INFLUENCE OF TRASH EXIT DESIGN ON CYCLONE PERFORMANCE

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Abstract

Twelve cyclone trash exit arrangements were evaluated using a 34-inch diameter 1D3D cyclone and trash from stripper harvested cotton. Four of the experimental arrangements outperformed the standard cyclone configuration. Superior arrangements included an air bleed system that extracted 9% of the process air along with the trash, a linear flight design discharging into an unsealed trash system, a large expansion chamber discharging into a sealed trash system, and a spiral flight design discharging into a sealed system. Of these arrangements, the large expansion chamber appeared to be the most practical candidate for retrofitting an existing gin's cyclone system.

Introduction

Cyclones have been used as trash and dust collectors at cotton gins for many years. Early cyclones were large-diameter, low-velocity units that were designed primarily for the collection of large trash. At that time fine dust collection was a secondary consideration. Then, in the 1960's, dust abatement became a much more important consideration for cotton gins. New State and Federal air quality regulations promulgated during that era caused the ginning industry to search for more effective dust abatement equipment. One result of this effort was the introduction to the ginning industry of the high-efficiency, small-diameter cyclone commonly referred to today as the 2D2D design (Harrell and Moore, 1962, Baker and Stedronsky, 1967). Later a somewhat more efficient 1D3D design was developed (Parnell and Davis, 1979). Thus, cotton gin cyclone design has evolved from a device suitable mainly for rough trash collection, to very efficient designs that collect virtually all dust over about 20µm in size.

While the ginning industry has made a lot of progress over the last 30 years in cleaning up the environment around cotton gins, additional improvements will be needed in the future to meet the public's ever increasing air quality expectations. Although present technology will meet current air quality standards in most areas, our industry needs to continue to pursue research and technology transfer efforts that will anticipate and provide for future air quality needs. To meet these needs, several research groups continue to pursue objectives related to cotton gin air quality. A part of this ongoing program includes attempts to improve the cyclone collector, and to extend its range of application. For example, a special low-pressure 1D2D design was recently introduced for control of dust and lint-fly emissions from lint cleaner condenser exhausts (Simpson and Parnell, 1995). Currently, work is also in progress at the ginning laboratories in Mesilla Park, NM and Lubbock, TX on other designs that show promise for improved performance in high-pressure applications (Hughs and Baker, 1996).

While development and proof-testing of new cyclone designs are exciting and potentially rewarding endeavors, there also exists a potential for improving the operation and performance of existing 2D2D and 1D3D collectors. Recent research suggests that present-day cyclone systems might be improved substantially if we could overcome several operating problems that seem to be limiting their effectiveness (Baker et al., 1995). We accidently identified one such problem last year in our evaluation of several pre-separator and cyclone combinations. In those tests we encountered what we thought were performance limiting problems with lint and trash re-circulation near the cyclone's trash exit. This problem prompted this year's evaluation of several alternative trash exit designs.

The purpose of this investigation was to identify techniques that could be used to reduce re-circulation near the trash exit, and to measure the effects of this change on cyclone dust emissions. We also wanted to re-evaluate a pre-separator under these improved operating conditions.

Methods and Materials

Trash Exit Arrangements

Altogether, 12 combinations of trash exit design, air flow condition at the trash exit, and pre-separator usage were evaluated. The trash exit designs evaluated in this study included large and small expansion chambers, straight and spiral flighting inside the lower 1/3 of the cone section, and a conventional cone section, Figures 1-4. All of these designs except the small expansion chamber were evaluated under both sealed and unsealed conditions at the trash exit. When sealed, there was no air leakage into or out of the cyclone's trash exit. The unsealed condition was obtained by opening a slide valve in a 6-inch diameter vent attached to a chute under the cyclone, Figure 1. When unsealed, air could be induced into or discharged from the trash exit depending upon the static pressure at the exit. This pressure varied with trash exit design. The small

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expansion chamber was evaluated under the unsealed condition, but due to an oversight, was not evaluated under the sealed condition. In addition, the regular cone was used to evaluate a special air-bleed system that used a small auxiliary fan to extract about 9% of the process air from the cyclone through its trash exit with the trash. These 10 arrangements were evaluated using a 1D3D cyclone following a pre-separator. The regular cone and the straight flighted cone were also tested under the unsealed condition without use of the pre-separator.

