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ENGINEERING AND GINNING

Battery Condenser System $PM_{2.5}$ Emission Factors and Rates for Cotton Gins: Method 201A Combination PM_{10} and $PM_{2.5}$ Sizing Cyclones

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ABSTRACT

This report is part of a project to characterize cotton gin emissions from the standpoint of stack sampling. In 2006, EPA finalized and published a more stringent standard for particulate matter with nominal diameter less than or equal to 2.5 µm ($PM_{2.5}$). This created an urgent need to collect additional cotton gin emissions data to address current regulatory issues, because current EPA AP-42 cotton gin $PM_{2.5}$ emission factors did not exist. The objective of this study was the development of $PM_{2.5}$ emission factors for cotton gin battery condenser systems based on the EPA-approved stack sampling methodology, Method 201A. The project plan included sampling seven cotton gins across the cotton belt. Key factors for selecting specific cotton gins included: 1) facility location (geographically diverse), 2) industry representative production capacity, 3) typical processing systems, and 4) equipped with properly designed and maintained 1D3D cyclones. Six of the seven gins were equipped with battery condensers with cyclones on the system exhausts. In terms of capacity, the six gins were typical of the industry, averaging 30.9 bales/h during testing. Some test runs were excluded from the test averages because they failed to meet EPA Method 201A test criteria. Also, other test runs included in the analyses had cotton lint fibers that collected in the ≤ 10 µm and/or ≤ 2.5 µm samples. This larger lint material can impact the reported emissions data, but EPA Method 201A does not suggest methods to account for these anomalies. Average measured battery condenser system $PM_{2.5}$ emission factor based on the six tests (15 total test runs) was 0.0037 kg/227-kg bale (0.0081 lb/500-lb bale). The battery condenser system average emission factors for PM_{10} and total particulate were 0.012 kg/bale (0.026 lb/bale) and 0.037 kg/bale (0.081 lb/bale), respectively. The battery condenser system $PM_{2.5}$ emission rate from test averages ranged from 0.044 to 0.14 kg/h (0.10-0.30 lb/h). System average PM_{10} and total particulate emission factors were higher than those currently published in EPA AP-42. The ratios of battery condenser system $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 10.0, 30.9, and 32.3%, respectively.

In 2006, the U.S. Environmental Protection Agency (EPA) finalized a more stringent standard for particulate matter with a particle diameter less than or equal to a nominal 2.5-µm ($PM_{2.5}$) aerodynamic equivalent diameter (CFR, 2006). The cotton industry's primary concern with this standard was that there were no published cotton gin $PM_{2.5}$ emissions data. 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 $PM_{2.5}$ cotton gin emissions data to address the implementation of the $PM_{2.5}$ standards. Working with 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

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mote, combined mote, mote cyclone robber, mote cleaner, mote trash, battery condenser, and master trash. This report focuses on $PM_{2.5}$ emissions from battery condenser systems.

There are published PM_{10} (particulate matter with a particle diameter less than or equal to a nominal 10-µm aerodynamic equivalent diameter) and total particulate emission factors for cotton gins in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996a, b); however, there are no $PM_{2.5}$ emission factors. The AP-42 average PM_{10} emission factor for the battery condenser with high-efficiency cyclones was 0.0064 kg (0.014 lb) per 217-kg (480-lb) equivalent bale with a range of 0.0036 to 0.011 kg (0.0079-0.025 lb) per bale. The AP-42 average total particulate emission factor was 0.018 kg (0.039 lb) bale with a range of 0.0059 to 0.037 kg (0.013-0.082 lb) per bale. These PM_{10} and total factors were each based on five tests and were assigned EPA emission factor quality ratings of D; 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 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 methods of handling material 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 with the ginning season 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 about 17 million bales per year during the last 20 years, production from one year to the next often 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 less 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).

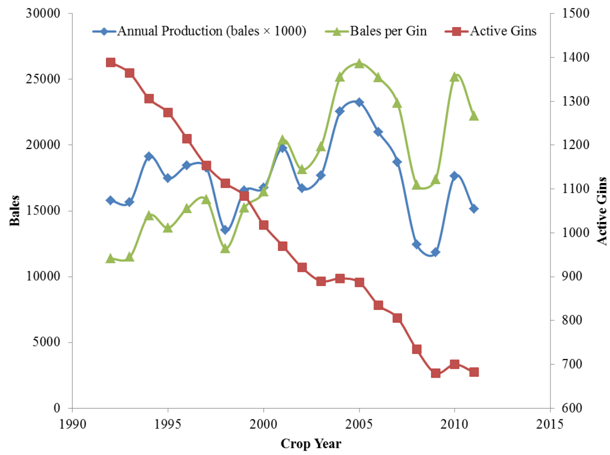

Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

Typical cotton gin processing systems include: 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 can vary. 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 efficient 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.

