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DUST COLLECTION EFFICIENCY OF OVER-SIZED COTTON GIN CYCLONES

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Abstract

Three model cyclones were tested at four trash loading rates. Cyclone collection efficiency for over-sized cyclones was slightly less than the efficiency of a standard-sized cyclone, averaging 98.63 and 98.42%, respectively. Cyclone collection efficiency increased as trash loading rate increased, with average values ranging from 97.93% at a trash loading rate of 0.88 grain/ft^3 (2 g/m^3) to an average of 98.95% at a trash loading rate of 7.0 grain/ft^3 (16 g/m^3). Cyclone pressure drops for over-sized cyclones were much less than pressure drops for standard-sized cyclones, with the pressure drop in an over-sized cyclone averaging 28% of the value for pressure drop in a standard-sized cyclone. The authors concluded that, with their lower pressure drop, over-sized cyclones are more compatible than standard-sized cyclones on airflow systems that use axial-flow fans. Collection efficiency of over-sized cyclones was just slightly less than that of standard-sized cyclones.

Introduction

Air quality regulations in some areas are requiring that devices such as screen baskets on lint cleaning systems be replaced with devices that remove a much larger percentage of suspended dust particles from the conveying air stream. Many of these air streams use axial-flow fans which are limited in the amount of air pressure against which they can operate. If a standard-sized cyclone were used to replace the screen basket (or other less efficient device), airflow rates would drop significantly due to the large increase in system pressure. By installing a cyclone with a larger diameter than the standard size (over-sized cyclone), the reduction in airflow would be much less than if a standard-sized cyclone were used, since the additional pressure would not be as great. Thus, using an over-sized cyclone would avoid replacing the axial-flow fans on most systems with more expensive centrifugal fans. However; an over-sized cyclone (with a lower air inlet velocity) is likely to remove a somewhat smaller percentage of dust particles from the air than would a standard-sized cyclone, but should certainly remove a larger percentage of dust particles than would a screen basket (or other less efficient device) (Funk, et al., 2000 and Gillum and Hughs, 1983).

Objectives

The objectives of this study were:

- to determine and compare the collection efficiency and pressure drop of a model standard-sized 1D3D cyclone (with the recommended inlet air velocity of 3200 ft/min or 16.3 m/s) to that of modeled over-sized 1D3D and 2D2D cyclones with twice the area (42% larger diameter) and with an inlet air velocity that was half of the recommended value.

Materials and Methods

Tests were conducted using the model cyclone test stand at the USDA, Agricultural Research Service, Southwestern Cotton Ginning Research Laboratory in Mesilla Park, NM. Three model cyclones were used in this study including a standard-sized 1D3D cyclone (12 inch or 0.305 m diameter), an over-sized 1D3D cyclone (17 inch or 0.432 m diameter), and a similarly over-sized 2D2D cyclone (Table 1). Both of the 1D3D cyclones had the 2D2D style of air inlets rather than the conventional 1D3D style of air inlet.

Gin trash used in this study was collected from the unloading fan separator screen and contained a small amount of lint fiber, as well as leaf trash and fine dust. The particle size distribution of this trash was appropriate for the model tests conducted in this study (Table 2).

Four trash loading rates were used, including initial average cyclone inlet concentrations of 0.875, 1.75, 3.5, and 7.0 grain/ft^3 (2, 4, 8, and 16 g/m^3). A randomized complete block experimental design was used with four replicates serving as the blocks. Within each block were 12 test runs (3 cyclones x 4 trash loading rates) conducted in a different random order for each block.

