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M.N. Gillum and S.E. Hughs

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Velocity Effects on Operating Parameters of Series Cyclones

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M. N. Gillum, S. E. Hughs
ASSOC. MEMBER ASAE ASSOC. MEMBER ASAE

ABSTRACT

PRIOR research by the USDA Southwestern Cotton Ginning Research Laboratory has shown that adding a cyclone in series with a primary cyclone collector can reduce cotton gin dust emissions by 45 to 54 percent. However, the addition of the secondary cyclone about doubles the air horsepower required to operate the collection system when operated at the industry standard of 15.2 m/s (3000 ft/min) air inlet velocity. Current research has shown that the cyclone system inlet air speed can be lowered from 15.2 m/s (3000 ft/min) to 11.8 m/s (2323 ft/min) without significantly affecting the system collection efficiency. The system pressure drop was lowered from 1.98 kPa (7197 in. water) to 1.20 kPa (4.86 in. water) with the reduction in air inlet velocity. This study shows that a properly designed series cyclone system operated at reduced velocity can reduce gin emissions by over 40 percent without greatly increasing the air horsepower currently required to operate a single cyclone at the current standard air inlet velocity.

INTRODUCTION

Small-diameter cyclones (Harrell and Moore, 1962) have been in use as trash collectors on the seed-cotton exhaust systems of gins for many years. Baker and Stedronsky (1967) showed that the small-diameter cyclone had collection efficiencies greater than 99% on gin trash over a wide range of cyclone inlet air velocities and trash feed rates. Baker and Stedronsky showed that gin trash feed rates could vary from 38 kg/h (84 lb/h) to 1110 kg/h (2447 lb/h), and inlet air velocities could vary from 655.3 m/min (2150 ft/min) to 1447.8 m/min (4750 ft/min) without any significant loss in trash collection efficiency.

Cyclone tests conducted by Wesley et al. (1972) confirmed the high collection efficiencies reported by Baker and Stedronsky. In addition, Wesley et al. (1972) reported that the highest efficiency occurred in the air inlet velocity range of 914.4 m/min (3000 ft/min). Their data also indicated that the small-diameter cyclone collected virtually 100 percent of all particles larger than 20 microns in diameter. Particles smaller than 20 microns were partly collected in decreasing amounts as they became smaller.

All of the tests involving small-diameter cyclones discussed so far used the 2D2D design (Cotton Ginners Handbook, 1977). That is, both the body and cone length dimension were twice the diameter of the body. Parnell and Davis (1979) have tested what they call the Texas A&M long-cone cyclone. This long-cone cyclone is of the 1D3D design. The body length is equal to the body diameter and the cone length is equal to three body diameters. Parnell and Davis state that a California oil mill was able to reduce its particulate emissions by replacing its standard high-efficiency (2D2D) cyclones with long-cone (1D3D) cyclones.

Gillum et al. (1982) tested the collection efficiency of cyclones on cotton gin trash when used as secondary collectors on the exhaust of a primary cyclone collector. The primary cyclone was a 2D2D high-efficiency cyclone. Both the 2D2D and the 1D3D high-efficiency cyclone designs were evaluated as secondary collectors. The collection efficiency of the primary cyclone averaged 99.6 percent through the test. The 2D2D and the 1D3D high-efficiency cyclone designs had average collection efficiencies of 45.7 and 54.0 percent, respectively, as secondary collectors. This showed that the addition of high-efficiency cyclones as secondary collectors could reduce particulate emissions from currently used primary cyclones by approximately 50 percent. The combined collection system efficiency averaged 99.82 and 99.86 percent for the system using secondary 2D2D and a 1D3D cyclone designs, respectively. The penalty for the increased collection efficiency was an increased power requirement to overcome the added pressure drop across the secondary cyclone.

Gillum et al. reported that, at the cyclone air inlet velocity of 14.8 to 14.9 m/s (2910 to 2930 ft/min), the primary cyclone had an average pressure drop of 896 Pa (3.60 in. water). The secondary 2D2D and 1D3D cyclones had pressure drops of 1010 Pa (4.06 in. water) and 1116 Pa (4.48 in. water), respectively, at the same inlet air velocity as the primary cyclone. The air flow resistance of the collection system was more than doubled as the particulate emissions were reduced by approximately 50 percent.

