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Use of Secondary Cyclones for Reducing Gin Emissions

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ABSTRACT

MEETING particulate emission standards set by the Environmental Protection Agency is currently a problem for the ginning industry. Small-diameter cyclones are currently used as primary collectors on some gin exhausts. A study was conducted to determine the effectiveness of three types of cyclones as secondary collectors. A standard small-diameter cyclone operating as a secondary collector captured 45 percent, by weight, of particulates that would normally be emitted to the atmosphere. Other cyclone designs tested in the secondary position reduced particulate emissions by up to 54 percent. This information should be useful to the ginning industry in designing particulate collection systems to meet particulate emission standards.

INTRODUCTION

Fifty years ago, most of the cotton in the United States was hand picked and contained very little foreign matter when it was brought to a gin. The ginner was primarily concerned with removing the lint from the seed and had little concern with handling and disposing of any foreign matter in the cotton. Because of economic forces, the harvesting of cotton is now almost totally mechanized. This increased mechanization has led to increases in harvesting rates and in the percentage of foreign matter in cotton brought to the gin.

Today's gin must handle the increased amounts of cotton that have resulted from the increased harvesting rates, along with the accompanying increase in foreign matter content. Gins have added additional cleaning machinery, and the additional machinery requires increased material-conveying air to remove and handle the increased levels of foreign matter. This foreign matter must then be removed and consolidated from large volumes of conveying air.

The encroachment of cities into once rural areas, coupled with the increased public concern about air pollution, is causing pressure on the ginning industry to reduce particulate emissions. Gins have put small-diameter cyclones (Harrell and Moore, 1962) into use on many of their air exhausts. The small-diameter cyclone is highly efficient and very reliable when properly designed and installed. However, very low permissible emission levels and increased public pressure are forcing the ginning industry to search for still better methods of particulate emission control.

Baker and Stedronsky (1967) tested the dust collection efficiency of a standard 30-in. small-diameter cyclone for different air velocities at the inlet and different rates of trash input. The optimum air velocity at the inlet was found to be 914 m/min (3,000 ft/min). Any increase in air velocity above this point tended to decrease efficiency, and speeds between 914 m/min (3,000 ft/min) and 655 m/min (2,150 ft/min) had very little effect on dust collection efficiency. Trash collection efficiency tended to increase with trash input rate. Cyclone collection efficiency increased from 99.94 percent to 99.96 percent as trash input rate increased from 38.2 kg/h (84 lb/h) to 1,100 kg/h (2,450 lb/h). Particulate emissions from the cyclone per 22.7 kg (50 lb) of trash input ranged from 12.5 g at the low trash input rate to 8.6 g at the high trash input rate.

Wesley et al. (1970) tested the efficiency of the small-diameter cyclone, using small particles of gin trash at various intake airflow rates and trash feed rates. Small gin trash was defined as anything that would pass through a 16 x 16 mesh corrugated wire. They reported that the small-diameter cyclone had an average efficiency of about 99.9 percent over the airflow rates and the trash feed rates tested. They determined that the small-diameter cyclone collected virtually 100 percent of any particles larger than 24 μ in diameter.

Parnell and Davis (1979) tested the collection efficiency of two cyclones in series on grain dust. The first cyclone was a large-diameter cyclone (Harrell and Moore, 1962). The second was a modified small-diameter cyclone called "Texas A&M long-cone cyclone." It had an overall particle collection efficiency of 79 percent when operated as a secondary collector. Particulate loading of the cyclone input was 834 mg/m^3, which resulted in a particulate emission rate of 172 mg/m^3. Eighty-six percent of the grain dust particles were 22.8 μ in diameter or smaller.

The primary objective of this study was to evaluate three designs of small-diameter cyclones as secondary collection devices.

