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ENGINEERING AND GINNING

Entrance Velocity Optimization for Modified Dust Cyclones

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INTERPRETIVE SUMMARY

Dust cyclones are a cost-effective way to clean the air that transports materials within a cotton gin before it is released to the atmosphere. Operating cyclones at the proper entrance velocity is important to maximize their dust collection efficiency and because fan motors pushing air through cyclones consume a significant portion of the energy used by a modern cotton gin. Because design recommendations for dust cyclones are different now than they were when cyclone operating parameters were first studied, re-examining entrance velocity seemed timely. Many gins employ cyclones with a one diameter high body and a cone section three diameters high (1D3D) that use the newly recommended modifications: 1) a 2D2D-style entrance that is wider and shorter (D/4 by D/2); 2) a trash outlet that is larger (D/3). Cyclones modified according to the new design recommendations were tested at entrance air velocities of 2600 to 3500 ft min^{-1}. The published recommended entrance velocity value for standard cyclone designs was found to work well with modified cyclones. This test also confirmed the advantages of employing the currently recommended design modifications. Dust collection efficiency improved significantly with either modification.

ABSTRACT

Entrance air velocity affects both the fan energy consumption and the dust collection efficiency of cotton gin cyclones. Recent findings have resulted in changes in cyclone design recommendations. Entrance air velocity was varied on both conventional and modified cyclones to determine whether air velocity recommendations need to be updated for the new designs. High efficiency cyclones were constructed 30 cm (12 in) in diameter (D). The cyclone body was one D high, the cone section 3D high (1D3D). The cyclones either had a standard entrance D/8 wide by D tall, or a 2D2D-style entrance D/4 wide and D/2 tall. Trash outlets at the terminus of the cone section were either a standard D/4 or a modified D/3 wide. Four levels of entrance air velocity were tested from 13.2 to 17.8 m s^{-1} (2600 to 3500 ft min^{-1}). Dust collection efficiency was determined by weighing filters through which cyclone exhaust air had passed. There was not a statistically significant difference in dust collection due to entrance air velocity, but cyclone modifications clearly improved performance. Pressure drop, which relates to fan energy requirements, increased 20% with both modifications. Pressure drop was observed to increase linearly with entrance air velocity. There is insufficient evidence based on dust collection efficiency to change design velocity recommendations for either standard or modified 1D3D cyclones. However, the potential exists to save energy by reducing entrance velocity since the pressure drop in modified cyclones is 30% lower at 13.2 m s^{-1} (2600 ft min^{-1}) entrance velocity compared to 16.3 m s^{-1} (3200 ft min^{-1}).

Dust cyclones are the most cost-effective technology available to control dust emissions from cotton gins (Flannigan et al., 1998). Meeting increasingly stringent state and county air quality regulatory agency requirements with cyclones alone is, therefore, desirable. Recent research indicates a significant improvement in the collection efficiency of the widely used 1D3D cyclone may be realized by modifying the 1D3D design to employ a 2D2D-style entrance (Hughs and Baker, 1997). Improvements

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Abbreviations: 1D3D, A cyclone of diameter D with the body height 1 x D and the cone height 3 x D; 2D2D, A cyclone of diameter D with the body height 2 x D and the cone height 2 x D; D/3, A cyclone of diameter D with the cone bottom terminating at diameter D/3; D/4, A cyclone of diameter D with the cone bottom terminating at diameter D/4.

Table 1. Sieve analysis of trash material†.

Sieve	Size range	Average	Standard deviation
no.	mm	% by weight	
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

† Data by Hughs and Baker (1997).

also were observed when the D/4 trash exit was enlarged to D/3 (Baker and Hughs, 1999). In the above studies the 1D3D cyclone was modified but the standard entrance velocity of 16.3 m s^{-1} (3,200 ft min^{-1}) from the Cotton Ginners Handbook (Parnell et al., 1994) was not altered when the dust collection effectiveness was being measured. The study herein attempts to find the optimum entrance velocity for the 1D3D cyclone modified according to current design recommendations (Green et al., 2000). Four 1D3D cyclones were tested over a range of entrance velocities from 13 to 18 m s^{-1} (2600 to 3500 ft min^{-1}). Dust collection efficiency was measured by weighing fiberglass filters through which all the exhaust air had passed. Pressure drop also was recorded.

