LABORATORY EVALUATION OF VARIOUS CYCLONE DESIGNS

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Abstract

Experiments were conducted to evaluate the particulate collection performance of several model cyclone designs against the standard 1D3D cyclone. The design of the cyclone inlet and the inlet transition significantly affected cyclone effectiveness. The type of inlet transition to a 1D3D cyclone could affect particulate collection by as much as a factor of 1.37. A 3/4D4D and an alternate 1D3D design, both with 2D2D style inlets, improved particulate collection over the best standard 1D3D by factors of 1.23 and 1.29, respectively. These results will be verified by performance testing of full-size cyclones.

Introduction

Shepherd and Lapple (1939) stated over 50 years ago that, "Cyclones are commonly reported to be suitable for coarse dusts only, but when properly designed and applied these collectors will give efficient and economic performance when handling subsieve dust particles as small as 10 microns." Cyclones were used then because they were simple to construct and to operate. Work is still being done on the proper design and application of cyclone collectors to various industrial as well as agricultural processes.

The 1D3D cyclone was introduced in the late 1970's as a more efficient fine-dust collector than the high efficiency 2D2D design (Parnell and Davis, 1979). Gillum et. al (1982) showed that a properly designed and applied 1D3D design cyclone was approximately 16% more efficient in collecting fine dust than was the 2D2D design. Gillum et. al (1981) also showed that the 1D3D cyclone would collect approximately 97% by weight of the fine dust and lint emitted from gin lint-cleaner exhausts. As a result of these and other studies, the 1D3D cyclone has been widely used on gin exhausts, not only as a dust collector, but also as a trash collector. Collecting bulky gin trash sometimes leads to a chokage problem in the transition and narrow inlet, as well as the relatively small-diameter outlet of the 1D3D cyclone. Another problem associated with the collection of bulky gin trash, which often contains very abrasive material, is the rapid wear of both the 2D2D and the 1D3D cyclone designs. One way proposed to help reduce the cyclone wear problem and to eliminate the chokage problem of the 1D3D design is to pre-separate the heavier and more bulky gin trash before the gin exhaust air goes through the cyclones. Pre-separators have been installed on a few commercial gins, but very little design criteria or performance information exists to guide in their application.

Baker et. al (1995) evaluated design parameters for a full-size pre-separator used in conjunction with both 2D2D and 1D3D cyclones. Mihalski et. al (1994) also evaluated a small model pre-separator used in series with several model cyclone configurations. The results of both Baker et. al (1995) and Mihalski et. al (1994) showed that,in some applications, a 2D2D cyclone design gave superior performance over a 1D3D design. These results illustrate the need to further investigate the design and performance of high-efficiency cyclones under different operating conditions.

Most cyclone research has been done on either full-size units or very small models of 10.16 cm (4 in.) in diameter. The advantages of using full-size cyclones is that actual gin conditions can be relatively closely duplicated by using normal gin trash and process rates. The disadvantages are that the cyclone units are large and expensive to fabricate, relatively slow and cumbersome to install and modify, and performance must be measured by an EPA Method 5 or equivalent sampling method. The Method 5 sampling method is expensive and time consuming to use.

Model cyclones have the advantage of being relatively easy to fabricate, install, and modify. The air flows are small enough that all of the exhaust can be caught on a filter and weighed without having to be sampled with a Method 5 type sampler. The disadvantage is in selecting a material of the proper scale to model the particulate as well as the material to construct the model cyclone. Normal gin trash cannot be used in a 10.16 cm (4 in.)-diameter model because of its large size. This report documents the results of an intermediate approach to cyclone testing that attempts to capitalize on advantages of both full-size units and small models.