TEST DESIGN AND TEST

The test design was a randomized complete-block, with replications. Each block contained two treatments, the control cyclone and the experimental cyclone as a secondary collector. The experimental cyclone was either the long-cone cyclone or the cyclone cluster. The order of the treatments was randomized within each block. Each test run was 56 min long. The first test series consisted of nine replications with the control cyclone and cyclone cluster. The second series consisted of nine replications

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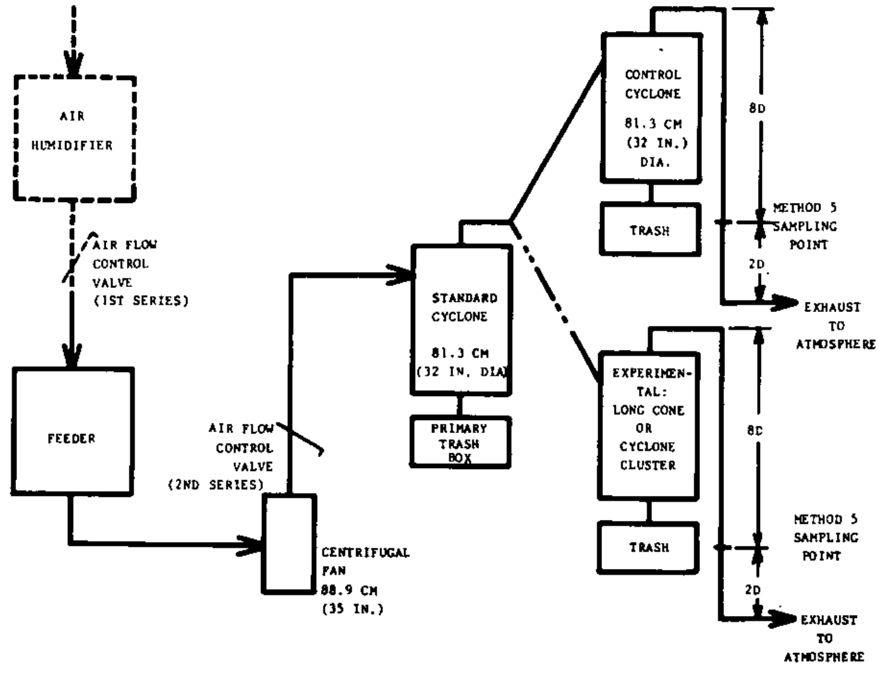

FIG. 1 Test installation.

with the control and long-cone cyclone. Analysis of variance was run to compare results from each experimental cyclone with results from the control.

Fig. 1 is a schematic of the test equipment used. The order of basic test equipment, in airflow sequence, was as follows; air humidifier, cotton-trash hopper with feeder, centrifugal fan, airflow control valve, and 81.3-cm (32-in.) small-diameter cyclone with sealed trash box as a primary cotton-trash collector. The primary cyclone was followed by one of the following three small-diameter secondary collectors with sealed trash-collection bowls:

1 An 81.3-cm (32-in.) cyclone identical to the primary cyclone, hereafter referred to as the control cyclone

2 An 81.3-cm (32-in.) diameter Texas A&M long-cone cyclone (Parnell and Davis, 1979), hereafter referred to as the long-cone cyclone

3 A set of four 40.6-cm (16-in.) cyclones in parallel, hereafter referred to as the cyclone cluster. The exhaust from the secondary cyclones was then vented past sampling ports to the atmosphere.

The temperature and dewpoint temperature of the conveying air were measured, along with the relative humidity, before the air-trash mixing point at the trash feeder and after the secondary cyclone. The pressure drops across the primary cyclone and test cyclone were measured. The airflow rate through the cyclones was measured by a standard pitot tube in the center of the air duct after the secondary cyclone being tested and also by EPA Method 5 (Environmental Protection Agency (EPA), 1977).

