

ENGINEERING AND GINNING

First Stage Lint Cleaning System Total Particulate Emission Factors and Rates for Cotton Gins: Method 17

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ABSTRACT

This report is part of a project to characterize cotton gin emissions from the standpoint of stack sampling. The impetus behind this project was the urgent need to collect additional cotton gin emissions data to address current regulatory issues. A key component of this study was focused on Environmental Protection Agency (EPA) total particulate emission factors. There is no total particulate emission factor published for 1st stage lint cleaning systems in the 1996 EPA AP-42. The current AP-42 factor represents 1st and 2nd stage lint cleaning systems combined. The objective of this study was to collect total particulate emission factor data for 1st stage lint cleaning systems from cotton gins located in regions across the cotton belt using EPA-approved stack sampling methodology. The project plan included sampling seven cotton gins. Key factors for selecting specific cotton gins included: 1) facility location, 2) production capacity, 3) processing systems, and 4) abatement technologies. Four gins with 1st stage lint cleaning system exhausts that were not combined with 2nd stage lint cleaning system exhausts were sampled. The average production rate during testing for the four gins was 25.7 bales/h. The average 1st stage lint cleaning system total particulate emission factor based on four tests (12 total test runs) was 0.070 kg/227-kg bale (0.155 lb/500-lb bale). The 1st stage lint cleaning system emission rate test averages ranged from 0.67 to 3.56 kg/h (1.49-7.84 lb/h).

U.S. Environmental Protection Agency (EPA) emission factors were published in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996b). These factors were assigned a rating from A (excellent) to E (poor) that is used to assess the quality of the data being referenced. In the 1996 EPA AP-42, there are emission factors for total particulate listed for 11 common cotton gin systems. The EPA emission factor quality ratings for these data are extremely low. Cotton gin data received these low ratings because they were collected almost exclusively from a single geographical region, the far western U.S. (EPA, 1996a). The AP-42 data are limited in that some systems commonly used in cotton gins are not represented or are combined with another system under a single emission factor (e.g., 1st and 2nd stage lint cleaning are represented by lint cleaners). Cotton ginners' associations across the cotton belt, including the National, Texas, Southern, Southeastern, and California associations, agreed that there was an urgent need to collect additional cotton gin emissions data to address current regulatory issues. Working with the cotton ginning associations across the country, state and federal regulatory agencies, Oklahoma State University, and USDA-Agricultural Research Service (ARS) researchers developed a proposal and sampling plan that was initiated in 2008 to address this need for additional data. This report is part of a series that details cotton gin emissions measured by stack sampling. Each manuscript in the series addresses a specific cotton ginning system. The systems covered in the series include: unloading, 1st stage seed-cotton cleaning, 2nd stage seed-cotton cleaning, 3rd stage seed-cotton cleaning, overflow, 1st stage lint cleaning, 2nd stage lint cleaning, combined lint cleaning, cyclone robber, 1st stage mote, 2nd stage mote, combined mote, mote cyclone robber, mote cleaner, mote trash, battery condenser, and master trash. This report focuses on total particulate emissions from 1st stage lint cleaning systems.

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There are no 1996 EPA AP-42 emission factors for 1st stage lint cleaning systems (EPA, 1996b). First stage lint cleaning systems would be similar to lint cleaners listed in AP-42, but the AP-42 factor represents 1st and 2nd stage lint cleaning systems combined. The AP-42 average total particulate emission factor for combined lint cleaning (1st and 2nd stage lint cleaning systems were combined) was 0.26 kg (0.58 lb) per 217-kg [480-lb] equivalent bale with a range of 0.041 to 1.0 kg (0.09-2.3 lb) per bale (EPA, 1996a, b). This average and range was based on six tests conducted in one geographical location. The EPA emission factor quality rating was D, which is the second lowest possible rating (EPA, 1996a).

