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ENGINEERING AND GINNING

Battery Condenser 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. EPA AP-42 emission factors generally are assigned a rating, from A (excellent) to E (poor), to assess the quality of the data being referenced. Current EPA total particulate emission factor ratings for cotton gins are extremely low. Cotton gin data received these low ratings because the data were collected almost exclusively from a single geographical region. The objective of this study was to collect additional total particulate emission factor data for battery condenser 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. Six gins with battery condenser system exhausts equipped with cyclones were sampled. The average production rate during testing for the six gins was 30.8 bales/h. The average battery condenser system total particulate emission factor based on six tests (18 total test runs) was 0.032 kg/227-kg bale (0.070 lb/500-lb bale). This average total particulate emission factor was higher than that currently published in 1996 EPA AP-42, which was 0.018 kg/bale (0.039 lb/bale). The battery condenser system emission rate test averages ranged from 0.17 to 1.40 kg/h (0.37-3.09 lb/h).

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U.S. Environmental Protection Agency (EPA) emission factors published in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996b) are assigned a rating that is used to assess the quality of the data being referenced. Ratings can range from A (excellent) to E (poor). Current EPA emission factor quality ratings for total particulate from cotton gins are extremely low. Cotton gin data received these low ratings because they were collected almost exclusively from a single geographical region, far western U.S. (EPA, 1996a). 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 battery condenser systems.

The 1996 EPA AP-42 average total particulate emission factor for the battery condenser with high-efficiency cyclones was 0.018 kg (0.039 lb) per 217-kg [480-lb] equivalent bale with a range of 0.006 to 0.037 kg (0.013-0.082 lb) per bale (EPA, 1996a, b). This average and range was based on five 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).

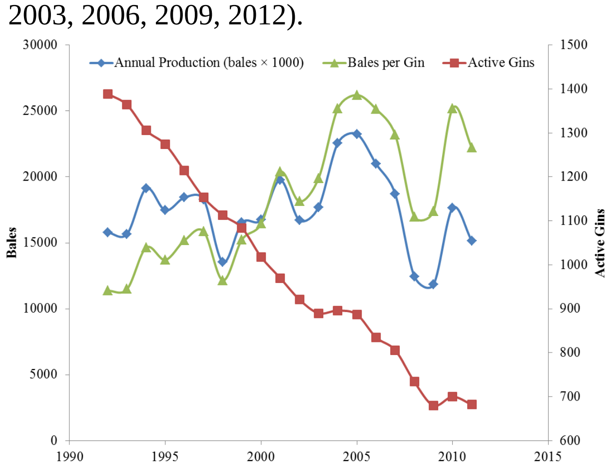

Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

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.