Equipment and Materials

Cyclones used in the ginning industry are selected for the quantity of material to be handled and to maintain, for a given air volume, the recommended air entrance velocity of 15.24 m/s (3,000 ft/min) for 2D2D and 16.26 m/s (3,200 ft/min) for 1D3D cyclones (Armijo et al., 1993) The criteria for selection of the model size was that the model be large enough to handle regular gin trash, be constructed using normal materials and construction techniques, and that the results might reasonably be expected to apply to full-size cyclones. Also, the model should be small enough to be easily built and installed and small enough that its air

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volume requirement could be caught by a single filter. A 0.305 m (12 in.)-diameter model cyclone dimension was chosen. This size required a design air-flow rate of approximately 0.189 m^3/s (400 ft^3/min). This flow can be moved through a 0.61 m (2 ft) square Hi-vol type filter with a reasonable face flow rate and head loss. The outlet of the model test cyclone was connected directly to the filter holder (Figure 1).

A flat-blade fan operated at a constant speed was the primary air supply. A small variable-speed fan was connected to the inlet of the primary fan to compensate for flow loss due to the increase in static pressure across the filter during a test run. A small s-type pitot was placed in the center of the outlet pipe connecting the cyclone to the filter holder. The velocity pressure (P_v) of the exhaust air stream, and therefore the air velocity and flow, was held constant during a test run by monitoring the P_v reading on a manometer and slowly increasing the speed of the variable-speed fan to maintain the same P_v reading. Gin trash was fed into the inlet of the variable-speed fan by means of a variable-speed belt.

The gin trash used for the test was given the designations of "fine" and "coarse" trash. The fine trash was obtained from the unloading separator screen. The coarse trash was collected from the first 6-cylinder cleaner in the seed-cotton cleaning system.

The particle sizes for each type of material were determined using a variation of the ASTM Standard Sieve Analysis Method (ASTM C 136, 1984). Sizing was done by sieving a 100 gram sample for 10 minutes. This process was repeated three times to obtain an average for each type of trash. The average bulk density was 0.332 and 0.158 g/cm^3 for the fine and coarse trash, respectively. The fine trash averaged 31.4% particles, and the coarse trash averaged 0.9% particles less than 50 microns by weight.

Test Procedure

Initially, replicated tests were performed comparing the 2D2D and 1D3D cyclone designs against each other as well as comparing trash mixes for baseline performance. A baseline cyclone design was selected as well as the trash mixes that would be used for performance testing.

The actual test procedure for each test run was as follows:

1. The required amounts of both fine and coarse trash for each replicated test were mixed to reduce variability due to sampling.

2. Airflow to each cyclone was measured and adjusted to the required level by means of a slide valve on the inlet of the first fan.

3. The P_v reading of the pitot tube mounted in the center of the cyclone outlet pipe was noted, recorded and used for control during the test run.

4. The amount of trash required for the run was placed in a strip on the belt. Each individual run was timed (approximately 120 sec).

5. At the end of each run, the trash caught by the cyclone, and the filter was weighed. Also, sometime during the test series, a sample of both the coarse and fine trash before running, as well as a sample of the cyclone catch, were taken for sieve analysis.

Test Results and Discussion

Table 1 gives the results of the preliminary tests. The average cyclone inlet and outlet particulate concentrations in Table 1 were calculated numbers based on the weight of material caught by the cyclone and the weight of material caught by the filter. The assumption was made that any of the cyclones would catch all material that was larger than 50 microns, so that what would escape the cyclone and be caught on the filter would be less than 50 microns. Assuming this assumption is true, the weight of material caught on the filter would be influenced primarily by the amount of dust fed to the cyclone in the range of 50 microns and less. In order to determine the amount of material that was less than 50 microns, samples of the cyclone catch were taken during each test series and were sized by using a mechanical sieve. The concentrations were determined then according to the following general relations:

Inlet concentration(INCON)=(wt. of cyclone catch
+ filter wt.)/((air flow)(run time))

Outlet concentration(OUTCON)= (filter wt.)
/((air flow)(run time))

where, wt. of cyclone catch=weight of the portion of the total catch <50 microns

then, Cyclone effectiveness=OUTCON/INCON

Calculating the inlet and outlet concentrations in this way tends to normalize the data for dust less than 50 microns in diameter, so that direct comparisons can be made. The smaller the effectiveness ratio number, the less fine dust that escaped from the cyclone outlet. Subtracting the effectiveness ratio from 1.0 would yield something like a cyclone efficiency for the dust range less than 50 microns in diameter.

