

ENGINEERING AND GINNING

First Stage Mote System PM_{2.5} Emission Factors and Rates for Cotton Gins: Method 201A Combination PM₁₀ and PM_{2.5} Sizing Cyclones

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ABSTRACT

This report is part of a project to characterize cotton gin emissions using stack sampling. In 2006, the Environmental Protection Agency (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. Current EPA AP-42 cotton gin PM_{2.5} emission factors did not exist prior to this point. The objective of this study is the development of PM_{2.5} emission factors for cotton gin first-stage mote systems based on the EPA-approved stack sampling methodology, Method 201A. The project plan included sampling seven cotton gins across the Cotton Belt. Five of the seven gins were equipped with first-stage mote systems where the exhaust airstream was not combined with a second-stage mote system. In terms of capacity, the five gins were typical of the industry, averaging 27.5 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 $\leq 10 \mu\text{m}$ and/or $\leq 2.5 \mu\text{m}$ 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 first-stage mote system PM_{2.5} emission factor based on the five tests (14 total test runs) was 0.0041 kg/227-kg

bale (0.0090 lb/500-lb bale). The first-stage mote system average emission factors for PM₁₀ and total particulate were 0.023 kg/bale (0.051 lb/bale) and 0.032 kg/bale (0.071 lb/bale), respectively. The first-stage mote system PM_{2.5} emission rate from test averages ranged from 0.026 to 0.19 kg/h (0.057–0.43 lb/h). System average PM₁₀ and total particulate emission factors were lower than those currently published in EPA AP-42. The ratios of first-stage mote system PM_{2.5} to total particulate, PM_{2.5} to PM₁₀, and PM₁₀ to total particulate were 12.7, 17.9, and 70.8%, 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 the lack of 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 and 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, first-stage seed cotton cleaning, second-stage seed-cotton cleaning, third-stage seed-cotton cleaning, overflow, first-stage lint cleaning, second-stage lint cleaning, combined lint cleaning, cyclone robber, first-stage mote, second-stage mote, combined mote, mote cyclone robber, mote cleaner, mote trash, battery condenser and master trash. This report focuses on PM_{2.5} emissions from first-stage mote systems.

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Published PM₁₀ (particulate matter with a particle diameter less than or equal to a nominal 10- μ m aerodynamic equivalent diameter) and total particulate emission factors for cotton gins can be found in EPA's Compilation of Air Pollution Emission Factors, AP-42 (EPA, 1996a, 1996b); however, there are no PM_{2.5} emission factors. The AP-42 average PM₁₀ emission factor for the mote fan, which is an equivalent system to the combined first and second-stage mote systems was 0.060 kg (0.13 lb) per 217-kg (480-lb) equivalent bale with a range of 0.023 to 0.14 kg (0.050-0.30 lb) per bale. The AP-42 average total particulate emission factor for the mote fan was 0.13 kg (0.28 lb) per bale with a range of 0.045 to 0.47 kg (0.099-1.0 lb) per bale. These PM₁₀ and total factors were based on six and nine tests respectively, 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 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 with the ginning season lasting from 75 to 120 days, depending on the size and condition of the crop. Although the trend for United States (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 varies 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 processing capacity has increased to an average of about 25 bales per hour across the Cotton Belt (Valco et al., 2003, 2006, 2009, 2012).

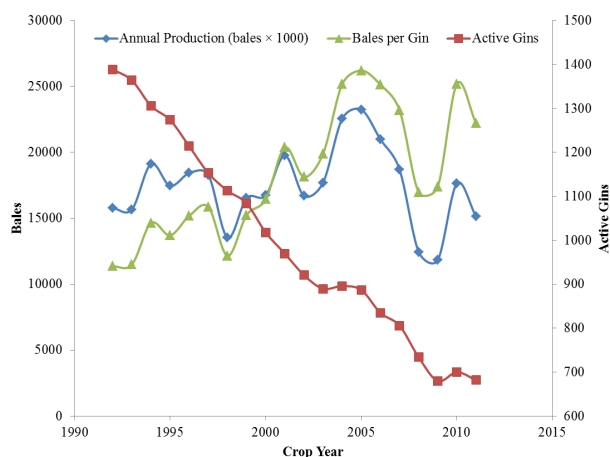


Figure 1. Annual U.S. cotton production, active U.S. gins, and average ginning volume (bales per gin) (NASS, 1993-2012).