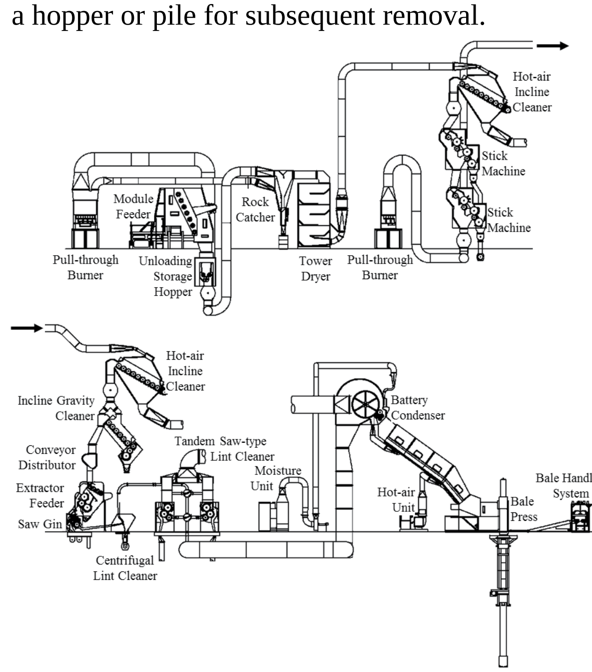

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

Lint from the final stages of lint cleaning is combined (cotton gins typically split the precleaned seed-cotton among multiple, parallel gin stand/lint cleaning lines) and pneumatically conveyed to the bale packaging system via the lint flue and separated from the airstream by a large, screened, rotating drum separator called the “battery condenser”. A schematic of the battery condenser system is shown in Fig. 3. The battery condenser drops the lint onto the lint slide, which feeds lint into the bale press for compressing and packaging into a 500-lb bale. The airstream from the battery condenser system continues through a large centrifugal fan to one or more particulate abatement cyclones. Some battery condenser systems utilize a vane-axial fan, but these systems typically do not have cyclones and exhaust directly to ambient air. The material handled by the battery condenser cyclones typically includes small trash and particulate, and lint fibers (Fig. 4).

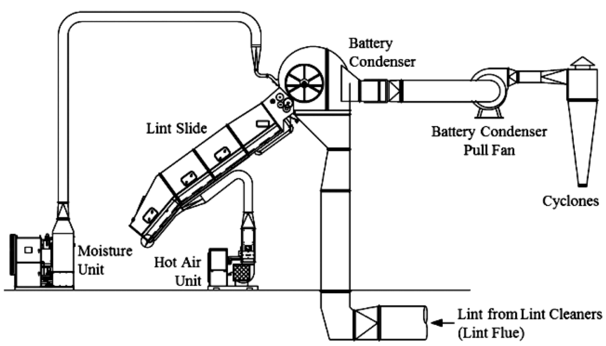

Figure 3. Typical cotton gin battery condenser system layout (Courtesy Lummus Corporation, Savannah, GA).

Figure 4. Photograph of typical trash captured by the battery condenser system cyclones.

Cyclones are the most common particulate matter (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).

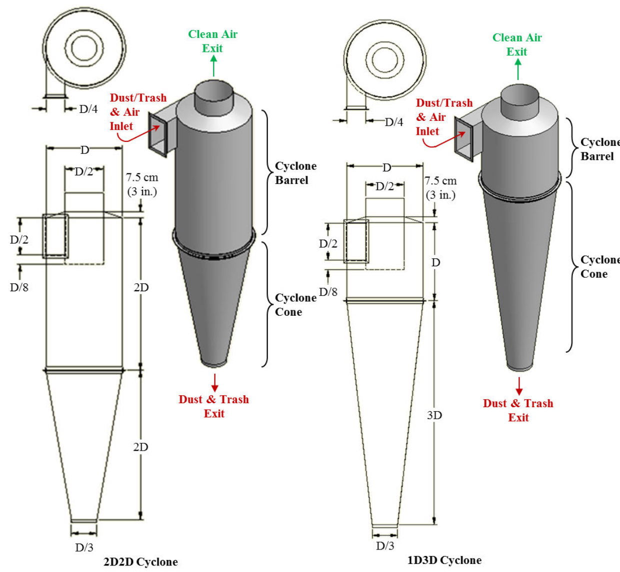

Figure 5. 2D2D and 1D3D cyclone schematics.

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

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 battery condenser 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.

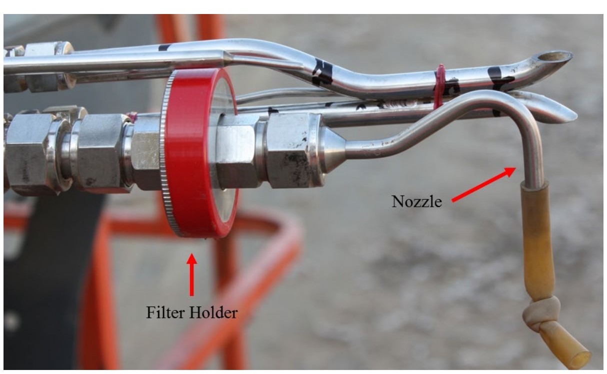

Figure 6. EPA Method 17 total particulate button nozzle and in-stack filter holder photograph.

Only one stack from each battery condenser 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 Zefluor 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 ≥ 99.5%). Filters, wash tubs, and lids were prelabeled 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.