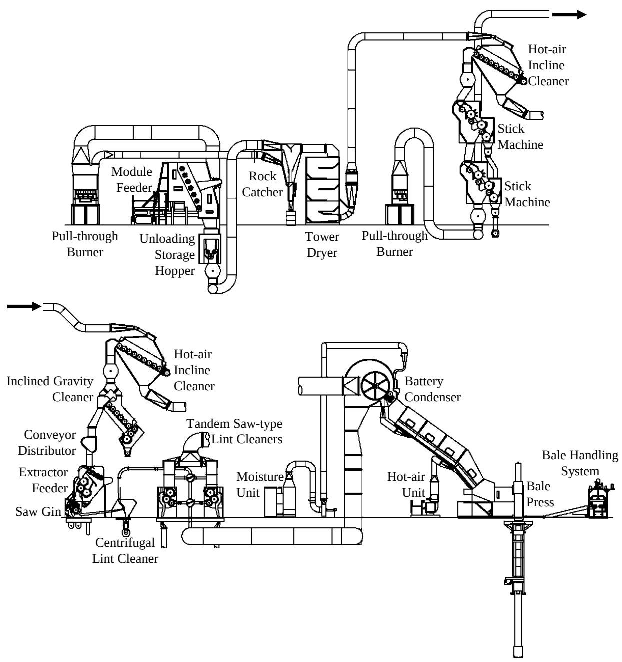

Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corp., Savannah, GA).

Lint from the final stages of lint cleaning are 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 the lint into a 500-lb bale. The airstream from the battery condenser system continues through a large centrifugal fan to one to four 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).

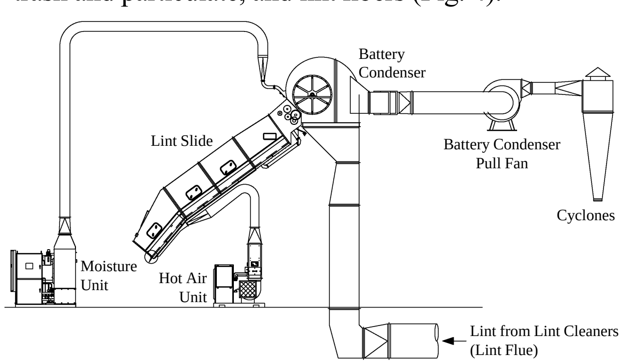

Figure 3. Typical cotton gin battery condenser system layout (Courtesy Lummus Corp., Savannah, GA).

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

Cyclones are the most common particulate matter 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).

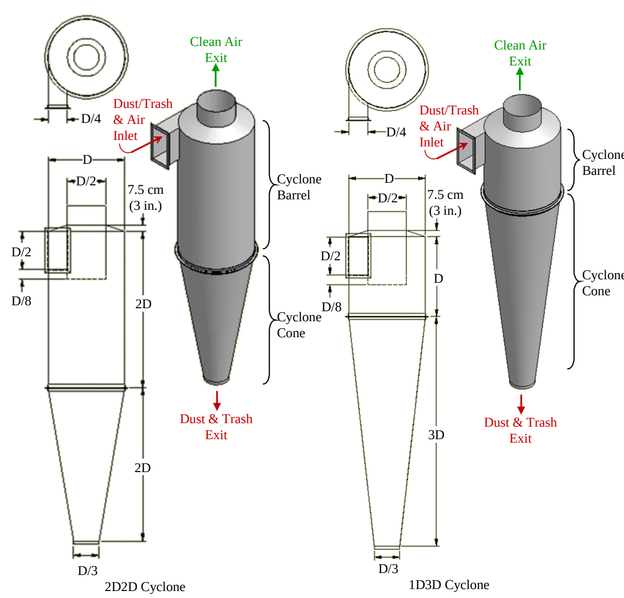

Figure 5. 2D2D and 1D3D cyclone schematics.