Table 1 shows that there is a significant statistical difference in the basic cyclone effectiveness between collecting fine trash only or a mixture of fine and coarse trash. Parnell (1993) stated that cyclones were primarily designed as fine-dust collectors. Using cyclones for collecting both fine and coarse trash may cause the coarse trash to interfere with the collection of fine dust by disrupting the normal flow patterns within the cyclones and actually increase their emissions. The difference in the effectiveness ratio between fine dust only and a mixture of fine and coarse trash tends to confirm the observation by Parnell (1993).

Table 1 also shows that the type of inlet for a 1D3D cyclone can significantly affect its dust collection performance (see Figure 2). Mihalski et al. (1994) showed a similar result on 10.2 cm. (4 in.)-model cyclones, but showed emission increases in the range of 5 to 15 times. Here the increase is about 1.4 times. This result illustrates the similitude problem of using small-cyclone models to predict the performance of full-size units. The results of these tests should be verified by full-size cyclone units in order to be fully confident of the test results. These tests also showed no statistical difference between the 2D2D and 1D3D cyclones.

From the preliminary tests shown in Table 1, the 1D3D cyclone using Inlet B was selected as the baseline control cyclone. Also, all subsequent tests used trash as two of the treatments (fine only and equal mixture by weight of fine and coarse).

Kasper et. al (1994) reported on the design of a 1D2D cyclone that utilized both 2D2D and 1D3D design parameters to achieve reasonable collection efficiency with a lower pressure drop than either a 2D2D or 1D3D cyclone. Table 2 does show that the 1D2D achieved a statistically comparable effectiveness with a 1D3D on collection of fine dust. The fine trash contained about 1 to 1.5% cotton fiber by weight, most of which was very short. For collection of mixed trash, the 1D2D was significantly lower in effectiveness. Average pressure drop for the model 1D3D during the test was 8.38 cm (3.3 in.) water and 6.10 cm (2.4 in.) for the 1D2D. The pressure drop for the 1D3D seems low at 3.3 inches, but is at the low end of the range as specified by Armijo et al. (1993).

The 3/4D4D cyclone was designed utilizing a set of equations for cyclone design by Muschelknautz (1970). The design featured a 2D2D style inlet and a tapered outlet tube to lower the pressure loss. The experimental cyclone was significantly better for both fine trash only and for fine and coarse trash mixed. Pressure drop for the 3/4D4D during the test averaged 8.30 cm (3.3 in.) water as did the 1D3D cyclone.

One of the commercial operational problems with a 1D3D cyclone is occasional plugging of its relatively narrow and long inlet. The 1D3D(HV) was tested to determine if increasing the inlet air velocity without changing the volume would affect the cyclone's efficiency. An increase in the air velocity might help keep trash from building up and plugging the cyclone inlet. Air inlet velocity was increased by keeping the same inlet width but shortening the height by one third. This increased the design inlet velocity of the model from 16.3 m/sec (3,200 ft/min) to 23.9 m/sec (4,700 ft/min) with the same air volume. Increasing the inlet air velocity raised the pressure drop of the model from approximately 8.30 cm (3.3 in.) water to an average of 12.4 cm (4.9 in.). Test results are mixed with the 1D3D(HV) having a significantly higher collection of fine trash, but a significantly lower collection of mixed trash when compared to a regular 1D3D design.

Another way to stop the plugging of 1D3D cyclones in the field might be to use an inlet transition where the feed line comes into the center of the transition and not at either the top or the bottom as is shown in Figure 2. All three types of inlets are actually currently utilized in the field, but their effects on collection efficiency are currently unknown. Table 2 shows that the 1D3D(CI) has a significantly lower effectiveness ratio for both fine and mixed trash than does the regular 1D3D utilizing Inlet B (Figure 2, and Table 1). However, the effectiveness ratio of 0.0366 for the center inlet for fine trash is better than the effectiveness ratio of 0.0414 for Inlet A (Table 1).