Each test run was 2 minutes long. Prior to each test, gin trash was measured and distributed evenly along a cloth conveyor belt that was driven by a variable-speed motor (Figure 1). At the start of each test, the variable speed fan was adjusted to give the desired air velocity to the cyclone inlet. During the test, trash was pulled into the system from the moving conveyor belt by the fan, then forced into the selected cyclone. Dust removed by the cyclone was collected in a bucket sealed tightly to the bottom of the cyclone cone. Exhaust air was pulled from the top of the cyclone by a second fan. Dust in the cyclone exhaust was collected on a fiberglass filter with an exposed area of 23.0 x 23.0 inches (58.4 x 58.4 cm). The second fan was necessary to overcome the additional flow resistance of the filter.

Each test used a new fiberglass filter that was conditioned at 70 ^{o}F (21 ^{o}C) and 50 % relative humidity prior to being initially weighed. After each test, the used filter was carefully folded and placed in a sealed envelope, then returned to the conditioning chamber for at least 48 hours before determining the final weight. Dust in the cyclone exhaust was calculated from the difference in the two weights. Dust removed by the cyclone was determined for each test by the change in weight of the catch bucket.

A Venturi meter, installed between the variable speed fan and the cyclone, was used to determine airflow through the cyclone (Figure 1). The pressure drop was recorded at 1 second intervals during the test. The pressure drop was also monitored, and fan speed adjusted to keep the airflow within 2% of the desired level of 400 ft^3/min (0.19 m^3/s). A Pitot tube, installed in the duct between the filter and the second fan, was used to determine airflow from the cyclone exhaust. The pressure difference for the Pitot tube was recorded at 1 second intervals during the test. The pressure difference was also monitored, and fan throttle opening manually adjusted to keep the airflow within 5% of the desired level. Airflow through each segment of the system was the same.

Pressure drops through the cyclone and across the filter were recorded at 1 second intervals during the test, as were temperatures at each of the airflow measuring sites. Room air temperature, barometric pressure, and relative humidity were determined once during each test. Cyclone efficiency was computed by dividing the weight of trash collected by the filter by the sum of the weights of trash collected on the filter and in the trash bucket and expressing the result as a percentage. This method was used to reduce errors that may have been caused by dust accumulation in the system, as discussed in the results section below.

Results and Discussion

Cyclone collection efficiency for the over-sized cyclones was slightly less than the efficiency of the standard-sized cyclone (Figure 2). Collection efficiency for the standard-sized 1D3D cyclone averaged 98.63% which was significantly more than that for the over-sized cyclones which averaged 98.44% and 98.40% for the 1D3D and 2D2D designs, respectively (Table 3). Although the over-sized 1D3D cyclone averaged slightly better efficiency than the over-sized 2D2D cyclone, the difference was not statistically significant. Comparing the average efficiencies of the standard-sized and over-sized cyclones, use of an over-sized cyclone would allow about 14% more trash to escape into the cyclone exhaust than the standard-sized cyclone. However, use of an over-sized cyclone with 42% larger diameter would be a definite improvement over use of a screen basket (or other less efficient device).

Cyclone collection efficiency increased as trash loading rate increased (Figure 2). Collection efficiency ranged from an average of 97.93% at a trash loading rate of 0.88 grain/ft^3 (2 g/m^3) to an average of 98.95% at a trash loading rate of 7.0 grain/ft^3 (16 g/m^3, Table 3). The differences in collection efficiency were statistically significant between each of the trash loading rates studied. Estimates from a production gin indicated that trash loading rates from the first lint cleaner typically are in the range of 1.8 to 3.0 grain/ft^3 (4 to 7 g/m^3) and that trash loading rates from the second lint cleaner typically are in the range of 0.9 to 1.5 grain/ft^3 (2 to 3.5 g/m^3). Thus, results from this model study should apply to trash systems from first and second stage lint cleaners. Trash loading rates from battery condensers would be considerably less than 0.9 grain/ft^3 (2 g/m^3) and collection efficiency for a cyclone on a battery condenser could be lower than the values determined in this study.