Seed-cotton is a perishable commodity that has no real value until the fiber and seed are separated (Wakelyn et al., 2005). Cotton must first be processed or ginned at the cotton gin to separate the fiber and seed, producing 227-kg (500-lb) bales of marketable cotton fiber. Cotton ginning is considered an agricultural process and an extension of the harvest by several federal and state agencies (Wakelyn et al., 2005). Although the main function of the cotton gin is to remove the lint fiber from the seed, many other processes also occur during ginning, such as cleaning, drying, and packaging the lint. Pneumatic conveying systems are the primary method of material handling in the cotton gin. As material reaches a processing point, the conveying air is separated and emitted outside the gin through a pollution control device. The amount of dust emitted by a system varies with the process and the condition of the material in the process.

Cotton ginning is a seasonal industry lasting from 75 to 120 days, depending on the size and condition of the crop. Although the trend for U.S. cotton production remained generally flat at approximately 17 million bales per year during the last 20 years, annual production varied greatly for various reasons, including climate and market pressure (Fig. 1). The number of active gins in the U.S. has not remained constant, steadily declining to fewer than 700 in 2011. Consequently, the average volume of cotton handled by each gin has risen and gin capacity has increased to an average of approximately 25 bales per hour across the U.S. cotton belt (Valco et al., 2003, 2006, 2009, 2012).

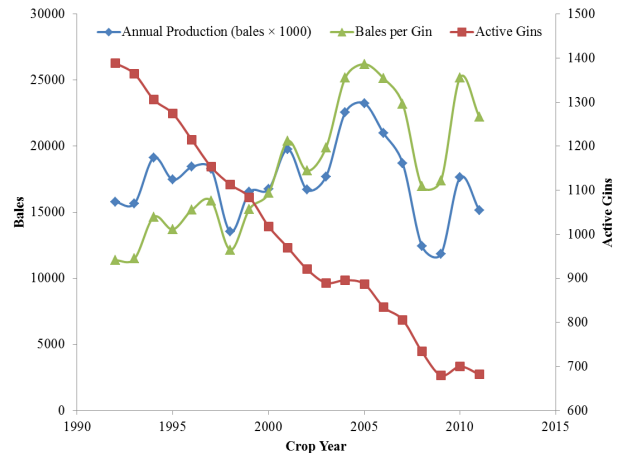


Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

The typical cotton gin facility includes: unloading system, dryers, seed-cotton cleaners, gin stands, overflow collector, lint cleaners, battery condenser, bale packaging system, and trash handling systems (Fig. 2); however, the number and type of machines and processes varies. Each of these systems serves a unique function with the ultimate goal of “ginning” the cotton to produce a marketable product. Raw seed-cotton harvested from the field is compacted into large units called “modules” for delivery to the gin. The unloading system removes seed-cotton either mechanically or pneumatically from the module feed system and conveys the seed-cotton to the seed-cotton cleaning systems. Seed-cotton cleaning systems dry the seed-cotton and remove foreign matter prior to ginning. Ginning systems also remove foreign matter and separate the cotton fiber from the seed. Lint cleaning systems further clean the cotton lint after ginning. The battery condenser and packaging systems combine lint from the lint cleaning systems and compress the lint into dense bales for easy transport. Gin systems produce some type of by-product or trash, such as rocks, soil, sticks, hulls, leaf material, and short or tangled immature fiber (motes), as a result of processing the seed-cotton or lint. These streams of by-products must be removed from the machinery and handled by trash collection systems. These trash systems typically further process the by-products (e.g., mote cleaners) and/or consolidate the trash from the gin systems into a hopper or pile for subsequent removal.