The objective of this study was the development of $PM_{2.5}$ emission factors for cotton gin battery condenser systems with cyclones for emissions control 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 (geographically diverse), 2) industry representative production capacity, 3) typical processing systems, and 4) equipped with properly designed and maintained 1D3D cyclones. 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 Other Test Method 27 (OTM27) was used to sample the battery condenser system at each gin. When testing for this project began in 2008, OTM27 was the EPA method for determination of PM_{10} and $PM_{2.5}$ from stationary sources. In December 2010, OTM27 was replaced with a revised and finalized Method 201A (CFR, 2010). The revised Method 201A was a successor to OTM27. The two methods were similar to the point that EPA stated in an answer to a frequently asked question for Method 201A (EPA, 2010) that "If the source was using OTM 27 (and 28) for measuring either PM_{10} or $PM_{2.5}$ then using the revised reference methods Method 201A (and 202) should not be a concern and should give equivalent results." Accordingly, OTM27 is no longer an EPA method that can be cited, and the revised Method 201A will be cited in this manuscript. Using Method 201A to sample $PM_{2.5}$, the particulate-laden stack gas was withdrawn isokinetically (the velocity of the gas entering the sampler was equal to the velocity of the gas in the stack) through a PM_{10} sizing cyclone and a $PM_{2.5}$ sizing cyclone, and then collected on an in-stack filter (Fig. 6). The methods for retrieving the filter and conducting acetone washes of the sizing cyclones are described in detail in Method 201A (CFR, 2010). The mass of each size fraction was determined by gravimetric analysis and included: > 10 µm (PM_{10} sizing cyclone catch acetone wash); 10 to 2.5 µm (PM_{10} sizing cyclone exit acetone wash and $PM_{2.5}$ sizing cyclone catch acetone wash); and ≤ 2.5 µm ($PM_{2.5}$ sizing cyclone exit acetone wash and filter). The $PM_{2.5}$ mass was determined by adding the mass of particulates captured on the filter and the ≤ 2.5 µm wash. The PM_{10} mass was determined by adding the $PM_{2.5}$ mass and the mass of the 10 to 2.5 µm wash. Total particulate was determined by adding the PM_{10} mass and the mass of the > 10 µm wash.

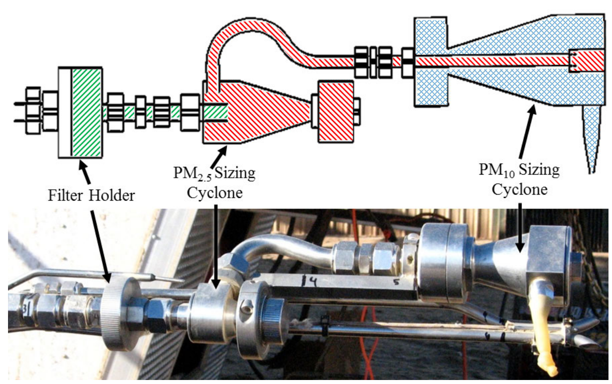

Figure 6. EPA Method 201A PM10 and PM2.5 sizing cyclones and in-stack filter holder schematic (CFR, 2010) and photograph (≤ 2.5 µm, 10 to 2.5 µm, > 10 µm).

Figure 7 shows the performance curves for the PM_{10} and $PM_{2.5}$ sizing cyclones. To measure both PM_{10} and $PM_{2.5}$, Method 201A requires selecting a gas sampling rate in the middle of the overlap zone of the performance curves for both sizing cyclones. For this study, the method was specifically used to collect filterable $PM_{2.5}$ emissions (solid particles emitted by a source at the stack and captured in the ≤ 2.5 µm wash and on the filter [CFR, 2010]). The PM_{10} sizing cyclone was used to scrub larger particles from airstream to minimize their impact on the $PM_{2.5}$ sizing cyclone. Thus, the gas sampling rate was targeted to optimize the $PM_{2.5}$ cyclone performance.

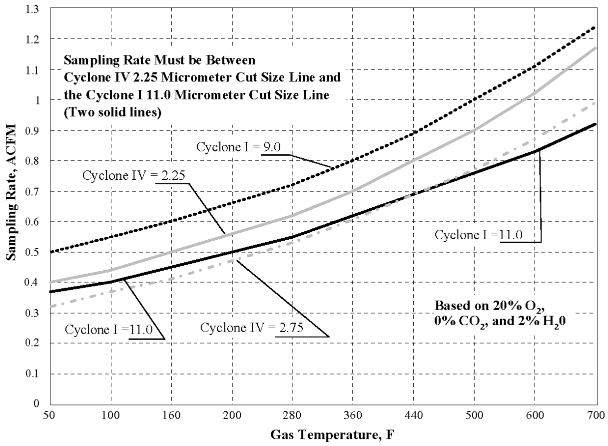

Figure 7. Acceptable sampling rate for combined cyclone heads (CFR, 2010). Cyclone I = PM10 sizing cyclone and Cyclone IV = PM2.5 sizing cyclone (gas temperatures for the battery condenser systems tested ranged from 12 to 41°C [54-107°F]).

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 and the total emissions 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 the tests at all seven cotton gins.

All stack sampling equipment, including the sizing cyclones, was purchased from Apex Instruments (Fuquay-Varina, NC) and met specifications of Method 201A. 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 certified stack testing technician conducted calibrations and checks on all stack sampling equipment according to EPA Method 201A.

Each cyclone tested 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. 8). 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.