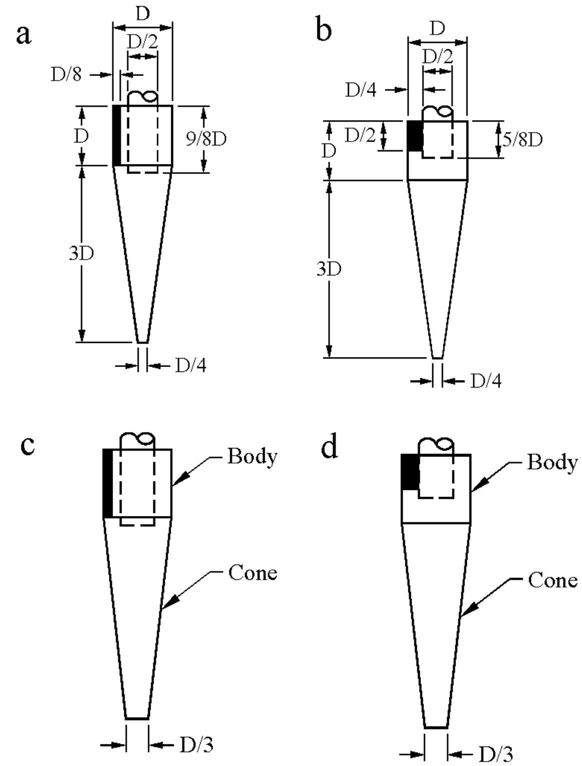

Figure 1. 1D3D cyclones of diameter D including a) standard entrance (D/8 wide), standard trash outlet (D/4); b) modified entrance (D/4 wide), standard trash outlet (D/4); c) standard entrance (D/8 wide), modified trash outlet (D/3); d) modified entrance (D/4 wide), modified trash outlet (D/3).

MATERIALS AND METHODS

The four cyclones constructed for this study were 30 cm (12 in) in diameter. The upper (body) sections and the lower (cone) sections of each cyclone were 30 and 90 cm (12 and 36 in) high, respectively. Two cyclones had the standard 3.75 x 30 cm (1.5 x 12 in) inlets. Two had the recommended modification (called a 2D2D inlet) that was 7.5 x 15 cm (3 x 6 in). The clean air outlet duct extended 3.75 cm (1.5 in) below the bottom of each inlet (Fig. 1). Trash outlets were 7.5 cm (3 in) and 10 cm (4 in) in diameter, so both inlet styles were tested with a standard D/4 and a new (currently recommended) D/3 outlet.

Trash material that had passed through the unloading separator screen of a cotton gin was used for two reasons. It contained lint fiber, leaf trash and fine dust typical of the dust burden handled by cotton gin cyclones. Also, the particle size distribution (Table 1) was appropriate for 30 cm diameter test cyclones. Previous experiments with this trash material in 30 cm cyclones have indicated that results thus obtained are representative of results obtained with regular gin trash in full-size cyclones (Holt et al., 1999).

A cloth conveyor belt dropped 1.66 g s^{-1} (13 lb h^{-1}) of trash material into the suction side of a variable speed fan drawing from 0.153 to 0.207 m^3 s^{-1} (324 to 438 ft^3 min^{-1}) air, resulting in a 10.9 to 8.02 g m^{-3} (4.7 to 3.5 grains ft^{-3}) trash loading rate. This rate corresponds to more heavily loaded exhausts in a cotton gin. A constant speed fan propelled the dust-laden air into the test cyclones. Transducers connected to a data logger recorded pressure drop. Material caught by the cyclone was collected in an airtight bucket attached below the trash outlet for later weighing. Material escaping with the clean air was collected on a 60 x 60 cm (24 x 24 in) Hi-vol fiberglass filter (Hi-Q Environmental Products, San Diego, CA). Filters were weighed to

Table 2. Dust collection results from cyclone entrance velocities (average of all four cyclone designs) tested and their associated Duncan's multiple range values.

