyclone. Figure 3 illustrates the model of 1D2D cyclone design.

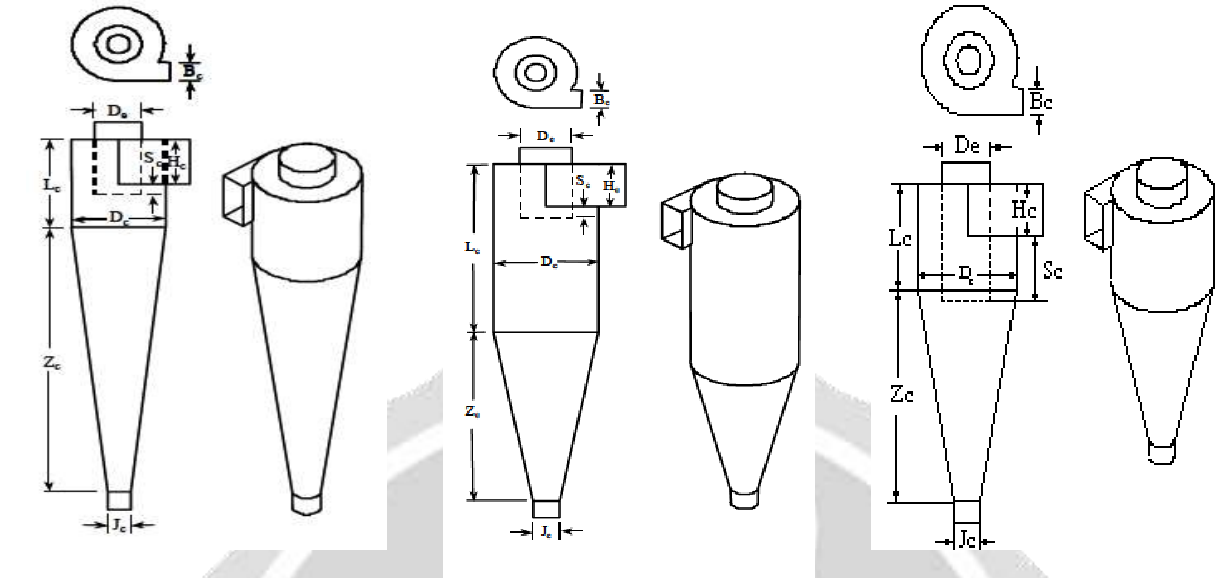

Figure 2- 1D3D, 2D2D & 1D2D Cyclone models respectively.

2. CLASSICAL CYCLONE DESIGN (CCD)

The cyclone design procedure outlined in Cooper and Alley (1994), hereafter referred to as the classical cyclone design (CCD) process, was developed by Lapple in the early 1950s. The CCD process (Shepherd & Lapple model) is perceived as a standard method and has been considered by some engineers to be acceptable.

In order to use the CCD process, it is assumed that the design engineer will have knowledge of (1) flow conditions, (2) particulate matter (PM) concentrations and particle size distribution (PSD) and (3) the type of cyclone to be designed (high efficiency, conventional, or high throughout). The cyclone type will provide all principle dimensions as a function of the cyclone barrel diameter (Dc). With these given data, the CCD process is as follows:

a) The Number of Effective Turns (Ne)

The first step of CCD process is to calculate the number of effective turns. The number of effective turns in a cyclone is the number of revolutions the gas spins while passing through the cyclone outer vortex. A higher number of turns of the air stream result in a higher collection efficiency. The lapel model for Ne calculation is as follows:

$$\mathbf{Ne} = \frac{\mathbf{1}}{\mathbf{H}} \times \left[\mathbf{Lc} + \frac{\mathbf{Zc}}{\mathbf{2}}\right]$$

Where,

Ne = number of turns inside the device (no units)

H = height of inlet duct (m or ft)

Lc = length of cyclone body (m or ft)

Zc = length (vertical) of cyclone cone (m or ft).

b) Cut-point Diameter (Dpc)

The second step of the CCD Process is the calculation of the cut-point diameter. The cut-point of a cyclone is the aerodynamic equivalent diameter (AED) of the particle collected with 50% efficiency. As the cut-point diameter increases, the collective efficiency decreases. The Lapple cut-point model was developed based upon force balance theory. The Lappel model for cut-point (Dpc) is as follows:

$$\mathbf{Dpc} = \left[\frac{\mathbf{9 \times \mu \times W}}{\mathbf{2 \times \pi \times Ne \times Vi \times (\rho p - \rho g)}}\right]^{\frac{1}{2}}$$

Where,

Dpc = diameter of the smallest particle that will be collected by the cyclone with 50% efficiency.