Equipment

The trash handling equipment, pre-separator, and cyclone used in this study were the identical to those used in earlier studies (Baker et al., 1995). An auger feeder was used to feed gin trash into a 12"φ air suction line leading to a centrifugal trash fan, Figure 5. A cone shaped air control device at the inlet of this air line was used to regulate air flow. From the fan the trash was delivered to an overhead pre-separator unit. Trash separated by the pre-separator was directed through a vacuum dropper into a 12"φ trash auger for final disposal. Air discharging from the pre-separator was then directed to a 1D3D cyclone. Trash collected by the cyclone was dropped into a collection box. Air from the cyclone was directed through an 18"φ exhaust line to sampling ports located about 3 feet from the end of the line. The line was arranged in a "candy cane" design to provide a suitable sampling location for an EPA Method 201A sampling probe.

The pre-separator was about 38" wide (Baker et al., 1995). At an airflow of 3200 cfm, this width produced a critical separation velocity on the inlet side of the separation baffle of about 700 fpm. The air velocity on the outlet side of the baffle was about 300 fpm.

The cyclone was a standard 34"φ 1D3D unit constructed of 20 ga. galvanized sheet metal. When configured as a standard cyclone, it was equipped with a conventional 3D cone section having an 8½"φ trash exit. The inlet transition was of the flattop design, and the outside wall of the transition was tangent to the cyclone body.

Sampling Procedures

Particulate sampling was by EPA Method 201A. A standard Method 5 sampling train equipped with an in-stack sizing cyclone was used to isokinetically collect samples at four traverse points across each of 2 diameters (8 points) in the 18"φ exhaust lines. The sampling location was 20 feet (13.3 diameters) downstream from two 90° elbows on the cyclones' 17"φ exhaust outlets, and about 3 feet (2 diameters) from the end of the exhaust lines, Figure 5.

Method 201A requires the use of a constant air sampling rate in order to maintain a constant 10µm cut point (D_{50}) in the sizing cyclone. Isokinetic sampling must be maintained within ± 20% by selection of appropriately sized sampling nozzles. Fortunately, in our case, the velocity heads at the 8 sampling points did not vary excessively and we were able to use the same sampling nozzle at all points without violating the isokinetic sampling requirements. The particulate that passes through the sizing cyclone is collected by a final glass fiber filter, and this material along with that removed by washing the cyclone's outlet tube with acetone is by definition referred to as PM_{10} in Method 201A. The particulate collected by the sizing cyclone, and that removed by washing the interior of the sampling nozzle and cyclone body, is considered to be larger than PM_{10}. The sum of these 2 size ranges is referred to as "total suspended particulate" (TSP).

Pre-Test Calibrations

Pitot traverses were made prior to these tests to evaluate the sampling locations, to leak check the pre-separator unit, and to calibrate standard pitot tube mounted in the center of the exhaust line ahead of the particulate sampling location. In addition to these pre-test measurements, we also checked the calibration of the dry gas meter used in the stack sampling train with a wet test meter.

Trash Material

The trash used in these experiments was from cotton that had been ginned in our Laboratory's full-scale gin plant during the 1994-95 ginning season. It consisted of trash that had been collected with our battery of 2D2D cyclones. Basically, the trash consisted of material removed by our unloading separator, airline cleaner, two hot-air inclined cleaners, two stick extractors, the feeder and gin stand, and the two additional separators. This trash did not, however, contain waste (motes) from our normal two-stage lint cleaning operation. Despite the fact that lint cleaner waste was left out of the trash mixture, the trash still contained a substantial amount (1.4%) of fiber. The fine dust content (<100µm) of the trash averaged 3.1%. Initially, the trash was collected in a conventional bur hopper in the normal manner. It was then dumped into a truck and delivered to a nearby metal building for storage until needed in these studies. Trash feed rates of approximately 750 lb/h were used in these tests to provide a typical stripper-trash loading rate for the collection equipment of about 3.9 lb/1000 ft^3 (62 g/m^3) of conveying air.

Data Analysis

Standard analysis of variance techniques were used to analyze the data, and statistically significant differences between the trash exit designs were determined by Duncan's Multiple Range Test at the 0.05 level of significance.