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).

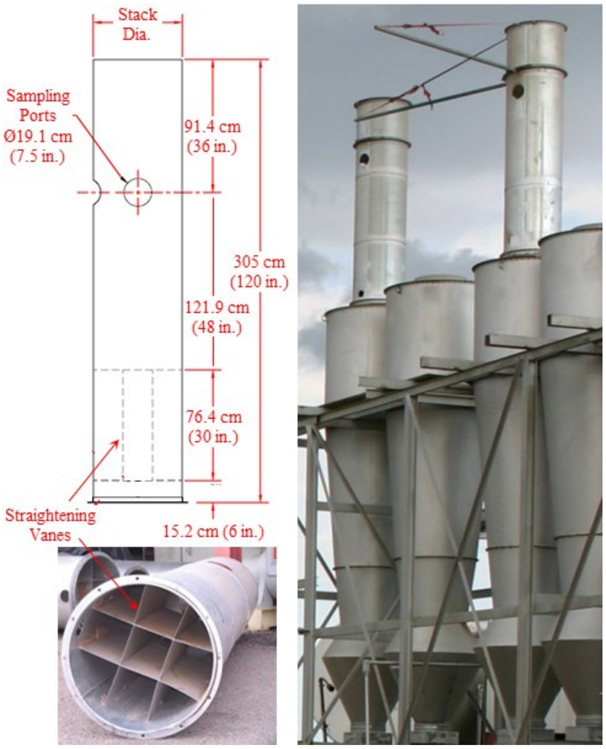

Figure 7. Schematic and photographs of stack extensions with sampling port and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

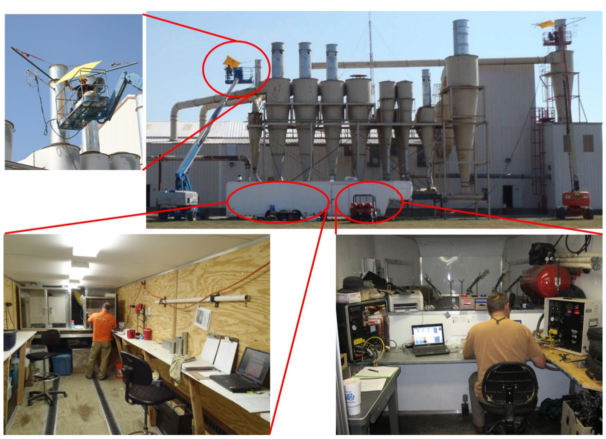

Figure 8. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

All laboratory analyses were conducted at the AQL. All filters were conditioned in an environmental chamber (21 ± 2°C [70 ± 3.6°F]; 35 ± 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 µg readability and 0.9 µg 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 µg, 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.

Six of the seven gins (A, C, D, E, F, and G) had battery condenser systems with cyclones on the systems exhausts. The battery condenser systems sampled were typical for the industry, but varied among the gins. After the cotton fiber or lint was cleaned in the three 1st stage lint cleaning systems and then three 2nd stage lint cleaning systems at gins A and E, the lint was combined and pneumatically conveyed from the 2nd stage lint cleaners to the battery condenser. The battery condenser separated the lint from the conveying air and fed the lint, via the lint slide, to the bale packaging press. The airstream then passed through a fan and exhausted through one or more cyclones (Fig. 9). The battery condenser systems at gins C and G were essentially the same as those at gins A and E, except the system combined lint from two 2nd stage lint cleaning systems (Fig. 10). The battery condenser systems at gins D and F also were similar, but the systems at those gins combined lint from four 2nd stage lint cleaning systems (Fig. 11).

All battery condenser systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were some cyclone design variations among the gins (Table 1 and Figs. 12 and 13). All the gins, except gin E, split the system exhaust flow between three cyclones. Gins A, F, and G used a triple (side-by-side) cyclone configuration and gins C and D used a tandem (one-behind-another) cyclone configuration. The system airstream for gin E was exhausted through a single cyclone. At four gins, inlets on all the battery condenser cyclones were 2D2D type; whereas, gin C had inverted 1D3D inlets and gin D that had center-line 1D3D inlets. Standard cones were present on battery condenser cyclones at all gins, except gin A that had expansion chambers. The cyclones tested at gins C, D, F, and G 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).