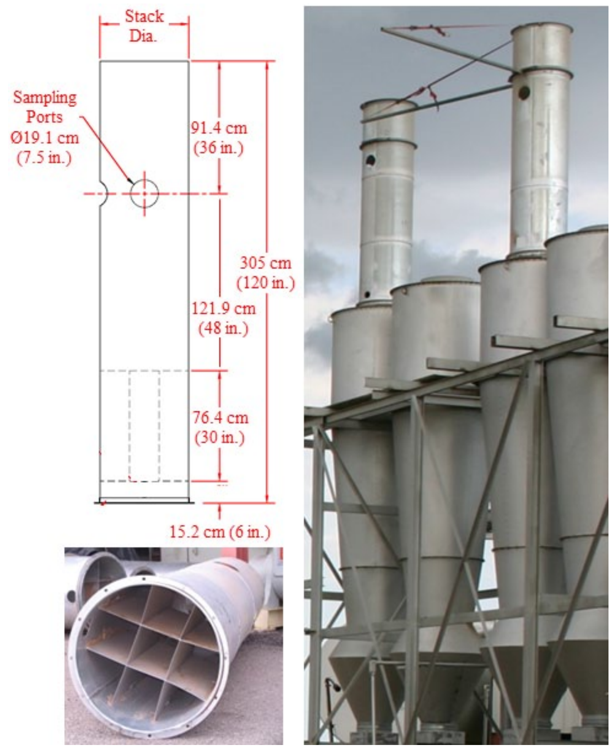

Figure 8. Schematic and photographs of stack extensions with sampling ports and staightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

The tests were conducted by the certified stack sampling technician in an enclosed sampling trailer at the base of the cyclone bank (Fig. 9). Sample retrieval, including filters and sampler head acetone washes, was conducted according to Method 201A. 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 201A and ASAE Standard S582 (ASABE, 2005).

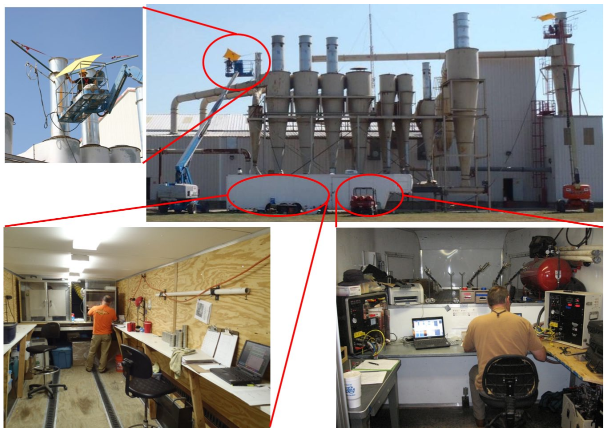

Figure 9. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

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 digitally 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 prior to further analyses. After the laboratory analyses were completed all stack sampling, cotton gin production, and laboratory data were merged.

Six of the seven gins 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. 10). 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. 11). The battery condenser systems at gins D and F were also similar, but the systems at those gins combined lint from four 2nd stage lint cleaning systems (Fig. 12).

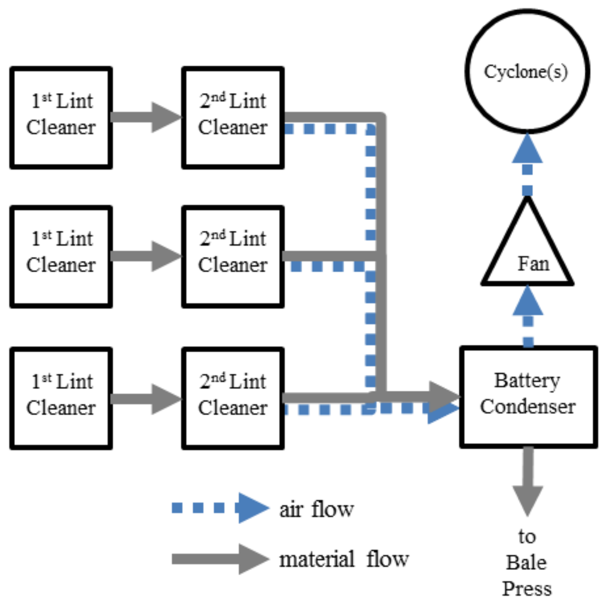

Figure 10. Schematic of battery condenser system pulling material from three 2nd stage lint cleaning systems (gins A and E).