The trash collected from the primary cyclone was weighed to the nearest 0.23 kg (0.5 lb). The dust collected from either the control or the long-cone or cluster cyclones being tested was weighed to the nearest 0.1 g. The particulates emitted from the secondary cyclone under test was measured by the Method 5 procedures (EPA, 1977). The efficiencies of the primary and secondary cyclone under test were then calculated from the three measurements.

During the test, it was found that the coefficient of variation of the Method 5 measurements was much higher than any of the other measurements. Two reasons for this variation are the trash collection measurement methods and the design of the sampling train. The trash collection measurements are the scale weights of all the material collected. Weighing can be done with an accuracy of about 0.1 percent, so the major source of variation in trash measurements between lots would be from small uncontrolled changes, such as trash feed rate or trash density. The particulate concentration, on the other hand, is determined by sampling a portion of an air stream at different points at different times. Particulate concentration in an air stream may be considered to be uniform over an extended period of time, but at any given instant of time at a given place, the concentration may vary over a wide range. A spot sample would be subject to this variation.

The second reason for the large coefficient of variation of the Method 5 particulate concentration measurement is that the Method 5 sampling train was designed as a probe to be inserted through the side of an exhaust stack, perhaps as much as 9.1 m (30 ft) in diameter. The effects on the airflow from the projected area of the probe or from the sampling ports cut in the side of the stack are minimal in a stack this large. Also, when the cross-sectional area of the large stack is divided into quadrants for sampling, the probe is not used to sample close to the stack wall where there is a sudden discontinuity in airflow. In our application, however, the probe was used in a pipe with a diameter of 0.318 m (12.5 in.). At times, the sampling probe took up as much as 12 percent of the pipe's cross-sectional area and, therefore, disturbed the normal airflow. The sampling ports were larger than the pipe diameter and caused a serious airflow disturbance. The probe was used to sample within 21 mm (0.84 in.) of the pipe wall where there was a discontinuity in airflow. There were no other operational problems with the Method 5 sampling train. All sampling tests were within the specified Method 5 limits of the isokinetic sampling rate.

System airflow was adjusted to obtain a cyclone inlet velocity of 914 m/min (3,000 ft/min). Trash flow rate

TABLE 1. RESULTS WITH CONTROL CYCLONE VS. RESULTS WITH CYCLONE CLUSTER

Measurement	Treatment means: Control	Treatment means: Cyclone cluster	Standard deviation	Coefficient of variability	Significance* level
				%	%
Actual cyclone inlet velocity (Method 5), m/s (ft/min)	16.1(3170)	14.9(2930)	0.4(79)	2.4	0.02
Pressure drop across primary cyclone, Pa (in. water)†	912(3.67)	941(3.78)	20(.08)	2.2	NS
Pressure drop across secondary cyclone, Pa (in. water)†	1061(4.26)	1075(4.32)	12(.05)	1.1	NS
Particulate concentration, secondary cyclone exhaust, mg/m^3 ($grain/ft^3$)	39.1(.017)	37.7(.016)	11.8(.005)	30.7	NS
Trash collected, primary cyclone, g/s (lb/h)	17.0(135)	19.1(152)	3.2(25)	17.5	NS
Trash collected, secondary cyclone, g/s (lb/h)	0.034(.272)	0.046(.365)	0.007(.057)	17.9	1.0
Emission rate from secondary cyclone, g/s (lb/h)	0.043(.343)	0.039(.306)	0.013(.099)	30.6	NS
Primary cyclone collection efficiency, %	99.54	99.55	0.06	0.06	NS
Secondary cyclone collection efficiency, %	44.40	54.70	6.70	13.50	2.5
Combined collection system efficiency, %	99.74	99.79	0.06	0.06	NS

*Nonsignificant probability > 5 percent
†Analysis of covariance—SAS (1979)

was controlled by the speed of the auger in the cotton trash feeder. A Hewlett-Packart (H-P) 21 MX microprocessor was used with an H-P 6940 multiprogrammer to control the test equipment, direct data taking, and time all sampling.