W = width of inlet duct (m)

μ = viscosity of gas or air (kg/m^3)

$\mathrm{Ne} = \frac{1}{\mathrm{H}} \times \left[\mathrm{Lc} + \frac{\mathrm{Zc}}{2}\right]$ = number of turns

$\mathrm{Vi} = \frac{\pi \times \mathrm{D} \times \mathrm{N}}{60}$, m/s = inlet gas velocity (m/s)

ρp = particle density (kg/m^3)

ρg = density of air (kg/m^3)

c) Fractional Efficiency (η_f)

The thirdstep of CCD process is to determine the fractional efficiency. Based upon the cut-point diameter, Lappel then developed an empirical model for the prediction of the collection efficiency for any particle size, which is also known as fractional efficiency curve:

$$\boldsymbol{\eta_f} = \frac{\mathbf{1}}{\mathbf{1} + \left(\frac{\mathbf{Dpc}}{\mathbf{dpc}}\right)^{\mathbf{2}}}$$

Where,

Dpc = diameter of the particle collected with 50% efficiency

dpc = smallest particle size

d) Pressure Drop (ΔP)

Cyclone pressure drop is another major parameter to be considered in the process of designing a cyclone system. Two steps are involved in the Lapple approach to estimation of cyclone pressure drop. The first step in this approach is to calculate the pressure drop in the number of inlet velocity heads (H_v). The second step in this approach is to convert the number of inlet velocity heads to a static pressure drop (ΔP):

$$\mathbf{\Delta P} = \frac{\mathbf{1}}{\mathbf{2}} \times \mathbf{\rho g} \times \mathbf{Vi^2} \times \mathbf{Hv}$$

& $$\mathbf{Hv = K \times \frac{H \times W}{De^2}}$$

Where,

Hv = pressure drop, expressed in number of inlet velocity heads

K = constant that depends on cyclone configurations and operating conditions
Based on TCD model K is a dimensionless empirical constant and equals to 5.1, 4.7 and 3.4 for the 1D3D, 2D2D and 1D2D cyclones, respectively.

3.DESIGN & FABRICATION

3.1 Design of Cyclone Separator

To design 2D2D model of cyclone separator Shepherd & Lappel model (1939) and Classical Cyclone Design (CCD) model are adopted in this project work.

Table 1: Cyclone Separator Dimensions.

Dimensions	Ratio		Value (m)
Diameter of Barrel	Dc	Dc	0.25
Length of the Body	Lb	2Dc	0.5
Length of the Cone	Zc	2Dc	0.5
Height of the Inlet	H	Dc/2	0.125
Width of the Inlet	W=Bc	Dc/4	0.0625
Diameter of Gas Exit	De	Dc/2	0.125
Diameter of Dust outlet	Jc	Dc/4	0.0625
Length of Sc	Sc	Dc/8	0.03125
Length of vortex Finder	S	Sc+H	0.15625
Total length of cyclone	Lb+Lc	4Dc	1

2D2D Model
Bc=Dc/4
Jc=Dc/4
Dc=Dc/2
Sc=Dc/8
Hc=Dc/2
Lc=2×Dc
Zc=2×Dc

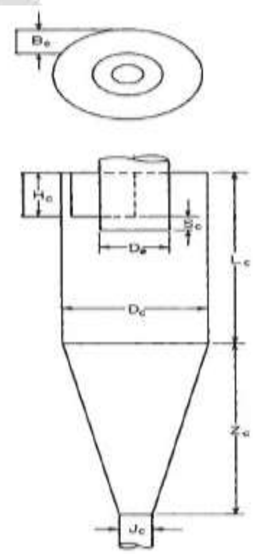

Figure 3- 2D2D Cyclone Configuration

3.2 Designing of CAD Model

The CAD Model of Cyclone Separator 2D2D model was designed on **CATIA V5** with the standard dimensions calculated in Table 1.

In this work we have generated a multi inlet cyclone separator with 4 symmetrical inlets in tangential direction to the cyclone body. We have provided only one outlet at the top of the cyclone body.