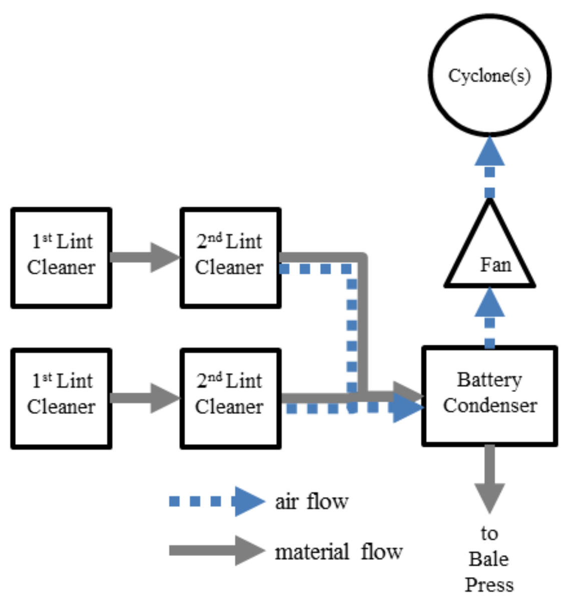

Figure 11. Schematic of battery condenser system pulling material from two 2nd stage lint cleaning systems (gins C and G).

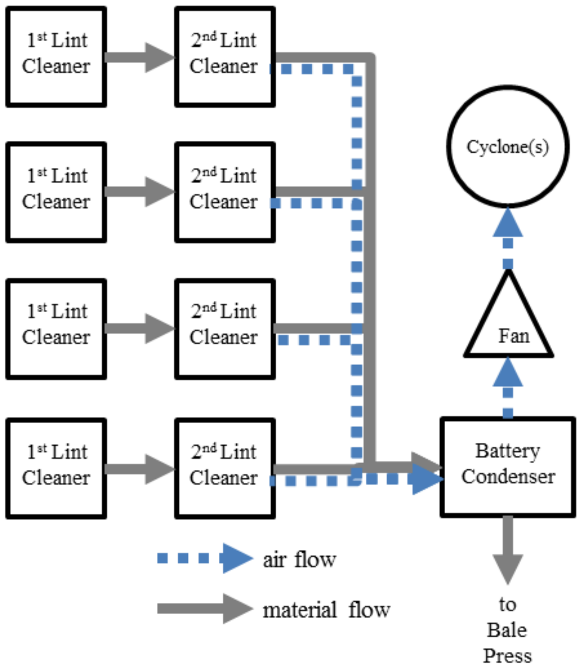

Figure 12. Schematic of battery condenser system pulling material from four 2nd stage lint cleaning systems (gins D and F).

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. 13 and 14). 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. Inlets on all the battery condenser cyclones were 2D2D type, except gin C, which had inverted 1D3D inlets and gin D, which had center-line 1D3D inlets. Standard cones were present on battery condenser cyclones at all gins, except gin A, which 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 13. 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.

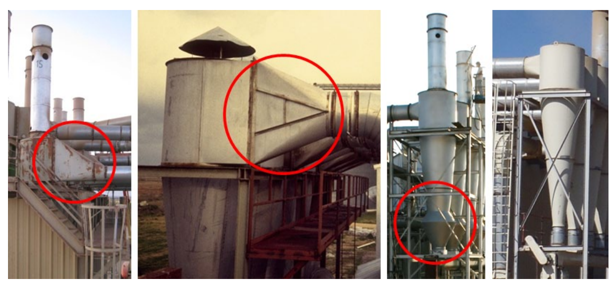

Figure 14. Cyclone design variations for the tested systems (left to right): 1D3D cyclone with an inverted 1D3D inlet; 1D3D cyclone with a center-line 1D3D inlet; 1D3D cyclone with 2D2D inlet and expansion chamber on the cone; 1D3D cyclone with 2D2D inlet and standard cone.

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 Exits to[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, 13, and 14

[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 201A test run for the battery condenser systems sampled at the six gins. The system average ginning rate was 30.9 bales/h and the test average ginning rate for each gin tested ranged from 16.9 to 46.4 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. Test run one from Gin C was not included in test averages because of inconsistent gin operation. 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 gin E, which were outside the design range due to limitations in available system adjustments.

There are criteria specified in EPA Method 201A for test runs to be valid for $PM_{2.5}$, PM_{10}, or total particulate measurements (CFR, 2010). Isokinetic sampling must fall within EPA defined ranges (100 ± 20%) for valid $PM_{2.5}$ and PM_{10} test runs. All tests met the isokinetic criteria (Table 2). To use Method 201A to obtain total filterable particulate also, sampling must be within 90 to 110% of isokinetic flow. This criterion was not met in test run two for gins A or C, test run three for gins D or E, or the first test run for gin F; thus the data associated with these runs were omitted from the total particulate test averages. The $PM_{2.5}$ aerodynamic cut size must fall within EPA

