EVALUATION OF MODIFIED 1D-3D CYCLONES

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Abstract

Five modifications of a standard 1D3D cyclone were tested and compared against the standard 1D3D design. The modifications to the 1D3D design included: 1) a 2D2D air inlet, 2) a 2D2D air outlet, 3) a D/3 trash exit, 4) an expansion chamber with a D/3 trash outlet, and 5) a tapered air outlet duct. The 1D3D modifications that exhibited a significant improvement in reducing both PM10 and total suspended particulate (TSP) emissions were the designs with the 2D2D inlet and air exhaust combined with either the regular D/3 tail cone or the expansion chamber . In reference to the standard 1D3D, the average reduction in PM10 emissions was 24 to 29% with a 29 to 35% reduction observed in TSP emissions. The modifications with the tapered air outlets did not show any significant improvements in controlling PM10 emissions compared to the standard 1D3D. However, the modification with the tapered air outlet/expansion chamber combination exhibited statistical significance in reducing TSP emissions by 18% compared to the 1D3D cyclone.

Introduction

Cyclone trash and dust collectors have been used at cotton gins for many years. From the early large-diameter, low-velocity units to today’s high-efficiency designs, the cyclone has served the industry well (Harrell and Moore, 1962, Baker and Stedronsky, 1967, Baker et al. 1998). While the ginning industry has made a lot of progress over the years in cleaning up the environment around cotton gins, additional improvements will likely be needed in the future to meet the public's ever increasing air quality expectations. Although present cyclone technology allows cotton gins to adequately meet current air quality standards in most areas, our industry needs to continue to pursue research that will anticipate and provide for future air quality needs. Since cyclones are one of the most cost effective and efficient means of controlling particulate emissions at cotton gins, any improvement in their performance can only help cotton gins comply with future changes in particulate air emission standards (Mihalski et al. 1992).

In recent years, the 1D3D has become the cotton ginning industry’s standard cyclone design. The 1D3D was introduced in the late 1970's in an attempt to provide a more efficient fine dust collector (Parnell and Davis, 1979, Parnell 1980). In laboratory tests the original 1D3D design, which featured a flattop transition, was found to have a slightly higher collection efficiency than the conventional 2D2D design (Gillum et al., 1982). Operational problems in the field, however, have occasionally prevented ginners from realizing these advantages. Many cotton ginners have been troubled with choke ups when operating 1D3D cyclones in air streams containing a large quantity of gin trash. In response to choke ups, many ginners now turn the original transition, which was equipped with the original flat-top inlet design, upside down. While this arrangement keeps the transition swept free of troublesome accumulations, recent research indicates that lowering the entry point of a cyclone in such a manner may adversely affect its particulate collection performance (Mihalski et al., 1994; Hughs and Baker 1996).

Another operational problem involves the recirculation of trash and fiber in the lower cone section of 1D3D cyclones. Recirculation not only increases the cyclone's dust emissions, but it also causes the cone to wear more quickly than normal (Baker et al. 1996). Recirculation was found to be related to the amount of fiber in the gin trash and to the amount of air that was inadvertently induced into the trash exit when the trash receiving system was not perfectly sealed. The cone of the 1D3D cyclone appears to be particularly susceptible to this problem because of its tendency to create a large negative pressure just below the trash exit.

Recent research has shown that modifications to the original 1D3D design could remedy most of these operational problems and improve the cyclone’s collection efficiency (Baker et al., 1996; Zwicke 1997; Baker and Hughs 1998). The 1D3D cyclone modifications investigated in these studies included: 1) various trash exit designs including the use of an expansion chamber, 2) substituting a 2D2D inlet for the conventional inlet, 3) using a 2D2D type air outlet, and 3) using an enlarged, D/3, trash exit for the cone. Other research evaluating general modifications to cyclones (Baker and Hughs, 1997) showed an improved collection efficiency and a lower back pressure for an experimental cyclone featuring a 2D2D inlet, a D/3 trash exit, a tapered outlet duct, and an elongated cone.

This report describes additional research on four of these prospective modification combinations. The objective of the current research was to evaluate the effectiveness of five modifications to a standard 1D3D design in reducing PM emissions. The modifications were 1) a 2D2D air inlet, 2) a 2D2D air outlet, 3) a D/3 trash exit, 4) an expansion chamber with a D/3 trash outlet, and 5) a tapered air outlet duct. Even though each of these modifications has been investigated to some extent in previous studies, additional

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information was needed on any benefits that might be gained from their use. Consequently, we decided to further test these modifications using different cyclone configurations than those that had been previously tested to see if the modifications might be combined into a more optimum design for controlling PM emissions.