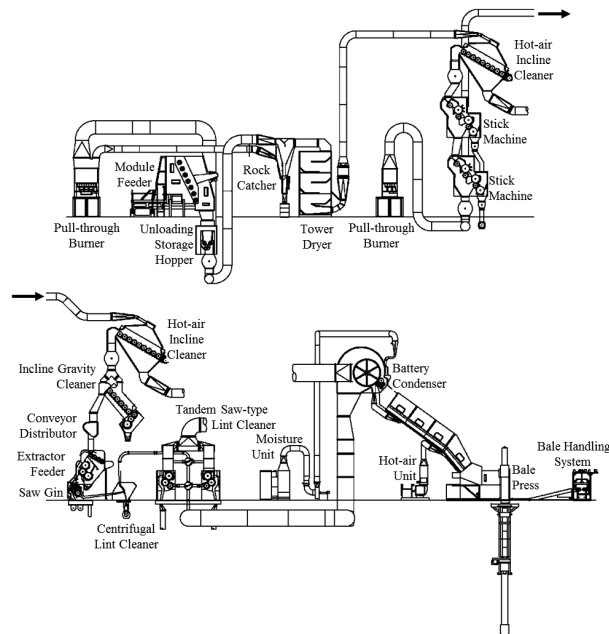


Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

Cotton lint is cleaned in the lint cleaning systems (Fig. 3). In the typical 1st and 2nd stage lint cleaning system, cotton fiber or lint is pneumatically conveyed from the gin stands, through a centrifugal lint cleaner, to the 1st stage lint cleaners (cotton gins typically split the pre-cleaned seed-cotton among multiple, parallel gin stand/lint cleaning lines that are recombined at packaging) for further foreign matter removal. The lint is removed from the airstream with a rotating, screened separator drum and directed into the lint cleaner feed works. Lint cleaners remove fine trash, seed, and some lint. The material removed by lint cleaners is referred to as “motes”. Lint is directed from the lint cleaner to either a subsequent stage of lint cleaning or into the bale packaging system. A 2nd stage of lint cleaning is sometimes used and is essentially identical to the 1st stage. The airstream from the lint cleaner screened separators continues through a centrifugal fan to one or two particulate matter (PM) abatement cyclones. Some lint cleaning systems utilize a vane-axial fan, but these systems typically do not have cyclones and exhaust directly to ambient air. The pneumatic systems of the two lint cleaning stages might share a fan and abatement device or might operate independently, as is the case with 1st stage lint cleaning systems. The material handled by the lint cleaner cyclones typically includes small trash and particulate, and lint fibers (Fig. 4).

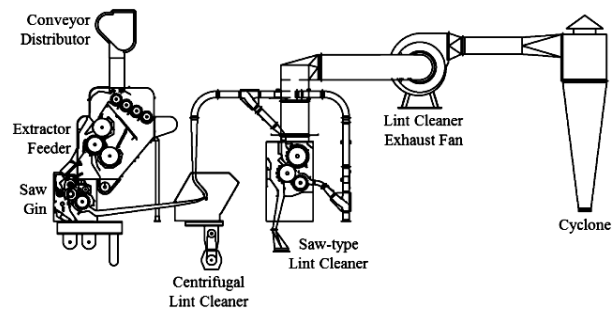


Figure 3. Typical cotton gin 1st stage lint cleaning system layout (Courtesy Lummus Corporation, Savannah, GA).



Figure 4. Photograph of typical trash captured by the 1st stage lint cleaning cyclones.

Cyclones are the most common PM abatement devices used at cotton gins. Standard cyclone designs used at cotton ginning facilities are the 2D2D and 1D3D (Whitelock, et al., 2009). The first D in the designation indicates the length of the cyclone barrel relative to the cyclone barrel diameter and the second D indicates the length of the cyclone cone relative to the cyclone barrel diameter. A standard 2D2D cyclone (Fig. 5) has an inlet height of D/2 and width of D/4 and design inlet velocity of 15.2 ± 2 m/s (3000 ± 400 fpm). The standard 1D3D cyclone (Fig. 5) has the same inlet dimensions as the 2D2D or might have the original 1D3D inlet with height of D and width D/8. Also, it has a design inlet velocity of 16.3 ± 2 m/s (3200 ± 400 fpm).

The objective of this study was to collect total particulate emission factor data for 1st stage lint cleaning systems with cyclones for emissions control at cotton gins located in regions across the cotton belt based on EPA-approved stack sampling methodologies.