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

Gin	Test Run	Ginning Rate bales/h[z]	Cyclone Inlet Velocity		Isokinetic Sampling %	Aerodynamic Cut Size D_{50}		Sampling Rate[y]		Stack Temperature	
			m/s	fpm		$PM_{2.5}$ µm	PM_{10} µm	slpm	scfm	°C	°F
A	1	26.4	16.1	3161	92	2.49	11.1[v]	10.9	0.384	12	54
	2	26.7	16.3	3206	87[w]	2.66	11.5[v]	10.4	0.369	16	60
	3	27.4	16.4	3224	104	2.15[v]	10.1	12.6	0.444	18	64
Test Average		26.8	16.2	3197							
C	1[x]	5.5	13.6	2668	90	2.45	11.2[v]	10.9	0.385	27	80
	2	17.0	12.7	2494	111[w]	2.47	11.2[v]	10.9	0.383	27	80
	3	16.8	12.7	2493	96	2.46	11.2[v]	10.9	0.385	27	81
Test Average		16.9	12.7	2494							
D	1	29.5	15.6	3079	96	2.31	10.8	11.6	0.411	32	89
	2	30.9	15.6	3076	97	2.30	10.7	11.7	0.414	33	91
	3	31.6	15.7	3082	111[w]	2.22[v]	10.5	12.1	0.428	33	92
Test Average		30.7	15.6	3079							
E	1	33.1	10.7	2098	110	2.33	10.8	12.0	0.423	39	103
	2	28.7	10.7	2109	108	2.37	10.8	11.9	0.420	41	105
	3	33.8	9.8	1923	114[w]	2.50	11.2[v]	11.4	0.402	41	107
Test Average		31.8	10.4	2043							
F	1	46.5	17.1	3364	89[w]	2.45	10.9	11.8	0.417	36	97
	2	45.8	16.4	3222	94	2.44	10.9	11.9	0.422	38	101
	3	47.0	16.8	3297	91	2.46	11.0	11.9	0.419	38	100
Test Average		46.4	16.7	3295							
G	1	32.9	14.4	2841	100	2.42	11.1[v]	11.2	0.394	31	88
	2	32.5	14.7	2887	97	2.45	11.2[v]	11.1	0.390	32	89
	3	33.7	14.6	2872	99	2.44	11.1[v]	11.2	0.396	34	93
Test Average		33.0	14.6	2867							
System Average		30.9	14.4	2829							

[z] 227 kg (500 lb) equivalent bales

[y] slpm = standard l/m, scfm = standard ft^3/m

[x] Test run omitted from test averages because of inconsistent gin operation during test.

[w] Did not meet total particulate isokinetic sampling rate criteria (100 ± 10%)

[v] Did not meet $PM_{2.5}$ (2.50 ± 0.25 µm) or PM_{10} (10.0 ± 1.0 µm) aerodynamic cut size criteria

defined ranges (2.50 ± 0.25 mm) for valid $PM_{2.5}$ test runs. $PM_{2.5}$ cut size criteria were not met in the third test run for either gins A or D, thus the data associated with these runs were omitted from the $PM_{2.5}$ test averages. The PM_{10} aerodynamic cut size must fall within EPA defined ranges (10.0 ± 1.0 mm) for valid PM_{10} test runs. PM_{10} cut size criteria were not met in test runs one or two for gin A, all test runs for gin C or G, or the third test run for gin E, thus the data associated with these runs were omitted from the PM_{10} test averages.

Sampling rates ranged from 10.4 to 12.6 standard l/min (0.37-0.44 standard ft^3/min) (Table 2). The stack gas temperatures ranged from 12 to 41°C (54-107°F). The sampling method documentation (CFR, 2010) warns that the acceptable gas sampling rate range is limited at the stack gas temperatures encountered during this project's testing, as indicated by the narrow difference between the solid lines in Fig. 7 for the temperatures listed above. These stack gas characteristics justified targeting the $PM_{2.5}$ cut size criteria and treating the PM_{10} cut size criteria as secondary.

$PM_{2.5}$ emissions data (ginning and emission rates and corresponding emission factors) for the battery condenser system are shown in Table 3. The system average $PM_{2.5}$ emission factor was 0.0037 kg/bale (0.0081 lb/bale). The test average emission factors at each gin ranged from 0.0013 to 0.0077 kg (0.0029-0.017 lb) per bale and $PM_{2.5}$ emission rates ranged from 0.044 to 0.14 kg/h (0.10-0.30 lb/h). PM_{10} emissions data (ginning and emission rates and corresponding emission factors) for the battery condenser system are shown in Table 4. The system average PM_{10} emission factor was 0.012 kg/bale (0.026 lb/bale). The test average emission factors ranged from 0.0045 to 0.020 kg (0.010-0.045 lb) per bale and emission rates ranged from 0.21 to 0.62 kg/h (0.46-1.37 lb/h). Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the battery condenser system are shown in Table 5. The system average total particulate emission factor was 0.037 kg/bale (0.081 lb/bale). The test average emission factors ranged from 0.0080 to 0.095 kg (0.018-0.210 lb) per bale. Test average total particulate emission rates ranged from 0.37 to 1.60 kg/h (0.82-3.52 lb/h).The ratios of $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 10.0, 30.9, and 32.3%, respectively (ratios calculated using Tables 3, 4, and 5 might vary slightly from those listed due to rounding).