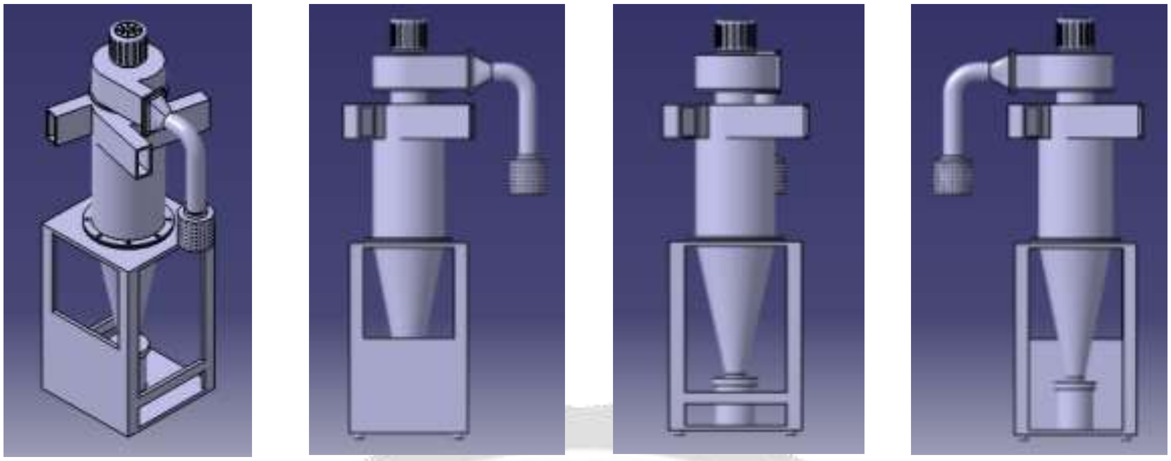

Figure 4 - Different views of Generated CAD model

3.3 Material of Construction

Material selection is a very important consideration when choosing a cyclone separator for a specific application. Some process systems may contain erosive or corrosive flowing mediums, so it is necessary to add a protection layer to the cyclone's internal surfaces.

Suitable materials for protecting the separator within erosive systems might include materials such as ceramic or some form of enamel. Separators operating within corrosive systems may have some form of enamel or poly-based material coating to protect the cyclone metal body beneath.

In this work material used for fabrication of cyclone separator is Colled Rolled Steel. Cold rolled sheets are hot rolled products which provides a superior surface finish, with improved physical properties of the steel, such as high formability, high strength, excellent dent resistance, good magnetic properties, tensile strength, and workability and welding properties. With Cold Rolling its thickness is reduced to precise gauges. CR Sheets are available in sheets and coils.

Again the material used for fabrication of Support Stand is Mild Steel L angles which will hold the cyclone separator assembly.

3.4 Fabrication of Cyclone Separator

The Cyclone was fabricated using MIG welding.

MIG Welding is an arc welding process in which a continuous solid wire electrode is fed through a welding gun and into the weld pool, joining the two base materials together. A shielding gas is also sent through the welding gun and protects the weld pool from contamination. In fact, MIG stands for Metal Inert Gas welding. The technical name for it Gas Metal Arc Welding (GMAW).

Whereas the support stand was fabricated using Electric Arc Welding process.

Arc welding is a type of welding process using an electric arc to create heat to melt and join metals. A power supply creates an electric arc between a consumable or non-consumable electrode and the base material using either direct (DC) or alternating (AC) currents.

The whole setup of cyclone separator is fixed or assembled with Nuts & Bolts.

4. EXPERIMENTAL PROCEDURE

Feed stock samples of Fly ash (200 kg/m^3), Coal dust (300 kg/m^3), Lime stone (300 kg/m^3) and Saw dust (200 kg/m^3) with constant average size is prepared.

The cyclone is run with air at a fixed velocity V_i . At the same time the pressure drop across the cyclone inlet and outlet is measured i.e $\Delta P= 0$. Dust particles of average size 1µm to 10µm are fed at constant rate for 120 seconds and solid particles are colleted at the outlet of the cyclone.The pressure drop across the cyclone is measured & fractional efficiency is calculated.

This experiment is repeated for the average sizes from (10µm to 20µm), (20µm to 30µm), (30µm to 40µm), (40 to 5 µm) & (50µm to 60µm).

5. RESULTS & DISCUSSIONS

Operating Conditions-
Temperature =30º C.
Corresponding Density of Air (ρg) =1.164 kg/m^3.
Dynamic viscosity of Air (μ) =1.872×10^{-5} Kg/ms.

