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Effect of Air Density on Cyclone Performance and System Design

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Abstract. *1D3D and 2D2D cyclones were tested at Amarillo, Texas to evaluate the effect of air density on cyclone performance. Two sets of inlet design velocities were used for the tests – one set based on the actual airflow and the other set based on standard airflow. Experimental results indicate the design velocities are 3200 feet per minute of standard air for 1D3D cyclone design and 3000 feet per minute of standard air for 2D2D cyclone design. It is important to consider the air density effect on cyclone performance in the design of cyclone abatement systems. The proposed design velocities should be the basis for sizing cyclones and determining the cyclone pressure drop. The recommended sizes for 1D3D, 2D2D and 1D2D cyclones are reported in this paper.*

Keywords. Cyclone, air density, design velocity, particulate emission, pressure drop, sizing cyclone

Introduction

The cyclone, because of its simplicity and low operating cost, is probably the most widely used dust collector in industry. With the growing concern for the environmental effects of particulate pollution, it becomes increasingly important to be able to optimize the design of pollution control systems. As a result, many studies have been made to characterize cyclone performance as affected by design and operational parameters. Unfortunately, there is no information available on the effect of air density on the cyclone performance.

The Classical Cyclone Design (CCD) Procedure outlined in Air Pollution Control – A Design Approach (Cooper and Alley, 1994) is referred to as a standard method and has been considered by some engineers to be acceptable. However, the CCD process does not consider the cyclone inlet velocity in developing cyclone dimensions. Previous research at Texas A&M University (TAMU) indicated that the efficiency of a cyclone increased, and emission concentration decreased with increasing inlet velocity. But at relatively high inlet velocity, the cyclone efficiency actually began to decrease. A dramatic increase in emission concentration has been observed at velocities higher than a certain threshold level (Parnell, 1996). The level at which the inlet velocities were too high and caused increased emissions was different for each cyclone design. The Texas A&M Cyclone Design (TCD) process specifies the "ideal" cyclone inlet velocities (design velocities) for the different cyclone designs to optimize cyclone performance. The design inlet velocities for the 1D3D, 2D2D and 1D2D cyclones are 975 m/min ± 122 m/min (3200fpm ± 400 fpm), 914 m/min ± 122 m/min (3000fpm ± 400 fpm) and 732 m/min ± 122 m/min (2400fpm ± 400 fpm), respectively. The TCD process allows an engineer to design the cyclone using a cyclone inlet velocity specific for the type of cyclone being considered. However, there is one problem with the CCD and TCD cyclone design process – no specification of the air condition, i.e. air density. None of these cyclone design methods specify whether the cyclone design should be based upon the standard air density or actual air density. It was assumed that the air density affects cyclone performance and energy consumption significantly. Research is needed to investigate the air condition effects on cyclone performance.

Objective

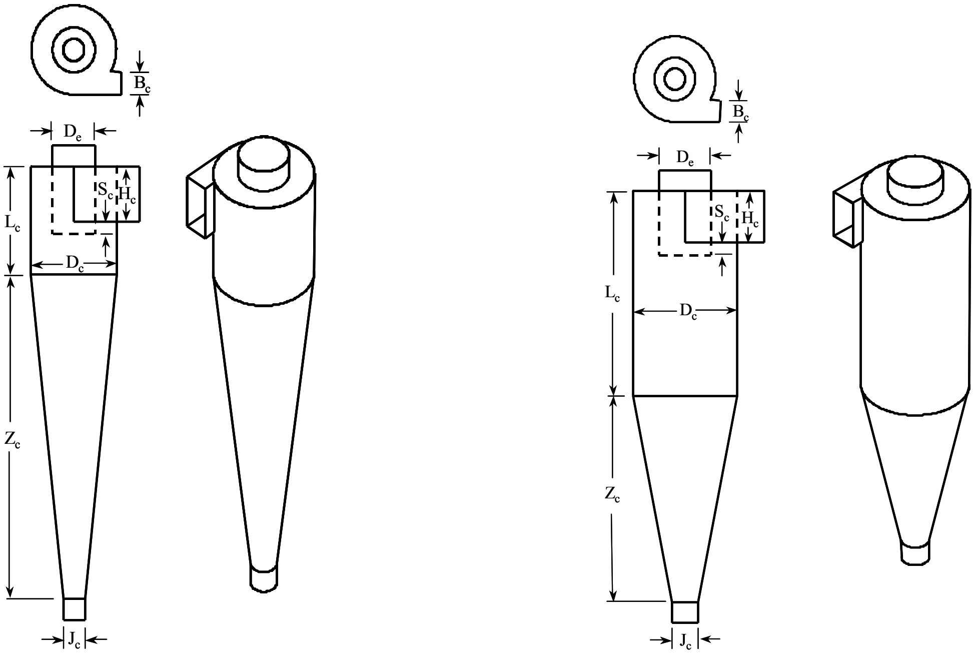
With the enforcement of air pollution regulations at a higher level by the Federal Clean Air Act of 1990, the next level of cyclone technology requires the design and operation of cyclone systems at their optimum condition. This research attempts to investigate the air density effect on cyclone performance.