Typical cotton gin processing systems include: an unloading system, dryers, seed cotton cleaners, gin stands, an overflow collector, lint cleaners, battery condenser, a 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 by-products 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. These streams of by-products must be removed from the machinery and handled by trash collection systems. These 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.

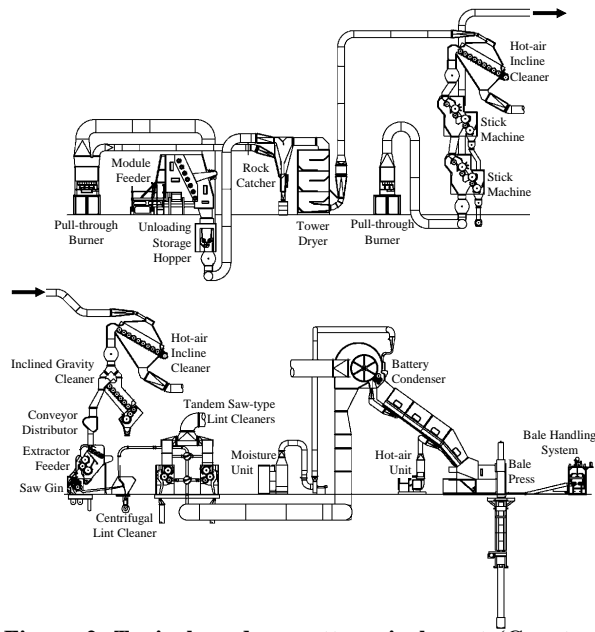


Figure 2. Typical modern cotton gin layout (Courtesy Lummus Corporation, Savannah, GA).

After the seed and lint are separated at the gin stand, the lint is cleaned by one or more stages of lint cleaners. The material removed by lint cleaners is referred to as “motes” and is handled by the mote systems (Fig. 3). Motes are pneumatically conveyed by suction away from the lint cleaners, through a centrifugal fan, to one or two particulate abatement cyclones. Depending on the gin facility, the first and second stages of lint cleaning may share a mote system, thus sharing a fan and abatement devices, or lint-cleaning stages may have a mote system that operates independently with separate fans and cyclones, denoted as first-stage mote systems or second-stage mote systems. The material handled by the mote system cyclones typically includes small trash and particulate, and large amounts of lint fibers (Fig. 4).

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 $15.2 \pm 2 \text{ m/s}$ ($3000 \pm 400 \text{ fpm}$). The standard 1D3D cyclone (Fig. 5) has the same inlet dimensions as the 2D2D or may have the original 1D3D inlet with height of D and width D/8. Also, it has a design inlet velocity of $16.3 \pm 2 \text{ m/s}$ ($3200 \pm 400 \text{ fpm}$).

The objective of this study was the development of $\text{PM}_{2.5}$ emission factors for cotton gin first-stage mote systems with cyclones for emissions control based on EPA-approved stack sampling methodologies.

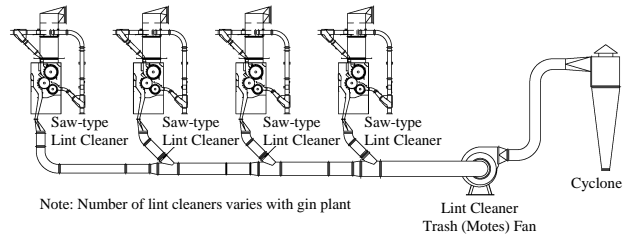


Figure 3. Typical cotton gin first-stage mote system layout (Courtesy Lummus Corporation, Savannah, GA).



Figure 4. Photograph of typical trash captured by the first-stage mote system cyclones.