The gin trash used for the study came from local gins and consisted of all trash collected in the hopper under the cyclones for the seed-cotton system. Gin trash from both 1978 and 1979 crop years was used in the study.

RESULTS AND DISCUSSION

Tables 1 and 2 summarize results of the analysis comparing results with the cyclone cluster and long-cone cyclone, respectively, with results from the control cyclone. Data in Table 1 indicate that the inlet velocity with the control cyclone and the cyclone cluster differed significantly. This difference was due primarily to the type of valve that used to control airflow and to an inaccurate calibration of the pitot tube used for initial airflow readings. The valve was changed between the first and second test series, and the velocity-control problem was eliminated. Analysis of covariance (SAS User's Guide, 1979) was performed on the pressure-drop data summarized in Table 1 to remove the effect of velocity difference. The data were then analyzed and summarized as presented in Table 1. The cyclone cluster collected significantly more trash than the control cyclone. This higher collection rate was reflected in an average efficiency of 54.7 percent for the cyclone cluster, versus 44.4 percent for the control.

Table 2 data indicate that the long-cone cyclone had a significantly higher particulate collection efficiency than the control — 54.0 percent versus 45.7 percent. The long-cone cyclone also had a significantly higher operating pressure drop than did the control.

Both the long-cone cyclone and the cyclone cluster had higher particulate collection efficiencies than did the control cyclone. However, the combined collection system efficiencies were not significantly different from the control efficiency. The magnitude of the trash collection and the collection efficiency of the primary cyclone were so large that the effects of the secondary cyclone were dminished enough in the overall system efficiency calculations to be made nonsignificant.

Emission rates from both experimental cyclones were lower than the rate from the control cyclone, but not significantly so, even though the collection efficiencies of the experimental cyclones were significantly higher. Emission rates from the secondary cyclone were calculated from the particulate concentration of the secondary cyclone exhaust, as determined from Method 5 procedures. The particulate concentration measurement had a much higher coefficient of variation than any other measurement. This high coefficient of variation indicated that the particulate concentration could be determined with as much precision as the other measurements given in Tables 1 and 2. Differences in

TABLE 2. RESULTS WITH CONTROL CYCLONE VS. RESULTS WITH LONG-CONE CYCLONE

Measurement	Treatment means: Control	Treatment means: Long cone	Standard deviation	Coefficient of variability	Significance* level
				%	&
Actual cyclone inlet velocity (Method 5), m/s (ft/min)	14.8(2910)	14.9(2930)	0.1(20)	1.0	NS
Pressure drop across primary cyclone, Pa (in. water)	896(3.60)	899(3.61)	12(.05)	1.3	NS
Pressure drop across secondary cyclone, Pa (in. water)	1010(4.06)	1116(4.48)	25(.10)	2.3	.01
Particulate concentration, secondary cyclone exhaust, mg/m^3 ($grain/ft^3$)	37.5(.016)	26.3(.011)	23.1(.010)	72.3	NS
Trash collected, primary cyclone, g/s (lb/h)	16.2(129)	17.3(137)	1.7(13)	10.0	NS
Trash collected, secondary cyclone, g/s (lb/h)	0.052(.416)	0.051(.406)	0.13(.105)	25.6	NS
Emission rate from secondary cyclone, g/s (lb/h)	0.040(.314)	0.028(.224)	0.024(.190)	70.9	NS
Primary cyclone collection efficiency, %	99.63	99.66	0.07	0.07	NS
Secondary cyclone collection efficiency, %	45.70	54.00	5.70	11.30	2.5
Combined collection system efficiency, %	99.82	99.86	0.05	0.05	NS

*Nonsignificant probability > 5 percent.