Experimental Method

Cyclone airflow rate and inlet velocity changes with the change of air density. In this research, tests were conducted to evaluate 1D3D & 2D2D cyclone emission concentration and pressure drop with two sets of inlet design velocities -- one set based on actual air flow rate and the other set based on dry standard air flow rate. All the tests were conducted at Amarillo, Texas where the altitude is 3700 feet and consequently the air density is relatively low.

Cyclones

In the agricultural processing industry, 2D2D and1D3D cyclones have been used for particulate matter control for many years. The configurations of these two cyclone designs are shown in the Figure1. The previous research (Wang, 2000) indicated that 1D3D and 2D2D are the most efficient collectors for fine dust. In this research, only fine dust and 1D3D with 2D2D inlet and 2D2D cyclones were used to conduct experiments. Both 1D3D and 2D2D cyclones used in this research were 15.24 cm (6 inches) in diameter.



$B_c = D_c/4 \quad H_c = D_c/2 \quad S_c = D_c/8$
$D_e = D_c/2 \quad J_c = D_c/4 \quad L_c = 1*D_c$
$Z_c = 3*D_c$

$B_c = D_c/4 \quad H_c = D_c/2 \quad S_c = D_c/8$
$D_e = D_c/2 \quad J_c = D_c/4 \quad L_c = 2*D_c$
$Z_c = 2*D_c$

Figure 1. 1D3D & 2D2D cyclone layouts

Testing Material

Fly ash, cornstarch, 100µm meshed manure dust and regular manure dust was used as test material in this research. The density of the fly ash, cornstarch and manure dust is 2.7 g/cm^3, 1.5 g/cm^3, and 1.8 g/cm^3, respectively. The emission concentration for a specific cyclone design is directly related to the fine dust inlet loading and the particle size distribution (PSD) of inlet particulate matter (PM). Tests were conducted with inlet concentrations of the dust at 1 and 2 g/m^3. The Coulter Counter Multisizer^{TM}3 was used to analyze PSD's. Figures 2-5 show PSD's of the inlet PM. Mass median diameter (MMD) and geometric standard deviation (GSD) are two parameters to characterize PSD's. The MMD is the aerodynamic equivalent diameter (AED) where 50% of PM mass is larger or smaller than this diameter. The GSD is defined by the following equation (Cooper and Alley, 1994):

$$GSD = D_{84.1} / D_{50} = D_{50} / D_{15.9} \quad \ldots\ldots\ldots\ldots (1)$$

Where

$D_{84.1}$ = diameter such that particles constituting 84.1% of the total mass of particles are smaller than this size,

D_{50} = mass median diameter (50% of the total mass of particles are smaller than this size), and

$D_{15.9}$ = diameter such that particles constituting 15.9% of the total mass of particles are smaller than this size.

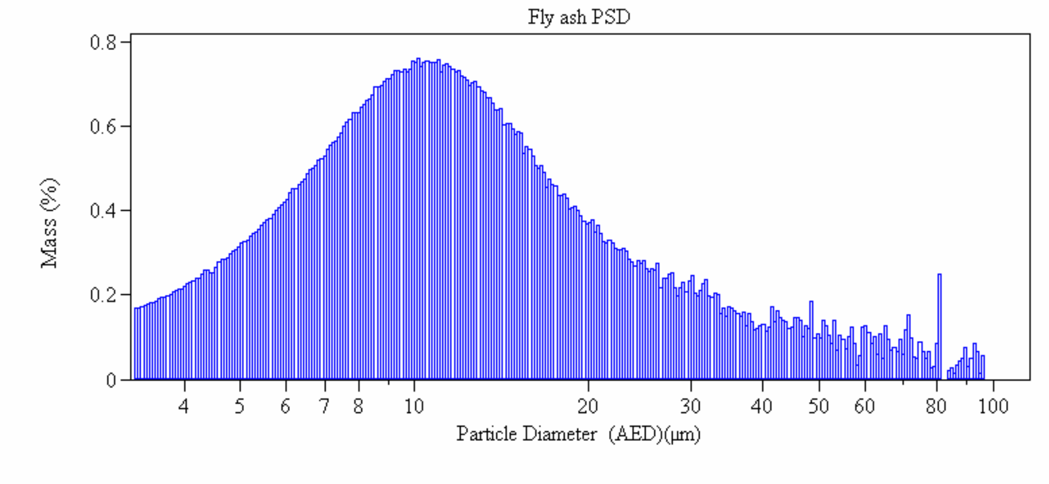


Figure 2. Coulter counter PSD for fly ash (MMD = 11.34 µm, GSD = 1.82)

