Design, Fabrication and Performance Evaluation of a Cyclone System for Saw Dust Emission Control

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Abstract
This paper presents the details of the design, fabrication and testing of a Saw dust Cyclone system suitable for particulate emission control in wood processing shops and industries. The cyclone was proportioned and designed using the Lapple and the Classical Cyclone Design models with a design air flow of 14.7m/s. Collection efficiency and pressure drop were measured over a range of air flows at ambient temperature and pressure. Saw dust of different particle sizes was used as a test sample to evaluate the cyclone performance. The designed cyclone is compared with a standard high efficiency cyclone, and is found theoretically to have better efficiency under identical operating conditions. Performance evaluation and computational analysis shows that static pressure drop, particulate size, cyclone dimensions, inlet particulate speed and particulate concentration in air are the essential factors in evaluating the cyclone collection performance. The designed cyclone has cut point of 15.2 μm *and an average fractional efficiency of 67%. 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.*

Keywords: *Particulate, Cyclone, Design, Pressure drop, Pollution, Pollutant, CCD, Lapple model.*

1. Introduction

The control of air pollution has become a matter of great importance in our society. The Engineer's Joint Council on Air Pollution and its Control defines air pollution as "the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odor, smoke or vapor in quantities, of characteristics, and of duration, such as to be injurious to human, plant, or property, or which unreasonably interferes with the comfortable enjoyment of life and property" (Lawrence et al, 2004). Air pollution adversely affects human health, vegetation, materials or the environment. The sources of pollutants can be natural or man-made source (Mohd et al, 2009). And many of the pollutants enter the atmosphere from sources currently beyond our control. However, the principal sources of these pollutants are human activities. Man-made activities such as fuel combustion, industrial processes, steel industry, petroleum foundries, cement, glass manufacturing industry, smelting and mining operations, fly-ash emissions from power plant, dust emissions from wood processing, burning of coal and agricultural refuse release millions of tonnes of particulate matter every year. (John, 1886; Dara, 1992). Several engineered systems have been designed to control particulate emission into the air. Some of the important particulate collection devices include Gravity settling chamber, Fabric filter, Electrostatic precipitators (ESP), Scrubbers (wet collectors) and Cyclone (centrifugal) separators.

Cyclone separators provide a method of removing particulate matter from air or other gas streams at low cost and low maintenance (Lingjuan, 2004). A cyclone is a device that separates particulate from gas (fluid) by centrifugal force. It works simply by the kinetic energy of the incoming mixture (flow stream) and the geometry of the cyclone. Cyclones are somewhat more complicated in design than simple gravity settling systems, and their removal efficiency is much better than that of settling chamber. 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 (Figure 1). 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.

(a) **(b)**

Figure 1: Pictorial and Schematic flow diagrams of a cyclone

Cyclones are generally classified into four types, depending on how the gas stream is introduced into the device and how the collected dust is discharged. The four types include tangential inlet, axial discharge; axial inlet, axial discharge; tangential inlet, peripheral discharge; and axial inlet, peripheral discharge. The first two types are the most common (AWMA, 1998). The advantages of cyclones include (AWMA, 1992; Copper and Alley, 1994; and EPA, 1998): Low capital cost, few maintenance requirements and low operating costs, relatively low pressure drop (2 to 6 inches water column), compared to amount of particulate removed; dry collection and disposal, and relatively small space requirements. Its limitations include (AWMA, 1992; Copper and Alley, 1994; and EPA, 1998): Relatively low particulate collection efficiencies, particularly for particulates less than 10μm in size, Unable to handle sticky or tacky materials and high pressure drops associated with high efficiency units.

2. Literature Review

Large amount of literature is available describing various theories related to cyclone separator. Various methods are explored by numerous scientists to describe theories of particle collection in a cyclone separator.