Entrance velocity	Efficiency	Emissions	Exhaust loading
m s^{-1}	%	g kg^{-1}	g m^{-3}
(ft min^{-1})		(lb lb^{-1})	(grains ft^{-3})
13.2	98.95 ab *	10.52 ab	0.0899b
(2600)		(0.0105)	(0.0393)
14.7	98.96 a	10.37b	0.0907b
(2900)		(0.0104)	(0.0396)
16.3	98.94 ab	10.65 ab	0.0947 ab
(3200)		(0.0107)	(0.0414)
17.8	98.85b	11.50 a	0.1010 a
(3500)		(0.0115)	(0.0441)

* Means for a given measurement followed by the same letter are not significantly different at the 0.05 level of confidence.

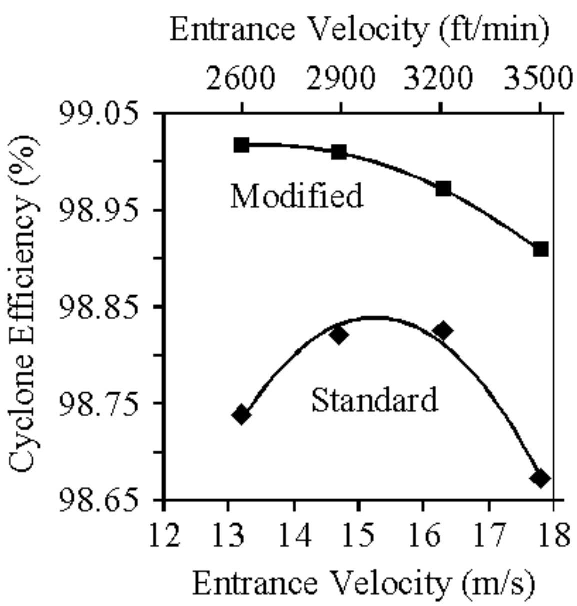

Figure 2. Plot of cyclone efficiency vs. entrance air velocity for standard design and average of all three modified designs.

determine exhaust loading and cyclone efficiency. The variable speed fan pushing into the constant speed fan both achieved target entrance velocities and maintained a constant volumetric airflow through the cyclone as filter backpressure increased with loading.

A randomized block experimental design was selected with three replicates serving as blocks, and four cyclone designs by four entrance velocities (16 lots) being fully randomized within each block. Velocity pressures corresponding to target velocities of 13.2, 14.7, 16.3 and 17.8 m s^{-1} (2600, 2900, 3200 and 3500 ft min^{-1}) were calculated to account for local air density at the time of the test. After airflow was established and verified with a Pitot tube, pre-weighed trash material was fed for 120 s.

Table 3. Dust collection results from cyclone designs (average of all four entrance velocities).

Design (entrance-trash outlet)	Efficiency	Emissions	Exhaust loading
	%	g kg^{-1} (lb lb^{-1})	g m^{-3} (grains ft^{-3})
Std - Std	98.77 b *	12.35 a	0.1092 a
		(0.0124)	(0.0477)
Std - D/3	98.97 a	10.35 b	0.0918 b
		(0.0104)	(0.0401)
2D2D - Std	98.95 a	10.46 b	0.0919 b
		(0.0105)	(0.0402)
2D2D - D/3	99.01 a	9.87 b	0.0862 b
		(0.0099)	(0.0377)

* Means for a given measurement followed by the same letter are not significantly different at the 0.05 level of confidence.