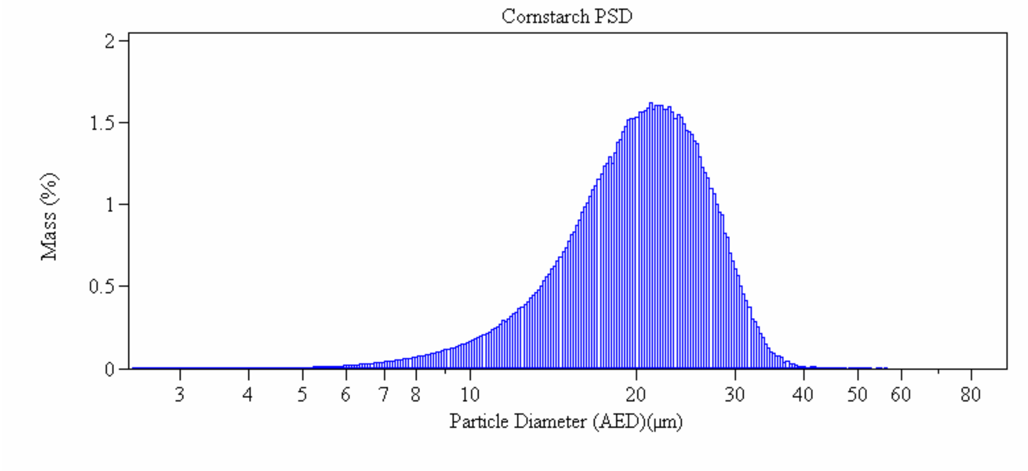


Figure 3. Coulter Counter PSD for cornstarch (MMD = 20.38 µm, GSD = 1.39)

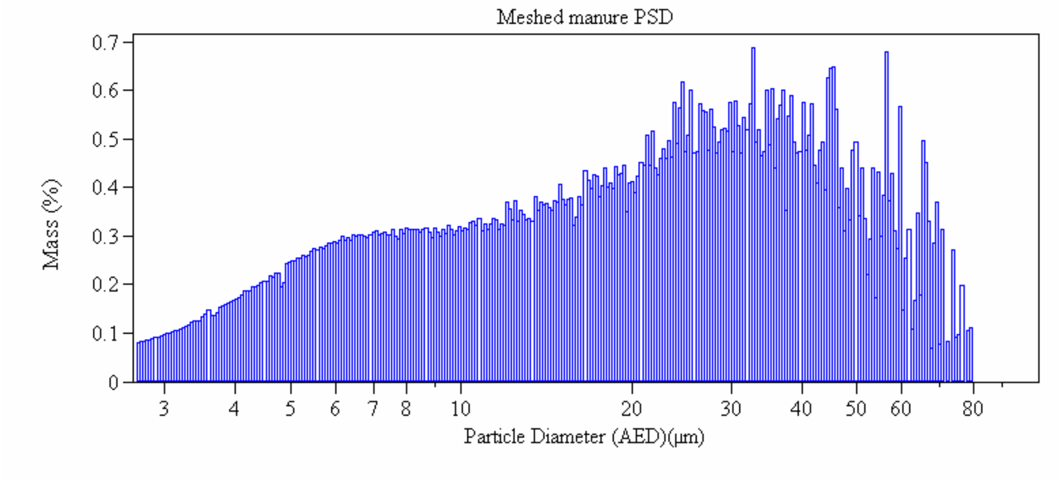


Figure 4. Coulter Counter PSD for 100mu meshed manure dust (MMD = 20.81 µm, GSD = 3.04)