Results

Trash Exit Air Flow

Static pressure readings ahead of the cyclone and at the trash exit indicated that all exit designs, except for the linear flighting, produced negative pressures at the trash exit of the cyclone, Table 1. The linear flight design produced a slightly positive static pressure, or a neutral pressure, at the exit depending on whether the exit was sealed or unsealed. The regular cone, the spiral flighting, and both sizes of expansion chambers produced static pressures ranging from -0.7 to -1.5 in. w.g. when the cyclone discharged trash into a sealed collection system. When the trash system was unsealed, these negative pressures caused air to be induced into the cyclone's trash exit. The highest induced air flows were produced by the lowest static pressures, and vice versa. Induced air flow, which ranged from 130 to 200 cfm in these studies, averaged 4 to 6% of the input air flow to the cyclone. The linear flighting produced a slight discharge of air (60 cfm) through the exit when the trash system was unsealed. The air bleed system was adjusted to draw 280 cfm, or about 9% of the input air, from the cyclone's trash exit. These variations in exit static pressure and air flow had only minor effects on the static pressure measured ahead of the cyclone, Table 1.

Re-circulation

Five-inch diameter viewing windows were installed in the top of the cyclone for observation and video recording of the collection process. These observations allowed us to visually determine the extent of the re-circulation problem for each test arrangement. In addition to observations during tests using conventional trash, we also observed the process while collecting lint cleaner waste. Five pounds of lint cleaner waste was hand fed to the system over a period of about 1 minute. After viewing and recording the collection action, the material re-circulating in the cyclone was then collected and weighed. These observations and measurements formed the basis for the qualitative assessment of lint and trash re-circulation that is presented in Table 2.

The air bleed and unsealed linear flighting designs virtually eliminated any visual evidence of re-circulation in the lower cone section of the cyclone. Apparently, the discharge of a small amount of air along with the trash helped streamline the flow of trash through these two types of trash exits. A slight amount of re-circulation was observed for the sealed systems featuring the large expansion chamber and the spiral and linear flighting designs. Even though some re-circulation was present with these three designs, it did not appear to be extensive enough to greatly effect trash flow from these exits. A moderate amount of re-circulation was observed for the sealed regular cone and the unsealed large expansion chamber and spiral flighting design. The re-circulation encountered with these three designs appeared to interfere to a considerable degree with the smooth discharge of trash from the exits. However, the most extensive evidence of re-circulation was observed with unsealed systems featuring the regular cone and the small expansion chamber. Apparently, the air induced into the center portion of these trash exits was responsible for a complete breakdown of the established trash flow patterns. Re-circulation with these three designs was so extensive that the orderly streamline patterns of trash flow were completely disrupted in the lower quarter of the cone section. At this level of re-circulation and disruption, the overhead view of the trash exit was completely obscured.

Particulate Emissions

Cyclone particulate emissions were significantly affected by variations in trash exit design and exit air flow, Table 3. The designs and air flow conditions that produced the least amount of turbulence in the trash exit zone also tended to produce the lowest emissions, and vice versa. Generally, the particulate emissions can be grouped into low, medium and high categories. The air bleed system, the unsealed linear flight design, and a sealed system using the large expansion chamber produced the lowest emissions (TSP of 1.09 to 1.19 lb/1000 lb trash). The spiral flighting designs, both sealed and unsealed, and the sealed linear flight design produced intermediate emissions within the range of 1.26 to 1.34 lb/1000 lb. The highest emissions (TSP of 1.45 to 1.54 lb/1000 lb) were produced by the sealed regular cone and the three unsealed systems featuring the regular cone and the large and small expansion chambers.

Of the three designs producing the lowest emissions, a sealed system with the large expansion chamber appears to be the one that could be most easily adopted at existing cotton gins. The other two low-emission systems, while effective from an emission standpoint, suffer the disadvantage of not completely separating collected trash material from the air. The small amount of air that is discharged along with the trash when using these two systems would have to be further handled and cleaned before it could be returned to the atmosphere. Any additional emissions from this final cleaning process would of course negate to some degree these system's apparent high performance characteristics. While the large expansion chamber performed very well when the cyclone discharged into a sealed trash system, it did not provide these same benefits with an unsealed system. Thus, it appears that special efforts would have to be made to prevent air leakage into these devices in order to take full advantage of their potential.

