CYCLONE EFFICIENCY SENSITIVITY
TO ENTRANCE VELOCITY

P. A. Funk and S. E. Hughs
USDA ARS
Southwestern Cotton Ginning Research Laboratory
Mesilla Park, NM
R. V. Baker
USDA ARS
Cotton Production and Processing Research Unit
Lubbock, TX

Abstract

Four versions of a 1D3D type cyclone were tested at four entrance velocities. The cyclones tested were a standard 1D3D design, a 1D3D with a 2D2D air inlet, a 1D3D with a D/3 trash outlet, and a 1D3D with both a 2D2D air inlet and a D/3 trash outlet. Air containing a heavy load of gin trash was fed to the cyclones. Dust escaping with the clean air was captured on pre-weighed filter membranes. The cyclone catch was also weighed. The design with both modifications had the highest efficiency. The highest efficiency for all designs occurred at entrance velocities near 3,000 fpm.

Introduction

Cotton gins must comply with increasingly stringent air borne dust emissions standards to receive operating permits. For reducing air pollution, cyclones are as efficient and more cost effective than rotary drum filters (Flannigan et al. 1998). Compliance with state air quality regulatory agency rules and regulations using cyclones alone is therefore desirable, and optimizing cyclone performance will help cotton gins to do so. Some currently recommended design practices have not yet been optimized.

Recent research indicates a significant improvement in cyclone efficiency may be realized by modifying the 1D3D design to employ a 2D2D entrance (Hughs and Baker 1996, Baker and Hughs 1998). Improvements were also observed when the D/4 trash exit was enlarged to D/3 (Baker and Hughs 1998). In these studies the 1D3D cyclone was modified but the standard entrance velocity (3200 ft/sec) was not altered.

The objective of this present research is to find the optimum entrance velocity for the types of 1D3D cyclones being tested. The results can be used to help select and size replacement cyclones providing the minimum particle emissions. This information may also be used to minimize the design pressure drop and hence the energy (and pollution) cost associated with operating a cyclone.

Equipment and Materials

Test Cyclones

Four twelve-inch diameter cyclones were evaluated in this experiment. This diameter is small enough that all the dust carried by the air volume requirement can be captured on a single 24 x 24 inch filter. The volumetric air flow ranged from 325 to 438 cubic feet per minute. Twelve-inch diameter cyclones are large enough to handle common gin trash, including lint. Airflow similitude is satisfied because there is enough turbulence in the cyclone air stream to make viscous resistance negligible compared to inertial resistance (Roberson and Crowe 1980).

The four cyclone configurations (Figure 1) were the product of two air inlet designs and two trash outlet sizes. The inlets were either 1.5 x 12 inches (D/8 x D) standard 1D3D inlets or 3 x 6 inches (D/4 x D/2) 2D2D-style inlets with the air outlet duct shortened accordingly to 7.5 inches (5/8D). The trash outlet points at the bottom of the lower cones were either 3 inches (D/4) or 4 inches (D/3) in diameter. The cyclones had a sealed bucket mounted on the bottom to catch the collected trash. Pressures at the inlet (P2), outlet (P1) and trash bucket (P3) were recorded to indicate pressure drop of the cyclone and air entrainment potential (suction) at the bottom of the cone (Figure 2).

Test Apparatus

A 24 x 24 inch Hi-vol fiberglass filter captured the particles that were not removed from the air stream by the cyclone. A flat-blade fan operating at constant speed was the primary air mover. A smaller variable speed fan was used to hold the velocity pressure (and hence velocity and flow) constant as filter resistance increased with dirt loading during the course of the test. A conveyor belt loaded with gin trash metered a steady stream of particles into the inlet of the variable speed fan. The test apparatus is depicted in Figure 2.

Trash Material

Trash for these twelve-inch diameter cyclones was fed at 0.22 pounds per minute or 3.5 to 4.7 grains per cubic foot, a rate corresponding to more heavily loaded exhausts in a cotton ginning system. Particle size similitude was achieved by using material that had passed through the screen of the unloading separator at the USDA ARS Southwestern Cotton Ginning Research Laboratory. Particle size distribution was determined previously (Hughs and Baker, 1998) using a variation of the ASTM Standard Sieve Analysis Method (ASTM C 136, 1984). Sizing was done by sieving a 100 gram sample for ten minutes. The average of three replicates is presented in Table 1. The average bulk density was 0.332 g/cm^3. Particles less than 53µm averaged 25.1% by weight. Previous experiments examining cyclone efficiency have established that results obtained using this trash in a twelve-inch diameter cyclone is representative of results obtained by full-scale cyclones using regular gin trash (Hughs and Baker 1996, Baker and Hughs 1998).