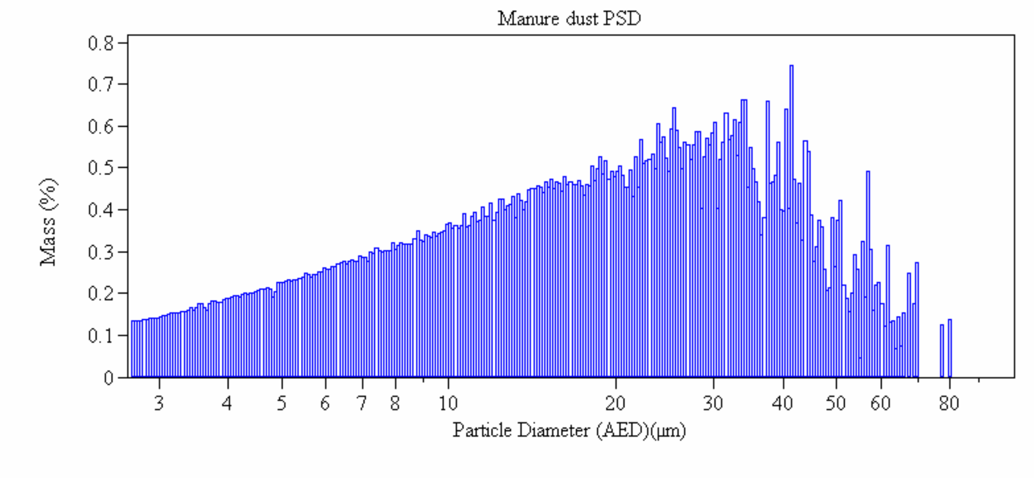


Figure 5. Coulter Counter PSD for regular manure dust (MMD = 18.43 µm, GSD = 2.76)

Testing System

The testing system is shown in Figure 6. The cyclone collection hopper and dust filter were placed in their respective positions, and the system components were connected and sealed. The pressure drop across the orifice meter was monitored to ensure that the proper airflow rate was maintained during the test. Three replications were conducted for each treatment, to obtain an average emission concentration. For each test, testing time was 3 minutes. The system was cleaned between tests. The filters were conditioned in an environmental chamber for 24 hours at 25°C and 46% relative humidity as specified by EPA and weighed before and after testing to determine total penetrating weights. The feeding rates and emission concentrations were determined with the following equations:

$$F = L * Q \quad \text{(2)}$$

where

F = feeding rate (g/min),

L = total inlet loading rate (g/m^3), and

Q = system air-flow rate (m^3/min).

$$EC = \frac{FW_2 - FW_1}{Q * T} * 1000 \quad \text{(3)}$$

where

EC = emission concentration (mg/m^3),

FW$_1$ = pre-weight of filter (g),

FW$_2$ = post-weight of filter (g),

Q = system air flow rate (m^3/min.), and

T = testing time for each sample (min).

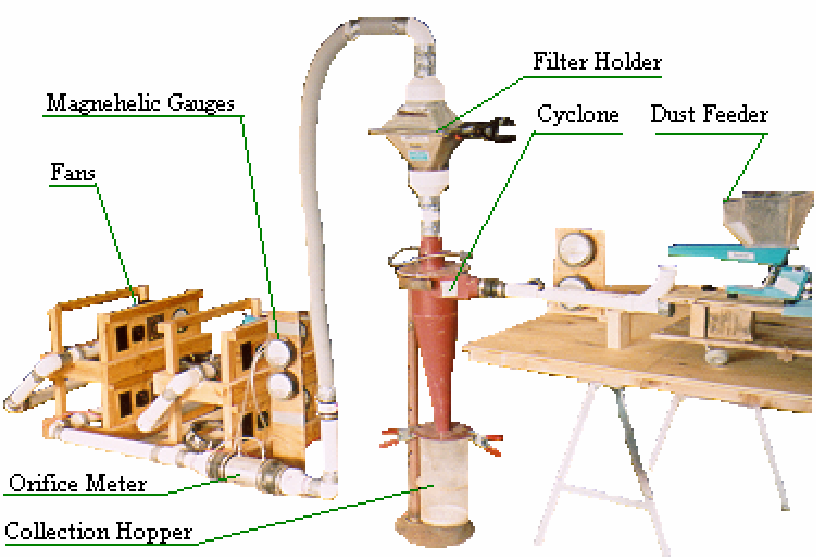


Figure 6. Cyclone testing system

The airflow rates of the testing system were determined by using the TCD design velocity. Table 1 shows the airflow rate and cyclone inlet velocity. The hypothesis in this research was that the air density could significantly affect cyclone performance. Using cyclone actual air design velocity or standard air design velocity would produce significantly different results. Equations 4 and 5 were used to convert the cyclone inlet velocity and flow rate from actual air to standard air inlet velocity and flow rate.