Pre-separation Performance

Previous research on a pre-separator ahead of a 1D3D cyclone suggested the possibility of a link between pre-separator performance and re-circulation in the cyclone. This possibility was further investigated in this study. Two versions of the 1D3D cyclone were tested with and without use of a pre-separator. One version consisted of the regular cone discharging into a unsealed trash system. This version was similar to those tested previously and represented a situation conducive to a considerable amount of re-circulation in the cyclone's lower cone section. The other version featured an unsealed linear flight design that virtually eliminated re-circulation. Emission data for these four arrangements are presented in Table 4. The pre-separator did not significantly affect emissions from either version of the 1D3D cyclone. The exit design featuring linear flighting in the cyclone's cone section produced lower emissions than the cyclone with the regular cone, with and without use of the pre-separator.

Summary

1. Increased re-circulation of lint and trash material in the lower portion of a 1D3D cyclone's cone section was associated with an increase in particulate emissions from the cyclone.

2. Unsealed trash systems that allowed air to be induced into the cyclone through its trash exit contributed greatly to the re-circulation problem in the cyclone. On the other hand, only slight to moderate levels of re-circulation were observed with sealed trash systems.

3. Trash exit designs and conditions that caused a small amount of air to exit the cyclone along with the trash completely eliminated any visual evidence of re-circulation. In this study these conditions were met by the air bleed system and the unsealed linear flight design. These two systems also produced the lowest particulate emissions encountered in the study.

4. The sealed and unsealed spiral flight designs and the sealed large expansion chamber also effectively reduced re-circulation. Even though these three systems did not completely eliminate re-circulation, they represented a marked improvement in emission performance over that of the regular 1D3D cone. Actually, the cyclone equipped with a large expansion chamber and discharging into a sealed trash system produced emissions that were roughly comparable to those of the air bleed and linear flight designs.

5. Relatively poor control of the re-circulation problem was provided by sealed and unsealed regular cones, and the unsealed large and small expansion chambers. These four arrangements also produced the study's highest particulate emissions.

6. Of the three designs producing the lowest emissions, a sealed system with the large expansion chamber appears to be the one that could be most easily adopted at existing cotton gins. The other two low-emission systems, while effective from an emission standpoint, suffer the disadvantage of not completely separating collected trash material from the air.

7. A pre-separation chamber ahead of 1D3D cyclones equipped with both the regular cone and the linear flighting design had no significant effect on particulate emissions. Thus, pre-separator performance did not improve when the cyclone re-circulation problem was eliminated.

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Table 1. Static pressure and air flow measurements for a 1D3D cyclone equipped with various trash exit designs.[@]

Cyclone Trash Exit Design	Trash Discharge System	Static Pressure Cyclone Inlet	Static Pressure Trash Outlet	Trash Exit Air Flow
		in.[#]	in.	cfm
Regular Cone	Unsealed	4.6	-0.8	-180[+]
Regular Cone	Sealed	4.6	-1.3	0
Regular Cone	Air Bleed	4.6	-2.6	280
Linear Flight	Unsealed	4.4	0.0	60
Linear Flight	Sealed	4.4	0.1	0
Spiral Flight	Unsealed	4.7	-0.4	-130
Spiral Flight	Sealed	4.7	-0.7	0
Small E.C.[*]	Unsealed	4.6	-0.8	-180
Small E.C. Sealed	4.6	-1.4	0	
Large E.C. Unsealed		4.7	-1.1	-200
Large E.C. Sealed	4.7	-1.5	0	

[@] Standard inlet air velocity of 3200 fpm without trash.

[#] Static pressure in inches of water.

[*] Expansion Chamber

[+] A negative air flow indicates that air was drawn into the cyclone through its trash exit. A positive air flow indicates that air was discharged from the trash exit.

Table 2. Effect of trash exit design and exit sealing on lint and trash re-circulation in the lower cone of a 1D3D cyclone.