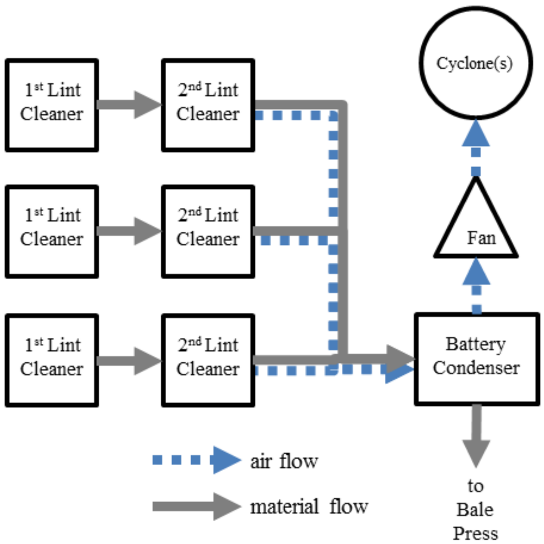

Figure 9. Schematic of battery condenser system pulling material from three 2nd stage lint cleaning systems (gins A and E).

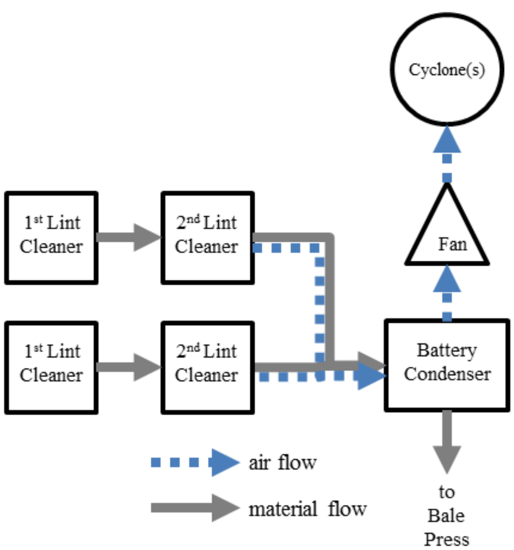

Figure 10. Schematic of battery condenser system pulling material from two 2nd stage lint cleaning systems (gins C and G).

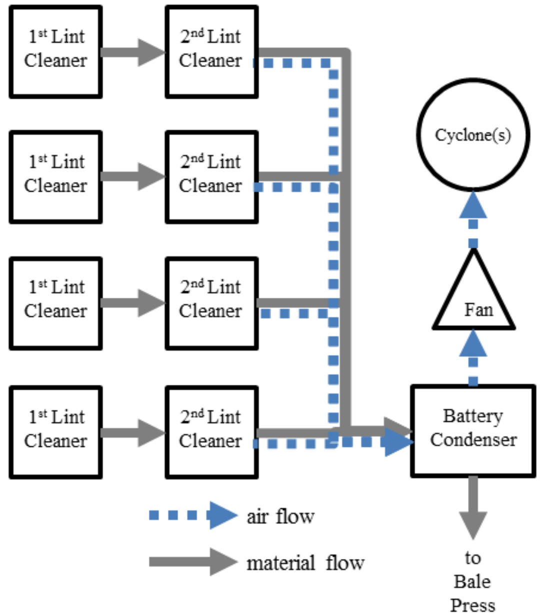

Figure 11. Schematic of battery condenser system pulling material from four 2nd stage lint cleaning systems (gins D and F).

Figure 12. Photographs triple cyclone conrfigurations (left to right): triple cyclone configuration with flow split among three, side-by-side, identical cyclones; triple cyclones in a tandem configuration with flow split among three, one-behind-another, identical cyclones.