Equipment and Materials

Test Cyclones

Five cyclone configurations were evaluated in this experiment, Figure 1. The five test configurations included a standard 1D3D cyclone as the control, and four modified 1D3D cyclones. All of the modified 1D3D cyclones were equipped with a 2D2D type inlet and a D/3 trash exit. In addition, two of the modified cyclones were equipped with a 2D2D type air outlet duct and two were equipped with an experimental tapered air outlet (Figure 2). These two types of air outlets were tested in combination with two lower cone configurations. The cones of all cyclones were two-piece units consisting of upper and lower sections. The standard 1D3D cyclone featured an upper cone section that was 62 inches in height, and a lower section that was 40 inches in height. This arrangement produced a sidewall taper of 7.1 degrees. The heights of the upper and lower cone sections of the modified cyclones were 64 and 38 inches, respectively. The sidewall taper of the modified cyclones' cones was 6.3 degrees. The two types of lower cone sections that were evaluated included a regular conical tail cone and an expansion chamber (Figure 2). Both of these two types of lower sections were equipped with 11.3-inch diameter trash exits. All cyclone bodies were 34 inches in diameter. The cyclone bodies and cone sections were constructed of 16 ga. painted steel sheet metal, and each cyclone body was equipped with a flat-top inlet transition that was 20 inches in length for the 2D2D inlets and 32 inches in length for the control 1D3D.

Test Setup

The trash handling system used in this study was similar to that used in earlier studies (Baker et al., 1995). A schematic of the test configuration is shown in Figure 3. Basically, a hopper containing gin trash used an auger to feed gin trash into a vacuum which supplied the trash to a 12-inch diameter air suction line leading to a centrifugal trash fan. 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 sent to the unmodified cyclone, or to one of the two modified cyclones by means of routing valves located in the trash conveying line. Trash collected by the cyclones dropped into a 12-inch diameter trash auger positioned under the bank of cyclones. The trash auger was covered with metal lids, and the other cyclones not used during the test were sealed off from the auger by means of a slide valve located under each cyclone. The exhaust from each cyclone was routed through a common manifold into an exhaust duct. Selection valves in the manifold section controlled exhaust airflow from each test cyclone. When a cyclone was not being used, its valve was closed to completely seal its exit. Conversely, the valve on the cyclone being tested was opened to allow its exhaust air to enter the exhaust duct.

Sampling Procedures

Prior to sampling, the trash was weighed and loaded into a feed hopper and the velocity pressure of the air flowing into the trash fan was adjusted to produce an air flow rate of 3200 ft^3/min into the test cyclones. The trash was then fed into the system under controlled conditions and the amount of time required to fed all the trash recorded.

The air discharging from each cyclone was routed through the valved manifold into an 18-inch diameter exhaust line leading to dust 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 testing. Testing was performed using EPA Method 201A (U.S. EPA, 1996). The Method 201A sampling train used a standard Method 5 sampling train equipped with an in-stack sizing cyclone which was used to isokinetically collect samples at four traverse points across each of 2 diameters (8 points) in the 18-inch diameter exhaust line. The sampling location was 20 feet downstream from the 90° elbow connecting the exhaust manifold and the exhaust line. (Baker et al. 1995).

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. The velocity heads at the 8 sampling points did not vary excessively in this experiment thereby making it possible to use the same sampling nozzle at all points without violating the isokinetic sampling requirements. The particulate that passed through the sizing cyclone was collected by a glass fiber filter, and this material along with that removed by washing the cyclone's outlet tube with acetone was considered to be PM10. The particulate collected by the sizing cyclone, and that removed by washing the interior of the sampling nozzle and cyclone body, was larger in size than PM10. The sum of these 2 size ranges is referred to in this report as "total suspended particulate" (TSP).

Pre and Post-Test Calibrations

Pitot traverses were made prior to these tests to evaluate the sampling locations, to verify the absence of cyclonic flow, and to relate the readings of the standard pitot tube mounted in the center of the exhaust line ahead of the particulate sampling location to the readings obtained using the S-type pitot tube on the sampling train. In addition to these pre-test measurements, the calibration of the dry gas meter used in the stack sampling train was also checked using calibrated critical orifices. A post calibration check was also performed to verify that the dry gas meter calibration factor was still within specifications.