Cyclone Trash Exit Design	Trash Discharge System	Amount of Re-circulation			
		None	Slight	Moderate	Extensive
Regular Cone	Unsealed				X
Regular Cone	Sealed			X	
Regular Cone	Air Bleed	X			
Linear Flight	Unsealed	X			
Linear Flight	Sealed		X		
Spiral Flight	Unsealed			X	
Spiral Flight	Sealed		X		
Small E.C.[*]	Unsealed				X
Large E.C. Unsealed				X	
Large E.C. Sealed		X			

[*] Expansion Chamber

Table 3. Particulate emissions from a 1D3D cyclone equipped with various trash exit designs.[@]

Cyclone Trash Exit Design	Trash Discharge System	Emissions, lb/1000 lb input trash		
		PM_{10}	$>PM_{10}$	TSP
Regular Cone	Unsealed	1.13ab[#]	0.39ab	1.52a
Regular Cone	Sealed	1.08ab	0.37b	1.45ab
Regular Cone	Air Bleed	0.85e	0.24d	1.09e
Linear Flight	Unsealed	0.88e	0.25d	1.13de
Linear Flight	Sealed	1.03bcd	0.31c	1.34bc
Spiral Flight	Unsealed	1.05bc	0.28cd	1.33bc
Spiral Flight	Sealed	0.95cde	0.31c	1.26cd
Small E.C.[*]	Unsealed	1.12ab	0.42a	1.54a
Large E.C. Unsealed		1.17a	0.31c	1.48ab
Large E.C. Sealed		0.92de	0.27d	1.19de

[@] Cyclone preceded by a pre-separation chamber.

[#] Means followed by a different letter are significantly different at the 0.05 level of significance.

[*] Expansion Chamber

Table 4. Particulate emissions from a 1D3D cyclone with and without a pre-separation chamber.[@]

Cyclone Trash Exit Design	Pre-Sepr. Chamber	Emissions, lb/1000 lb input trash		
		PM_{10}	$>PM_{10}$	TSP
		Extensive Re-circulation		
Regular Cone	Used	1.13a[#]	0.39a	1.52a
Regular Cone	Bypassed	1.13a	0.41a	1.54a
		No Re-circulation		
Linear Flight	Used	0.88b	0.25b	1.13b
Linear Flight	Bypassed	0.85b	0.28b	1.13b

[@] The trash exits were unsealed in these tests.

[#] Means followed by a different letter are significantly different at the 0.05 level of significance.

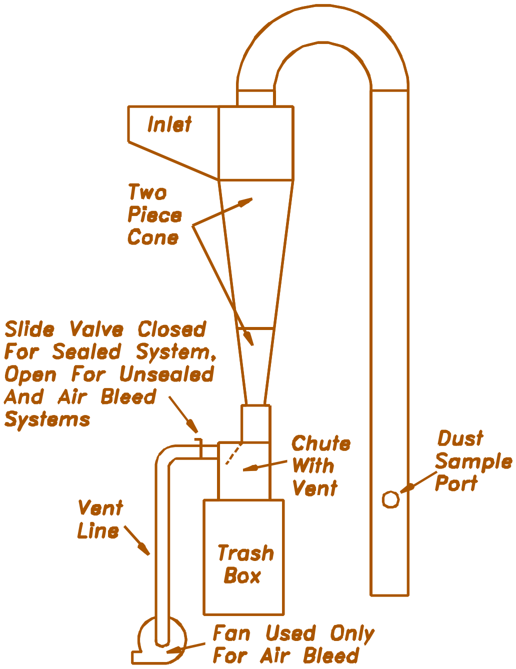

Figure 1. Standard 1D3D cyclone and trash collection system.

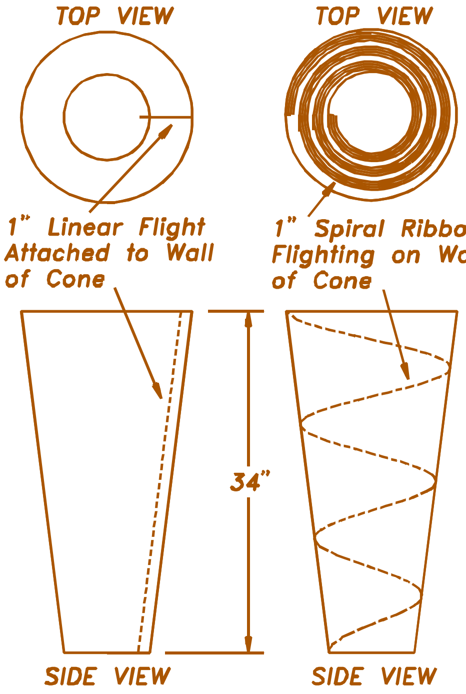

Figure 2. Linear and spiral flighting designs for the lower cone section.