The results of the last test shown in Table 2 are a comparison test of an experimental 1D3D cyclone with a 2D2D inlet. The experimental cyclone was significantly better than the baseline cyclone on both fine and mixed trash by a ratio of 1.29 and 1.17, respectively. The experimental cyclone had a pressure drop of 9.1 cm (3.6 in.) of water compared to 8.4 cm (3.3 in.) for the baseline cyclone. This series of tests has shown that the entrance conditions to a cyclone are important to its dust-collection performance as discussed earlier by the differences between Inlet A, B, and the center inlet, and now the 2D2D inlet on the 1D3D cyclone.

Particle size analyses performed on the cyclone emissions caught by selected filters during the test series showed that very few particles larger than 20 microns were emitted by any of the cyclones tested.

Summary

1. The design of the inlet transition to a 1D3D cyclone is important and can limit its overall effectiveness as a dust collector.

2. The type of gin trash being handled has an effect on the performance of a high-efficiency cyclone.

3. The 3/4D4D, 1D3D with a high-velocity inlet, and a 1D3D with a 2D2D style inlet (Table 2) had significantly improved dust-collection- performance over the baseline 1D3D cyclone in this test series.

4. The 1D2D, while not as effective overall as a 1D3D, may still be a reasonable alternative as a fine-dust collector on gin exhausts that contain a significant amount of fiber, as proposed by Kasper et. al (1994).

5. The results from this test series will be used to guide tests of full- size cyclones that will be conducted later at the USDA, ARS, Cotton Production and Processing Research Unit, Lubbock, TX.

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Table 1. Baseline Performance Data.

Treatment	Avg. inlet concentration	Avg. outlet concentration	Avg. cyclone effectiveness ratio	Observed significance ratio (OSL)
	gr/ft³	gr/ft³		
Trash A[1]	1.04	0.046	0.0442	0.0119
Trash B	1.29	0.069	0.0540	
1D3D w/inlet A[2]	1.56	0.0647	0.0414	0.0311
1D3D w/inlet B	1.54	0.0463	0.0301	
1D3D w/inlet B[3]	1.59	0.0506	0.0318	0.7552
2D2D	1.65	0.0505	0.0305	
1D3D w/inlet B[4]	1.33	0.0456	0.0344	0.8126
2D2D	1.41	0.0490	0.0346	

[1] Trash A was the "fine" trash only. Trash B was an equal mixture by weight of "fine" and "coarse" trash.
[2] Inlet A and Inlet B are shown in Figure 2.
[3] Used a mixture of equal weights of coarse and fine trash.
[4] Used fine trash only.

Table 2. Cyclone Test Results.

Treatment	Avg. inlet concentration	Avg. outlet concentration	Avg. cyclone effectiveness ratio	Observed significance ratio (OSL)
	gr/ft³	gr/ft³		
1D3D, T1[1]	1.18	0.0338	0.0288 b	0.0002
1D3D, T2	1.38	0.0452	0.0326 b	
1D2D, T1	1.24	0.0395	0.0319 b	
1D2D, T2	1.44	0.0686	0.0476 a	
1D3D, T1	1.21	0.0350	0.0289 c	0.0001
1D3D, T2	1.00	0.0477	0.0477 a	
3/4D4D, T1	1.29	0.0303	0.0235 d	
3/4D4D, T2	1.04	0.0430	0.0415 b	
1D3D, T1	1.45	0.0422	0.0291 c	0.0002
1D3D, T2	1.74	0.0529	0.0305 b	
1D3D(HV)[2], T1	1.49	0.0412	0.0276 d	
1D3D(HV), T2	1.71	0.0562	0.0328 a	
1D3D, T1	1.19	0.0400	0.0337 c	0.0003
1D3D, T2	1.30	0.0542	0.0416 b	
1D3D(CI)[3], T1	1.24	0.0453	0.0366 c	
1D3D(CI), T2	1.33	0.0650	0.0454 a	
D3D, T1	1.056	0.0373	0.0353 c	0.0001
1D3D, T2	1.030	0.0524	0.0509 a	
1D3D(2Din)[4], T1	1.086	0.0297	0.0273 d	
1D3D(2Din), T2	1.005	0.0436	0.0434 b	