Table 3. $PM_{2.5}$ emissions data for the battery condenser system.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.10	0.22	0.0039	0.0085
	2	0.069	0.15	0.0026	0.0057
	3[y]	0.037	0.082	0.0014	0.0030
Test Average (n=2)		0.086	0.19	0.0032	0.0071
C	1[x]	0.054	0.12	0.010	0.021
	2	0.17	0.37	0.010	0.022
	3	0.095	0.21	0.0057	0.012
Test Average (n=2)		0.13	0.29	0.0077	0.017
D	1	0.14	0.32	0.0049	0.011
	2	0.13	0.28	0.0042	0.0092
	3[y]	0.089	0.20	0.0028	0.0062
Test Average (n=2)		0.14	0.30	0.0045	0.010
E	1	0.040	0.088	0.0012	0.0027
	2	0.042	0.092	0.0015	0.0032
	3	0.050	0.11	0.0015	0.0032
Test Average (n=3)		0.044	0.10	0.0014	0.0030
F	1	0.041	0.091	0.0009	0.0019
	2	0.055	0.12	0.0012	0.0027
	3	0.085	0.19	0.0018	0.0040
Test Average (n=3)		0.060	0.13	0.0013	0.0029
G	1	0.11	0.23	0.0032	0.0070
	2	0.11	0.25	0.0035	0.0076
	3	0.17	0.38	0.0051	0.011
Test Average (n=3)		0.13	0.29	0.0039	0.0087
System Average (n=6)				0.0037	0.0081

[z] 227 kg (500 lb) equivalent bales

[y] Test run omitted from test average because aerodynamic cut size (2.50 ± 0.25 µm) was not met.

[x] Test run omitted from test average because of inconsistent gin operation during test.

The battery condenser system total particulate emission factor average for this project was about 2.1 times the EPA AP-42 published value for the battery condenser with high-efficiency cyclones (EPA, 1996a, b). The range of test average total particulate emission factors determined for this project and the range of AP-42 emission factor data overlapped. The battery condenser system PM_{10} emission factor average for this project was 1.9 times the EPA AP-42 published value for the battery condenser with high-efficiency cyclones. The test average PM_{10} emission factor range also overlapped with AP-42 emission factor data range.

Table 4. PM_{10} emissions data for the battery condenser system.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1[y]	0.37	0.81	0.014	0.031
	2[y]	0.44	0.96	0.016	0.036
	3	0.29	0.64	0.011	0.023
Test Average (n=1)		0.29	0.64	0.011	0.023
C	1[xy]	0.37	0.82	0.067	0.147
	2[y]	0.48	1.06	0.028	0.063
	3[y]	0.73	1.61	0.044	0.096
Test Average (n=0)					
D	1	0.63	1.39	0.021	0.047
	2	0.63	1.39	0.020	0.045
	3	0.61	1.34	0.019	0.042
Test Average (n=3)		0.62	1.37	0.020	0.045
E	1	0.37	0.81	0.011	0.024
	2	0.40	0.87	0.014	0.030
	3[y]	0.36	0.80	0.011	0.024
Test Average (n=2)		0.38	0.84	0.012	0.027
F	1	0.14	0.32	0.0031	0.0068
	2	0.23	0.50	0.0049	0.011
	3	0.25	0.55	0.0053	0.012
Test Average (n=3)		0.21	0.46	0.0045	0.010
G	1[y]	0.90	1.98	0.027	0.060
	2[y]	0.83	1.84	0.026	0.057
	3[y]	1.49	3.28	0.044	0.097
Test Average (n=0)					
System Average (n=4)				0.012	0.026

[z] 227 kg (500 lb) equivalent bales

[y] Test run omitted from test averages because aerodynamic cut size (10.0 ± 1.0 µm) was not met.

[x] Test run omitted from test averages because of inconsistent gin operation during test.

Table 5. Total particulate emissions data for the battery condenser system.