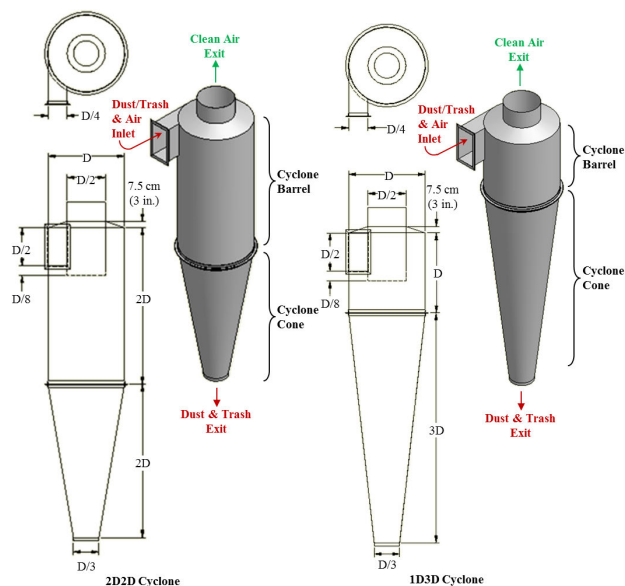


Figure 5. 2D2D and 1D3D cyclone schematics.

METHODS

Two advisory groups were established for this project. The industry group consisted of cotton ginning industry leaders and university and government researchers. The air quality group included members from state and federal regulatory agencies, and university and government researchers. Both groups were formed to aid in project planning, gin selection, data analyses, and reporting. The project plan was described in detail by Buser et al. (2012).

Seven cotton gins were sampled across the cotton belt. Key factors for selecting specific cotton gins included: 1) facility location, 2) production capacity, 3) processing systems, and 4) abatement technologies. Operating permits, site plans, and aerial photographs were reviewed to evaluate potential sites. On-site visits were conducted on all candidate gins to evaluate the process systems and gather information including system condition, layout, capacities, and standard operation. Using this information, several gins from each selected geographical region were selected and prioritized based on industry advisory group discussions. Final gin selection from the prioritized list was influenced by crop limitations and adverse weather events in the region.

Based on air quality advisory group consensus, EPA Method 17 (CFR, 1978) was used to sample the 1st stage lint cleaning system at each gin. Method 17 was selected over Method 5 (CFR, 1987) because of the relatively low stack temperatures found at cotton gins. Method 5 requires a heated glass probe and

filter holder to maintain the sampled gas temperature of 120°C (248°F). Key benefits of using Method 17 over Method 5 are where particulate concentrations are independent of temperature and the sampled gas contains no liquid droplets or is not saturated with water vapor, the heating systems can be eliminated and sampling can occur at stack temperature with an in-stack filter. Methodology for sampling total particulate called for withdrawing particulate-laden stack gas isokinetically (the velocity of the gas entering the sampler was equal to the velocity of the gas in the stack) through a button-hook nozzle and then collecting particles on an in-stack filter (Fig. 6). The methods for retrieving the filter and conducting acetone washes of the sampling nozzle are described in Method 17 (CFR, 1978). The mass of particulate on the filter and in the nozzle wash was determined by gravimetric analyses. The total particulate mass was determined by summing the mass of particulates on the filter and the front half wash. Stack gas temperature and moisture content were also measured using EPA Method 17.

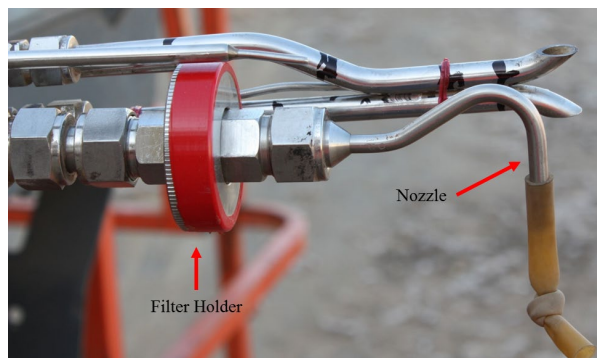


Figure 6. EPA Method 17 total particulate button-hook nozzle and in-stack filter holder photograph.