1 T1=fine trash only and T2=equal mixture by weight of fine and coarse trash.
[2] HV=high-velocity cyclone inlet transition.
[3] CI=center of inlet transition.
[4] 2Din=1D3D cyclone overall design with a 2D2D inlet.

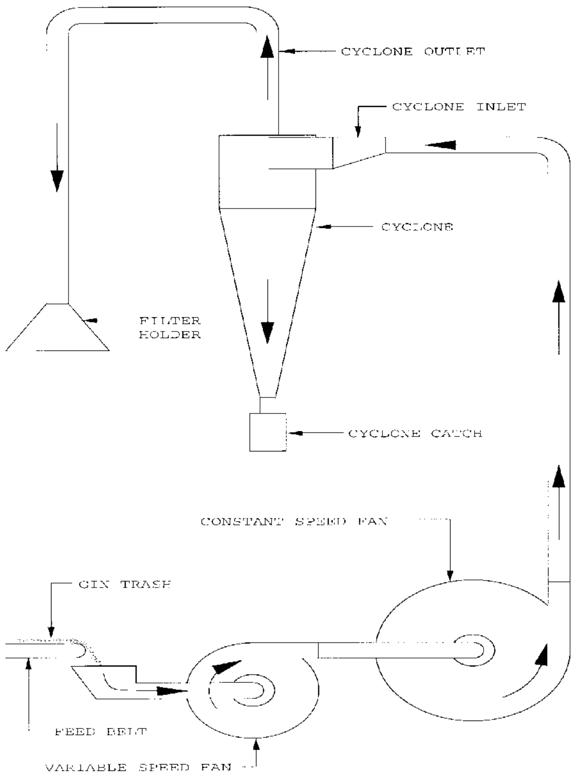

Figure 1. Cyclone Test Configuration

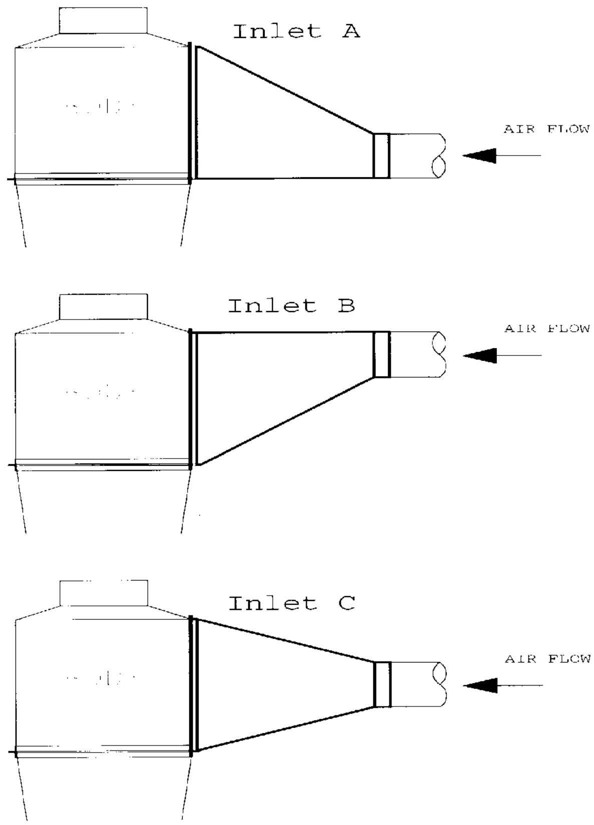

Figure 2. 1D3D Inlet Transition