Table1. Airflow rate of the testing system

	diameter of cyclone	design velocity	airflow rate of system
1D3D	15.24 cm (6 inch)	975 m/min (3200 fpm)	2.83 m^3/min (100 cfm)
2D2D	15.24 cm (6 inch)	914 m/min (3000 fpm)	2.66 m^3/min (94 cfm)

- fpm = feet per minute,
- cfm = cubic feet per minute.

$$V_a = \left(\frac{\rho_s}{\rho_a} \right) * V_s \text{ ………………………………………………..(4)}$$

where

V_a = actual air inlet velocity (fpm),

V_s = standard air inlet velocity (fpm),

ρ_a = actual air density (lb/ft^3), and

ρ_s = standard air density (0.075 lb/ft^3).

$$Q_a = \left(\frac{\rho_s}{\rho_a} \right) * Q_s \text{ ………………………………………………..(5)}$$

where

Q_a = actual air inlet velocity (cfm),

Q_s = standard air inlet velocity (cfm),

ρ_a = actual air density (lb/ft^3), and

ρ_s = standard air density (0.075 lb/ft^3).

Experimental Design & Data Analysis

The experiment was conducted as 4-factorial experiment. The 4 factors were (1) inlet velocity (optimum design velocity at actual air condition, optimum design velocity at standard air condition), (2) cyclone design (1D3D, 2D2D), (3) inlet PSD's (fly ash, cornstarch and manure dust), (4) inlet loading rates (1 g/m^3 and 2 g/m^3). Each treatment was based on three repeating observations for a total of 60 observations. ANOVA tests, using Tukey's Studentized Range (HSD) test at 95% confidence interval, were performed on the results.

Equation 6 was used to convert the actual air emission concentration to standard air emission concentration for the comparison.

$$EC_a = \left(\frac{\rho_a}{\rho_s} \right) * EC_s \text{ ……………………………………..……..(6)}$$

where

EC_a = actual air emission concentration (mg/m^3),

EC_s = standard air emission concentration (mg/dscm),
(dscm – dry standard cubic meter)

ρ_a = actual air density (lb/ft^3), and

ρ_s = standard air density (0.075 lb/ft^3).

Besides the emission concentration, another important parameter to characterize cyclone performance is cyclone fractional efficiency. Cyclone fractional efficiency curves were developed based on the cyclone inlet concentration, inlet PSD, emission concentration, and the PSD of dust emitted. The inlet and outlet concentrations for various size ranges were calculated using inlet and outlet dust concentrations and the fraction of particulate in those size ranges obtained from the Coulter Counter PSD analysis. The outlet concentration was divided by the corresponding inlet concentration for each particle size range and subtracted from one with the resulting values being the fractional efficiency for each particle size range:

$$\eta_j = (1 - Conc_{outj}/Conc_{inj}) \text{ ……………..…………………... (7)}$$

where

η_j = fractional efficiency of jth size range,

$Conc_{outj}$ = outlet concentration of jth size range, and

$Conc_{inj}$ = inlet concentration of jth size range.

The cyclone fractional efficiency curve (FEC) can be defined by a lognormal distribution can be characterized by the cut-point (D_{50}) and sharpness-of-cut (the slope of the FEC) (Wang, et al., 2002). 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 cyclone collection efficiency decreases. The sharpness-of-cut (slope) can be determined by the following equation (Cooper and Alley, 1994):

$$Slope = D_{84.1}/D_{50} = D_{50}/D_{15.9} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

where

$D_{84.1}$ = diameter of particle collected with 84.1% efficiency,

D_{50} = diameter of particle collected with 50% efficiency, and

$D_{15.9}$ = diameter of particle collected with 15.9% efficiency.

Test Results and Discussion

Emission Concentration Measurement

Tables 2, 3 and 4 contain the average emission concentration for the tests conducted on the 1D3D and 2D2D cyclones. For comparison, all the emission concentrations were converted from milligram per cubic meter actual air into milligram per cubic meter dry standard air. The statistical analyses indicated that the cyclone emission concentrations were highly dependent upon cyclone design, inlet loading rates, PSD's of inlet PM as well as air density. The following observations were noted:

1. For the fly ash, both 1D3D and 2D2D cyclone average emission concentrations are significantly higher when the tests were conducted at actual air design velocity than the results from the tests, which were conducted at standard air design velocity. When the air density was 0.0635 lb/ft^3, the 3200 sfpm was equivalent to 3800 afpm. This velocity was outside of the TCD ideal design velocity range (3200 ± 400 fpm) for 1D3D cyclone. One would assume that the higher emissions would occur because of such high inlet velocity. However, the measured data did not support this assumption. Experimental results indicate that the optimum design velocity for 1D3D cyclone is 3200 sfpm but not 3200 afpm. The same observations were obtained for 2D2D cyclone. With 0.0630 lb/ft^3 air density, the 3000 sfpm inlet velocity was equivalent to 3600 afpm, it was also outside of the TCD ideal design velocity range (3000± 400 fpm) for 2D2D cyclone. Again, the experimental data indicate that the optimum design velocity for 2D2D cyclone should be 3000 sfpm, but not 3000 afpm.
2. For agricultural dust with larger MMD, such as cornstarch and manure dust, the trend of decreasing emission concentration for 1D3D and 2D2D cyclones was observed when the inlet design velocity was changed from actual air design velocity to standard air design velocity. However, these differences of the emission concentration are not statistically significant.
3. Among the four types of testing dust, fly ash has the smallest MMD, and then regular manure, cornstarch and 100 μm meshed manure (see Figures 2-5). The test results suggest that the smaller the MMD, the higher the effect of air density on the emission.
4. The results from both 1D3D and 2D2D cyclones also indicate that the higher the inlet loading rate, the higher the difference of the emission concentration with different inlet velocity treatment. It implies that the higher effect of air density on emissions occurs.