The objective of the study reported here was to determine how far the inlet velocity to a set of series cyclones can be reduced from the industry standard of 15.24 m/s (3000 ft/min) without significantly affecting the combined collection system efficiency. Reduced cyclone inlet velocity corresponds with reduced pressure drop across the cyclone and therefore reduced fan power requirements.

TEST DESIGN

The cyclone test equipment in airflow sequence was as follows (Fig. 1): trash feeder, centrifugal fan, air flow control valve, 813 mm (32-in.)-diameter cyclone (2D2D design) with sealed trash box, hereafter called the primary cyclone, 813 mm (32-in.)-diameter cyclone (2D2D design), hereafter referred to as the control

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The authors are: M. N. GILLUM, Agricultural Engineer, and S. E. HUGHS, Research Leader, Southwestern Cotton Ginning Research Laboratory, Mesilla Park, NM.

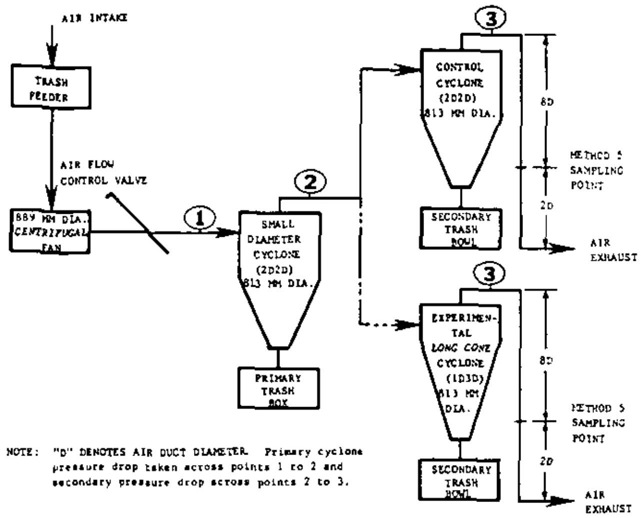

Fig. 1—Test equipment in air flow sequence.

cyclone, or an 813 mm (32-in.)-diameter long-cone cyclone (1D3D design), hereafter referred to as the long-cone cyclone, with sealed trash bowls and sampling ports for measurement of the emissions from the secondary cyclone. The primary cyclone was always a 2D2D, while the secondary was either a 1D3D or a 2D2D.

Measurements were made of the conveying air temperature, air dewpoint temperature, and relative humidity before the air-trash mix point and after the air sampling ports. The pressure drops across the primary and secondary cyclones were measured using static probes. Included in the pressure drop measurement were cyclones and inlet transitions and outlet involutes. The air flow through the cyclones (cyclone inlet velocity) was measured with a standard pitot tube in the center of the exhaust duct for setting the air flow control valve to the desired velocity before each lot. The air flow through the cyclones during each lot was measured with a standard pitot tube in the center of the pipe and the Method 5 (Environmental Protection Agency (EPA), 1977) sampling train. The trash collected from the primary cyclone was weighed on a scale whose smallest division was 0.5 pound. The dust collected from the secondary cyclone was weighed to the nearest 0.1 g. The dust exhausted from the secondary cyclone was measured using EPA Method 5 procedures. The primary, secondary, and combined cyclone efficiencies were calculated from the three measurements.

Two secondary cyclone designs with six levels of cyclone inlet velocity were tested in a randomized complete block factorial design with three replications. The cyclone inlet velocity test levels ranged from 10.5 m/s (2067 ft/min) to 18 m/s (3543 ft/min) by 1.5 m/s (295 ft/min) steps. Gin trash feed rates to the primary cyclone were to be held constant while air flow rates varied. Each test run was 56 min long and included eight measurements as per EPA Method 5 protocol.

