1D2D LOW PRESSURE CYCLONE: LARGE DUST, HIGH LINT COLLECTOR

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Abstract

A new Low Pressure Cyclone (LPC) was design and evaluated for use on axial-flow fan exhausts and high fibrous trash exhausts. Axial-flow fan exhausts in cotton gins can not operate with large back pressures. Typical "high-efficiency" cyclones generate 996 to 1245 Pa (4 to 5 in wg) pressure. The pressure drop across the newly-designed LPC was 373 Pa (1.5 in wg) at the optimal design inlet velocity of 732 m/min ± 122 m/min (2400 fpm ± 400 fpm). The LPC has a body section one diameter (D) in length and cone section two diameters in length (1D2D). The dust outlet is wider than conventional cyclone dust outlets at D/2 as is the air exit tube at D/1.6. Theoretical equations were used to determine the 1D2D LPC had a cut-point of 7.5 µm.

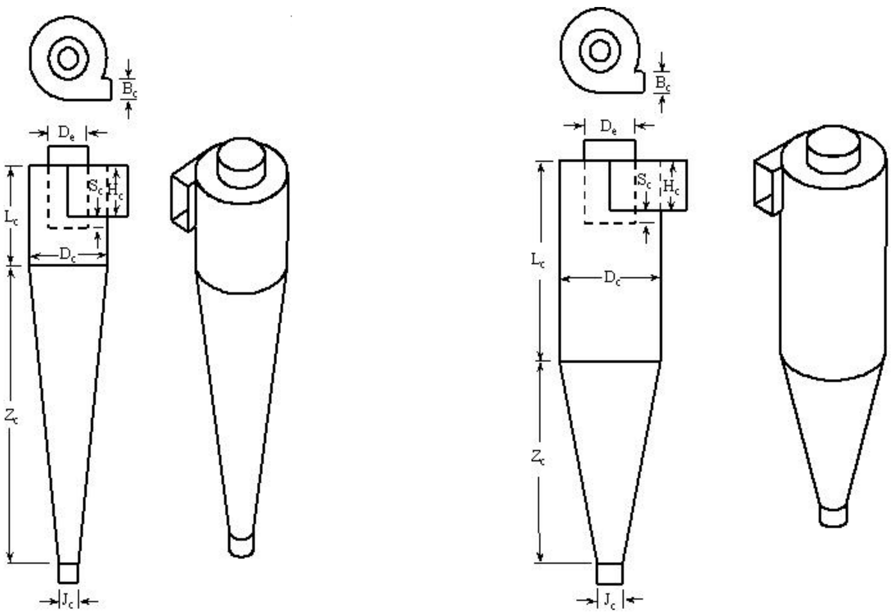
Introduction

Cotton gin processing is normally accomplished by pneumatic conveyance of seed cotton and lint through cleaners, gin stands, and other equipment. As a consequence, gin processing results in numerous emission points. The amendments made in 1990 to the Federal Clean Air Act require all sources of air pollution, including cotton gins, to be subject to rules and regulations that will reduce allowable emissions. Emission factors for cotton ginning published by U.S. EPA (1996) and extended factors published by ASABE (2006) are summarized in Table 1. State Air Pollution Regulatory Agencies (SAPRA) are responsible for ensuring compliance with rules and regulations and require cotton gins to have abatement equipment. Cyclones, condenser drums or screen cages are used at cotton gins for collection of particulate matter (PM) before an air stream is exhausted to the atmosphere.

Table 1. Cotton gin emission factors.