Lingjuan (2004) studied the theoretical design of cyclone using 1D3D and 2D2D cyclones models. In his study, new theoretical methods for computing travel distance, numbers of turns and cyclone pressure drop were developed. The new theoretical analysis of cyclone pressure drop was tested against measured data at different inlet velocities. The results show that cyclone pressure drop varies with the inlet velocity, but not with cyclone diameter, and flow pattern and cyclone dimensions determine the travel distance in a cyclone.

Ramachandran, and Sivakumar (2015) reported the design and development of cyclone separator interconnected CFBC aimed at optimizing the vortex finder configuration to reduce the pressure drop and denudation rate, for a given collection efficiency of the cyclone separator. In this study, six existing cyclone separator designs were chosen and the more efficient Coker model was used to find pressure drop in each case. Four different models, with 25%, 50%, 75% and 100% RPDS length were developed for each design and CFD analysis of the existing designs with and without the RPDS were done. A mass flow rate of 500m^3/hr, an inlet flow velocity of 15 m/s and the k-Ɛ turbulence model were chosen for flow simulation. By fixing constraints for pressure drop, denudation rate and collection efficiency, an optimum model was developed by the dynamic programming method of optimization. The 50% RPDS length model was found to be best suited for any CFBC cyclone separator.

Mahesh (2014) reported the design of cyclone and study of its performance parameters. In his investigation, the characteristics of flour mill cyclone were studied for various flow rates (inlet velocities) and its effect on performance parameters like pressure drop and efficiency are studied. The Cyclone is designed with two symmetrical tangential inlets and a single tangential outlet at the barrel top area where impeller is mounted. Simulation of flow was done with the help of CFD software and validated with experimental work. Results showed that these new designs can improve the cyclone performance parameters significantly and very interesting details were found on cyclone fluid dynamics properties.

Halasz and Massarani (2000) reported the performance analysis and design of small diameter cyclones, in which the effect of the configuration on the collection efficiency and pressure drop in small diameter cyclones were evaluated based on neural networks (Functional Link Networks). The experiments were conducted in a Stairmand high efficiency prototype (D_c = 5 cm) with variable overflow diameter. Three different configurations were tested, and the results indicate a significant increase in the collection efficiency with the reduction of the overflow diameter.

Li and Chen (2007) predicted the influence of operating temperatures on cyclone performance, using experiments conducted on particle separation in a reverse flow, tangential volute-inlet cyclone separator with a diameter of 300mm and with air heated up to 973K. The test powder silica has a mass median diameter of 10μm, while inlet velocity range was 12−36m/s. Both the separation efficiency and pressure drop of the cyclone were measured as a function of the inlet velocity and operating temperature. At the same inlet velocity, both the separation efficiency and pressure drop decrease with increasing temperature. In addition, optimum inlet velocity, at which the cyclone has its highest separation efficiency, tends to increase with a rise in temperature. The results indicate a fairly good agreement of predicted temperature-dependent efficiencies and pressure drops with experimental results.

In this work however, a cyclone system is designed, fabricated and tested for operational effectiveness for saw dust emission control. The system requires input power source from electric energy for its operation. It is proposed for use in small woodwork shops and small wood processing industries.

3. Materials/Equipment's and Methods

The materials used for the fabrication of the Cyclone are mild steel sheets, galvanized aluminium sheets, angle iron (mild steel), and bearings. Other materials used were bolts and nuts. These materials were chosen because of their excellent mechanical and physical properties such strength, ductility, machinability, weldability, availability, corrosion resistance, low weight and affordability (Rajput, 2010; Adebayo, 2014). The equipment's used include electric arc welding machine, 2 hp electric motor, etc.

3.1 Design: Lapple and CCD Models

The 2D2D (Shepherd and Lapple, 1939) cyclone design (Figure 2) and the Classical cyclone design (CCD) approaches are adopted in this work.