Only one stack from each 1st stage lint cleaning system was tested. For systems with multiple stacks, it was assumed that emissions from each stack of the system were equivalent. The total particulate emissions for the system were calculated by multiplying the measured emission rates by the total number of cyclones used to control the process tested (EPA, 1996a). To obtain reliable results, the same technician from the same certified stack sampling company (Reliable Emissions Measurements, Auberry, CA), trained and experienced in stack sampling cotton gins, conducted all the tests at all the cotton gins.

All stack sampling equipment was purchased from Apex Instruments (Fuquay-Varina, NC) and met Method 17 specifications. The sampling media were 47-mm Zeflour filters (Pall Corporation, Port

Washington, NY) and the sample recovery and analytical reagent was American Chemical Society certified acetone (A18-4, Fisher Chemical, Pittsburgh, PA; assay $\geq 99.5\%$). Filters, wash tubs, and lids were pre-labeled and preweighed and stored in sealed containers at the USDA-ARS Air Quality Lab (AQL) in Lubbock, TX, and then transported to each test site. Prior to testing, the technician calibrated all sampling equipment according to EPA Method 17.

Each cyclone selected for testing was fitted with a cyclone stack extension that incorporated two sampling ports (90° apart) and airflow straightening vanes to eliminate the cyclonic flow of the air exiting the cyclone (Fig. 7). The extensions were designed to meet EPA criteria (EPA, 1989) with an overall length of 3 m (10 ft) and sampling ports 1.2-m (48-in) downstream from the straightening vanes and 0.9-m (36-in) upstream from the extension exit.



Figure 7. Schematic and photographs of stack extensions with sampling port and straightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

The tests were conducted by the technician in an enclosed sampling trailer at the base of the cyclone bank (Fig. 8). Sample retrieval, including filters and nozzle acetone washes, was conducted according to Method 17. After retrieval, filters were sealed in individual Petri dishes and acetone washes were dried on-site in a conduction oven at 49°C (120°F) and then

sealed with preweighed lids and placed in individual plastic bags for transport to the AQL in Lubbock, TX for gravimetric analyses. During testing, bale data (ID number, weight, and date/time of bale pressing) were either manually recorded by the bale press operator or captured electronically by the gin's computer system for use in calculating emission factors in terms of kg/227-kg bale (lb/500-lb bale). Emission factors and rates were calculated in accordance with Method 17 and ASAE Standard S582 (ASABE, 2005).

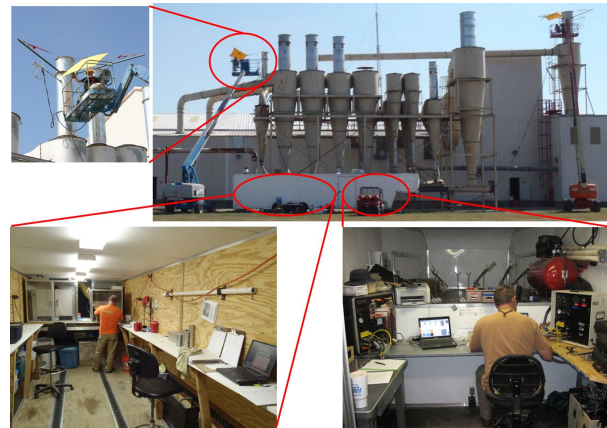


Figure 8. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

All laboratory analyses were conducted at the AQL. All filters were conditioned in an environmental chamber ($21 \pm 2^\circ\text{C}$ [$70 \pm 3.6^\circ\text{F}$]; $35 \pm 5\%$ RH) for 48 h prior to gravimetric analyses. Filters were weighed in the environmental chamber on a Mettler MX-5 microbalance (Mettler-Toledo Inc., Columbus, OH; $1 \mu\text{g}$ readability and $0.9 \mu\text{g}$ repeatability) after being passed through an antistatic device. The MX-5 microbalance was leveled on a marble table and housed inside an acrylic box to minimize the effects of air currents and vibrations. To reduce recording errors, weights were electronically transferred from the microbalance directly to a spreadsheet. Technicians wore latex gloves and a particulate respirator mask to avoid contamination. AQL procedures required that each sample be weighed three times. If the standard deviation of the weights for a given sample exceeded $10 \mu\text{g}$, the sample was reweighed. Gravimetric procedures for the acetone wash tubs were the same as those used for filters.