Cyclone pressure drop results were nearly as expected (Figure 3). The over-sized 1D3D cyclone had an average pressure drop of 0.97 inches w.c. (242 Pa). This pressure drop was 28% of the average value for the standard-sized cyclone (3.43 inches w.c. or 854 Pa). The difference was close to the theoretical value of 25%, which was computed based on the air velocity in the over-sized cyclone being 50% of that in the standard-sized cyclone (Parnell et al., 1994). The over-sized 2D2D cyclone had an average pressure drop of 0.65 inches w.c. (162 Pa). This pressure drop was 67% of the average value for the 1D3D cyclone of the same size. Theoretical pressure drops for 2D2D cyclones are less than those for 1D3D cyclones, all other factors being equal. Pressure drops measured in this study are lower than often encountered at other ginning locations because of the higher elevation of the lab and resulting lower air density. The average air density for these tests was 0.067 lb/ft^3 (1.07 kg/m^3).

A shortcoming of the test apparatus and procedures is the fact that dust can accumulate on the conveyor belt and on the inside of the equipment. At times the accumulated dust may flake off and be re-introduced into the air stream. A particularly critical section of the apparatus is the duct section from the cyclone exhaust to the filter (Figure 1). This section of duct was equipped with two hoses approximately 3.3 ft (1 m) in length. These hoses were connected to a compressed air source. At the end of each test run, valves to each of these hoses were opened for 10 seconds while the fan continued to run. During this time, the hoses would knock against the duct walls and reduce the amount of dust that accumulated there. Overall, 98.5% of the dust fed into the system was collected either in the catch bucket or on the filter. Thus, 1.5% of the dust was not accounted for. The amount of dust collected for each test was fairly consistent, ranging from a low of 96% to a high of 102%. The low mean square error for the test also indicated that dust accumulation did not significantly affect the test results.

This study measured and reported differences in collection efficiency and pressure drop for standard-sized and over-sized cyclones. The lower pressure drop of an over-sized cyclone means that an axial-flow fan may possibly be used with it, thus avoiding the cost of replacing an existing axial-flow fan with a centrifugal fan. Other factors to consider when comparing the two sizes of cyclones include one advantage - the larger size of an over-sized cyclone makes it less susceptible to choking than a standard-sized cyclone. There is also a disadvantage - the larger size of an over-sized cyclone makes it more costly to manufacture and requires more space than would be needed for a standard-sized cyclone.

Summary and Conclusions

Air quality regulations in some areas are requiring that devices such as screen baskets on lint cleaning systems be replaced with more efficient air cleaners. Cyclones are a viable option, but the large pressure drop in standard-sized cyclones may prevent them from being used on lint cleaning systems which use axial-flow fans. This study was conducted to determine the effectiveness of over-sized cyclones which would have a much lower pressure drop than that of a standard-sized cyclone.

Tests were conducted using three model cyclones at four trash loading rates. Cyclone collection efficiency for over-sized cyclones was slightly less than the efficiency of a standard-sized cyclone, averaging 98.63 and 98.42%, respectively. Cyclone collection efficiency increased as trash loading rate increased, with average values ranging from 97.93% at a trash loading rate of 0.88 grain/ft^3 (2 g/m^3) to an average of 98.95% at a trash loading rate of 7.0 grain/ft^3 (16 g/m^3). Cyclone pressure drops for over-sized cyclones were much less than pressure drops for standard-sized cyclones, with the pressure drop in an over-sized cyclone averaging 28% of the value for pressure drop in a standard-sized cyclone.

Based on the results from this study, the authors conclude that, with their lower pressure drop, over-sized cyclones are more compatible than standard-sized cyclones on airflow systems that use axial-flow fans. Collection efficiency of over-sized cyclones was just slightly less than that of standard-sized cyclones.

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Table 1. A comparison of the construction of the 3 cyclones used in this study.