2D2D Model

$\mathbf{B_c = D_c/4}$ $\quad$ $\mathbf{J_c = D_c/4}$

$\mathbf{D_c = D_c/2}$ $\quad$ $\mathbf{S_c = D_c/8}$

$\mathbf{H_c = D_c/2}$ $\quad$ $\mathbf{L_c = 2 \times D_c}$

$\mathbf{Z_c = 2 \times D_c}$

In this work, $D_c = 0.63$m, hence:

$B_c = J_c = D_c/4 = 0.63/4 = 0.16$ m

$D_c = H_c = D_c/2 = 0.63/2 = 0.32$m

$S_c = D_c/8 = 0.63/8 = 0.08$m

$L_c = Z_c = 2 \times D_c = 2 \times 0.63 = 1.26$m

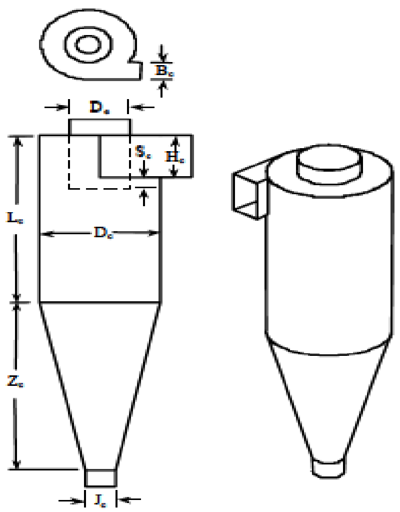

Figure 2: 2D2D Cyclone Configuration

Number of Effective Turns, N_e: The number of effective turns which is the number of revolutions the particle laden gas spins while passing through the cyclone outer vortex, is estimated using (Lapple, 1939),

$$\mathbf{N_e = \frac{1}{H_c}\left[L_c + \frac{Z_c}{2}\right]} \quad (1)$$

Cut-Point, d_{50}: This is the aerodynamic equivalent diameter of the particle collected with 50% efficiency. This is estimated using (Lapple, 1939),

$$\mathbf{d_{50} = \left[\frac{9\mu W}{2\pi N_e V_{i(\rho_p - \rho_g)}}\right]^{1/2}} \quad (2a)$$

The smallest particle size that will be collected in the cyclone is estimated using,

$$\mathbf{d_p = \left[\frac{9\mu W}{\pi N_e V_{i(\rho_p - \rho_a)}}\right]^{1/2}} \quad (2b)$$

where, μ = dynamic viscosity of air = 18.5×10^{-6}kg/ms {W= $B_c = 0.16$m}

V_i = inlet air speed = $\frac{\pi DN}{60}$ m/s {D= impeller diameter = 0.1m; N = 2800 rpm}

ρ_p = particulate density, Kg/m^3 = 210 Kg/m^3

ρ_a = air density, Kg/m^3 = 1.2 Kg/m^3

Fractional Efficiency, η_f: The fractional efficiency of the cyclone is estimated using (Lapple, 1939),

$$\eta_f = \frac{1}{1+\left(\frac{d_{50}}{d_{pi}}\right)^2} \quad (3)$$

Overall Efficiency (Performance), η: This is a weighted average of the collection efficiencies for the various size ranges, and is estimated using,

$$\eta = \frac{\sum \eta_i m_i}{M} \quad (4)$$

where η = overall collection efficiency (0 η < η < 1)
m_i = mass of particles in the *i*th size range
M = total mass of particles.

Pressure Drop, ΔP: This is estimated using (Lapple, 1939),

$$\Delta P = 0.5\rho_a V_i^2 H_v \quad (5a)$$

$$H_v = 19.7\left[\frac{WH_c}{{D_c}^2}\right]^{0.99} \times \left(\frac{S_c}{D_c}\right)^{0.35} \times \left(\frac{L_c}{D_c}\right)^{-0.34} \times \left(\frac{Z_c}{D_c}\right)^{-0.35} \times \left(\frac{J_c}{D_c}\right)^{-0.33} \quad (5b)$$

Dust Collector Capacity, V_{dc}: The capacity (volume) of the dust collector is estimated using,

$$V_{dc} = \frac{\pi d_{dc}^2 h}{4} \quad (6)$$

where, d_{dc} = diameter of dust collector = 0.61m
h = height of dust collector = 0.81m

3.2 Fabrication

The Cyclone was fabricated using electric arc welding process. The entire cyclone body was paint with aluminium paint and the cyclone support painted with red oil paint. This was done for aesthetics and corrosion prevention. Figure 3 and Figure 4 show the diagrammatic and pictorial representation of the fabricated cyclone.