In addition to gravimetric analyses, each sample was visually inspected for unusual characteristics, such as cotton lint content or extraneous material. Digital pictures were taken of all filters and washes

for documentation purposes. After the laboratory analyses were completed all stack sampling, cotton gin production, and laboratory data were merged.

Four of the seven gins (A, B, C, and F) sampled had 1st stage lint cleaning systems that were not combined with 2nd stage lint cleaning systems. The 1st stage lint cleaning systems sampled were typical for the industry. Three gins (A, B, and F) had similar system configurations (Fig. 9). For these systems, the cotton fiber or lint material was pneumatically conveyed from the gin stand, through a centrifugal lint cleaner where some larger trash was ejected. The air/material then proceeded to the 1st lint cleaner. At the lint cleaner, the lint was separated from the conveying air by a screened separator and fed into the lint cleaner. The airstream then passed through a fan and exhausted through one or more cyclones. The gin C 1st stage lint cleaning system was similar to the other three gins, except there were no centrifugal lint cleaners between the gin stands and 1st lint cleaners (Fig. 10).

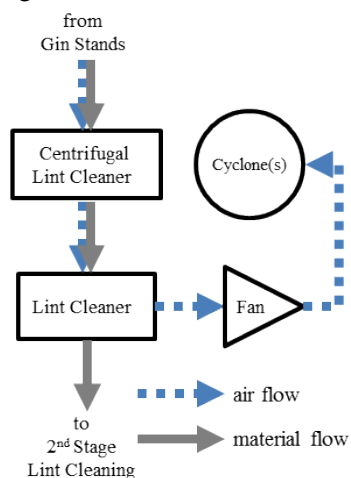


Figure 9. Schematic of 1st stage lint cleaning system with centrifugal lint cleaner (gins A, B, and F).

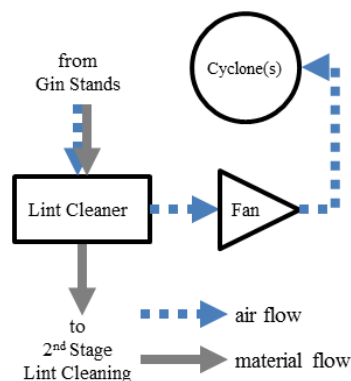


Figure 10. Schematic of 1st stage lint cleaning system without centrifugal lint cleaner (gins C).

All 1st stage lint cleaning systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were some cyclone design variations among the gins (Table 1 and Fig. 11). Gin C split the system exhaust flow between two cyclones in a dual configuration (side by side as opposed to one behind another). The system airstream for gins A, B, and F was exhausted through a single cyclone. Inlets on all the 1st stage lint cleaning cyclones were 2D2D type, except the cyclones at gin C that had 1D3D inlets with the duct in line with midpoint between the top and bottom of the inlet. Expansion chambers were present on 1st stage lint cleaning cyclones at gins A and B, whereas gins C and F had standard cones. The cyclones tested at gins C and F had cyclone robber systems pulling airflow from their trash exits. This configuration helps remove lint and other trash from the cyclone that could otherwise circulate near the trash exit at the bottom of the cone for a period of time before dropping out. All of the cyclone variations outlined above, if properly designed and maintained, are recommended for controlling cotton gin emissions (Whitelock et al., 2009).

Table 1. Abatement device configuration^z for 1st stage lint cleaning systems tested.