Cyclone	Standard 1D3D	Over-sized 1D3D	Over-sized 2D2D
Diameter	12 inches (0.305 m)	17 inches (0.432 m)	17 inches (0.432 m)
Body/cone style	1D3D	1D3D	2D2D
Air inlet style	2D2D	2D2D	2D2D
Air inlet dimensions (width x height)	3 x 6 inches (0.076 x 0.153 m)	4.25 x 8.5 inches (0.108 x 0.216 m)	4.25 x 8.5 inches (0.108 x 0.216 m)
Average air speed at inlet	3200 ft/min (16.3 m/s)	1600 ft/min (8.1 m/s)	1600 ft/min (8.1 m/s)
Terminal cone diameter (D/4)	3 inches (0.076 m)	4.25 inches (0.108 m)	4.25 inches (0.108 m)
Cyclone top style	Flat	Flat	Flat
Cyclone air exhaust diameter (D/2)	6 inches (0.153 m)	8.5 inches (0.216 m)	8.5 inches (0.216 m)
Distance exhaust extends into cyclone body (5/8D)	7.5 inches (0.191 m)	10.6 inches (0.270 m)	10.6 inches (0.270 m)

Table 2. Sieve analysis of gin trash introduced into the cyclones.*

Sieve no. (U.S. Series)	Size range (microns)	Average catch, % 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

* Data from Hughs and Baker (1997).

Table 3. Average cyclone efficiencies for the three cyclone designs and the four trash loading rates and the statistical results.

Source	Treatment	Mean cyclone efficiency, %	Probability > F
Cyclone design	Standard 1D3D	98.63[a]	0.0056
	Over-sized 1D3D	98.44[b]	
	Over-sized 2D2D	98.40[b]	
Trash loading rate	0.88 grain/ft^3	97.93[d]	<0.0001
	1.75 grain/ft^3	98.45[c]	
	3.5 grain/ft^3	98.63[b]	
	7.0 grain/ft^3	98.95[a]	
Mean square error		0.047	

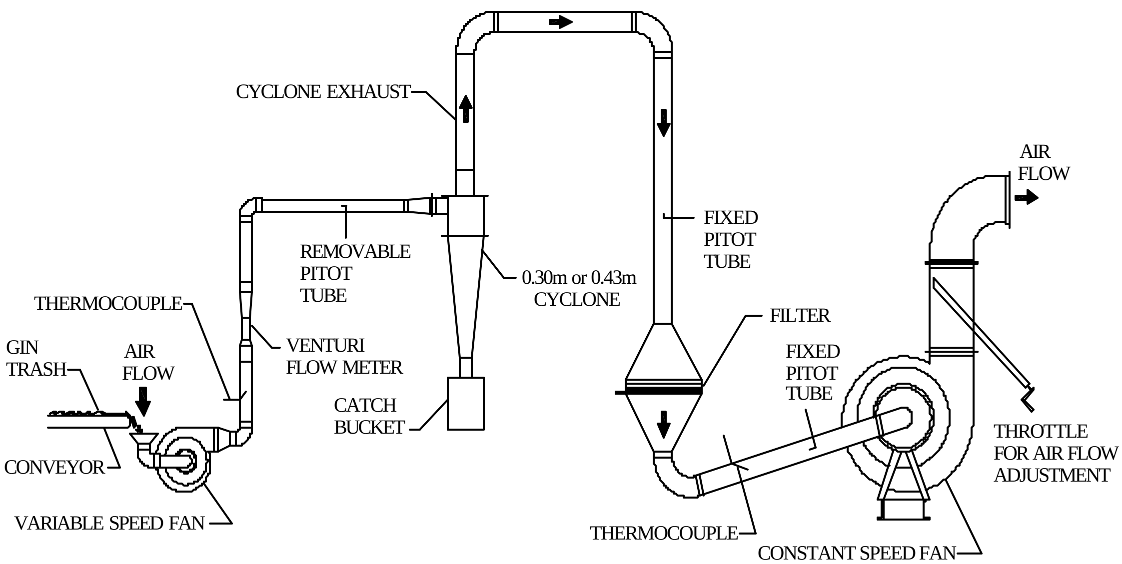

Figure 1. Apparatus used to perform tests.