TEST RESULTS AND DISCUSSION

There were no significant differences due to treatments for trash conveying air temperature, dewpoint temperature, and relative humidity before the trash-air mix point and after the secondary cyclone. Average cyclone inlet air velocities, as calculated from EPA Method 5 air flow data, and average cyclone pressure losses are shown in Table 1 along with analysis of covariance results.

TABLE 1. AVERAGE CYCLONE INLET VELOCITY AND HEAD LOSS

Flow setting and type of secondary cyclone	Cyclone inlet velocity*	Pressure drop across cyclones: Primary	Secondary	Combined
	m/s(ft/min)	kPa(in. water)	kPa(in. water)	kPa(in. water)
1				
Control	10.6(2088)	0.43(1.74)	0.47(1.90)	0.90(3.64)
Long-cone	10.6(2077)	0.43(1.72)	0.50(2.01)	0.93(3.73)
2				
Control	11.7(2311)	0.56(2.24)	0.61(2.46)	1.17(4.70)
Long-cone	12.0(2352)	0.57(2.29)	0.64(2.71)	1.24(5.00)
3				
Control	13.4(2647)	0.71(2.86)	0.79(3.19)	1.50(6.05)
Long-cone	13.9(2729)	0.74(2.97)	0.88(3.54)	1.62(6.51)
4				
Control	15.1(2977)	0.92(3.68)	1.04(4.17)	1.96(7.85)
Long-cone	15.5(3052)	0.91(3.65)	1.10(4.44)	2.01(8.09)
5				
Control	16.6(3267)	1.08(4.35)	1.24(5.00)	2.32(9.35)
Long-cone	16.8(3306)	1.11(4.45)	1.38(5.53)	2.49(9.98)
6				
Control	18.2(3581)	1.27(5.09)	1.51(6.09)	2.78(11.18)
Long-cone	18.4(3614)	1.27(5.12)	1.64(6.61)	2.91(11.73)
Analysis of co-variance†				
A (design)	0.5	NS	0.1	0.1
B (velocity)	0.1	2.0	1.0	3.0
AxB (design x velocity)	NS	NS	2.0	NS

* Cyclone inlet velocity based upon actual exhaust air flow as measured by EPA Method 5 at an average air density of 1.0001 kg/m³ (0.0624 lb/ft³) and an average exhaust air pressure of 88.626 kPa (26.245 in. Hg).

† A = secondary cyclone design, B = cyclone inlet velocity, NS = means not significant at the 5.0-percent level or higher. All other numbers are highest level of significance in percent for the particular treatment and column.

TABLE 2. AVERAGE CYCLONE PERFORMANCE

Flow setting and type of secondary cyclone	Cyclone inlet velocity	Trash collected		Secondary cyclone emission rate	Cyclone efficiency		
		Primary	Secondary		Primary	Secondary	Combined
	m/s(ft/min)	kg/h(lb/h)	kg/h(lb/h)	kg/h(lb/h)	%	%	%
1							
Control······	10.6(2088)	37.3(82.3)	0.14(.30)	0.17(.37)	99.20	44.71	99.55
Long-cone····	10.6(2077)	41.7(92.0)	0.16(.36)	0.17(.38)	99.20	49.32	99.59
2							
Control······	11.7(2311)	38.8(85.6)	0.13(.28)	0.15(.33)	99.30	45.13	99.62
Long-cone····	12.0(2352)	37.5(82.7)	0.12(.27)	0.14(30)	99.31	46.76	99.63
3							
Control······	13.4(2647)	41.7(92.0)	0.13(.28)	0.16(.35)	99.32	45.19	99.63
Long-cone····	13.9(2729)	47.4(104.6)	0.14(.31)	0.14(.32)	99.40	49.97	99.70
4							
Control······	15.1(2977)	45.0(99.2)	0.12(.26)	0.14(.31)	99.43	45.68	99.69
Long-cone····	15.5(3052)	36.8(81.1)	0.10(.23)	0.12(.27)	99.37	46.52	99.66
5							
Control······	16.6(3267)	39.2(86.4)	0.10(.21)	0.15(.33)	99.35	38.58	99.60
Long-cone····	16.8(3306)	40.6(89.4)	0.11(.25)	0.14(.31)	99.39	45.42	99.66
6							
Control······	18.2(3581)	45.2(99.7)	0.10(.23)	0.16(.35)	99.44	39.91	99.66
Long-cone····	18.4(3614)	39.9(87.9)	0.10(.23)	0.13(.29)	99.41	44.01	99.67
Analysis of Variance*							
A (design)		NS	NS	NS	NS	1.0	5.0
B (velocity)		NS	5.0	NS	0.1	5.0	0.5
AxB (design x velocity)		NS	NS	NS	NS	NS	NS