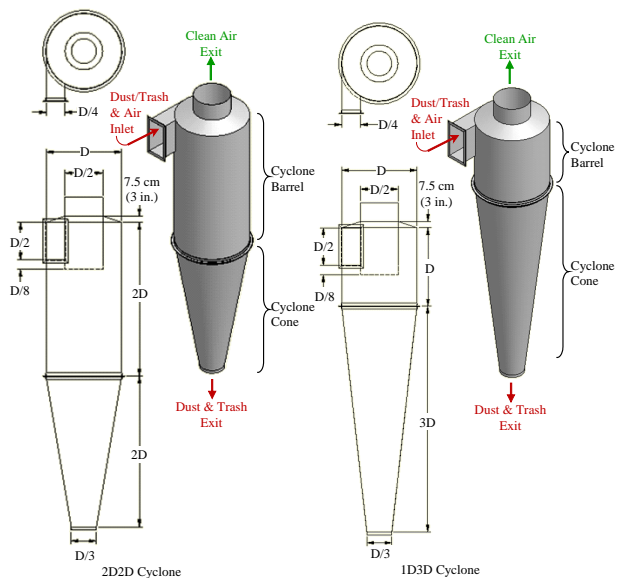


Figure 5. 2D2D and 1D3D cyclone schematics.

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 is 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) gins 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 at 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 first-stage mote system at each gin. When testing for this project began in 2008, OTM27 was the EPA method for determination of PM₁₀ 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 grew out of 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 PM₁₀ 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 PM₁₀ 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 (PM₁₀ sizing cyclone catch acetone wash); 10 to 2.5 μm (PM₁₀ 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 PM₁₀ 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 PM₁₀ mass and the mass of the > 10 μm wash.

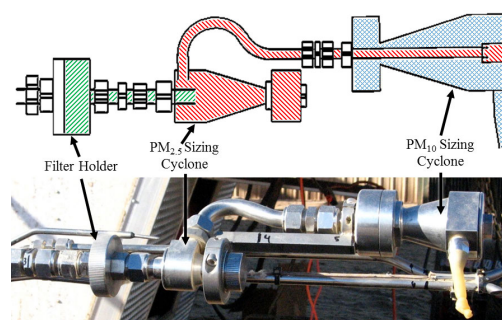


Figure 6. EPA Method 201A PM₁₀ and PM_{2.5} sizing cyclones and in-stack filter holder schematic (CFR, 2010) and photograph (/// ≤ 2.5 μm, // 10 to 2.5 μm, ▒ > 10 μm).

Figure 7 shows the performance curves for the PM₁₀ and PM_{2.5} sizing cyclones. To measure both PM₁₀ and PM_{2.5}, Method 201A a gas sampling rate in the middle of the overlap zone of the performance curves for both sizing cyclones must be selected. 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 PM₁₀ sizing cyclone was used to scrub larger particles from the 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.

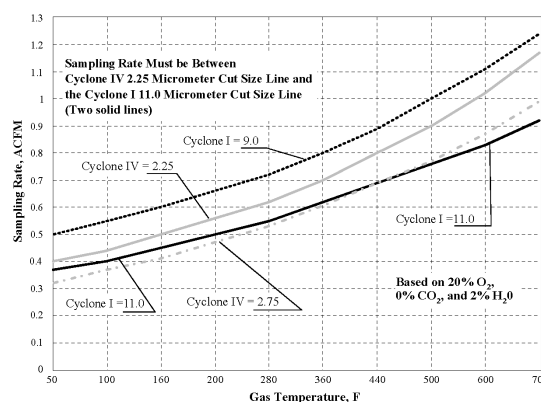


Figure 7. Acceptable sampling rate for combined cyclone heads (CFR, 2010). Cyclone I = PM₁₀ sizing cyclone and Cyclone IV = PM_{2.5} sizing cyclone (Gas temperatures for the 1st stage mote systems tested ranged from 17 to 40°C [62-103°F]).

Only one stack from each first-stage mote 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 included 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 $\geq 99.5\%$). Filters and wash tubs and lids were pre-labeled and pre-weighed 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 above straightening vanes and 0.9-m (36-in) upstream from the extension exit.

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 protocols. After retrieval, filters were sealed in individual Petri dishes and acetone washes were dried on-site in a conduction oven at 49°C and then sealed with pre-weighed 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).