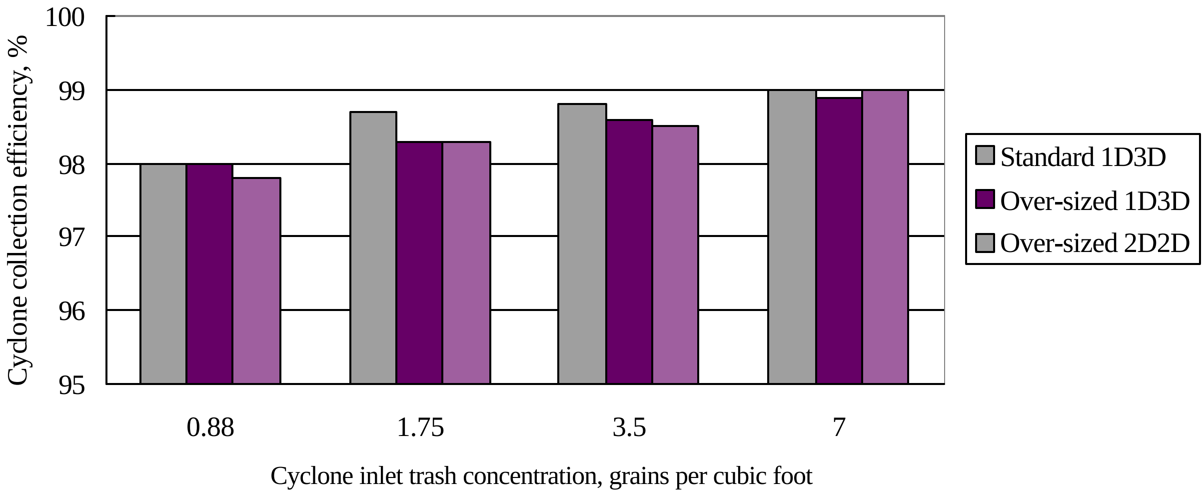

Figure 2. Average cyclone collection efficiencies for the cyclones used in this study. Each bar represents an average of 4 tests for each of the four trash loading rates.

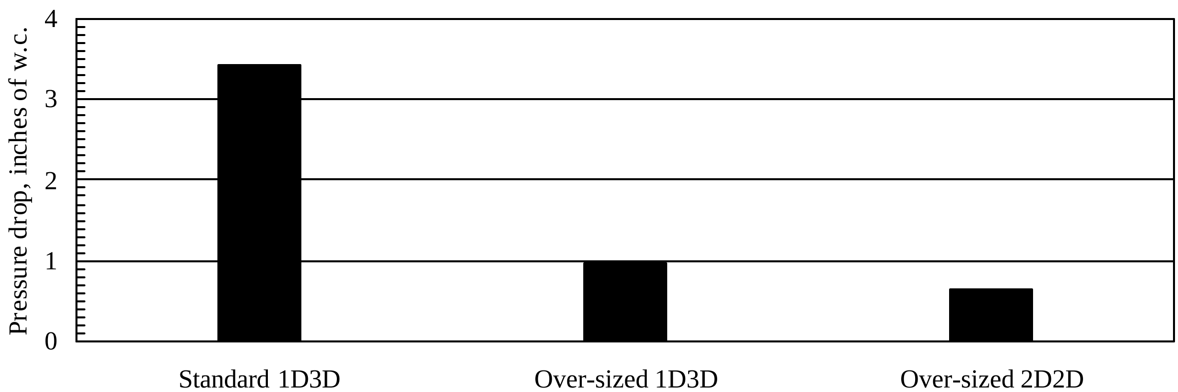

Figure 3. Average pressure drop for the cyclones used in this study. Each bar represents an average of 16 tests over the four trash loading rates.