* A = secondary cyclone design, B = cyclone inlet velocity, NS = not significant at the 5.0-percent level or higher. All other numbers are highest level of significance in percent for the particular treatment and column.

The significant effect of cyclone design on cyclone inlet velocity (first column) was probably due to an error in calibration coefficients of the two stationary pitot tubes used for setting the flow velocity or a difference in the effect of trash flow versus pressure loss for the different cyclone designs. The air flow was set before each lot in response to the pitot tube measurements made with no trash flow. The cyclone inlet velocities shown in Table 1 are based upon actual exhaust air flow as measured by EPA Method 5 during each lot. Recognizing that the 0.5-percent significance level of cyclone design on velocity was probably due to error in setting the initial air flow rate, an analysis of covariance was performed using inlet velocity as a covariable. This analysis removed the effect of the error in initial velocity set point. Inlet velocity squared was shown to be a significant covariable on pressure drops shown in Table 1, but was not significant at the 5-percent level for primary trash collections or secondary cyclone emission rates shown in Table 2. The significance levels shown in Table 1, excluding inlet velocity, are from the analysis of covariance. All means shown are real means and not least squares means from analysis of covariance. The analysis of covariance given on Table 1 shows that air velocity had a significant effect on pressure drop across the cyclones with the secondary long-cone cyclone having a higher pressure drop at a given air velocity than the secondary control cyclone (Fig. 2).

Table 2 shows that there was a significant reduction in primary cyclone collection efficiency with reduced air flow. On the other hand, the efficiency of the secondary cyclone tended to remain constant or increase at the lower air flows (see Fig. 3). This increase in efficiency is due to the heavier loading of the secondary due to the decreased collection efficiency of the primary cyclone. Baker and Stedronsky (1967) state that cyclone collection efficiency increases as loading rate increases. Also, Table 2 and Fig. 3 show that the long-cone cyclone had a significantly higher collection efficiency than the control

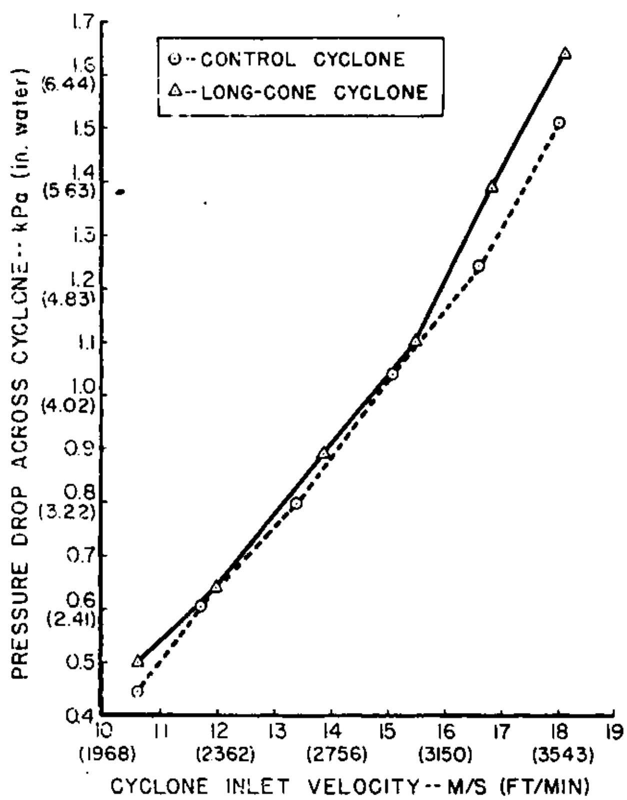

Fig. 2—Inlet velocity vs. pressure drop.