Gin	Test Run	Emission Rate		Emission Factor	
		kg/h	lb/h	kg/bale[z]	lb/bale[z]
A	1	0.60	1.32	0.023	0.050
	2[y]	0.77	1.70	0.029	0.064
	3	0.50	1.10	0.018	0.040
Test Average (n=2)		0.55	1.21	0.020	0.045
C	1[x]	0.97	2.15	0.176	0.387
	2[y]	1.58	3.49	0.093	0.205
	3	1.60	3.52	0.095	0.210
Test Average (n=1)		1.60	3.52	0.095	0.210
D	1	1.08	2.37	0.036	0.080
	2	1.21	2.67	0.039	0.086
	3[y]	1.13	2.48	0.036	0.079
Test Average (n=2)		1.14	2.52	0.038	0.083
E	1	0.55	1.22	0.017	0.037
	2	0.60	1.32	0.021	0.046
	3[y]	0.55	1.20	0.016	0.036
Test Average (n=2)		0.58	1.25	0.019	0.041
F	1[y]	0.24	0.53	0.0052	0.011
	2	0.37	0.82	0.0081	0.018
	3	0.37	0.82	0.0079	0.017
Test Average (n=2)		0.37	0.82	0.0080	0.018
G	1	1.23	2.70	0.037	0.082
	2	1.07	2.35	0.033	0.072
	3	1.80	3.97	0.053	0.118
Test Average (n=3)		1.36	3.01	0.041	0.091
System Average (n=6)				0.037	0.081

[z] 227 kg (500 lb) equivalent bales

[y] Test run omitted from test averages because isokinetic sampling rate (100 ± 10%) was not met.

[x] Test run omitted from test averages because of inconsistent gin operation during test.

Figure 15 shows an example of samples recovered from a typical battery condenser system test run. Often, there were cotton lint fibers, which have cross-sectional diameters much greater than 2.5 mm, in the cotton gin cyclone exhausts. Therefore, it was not unusual to find lint fiber in the > 10 µm wash from Method 201A. However, lint fibers could pass through the PM_{10} cyclone and collect in the 10 to 2.5 µm and ≤ 2.5 µm washes and on the filter. This type of material carryover can bias the gravimetric measurements and impact reported $PM_{2.5}$ emission data. EPA Method 201A does not suggest methods to account for these anomalies. Thus, no effort was made to adjust the data reported in this manuscript to account for these issues.

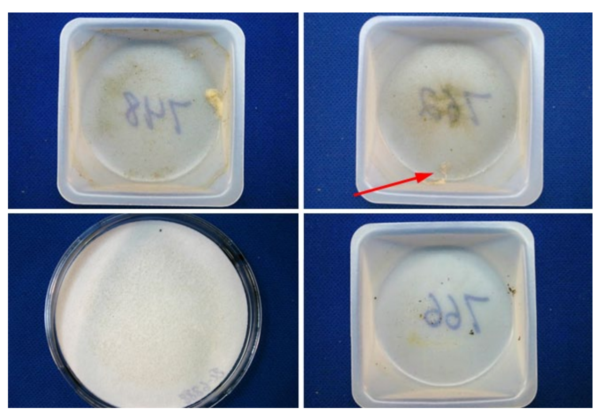

Figure 15. Typical EPA Method 201A filter and sampler head acetone washes from the battery condenser system with lint fiber in the 10 to 2.5 µm wash. Clockwise from top left: > 10 µm wash, 10 to 2.5 µm wash, ≤ 2.5 µm wash, and filter.

SUMMARY

Seven cotton gins across the U.S. cotton belt were stack sampled using EPA Method 201A to fill the data gap that exists for $PM_{2.5}$ cotton gin emissions data. Six of the seven gins had battery condenser systems with high-efficiency cyclones on the system exhausts. The tested systems were similar in design and typical of the ginning industry. All the systems were equipped with 1D3D cyclones for emissions control with some slight variations in inlet and cone design. In terms of capacity, the six gins were typical of the industry, averaging 30.9 bales/h during testing. Some test runs were excluded from the test averages because they failed to meet EPA Method 201A test criteria. Also, other test runs included in the analyses had cotton lint fibers that collected in the ≤ 10 µm and/or ≤ 2.5 µm samples. This larger lint material can impact the reported emissions data, but EPA Method 201A does not suggest methods to account for these anomalies. Average measured battery condenser system $PM_{2.5}$ emission factor based on the six gins tested (15 total test runs) was 0.0037 kg/277-kg bale (0.0081 lb/500-lb bale). The battery condenser system emission factors for PM_{10} and total particulate were 0.012 kg/bale (0.026 lb/bale) and 0.037 kg/bale (0.081 lb/bale), respectively. The gin test average $PM_{2.5}$, PM_{10}, and total particulate emission rates ranged from 0.044 to 0.14 kg/h (0.10-0.30 lb/h), 0.21 to 0.62 kg/h (0.46-1.37 lb/h), and 0.37 to 1.60 kg/h (0.82-3.52 lb/h), respectively. System average PM_{10} and total particulate emission factors were higher than those currently published in EPA AP-42. The ratios of battery condenser system $PM_{2.5}$ to total particulate, $PM_{2.5}$ to PM_{10}, and PM_{10} to total particulate were 10.0, 30.9, and 32.3%, respectively. These data are the first published data to document $PM_{2.5}$ emissions from battery condenser systems at cotton gins.

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DISCLAIMER

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