		1996 AP-42 Emission Factor				Extended Emission Factor			
Process Stream	Emission Point	TSP, kg/bale (lb/bale)		PM_{10}, kg/bale (lb/bale)		TSP, kg/bale (lb/bale)		PM10, kg/bale (lb/bale)	
Unloading	1 or 1a	0.132	(0.29)	0.054	(0.12)	0.132	(0.29)	0.054	(0.12)
1st Stage Seed Cotton Cleaning	2	0.163	(0.36)	0.054	(0.12)	0.163	(0.36)	0.054	(0.12)
2nd Stage Seed Cotton Cleaning	3	0.109	(0.24)	0.042	(0.093)	0.109	(0.24)	0.042	(0.093)
3rd Stage Seed Cotton Cleaning	3a	0.043	(0.095)	0.015	(0.033)	0.043	(0.095)	0.015	(0.033)
Distributor/Overflow	4 or 4a	0.032	(0.071)	0.012	(0.026)	0.032	(0.071)	0.012	(0.026)
Trash	5	0.245	(0.54)	0.034	(0.074)	0.245	(0.54)	0.034	(0.074)
Cyclone Robber	5a	0.082	(0.18)	0.024	(0.052)	0.082	(0.18)	0.024	(0.052)
Mote	6	0.127	(0.28)	0.059	(0.13)	0.127	(0.28)	0.059	(0.13)
1st Stage Lint Cleaning	7								
(Covered Condenser Drum)						0.422	(0.93)	0.177	(0.390)
(Cyclone)						0.222	(0.49)	0.092	(0.203)
2nd Stage Lint Cleaning	8	1st and 2nd Stages Combined							
(Covered Condenser Drum)		0.499	(1.1)	Not Reported		0.077	(0.17)	0.032	(0.070)
(Cyclone)		0.263	(0.58)	0.109	(0.24)	0.041	(0.09)	0.017	(0.037)
3rd Stage Lint Cleaning	8a								
(Covered Condenser Drum)		Not Reported		Not Reported		0.039	(0.085)	0.016	(0.035)
(Cyclone)		Not Reported		Not Reported		0.020	(0.045)	0.009	(0.019)
Battery Condenser	9								
(Covered Condenser Drum)		0.077	(0.17)	Not Reported		0.077	(0.17)	0.028	(0.061)
(Cyclone)		0.018	(0.039)	0.006	(0.014)	0.018	(0.039)	0.006	(0.014)

Best Available Control Technology (BACT) was defined by the Texas Commission on Environmental Quality (TCEQ), the SAPRA in Texas, as the best level of abatement technology applied to all new or modified facilities in which consideration is given to "technical practicability and economic reasonableness" (TACB, 1992). Guidelines for determining BACT are somewhat flexible and the permitting engineer is given limited authority to require a particular air pollution abatement system for each gin. In Texas, Baseline BACT is condenser drums covered with fine mesh screens for axial-flow fan exhausts and 1D3D or 2D2D cyclones (figure 2) for centrifugal fan exhausts.



1D3D Cyclone
$B_c = D_c/4$ $H_c = D_c/2$ $S_c = D_c/8$
$D_e = D_c/2$ $J_c = D_c/4$ $L_c = D_c$
$Z_c = 3D_c$

2D2D Cyclone
$B_c = D_c/4$ $H_c = D_c/2$ $S_c = D_c/8$
$D_e = D_c/2$ $J_c = D_c/4$ $L_c = 2D_c$
$Z_c = 2D_c$

Figure 2. Cyclones are used on centrifugal fan exhausts.

The 1D3D and 2D2D cyclones, called "high-efficiency," are standard cyclone configurations used in the cotton industry as an abatement device. The D refers to the diameter of the cyclone body and the basis for sizing all components of the cyclone as illustrated by the equations in figure 2. The pressure drop across 1D3D and 2D2D cyclones is typically 996 to 1245 Pa (4 to 5 in wg) such that centrifugal fans are required to overcome the air resistance caused by the cyclone backpressure and convey the PM.

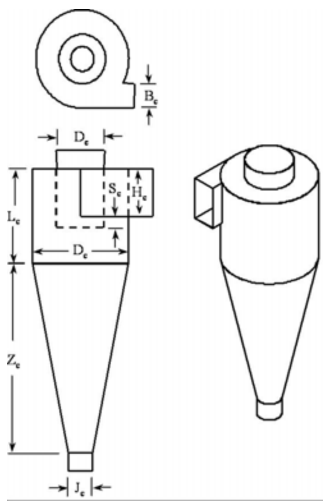
Axial-flow fans are more sensitive to backpressures created by 1D3D and 2D2D cyclones. In the ginning process, axial-flow fans are used to convey lint in three air stream types, 1) from the gin stand to a condenser drum associated with the first-stage of lint cleaning, 2) from a lint cleaner to another condenser drum associated with a second or third-stage of lint cleaning, and 3) from the final stage of lint cleaning to the battery condenser above the lint slide. Condenser drums serve the purpose of separating the lint from the conveying air and require large volumes of air to accumulate or "bat" the lint onto the surface of the drum. Since pressure drops associated with conveying and "batting" lint onto condenser drums are relatively small, axial-flow fans are used.