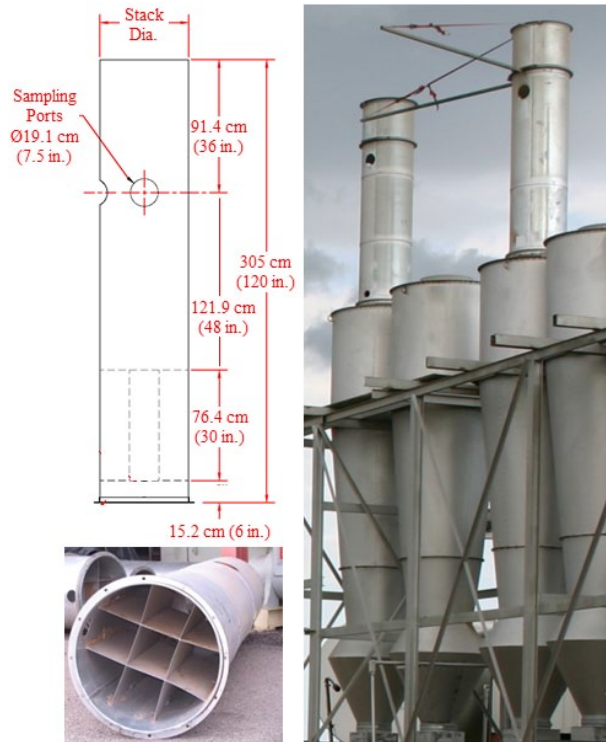


Figure 8. Schematic and photographs of stack extensions with sampling ports and straightening vanes (rail attached to extension above sampling port, at right, supports sampling probe during testing traverse).

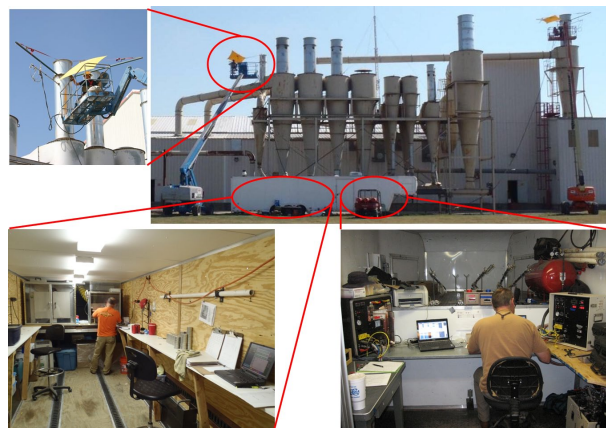


Figure 9. Clockwise from top right: cotton gin stack sampling with air quality lab trailer and technicians on lifts; certified stack sampling technician in the trailer control room conducting tests; sample recovery in trailer clean room; technician operating the probe at stack level.

All laboratory analyses were conducted at the AQL. All filters were conditioned in an environmental chamber ($21 \pm 2^\circ\text{C}$; $35 \pm 5\%$ 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 anti-static 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 require 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.

Five of the seven gins were equipped with first-stage mote systems that were not combined with second-stage mote systems. The first-stage mote systems sampled were typical for the industry, but varied among the gins. As the lint was cleaned in three first-stage lint cleaning systems at gin A, the trash removed from the lint was combined in the first-stage mote system and pneumatically conveyed from the lint cleaners through a fan and exhausted through one or more cyclones (Fig. 10). The first-stage mote system at gin C was essentially the same, except the mote system pulled trash from two first-stage lint cleaning systems (Fig. 11). The first-stage mote systems at gins B, D, and F were also similar, but the systems at those gins pulled material from four first-stage lint cleaning systems (Fig. 12).

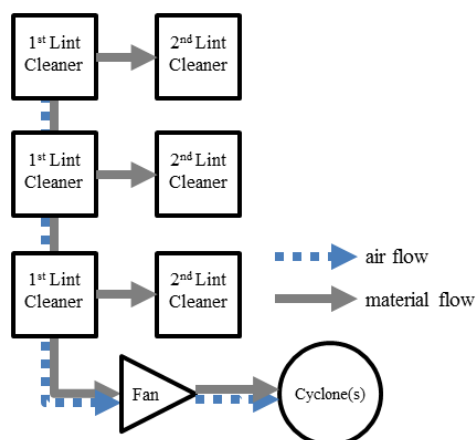


Figure 10. Schematic of first-stage mote system pulling material from three first-stage lint cleaning systems (gin A).