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Methodology

A standard pitot tube was used to set the air flow before each run to one of four velocity pressure levels corresponding to actual cyclone inlet air velocities of 2,600, 2,900, 3,200 and 3,500 feet per minute. Airflow was regulated by choking the inlet to the small variable speed fan (low speeds) or by increasing the variable fan's speed (high speed).

Pre-weighed fiberglass filters were placed in the filter holder. The trash catch bucket was weighed and attached to the bottom of the cyclone being tested. Airflow was adjusted using a standard pitot tube in the supply duct. The trash conveyor with a 200 gram sample of gin trash spread along its length was run for 120 seconds. An S-type pitot tube in the exhaust duct provided the feedback used to maintain constant air flow as dust loading increased filter resistance. The cyclone catch bucket and filter were weighed again to determine the proportion of material captured by the cyclone and lost in its exhaust.

Data Analysis

This study was statistically analyzed as a factorial experiment consisting of two factors (air inlet and trash outlet) at two levels, and one factor (inlet velocity) at four levels. The four cyclone designs and four velocities (16 runs) were tested three times each in a randomized complete block design, for a total of 48 runs. The three response variables were overall cyclone efficiency (the percent by weight of the total dirt captured that was removed from the air stream by the cyclone), cyclone emissions (pounds of dirt remaining in the exhaust air per thousand pounds contained in the inlet air) and exhaust loading (grains of dirt per cubic foot of standard air present in the exhaust). Means of the three replicates are presented in Table 2.

Results

Cyclone Design

At the five percent level of statistical significance each of the modifications improved performance over the standard 1D3D entrance D/4 trash outlet cyclone. The design that combined both modifications realized the highest efficiency (Table 3). The larger trash outlet (D/3) improved cyclone performance slightly more than the 2D2D inlet did. Table 3 presents the statistical significance of efficiency, emissions and loading for each design. The modifications were not statistically different from each other, but they all were a significant improvement over the standard 1D3D cyclone.

Entrance Velocity

Theoretically, the efficiency of a cyclone should increase as air velocity and inertia increase. But turbulence caused by minor surface imperfections also increases, and dust particles that were at the wall can be thrown back into the air stream. In this study, the reduction in efficiency attributed to turbulence exceeded the gains attributed to particle inertia above 2860 feet per minute (Figure 3). However, this optimum is based on a second order polynomial regression with a coefficient of determination (r^2) of only 0.12 for all cyclones, and it is based on a very limited number of small-scale prototypes. (The regression was statistically significant at the five percent level but the coefficient of determination was small because of the variance between cyclones.) Further testing on full-scale cyclones is necessary before any conclusions may be drawn. The same trend can be observed when looking at exhaust loading (Figure 4) corrected for inlet air trash loading. Table 4 presents the statistical significance of efficiency, emissions and loading for each entrance velocity. Only the highest velocity stood out as different (worse) statistically. Again, results obtained with our small-scale cyclones need to be verified with full sized ones connected to typical trash discharge systems.

Discussion

Figure 5 is a plot of the difference in pressure between the trash outlet and the air outlet ($P_1 – P_3$ in Figure 2). The air outlet would be at atmospheric pressure in a normal working cyclone, and the trash outlet would be connected to a trash auger, in communication with other cyclones. This illustrates one possible explanation for the improvement earlier experiments showed with the larger (D/3) trash outlet; there is less suction and probably less air flow to re-entrain dust particles at the trash outlet opening. However, in this experiment the trash outlet was connected to a sealed container, preventing air movement, and there were still gains realized from utilizing the D/3 outlet. This emphasizes once again the need for testing with full sized cyclones in a typical setup to confirm these findings.

Summary

A model 1D3D cyclone with either a 2D2D air inlet or a D/3 trash outlet, or both modifications, was more efficient at the five percent level than the standard 1D3D cyclone over the range of air inlet velocities from 2,600 to 3,500 feet per minute. For these particular small-scale cyclones, an entrance velocity of about 3,000 feet per minute resulted in the greatest efficiencies. This velocity corresponds to that recommended for 2D2D cyclones (Anthony and Mayfield, 1994). However, full sized modified 1D3D cyclones connected in a more typical manner must be tested before any conclusions about optimum entrance velocity can be drawn.