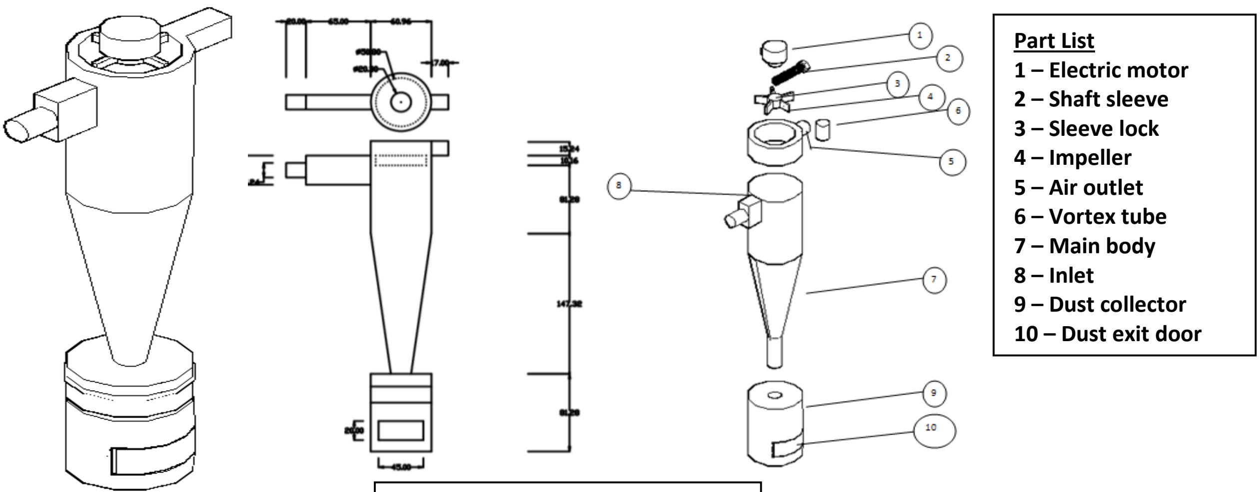

Figure 3: Fabricated cyclone

Figure 4: Pictorial view of the cyclone

3.3 Experimentation and Performance Evaluation

To design a cyclone abatement system for particulate control, it is necessary to accurately estimate cyclone performance. The performance evaluation of the newly designed cyclone is carried out by comparing the output design data and its experimental test results with those of other investigators. A fair proximate agreement indicates the suitability of the device to its application. To this end, five samples of saw dust (equal weight) of different sizes were collected from Timber shop in Bori, Nigeria. Each saw dust sample was run through the cyclone for 120 seconds, and the weights of the sample remaining in the hooper, collected particles and escaped particles were measured in each case.

4. Results and Discussion

The results of the equipment design, performance test and computational analysis are given in Tables 1, 2&3 and Figure 5.

Table 1: Equipment Design Output

S/N	Parameters	Design output
1	Number of effective turn, N_e	6 [-]
2	Cyclone cut-point, d_{50}	15.2 [μm]
3	Inlet air speed, V_i	14.7 [m/s]
4	Smallest particulate size, d_p	21.5 [μm]
5	Fractional efficiency	67 [%]
6	Pressure drop, ΔP	160 [N/m^2]
7	Dust collector capacity, V_{dc}	0.24 [m^3]