RESULTS AND DISCUSSION

Table 2 presents emissions for the entrance velocities tested and their associated Duncan's multiple range values. (The results were the same using Student-Newman-Keuls and Ryan-Einot-Gabriel-Welsch multiple range tests.) These values were used to group means that are not statistically different. With the statistical uncertainty surrounding the cyclone bodies tested, there was not a conclusive optimum entrance velocity, but there was a tendency for the higher entrance velocities to result in more emissions. Increasing entrance velocity was expected to increase cyclone efficiency. However, irregularities in the cyclone body and cone possibly introduced disturbances in the turbulent boundary layer, entraining previously separated dust particles. Cyclone efficiency (emissions) was not strongly dependent on entrance velocity over the range of this experiment. The highest velocity, 17.8 m s^{-1} (3500 ft min^{-1}), resulted in poorer dust collection performance, compared with an intermediate velocity of 14.7 m s^{-1} (2900 ft min^{-1}) (Fig. 2).

Table 3 presents the same data grouped by cyclone design. There was not a significant difference between the modified entrance and the modified trash outlet, or the two modifications combined. However, either of the recommended

Table 4. Pressure drop results from cyclone entrance velocities (average of all four cyclone designs).

Entrance velocity	Pressure drop
m s^{-1} (ft min^{-1})	**Pa (in H_2O)**
13.2	**561 c ***
(2600)	**(2.25)**
14.7	**747 b**
(2900)	**(3.00)**
16.3	**831 b**
(3200)	**(3.33)**
17.8	**1038 a**
(3500)	**(4.17)**

*** Means for a given measurement followed by the same letter are not significantly different at the 0.05 level of confidence.**

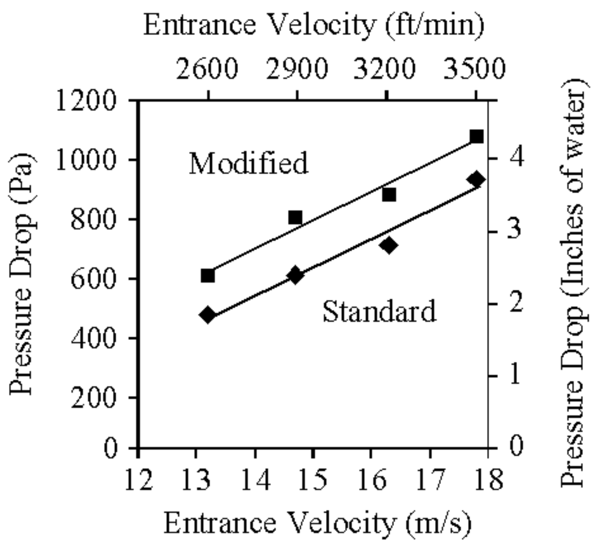

Figure 3. Plot of cyclone pressure drop vs. entrance air velocity for standard design and average of all three modified designs.

modifications, singly or in combination, showed a significant improvement in dust collection independent of entrance velocity. This confirms earlier work by Baker and Hughs (1999).

Pressure drop through the test cyclones nearly doubled over the tested range of entrance velocity (Table 4). The increase in energy required to operate cyclones is accompanied by a penalty due to the pollution associated with energy generation. Because pressure drop is a linear function of entrance velocity (Fig. 3), decreasing entrance velocity would be favored if dust emissions were not significantly increased.

In this study, pressure drop through the test cyclones was significantly higher with entrance design modifications (Table 5). There was not a

Table 5. Pressure drop results from cyclone designs (average of all four entrance velocities).

Design(entrance - trash outlet)	Pressure drop
	Pa (in H_2O)
Std - Std	**671 b ***
	(2.69)
Std - D/3	**804 a**
	(3.23)
2D2D - Std	**894 a**
	(3.59)
2D2D - D/3	**807 a**
	(3.23)

*** Means for a given measurement followed by the same letter are not significantly different at the 0.05 level of confidence.**

significant influence on pressure drop from trash outlet modifications at the 10% level. However, trash outlet modifications interacted with inlet modifications in a way that was statistically significant, with the D/3 outlet being needed to reduce the impact of converting to the 2D2D inlet. This finding supports published recommendations (Green et al., 2000) encouraging ginners to first enlarge the trash outlet during routine annual repairs, and to replace the cyclone entrance later, when performing a major air-system upgrade.