Other Data required-
Revolutions per minute of motor (N) =1000 r.p.m.
Diameter of impeller (D)= 0.2 m
Total particle density of feedstock = 1000 kg/m^3.

The results of the Equipment Design based on CCD is given in **Table 2**.

Table 2- Equipment Design Output

Sr. No.	Parameters	Design output
1	Number of effective turn, Ne	6
2	Cut-point diameter of particle with 50% efficiency, Dpc	5.17 µm
3	Cut-point diameter of smallest particulate size, dpc	7.31 µm.
4	Velocity of air at Inlet, Vi	10.47 m/s
5	Fractional efficiency, η_f	67 %
6	Pressure drop, ΔP	149.92 N/m^2
7	Dust collector capacity, Vdc	0.002924 m^3

The result of variation of fractional efficiency with particulate diameter size is shown in the **Table 3** and **Figure 5**.

Each point represents the mean cyclone efficiency for mean particle size over a range of 10μm.

Table 3- Fractional Efficiencies for various particle sizes

Sr. No.	Size of particulates dpc (µm)	Range mean dpc (µm)	Fractional efficiency (%η_f)
1	0 – 10	5	45
2	10 – 20	15	89
3	20 – 30	25	95
4	30 – 40	35	97
5	40 – 50	45	98
6	50 – 60	55	99

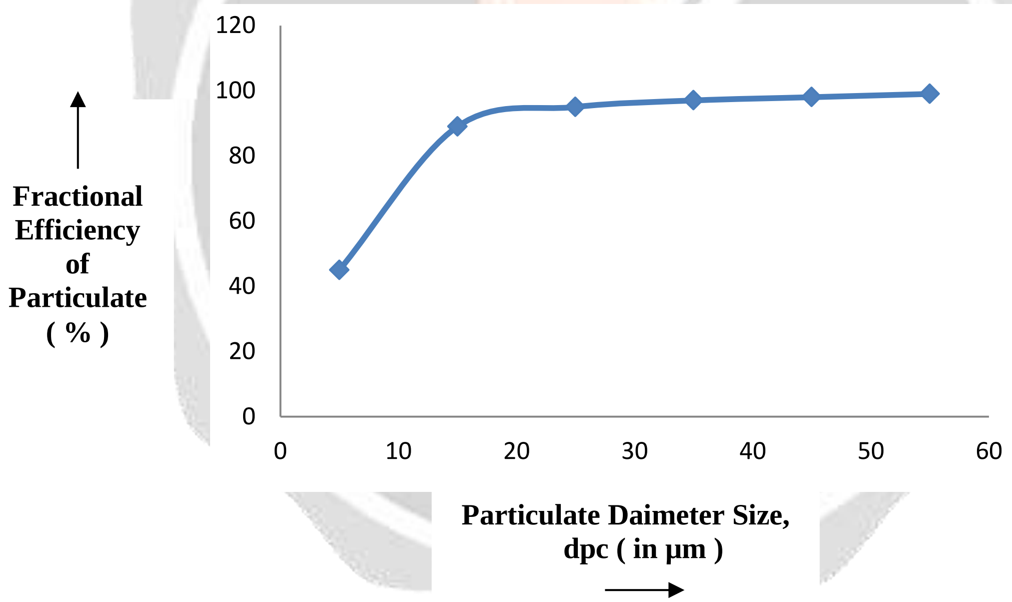

Figure 5- Variation of particulate fractional efficiency with particulate size.

6. CONCLUSION

Cyclone separators are mechanical systems that control particulate emissions by use of centrifugal separation process. Static pressure drop is the most important factor in evaluating the performance of this pollutant control device. Other factors such as particulate size, cyclone dimensions, inlet particulate speed and particulate concentration in air are very essential in evaluating the cyclone collection performance. The cyclone particulates collection efficiency increases with increasing particulate size. Thus large-diameter cyclones are most effective for removing large particulates from a large particulates-laden gas stream. Cyclonic separation remains one of the most effective particulate pollutant control measures. If the size of the sample is more than 50µm, the collection efficiency is almost same for the sample. With an increase in density of the sample, collection efficiency increases linearly. For the same velocity (or for the same power consumption), highly dense particles are removes with higher collection efficiency compare to low dense particles.

7. REFERENCES

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