Trash Material

The trash used in these experiments was from Paymaster HS-26 cotton produced under irrigation at Texas Tech University. The cotton was stripper harvested during the first week of November 1997 and ginned later that same month in the Laboratory's full-scale gin plant. The trash removed from this cotton was collected with a battery of 2D2D cyclones and consisted of material removed by an unloading separator, airline cleaner, two hot-air inclined cleaners, two stick extractors, an overflow separator, a separator over the distributor, the feeder and gin stand, and two saw-type lint cleaners. Approximately 17,000 pounds of bulk trash were collected and stored in the Laboratory's module shed until these tests were conducted. Trash feed rates of approximately 801 lbs/hour were used in these tests to provide a stripper-trash loading rate for the cyclones of about 4.2 lbs/1000 ft^3 of conveying air. This high feed rate is typical of cyclones used on heavily loaded main trash lines at commercial gins.

Experiment Design and Analysis

This experiment was conducted as a randomized complete block experiment consisting of five cyclone configurations and five replications. Standard analysis of variance techniques were used to analyze the data to determine statistically significant differences among the five cyclone configurations by the Student-Newman-Keuls Method at the 0.05 level of significance.

Results

The Tests

Even though the air flow into the test cyclones was adjusted prior to each test to provide an initial inlet air velocity corresponding to a volumetric flow rate of 3200 cfm, air flow varied slightly during the tests due to the presence of trash in the air stream. At the time this paper was prepared, the pressure drop data was not yet available.

Particulate Emissions

The measured emission rates for both PM10 and TSP for all cyclone configurations are presented in Table 1. The statistical analysis indicated significant differences between the emissions from the standard 1D3D cyclone and the two modified cyclones equipped with the 2D2D inlet and air outlet. These results indicate that both PM10 and TSP emissions were significantly reduced by modifying the 1D3D cyclones with both a 2D2D type inlet, a 2D2D air outlet and a D/3 trash discharge. These two cyclones produced PM10 emissions that were, on average, 24 and 29% lower than that of the standard 1D3D cyclone. Likewise, the TSP emissions were 29 and 35% lower than the conventional 1D3D cyclone. The only difference between these two cyclone configurations was in the lower cone sections. One of the configurations was equipped with a regular conical tail cone and the other with an expansion chamber. There were no statistically significant differences between these two lower cone sections in either PM10 or TSP. Therefore, the use of an expansion chamber did not provide any further reductions in particulate emissions over that obtained from the cyclone equipped with the regular D/3 tail cone.

Due to promising results encountered in other research (Baker and Hughs 1997), the tapered outlet seemed to be a viable modification to the 1D3D since it resulted in a lower static pressure drop across the cyclone. In that study, however, it was not possible to determine its effect on particulate emissions. In this study the two cyclone configurations utilizing a tapered outlet produced PM10 emissions that were not significantly lower than that from the standard 1D3D cyclone. The only statistically significant difference in emissions that was observed for the tapered outlet was the 18% reduction in TSP that occurred when the tapered outlet was combined with an expansion chamber. Since both of the cyclone configurations with tapered outlets produced higher emissions than those with the 2D2D outlets, it appears that, from an emission standpoint, the tapered outlet provides very little benefit. However, the use of the tapered outlet did not increase emissions over that obtained with the standard 1D3D cyclone. For the two configurations utilizing the tapered air outlets, the expansion chamber appeared to be of some benefit in reducing emissions. The tapered outlet configuration with the expansion chamber produced significantly lower TSP emissions than did the one with the regular D/3 tail cone.

In this study the two modified cyclones equipped with 2D2D inlets, 2D2D air outlets and the D/3 trash exits outperformed the standard 1D3D cyclone by a substantial margin. While the two cyclones equipped with 2D2D inlets and tapered outlets did not significantly improve cyclone performance, neither did they adversely affect cyclone performance. Generally, the emission results obtained from this study combined with results obtained in previous studies (Baker et al., 1996, Hughs and Baker, 1996, Baker and Hughs, 1997, and Baker and Hughs, 1998) support the hypothesis that the 2D2D type inlet in conjunction with other modifications can improve the performance of the 1D3D cyclone over that of the original design.

Summary

Five cyclone configurations were evaluated in an experiment using bulk gin trash from stripper cotton to study several modifications to a standard 1D3D cyclone. This study investigated the impact on performance of using the combination of a 2D2D inlet with a D/3 trash outlet along with (1) replacing the long outlet duct of the 1D3D cyclone with either a tapered outlet duct or conventional 2D2D type outlet, and (2) replacing the conventional conical tail cone with an expansion chamber. The use of a 2D2D type inlet on a 1D3D cyclone, combined with the 2D2D air outlet duct and a D/3 trash discharge, showed improvements in reducing PM10 emissions ranging, on average, from 24 to 29% over the standard 1D3D cyclone with its tall narrow inlet, long air outlet duct and D/4 trash discharge. Mixed results were obtained with the modifications using the tapered air outlets. The combination that utilized both the tapered outlet and expansion chamber demonstrated statistical significance in reducing TSP emissions by 18% compared to the standard 1D3D. However, this reduction was more likely the result of using an expansion chamber with a D/3 trash exit than from using the tapered outlet. The tapered outlet combination with the D/3 tail cone performed no better or worse than the standard 1D3D cyclone.