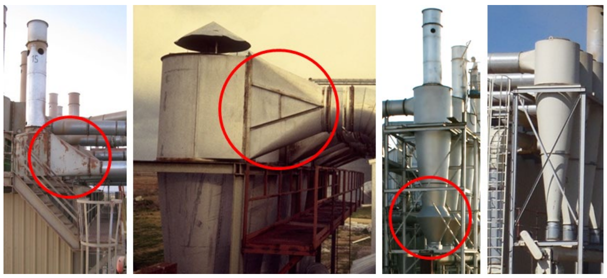

Figure 13. Cyclone design variations for the tested systems (left to right): 1D3D cyclone with an inverted 1D3D inlet; 1D3D cyclone with a center-line 1D3D inlet; 1D3D cyclone with 2D2D inlet and expansion chamber on the cone; 1D3D cyclone with 2D2D inlet and standard cone.

Table 1. Abatement device configuration[z] for battery condenser systems tested

Gin	Cyclone Type	Inlet Design[y]	Systems per Gin	Cyclones per Gin	Configuration	Cone Design	Trash Exit[x]
A	1D3D	2D2D	1	3	triple	expansion chamber	auger
C	1D3D	inverted 1D3D	1	3	triple (tandem)	standard	robber
D	1D3D	center-line 1D3D	1	3	triple (tandem)	standard	robber
E	1D3D	2D2D	1	1	single	standard	auger
F	1D3D	2D2D	1	3	triple	standard	robber
G	1D3D	2D2D	1	3	triple	standard	robber

[z] Figures 5, 12, and 13

[y] Inverted 1D3D has duct in line with bottom of cyclone inlet, 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

RESULTS

Table 2 shows the test parameters for each Method 17 test run for the battery condenser systems sampled at the six gins. The average ginning rate for the six gins was 30.8 bales/h and the test average ginning rate at each gin ranged from 16.4 to 43.9 bales/h (based on 227-kg [500-lb] equivalent bales). 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 gins C and E 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 15 to 43°C (59-109°F) and moisture content ranged from 1.0 to 2.8% w.b.

Total particulate emissions data (emission rates and corresponding emission factors) for the battery condenser systems are shown in Table 3. The system average emission factor for the six gins was 0.032 kg/bale (0.070 lb/bale). The test average emission factors ranged from 0.0039 to 0.086 kg (0.0086 to 0.191 lb) per bale. The average battery condenser system total particulate emission factor average for this project was approximately 1.8 times that published in the current 1996 EPA AP-42 for battery condenser systems with high-efficiency cyclones, which is 0.018 kg/bale (0.039 lb/bale) (EPA, 1996a, b). The range of test average total particulate emission factors determined for this project encompassed the AP-42 emission factor data range. The test average emission rates ranged from 0.17 to 1.40 kg/h (0.37-3.09 lb/h).

Figure 14 shows an example of samples recovered from a typical battery condenser 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 15 shows an example of samples recovered from an atypical battery condenser test run with no lint present.

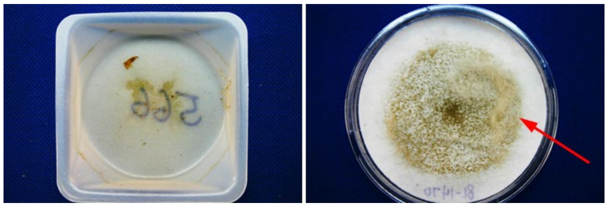

Figure 14. Typical EPA Method 17 filter and sampler head acetone wash from the battery condenser system with lint on the filter (indicated by arrow). From left to right: front half wash and filter.

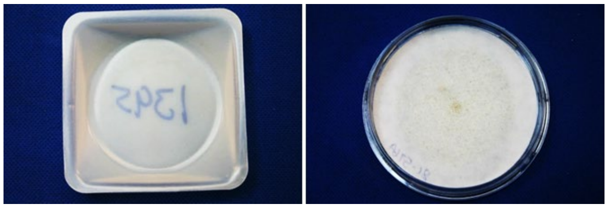

Figure 15. EPA Method 17 filter and sampler head acetone wash from the battery condenerser system with no lint present. From left to right: front half wash and filter.