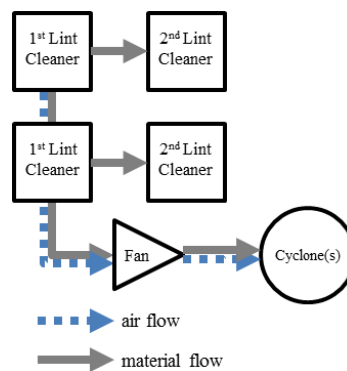


Figure 11. Schematic of first-stage mote system pulling material from two first-stage lint cleaning systems (gin C).

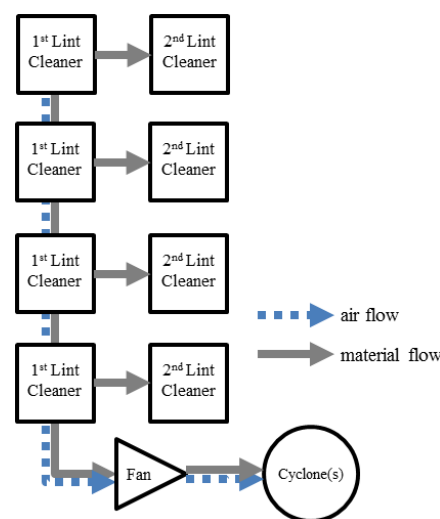


Figure 12. Schematic of first-stage mote system pulling material from four first-stage lint cleaning systems (gins B, D, and F).

All first-stage mote systems sampled utilized 1D3D cyclones to control emissions (Fig. 5), but there were cyclone design variations among the gins (Table 1 and Fig. 13). Gins D and F 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 C was exhausted through a single cyclone. Inlets on the first-stage mote cyclones for gins B, D and F were 2D2D type, while gins A and C had inverted 1D3D inlets. Standard cones were present on first-stage mote cyclones at all gins, except gin B, which had an expansion chamber. The cyclones tested at gins A, B, D and F had mote 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 first-stage mote systems tested.

Gin	Cyclone Type	Inlet Design ^y	Systems per Gin	Cyclones per Gin	Configuration	Cone Design	Trash exits to ^x
A	1D3D	inverted 1D3D	1	1	single	standard	robber
B	1D3D	2D2D	1	1	single	expansion chamber	robber
C	1D3D	inverted 1D3D	1	1	single	standard	hopper
D	1D3D	2D2D	1	2	dual	standard	robber
F	1D3D	2D2D	1	2	dual	standard	robber

^z Figures 5 and 13

^y Inverted 1D3D inlet has duct in line with the bottom of the inlet

^x Systems to remove material from cyclone trash exits: hopper = large storage container directly under cyclone trash exit; robber = pneumatic suction system



Figure 13. 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 an inverted 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 201A test run for the first-stage mote systems sampled at the five gins. The system average ginning rate was 27.5 bales/h and the test average ginning rates at each gin ranged from 20.9 to 38.5 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 test runs one and two at gin A and test run one at gin B that were outside the design range due to limitations in available system adjustments.

Criteria are specified in EPA Method 201A for test runs to be valid for PM_{2.5}, PM₁₀, or total particulate measurements (CFR, 2010). Iso-

kinetic sampling must fall within EPA defined ranges ($100 \pm 20\%$) for valid PM_{2.5} and PM₁₀ test runs. All tests met the isokinetic criteria (Table 2). To use the method to also obtain total filterable particulate, sampling must be within 90 to 110% of isokinetic flow. This criterion was not met in the third test run for gins A and B, the second and third runs for gin C, the second test run for gin D, and the first and second test runs 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 defined ranges (2.50 ± 0.25 mm) for valid PM_{2.5} test runs. PM_{2.5} cut size criteria was not met in the third test run for gin A, thus the data associated with these runs were omitted from the PM_{2.5} test averages. The PM₁₀ aerodynamic cut size must fall within EPA defined ranges (10.0 ± 1.0 mm) for valid PM₁₀ test runs. PM₁₀ cut size criteria were not met in the first test run for gin B, all test runs for gin C, the second test run for gin D, or the first test run for gin F, thus the data associated with these runs were omitted from the PM₁₀ test averages.