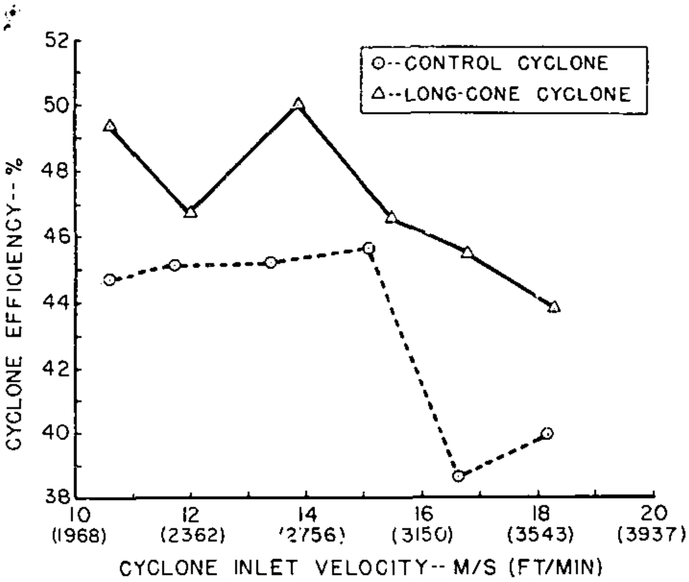

Fig. 3—Inlet velocity vs. efficiency.

cyclone at all air flow rates. The collection efficiency of the two cyclones in series was always higher, even at the lowest air flow rate, than just the primary cyclone at its highest efficiency.

Table 3 shows a comparison of cyclone inlet velocity and collection efficiencies with the control and long-cone cyclone averaged together. The combined collection efficiency of the series cyclone system did not change significantly until the cyclone inlet velocity fell below 11.8 m/s (2323 ft/min). Also, at 11.8 m/s (2323 ft/min) the combined system pressure drop was 1.20 kPa (4.85 in. water) or only 61 percent of the system pressure drop of 1.98 kPa (8.00 in. water) which occurred at the standard cyclone inlet air velocity of 15.2 m/s (3000 ft/min).

SUMMARY

The data from this study show that the benefit of the added collection efficiency of the secondary cyclone can be realized with little added burden of increased system pressure drop. The primary and secondary cyclone collection system can be operated with an inlet velocity of 11.8 m/s (2323 ft/min), a system pressure drop of 1.20 kPa (4.85 in. water) and a system collection efficiency of 99.63 percent versus 15.2 m/s (3000 ft/min), 0.91 kPa (3.65 in. water) and 99.40 percent as currently recommended for cyclones. This means that gins should be able to cut their present cyclone emissions by approximately 40 percent without adding or increasing fan size or horsepower. This information should aid the cotton ginning industry in meeting current and future particulate emission control requirements.

TABLE 3. AVERAGE EFFECTS OF CYCLONE INLET VELOCITY ON CYCLONE COLLECTION EFFICIENCY

Cyclone inlet velocity	Total system pressure drop	Cyclone efficiency*		
		Primary	Secondary	Combined
m/s(ft/min)	kPa(in. water)	%	%	%
10.6(2087)	0.92(3.68)	99.20 c	47.02a	99.57 b
11.8(2323)	1.20(4.85)	99.31 b	45.95ab	99.63a
13.7(2697)	1.56(6.28)	99.36ab	47.58a	99.66a
15.3(3012)	1.98(7.97)	99.40a	46.10ab	99.68a
16.7(3287)	2.40(9.66)	99.37ab	42.00 b	99.63a
18.3(3602)	2.85(11.46)	99.42a	41.96 b	99.66a

* Means followed by the same letter or group of letters are not different based on Duncan's New Multiple Range test at the 95-percent level.

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