Table 2. Cotton gin production data and stack sampling performance metrics for the battery condenser cleaning systems

Gin	Test Run	Ginning Rate bales/h[z]	Cyclone Inlet Velocity		Isokinetic Sampling %	Stack Gas		
						Moisture Content	Temperature	
			m/s	fpm		% w.b.	°C	°F
A	1	23.4	16.0	3152	103	1.9	18	65
	2	23.1	15.6	3063	103	1.4	16	61
	3	26.0	15.6	3068	102	1.5	15	59
Test Average		24.1	15.7	3094				
C	1	18.4	12.6	2481	94	1.5	39	102
	2	14.0	13.0	2563	97	1.6	40	104
	3	16.8	12.9	2545	106	1.3	39	102
Test Average		16.4	12.9	2530				
D	1	31.0	15.0	2960	105	1.3	22	72
	2	37.0	14.4	2831	106	1.5	27	80
	3	34.6	14.6	2868	106	1.0	30	86
Test Average		34.2	14.7	2886				
E	1	24.7	12.6	2473	94	1.7	30	86
	2	31.8	11.3	2219	97	2.2	37	99
	3	32.5	10.9	2144	101	1.0	43	109
Test Average		29.7	11.6	2279				
F	1	39.4	17.1	3368	103	1.4	33	91
	2	45.4	16.9	3336	98	2.8	36	97
	3	47.0	16.6	3277	102	2.0	39	102
Test Average		43.9	16.9	3327				
G	1	36.6	14.6	2874	101	2.5	36	97
	2	35.1	14.7	2902	101	2.6	36	97
	3	37.2	14.3	2817	103	1.9	36	96
Test Average		36.3	14.6	2865				
System Average		30.8	14.4	2830				

[z] 227 kg (500 lb) equivalent bales

Table 3. Total particulate emissions data for the battery condenser systems

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.73	1.62	0.031	0.069
	2	0.72	1.59	0.031	0.069
	3	0.67	1.47	0.026	0.057
Test Average (n=3)		0.71	1.56	0.029	0.065
C	1	1.53	3.37	0.083	0.183
	2	1.42	3.13	0.101	0.223
	3	1.26	2.78	0.075	0.166
Test Average (n=3)		1.40	3.09	0.086	0.191
D	1	0.61	1.35	0.020	0.043
	2	0.70	1.54	0.019	0.042
	3	0.70	1.55	0.020	0.045
Test Average (n=3)		0.67	1.48	0.020	0.043
E	1	0.57	1.25	0.023	0.051
	2	0.52	1.14	0.016	0.036
	3	0.46	1.02	0.014	0.031
Test Average (n=3)		0.52	1.14	0.018	0.039
F	1	0.17	0.38	0.0044	0.010
	2	0.20	0.43	0.0043	0.0095
	3	0.14	0.30	0.0029	0.0064
Test Average (n=3)		0.17	0.37	0.0039	0.0086
G	1	1.52	3.35	0.041	0.091
	2	1.16	2.56	0.033	0.073
	3	1.04	2.30	0.028	0.062
Test Average (n=3)		1.24	2.74	0.034	0.075
System Average (n=6)				0.032	0.070

[z] 227 kg (500 lb) equivalent bales

SUMMARY

Six cotton gins with battery condenser systems were sampled using EPA Method 17 to collect additional data to improve the EPA AP-42 total particulate emission factor quality ratings for cotton gins. Each of the gins had battery condenser systems with cyclones on the 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 six gins was 30.8 bales/h. The average battery condenser system total particulate emission factor based on the six gins tested (18 total test runs) was 0.032 kg/227-kg bale (0.070 lb/500-lb bale). The average battery condenser system total particulate emission factor for this project was approximately 1.8 times that currently published in the 1996 EPA AP-42, which is 0.018 kg/bale (0.039 lb/bale) (EPA, 1996 a, b). The gin test average emission rates ranged from 0.17 to 1.40 kg/h (0.37-3.09 lb/h).

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