Sampling rates ranged from 10.0 to 13.0 slpm (0.352-0.458 scfm). The stack gas temperatures ranged from 17 to 40°C. 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 Figure 7 for the temperatures listed above. These stack gas characteristics justified targeting the PM_{2.5} cut size criteria and treating the PM₁₀ cut size criteria as secondary.

Table 2. Cotton gin production data and stack sampling performance metrics for the first-stage mote systems.

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	27.1	18.4	3613	100	2.41	10.9	11.6	0.408	21	69
	2	20.2	18.8	3701	103	2.31	10.6	12.2	0.429	24	75
	3	19.0	17.7	3482	117 ^x	2.15 ^w	10.1	13.0	0.458	25	77
	Test Average	22.1	18.3	3599							
B	1	9.9	18.8	3702	96	2.47	11.1 ^w	11.3	0.401	38	101
	2	21.7	17.7	3480	106	2.38	10.9	11.7	0.414	39	102
	3	31.0	17.2	3382	112 ^x	2.30	10.7	12.1	0.427	40	103
	Test Average	20.9	17.9	3521							
C	1	23.0	17.1	3368	103	2.49	11.2 ^w	11.1	0.391	33	92
	2	19.6	15.8	3102	112 ^x	2.47	11.2 ^w	11.1	0.391	32	90
	3	20.2	17.1	3357	87 ^x	2.49	11.3 ^w	10.9	0.386	31	88
	Test Average	20.9	16.6	3276							
D	1	32.0	14.8	2905	94	2.37	11.0	10.7	0.378	17	62
	2	36.2	14.9	2941	86 ^x	2.61	11.7 ^w	10.0	0.352	19	67
	3	36.5	14.6	2874	98	2.34	10.9	11.1	0.390	22	72
	Test Average	34.9	14.8	2906							
F	1	32.6	16.2	3198	87 ^x	2.60	11.4 ^w	11.0	0.387	30	86
	2	41.0	16.8	3306	89 ^x	2.45	11.0	11.6	0.409	31	87
	3	41.8	16.4	3229	92	2.42	10.9	11.7	0.414	32	90
	Test Average	38.5	16.5	3244							
System Average	27.5	16.8	3309								

^z 227 kg (500 lb) equivalent bales

^y slpm = standard l/min, scfm = standard ft³/min

^x Did not meet total particulate isokinetic sampling rate criteria (100 ± 10%)

^w Did not meet PM_{2.5} (2.50 ± 0.25 μm) or PM₁₀ (10.0 ± 1.0 μm) aerodynamic cut size criteria

PM_{2.5} emissions data (ginning and emission rates and corresponding emission factors) for the first-stage mote systems are shown in Table 3. The system average PM_{2.5} emissions factor was 0.0041 kg/bale (0.0090 lb/bale). The test average PM_{2.5} emission factors at each gin ranged from 0.0012 to 0.0086 kg (0.0027-0.019 lb) per bale and test average PM_{2.5} emission rates ranged from 0.026 to 0.19 kg/h (0.057-0.43 lb/h). PM₁₀ emissions data (ginning and emission rates and corresponding emission factors) for the first-stage mote systems are shown in Table 4. The system average PM₁₀ emissions factor was 0.023 kg/bale (0.051 lb/bale). The test average PM₁₀ emission factors ranged from 0.015 to 0.031 kg (0.033-0.069 lb) per bale and emission rates ranged from 0.38 to 1.06 kg/h (0.83-2.34 lb/h). Total particulate emissions data (ginning and emission rates and corresponding emission factors) for the first-stage mote systems are shown in Table 5. The system average total particulate emissions factor was 0.032 kg/bale (0.071 lb/bale). The test average

total particulate emission factors ranged from 0.020 to 0.048 kg (0.043-0.105 lb) per bale. Test average total particulate emission rates ranged from 0.35 to 1.43 kg/h (0.78-3.16 lb/h). The ratios of PM_{2.5} to total particulate, PM_{2.5} to PM₁₀, and PM₁₀ to total particulate were 12.7, 17.9, and 70.8%, respectively (ratios calculated using tables 3, 4, and 5 may vary slightly from those listed due to rounding).