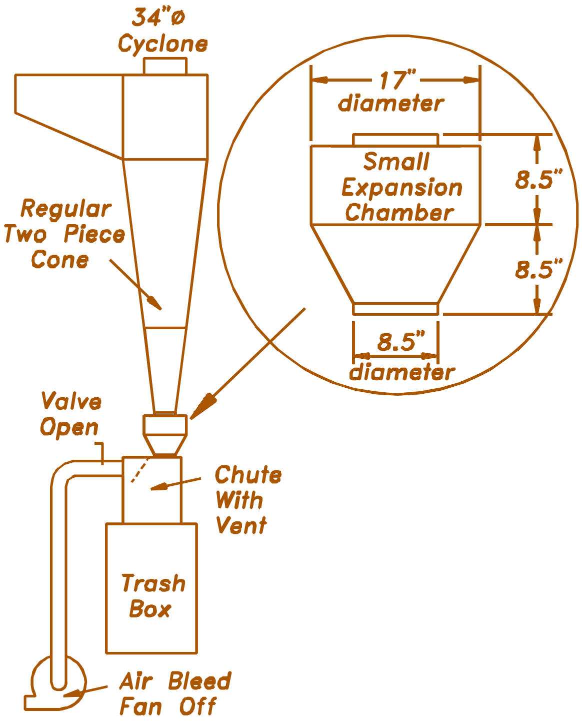

Figure 3. Small expansion chamber design.

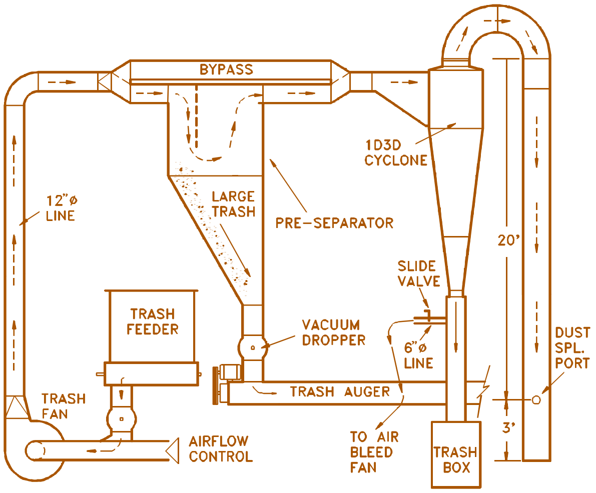

Figure 5. Diagram of trash handling and collecting equipment used in this study.

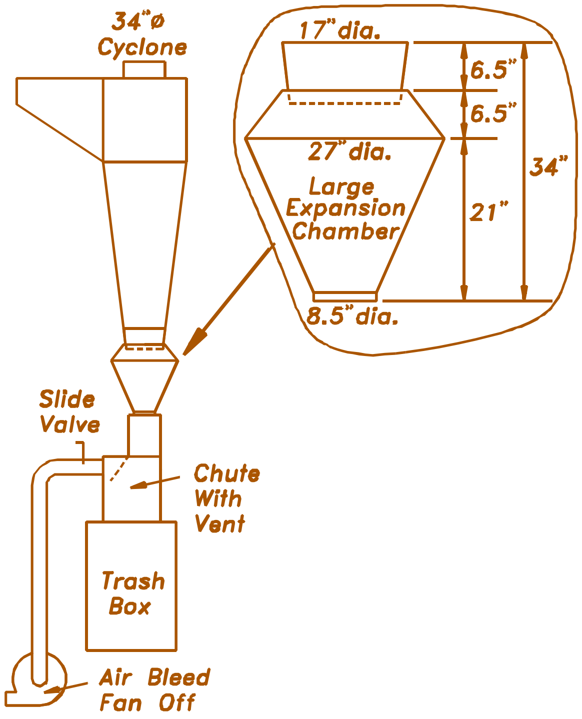

Figure 4. Large expansion chamber in the lower cone section of a 1D3D cyclone.