Previous studies had different absolute (higher by a factor of two) and relative (modified was lower) pressure drop values (Holt et al., 1999; Baker and Hughs, 1998). Several factors may explain the difference. Prior studies were conducted with full-scale cyclones. Pressure drop in previous studies was recorded when the system was handling air only (no trash). There is a great deal of fluctuation in pressure in a cyclone that is handling air and dust, and hence considerable uncertainty. But the findings of this and previous studies are in agreement as to the linear relationship between velocity and pressure drop. Additional work is required to identify the energy cost or savings with cyclones that have pressure drops similar to those installed at gin plants with typical trash loading.

SUMMARY AND CONCLUSIONS

Cyclones modified either by increasing the trash outlet from D/4 to D/3, or by substituting a 2D2D inlet for the long narrow standard one, or both, had significantly less emissions at all entrance air velocities. Although there was a linear relationship between pressure drop and entrance air velocity, small changes in velocity did not result in statistically significant differences in dust collection performance.

Until the experiment can be replicated with full-size cyclones or with replicate cyclone bodies for each design, there is not sufficient statistical evidence to change the recommended entrance velocity for a 1D3D cyclone based on emissions. Even when modified to include the 2D2D-type entrance and/or the D/3 trash outlet, the cyclone can be operated at 16.25 m s^{-1} (3200 ft min^{-1}) without adversely affecting collection efficiency.

Because fan motors pushing air through cyclones consume a significant portion of the energy used by a modern cotton gin, and reductions in entrance velocity can reduce fan energy requirements, reducing entrance velocity to 15 m s^{-1} (3000 ft min^{-1}) may be desirable (Fig. 2). This warrants further investigation. Pressure drop data typical of loaded cyclones will identify part of the cost of operating modified cyclones.

The lack of a clear optimum entrance velocity indicates that cyclones are robust to small changes in operating speed. From a compliance standpoint, this finding means small changes that naturally come about as fan blades wear or as air streams fluctuate most likely will not result in measurable changes in dust emissions. Some increase in air flow velocities brought about by gin plant modification may not put air quality out of compliance with the modified cyclones.

REFERENCES

Baker, R.V., and S.E. Hughs. 1998. Evaluation of two long-cone cyclone designs. Trans. ASAE 42(1):11-16.

Baker, R.V., and S.E. Hughs. 1999. Influence of air inlet and outlet design and trash exit size on 1D3D cyclone performance. Trans. ASAE 42(1):17-21.

Flannigan, S., C.B. Parnell, and B.W. Shaw. 1998. Minimum cost air pollution control for cotton gins. p. 1674-1687. *In* Proc. Beltwide Cotton Conf., San Diego, CA. 5-9 Jan. 1998. Natl. Cotton Counc. Am., Memphis, TN.

Green, J.K., P.A. Funk, and G.A. Holt. 2000. Current recommendations for gin emission control. p. 474-475. *In* Proc. Beltwide Cotton Conf., San Antonio, TX. 3-7 Jan. 2000. Natl. Cotton Counc. Am., Memphis, TN.

Holt, G.A., R.V. Baker, and S.E. Hughs. 1999. Evaluation of static pressure drops and PM10 and TSP emissions for modified 1D-3D cyclones. Trans. ASAE 42(6):1541-1547.

Hughs, S.E., and R.V. Baker. 1997. Laboratory evaluation of various cyclone designs. Cotton Ginning J. 96:62-65.

Parnell, C.B. Jr., E.P. Columbus, and W.D. Mayfield. 1994. Abatement of air pollution and disposal of gin waste. p. 172-194. *In* W.S. Anthony and W.D. Mayfield (ed.) Cotton ginner's handbook. USDA Agricultural Handbook 503. U.S. Gov. Print. Office, Washington, DC.