The first-stage mote system total particulate emission factor average for this project was about 25.5% of the EPA AP-42 published value for the mote fan (EPA, 1996a, 1996b), which is an equivalent system to the combined first and second-stage mote system. The range of test average total particulate emission factors determined for this project and the range of AP-42 emission factor data overlapped. The first-stage mote system PM₁₀ emission factor average for this project was 38.9% of the EPA AP-42 published value for the mote fan. The test average PM₁₀ emission factor range also overlapped with AP-42 emission factor data range.

Table 3. PM_{2.5} emissions data for the first-stage mote systems.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale ^z	lb/bale ^z
A	1	0.16	0.35	0.0059	0.013
	2	0.23	0.51	0.011	0.025
	3 ^y	0.10	0.21	0.0050	0.011
Test Average (n=2)		0.19	0.43	0.0086	0.019
B	1	0.017	0.037	0.0017	0.0038
	2	0.056	0.12	0.0026	0.0057
	3	0.095	0.21	0.0031	0.0067
Test Average (n=3)		0.056	0.12	0.0025	0.0054
C	1	0.027	0.059	0.0012	0.0026
	2	0.028	0.061	0.0014	0.0031
	3	0.023	0.050	0.0011	0.0025
Test Average (n=3)		0.026	0.057	0.0012	0.0027
D	1	0.13	0.28	0.0040	0.0087
	2	0.22	0.49	0.0062	0.014
	3	0.16	0.34	0.0042	0.0093
Test Average (n=3)		0.17	0.37	0.0048	0.011
F	1	0.12	0.26	0.0036	0.0079
	2	0.14	0.31	0.0034	0.0076
	3	0.13	0.29	0.0032	0.0070
Test Average (n=3)		0.13	0.29	0.0034	0.0075
System Average (n=5)				0.0041	0.0090

^z 227 kg (500 lb) equivalent bales

^y Test run omitted from test averages because aerodynamic cut size (2.50 ± 0.25 μm) was not met

Table 4. PM₁₀ emissions data for the first-stage mote systems.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale ^z	lb/bale ^z
A	1	0.54	1.18	0.020	0.044
	2	0.65	1.44	0.032	0.071
	3	0.42	0.92	0.022	0.048
Test Average (n=3)		0.53	1.18	0.025	0.054
B	1 ^y	0.13	0.28	0.013	0.028
	2	0.43	0.94	0.020	0.043
	3	0.33	0.73	0.011	0.023
Test Average (n=2)		0.38	0.84	0.015	0.033
C	1 ^y	0.30	0.65	0.013	0.028
	2 ^y	0.22	0.49	0.011	0.025
	3 ^y	0.26	0.57	0.013	0.028
Test Average (n=0)					
D	1	1.15	2.54	0.036	0.079
	2 ^y	1.37	3.02	0.038	0.083
	3	0.97	2.14	0.027	0.059
Test Average (n=2)		1.06	2.34	0.031	0.069
F	1 ^y	0.35	0.78	0.011	0.024
	2	0.47	1.03	0.011	0.025
	3	1.26	2.77	0.030	0.066
Test Average (n=2)		0.86	1.90	0.021	0.046
System Average (n=4)				0.023	0.051

^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

Table 5. Total particulate emissions data for the first-stage mote systems.