Table 2. Average emission concentration from 1D3D cyclone

inlet velocity	air density (lb/ft^3)	fly ash		corn starch	
		inlet loading			
		1 g/m^3	2 g/m^3	1 g/m^3	2 g/m^3
v_{in}=3200 afpm	0.0636	49.81	92.49	6.45 [a]	17.59 [b]
v_{in}=3200 sfpm	0.0635	42.36	73.30	6.15 [a]	16.66 [b]

- emission concentration: mg/dscm,
- dscm = cubic meter of dry standard air,
- afpm = feet per minute of actual air,
- sfpm = feet per minute of dry standard air,
- three tests were performed for each condition,
- means with the same letter are not significantly different at 0.05 level.

Table 3. Average emission concentration from 1D3D cyclone (continued)

inlet velocity	air density (lb/ft^3)	manure #1	manure #2
		inlet loading	
		2 g/m^3	2 g/m^3
v_{in}=3200 afpm	0.0631	75.30 [c]	49.87
v_{in}=3200 sfpm	0.0631	73.83 [c]	43.40

- emission concentration: mg/dscm,
- mnure #1: 100 μm meshed manue dust,
- manure #2: regular manure dust,
- dscm = cubic meter of dry standard air,
- afpm = feet per minute of actual air,
- sfpm = feet per minute of dry standard air,
- three tests were performed for each condition,
- means with the same letter are not significantly different at 0.05 level.

Table 4. Average emission concentration from 2D2D cyclone

inlet velocity	air density (lb/ft^3)	fly ash		corn starch	
		inlet loading			
		1 g/m^3	2 g/m^3	1 g/m^3	2 g/m^3
v_{in}=3000 afpm	0.0635	56.60 [a]	109.25	8.81 [b]	19.55 [c]
v_{in}=3000 sfpm	0.0630	51.23 [a]	95.97	7.93 [b]	17.68 [c]

- emission concentration: mg/dscm,
- dscm = cubic meter of dry standard air,
- afpm = feet per minute of actual air,
- sfpm = feet per minute of dry standard air,
- three tests were performed for each condition,
- means with the same letter are not significantly different at 0.05 level.

The emission concentrations associated with inlet and outlet PSD's were also used to calculate cyclone fractional efficiency and to develop cyclone fractional efficiency curves. The methodology used to develop fractional efficiency curves is similar to the one developed by Wang (2002). It includes the following three steps:

1. Obtain PSD's of inlet and outlet PM using Coulter Counter Multisizer^{TM}3,
2. Calculate the fractional efficiency curves using inlet and outlet concentrations and the PSD's,
3. Obtain the "best-fit" lognormal distribution for the fractional efficiency curves obtained above.

Statistical analyses were also conducted on the cyclone cut-points and slopes. Tables 5 and 6 list the average cut-points and slopes for 1D3D and 2D2D cyclones with fly ash. For the 1D3D cyclone, the cut-points are significantly different with different inlet velocity treatments and two inlet loading rates. However, for 2D2D cyclone, the differences of cut-points with different inlet velocity treatment are not significantly different. Air density effect on 1D3D cyclone cut-point is greater than on 2D2D cyclone.

Table 5. 1D3D cyclone cut-point & slope with fly ash

		inlet loading			
inlet	air density	1 g/m^3		2 g/m^3	
velocity	(lb/ft^3)	cut-point	slope	cut-point	slope
v_{in}=3200 afpm	0.0636	3.92	1.29 ^{a}	4.10	1.24
v_{in}=3200 sfpm	0.0635	3.43	1.43 ^{a}	3.60	1.35

- cut-point: µm,
- afpm = feet per minute of actual air,
- sfpm = feet per minute of dry standard air,
- three tests were performed for each condition,
- means with the same letter are not significantly different at 0.05 level.