TABLE 3. SOURCE OF PARTICULATE EMISSIONS IN FIVE WESTERN COTTON GINS*

State	Seed cotton processing rate,‡ kg/h(1b/h)	Total emissions, kg/h(1b/h)	Seed cotton system, kg/h(1b/h)	Lint system, kg/h(1b/h)	Total allowable emissions,§ kg/h(1b/h)
Arizona	2318(5100)	3.4(7.5)	1.9(4.1)c	1.5(3.4)1	2.7(6.0)
Arizona	5864(12900)	13.4(29.5)	7.3(16.1)c	6.1(13.5)1	5.1(11.2)
California	8864(19500)	23.7(52.2)	11.9(26.2)c	11.8(26.0)1	7.0(15.4)
California	14045(30900)	15.6(34.3)	10.0(22.0)u+c	5.6(12.4)† u+c	9.3(20.4)
California	15682(34500)	18.0(39.6)	9.5(20.9)† u+c	8.5(18.8)u+c	9.9(21.8)

* Gillum, Hughs, Rakoff, and Wright, 1980.
† Not measured, a calculated estimate, c = cyclones, 1 = lint cages, u = unifilter. Some of the lint-system exhausts may not have been going into the unifilter.
‡ Using 682 kg(1500 1b) of seed cotton/bale of cotton lint.
§ From process weight table for approximate state.

treatments would have to be very large before the Method 5 particulate concentration measurement would be significant.

Secondary cyclone collection efficiency was determined from the sum of the secondary cyclone emission rate and the trash collected by the secondary cyclone divided into the trash collected by the secondary cyclone. The measurement of the trash collected by the secondary cyclone had a much lower coefficient of variation than did the measurement of emission rate from the secondary cyclone. Due to the combination of the two measurements to determine the efficiency of collection by the secondary cyclone, the differences in secondary-cyclone collection efficiency between treatments would not have to be as great as the particulate concentration measurement to be statistically significant.

APPLICATION

Table 3 presents the results of EPA emission tests in several western gins. The first three gins in the table were equipped with cyclone collectors on all seed-cotton system exhausts and lint cages on all lint-system exhausts. In the last two gins, most of the exhausts went to a unifilter. The particulates caught by the unifilter were then fed through a fan and finally trapped by a set of cyclone collectors. This set of cyclone collectors after the unifilter became, in effect, the primary particulate collectors since all the particulates collected by the unifilter were put back into an air stream and recollected by a set of cyclones.

The authors do not consider the test data for the last two gins shown in Table 3 to be valid particulate emission source data but is included for reference only. The reasons the authors do not consider the data valid are that in both cases (a) the number of sample measurements taken were less than the number required by EPA Method 5 sampling procedure for a valid test and (b) all exhausts were not sampled, some were only estimated. In any case, the way the unifilters were being used in both ginning systems resulted in double handling of trash and probably higher real emission rates than if the trash had just been collected initially with cyclone collectors. McCaskill and Wesley (1976), the original developers of the unifilter, show that the unifilter with a foam media and a small-diameter cyclone both have a trash collection efficiency of about 99.5 percent. This means that both should emit the same amount of particulates to the atmosphere for a given operating condition. Having the same collection efficiency further implies that if a particulate collection system utilizing cyclones as primary collectors can benefit from using secondary cyclone collectors, then a system using a combination of cyclones and a unifilter can also show the same benefit.

Gillum et al. (1980) indicated that the installation of cyclones on lint-system exhausts would reduce emissions from those exhausts by more than 90 percent. Reducing lint-system emissions by 90 percent still would not allow the gins in Table 3 to meet the total allowable emissions requirement because of the amount of emissions from their seed-cotton systems. The data in Tables 1 and 2 indicate that the installation of cyclones as secondary collectors after the primary cyclone collectors should reduce emissions by about 50 percent. If such cyclones were added as secondary collectors on the seed-cotton systems listed in Table 3, in addition to installing cyclones on the lint systems, all of those gins measured should come closer to meeting their total allowable emissions requirement. Additional cyclones would cause increased pressure drops in the seed-cotton and lint systems. This pressure drop would have to be offset with increased fan horsepower.

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