Gin	Test Run	Emission Rate,		Emission Factor,	
		kg/h	lb/h	kg/bale ^z	lb/bale ^z
A	1	1.00	2.20	0.037	0.081
	2	1.19	2.62	0.059	0.130
	3 ^y	0.81	1.78	0.042	0.094
Test Average (n=2)		1.09	2.41	0.048	0.105
B	1	0.18	0.40	0.018	0.040
	2	0.52	1.16	0.024	0.053
	3 ^y	0.56	1.24	0.018	0.040
Test Average (n=2)		0.35	0.78	0.021	0.047
C	1	0.45	0.99	0.020	0.043
	2 ^y	0.36	0.79	0.018	0.040
	3 ^y	0.42	0.93	0.021	0.046
Test Average (n=1)		0.45	0.99	0.020	0.043
D	1	1.36	3.00	0.043	0.094
	2 ^y	1.72	3.79	0.047	0.105
	3	1.30	2.87	0.036	0.079
Test Average (n=2)		1.33	2.93	0.039	0.086
F	1 ^y	0.48	1.06	0.015	0.032
	2 ^y	0.59	1.29	0.014	0.031
	3	1.43	3.16	0.034	0.076
Test Average (n=1)		1.43	3.16	0.034	0.076
System Average (n=5)				0.032	0.071

^z 227 kg (500 lb) equivalent bales

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

Figure 14 shows an example of samples recovered from a typical first-stage mote system test run. Often, there were cotton lint fibers, which have cross-sectional diameters much greater than 2.5 μm, in the cotton gin cyclone exhausts. Therefore, it was not unusual to find lint fiber in the > 10 μm wash from Method 201A. However, in the atypical sample shown in Figure 15, lint fibers passed through the PM₁₀ and PM_{2.5} cyclones and collected 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 emissions 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.

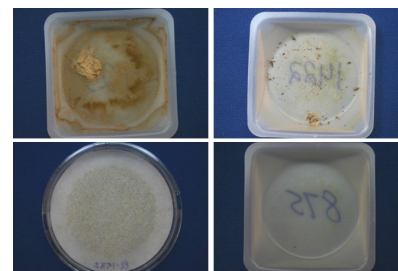


Figure 14. Typical EPA Method 201A filter and sampler head acetone washes from the first-stage mote system. Clockwise from top left: > 10 μm wash, 10 to 2.5 μm wash, ≤ 2.5 μm wash, and filter.

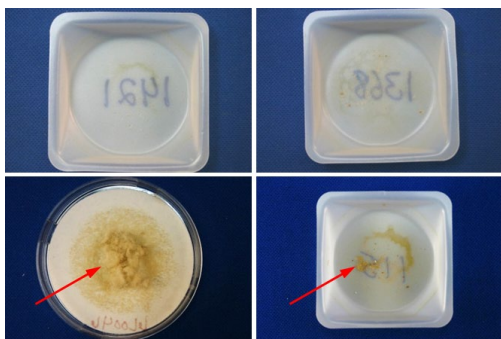


Figure 15. Atypical EPA Method 201A filter and sampler head acetone washes from the first-stage mote system with lint fiber in the $\leq 2.5 \mu\text{m}$ wash and on the filter. Clockwise from top left: $> 10 \mu\text{m}$ wash, 10 to $2.5 \mu\text{m}$ wash, $\leq 2.5 \mu\text{m}$ wash, and filter.

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. Five of the seven gins were equipped with first-stage mote systems where the airstream exhausts were not combined with a Second-stage mote system. 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 five gins were typical of the industry, averaging 27.5 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 $\leq 10 \mu\text{m}$ and/or $\leq 2.5 \mu\text{m}$ 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 first-stage mote system PM_{2.5} emission factor based on the five gins tested (14 total test runs) was 0.0041 kg/227-kg bale (0.0090 lb/500-lb bale). The first-stage mote system average emission factors for PM₁₀ and total particulate were 0.023 kg/bale (0.051 lb/bale) and 0.032 kg/bale (0.071 lb/bale), respectively. The gin test average PM_{2.5}, PM₁₀ and total particulate emission rates ranged from 0.026 to 0.19 kg/h (0.057-0.43 lb/h), 0.38 to 1.06 kg/h (0.83-2.34 lb/h) and 0.35 to 1.43 kg/h (0.78-3.16 lb/h), respectively. System average PM₁₀ and total particulate emission factors were lower than those currently published in EPA AP-42. The ratios of first-stage mote system PM_{2.5} to total particulate, PM_{2.5} to PM₁₀, and

PM₁₀ to total particulate were 12.7, 17.9, and 70.8%, respectively. These data are the first published data to document PM_{2.5} emissions from first-stage seed-cotton cleaning systems at cotton gins.

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DISCLAIMER

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