Table 6. 2D2D cyclone cut-point & slope with fly ash

		inlet loading			
inlet	air density	1 g/m^3		2 g/m^3	
velocity	(lb/ft^3)	cut-point	slope	cut-point	slope
v_{in}=3000 afpm	0.0635	4.18 ^{a}	1.23 ^{b}	4.20 ^{a}	1.26 ^{b}
v_{in}=3000 sfpm	0.0630	3.98 ^{a}	1.30 ^{b}	4.03 ^{a}	1.28 ^{b}

- cut-point: µm,
- afpm = feet per minute of actual air,
- sfpm = feet per minute of dry standard air,
- three tests were performed for each condition,
- means with the same letter are not significantly different at 0.05 level.

Pressure Drop Measurement

The same testing system was used to measure cyclone pressure drops at two inlet velocity treatments. Table 7 lists the testing results. In order to accurately measure the static pressure drop across the cyclones, the static pressure taps were inserted into the air stream such that the static pressure sensing position was in the direction of air flow (Wang, et al., 2001). The pressure drop measurement was conducted without any dust feeding.

Table 7. Cyclone pressure drop measurement

Inlet velocity	air density (lb/ft^3)	1D3D ΔP_{1D3D}	inlet velocity	air density (lb/ft^3)	2D2D ΔP_{2D2D}
v_{in}=3200 afpm	0.0636	3.03	v_{in}=3000 afpm	0.0635	2.33
v_{in}=3200 sfpm	0.0635	4.97	v_{in}=3000 sfpm	0.0630	3.32

- ΔP_{1D3D}: 1D3D cyclone pressure drop in inch water gauge (in. H_2O),
- ΔP_{2D2D}: 2D2D cyclone pressure drop in inch water gauge (in. H_2O),
- afpm = feet per minute of actual air,
- sfpm = feet per minute of dry standard air,
- five tests were performed for each condition,
- means with the same letter are not significantly different at 0.05 level.

Parnell (1990) reported that pressure drops for 1D3D and 2D2D cyclones operating at design velocities were 4.6 and 3.7 inches of water gauge. However, the experimental data above indicate that cyclone pressure drop is strongly dependent upon air density. Only when 1D3D and 2D2D cyclones operate at their respective design velocities of standard air, will their pressure drops be around the previous reported value i.e. 4.6 in.H_2O for 1D3D and 3.7 in.H_2O for 2D2D. It is important that air density be considered in the design of cyclone systems.

Cyclone System Design - Sizing Cyclones

The first step in designing a cyclone abatement system is to size the cyclone. Cyclone size and configuration depends on the cyclone design velocity and the volume of air to be handled. The following equation can be used to size 1D3D or 2D2D cyclones.

$$D_c = \sqrt{\frac{8*Q}{V_{in}}} \qquad \ldots\ldots(9)$$

where:

D_c = cyclone diameter (ft),

Q = air flow rate into cyclone (dscf/min), and
(dscf = cubic meter of dry standard air)

V_{in} = cyclone design inlet velocity (dsfpm)
(dsfpm = feet per minute of dry standard air)
V_{in} = 3200 dsfpm for 1D3D
V_{in} = 3000 dsfpm for 2D2D.

Equations 4 and 5 can be used to calculate the standard airflow rate (Q) and standard air inlet velocity (V_{in}). Tables 8 and 9 list the recommended sizes for 1D3D and 2D2D cyclones. They are similar to the tables reported by Parnell (1990). This research supports the sizing of cyclones based upon the standard air volume flow rate.

Table 8. Recommended sizes for the 1D3D cyclone

	using 1 cyclone		using 2 cyclones		using 3 cyclones		using 4 cyclones	
air volume (dscf/min)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)
1,500	24	8	-	-	-	-	-	-
2,000	28	9	20	7	-	-	-	-
2,500	30	10	22	8	-	-	-	-
3,000	32	11	24	8	20	7	-	-
4,000	38	13	26	9	22	8	20	7
5,000	42	14	30	10	24	8	22	8
6,000	46	16	32	11	28	10	24	8
7,000	-	-	36	12	30	10	26	9
8,000	-	-	38	13	32	11	28	10
9,000	-	-	40	14	32	11	28	10
10,000	-	-	42	14	34	12	30	10
11,000	-	-	44	15	36	12	32	11
12,000	-	-	46	16	38	13	32	11
14,000	-	-	-	-	42	14	36	12
16,000	-	-	-	-	44	15	38	13
18,000	-	-	-	-	46	16	40	14
20,000	-	-	-	-	-	-	42	14
22,000	-	-	-	-	-	-	44	15
24,000	-	-	-	-	-	-	46	16