The first-stage lint cleaner is the emitting point in a gin with the highest emission rate of fine dust. One approach to abating this pollution is to cover the condenser drum with a fine mesh screen (covered condenser drums). The fine mesh screen is perceived to have an overall efficiency of 50% while cyclones are perceived to have an overall efficiency of 90% by TCEQ's Air Permits Division (2007). Faulkner and Shaw (2006), Hughs and Baker (1998), and Baker and Stedronsky (1967) demonstrated that 0.154 m (6 in), 0.305 m (12 in), and 0.762 m (30 in) cyclone models can achieve 98 and 99% overall efficiencies. Replacing fine mesh screens with cyclones as the abatement device for lint cleaning exhaust reduces PM emissions significantly. Table 1 indicates the reduction is at least two-fold for all stages of lint cleaning and battery condenser. However, installing 1D3D or 2D2D cyclones would require the retrofit of an in-line centrifugal fan to overcome the additional pressure losses.

A new low pressure cyclone could be retrofitted to axial-flow fan exhausts, making centrifugal fans unnecessary, while reducing emission rates from lint cleaning processes. The design and performance characteristics of a 1D2D Low Pressure Cyclone (LPC) are described herein.

1D2D Low Pressure Cyclone (LPC) Design

Kasper et. al. (1993) designed a new 1D2D Low Pressure Cyclone (LPC) configuration (figure 3) with a larger dust outlet (J_c=D_c/2) and a larger air exit tube (D_c/1.6). The cyclone first recommended by Kasper included a longer air exit tube that extended into the cone. While the longer air exit tube reduced exit emission concentrations, the pressure drop increased. Therefore, the shorter exit tube (H_c + Sc, where S_c = D_c/8) as depicted in figure 3 is recommended.



1D2D Cyclone

$B_c = D_c/4$ $H_c = D_c/2$ $S_c = D_c/8$

$D_e = D_c/1.6$ $J_c = D_c/2$ $L_c = D_c$

$Z_c = 2D_c$

Figure 3. 1D2D cyclone layout

Simpson (1996) determined the 1D2D LPC should be operated at a design inlet velocity of 732 m/min ± 122 m/min (2400 fpm ± 400 fpm), resulting in a pressure drop across the cyclone of 373 Pa (1.5 in wg). Wang et. al. (2006) further theoretically determined the 1D2D LPC to have 2.27 turns and that pressure drop does not vary with changing cyclone size.

According to Wang (2005), the theoretical cut point of a cyclone can be determined using mathematical equations. The 1D2D LPC has a theoretically determined cut point, d_{pc}, of 7.5 μm.

$$d_{pc} = \frac{1}{2}\sqrt{\frac{9\,\mu\,W}{\pi\,N_e\,V_i\,\rho_p}} \tag{1}$$

Where

- d_{pc}= diameter particle collected with 50% efficiency, m
- μ = Viscosity, kg/m·s
- W = Width of cyclone inlet, m
- N_e = Number of turns,
- V_i = Design inlet velocity, m/s
- ρ_p = Particle density, kg/m^3

A comparison of 1D2D to 1D3D and 2D2D cyclone characteristics is given in Table 2. The larger dust outlet, D/2, and air exit tube, D/1.6, dimensions of the 1D2D are key parameters that influence the pressure drop of the cyclone as well as the lower design inlet velocity, 732 m/min (2400 fpm). The number of turns is largely a function of the total height of a cyclone. The 1D2D cyclone number of turns at 2.6 is lower that 6.0 for both the 1D3D and 2D2D cyclones. The number of turns affects the cut point of the cyclone among other parameters such as particle density as shown in equation 1.

Table 2. Comparison of 1D2D to 1D3D and 2D2D cyclone characteristics.

Cyclone	Dust Outlet	Air Exit	Design Inlet Velocity, m/min (fpm)	Pressure Drop, Pa (in. wg)	No. Turns	Cut Point µm
1D2D	D/2	D/1.6	732 ± 122 (2400 ± 400)	373 (1.57)	2.6	7.5
1D3D	D/4	D/2	976 ± 122 (3200 ± 122)	1021 (4.3)	6.0	3.9
2D2D	D/4	D/2	915 ± 122 (3000 ± 122)	971 (4.1)	6.0	4.0

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