References

American Society for Testing and Materials. 1984. Standard method for sieve analysis of fine and coarse aggregates. ASTM C 136-84a.

Anthony, W.S. and W.D. Mayfield. 1994. Cotton Ginner's Handbook. U.S. Department of Agriculture, Agricultural Handbook 503. P 177.

Baker, R.V. and S.E. Hughs. 1998. Modifications for 1D3D cyclones. Proc. Beltwide Cotton Conferences 2:1666-1669.

Flannigan, S., C.B. Parnell, and B.W. Shaw. 1998. Minimum cost air pollution control for cotton gins. Proc. Beltwide Cotton Conferences 2:1674-1687.

Hughs, S.E. and R.V. Baker. 1996. Laboratory evaluation of various cyclone designs. Proc. Beltwide Cotton Conferences 2:1657-1660.

Hughs, S.E. and R.V. Baker. 1998. Effectiveness of Model Cyclone Designs in Collecting Gin Trash Particulate Emissions. Applied Engineering in Agriculture 14(3):317-322.

Roberson, J.A. and C.T. Crowe. 1980. Engineering Fluid Mechanics, 2nd ed. Boston. Houghton Mifflin Company.

Table 1. Sieve analysis of test trash.

Sieve (No.)	Size Range (µm)	Average (% by weight)	Standard Deviation
12	>1679	1.3	0.3
100	>149	56.4	8.7
140	>106	5.5	0.6
200	>75	5.2	1.0
270	>53	6.4	1.5
400	>37	5.7	1.5
Catch Pan	<37	19.4	5.3

Table 2. Summary of results.

Treatment		Results		
Design	Velocity (f.p.m.)	Efficiency (%)	Emissions (lbs./ 1,000 lbs.)	Loading (grains/ cu.ft.)
Standard 1D3D	2600	98.74	12.60	0.051
	2900	98.82	11.79	0.048
	3200	98.82	11.75	0.048
	3500	98.67	13.26	0.054
1D3D with 2D2D inlet	2600	99.04	9.53	0.041
	2900	98.97	10.31	0.041
	3200	98.94	10.63	0.040
	3500	98.86	11.39	0.045
1D3D with D/3 cone	2600	98.97	10.26	0.039
	2900	98.99	10.12	0.042
	3200	99.00	9.96	0.043
	3500	98.89	11.04	0.046
Both Modifications	2600	99.03	9.69	0.039
	2900	99.07	9.26	0.037
	3200	98.97	10.25	0.041
	3500	98.97	10.28	0.042

Table 3. Significance of different designs.

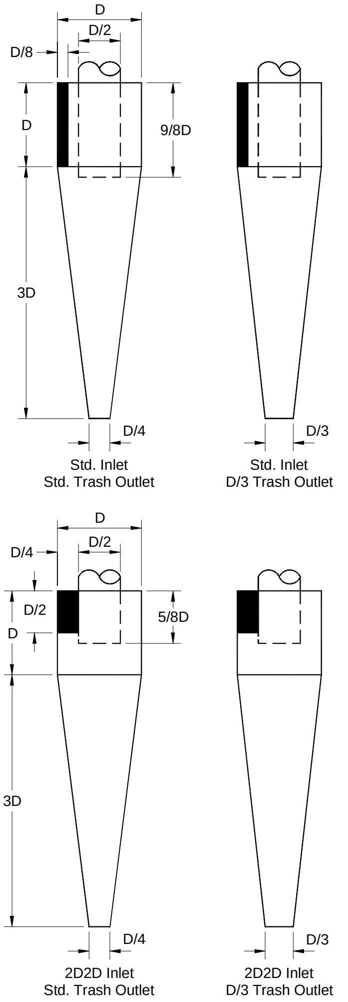
Design	Efficiency %	Emissions Lbs/1,000	Loading Grains/cu.ft.
Std Std	98.765 a	12.35 a	0.04998 a
Std D/3	98.969 b	10.31 b	0.04163 b
2D2D Std	98.954 b	10.46 b	0.04225 b
2D2D D/3	99.008 b	9.92 b	0.04004 b
Critical Range	0.055	0.55	0.0023

*Means with the same letter are not significantly different.