Table 2: Test Results

S/N	D_p [μm]	M_s[Kg]	M_t [Kg]	M_p [Kg]	M_b [Kg]	M_e [Kg]
1	15.98	4.8	0.74	0.00	4.26	4.80
2	18.11	4.8	3.11	2.21	3.15	4.58
3	22.36	4.8	4.13	2.52	2.14	4.28
4	25.58	4.8	4.80	2.62	2.01	4.10
5	26.30	4.8	5.23	2.86	1.88	3.95

D_p = Particle size
M_s = Mass of particulates sample
M_t = Mass of particulates trapped in dust collector
M_p = Mass particulates left in dust container after 120 seconds
$M_b = M_s - [M_t + M_p]$ =
Mass of particulates that escape through the blower outlet
$M_e = [M_t + M_b]$ = Mass of particulates collected in the cyclone dust collector

Table 3: Computed Fractional Efficiencies for various particle sizes

i	Size range d_{pi} [μm]	Mean size d_{pi} [μm]	Efficiency η_i [%]
1	0 – 10	5	9.8
2	10 – 20	15	49.3
3	20 – 30	25	62.2
4	30 – 40	35	84.1
5	40 – 50	45	89.8
6	50 – 60	55	92.9
7	60 – 70	65	94.8
8	70 – 80	75	96.1
9	80 – 90	85	96.9
10	90 – 100	95	97.5

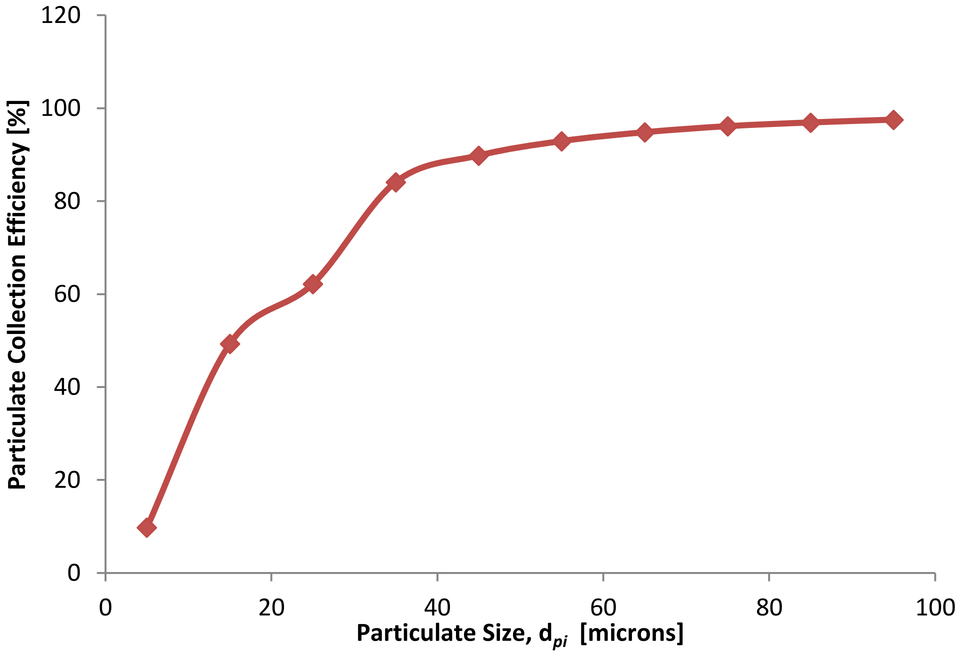

Figure 5: Variation of Particulate collection Efficiency with Particulate Size

Table 3 and Figure 5 show the variation of computed fractional efficiency with particulate diameter. Each point represents the mean cyclone efficiency for mean particle size over a range of 10μm. The effects of particle diameter and cyclone inlet velocity on efficiency are in general agreement with theoretical predictions (John and David, 2007). For any inlet velocity, efficiency increases with particle diameter. This is suggestive of large-diameter cyclones being most effective for removing large particulates from a large particulates-laden gas stream.

5. 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.

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