Gin	Cyclone Type	Inlet Design ^y	Systems per Gin	Cyclones per Gin	Configuration	Cone Design	Trash Exit ^x
A	1D3D	2D2D	3	3	single	expansion chamber	auger
B	1D3D	2D2D	4	4	single	expansion chamber	auger
C	1D3D	center-line 1D3D	2	4	dual	standard	robber
F	1D3D	2D2D	4	4	single	standard	robber

^z Figures 5 and 11

^y Center-line 1D3D inlet has duct in line with midpoint between the top and bottom of the inlet

^x Systems to remove material from cyclone trash exits: auger = enclosed, screw-type conveyor, robber = pneumatic suction system

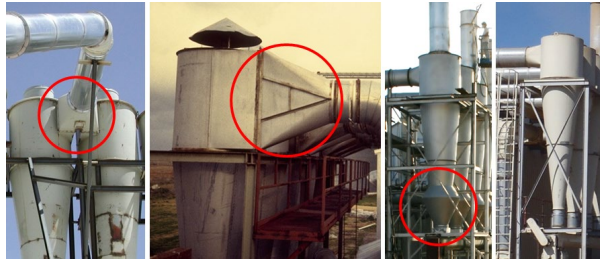


Figure 11. Cyclone design variations for the tested systems (left to right): dual configuration that splits flow between identical 1D3D cyclones with 2D2D inlets; 1D3D cyclone with a center-line 1D3D inlet; 1D3D cyclone with 2D2D inlet and expansion chamber on the cone; 1D3D cyclone with 2D2D inlet and standard cone.

RESULTS

Table 2 shows the test parameters for each Method 17 test run for the 1st stage lint cleaning systems sampled at the four gins. The system average ginning rate for the four gins was 25.7 bales/h and the test average ginning rate at each gin ranged from 20.1 to 34.2 bales/h (based on 227-kg [500-lb] equivalent bales). The capacity of gins sampled was representative of the industry average, approximately 25 bales/h. The 1D3D cyclones were all operated with inlet velocities within design criteria, 16.3 ± 2 m/s (3200 ± 400 fpm), except the test runs at gin C that were outside the design range due to limitations in available system adjustments.

There are criteria specified in EPA Method 17 for test runs to be valid for total particulate measurements (CFR, 1978). Isokinetic sampling must fall within the EPA defined range of 100 ± 10%. All tests met the isokinetic criteria (Table 2). The stack gas temperatures ranged from 19 to 39°C (66-102°F) and moisture content ranged from 0.6 to 3.6% w.b.

Total particulate emissions data (emission rates and corresponding emission factors) for the 1st stage lint cleaning systems are shown in Table 3. The system average emission factor for the four gins was 0.070 kg/bale (0.155 lb/bale). The test average emission factors ranged from 0.034 to 0.104 kg (0.075-0.230 lb) per bale. The average 1st stage lint cleaning system total PM emission factor for this project was approximately 27% of that published in the current 1996 EPA AP-42 for lint cleaners with high-efficiency cyclones (0.26 kg/bale [0.58 lb/bale]) (EPA, 1996a, b), which is an equivalent system to a combined 1st and 2nd stage lint cleaning system. The range of test average total particulate emission factors determined for this project and the AP-42 emission factor data range overlapped. The test average emission rates ranged from 0.67 to 3.56 kg/h (1.49-7.84 lb/h).

Table 2. Cotton gin production data and stack sampling performance metrics for the 1st stage lint cleaning system.

Gin	Test Run	Ginning Rate bales/h ^z	Cyclone Inlet Velocity		Isokinetic Sampling %	Stack Gas		
			m/s	fpm		Moisture Content % w.b.	Temperature	
							°C	°F
A	1	24.5	15.2	3001	101	0.6	19	66
	2	23.8	15.2	2985	104	0.6	20	69
	3	22.0	15.4	3029	105	0.9	22	71
	Test Average	23.4	15.3	3005				
B	1	23.3	17.1	3368	103	3.1	38	100
	2	24.6	16.9	3332	105	3.2	36	97
	3	27.0	16.7	3290	102	3.1	39	102
	Test Average	25.0	16.9	3330				
C	1	20.2	11.8	2323	94	2.7	31	88
	2	18.8	11.7	2312	97	3.6	30	86
	3	21.3	11.5	2271	95	2.5	28	83
	Test Average	20.1	11.7	2302				
F	1	32.9	16.4	3231	97	0.9	30	86
	2	34.0	15.8	3112	97	2.4	33	91
	3	35.7	15.8	3103	100	1.3	34	93
	Test Average	34.2	16.0	3149				
System Average		25.7	15.0	2946				