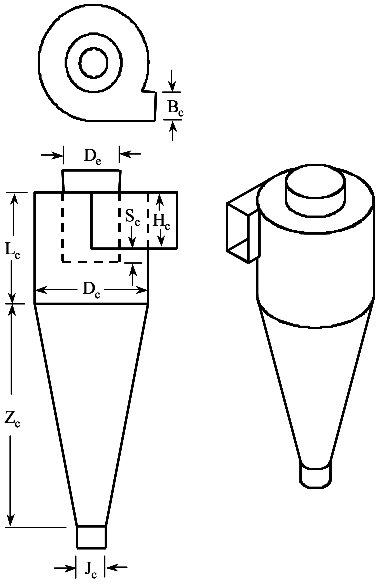
- dscf = cubic feet of dry standard air.

Table 9. Recommended sizes for the 2D2D cyclone

	using 1 cyclone		using 2 cyclones		using 3 cyclones		using 4 cyclones	
air volume (dscf/min)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)
1,500	24	8	-	-	-	-	-	-
2,000	28	10	20	7	-	-	-	-
2,500	30	10	22	8	-	-	-	-
3,000	34	12	24	8	20	7	-	-
4,000	40	14	28	10	22	8	20	7
5,000	44	15	30	10	26	9	22	8
6,000	48	16	34	12	28	10	24	8
7,000	-	-	36	12	30	10	26	9
8,000	-	-	40	14	32	11	28	10
9,000	-	-	42	14	34	12	30	10
10,000	-	-	44	15	36	12	30	10
11,000	-	-	46	16	38	13	32	11
12,000	-	-	48	16	40	14	34	12
14,000	-	-	-	-	42	14	36	12
16,000	-	-	-	-	46	16	40	14
18,000	-	-	-	-	48	16	42	14
20,000	-	-	-	-	-	-	44	15
22,000	-	-	-	-	-	-	46	16
24,000	-	-	-	-	-	-	48	16

- dscf = cubic feet of dry standard air.

Simpson and Parnell (1995) introduced a new low-pressure cyclone, called 1D2D cyclone (see Figure 7), for the cotton ginning industry to solve the cycling-lint problem. The 1D2D cyclone is a better design for high-lint content trash compared with 1D3D and 2D2D cyclones (Wang, et al., 1999). The design velocity for 1D2D cyclone is 2400 fpm (Simpson, 1996). The recommended sizes for 1D2D cyclone are listed in the Table 10.



$B_c = D_c/4$ $H_c = D_c/2$ $S_c = 5\,D_c/8$
$D_e = D_c/1.6$ $J_c = D_c/4$ $L_c = 1*D_c$
$Z_c = 2*D_c$

Figure 7. 1D2D cyclone layout

Table 10. Recommended sizes for the 1D2D cyclone

air volume (dscf/min)	using 1 cyclone		using 2 cyclones		using 3 cyclones		using 4 cyclones	
	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)	D_c (in.)	appro. height (ft)
1,500	26	7	-	-	-	-	-	-
2,000	30	8	22	6	-	-	-	-
2,500	34	9	24	6	-	-	-	-
3,000	38	10	26	7	22	6	-	-
4,000	44	11	30	8	26	7	22	6
5,000	48	12	34	9	28	7	24	6
6,000	54	14	38	10	30	8	26	7
7,000	-	-	40	10	34	9	28	7
8,000	-	-	44	11	36	9	30	8
9,000	-	-	46	12	38	10	32	8
10,000	-	-	48	12	40	10	34	9
11,000	-	-	52	13	42	11	36	9
12,000	-	-	54	14	44	11	38	10
14,000	-	-	-	-	48	12	40	10
16,000	-	-	-	-	50	13	44	11
18,000	-	-	-	-	54	14	46	12

20,000	-	-	-	-	-	-	48	12
22,000	-	-	-	-	-	-	52	13
24,000	-	-	-	-	-	-	54	14

- dscf = cubic feet of dry standard air

Conclusion

The performance of 1D3D and 2D2D cyclone is highly dependent upon the inlet air velocity and air density. Proposed cyclone design inlet velocities are:

- 3200 feet per minute of standard air for 1D3D cyclone.
- 3000 feet per minute of standard air for 2D2D cyclone.

It is important to consider the air density effect on the cyclone performance in the design of cyclone abatement systems. TCD ideal design velocity for 1D3D, 2D2D and 1D2D cyclones should be the ideal inlet velocity of standard air, not the ideal inlet velocity of actual air. In designing cyclone abatement systems, the proposed design velocity should be the basis for sizing the cyclone and determining the cyclone pressure drop. The recommended sizes for 1D3D, 2D2D and 1D2D cyclones are reported in this paper.

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