Acknowledgment

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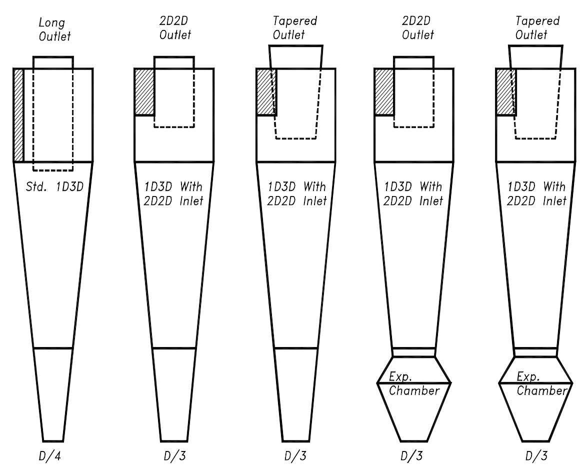

Figure 1. The five cyclone configurations evaluated. D=34 inches

Table 1. Measured emissions rates for both PM10 and TSP for all five cyclones tested in units of lbs. of emissions per 1000 pounds of trash and in lbs. of emissions per hour (corrected for the average feed rate).

Cyclones Evaluated	PM10 Emissions		TSP Emissions	
	(lb/1000 lb)	(lb/hr)	(lb/1000 lb)	(lb/hr)
Standard 1D3D	1.00a*	0.80a	1.47a	1.18a
Modified 1D3D cyclones**				
2D2D outlet, Reg. tail cone	0.76b	0.61b	1.05bc	0.84bc
Tapered outlet, Reg. tail cone	0.94a	0.75a	1.44a	1.15a
2D2D outlet, Exp. chamber	0.71b	0.57b	0.95c	0.76c
Tapered outlet, Exp. chamber	0.87ab	0.70ab	1.21b	0.97b

* Means followed by the same letter are not statistically different at the 0.05 level of significance.

** All modified 1D3D cyclones have 2D2D inlets and D/3 trash exits on the tail cones.

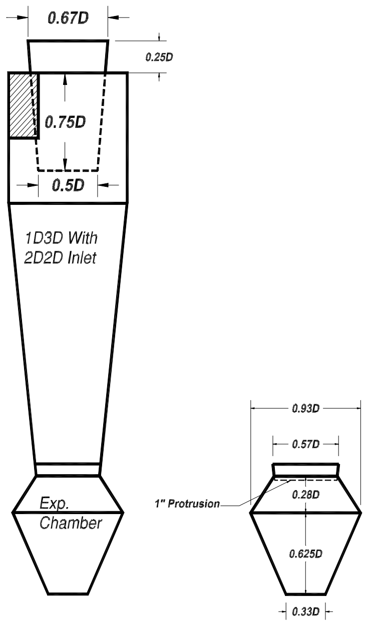

Figure 2. Modified 1D3D with tapered outlet and expansion chamber showing relative dimensions with regards to the diameter of the body of the cyclone.

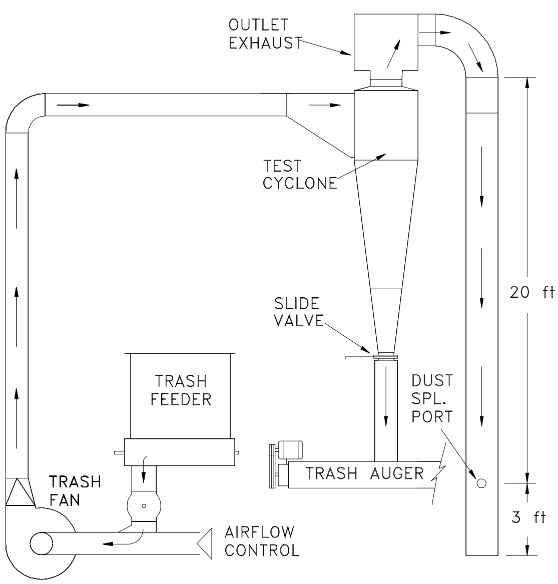

Figure 3. Schematic of cyclone test configuration