^z 227 kg (500 lb) equivalent bales

Table 3. Total particulate emissions data for the 1st stage lint cleaning system.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale ^z	lb/bale ^z
A	1	2.49	5.50	0.102	0.224
	2	2.30	5.06	0.097	0.213
	3	2.00	4.41	0.091	0.200
	Test Average (n=3)	2.26	4.99	0.096	0.212
B	1	1.18	2.61	0.051	0.112
	2	1.39	3.07	0.057	0.125
	3	0.90	1.98	0.033	0.074
	Test Average (n=3)	1.16	2.55	0.047	0.103
C	1	0.23	0.50	0.011	0.025
	2	0.99	2.18	0.053	0.116
	3	0.80	1.77	0.038	0.083
	Test Average (n=3)	0.67	1.49	0.034	0.075
F	1	3.88	8.55	0.118	0.260
	2	3.30	7.27	0.097	0.214
	3	3.50	7.71	0.098	0.216
	Test Average (n=3)	3.56	7.84	0.104	0.230
System Average (n=4)				0.070	0.155

^z 227 kg (500 lb) equivalent bales

Figure 12 shows an example of samples recovered from a typical 1st stage lint cleaning system test run. Often, there were cotton lint fibers in the cotton gin cyclone exhausts. Therefore, it was not unusual to find lint fiber on the Method 17 filter or in the front half wash, which was included in the total particulate emissions. Figure 13 shows an example of samples recovered from an atypical 1st stage lint cleaning system test run; heavily loaded with few lint fibers.

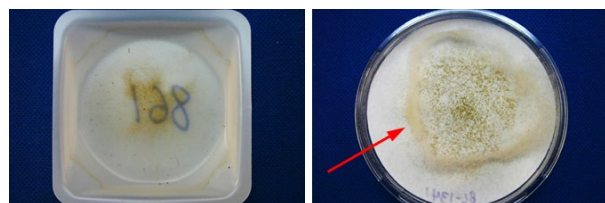


Figure 12. Typical EPA Method 17 filter and sampler head acetone wash with fiber (indicated by arrow) from the 1st stage lint cleaning system. From left to right: front half wash and filter.

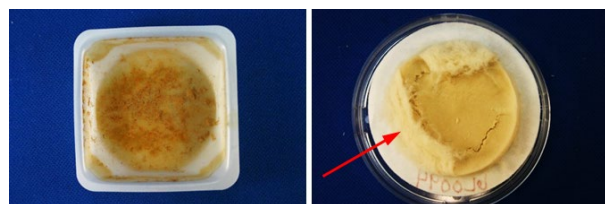


Figure 13. Heavily loaded EPA Method 17 filter and sampler head acetone wash with fiber (indicated by arrow) from the 1st stage lint cleaning system.

SUMMARY

Four cotton gins with 1st stage lint cleaning systems were sampled using EPA Method 17 to collect total particulate emission factor data for cotton gins. Each of the gins had 1st stage lint cleaning system exhausts that were not combined with 2nd stage lint cleaning system exhausts. The tested systems were similar in design and typical of the ginning industry. The system exhausts were equipped with 1D3D cyclones for emissions control with some variations in inlet and cone design. The average production rate during testing for the four gins was 25.7 bales/h. The average 1st stage lint cleaning system total particulate emission factor based on the four gins tested (12 total test runs) was 0.070 kg/227-kg bale (0.155 lb/500-lb bale). The gin test average emission rates ranged from 0.67 to 3.56 kg/h (1.49-7.84 lb/h).

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