Table 4. Significance of entrance velocity.

Design	Efficiency %	Emissions Lbs/1,000	Loading Grains/cu.ft.
2600	98.947 a	10.53 a	0.0425 a
2900	98.963 a	10.37 a	0.0419 a
3200	98.935 a	10.65 a	0.0430 a
3500	98.849 b	11.51 b	0.0465 b
Critical Range	0.055	0.55	0.0023

*Means with the same letter are not significantly different.



Std. Inlet
Std. Trash Outlet

Std. Inlet
D/3 Trash Outlet

2D2D Inlet
Std. Trash Outlet

2D2D Inlet
D/3 Trash Outlet

Figure 1. Basic dimensions of cyclones studied.

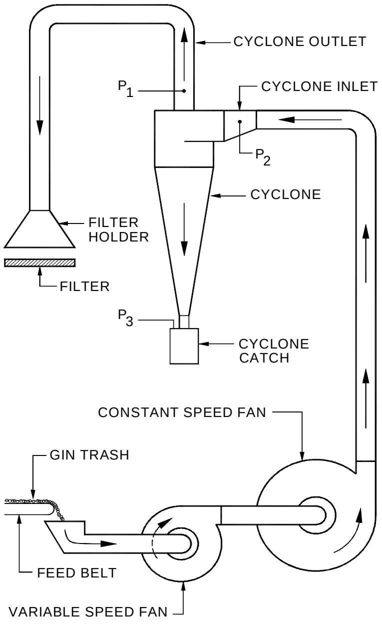


Figure 2. Cyclone test configuration.

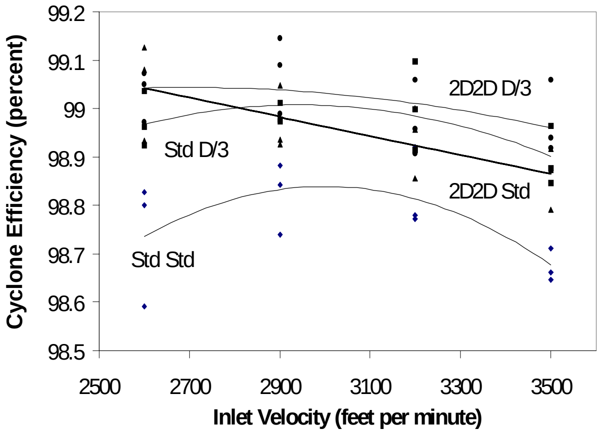


Figure 3. Cyclone efficiency for four designs.

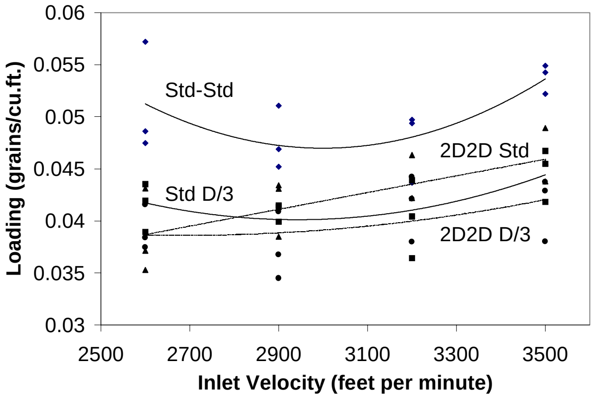


Figure 4. Exhaust loading for four designs.

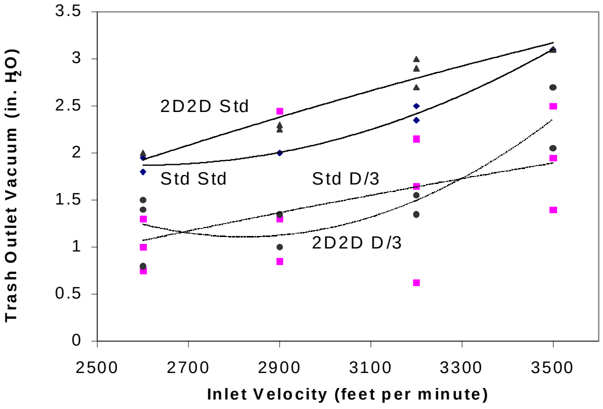


Figure 5. Air outlet-trash outlet pressure difference for four designs.